Estimation of System Performance and Technology Impacts to Support Future Year Planning

Final Report

Contract BDV29 977-37

Prepared for

Florida Department of Transportation

By

Florida International University

Lehman Center for Transportation Research

March 2019

Disclaimer

Metric Conversion Chart

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
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
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				
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")
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

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

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<tr><td colspan="5">16. Abstract
Transportation agencies are increasingly interested in measuring and forecasting system performance and the impact of advanced technologies and strategies on existing and future year conditions. The goal of this project is to support these measurements and forecasting by taking advantage of state-of-art models, methods, and parameters and available of data from multiple sources. The potential of using a tool as a basis for this support is explored. The specific objectives of this project are:
• identifying a set of performance measures that can be used as a basis for assessing system performance and comparing improvement alternatives;
• identifying methods to predict performance measures for use in performance and impact assessment;
• identifying business processes that can benefit from the utilization of the project development; and
• enhancing and extending models in an existing tool to allow the assessment of system performance and the impacts of additional advanced and emerging technologies</td></tr>
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EXECUTIVE SUMMARY

E1. BACKGROUND

Agencies are increasingly interested in measuring system performance and the impact of advanced technologies and strategies on existing and future year conditions. This interest increased with the MAP-21 and later the Fast-Act federal legislation emphasis on establishing performance goals focusing on seven areas: safety, infrastructure conditions, congestion reduction, system reliability, freight, environmental sustainability, and project delivery time. The federal legislations require states and metropolitan planning organizations (MPOs)/transportation planning organizations (TPO)/Transportation Planning agency (TPA) to identify performance measures and associated targets and including these targets in the state and MPO plans. For existing conditions, this estimation can be done based on data collected from multiple sources such as statistics office detectors, traffic management system detectors, incident and crash databases, weather agencies, and other sources of data. For future conditions, there is a need to identify models and methods that can be used to support the estimation of system performance. These models will have to be supported by data from multiple sources to ensure their accuracy in estimating future conditions. In 2008, the Florida Intelligent Transportation System (ITS) Evaluation (FITSEVAL) tool was developed for the Florida Department of Transportation (FDOT) to estimate the impacts of advanced strategies on system performance. This tool has the potential to be used to forecast system performance with and without technology and strategy deployment and thus support transportation agency investment decisions.

E2. GOALS AND OBJECTIVES

The goal of this project is to support agencies in measuring and forecasting system performance and the impact of advanced technologies and strategies on existing and future year conditions by taking advantage of state-of-art models, methods, and parameters and available of data from multiple sources. The potential of using a tool as a basis for this support is explored. The outcome of this project will allow a better selection of alternatives for implementation based on combinations of forecasted performance measures that are related to the state and regional goals and objectives. The specific objectives of this project are:

- identifying a set of performance measures that can be used as a basis for assessing system performance and comparing improvement alternatives;
- identifying methods to predict performance measures for use in performance and impact assessment;
- identifying FDOT and MPO business processes that can benefit from the utilization of the project development; and
- enhancing and extending existing models in FITSEVAL to allow the assessment of system performance and the impacts of additional advanced and emerging technologies

E3. POTENTIAL TOOL SUPPORT OF BUSINESS PROCESSES

Table E-1 summarizes the FDOT and MPO/TPO/TPA business processes and the corresponding potential support that can be provided by FITSEVAL. It should be noted that only a subset of these potential application will be implemented in the first version of the updated tool produced as part of this project. Additional applications can be implemented in future versions as needed.

Table E-1 Potential Support of FITSEVAL for Business Processes

Business Process		Potential FITSEVAL Support
FDOT Planning	Florida Transportation Plan	• Assess the performance metrics that corresponding to each goal for existing conditions based on real-world data, travel demand model, or other modeling methods and tools • Compare alternative improvements and prioritize projects
	Strategic Intermodal System	• Estimate the impacts of alternative improvement on SIS and prioritize projects
	Planning Studies	• Estimate the impacts of alternative improvements and prioritize projects
	Interchange Access Request	• Estimate the impacts of alternative improvements and prioritize projects
	Highway Capacity/LOS	• Calculate LOS • Estimate the impacts of highway capacity improvement and advanced strategies and technologies
	Statistics, Measures, and Trends	• Produce data-based statistics, measures, and forecasting
	Performance Measures	• Produce data-based and model-based performance measures that are required by MAP-21, FAST Act, and state rules
MPO/TPO/TPA	Long Range Transportation Plan	• Calculate performance measures that corresponding to each goal for existing conditions based on data and travel demand model • Compare alternative improvements and prioritize projects
	Transportation Improvement Program	• Compare alternative improvements and prioritize projects
	Unified Planning Work Program	• Calculate performance metrics for complete and ongoing projects • Compare alternative improvements and prioritize projects
	Congestion Management Process	• Assess the benefits and costs of congestion management strategies
	Bicycle/Pedestrian Program	• Evaluate the benefits and costs of bicycle/pedestrian projects
	Freight Program	• Evaluate freight-related improvements

Business Process		Potential FITSEVAL Support
	Transportation Alternative Program	• Compare alternative improvements and prioritize projects
	Connected and Autonomous Vehicle Program	• Add a new evaluation module for connected and autonomous vehicles in FITSEVAL
	Performance Measurement Program	• Produce performance measures that are required by MPO/TPO/TPA
	Transportation Disadvantaged Program	• Add a new module in FITSEVAL to evaluate the benefits and costs of transportation disadvantaged projects
PD&E Study		• Incorporate emission estimation for alternative projects • Compare alternative improvements and prioritize projects based on more detailed analysis such as Highway Capacity Manual procedures or simulation.
FDOT Traffic Engineering and Operations (Focusing on planning for operations)	Traffic Service	• Estimate the impacts of alternative improvements • Compare intersection control strategies
	TSM&O	• Assess the benefits and costs of TSM&O strategies by adding additional evaluation modules
	Traffic Incident Management/Commercial Vehicle Operations	• Update the parameters for incident management evaluation module based on latest data

As required by MAP-21 and FAST Act, planning is moving towards a performance-based process. In each transportation plan, performance measures are specified for each goal and objective. These performance measures are related to the safety, mobility, environment, economy, preservation, to collaboration and agency management objectives. The current version of FITSEVAL focuses on mobility, safety, and reliability. FITSEVAL can be upgraded as needed in to estimate performance measures related to other measures and show how these measures satisfy the federal and state requirements.

E4. EXISTING PERFORMANCE FORECATING AND ASSOCIATED TOOLS

Based review presented in this document, it can be concluded that there are a large number of metrics that have been identified and utilized at the national level, by FDOT departments, and by various MPO/TPO/TPA in Florida. Some of these measures will be calculated in the initial version of the updated FITSEVAL. Others, will be calculated in future versions as needed. Specifically, the following can be concluded:

- A wide range of performance measures have been selected, calculated, and reported by different FDOT departments for different purposes. These measures will be considered to be calculated by the developed tool. Examples of the measures are those identified in the FDOT Florida Transportation Plan (FTP), FDOT TSM&O Strategic Plan, and FDOT Multimodal Mobility Performance Measure Source Book)
- Metropolitan planning organization/transportation planning organization/transportation planning agency (MPO/TPO/TPA) in Florida have included performance management into their planning process. The performance measures used by MPOs/TPOs/TPAs vary with their specific goals and objectives. The safety performance measures are more consistent among MPO/TPO/PTAs, while there is a large variation in other performance measures. There is no standard regarding what performance measures should be reported. A number of MPOs/TPOs/TPAs have set up targets according to the required national performance measures.
- The final rule of the Moving Ahead for Progress in the 21st Century Act (MAP-21) MAP-21 have clearly specified the national performance measures in seven focus areas that need to be calculated by state and MPOs. The calculation method, data source, and reporting date for those performance measures are also provided in detail.
- As MPOs/TPOs/TPAs place more emphasis on multimodal transportation system, it is recommended not only to calculate automobile-related performance measures, but also multimodal performance measures that are related to transit, trucks, pedestrians, and bicycles. The developed tool should be updated to allow the calculation of multimodal performance measures based on modeling, where possible.
- A number of methods have been identified to calculate safety, mobility, reliability, and emission performance measures. These methods can be either data-based or model-based.

E.5 ESTIMATION OF PERFORMANCE MEASURES FOR BASE CONDITION

Different methods are reviewed in this study for potential use in FITSEVAL to estimate the mobility, reliability, and safety performance for the base conditions before implementing advanced technologies. The estimation can be based on real-world data, utilizing different analytical models or simulation. Methods to estimate travel time and travel time reliability are assessed in this study by comparing the resulting estimates from applying these methods to those estimated based on real-world data. Two corridors are used as case studies for assessing the accuracy of the estimates for freeways and urban arterial streets, respectively, as follows:

- I-95 northbound between NW 32nd Street and NW 103rd Street in Miami-Dade County, FL (used as a freeway case study)
- Sunrise Blvd. between US 441 and US 1 in Broward County, FL (used as an urban street case study)

Mobility Forecasting

The accuracy of the following functions to forecast speed/travel time were assessed based on comparison with data-based estimates of travel time:

- Bureau of Public Road (BPR) Curve with the parameters extracted from the S outheast Florida Regional Planning Model (SERPM) model.
- Akcelik Equation with the parameters extracted from the Express Lanes Time-of-Day (ELToD) software developed for managed lane toll assessment
- BPR Curve with the parameters calibrated in a study conducted by Florida State University (FSU)
- Akcelik Equation with the parameters calibrated in a study conducted by FSU
- Modified Davidson Equation with the parameters calibrated in a study conducted by FSU
- Conical Equation with the parameters calibrated in a study conducted by FSU
- Freeway and urban street Highway Capacity Manual (HCM) procedures

Based on the results presented in this study, the functions that produced the best results for all three periods are the FSU-calibrated Modified Davidson model, the Akcelik function used in ELTOD, and the HCM-based freeway facility procedure. The SERPM BPR relationship worked well for congested conditions but was somewhat less accurate than other methods for uncongested conditions. The other tested models were less accurate. In general, the estimation is much more accurate for less congested conditions for all tested methods.

The functions were also tested to estimate travel times during an incident conditions. The lowest error again was observed when using the ELTOD Akcelik model and the FSU-Calibrated Davidson model. The HCM procedure predicted higher travel time compared to the real-world measures. This model, however, performs well for the PM congested conditions, which raises questions on why this high delay is estimated during incident conditions. Further examination indicates that the traffic in the HCM-based procedure takes longer time to recover from congestion caused by the incident. This could be due to not considering diverted traffic in the analysis. It should be noted her that all models, except the Queueing Analysis and HCM-based procedure show that the delay occurs during the incident lane blockage duration and do not include the additional delay during queue dissipation (recovery) after incident lane-blockage clearance.

The findings suggest that the travel time forecasting methods are able to forecast travel time more accurately for freeways compared to arterial street facilities and for less congested periods. For the arterial street segment, the FSU-calibrated Modified Davidson model produced the most accurate results for the AM and PM peak periods. However, the BPR function in the SERPM model works better for the Mid-Day period. Overall, it appears that, for the arterial segment, the FSU-calibrated Davidson model performed the best, followed by the FSU calibrated BPR curve, and ELTOD Akcelik equation. Utilizing lower capacity in the equations using a previously identified function (662 veh/hr/lane vs. the 900 veh/hr/lane in the SERPM model) produced much better results.

The HCM procedures have the advantage of considering the temporal and spatial impacts of congestion since they consider the spillbacks between the roadway segments including ramps and the extended queue from one period to the next. However, these procedures require more time to prepare and fine-tune the model and the use of a software like FREEVAL, STREETVAL, or Highway Capacity Software (HCS).

Mobility measurements as required by national, state, and MPO/TPO/TPA guidance and procedures can be forecasted based on travel time estimates calculated using the functions listed above.

Reliability Forecasting

The travel time reliability measures reflect day-to-day variation in congestion levels due to contributing factors such as demand and capacity stochasticity, incidents, adverse weather, and work zones. Reliability can be estimated based on models that range from simple equations to HCM-based procedures to simulation-based procedures.

In this study, forecasted reliability measures was compared with reliability estimated for both the freeway case study (I-95 in Miami-Dade County) and the arterial segment (Sunrise Blvd. in Broward County) based on real-world data. The followings are the tested reliability forecasting methods in this project, all of which were developed as part of the Reliability Program of the Strategic Highway Research Program 2 (SHRP2):

- SHRP2 L03 Project Data-Poor Procedure
- SHRP2 L03 Project Data-Rich Procedure
- SHRP2 L07 Project Procedure with Default Parameters
- SHRP2 L07 Project Procedure Calibrated for Miami by Florida International University as part of the SHRP2 L38 project
- SHRP2 C11 Project Procedure
- SHRP2 C11 Project Procedure Calibrated for the Tampa Bay Region as part of a federal grant
- SHRP 2 L08 procedures as adopted in the HCM and implemented in FREEVAL and HCS.

When considering the three peaks, the models that produced the best forecasts of reliability compared to data-based reliability estimation for the freeway segment is the SHRP2 C11 model calibrated for the Tampa Bay Area and the SHRP2 L03 Data Poor Model. The model that produced the best forecasts of reliability compared to data-based reliability estimation for the urban arterial study segment is the L07 original model followed by the SHRP2 L03 data poor and L03 data rich model.

Safety Forecasting

This project identified two methods for predicting the safety performance - the Lookup Table method and the Florida Calibrated Safety Performance Functions (SPF). The Table Lookup method is based on the method used in the original version of FITSEVAL and presents the crash rate as a function of the volume to capacity ratio. The second method utilizes the calibrated SPF developed for Florida based on roadway inventory data and crash data. The updated version of FITSEVAL allows the user to estimate the safety for the base conditions using one of these two methods or estimate the base condition crashes based on real-world crash data.

E.6 EVALUATION OF ADVANCED APPLICATIONS

ITS evaluation tools require three types of parameters: 1) Outcome Performance Modification Parameters, 2) cost parameters, and 3) benefit dollar values. A discussion of these items as related to the updated FITSEVAL tool is listed below.

- ***Outcome Performance Modification Parameters:*** These parameters were identified in this study based on a review of multiple resources. For CV-based applications on arterials streets, the identified impact parameters were also in part based on a review of CV-based application that was conducted by the research team, as part of another research project sponsored by the FDOT research center.
- ***Cost Parameters:*** Cost estimation is another required component to benefit-cost analysis. The cost estimation must consider the number and types of equipment required for each type of evaluated ITS deployment. FITSEVAL includes initial cost, operation and maintenance cost, estimated interest rate, and equipment life-time. The study team reviewed various cost data sources and identified cost estimates. It should be pointed out that there is a lot of uncertainty in the cost of emerging technologies like those associated with CV and automated vehicle (AV)-based applications. Thus, the provided values should be considered as a starting point and further information should be used if more accurate costs can be estimated.
- **Conversion to Dollar Values:** An important component of benefit-cost analysis is to convert ITS impacts to dollar values. The original version of FITSEVAL has default parameters to convert the values of the estimated outcome performance measures to dollar values. An effort by the Florida Department of Transportation (FDOT) District 5 recommended updates to these parameters. The transportation Benefit-Cost Analysis wiki (B-C Wiki) that is sponsored by the TRB Committee on Transportation Economics (http://bca.transportationeconomics.org/) presents a detailed set of recommended values. These and other sources were reviewed and updated values were selected for use in the new version of FITSEVAL.
- **Uncertainty Consideration:** Benefit–cost analyses of ITS alternatives produce point estimates of the return on investment of ITS deployments. These analyses used default or user input values of the cost, benefit, and dollar values of the benefits. However, there is a great amount of uncertainty associated with these parameters. The values of the parameters as reported in previous evaluation studies vary widely. Decision makers may not be willing to accept an alternative that has an acceptable average or median benefit–cost ratio but has a 25% probability of having a low benefit–cost ratio or if there is a relatively high probability that the budget of the project will be high. The uncertainty is

even higher when dealing with connected and automated vehicle technologies. To account for the uncertainty, two approaches can be used: sensitivity analyses and risk analyses. A risk analysis approach was selected in this study for implemented in a future version of FITSEVAL to account for the uncertainty in return on investment by expressing the input parameters as probability distributions rather than as fixed values and utilizing Monte Carlo simulation to vary the input parameters and identify probability distributions for each resulting performance measure.

E.4 FITSEVAL UPDATE

The original version of FITSEVAL was produced utilizing the Script language of Cube. It works only as a processor to cube provided input and output files, in addition to analyst supplied parameters utilizing the user interface. The new version of FITSEVAL is a standalone desktop tool that reads files from multiple sources as long as it is provided in an acceptable format. The currently acceptable format are Cube files and Highway Capacity Software (HCS) file format. The source of the data can be any model or real-world data as long as it is converted to one of these two formats. The software itself is coded in the C# language. The user does not need to use the C# language to utilize the tool since it is compiled and used in an executable form. The final product is an executable file which could be run on any windows platform. Thus, the user only needs to interface with the tool through the graphical user interface (GUI), input files, and output files. Figure E-1 is an example of the screens of the updated FITSEVAL showing a comparison of the assessed mobility of a corridor with and without connected vehicle (CV)-based adaptive signal control implementation.

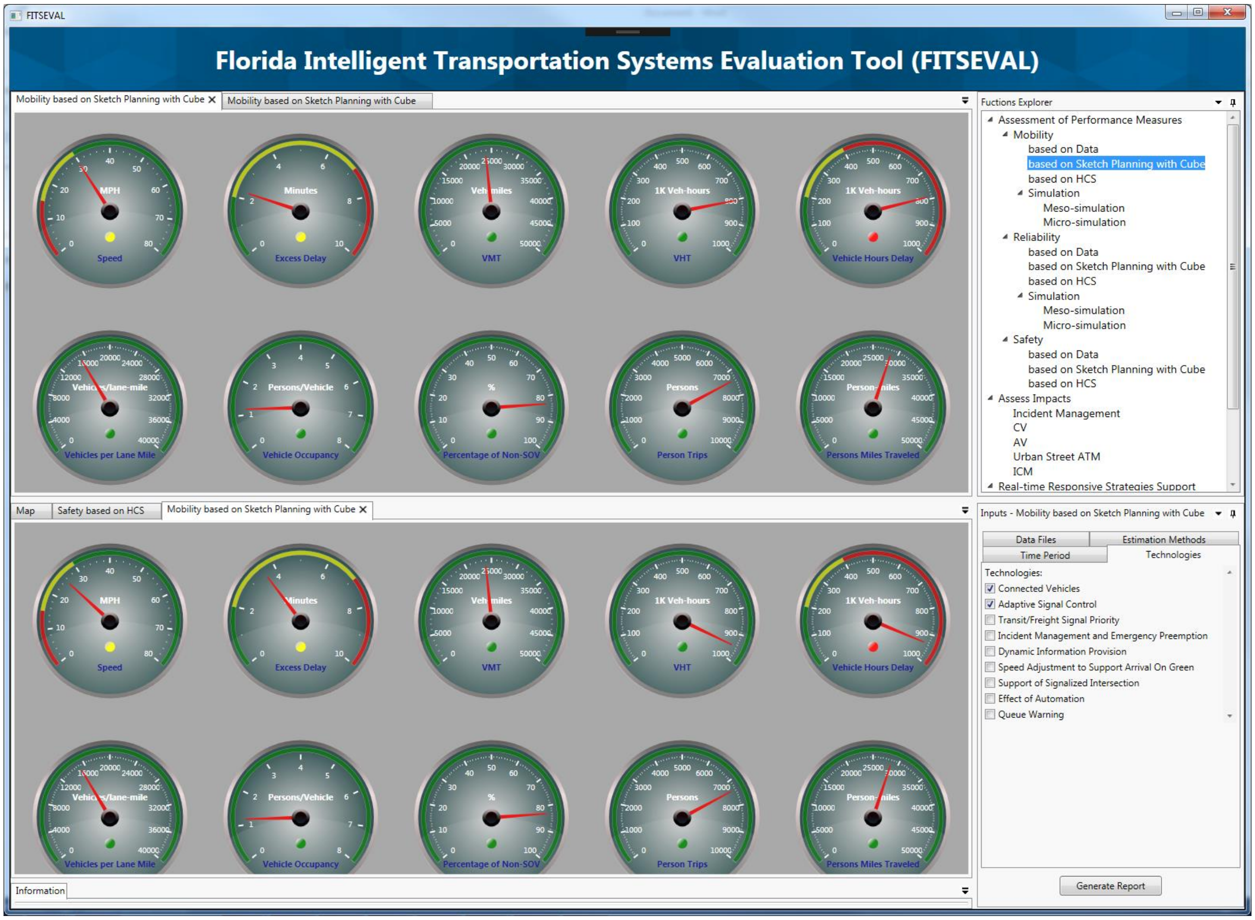

Figure E-1: Comparison of Mobility with and without CV –based Adaptive Signal Control

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AADT	Annual Average Daily Traffic
AAM	Active Arterial Management
ACC	Adaptive Cruise Control
ACES	Automated, Connected, Electric, and Shared
ADMS	Arterial Dynamic Message Signs
AEB	Automated Emergency Braking
AM	Ante Meridiem (Before Midday)
ASCT	Adaptive Signal Control Technology
ATDM	Active Transportation and Demand Management
ATIS	Advanced Travel Information Systems
ATSC	Adaptive Traffic Signal Control
AV	Automated Vehicle
AVL	Automatic Vehicle Location
BAS	Backup Assistant Systems
BERT	Bus Express Rapid Transit
BLOS	Bicycle Level of Service
BPR	Bureau of Public Roads
BSM	Blind Spot Monitoring
BSW	Blind Spot Warning
CAR	Crash Analysis Reporting
CCTV	Closed Circuit Television
CDF	Cumulative Density Function
CFR	Code of Federal Regulations
CFRPM	Central Florida Regional Planning Model
CMAQ	Congestion Mitigation and Air Quality
CMF	Crash Modification Factor
CMP	Congestion Management Plan/Process
CO	Carbon Monoxide
CSW	Curve Speed Warning
CV	Connected Vehicle
CVO	Commercial Vehicle Operations
D1RPM	District One Regional Planning Model
DIVAS	Data Integration and Video Aggregation System
DMS	Dynamic Message Sign
DSRC	Dedicated Short-Range Communication
DTA	Dynamic Traffic Assignment
ELToD	Express Lanes Time of Day
EPA	Environmental Protection Agency
ESC	Electronic Stability Control
ESU	Emergency Shoulder Use
EVP	Emergency Vehicle Preemption
FARS	Fatality Analysis Reporting System
FAST	Fixing America’s Surface Transportation
FCW	Forward Collision Warning

FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FIU	Florida International University
FITSEVAL	Florida ITS Evaluation
FREEVAL	FREeway EVALuation
FSP	Freight Signal Priority
FSU	Florida State University
FSUTMS	Florida Standard Urban Transportation Model Structure
FTP	Florida Transportation Plan
GHG	Greenhouse Gas
GLOSA	Green Light Optimal Speed Advisory
HAR	Highway Advisory Radio
HAWK	High-intensity Activated crossWalK
HC	Hydrocarbon
HCM	Highway Capacity Manual
HIA	Health Impact Assessment
HOT	High Occupancy Toll
HOV	High-Occupancy Vehicle
HPMS	Highway Performance Monitoring System
HSIP	Highway Safety Improvement Program
HSM	Highway Safety Manual
IAR	Interchange Access Request
ICE	Intersection Control Evaluation
ICM	Integrated Corridor Management
IMA	Intersection Movement Assist
IRI	International Roughness Index
ITS	Intelligent Transportation System
JPO	Joint Program Office
LCW	Lane Change Warning
LHL	Lane Hour Lost
LOS	Level of Service
LOTTR	Level Of Travel Time Reliability
LRTP	Long Range Transportation Plan
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MD	Mid-Day
MOVES	Motor Vehicle Emission Simulator
MPO	Metropolitan Planning Organization
MAP-21	Moving Ahead for Progress in the 21st Century
MPH	Mile Per Hour
MPO	Metropolitan Planning Organization
MTIP	Metropolitan Transportation Improvement Program
MMF	Mobility Modification Factor
MMUCC	Model Minimum Uniform Crash Criteria
MNAT	Mobility Needs Assessment Tool
MTTI	Mean Travel Time Index

MVDS	Microwave Vehicle Detection System
MVMT	Million Vehicle Miles Traveled
NBI	National Bridge Inventory
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act
NHPP	National Highway Performance Program
NHS	National Highway System
NHTSA	National Highway Traffic Safety Administration
NOAA	National Oceanic and Atmospheric Administration
NOx	Nitrogen Oxide
NPMRDS	National Performance Management Research Data Set
OD	Origin-Destination
OUATS	Orlando Urban Area Transportation Study
OVW	Oversize Vehicle Warning
PCW	Signalized Crosswalk Warning
PD&E	Project Development and Environmental
PDO	Property Damage Only
PEA	Planning Emphasis Areas
PHED	Peak Hour Excessive Delay
PLOS	Pedestrian Level of Service
PM	Post Meridiem (After Midday)
PMP	Performance Measurement Program
PMS	Pavement Management System
PTI	Planning Time Index
QLOS	Quality/Level of Service
RCVW	Railroad Crossing Violation Warning
RDCW	Road Departure Crash Warning
RISC	Rapid Incident Scene Clearance
RITIS	Regional Integrated Transportation Information System
RLVW	Red Light Violation Warning
RMF	Reliability Modification Factor
RMSE	Root Mean Square Error
RSD	Road Segment Delay
RSZW	Reduced Speed Zone Warning
RTMC	Regional Transportation Management Center
RWIS	Road Weather Information System
SERPM	South East Regional Planning Model
SIRV	Severe Incident Response Vehicle
SIS	Strategic Intermodal System
SLTA	Signalized Left Turn Assist
SMART	Strategic Miami Area Rapid Transit
SOV	Single Occupancy Vehicle
SPaT	Signal Phase and Timing
SPF	Safety Performance Function
SPM	Signal Performance Metrics
SSGA	Stop Sign Gap Assistance

SSVW	Stop Sign Violation Warning
STAMP	Statewide Arterial Management Program
STIP	Statewide Transportation Improvement Program
STREETVAL	STREET EVALuation
SWIW	Spot Weather Information Warning
TAP	Transportation Alternatives Program
TCRPM	Treasure Coast Regional Planning Model
TD	Transportation Disadvantaged
TFM	Traffic Flow Model
TIM	Traffic Incident Management
TIP	Transportation Improvement Program
TOPS-BC	Tool for Operations Benefit Cost Analysis
TMC	Transportation Management Center
TPA	Transportation Planning Agencies
TPM	Transportation Performance Management
TPO	Transportation Planning Organizations
TransVaIU	Transportation Value to You
TSM&O	Traffic System Management and Operation
TSP	Transit Signal Priority
TTI	Travel Time Index
TTTR	Truck Travel Time Reliability
UCF	University of Central Florida
UPWP	Unified Planning Work Program
USDOT	United States Department of Transportation
V2I	Vehicle to Infrastructure
V/C	Volume to Capacity
VCTIR	Virginia Center for Transportation Innovation and Research
VDF	Volume-Delay Function
VDOT	Virginia Department of Transportation
VOCs	Volatile Organic Compounds
VHT	Vehicle Hour Traveled
VMT	Vehicle Mile Traveled
VSP	Vehicle-Specific Power
WAN	Wide-Area Network
WSDOT	Washington State Department of Transportation

1. INTRODUCTION

1.1 Background Statement

Transportation agencies are increasingly interested in measuring system performance and the impact of advanced technologies and strategies on existing and future year conditions. This interest increased with the MAP-21 and later the Fast-Act federal legislation emphasis on establishing performance goals focusing on seven areas: safety, infrastructure conditions, congestion reduction, system reliability, freight, environmental sustainability, and project delivery time. The federal legislations require states and metropolitan planning organizations (MPOs) to identify performance measures and associated targets and including these targets in the state and MPO plans. For existing conditions, this estimation can be done based on data collected from multiple sources such as statistics office detectors, traffic management system detectors, incident and crash databases, weather agencies, and other sources of data. For future conditions, there is a need to identify models and methods that can be used to support the estimation of system performance. These models will have to be supported by data from multiple sources to ensure their accuracy in estimating future conditions. In 2010, the Florida Department of Transportation (FDOT) sponsored a one-day workshop with staff directors of Florida MPOs on the role of modeling in a performance measurement framework. This workshop was conducted as a step to assist MPOs in the use of travel demand models for developing valid and reliable output to inform a performance-based decision-making process. The objectives of this workshop were to: define performance measures MPOs need the most and provide recommendations to enhance travel demand models and develop analytical tools to evaluate these performance measures. Ideally, such a tool should be able to identify the impacts of conventional improvements as well as advanced strategies and technologies on system performance on the identified measures.

In 2008, the Florida Intelligent Transportation System (ITS) Evaluation (FITSEVAL) tool was developed to estimate the impacts of advanced strategies on system performance. The tool has been used in at least two FDOT districts (Districts 1 and 5). This tool has the potential to be used to forecast system performance with and without technology and strategy deployment and thus support transportation agency investment decisions.

1.2 Goals and Objectives

The goal of this project is to support agencies in measuring and forecasting system performance and the impact of advanced technologies and strategies on existing and future year conditions by taking advantage of state-of-art models, methods, and parameters and available of data from multiple sources. The potential of using a tool as a basis for this support is explored. The outcome of this project will allow a better selection of alternatives for implementation based on combinations of forecasted performance measures that are related to the state and regional goals and objectives. The specific objectives of this project are:

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1.6 Document Organization

This section includes a description of the remaining chapters of this document.

Chapter 2 reviews the experience with FITSEVAL and identifies the agency business processes that are expected to benefit from the developed environment including identifying the range of the business processes and the potential stakeholders of the tool.

Chapter 3 starts with a review of the national and state guidance and practice on performance measurements, and then focuses on the methods and tools for calculating performance measures.

Chapter 4 summarizes different methods to estimate the performance measurement including mobility, reliability, and safety has been described in this chapter.

Chapter 5 describes methods to estimate the impacts of the transportation system management and operations (TSM&O) and ITS applications that are implemented in the updated version of the FITSEVAL tool, produced as part of this project.

2. POTENTIAL TOOL SUPPORT OF BUSINESS PROCESSES

This Chapter first reviews the experience with FITSEVAL. Then, it identifies the agency business processes that are expected to benefit from the developed environment including identifying these processes and the potential stakeholders of the tool.

2.1 FITSEVAL

2.1.1 Review of FITSEVAL

The Florida ITS Evaluation (FITSEVAL) tool is a sketch planning-level Intelligent Transportation System (ITS) evaluation tool that was developed within the Florida Standard Urban Transportation Modeling Structure (FSUTMS)/Cube environment for FDOT by this research team in 2008. (Hadi et al., 2008). This tool can be used to assess the mobility, safety, environmental, and user-cost benefits as well as the costs of various ITS deployment as listed below.

- Ramp Metering
- Incident Management Systems
- Highway Advisory Radio (HAR) and Dynamic Message Signs (DMS)
- Advanced Travel Information Systems (ATIS)
- Managed Lane
- Signal Control
- Emergency Vehicle Signal Preemption
- Smart Work Zone
- Road Weather Information Systems
- Transit Vehicle Signal Preemption
- Transit Security Systems
- Transit Information Systems
- Transit Electronic Payment Systems

The evaluation methodology implemented in the FITSEVAL tool varies with the type of ITS deployments. The output of FITSEVAL includes the impacts of ITS on performance measures including mobility, safety, fuel consumption, emission, and other deployment-specific measures. FITSEVAL also outputs the benefits and costs in dollar values of ITS applications and the resulted benefit/cost ratio. These outputs can be used to assess the ITS deployment, prioritize alternatives, and support plan decisions. In an assessment conducted by the University of Virginia, twelve different existing tools were evaluated and FITSEVAL was recommended for use in Virginia (Ma and Demetsky, 2013).

2.1.2 User Experience with FITSEVAL Tool

2.1.2.1 Application of FITSEVAL in FDOT District 4

To justify the investments, FDOT District 4 traffic management center contracted this research team to evaluate the benefits and costs of a number of ITS components including the Road Ranger service patrol program, Closed Circuit Television (CCTV) camera subsystem, Severe Incident Response Vehicle (SIRV) program, fog warning system, and arterial Dynamic Message Signs (DMS) subsystem. The purpose was to justify to the decision makers in the district, the investment made in these deployments. To accomplish this, the incident management application in FITSEVAL was extended and applied to assess these ITS components. The number of incidents, reduction in incident duration, and diversion rate were updated based on the examination of related databases and interviews with agency personnel. The output of FITSEVAL was used to support the investment decisions of the FDOT D4 Transportation Management Center (TMC).

The original version of FITSEVAL only has a module for the evaluation of dynamic message signs along freeways. To help the FDOT District 4 to evaluate the Arterial Dynamic Message Signs (ADMS) at I-95 and I-75 interchanges in Broward County, FL, a new evaluation methodology for ADMS was developed and implemented in FITSEVAL by this research team in 2011. Similar to the ITS components discussed above, the benefits, costs, and benefit/cost ratio calculated from FITSEVAL were applied by FDOT District 4 TMC to justify the installation of ADMS.

2.1.2.2 FDOT District 5 Experience with FITSEVAL Tool

The FITSEVAL tool was applied to support the short and long range ITS planning of FDOT District Five by Leftwich Consulting Engineering, Inc. in 2016 (Leftwich Consulting Engineers, Inc., 2016a). The travel demand model used in FDOT District Five is the Central Florida Regional Planning Model (CFRPM), while FITSEVAL was originally developed based on Southeast Florida Regional Planning Model (SERPM). The variable naming in these two models is slightly different. Also, the CFRPM model consists of four time periods, that is, the AM, MD, PM, and night periods, while the SERPM model includes three time periods, the AM, PM, and Off-Peak periods. A number of conversions and modifications were first made such that the FITSEVAL tool can be applied to the CFRPM model. Examples include utilizing variable renaming through a conversion function provided with the FITSEVAL tool and creating new network attributes for the off-peak period based on the attributes for the midday and night periods in CFRPM.

In Phase 1 of this project, five Metropolitan Planning Organizations (MPOs)/Transportation Planning Organizations (TPOs) were contacted by the Leftwich Consulting Engineering, Inc. regarding the application of the FITSEVAL tool. As the results of this effort, FITSEVAL tool is recommended to be used as part of MPO/TPO’s planning efforts, for example, long range transportation plan, state of the system annual reports, ITS master plans, and ITS/Congestion Management Plans (CMS)/safety alternative selection and prioritization. Also, based on stakeholder priorities, this study evaluated signal timing improvement strategies for 36 signalized arterial segments within the regions of the five MPOs/TPOs in FITSEVAL. The results of benefits, costs, and benefit/cost ratios produced by FITSEVAL for these study segments provide reference for MPOs/TPOs to prioritize the signalized corridors for signal retiming. A number of updates to FITSEVAL were recommended by this study, as listed below.

- Have the ability to use existing traffic data
- Further review and enhance emission estimation
- Expand the strategies that can be assessed in FITSEVAL including allowing comparison to roadway capacity improvement.
- Consider corridor characteristics such as turn lanes, driveways, and round-about, and truck characteristics such as passing lanes and truck bypass lanes in the evaluation of signal timing.

Meetings through phone calls or in person were also held by Leftwich Consulting Engineering, Inc. with FDOT Central Office, and FDOT District 5 ITS Operations, Planning, PD&E, and TSM&O staff. These meetings identify the potential usage of FITSEVAL as follows.

- Use of FITSEVAL as a promising platform for individual MPO/TPO to review and prioritize ITS projects.
- FITSEVAL use for congestion management solutions and not only for ITS strategies
- Use of FITSEVAL as part of corridor analyses project as a tool for investigating the application of multi-modal solutions
- Integration of FDOT's Transportation Value to You (TransVaIU) spreadsheet, a tool for corridor-level economic and financial analyses for proposed transportation investment in FDOT District 5, with the FITSEVAL tool.

Extensive review of TransVaIU was conducted by Leftwich Consulting Engineering, Inc. following the stakeholder meeting, but it was determined to keep FITSEVAL and TransVaIU as separate tools and having FITSEVAL tool to continue to focus on ITS with an integration with the regional demand model.

In Phase 2, Leftwich Consulting Engineers, Inc. (2016b) focused on evaluating the methodologies and parameters used in FITSEVAL for 10 types of ITS deployments and updating them to be consistent with local conditions. A number of default values were recommended to be updated including the parameters for public transportation and emergency vehicle preemption. Instead of considering seven types of signal timing improvements, Leftwich Consulting Engineers, Inc. (2016b) suggested to combine some of the categories and only ask users to select between adaptive controller system and non-adaptive controller system. In addition, a user input of travel time reduction value due to signal timing improvement was proposed to reflect the local experience. It was also decided not to add safety as a benefit for signal timing improvements.

In addition to the original 10 types of ITS deployments, the evaluation methodologies for two new types of deployments were added to FITSEVAL in Phase 2 by Leftwich Consulting Engineers, Inc. (2016b): the first is High-intensity Activated crossWalK (HAWK) that allows pedestrians to safely cross streets, and the second is roadway widening for the purpose of comparison with ITS alternatives. A default reduction of 25% in crashes was assumed for the safety benefits of HAWK. For roadway widening project, the reductions in delay, fuel consumption and emissions are calculated based on the user input for the percentage increase in congested speed.

Leftwich Consulting Engineers, Inc. (2016b) also examined the base FITSEVAL calculations of safety, fuel consumption, emission, road ranger service patrol benefit, toll, and public transit application benefits in Phase 2. The study updated the default crash rates in FITSEVAL with the segment-based crash rate statistics reported by the Florida Crash Analysis Reporting (CAR) System for the Central Florida Region. With the continuous improvements in fuel efficiency, the study suggested a reduction in fuel consumption rates used in FITSEVAL to account for such improvements. A seven percent reduction for every five mph (Mile Per Hour) was recommended for fuel consumption rate when speed is greater than 60 mph. For emission rates, the study of Leftwich Consulting Engineers, Inc. (2016b) recommended to use the MOVES2014 program emission rate files when they are available. The costs of road ranger service patrol activities were inflated from the year 2008 to year 2016 by applying inflation rates. Since the managed lane post-processing tool, Express Lanes Time of Day (ELToD), have been developed by the Florida Turnpike, no changes were proposed for the managed lane in FITSEVAL since the module was not used. Only one change was made to the transit application benefit, that is, to change the default transit fare from $1.00 to $1.50.

Leftwich Consulting Engineers, Inc. (2016c) updated the costs of each type of deployments based on the cost data from the FDOT District 5 TSM&O Office, the FDOT ITS Maintenance Workload Database, and online literature. An inflation factor was also applied to convert the cost from the year 2008 to year 2016.

2.1.2.3 FDOT District 1 Experience with FITSEVAL Tool

Traf-O-Data Corp (2016) tested the application of FITSEVAL to FDOT District One by coding 10 types of ITS deployments in the District One Regional Planning Model (D1RPM). The review comments are summarized below.

- Applications such as smart work zone and road weather information system are easy to use and seem to provide reasonable results. Environmental sensor stations are recommended to install along roadways with less highway patrol coverage to detect poor weather conditions.
- A number of applications such as incident management and advanced traveler information system are also easy to use but are not useful to District One as dynamic message signs and highway advisory radios are already installed along the major corridors.
- The applications of public transportation and bus priority are not useful for District One as the system has hourly headways.
- The application of signal timing improvement is somewhat difficult to use but it provides reasonable results. Dynamic traffic assignment is recommended to be used for the evaluation of signal timing improvement.
- Managed lane and ramp metering applications are difficult to use as they require a separated loaded network which is not easy to generate. Note that this evaluation is based on the updated version of FITSEVAL by the Citilabs, Inc. in which the evaluation procedure has been changed from the original FITSEVAL version that provides a way to

calculate the delays with ramp metering and managed lanes without re-running the model.
- The application of emergency vehicle preemption is very difficult to use due to the required input that is not easy to obtain, for example, signal cycle length.

2.1.2.4 Virginia Department of Transportation (VDOT) Experience with FITSEVAL Tool

In order to help VDOT and the MPOs in Virginia to make planning decisions regarding the options of operational capacity improvement versus physical capacity expansion, Ma and Demetsky (2013) compared 12 different operational analysis tools for conducting benefit/cost analysis of intelligent transportation systems. Based on the literature review, FITSEVAL was recommended as the operational analysis tool for future sketch planning in Virginia because of its compatibility with the travel demand models in Virginia and also its sophisticated and widely used evaluation methodologies. Two strategies, incident management and managed lanes, were assessed for Hampton Roads area to demonstrate the application of FITSEVAL. The conclusions and recommendations based on the results are:

- The two models of incident management and managed lane can be successfully integrated with the travel demand model, which provides a valuable tool for evaluating operational strategies.
- Some level of manual integration is required during the integration process, including the definition of analysis period(s), facility and area type(s), link capacity, volume-delay function and operational strategy coding. Note that this study used an older version of FITSEVAL. The updated version of FITSEVAL provides a variable conversion function to help the automatic integration between different travel demand models with FITSEVAL.
- A methodology was developed to re-estimate network flows resulting from the implementation of managed lane.
- The default values of the parameters in FITSEVAL are applicable for most of cases.
- Time-of-day modeling is recommended for evaluating operational strategies.
- FITSEVAL should be applied by VDOT's Transportation Mobility Planning Division and VDOT's Operations Division as a part of travel demand models to analyze operational strategies. A pilot test in one volunteer district is recommended before wider implementations.
- Existing local data should be collected by Virginia Center for Transportation Innovation and Research (VCTIR) for the application in FITSEVAL.
- VCTIR should continuously work with FDOT on exchanging information regarding needed and developed enhancements to FITSEVAL.

2.2 RELATED FDOT AND MPO BUSINESS PROCESSES

The first step of this project is to examine the business processes of the FDOT, MPO/TPO/TPA, and other partner agencies that can be benefit from FITSEVAL.

2.2.1 FDOT Planning

The FDOT Central Office Planning consists of four divisions: policy planning, system implementation, forecasting and trends, and performance. Below is a list of FDOT planning processes.

Florida Transportation Plan (FTP): FTP is the statewide transportation plan that guides the planning and management of Florida transportation system. FTP includes three components: The FTP vision element, the FTP policy element, and the FTP implementation element. The FTP vision element outlines the look of the future Florida transportation system in the next 50 years, while the Florida policy element defines the Florida transportation system for the next 25 years. Developed as a web-based application, the FTP implementation element guides the state, regional, and local transportation agencies in implementing the short-term and medium-term actions and performance measures specified in FTP.

Strategic Intermodal System (SIS): SIS is a statewide network that consists of transportation facilities with high priorities for capacity investments such as airport, seaport, rail, waterways, trail, and highways. The establishment of SIS is to enhance the mobility of people and freights and to improve the economy competitiveness of the state. SIS facilities are selected based on the criteria of transportation and economic measures. The FDOT System Implementation Office produces documents of SIS Funding Strategy that identify the potential SIS capacity improvement projects.

Planning Studies: Planning studies aim at developing a strategic plan for a SIS corridor or a subarea. The studies examine the existing and future traffic conditions, identify the transportation issues, define the needs, and develop a range of multi-modal alternatives for the study area. Three types of studies are included in these planning studies, that is, corridor, alternative, and feasibility studies.

Access Management: Access management balances the accessibility and mobility of roadways by coordinately planning, regulating, and designing access between roadways and their neighboring land development. A permit is required from the FDOT for the access to the state highway systems. Design standard and handbooks such as the median handbook and driveway information guide have been developed by the FDOT as a guidance for access management. This process may require more detailed analysis than the one that can be provided by a sketch planning tool like FITSEVAL.

Interchange Access Request (IAR): To minimize the adverse impacts on interstate highway and non-interstate limited access facilities on the state highway system, IAR is required to demonstrate that a new or modified interchange is needed and viable that satisfies the requirements of traffic, environmental, engineering, and funding. An operational and safety analysis needs to be conducted to support such a request. This process may require more detailed analysis than the one that can be provided by a sketch planning tool like FITSEVAL.

Highway Capacity/Level of Service (LOS): The LOS has been used as a primary measure of current and future mobility needs. The FDOT sets an acceptable level of service for the planning, design and operation of the state highway system. The target LOS for automobile mode during peak travel hours is “D” for urbanized areas and “C” for outside urbanized areas. FDOT Quality/Level of Service (Q/LOS) Handbook and accompanying software (LOSPLAN) have been produced to assist the analysis of roadway capacity and quality/level of service for planning and preliminary level analysis. Each FDOT district prepares and maintains the LOS information.

Project Traffic Forecasting: Forecast of traffic count, turning movement, and various traffic count adjustment factors are required inputs for Planning and Project Development and Environmental (PD&E) studies and construction plans. Traffic forecasting can be conducted using travel demand model or based on historical trends. A Project Traffic Forecasting Handbook has been developed by FDOT to standardize the practice of traffic forecasting. Tools such as TURNS5 for turning movement analysis and traffic trends analysis tool were also developed to assist traffic forecasting.

Site Impact Analysis: Site impact analysis is conducted to examine the traffic-related impacts of new developments. The FDOT develops Transportation Site Impact Handbook and TIPS (Trip Generation, Internal Capture, and Pass-by Software) to guide impact studies. This process may require more detailed analysis than the one that can be provided by a sketch planning tool like FITSEVAL.

Shared Use Non-motorized (SUN) Trail Network: Sun trail network is a statewide system that consists of multiuse trails and shared-use paths but physically separated from motorized traffic. The creation of SUN trail network provides alternative travel mode for those origins and destinations with limited access to motorized vehicles. Financially feasible transportation projects on the SUN trail network are listed in the FDOT’s five year adopted work program.

Statistics, Measures, and Trends: FDOT tracks the trends of transportation-related statistics and measures. The 2017 FDOT Source book provides a centralized source for these trend information. It covers the trends that affect transportation, for example, demographics, visitor numbers and travel modes, roadway inventory changes, characteristics of vehicle use and seat belt usage, international trade, emissions, and freight growth. The source book also documents the trends of mobility-related performance measures for different types of travel modes. It considers the four dimension of mobility, that is, quantify, quality, accessibility, and utilization.

Performance Measures: Performance measures are integrated into three distinct levels of planning and programming process: to establish the goal and objectives at the strategic level, to support funding allocation at the decision-making level, and to monitor project effectiveness and efficiency at the project delivery level. To meet the requirements of MAP-21 and Fast-Act, the FDOT produces Performance Report annually. It covers five aspects of transportation system, including safety, preservation, mobility, economy, and environment, which are connected to the seven focus areas identified by MAP-21. A total number of 14 core measures and 73 supporting measures are reported in the Annual Performance Report.

2.2.2 Metropolitan Planning Organization (MPO)/Transportation Planning Organization (TPO)/Transportation Planning Agencies (TPA)

MPOs/TPOs/TPAs are the transportation planning organizations for metropolitan area mandated by the federal government, which develop and maintain the transportation plans that satisfy the federal requirements and ensure the federal funds for local improvements. Currently, Florida has a total number of 27 MPOs/TPOs/TPAs. Below lists the business processes of MPOs/TPOs/TPAs in Florida.

Long Range Transportation Plans (LRTP): Each MPO/TPO/TPA develops a LRTP for a metropolitan area that covers at least a 20-year planning horizon. The LRTP includes both long-range and short-range multimodal-related actions and strategies that address the increasing travel demand. The LRTP developed by each MPO/TPO/TPA should be consistent with the statewide transportation plan. MPO/TPO/TPA is required to review and update the LRTP at least every five years (FDOT Office of Policy Planning, 2018). The latest adopted plan is the 2040 LRTP. A number of MPOs/TPOs/TPAs currently start to work on developing the 2045 LRTP.

Transportation Improvement Program (TIP): TIP is a five-year program that reflects the short-term transportation improvement projects with high priorities. Federal law requires TIP to cover a period of four years or more and to be updated every four years. The fifth year of TIP is considered as informational for planning purpose. MPO/TPO/TPA in Florida develops and updates TIP annually.

Unified Planning Work Program (UPWP): Each MPO/TPO/TPA in Florida is required to develop a two-year UPWP that identifies the tasks that MPO will perform for the next two years and the associated costs and funding source. When developing UPWP, MPO/TPO/TPA needs to take Federal and State Planning Emphasis Areas (PEA) into consideration. The Florida Planning Emphasis Areas for 2018 is rural transportation planning, transportation performance measures, and ACES (Automated/Connected/Electric/Shared-use) vehicles.

Public Participation Plan (PPP): MPO/TPO/TPA develops PPP that explicitly describes how MPO/TPO/TPA involves multi-modal stakeholders, affected public agencies, and individuals into planning process. The effectiveness of PPP is reviewed by MPO/TPO/TPA periodically.

Congestion Management Process (CMP): The LRTP focuses on the capital investment solutions over a 20-year horizon, while CMP identifies current and short-term technology-based operational strategies that help reduce single occupancy vehicle travel and facilitates the usage of other modes of transportation such as transit services, community shuttles, bicycles and pedestrians. The CMP provides a standard approach to monitor and evaluate the performance of multimodal transportation system, identify the cause of congestion, identify and assess alternative strategies, identifies and assesses alternative strategies, provide information support for the implementation of actions, and evaluate the effectiveness of implemented actions.

Bicycle/Pedestrian Program: Bicycle and pedestrian plan has been developed by a number of MPO/TPO/TPA (e.g., Miami-Dade TPO, and Palm Beach TPA) to identify major bicycle and pedestrian transportation improvements with a purpose of creating safe places for walk and bicycle.

Freight Program: The three county MPOs (Miami-Dade, Broward, and Palm Beach Counties) in partnership with FDOT also developed South Florida Regional freight plan.

Transportation Alternatives Program (TAP): TAP is a federal fund program that was established by the U.S. DOT to guide the development and growth of the country's transportation infrastructure. This program is intended to replace the previous programs such as Transportation Enhancements, Recreational Trials, Safe Routes to School, and several other discretionary program.

Connected and Autonomous Vehicle Program: With the advancement in connected and automated vehicles, Miami-Dade TPO is working with partner agencies to plan for the new technologies of connected and autonomous vehicles.

Performance Measurement Program (PMP): PMP ensures the investment and policy decisions to satisfy the performance measure requirements specified by MAP-21 for both highway and transit system. It emphasizes the performance-based planning.

Transportation Disadvantaged (TD) Program: TD program ensures the availability of cost-effective and efficient transportation services to those persons that are unable to transport themselves or purchase transportation services due to mental or physical disability or because of age or income status.

Table 2-1 Examples of Main Focus Areas for Florida MPO/TPO/TPA’s Business Processespresents some examples of the main focus areas and activities of Florida MPO/TPO/TPA’s business processes. It can be seen from this table that the commonly focused areas for MPOs/TPOs/TPAs are multimodal improvements including transit, bicycle/pedestrian, freight in addition to highways, and congestion management through advanced demand and traffic management strategies. Some emerging areas for MPO/TPO/TPA are autonomous and connected vehicles including the autonomous vehicles for transit and freight, and safety improvements.

Table 2-1 Examples of Main Focus Areas for Florida MPO/TPO/TPA's Business Processes

MPO/ TPO/ TPA	LRTP	TIP	UPWP	CMP	Pedestrian/Bicycle Program	Others
Miami-Dade TPO	• Transit improvements including six corridors with enhanced bus, one corridor with bus rapid transit, two park-and-ride facility, one transit terminal, and one intermodal terminal • Highway improvements by adding more managed lanes • Non-motorized improvements including on-road bicycle lanes, off-road greenways/trails and sidewalk • Congestion management process involvement • Freight transportation improvements	• Support facilities for Metrorail • Express bus service, express transit along managed lanes, and additional bus transit and paratransit improvements • Interstate highway projects • Congestion management • Non-motorized projects • Arterial street improvements • Aviation and seaport facilities • Construction of major intermodal facilities • Deployment of ITS applications.	• The Strategic Miami Area Rapid Transit (SMART) Plan that advances six rapid transit corridors along with a network system of Bus Express Rapid Transit (BERT) service	• Develop CMP strategy toolbox that include ITS and transportation system management strategies, TDM, land use, parking, regulatory, transit, highway, bicycle and pedestrian, and access management	• Update a number of trails and corridors for bicycles and pedestrians	• Autonomous freight

MPO/ TPO/ TPA	LRTP	TIP	UPWP	CMP	Pedestrian/Bicycle Program	Others
Broward County MPO	• Transportation improvement program • Regional significant projects such as community shuttle service, Broward County signalization network, mobility hubs that serve as transit access points with frequent transit services, South Florida regional freight plan, and climate change research • Complete streets and other localized initiative program • Facilities extending beyond the MPO planning area such as strategic intermodal system	• Transit bus capital improvement and operating expenses • Construction of sidewalks, bike lanes, greenways, and multipurpose paths • Road and bridge construction • Maintenance • Road drainage • Traffic signalization • Airport and seaport improvements • Regionally significant transportation projects	Transportation system planning tasks covers • Long range/metropolitan transportation planning • Regional transportation planning • Congestion management/livability planning • Transportation improvement program • Freights and goods management/intermodal planning • Transit planning and development • Complete streets and transportation related enhancement	• Mobility hubs, location of stations, transit stops and other facilities, bike and pedestrian infrastructure, and safety improvements • Multimodal congestion management • Mobility strategies such as signal coordination • Transportation demand management	• Complete streets • Being develop bicycle and pedestrian safety action	• Complete streets and other localized initiative program for small local transportation projects • Emerging technologies such as automated/ connected/ electric/shared-use vehicles will be in 2045 MTP/LRTP

MPO/ TPO/ TPA	LRTP	TIP	UPWP	CMP	Pedestrian/Bicycle Program	Others
Palm Beach TPA	• Premium transit service and new mass transit lines • Major roadway improvements and new interchanges • New bicycle facilities, sidewalks, and multi-use paths • New vehicular and pedestrian bridges	• SIS capacity improvement • Operation, maintenance of roadways and transit • Major maintenance	• Coordinated multimodal transportation system plan • Develop performance measures • Guide various jurisdictions to collaborate • Develop a regional approach to transportation planning • Develop a regional approach to provide guidance and ensure integrity in integrated transportation analysis.	• Propose 27 measures and developed mitigation strategies for each measure	• Greenways and trails plan • Pedestrian and bicycle plan • Complete street	• 5-year strategic plan • Transition plan • South Florida Climate Change Vulnerability Assessment and Adaptation Pilot project

Metroplan Orlando	• LRTP consists of 7 goals: safety, balanced multi-modal system, integrated regional system, quality of life, energy and environmental stewardship, and economic vitality. Evaluation criteria, performance measures, and projects are developed around these goals	• Highway projects: major capacity improvements with adding toll lanes; Surface Transportation Program projects for arterials streets • TSM&O projects • Bicycle and Pedestrian projects • Transit projects including "premium transit" • Transportation regional incentive program projects	• Major focus areas are 1) and 2) Safety and security in the transportation planning process; 3) Linking planning and environmental NEPA process; 4) TSM&O within the planning process 5) Consultation with local officials; 6) Enhancing the technical capacity of planning processes; 7) Coordination of human service transportation ; 8) Regional planning; 9) Public involvement; 10) MPO TIP project prioritization process; 11) Transit quality of service; and 12) Promote consistency between transportation	• 15 objectives for CMP: Freight & goods movement; balanced system; bicycle and pedestrian systems; safety and security enhancements; system preservation; cost-effectiveness; mobility enhancements; ITS; system function and performance; air quality, and others	• Complete street policy report • Bicycle/Pedestrian manual and digital counts • Filling gaps in the trail and bicycle lane networks as well as pedestrian network • Bicyclist safety and education • Bike share program • Spot improvement for reporting safety hazards • Pedestrian safety action plan	• Health impacts • Air quality • Safety (Crash database) • Transportation disadvantaged program: Access LYNX and Medicaid transportation • Transit: buses, rail, and quiet zone • Regional freight plan: multiple solutions in infrastructure, operational, and institutional areas

MPO/ TPO/ TPA	LRTP	TIP	UPWP	CMP	Pedestrian/Bicycle Program	Others
			improvements and planned growth			
North Florida TPO	• Transit investment to bus rapid transit, trolleys, commuter rail and other modes • Complete street • Safety projects • TSM&O alternatives such as integrated corridor management, arterial traffic management systems, bus rapid transit, ramp metering, and hard shoulder running • Autonomous and connected vehicles	• Major projects are related to capacity improvement • Congestion management system includes transportation demand management strategies and traffic operations and access management strategies such as ITS and High Occupancy Toll (HOT) lanes • Transportation disadvantage projects	• Planning priority: alternative fuels/vehicles; congestion management; freight; ITS; local priorities of a number of transit, traffic, and safety studies; 2045 LRTP preparation; bicycle/pedestrian safety; regional transit system plan, and transit improvements	• Included in LRTP	• Some pedestrian and bicycle focus area study	• Transit study • Regional freight logistic zone • Ridesharing

MPO/ TPO/ TPA	LRTP	TIP	UPWP	CMP	Pedestrian/Bicycle Program	Others
Hillsborough MPO	5 performance areas: • Preserve the system in terms of pavement, bridge, and transit fleet • Reduce crashes and vulnerability through safety enhancement projects and investments to reduce hurricane and see-level rise impacts • Minimize traffic for drivers and shippers by congestion management for drivers and freight including intersection, signalization, incident management and ITS projects • Real choices when not driving: transit/bus service and transportation disadvantaged service; trails and sidepaths • Major investments for economic growth: key economic spaces; strategic intermodal system; development based needs; and long range vision	• The projects are prioritized and selected based on the five performance areas listed in LRTP	System and corridor planning in addition to transportation planning management • ITS, congestion management and crash mitigation planning • Security and emergency preparedness planning • Complete streets and non-motorized planning • Intermodal/freight planning • Transit and TDM planning • Transportation disadvantaged planning • Corridor, sub-area and environmental studies	• Included in LRTP	• Developed Comprehensive Bicycle and Pedestrian Plan • Maintain a Livable Roadways document	• Planning for health • Demographic and economic data production • Land use comprehensive plan • Tampa Bay Regional Goods Movement study • Vision zero for safety • Hillsborough River protection plan • ITS master plan

2.2.3 FDOT Project Development and Environment (PD&E) Studies

Five steps are involved in a typical transportation development process: 1) Long range planning; 2) Project development and environmental (PD&E) study; 3) Design; 4) Right-of-way acquisition; and 5) Construction. As the second step of this process, a PD&E study is conducted to ensure that transportation improvements comply with the requirements of the National Environmental Policy Act (NEPA) or the state requirements regarding environmental impacts. The more detailed steps of the FDOT Project Development and Environmental (PD&E) studies may require more detailed analysis than the one that can be provided by a sketch planning tool like FITSEVAL. More detailed modeling analyses such as those based on data analytics, the highway capacity manual facility procedures, or simulation are needed. During a PD&E study, the location and conceptual design of feasible build alternatives as well as their social, economic, and environmental impacts for transportation improvements are determined. The environmental conditions without build are also documented in the study. A PD&E study is finalized when the environmental documents are reviewed and approved by FHWA or FDOT District Secretary or Delegated Authority. To improve the efficiency of transportation decision making process, the PD&E study can be overlapped with design phase or conducted concurrently.

The Project Development and Environmental (PD&E) Manual developed by FDOT provides a framework for consistent development of transportation projects that comply with federal and state laws and also ensures the uniformity in their quality and exactness. The PD&E manual consists of two parts. Part 1 provides the guidance regarding project development process and required documentations. Part 2 focuses on each topic involved in a PD&E study and associated analysis. Below is a list of those topics and analysis covered in the PD&E manual Part 2.

- ***Project description and purpose and need***
- ***Traffic analysis***: This includes traffic analysis objectives, level of traffic analysis assessment, performance measures of effectiveness, traffic analysis tool, type and duration of data collection, project traffic forecasting with and without travel demand models, traffic analysis when capacity exceeds traffic demand and vice versa, historical crash analysis and quantitative safety analysis, environmental analyses, and project traffic analysis report.
- ***Engineering analysis***: This includes the level of detail of analysis, project coordination, preliminary engineering analysis of existing conditions, alternative analysis (including no-action alternative, TSM&O alternative, multimodal alternatives, and build alternatives), engineering considerations of build alternatives ranging from multimodal impacts and strategies to construction, utility, and storm water management, environmental consideration for build alternatives, comparative alternatives evaluation, value engineering, recommended alternative, and documentation.
- ***Sociocultural and aesthetic effects evaluation***
- ***Natural resources****:* Farmland, publicly owned parks, recreation area, wildlife and waterfowl refuges, wetlands and other surface waters, aquatic preserves and outstanding Florida waters, water quality and water quantity, wild and scenic rivers, floodplains,

coastal zone consistency, coastal barrier resources, protected species and habitat, and essential fish habitat.

- ***Cultural resources***: Archaeological and historic resources
- ***Physical impacts***: Highway noise, air quality, contamination, utilities and railroads
- ***Project commitments and FDOT commitment tracking***

2.2.4 FDOT Traffic Engineering and Operations

The mission of FDOT Traffic Engineering and Operations Office is to *"improve safety and mobility through the efficient application of traffic engineering principles and practice"* (FDOT, 2018a). The implementation of this mission is carried out by providing the following programs and services: traffic services, transportation systems management and operations (TSM&O), Traffic Incident Management (TIM) and Commercial Vehicle Operations (CVO), and traffic system.

Traffic Services

The traffic services provided by FDOT Traffic Engineering and Operations Office include traffic studies, intersection operations and safety, signing and pavement marking, signals, and aging road users. Traffic studies are conducted to evaluate transportation system. They typically consist of data collection, traffic volume projection, and identification of improvements for transportation system including intersection and non-intersection roadway segments, signals, and speed zones. A Manual on Uniform Traffic Studies was developed by FDOT to provide minimum standards for conducting traffic studies on the roads managed by FDOT. To improve intersection safety, FDOT focuses on Intersection Control Evaluation (ICE). In an ICE process, intersection control alternatives are quantitatively compared and ranked based on their impacts on operational and safety performance. FDOT is also responsible for providing a uniform system of traffic signal, signs, and pavement marking that comply with the national standards, and improving the safety and mobility of aging road users.

FDOT Transportation System Management and Operations (TSM&O) Program

Currently, FDOT TSM&O program focuses on six areas, including connected vehicle, ITS communications, managed lanes, management and deployments, software and architecture, and Statewide Arterial Management Program (STAMP). Below is a brief review of each program.

Connected Vehicle (CV): Connected vehicle is a new FDOT initiative that aims at applying automated and connected vehicle technologies to improve safety and mobility for all modes of travel. Currently, there are one CV project in operation, 10 CV projects in design and implementation, and five CV projects in planning in Florida. Table 2-2 summarizes those 16 CV projects and their focus areas.

Table 2-2 FDOT CV Projects and Their Focus Areas

Project	Project Status	Focus Areas
Osceola County Connected Vehicle Signals	In operation	• Testing Dedicated Short Range Communications (DSRC) equipment and intersection processing equipment
US 90 Signal Phase and Timing in Tallahassee	In design/ implementation	• Testing and implementation of Signal Phase and Timing (SPaT)
I-75 Florida's Regional Advanced Mobility Elements (FRAME) in the Cities of Gainesville and Ocala	In design/ implementation	• Testing automated traffic signal performance measures and connected vehicle technologies such as roadside units and on board units for effective traffic operations • Transit signal priority • Freight signal priority • Disseminate real-time information to motorists during freeway incidents
GAToRS in Gainesville	In design/ implementation	• Autonomous transit shuttle
Florida's Turnpike Enterprise SunTrax in Polk County	In design/ implementation	• Large-scale test facility for toll equipment, CV and AV technology for vehicle-to-vehicle, vehicle-to-infrastructure, vehicle-to-everything communication
THEA Connected Vehicle Pilot in Tampa	In design/ implementation	• Applications related to emergency electronic brake light warning, end of ramp deceleration warning, and forward collision warning • Wrong-way entry • Pedestrian safety-related applications such as pedestrian collision warning and pedestrian in a crosswalk vehicle warning • Pedestrian mobility • Pedestrian transit movement warning • Intelligent signal system • Intersection movement assist • Probe data enabled traffic monitoring • Transit signal priority • Vehicle turning right in front of transit vehicle
City of Orlando Greenway/Pedestrian Safety	In design/ implementation	• Pedestrian and bicycle collision avoidance • Optimization of traffic signal operations
SR 434 Connected Vehicle Deployment in Seminole County	In design/ implementation	• Signal Performance Metrics (SPM) • SPaT • Transit signal priority • Signal preemption

Project	Project Status	Focus Areas
Downtown Tampa Autonomous Transit Phase 1	In design/ implementation	• Low-speed, autonomous last-mile shuttle service out of mixed traffic
Orlando Smart Community 2017 ATCMTD	In design/ implementation	• Connecting three CV programs: PedSafe, GreenWay, and Smart Community • PedSafet program: Reduction of pedestrian and bicycle crashes by connecting advanced signal controller, CV technologies, and existing communication capabilities • GreenWay: Active management of traffic signals • SmartCommunity: Ridesharing and car-sharing
UF Accelerated Innovation Deployment in Gainesville	In planning	• Passive pedestrian and bicyclist detection • Real-time notification to transit, motorists, pedestrians, and bicyclists • SPaT data broadcasting with active pedestrian/bicyclist detection using roadside units
UF I-STREET in Gainesville	In planning	• Real-world test bed demonstration and testing of emerging technologies through partnership among different agencies
Gainesville SPaT Trapezium	In planning	• Improve travel time reliability, safety, throughput, and traveler information • Pedestrian and bicyclist safety applications in terms of web-based and smartphone-based applications
Central Florida Autonomous Vehicle Proving Ground	In planning	• AV research and development across all modes of travel through Central Florida AV partnership
Driver Assisted Truck Platooning (DATP) Pilot	In planning	• Impacts and feasibility of implementing driver assisted truck platooning

ITS Communications: ITS Communications supports telecommunications that are related to ITS deployments and operations. The work conducted by ITS Communications includes: manage, maintain, and update the statewide ITS Wide Area Network, guide the deployment of statewide fiber optic network, manage the statewide radio license database of the Federal Communications Commission, and manage the Wireless General Manager Agreement.

Managed Lanes: Managed lane is one of the high priority focus areas for FDOT TSM&O program. FDOT provides statewide guidance and procedures regarding managed lane implementation and operations. An express lane manual is being developed by FDOT Central Office and Florida Turnpike. FDOT is planning to provide additional express lanes that allows travelers to have more mobility choice, more accurate data collection for performance, and better decision making and planning for the future demand.

Management and Deployments: ITS management and deployment program manages the statewide funds on ITS deployments along five principal corridors with limited access in Florida. It provides technical, management, and administrative support to each aspect of ITS projects, including planning, architecture, standards, deployment, integration, operations, maintenance, telecommunication, and mainstreaming.

Software and Architecture: The ITS software and architecture-related functions of FDOT TSM&O program include the management of the statewide ITS Architecture and the SunGuide software, coordinate ITS training, and the unification of traffic information and management system for the statewide ITS traffic data.

Statewide Arterial Management Program (STAMP): The goal of STAMP program is to maximize throughput and provide a safe, reliable, and efficient arterial transportation system. The current focus of this program is to test Adaptive Signal Control Technology (ASCT) and provide guidance regarding the implementation of ASCT.

It should be noted that each FDOT District has its own TSM&O program that customizes the TSM&O concepts and applications to their local needs.

Traffic Incident Management (TIM)/Commercial Vehicle Operations (CVO)

Traffic incident management program explores ways to fast detect and respond to incidents through multi-agency collaborations. It also provides training for incident responders, free road ranger service to assist travelers, and Rapid Incident Scene Clearance (RISC) initiative (an incentive-based program) to help clear major incidents and truck crashes. In addition, as one of Florida’s innovative strategies, Emergency Shoulder Use (ESU) is planned to cover roadway sections along I-4, I-10, and I-75 during major hurricane evacuations.

Commercial vehicle operations cover the activities such as fleet administration and maintenance, commercial vehicle administration, electronic clearance, weight-in-motion, roadside CVO safety, on-board safety monitoring, hazardous material planning and incident response, freight administration, freight in-transit monitoring, and freight terminal management.

Traffic Systems

The FDOT Traffic System division conducts the technical testing and evaluation of transportation devices, develops standards and specifications for all traffic control signals and devices sold or installed in Florida, and manages Florida approved product list.

2.3 EXISTING TOOLS

The section review existing tools, other than FITSEVAL, that have been produced to support the business processes identified in Section 2.2.

2.3.1 SHRP2 L05 Reliability Implementation Guidance

SHRP2 L05 project recommended approaches to incorporate reliability measures into transportation planning and programming processes (FDOT, 2016d). This project recommends that travel time reliability measures to be considered in the following planning and programming products of FDOT. This is an indication that FITSEVAL is a good tool to use for these applications.

- State and metropolitan long-range transportation plan
- Congestion management process
- Studies that examine only portion of transportation system such as corridor, area, and modal studies
- Transportation improvement plan
- Plan for operations or plan for special events, adverse weather and other similar events
- Project development processes such as planning studies, PD&E studies, and design
- Environmental reviews
- Construction and work zone planning
- System operations and management

2.3.2 Recommended FDOT Traffic Analysis Tools

A Transportation Analysis Handbook was developed by FDOT to provide guidance and requirements for a uniform and consistent application of traffic analysis tools in Florida (FDOT System Planning Office, 2014). Within this handbook, a number of traffic analysis tools are summarized for different levels of analysis, as shown in Table 2-3. Table 2-4 lists the traffic analysis software by system element, while Table 2-5 summarized the safety analysis tools.

Table 2-3 Recommended FDOT Traffic Analysis Tools (FDOT System Planning Office, 2014)

Analysis Type	Level of Detail	Level of Analysis	Analysis Tool
Sketch Planning	Analyzing system elements to obtain general order-of-magnitude estimates of performance based capacity constraints and operational control	Generalized Planning	GSVT, LOSPLAN, HCM/HCS
Deterministic	Analyzing broad criteria and system performance based on geometric and physical capacity constraints; operational systems such traffic control and land use	Conceptual Planning & Preliminary Engineering; Design; Operation	LOSPLAN, HCM/ HCS, Synchro, SIDRA
Travel Demand Modeling	Analyzing regional travel demand patterns, land use impacts and long range plans. Outputs of demand models are applied in analytical and microscopic analysis	Conceptual Planning	Cube Voyager
Microscopic Simulation	Analyzing system performance based on detailed individual user interactions; geometry and operational elements	Preliminary Engineering; Design; Operation	CORSIM, VISSIM, SimTraffic

Table 2-4 FDOT Traffic Analysis Software by System Element (FDOT System Planning Office, 2014)

Facility	Level of Analysis	Project Need	Performance MOE	Recommended Software
Limited Access	Generalized Planning	Determining a need for additional capacity	LOS	GSVT, LOSPLAN
	Conceptual Planning	Determining number of lanes	LOS	LOSPLAN, HCS
	Preliminary Engineering and Design	Determining how the facility will operate	LOS, density, speed, Travel time	HCS CORSIM, VISSIM
	Operational	Determining how well the facility operates	LOS, density, speed, Travel time	HCS CORSIM, VISSIM
Interchanges	Conceptual Planning	Determining capacity of the weaving segment	Flow rate, LOS	HCS
	Preliminary Engineering and Design	Determining capacity of the weaving segment or ramp merge/diverge	Density, speed, LOS	HCS
		Evaluating effect of a queue backup from the ramp terminal to the weaving operation	Queue length	SYNCHRO, VISSIM, CORSIM
		Analyzing weaving from ramp terminal to the nearest signalized intersection	Speed, density	VISSIM/CORSIM
		Evaluating the operation of the entire interchange	Density, speed,	SYNCHRO, CORSI, VISSIM
	Operational	Evaluating weaving operation	LOS, density	HCS, SYNCHRO, VISSIM, CORSIM
Urban Arterials	Generalized Planning	Determining a need for additional capacity	LOS	GSVT, LOSPLAN
	Conceptual Planning	Determining number of lanes	LOS	LOSPLAN, HCM/HCS
	Preliminary Engineering and Design	Determining how the facility will operate	Speed	HCS
		Optimizing signals	Control delay, queue, V/C ratio	SYNCHRO/SIMTRAFFIC
	Operational	Coordinating traffic signals	Travel time, speed	SYNCHRO
		Evaluating existing signal timing plans	Travel time, speed	HCS, SYNCHRO
		Checking the effect of technology application or traffic demand management strategy	Travel time, speed	SYNCHRO/SIMTRAFFIC, VISSIM,CORSIM
Rural two-lane highways and Multilane highways	Generalized Planning	Determining a need for additional capacity	LOS	GSVT, LOSPLAN
	Conceptual Planning	Determining number of lanes	LOS	LOSPLAN, HCS
	Preliminary Engineering and Design	Determining how the facility will operate	LOS	HCS
	Operational	Determining how well the facility operates	LOS	HCS
Intersections	Conceptual Planning	Determining a need for additional intersection capacity	LOS, V/C, delay	HCS
	Preliminary Engineering and Design	Designing isolated intersection	LOS, V/C, delay	HCS, SYNCHRO
		Analyzing closely spaced intersections	LOS, V/C, delay, queue length	SYNCHRO/SIMTRAFFIC
		Analyzing unconventional (or complex) intersection	LOS, V/C, delay, queue length	CORSIM, VISSIM
		Analyzing multimodal interactions	LOS	VISSIM, HCS
	Operational	Evaluating the performance of signalized intersection	LOS, V/C, control delay, queue, ,Phase Failure	HCS, SYNCHRO
Roundabouts	Conceptual Planning	Evaluating the need for roundabout	V/C, LOS	SIDRA, HCS
	Preliminary Engineering and Design	Analyzing roundabout	V/C, LOS	SIDRA, HCS, SYNCHRO
	Operational	Evaluating the performance of roundabout	V/C, LOS, delay	SIDRA, HCM, SYNCHRO

Facility	Level of Analysis	Project Need	Performance MOE	Recommended Software
Networks & Systems	Planning	Forecasting system-wide future demand	vehicle-miles traveled, V/C	GSVT, LOSPLAN, CUBE, HCS
	Preliminary Engineering and Design	Evaluating the performance of the entire network/system	Speed, travel time, LOS, vehicle-miles traveled	SYNCHRO/SIMTRAFFIC, CORSIM, VISSIM
	Operational	Evaluating the performance of the entire network/system	Speed, travel time, LOS	SYNCHRO/SIMTRAFFIC, CORSIM, VISSIM
Multimodal Transportation District (MMTD)	Planning	Planning level assessment of different modes	LOS	GSVT, LOSPLAN, HCS
	Design and operational	Evaluate alternative multimodal improvements	Travel time, LOS, queue	VISSIM
		Assessing quality of service on a multimodal corridor	Travel time, LOS, queue, transit reliability	HCS, VISSIM

Table 2-5 FDOT Levels of Analysis and Safety Analysis Tool (FDOT System Planning Office, 2014)

Level of Analysis	Project Need	Performance MOE	Tool
Generalized Planning	Identify sites likely to benefit from a safety improvement	Crash Frequency	HSM Part B and D; CMF Clearinghouse, SafetyAnalyst
	Predicting future performance of an existing facility	Crash Frequency	HSM Part C, IHSDM
Conceptual Planning	Identifying locations with higher-than-expected crashes	Crash frequency and severity	SafetyAnalyst—Network Screen Tool
	Identifying safety issues and alternative solutions	Crash Frequency	HSM part B and D, SafetyAnalyst, CMF Clearinghouse
	Identifying ways to improve safety as part of a traffic impact study	Crash Frequency	HSM Part B and D, SafetyAnalyst, CMF Clearinghouse
	Assessing safety performance of different conceptual corridor designs related to changes in roadway geometry or operation	Crash Frequency	HSM Part C and D, IHSDM, CMF Clearinghouse
Preliminary Engineering and Design	Improving the performance of a roadway facility from a capacity or safety perspective	Crash Modification Factors (CMFs)	HSM Part D, CMF Clearinghouse
	Compare the effect on safety of different improvement alternatives	Crash frequency	HSM Part D, CMF Clearinghouse
	Predicting future performance of a proposed facility based on different design attributes	Crash frequency	HSM Part C, IHSDM
Operational	Estimating the change in crashes as the result of implementing countermeasures	Crash Modification Factors (CMFs)	HSM Part D , CMF Clearinghouse
	Identify countermeasures to reduce crash frequency and severity	Crash frequency and severity	HSM Part B, SafetyAnalyst—Counter measure evaluation
	Assess the effect of existing roadway element such as on-street parking, shoulder, etc.	Crash frequency	HSM Part B, SafetyAnalyst
	Monitoring safety of an existing facility	Crash frequency	HSM Part B, SafetyAnalyst

2.3.3 FDOT District Two Level of Service (LOS) Reporting Tools

The FDOT District Two developed two web-based level of service reporting tools, one for highways, and another one for bicycle and pedestrians, as shown in Figures 2-1 and 2-2. Both LOS reporting tools provide interactive map functions that allow users to configure map layout, search location and attributes, and generate LOS reports. Figure 2-3 shows an example of LOS report generated by the LOS reporting tool. These two LOS reporting tools ease the annual update of LOS.

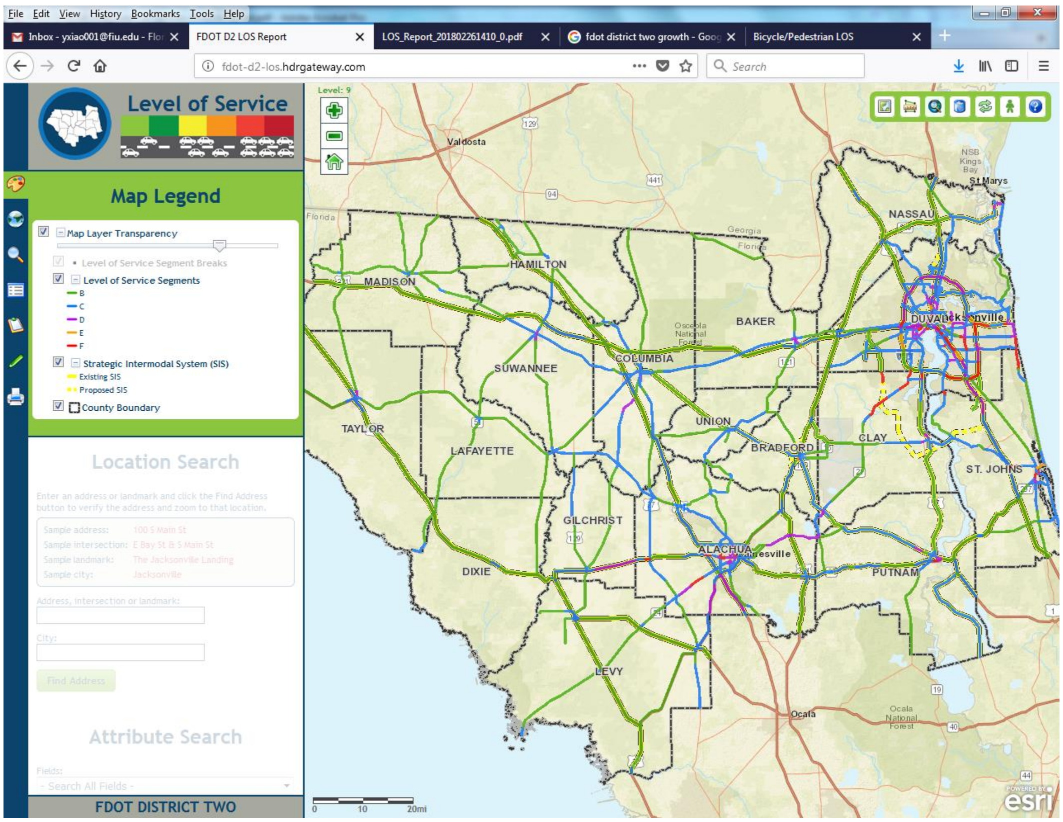


Figure 2-1 User Interface Snapshot of FDOT District Two LOS Reporting Tool

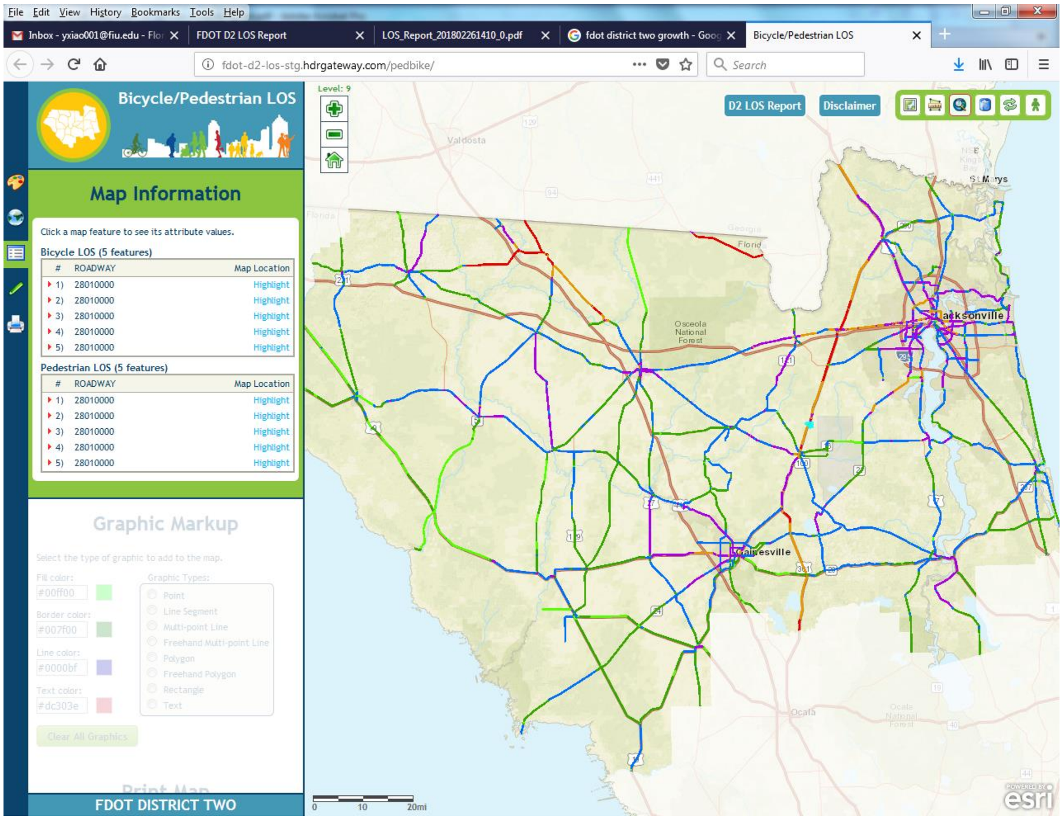
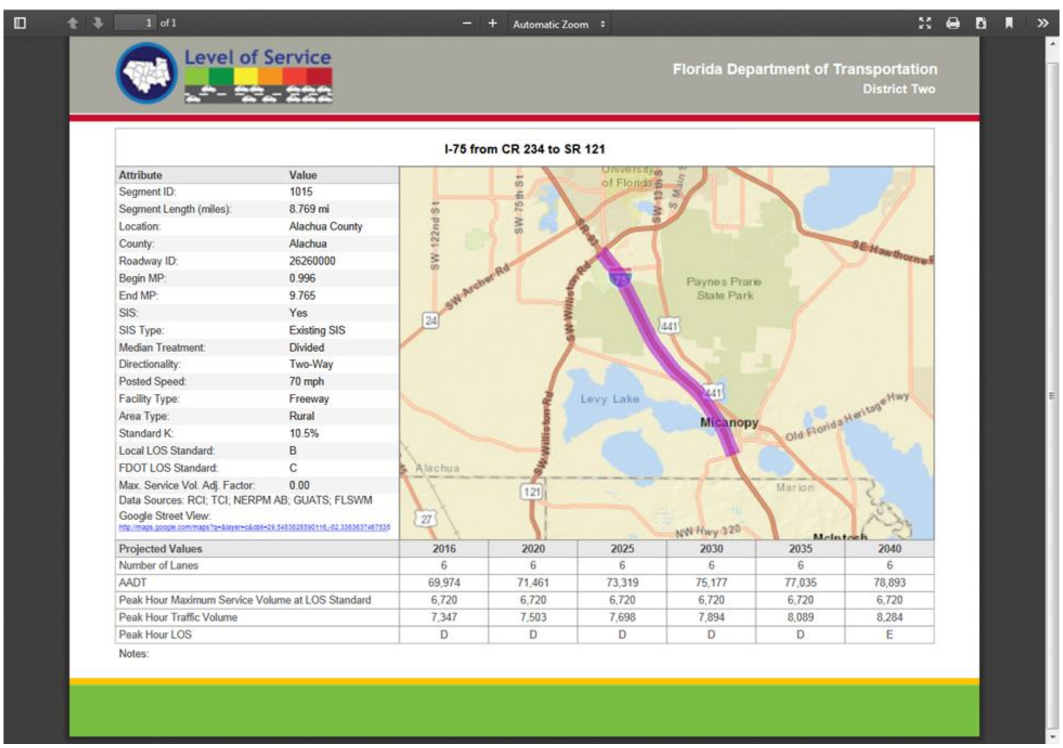


Figure 2-2 User Interface Snapshot of FDOT District Two Bicycle and Pedestrian LOS



I-75 from CR 234 to SR 121

Attribute	Value
Segment ID:	1015
Segment Length (miles):	8.769 mi
Location:	Alachua County
County:	Alachua
Roadway ID:	26260000
Begin MP:	0.996
End MP:	9.765
SIS:	Yes
SIS Type:	Existing SIS
Median Treatment:	Divided
Directionality:	Two-Way
Posted Speed:	70 mph
Facility Type:	Freeway
Area Type:	Rural
Standard K:	10.5%
Local LOS Standard:	B
FDOT LOS Standard:	C
Max. Service Vol. Adj. Factor:	0.00

Data Sources: RCI; TCI; NERPM AB; GUATS; FLSWM
Google Street View:

Projected Values	2016	2020	2025	2030	2035	2040
Number of Lanes	6	6	6	6	6	6
AADT	69,974	71,461	73,319	75,177	77,035	78,893
Peak Hour Maximum Service Volume at LOS Standard	6,720	6,720	6,720	6,720	6,720	6,720
Peak Hour Traffic Volume	7,347	7,503	7,698	7,894	8,089	8,284
Peak Hour LOS	D	D	D	D	D	E

Notes:

Figure 2-3 Example of LOS Report Generated by the FDOT District Two LOS Reporting Tool

2.3.4 SHRP 2 C11 Post-Processor Tool

The C11 sketch planning post-processor was originally developed by Cambridge Systematics, Inc. to help the Hillsborough County MPO in Tampa, FL, to estimate the safety and travel time reliability performance measures (Cambridge Systematics, Inc., 2016). This tool was further enhanced by implementing more robust technical relationships and re-programming for easy usage through a FDOT SHRP2 implementation assistance project. Figure 2-4 illustrates the basic structure of the C11 post-processor tool (Margiotta and Alden, 2016). As shown in this figure, the required input to the C11 post-processor tool includes crash data and loaded network from travel demand model. In the C11 post-processor, the number of crashes (including total crashes, fatalities, injuries, and PDOs) for each link are calculated based on based on the Florida-specific safety performance functions. The safety improvements resulted from countermeasures are captured through crash reduction factors recommended by FHWA's Desk Reference and the CMF Clearinghouse. Different percentiles of travel time index, including 50th percentile, 80th percentile, and 95th percentile travel time index, are calculated as a function of mean travel time index. Such relationships are obtained through a regression analysis over multiple freeway and arterial corridors using the National Performance Management Research Data Set (NPMRDS) data. The mean travel time under normal conditions is derived based on the modified Davidson volume-delay function. The impacts of non-recurrent congestions on delays due to incidents are considered by applying a lookup table for incident-related delays. The costs for operations and ITS strategies are also provided by the C11 post-processor, which can be combined with the improvements in safety and travel time reliability to prioritize projects.

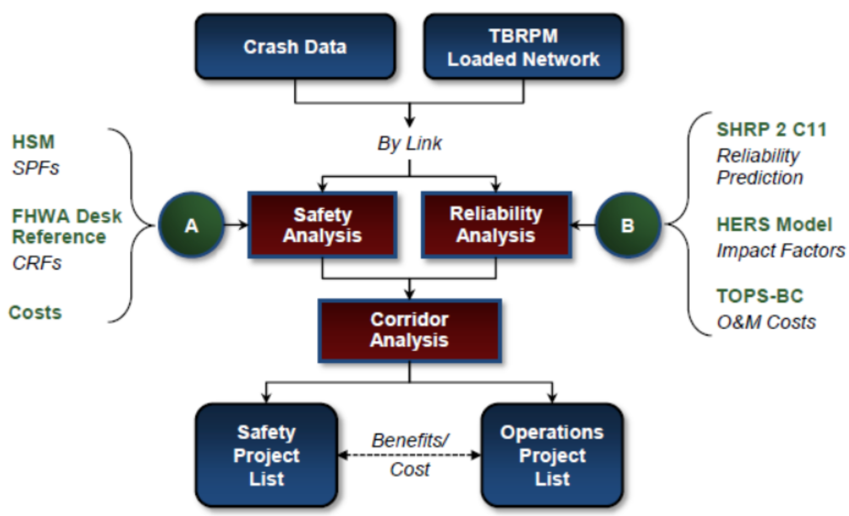


Figure 2-4 Basic Structure of C11 Post-Processor Tool (Margiotta and Alden, 2016)

2.3.5 Analysis Tools and Methods in Planning for Operations

With the sponsorship of FHWA, Jeannotte et al. (2009) provided recommendation to help planners and operation personnel systematically use existing analysis tools and methods to analyze, assess, and report the benefits of transportation operation improvements. It was mentioned that six methods and tools or their combinations are used in practice by planning and operation agencies, including sketch planning tools, deterministic models such as HCM procedures, travel demand forecasting models, macro-, meso-, and microscopic simulation tools, archived operations data, operations-oriented performance measures/metrics, and signal optimization tools. Table 2-6 presents transportation planning needs and corresponding operational analysis tools recommended in this brochure. Each of these tools has advantages and disadvantages, as shown in Figure 2-5. Agencies have to select analysis tools based on project characteristics and also available analysis resources and effort. This study identifies the challenge that there are only few established tools and methods for evaluating operational strategies at a regional scale. It also emphasizes the needs of additional guidance on using existing tools and methods for evaluating operations strategies within the planning process.

Table 2-6 Transportation Planning Needs and Operational Analysis Tools (Jeannotte et al., 2009)

Transportation Planning Needs	OPERATIONAL ANALYSIS TOOLS/METHODS						
	Sketch Planning Tools	Deterministic Models	Travel Demand Forecasting Models	Simulation	Archived Operations Data	Operations-Oriented Performance Metrics	Traffic Signal Optimization Tools
Needs Assessments/ Deficiency Analysis		•	•	•	•	•	•
Preliminary Screening Assessments	•					•	
Alternatives Analysis	•		•	•		•	
Strategic ITS Planning	•		•			•	
Project Scoring/ Ranking/ Prioritizing		•	•			•	
Corridor and Environmental Analysis		•	•	•		•	•
Planning for Nonrecurring Congestion	•		•	•	•	•	
Performance Monitoring		•			•	•	•
Evaluations of Developed Projects	•		•		•	•	

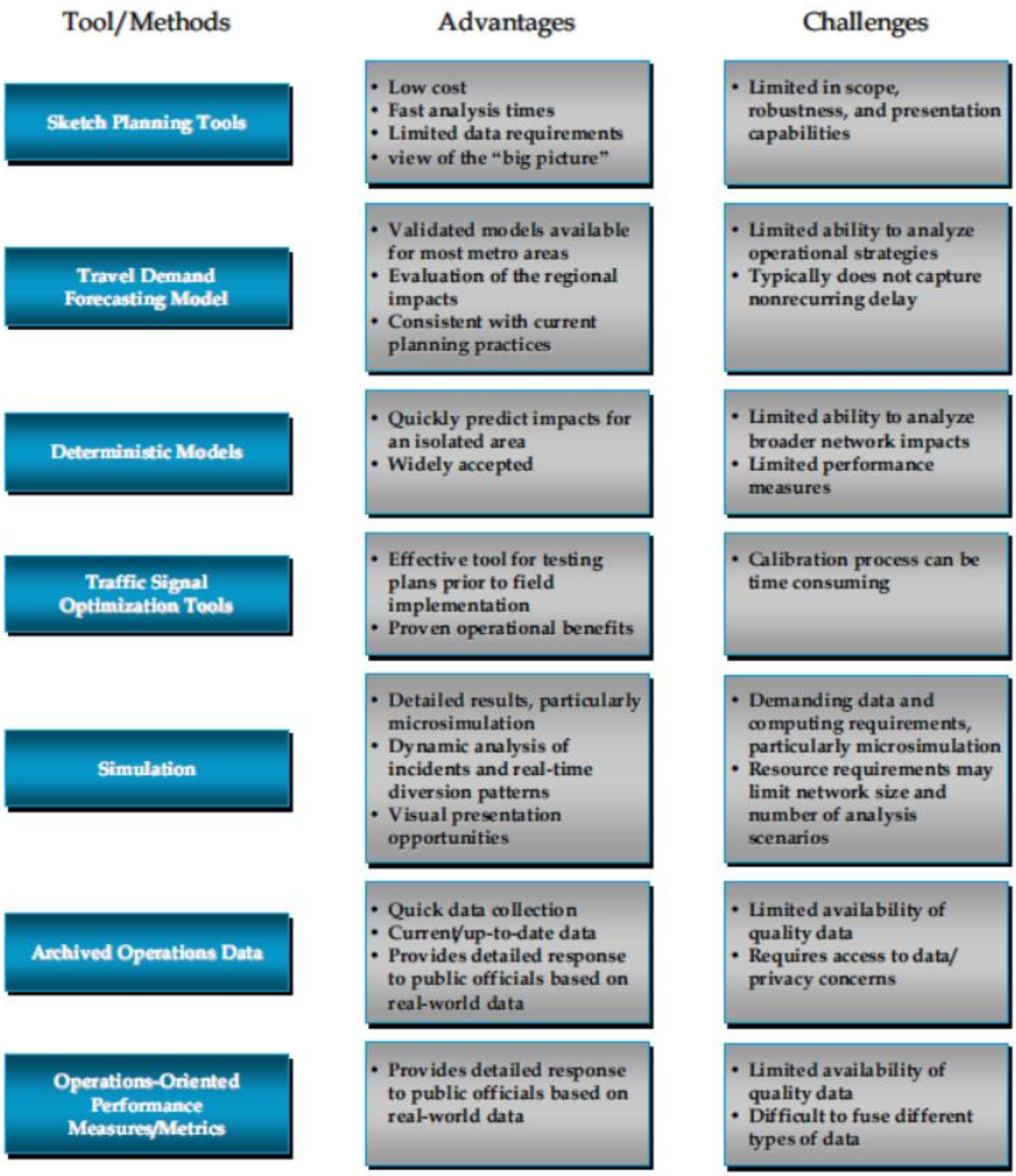


Figure 2-5 Advantages and Disadvantages of Operational Analysis Tools (Jeannotte et al., 2009)

2.3.6 Operations Benefit/Cost Analysis Desk Reference

Sallman et al. (2012) developed an Operations Benefit/Cost Analysis Desk Reference for FHWA. This desk reference intends to introduce basic information regarding benefit/cost analysis, and also provide guidance on how to conducting benefit/cost analysis for operational strategies. Table 2-7 summarizes the existing available tools and methods for benefit/cost analysis and Table 2-8 maps these tools to the strategies that can be analyzed using these tools. Among these tools, Tool for Operations Benefit Cost Analysis (TOPS-BC) and SCRITS developed by FHWA and Cal-BC developed by Caltrans are spreadsheet-based sketch-planning benefit/cost analysis methods. These methods rely on generally available input data and apply static default relationship to estimate the impacts, so they provide a quick, simple, and low-cost estimation of benefits and costs. The benefit/cost analysis tools such as IDAS developed by FHWA and FITSEVAL developed for FDOT are post-processor methods that calculate benefits and costs based on travel demand model. These post-processor methods can assess the impacts and measure of effectiveness beyond travel demand model but they require more analysis efforts. In addition, multiresolution and multiscenario methods can also be applied for benefit/cost analysis, however, they require much more efforts than the previous two types of methods and tools.

Table 2-7 Summary of Existing Benefit/Cost Tools and Methods for TSM&O (Sallman et al., 2012)

Tool/Method	Developed by	Web Site
BCA.Net	FHWA	http://www.fhwa.dot.gov/infrastructure/asstmgmt/bcanet.cfm
CAL-BC	Caltrans	http://www.dot.ca.gov/hq/tpp/offices/eab/LCBC_Analysis_Model.html
COMMUTER Model	U.S. EPA	http://www.epa.gov/oms/stateresources/policy/pag_transp.htm
EMFITS	New York State DOT	https://www.nysdot.gov/divisions/engineering/design/dqab/dqab-repository/pdmapp6.pdf
The Florida ITS Evaluation (FITSEval) Tool	Florida DOT	N/A
Highway Economic Requirements System – State Version (HERS-ST)	FHWA	http://www.fhwa.dot.gov/infrastructure/asstmgmt/hersindex.cfm
IDAS	FHWA	http://idas.camsys.com
IMPACTS	FHWA	http://www.fhwa.dot.gov/steam/impacts.htm
Screening Tool for ITS (SCRITS)	FHWA	http://www.fhwa.dot.gov/steam/scrits.htm
Surface Transportation Efficiency Analysis Model (STEAM)	FHWA	http://www.fhwa.dot.gov/steam/index.htm
Tool for Operations Benefit/Cost (*TOPS-BC*)	FHWA	N/A
Trip Reduction Impacts of Mobility Management Strategies (TRIMMS)	Center for Urban Transportation Research (CUTR) at the University of South Florida	http://www.nctr.usf.edu/abstracts/abs77805.htm

Table 2-8 Available Benefit/Cost Analysis Tools Mapped to Strategies Analyzed (Sallman et al., 2012)

Tool/Methodology	Travel Demand Management	Public Transit Systems	Arterial Traffic Mgmt	CVO	HOT Lanes	Freeway Management Systems	Incident Management Systems	Regional Multimodal Traveler Info	Work Zone Mgmt
BCA.Net			●			●			
Cal-B/C		O	●		●	●	●	●	
COMMUTER Model	●								
EMFITS			●			●	●	●	O
FITSEval			●			●	●	●	
HERS-ST (Preprocessor)			●			●	O		
IDAS	●	O	●	●	●	●	●	●	●
IMPACTS	O		O		O				
Multiresolution/Multiscenario Methods	●	●	●	●	●	●	●	●	●
NET_BC									
SCRITS			●		●	●	●	●	
STEAM			●			●	●	●	
TOPS-BC	O	O	●	O	●	●	●	●	●
TRIMMS	●	●							

● – Addresses most elements of strategy   O – Addresses some elements of strategy

2.3.7 Tool for Operations Benefit Cost Analysis (TOPS-BC)

TOPS-BC is an Excel-based sketch-planning level tool developed by the Federal Highway Administrative (FHWA) Office of Operation to support benefit and cost analysis, as part of the planning for operation initiative (Sallman et al, 2013). Figure 3-6 shows a snapshot of TOPS-BC tool. This tool provides four functions: 1) Investigate the potential impacts of various Transportation System Management and Operations (TSM&O) operation strategies; 2) Recommend evaluation methodology and tools based on use input criteria; 3) Estimate lifecycle costs of different types of deployments including capital cost, replacement cost, and operation and maintenance costs; and 4) Estimate the benefits of particular TSM&O strategies. Below is a list of TSM&O strategies that can be assessed in TOPS-BC.

- Traveler information
  - Dynamic Message Signs (DMS)
  - Highway Advisory Radio (HAR)
  - Pre-Trip travel information
- Traffic signal coordination system
  - Preset timing
  - Traffic actuated
  - Central control
  - Transit signal priority
- Ramp metering systems
  - Central control
  - Traffic actuated
  - Preset timing
- Traffic incident management systems
- Speed harmonization
- Employer based traveler demand management
- Hard shoulder running
- High occupancy toll lanes
- Road weather management
- Work zone
- Supporting strategies
  - Traffic management center
  - Loop detection
  - CCTV

A typical range of impact values are summarized based on literature and recommended to users in this tool. One disadvantage of this tool is that the regional demand model network cannot be directed import to this tool and user has to manually input roadway attributes.

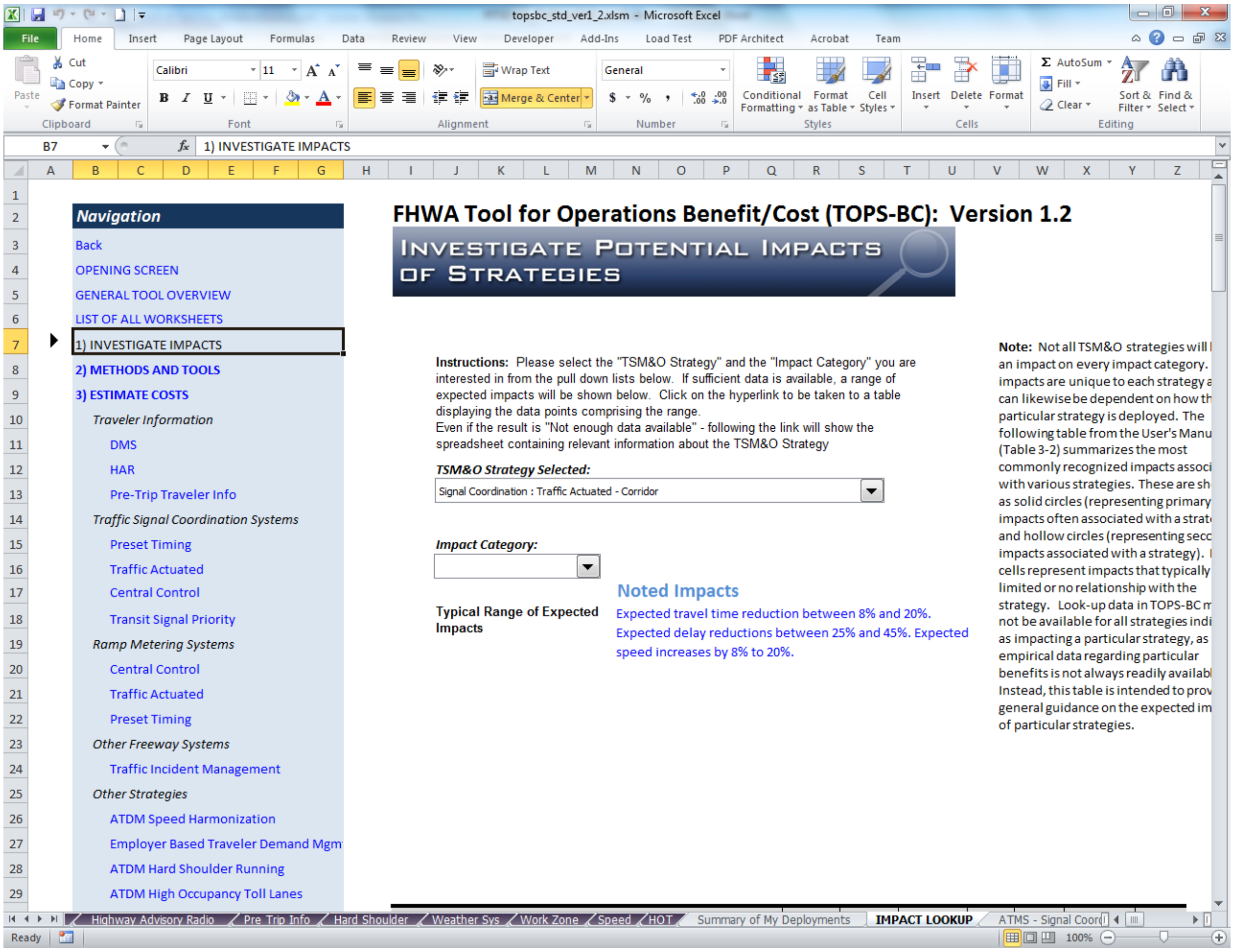


Figure 2-6 Snapshot of TOPS-BC Tool

2.3.8 PLANSAFE

PLANSAFE is a tool developed by Washington et al. (2010) to support regional and statewide safety planning efforts. It can be used to forecast the safety impacts of socio-demographic changes and safety countermeasures. Figure 3-7 shows the steps to evaluate safety projects. As shown in this figure, the core of this analysis is to estimate future baseline safety measures using safety performance functions. These safety performance functions include zone-based socio-demographic variables such as population, number of houses per acre, density of k-12 children, number of schools, average household income, and so on. The impacts of safety countermeasures are considered by applying crash reduction factors. However, PLANSAFE framework is not enough to make project level or site level decisions regarding investment.

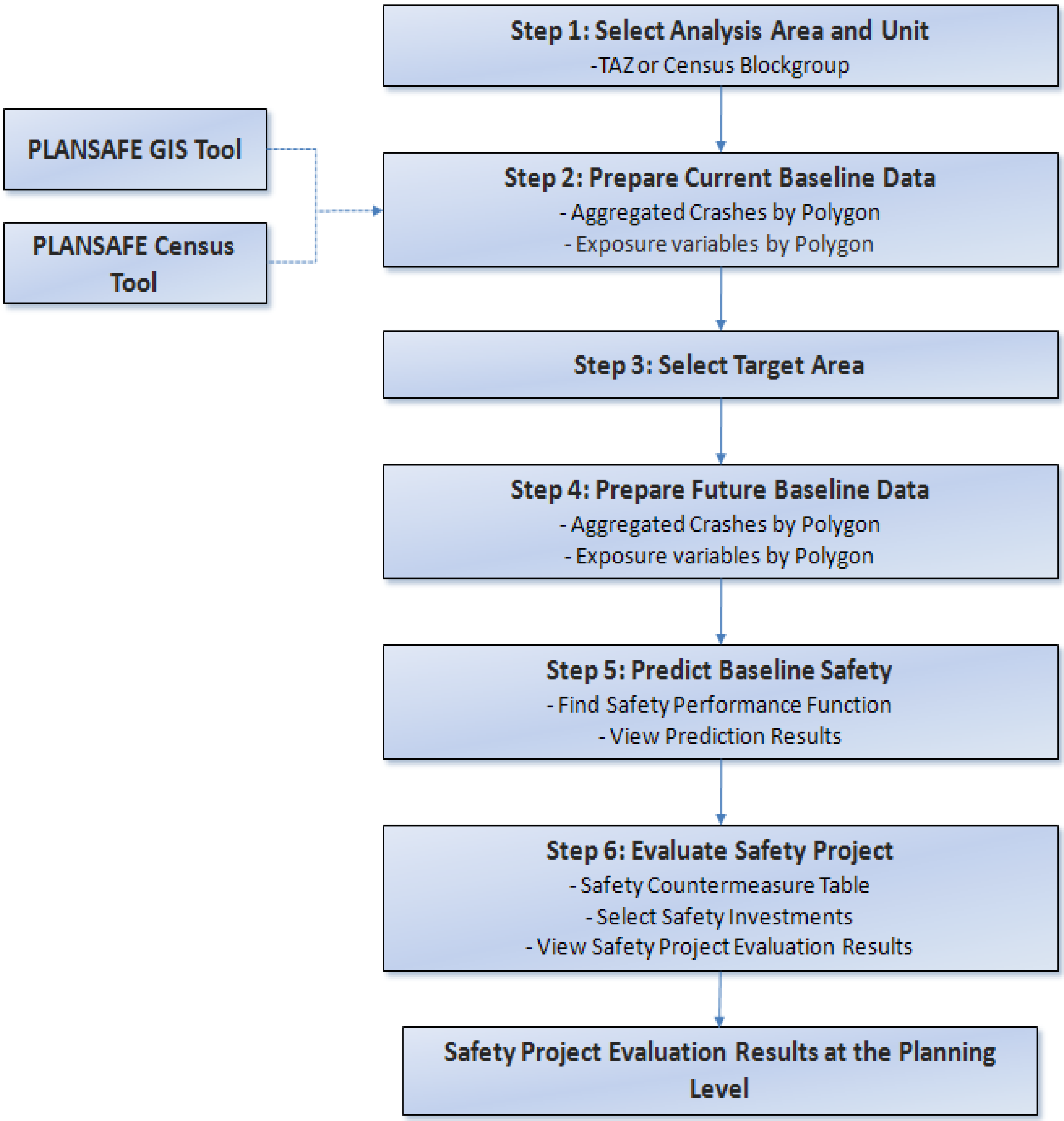


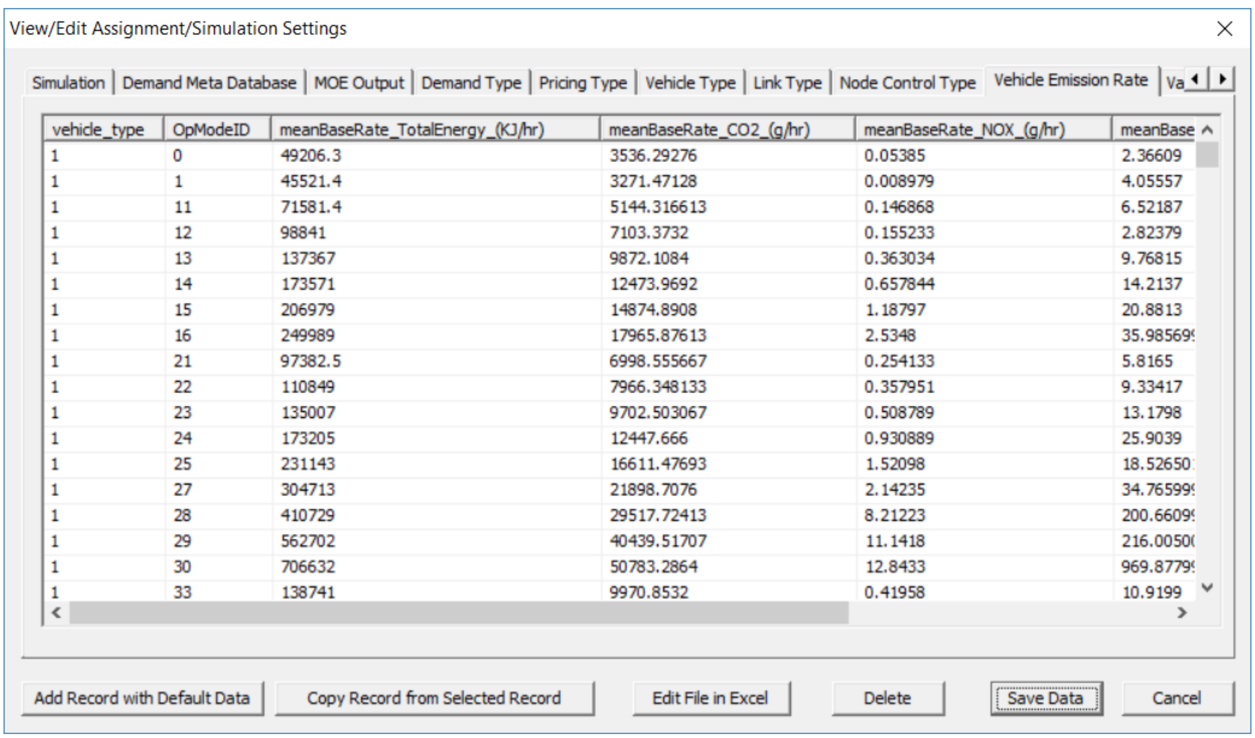
Figure 2-7 Flowchart of PLANSAFE

2.3.9 MOVES

Motor Vehicle Emission Simulator (MOVES) is an emission estimation tool released by the Environmental Protection Agency (EPA). The MOVES model can estimate emissions at three different scales: national, county, and project levels (U.S. Environmental Protection Agency, 2015). The national and county scales are usually used for a large or medium area while the project scale analysis is targeted for small to medium network. The project level is the finest level of vehicle emission estimation in MOVES. It includes three different estimation methods: the average speed approach, the drive schedule approach, and the operating mode distribution approach. The average speed approach is the simplest methods of the three approaches. It estimates emissions based on average speed and vehicle mile travelled by vehicle type. This approach can be integrated with various levels of modelling tools to estimate emission by using the link-based performance measures exported from these models as input. The drive schedule method estimates emissions based on second-by-second speed profiles of vehicles. However, this method only allows the input of one representative speed profile from traffic models. The operating mode distribution approach is a detailed emission estimation approach that requires the input of the distribution of each operating mode. Operating modes are defined based on Vehicle-Specific Power (VSP), vehicle speed, and vehicle acceleration. This information can be generated from mesoscopic or microscopic simulation outputs.

2.3.10 MOVES Lite

As MOVES is a computational intensive emission estimation model requiring a large number of data input, Liu and Frey (2013) developed a simplified and light version of MOVES called MOVES Lite. In MOVES Lite, the parameters, such as temperature, humidity, air conditioning load, fuel properties, and so on, are considered to be constant as modeling and simulation scenarios usually represent a short period of time on a typical day. Such an assumption greatly reduces the computation effort required by the full version of MOVES and leads to a simplified estimation of cycle average emission rates for different operating modes. MOVES Lite has implemented in the dynamic traffic assignment tool, DTALite. Figure 3-8 illustrates the vehicle emission rates used in DTALite.



vehicle_type	OpModeID	meanBaseRate_TotalEnergy_(KJ/hr)	meanBaseRate_CO2_(g/hr)	meanBaseRate_NOX_(g/hr)	meanBase
1	0	49206.3	3536.29276	0.05385	2.36609
1	1	45521.4	3271.47128	0.008979	4.05557
1	11	71581.4	5144.316613	0.146868	6.52187
1	12	98841	7103.3732	0.155233	2.82379
1	13	137367	9872.1084	0.363034	9.76815
1	14	173571	12473.9692	0.657844	14.2137
1	15	206979	14874.8908	1.18797	20.8813
1	16	249989	17965.87613	2.5348	35.98569
1	21	97382.5	6998.555667	0.254133	5.8165
1	22	110849	7966.348133	0.357951	9.33417
1	23	135007	9702.503067	0.508789	13.1798
1	24	173205	12447.666	0.930889	25.9039
1	25	231143	16611.47693	1.52098	18.52650
1	27	304713	21898.7076	2.14235	34.76599
1	28	410729	29517.72413	8.21223	200.6609
1	29	562702	40439.51707	11.1418	216.0050
1	30	706632	50783.2864	12.8433	969.8779
1	33	138741	9970.8532	0.41958	10.9199

Figure 2-8 Snapshot of Vehicle Emission Rates Used in DTALite

2.3.11 Mobility Needs Assessment Tool (MNAT)

Miami-Dade TPO developed a mobility needs assessment tool (MNAT) to support the transportation needs assessment process (Gannett Fleming, Inc. et al., 2014). It can be applied to quickly to assess the mobility impacts of highway and transit improvements for a given corridor without running travel demand model. MNAT is a spreadsheet-based tool. It uses the output of full travel demand model as an initial input, and then estimates the benefits of various capacity improvements such as adding highway lanes, improving operations over existing lanes, and increase transit service in spreadsheets.

2.3.12 Interactive Visualization Tools for Plans

In addition to the previously reviewed analysis tools, interactive visualization tools for various plans, such as long-range transportation plan, transportation improvement plan, strategic plan, and so on, have been used by FDOT and multiple MPOs. These interactive tools not only shows the locations of the projects listed in transportation plans but also provide a description of the project, time frame, costs, and funding agencies. As an example, Figure 3-9 shows the snapshot of the interactive web-based tool for the Metroplan Orlando 2040 long range transportation plan.

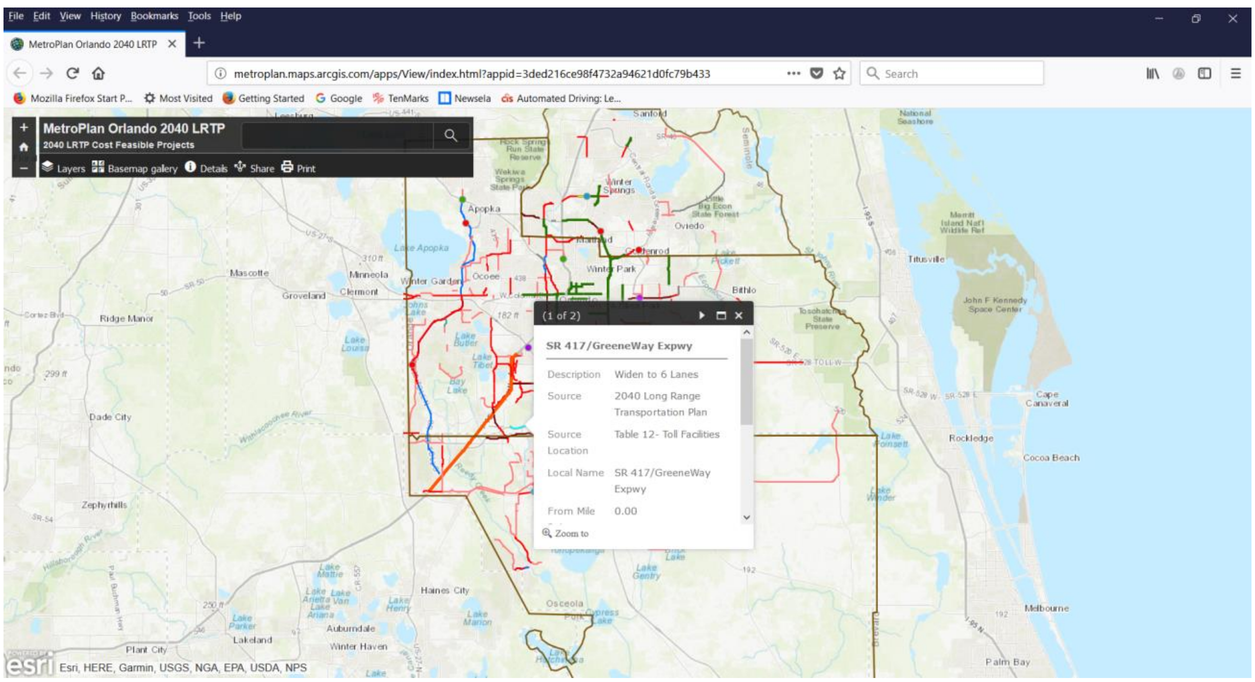


Figure 2-9 Snapshot of the Interactive Web-Based Tool for the Metroplan Orlando 2040 LRTP

2.4 Summary of Potential Support of FITSEVAL

This section discusses how FITSEVAL can be updated to better support for planning and planning for operations based on the reviews presented in the previous sections. Table 2-9 summarizes the FDOT and MPO/TPO/TPA business processes and the corresponding potential applications that can be provided by FITSEVAL to support the decisions. It should be noted that only a subset of these potential application will be implemented in the first version of the updated tool produced as part of this project. Additional applications can be implemented in future versions as needed.

Table 2-9 Potential Support of FITSEVAL for Business Processes

Business Process		Potential FITSEVAL Support
FDOT Planning	Florida Transportation Plan	• Assess the performance metrics that corresponding to each goal for existing conditions based on real-world data, travel demand model, or other modeling methods and tools • Compare alternative improvements and prioritize projects
	Strategic Intermodal System	• Estimate the impacts of alternative improvement on SIS and prioritize projects
	Planning Studies	• Estimate the impacts of alternative improvements and prioritize projects
	Interchange Access Request	• Estimate the impacts of alternative improvements and prioritize projects
	Highway Capacity/LOS	• Calculate LOS • Estimate the impacts of highway capacity improvement and advanced strategies and technologies
	Statistics, Measures, and Trends	• Produce data-based statistics, measures, and forecasting
	Performance Measures	• Produce data-based and model-based performance measures that are required by MAP-21, FAST Act, and state rules
MPO/TPO/TPA	Long Range Transportation Plan	• Calculate performance measures that corresponding to each goal for existing conditions based on data and travel demand model • Compare alternative improvements and prioritize projects
	Transportation Improvement Program	• Compare alternative improvements and prioritize projects

Business Process		Potential FITSEVAL Support
	Unified Planning Work Program	• Calculate performance metrics for complete and ongoing projects • Compare alternative improvements and prioritize projects
	Congestion Management Process	• Assess the benefits and costs of congestion management strategies
	Bicycle/Pedestrian Program	• Evaluate the benefits and costs of bicycle/pedestrian projects
	Freight Program	• Evaluate freight-related improvements
	Transportation Alternative Program	• Compare alternative improvements and prioritize projects
	Connected and Autonomous Vehicle Program	• Add a new evaluation module for connected and autonomous vehicles in FITSEVAL
	Performance Measurement Program	• Produce performance measures that are required by MPO/TPO/TPA
	Transportation Disadvantaged Program	• Add a new module in FITSEVAL to evaluate the benefits and costs of transportation disadvantaged projects
PD&E Study		• Incorporate emission estimation for alternative projects • Compare alternative improvements and prioritize projects based on more detailed analysis such as Highway Capacity Manual procedures or simulation.
FDOT Traffic Engineering and Operations (Focusing on planning for operations)	Traffic Service	• Estimate the impacts of alternative improvements • Compare intersection control strategies
	TSM&O	• Assess the benefits and costs of TSM&O strategies by adding additional evaluation modules
	Traffic Incident Management/Commercial Vehicle Operations	• Update the parameters for incident management evaluation module based on latest data

As required by MAP-21 and FAST Act, planning is moving towards a performance-based process. In each transportation plan, performance measures are specified for each goal and objective. These performance measures are related to the safety, mobility, environment, economy, preservation, to collaboration and agency management objectives. The current version of FITSEVAL focuses on mobility, safety, and reliability.   FITSEVAL can be upgraded as needed in to estimate performance measures related to other measures and show how these measures satisfy the federal and state requirements.

It is also recommended to update FITSEVAL to allow it to read data from multiple sources to estimate the impacts. As explained in this document, the range of the business processes of the FDOT and MPO/TPO/TPA that can be supported by FITSEVAL range from long range plans that require a very high-level analysis to more detailed analysis required in other business process. Thus, it is recommended that the FITSEVAL is modified to base its analysis on other information sources, in addition to demand model outputs, as is done by the previous versions of FITSEVAL. These additional sources can include real-world data and HCS facility procedure outputs. This could even include mesoscopic and microscopic simulation model outputs in future projects, by writing a translator of the outputs of simulation models to the input file format accepted by FITSEVAL.

Assessing the benefits and costs of transportation alternatives and prioritizing improvement project are important tasks conducted in the planning, planning for operation process, and PD&E studies. 13 ITS strategies can be evaluated in the previous version of FITSEVAL as follows:

- Ramp Metering
- Incident Management Systems
- Highway Advisory Radio (HAR) and Dynamic Message Signs (DMS)
- Advanced Travel Information Systems (ATIS)
- Managed Lane
- Signal Control
- Emergency Vehicle Signal Preemption
- Smart Work Zone
- Road Weather Information Systems
- Transit Vehicle Signal Preemption
- Transit Security Systems
- Transit Information Systems
- Transit Electronic Payment Systems

As new experiences with the 13 ITS strategies become available, the evaluation methodology, parameters, and costs used for these strategies can be updated accordingly. Also, with the emerge of new technologies and management strategies that are being considered or will be considered in planning and planning for operations, new modules can be added to FITSEVAL to assess them. The following additional strategies can be considered in new versions of FITSEVAL.

- Roadway capacity improvement for comparison purpose
- Lane control signals
- Hard shoulder running
- Variable speed limit
- Automated, Connected, Electric, and Shared (ACES) vehicles
- Emergency shoulder running
- Transit-related strategies such as exclusive lanes, bus rapid transit, queue jumper, bus bulb-out, enhanced bus, fare pre-payment, and express transit on managed lanes
- Commercial vehicle information system

- Bicycle facility and sidewalk improvement or dedicated bicycle/pedestrian facilities if bicycle and pedestrian data are available
- Complete street
- Advanced parking system

Based on the analysis in this document, it appears like evaluating signal control, connected, and automated vehicles are high priority areas for transportation agencies in Florida.

3. EXISTING PERFORMANCE FORECASTING AND ASSOCIATED TOOLS

Chapter 2 reviewed the agency business processes that are expected to benefit from the enhancements to FITSEVAL. This chapter starts with a review of the national and state guidance and practice on performance measurements, and then focuses on the methods and tools for calculating performance measures.

3.1 National Guidance and Practice On Performance Measurement

Transportation performance management has been defined by the Federal Highway Administration (FHWA) as “a strategic approach that uses system information to make investment and policy decisions to achieve national performance goals” (FHWA, 2017a). Recently, a strong emphasis has been placed on performance management through federal statutes and regulations. This section provides a detailed review of federal regulations and national experience with performance management.

3.1.1 MAP-21 and FAST Act

The Moving Ahead for Progress in the 21st Century Act (MAP-21) was signed into law in 2012. It aims at creating a performance- and outcome-based surface transportation program. The Fixing America’s Surface Transportation (FAST) Act was built upon MAP-21 and signed in 2015. It provides a long-term funding for surface transportation infrastructure planning and investment. The MAP-21 and FAST Act focus on seven areas. Table 3-1 lists these seven areas and the corresponding national goals. The national highway performance program, metropolitan transportation planning (MPO), and statewide transportation planning are required to consider the national goals and the established performance measures in these focus areas. FHWA has published the final rules for each of the seven areas to establish national performance measures. All the measures except the Greenhouse Gas (GHG) measure was effective on May 20, 2017. On May 31, 2018, the Federal Highway Administration (FHWA) published a final rule that repeals the GHG measure. As such, FHWA will no longer require State DOTs and MPOs to establish targets, calculate their progress toward their selected targets, report to FHWA, and determine a plan of action to make progress toward their selected targets of this measure, if they failed to make significant progress during a performance period.

Table 3-1 MAP-21 and FAST Act Focus Areas and National Goals (FHWA, 2013)

Goal Area	National Goal
Safety	To achieve a significant reduction in traffic fatalities and serious injuries on all public roads
Infrastructure condition	To maintain the highway infrastructure asset system in a state of good repair
Congestion reduction	To achieve a significant reduction in congestion on the National Highway System
System reliability	To improve the efficiency of the surface transportation system
Freight movement and economic vitality	To improve the national freight network, strengthen the ability of rural communities to access national and international trade markets, and support regional economic development
Environmental sustainability	To enhance the performance of the transportation system while protecting and enhancing the natural environment
Reduced project delivery delays	To reduce project costs, promote jobs and the economy, and expedite the movement of people and goods by accelerating project completion through eliminating delays in the project development and delivery process, including reducing regulatory burdens and improving agencies' work practices

A total number of 18 measures as shown in Table 3-2 were specified in the new Code of Federal Regulations (CFR) Title 23 Subchapter E Part 490 (23 CFR Part 490) (Cornell Law School, 2018). Table 3-2 also shows the applicability of these performance measures. State DOTs are required to establish performance target within one year from the effective date of the applicable final rules, and MPOs have 180 days to set their performance targets after the determination of state targets. State DOTs and MPOs need to coordinate with each other as well as public transportation providers when setting those targets. Various plans also require performance targets, including metropolitan transportation plans, metropolitan transportation improvement program (TIP), Statewide Transportation Improvement Program (STIP), state asset management plans under the National Highway Performance Program (NHPP), state performance plans under the Congestion Mitigation and Air Quality Improvement program, and Statewide transportation plans. States are required to report their progress toward achieving performance targets, the condition and performance of the National Highway System (NHS), the effectiveness of investment strategies in the State asset management plan for NHS, and how the state is addressing congestion at freight bottlenecks.

Table 3-2 MAP-21 Focus Areas and National Goals (FHWA, 2013)

Area	Performance Measures	Applicability
Safety	• Number of fatalities • Number of serious injuries • Rate of fatalities per 100 million VMT • Rate of serious injuries per 100 million VMT • Number of combined nonmotorized fatalities and nonmotorized serious injuries	• All public roads covered by the Highway Safety Improvement Program (HSIP)
Pavement Condition	• % of interstate pavements in Good condition • % of interstate pavements in Poor condition • % of non-interstate NHS pavements in Good condition • % of non-interstate NHS pavements in Poor condition	• Mainline highways on the Interstate System and on the non-Interstate NHS
Bridge Condition	• % of NHS bridges by deck area classified in Good condition • % of NHS bridges by deck area classified in Poor condition	• Bridges carrying the NHS including on- and off-ramps that connect to the NHS and bridges crossing State borders
National Highway System	• % of reliable person-miles traveled on the interstate • % of reliable person-miles traveled on the non-interstate NHS • % change in trailpipe emissions CO_2 emissions on the NHS as compared to the calendar year 2017 (this measure is later repealed)	• Travel time reliability is applicable to all directional mainline highways on the interstate and non-interstate NHS • The Greenhouse Gas (GHG) measure is applicable to all mainline highways on the interstate and non-interstate NHS (this measure is later repealed).
Freight Movement on the Interstate	• Truck travel time reliability index	• Freight movement on the interstate system

Area	Performance Measures	Applicability

CMAQ	• Traffic congestion
	  • Annual hours of Peak Hour Excessive Delay (PHED) per capita
	  • % of non-SOV travel
	• On-road mobile source emissions
	  • Total emission reductions
		• All urbanized areas that include NHS mileage and with a population greater than 1 million for the first performance period and with a population greater than 200,000 for the other performance periods and that are at least part of nonattainment or maintenance areas for ozone, CO, PM_{10}, and $PM_{2.5}$ National Ambient Air Quality Standards.

The following sessions provide a detailed description of performance measures in each focus area.

3.1.1.1 Safety Performance Measures

The safety performance measures are used by the Highway Safety Improvement Program (HSIP) and for State DOTs to assess serious injuries and fatalities per Vehicle Mile Traveled (VMT) and number of serious injuries and fatalities. The serious injuries are the injuries classified as "A" on the KABCO scale by using the conversion tables developed by National Highway Traffic Safety Administration (NHTSA) before April 15, 2019 and are "suspected serious injury (A) as identified by the Model Minimum Uniform Crash Criteria (MMUCC) guideline after that (Cornell Law School, 2018). Conversion tables are provided by NHTSA to help state to match the injuries reported by state to the serious injuries as defined above (FHWA, 2017b). As shown in Table 3-2, five safety-related performance measures are established by FHWA, including 1) number of fatalities, 2) number of serious injuries, 3) rate of fatalities per 100 MVMT (Million Vehicle Miles Traveled), 4) rate of serious injuries per 100 MVMT, and 5) number of combined non-motorized fatalities and serious injuries.

Each of these measures is calculated based on a 5-year rolling average. The number of motorized/non-motorized fatalities or serious injuries are calculated by summing the number of fatalities or serious injuries for each of the 5 consecutive years, dividing by 5, and then rounding to the tenth decimal place. The rate of fatalities or serious injuries are calculated by first calculating the number of fatalities or serious injuries per 100 MVMT for each of the 5 consecutive years, averaging these 5 numbers, and rounding it to the thousandth decimal place. It should be noted that the ending year of the 5 consecutive years is the year when the target is calculated.

The numbers of fatalities and serious injuries are obtained from the Fatality Analysis Reporting System (FARS) data. If Final FARS data is not available, the data from FARS Annual Report File (ARF) may be used. The state VMT data is are calculated from the Highway Performance Monitoring System (HPMS) and the MPO VMT is calculated by MPO.

State DOTs are required to establish an annual performance target for each of performance measure for all the public roads within the state and report the targets in the HSIP annual report. The information of the 2018 safety performance targets for each state can be found in the FHWA website (https://safety.fhwa.dot.gov/hsip/spm/state_safety_targets/). In addition to the statewide targets, additional targets can be established for portion of the state. MPOs need to establish performance targets by either agreeing to plan and program projects that help State DOT to achieve the performance targets or defining quantifiable performance targets for the metropolitan planning areas that they represent. State DOTs and MPOs should coordinate with each other to ensure the maximum consistency of the performance targets. The State DOT is required to report the targets to FHWA in the State's HSIP annual report. The MPOs need to report their targets, baseline safety performance measures, progress toward the targets to the State DOT annually in a way that is specified by both State DOT and MPOs.

The FHWA will evaluate whether a Sate DOT meets the performance targets first at the end of the calendar year after the targets are established and then annually. If at least four out of five safety performance measures met the targets or are better than the measures for the year prior to the establishment of the State's targets, a State is considered to have met or made significant progress toward the safety performance targets.

3.1.1.2 Pavement Condition Performance Measures

As shown in Table 3-2, four national performance measures are specified to assess pavement conditions, that is, percentages of pavements of the interstate system in Good and Poor condition, and percentage of pavements of the non-interstate NHS in Good or Poor condition (Cornell Law School, 2018). In order to calculate these performance measures, State DOTs are required to collect data for the following four condition metrics, International Roughness Index (IRI), rutting, faulting, and cracking percent for pavement. Since the development of this project are not anticipated to deal with these measures, no further discussion of these measures are presented in this document.

3.1.1.3 Bridge Condition Performance Measures

According to the final rules in 23 CFR Part 490, two performance measures are used to assess bridge conditions, including percentage of NHS bridges by deck area that classified as in Good condition, and percentage of NHS bridges by deck area classified as in Poor condition by deck area. Since the development of this project are not anticipated to deal with these measures, no further discussion of these measures are presented in this document.

3.1.1.4 National Highway System Performance Measures

According to the final rules in 23 CFR Part 490, three performance measures are used to assess National Highway System. Two of them (i.e., percentage of reliable person-miles traveled on the interstate and percentage of reliable person-miles traveled on the non-interstate NHS) are related to travel time reliability and another one is related to the GHG (the GHG measure was later repealed), as shown in Table 3-2. In order to estimate these performance measures, two performance metrics are needed, that is, the Level of Travel Time Reliability (LOTTR) and annual total tailpipe CO_2 emissions. The LOTTR for each HPMS segment is calculated based on one-year 15-minute travel time data between January 1st and December 31st for all vehicles either from NPMRDS or equivalent data set. The units for travel time is in seconds and the numbers are rounded to the nearest integer. Missing travel time data should not be replaced, and the time periods with road closure are also excluded from the calculation of LOTTR. Four LOTTRs are reported annually for each of four time periods: 6-10am, 10am-4pm, and 4-8pm on weekdays and 6am-8pm on weekends. The LOTTR is calculated as the 80th percentile travel time divided by the 50th percentile travel time and rounded to the nearest hundredth. The travel time reliability measures are calculated using the following expression.

$$100 \times \frac{\sum_{i=1}^{R} SL_i \times AV_i \times OF_j}{\sum_{i=1}^{T} SL_i \times AV_i \times OF_j} \tag{3-1}$$

where R is the total number of reporting segments with a LOTTR less than 1.5 during all of the four time periods and T is the total number of reporting segments. SL_i is the length of reporting segment i to the nearest thousandth of a mile. AV is the total annual traffic volume to the nearest single vehicle, which is calculated by Annual Average Daily Traffic (AADT) reported to HPMS in June of the reporting year multiplied by 365 days. OF_j is occupancy factor for vehicles in a geographic area j. The occupancy factor should be obtained from the latest data tables published by FHWA unless other allowable data sources. The latest value of the average vehicle occupancy factor listed by FHWA (2018c) is 1.7 persons per vehicle for travel time reliability measure.

3.1.1.5 Performance Measure for Freight Movement on the Interstate System

Truck Travel Time Reliability (TTTR) index, which is also referred to as the freight reliability measure, is specified in the final rules of 23 CFR Part 490 to assess freight movement on the interstate system. Truck travel time reliability is defined as 95th percentile travel time divided by normal truck travel time (that is, 50th percentile travel time). The travel time data used for the calculation of TTTR can be obtained from NPMRDS or equivalent data set at 15-minute intervals for each reporting segment specified by the HPMS. The unit for travel time is in seconds. If truck travel times are missing or not reported, they can be replaced by the travel time for all traffic on the roadway during the same 15-minute interval. Also, if a NHS roadway is closed for a certain time period, this time period will not be considered in the calculation of TTTR. TTTR is calculated for five time periods, including 6-10 am, 10am-4pm, and 4-8pm on weekdays from Monday to Friday, 6am-8pm on weekends, and 8pm-6am on all days. The freight reliability measure, TTTR index, is calculated as follows.

$$\frac{\sum_{i=1}^{T} SL_i \times \max TTTR_i}{\sum_{i=1}^{T} SL_i} \tag{3-2}$$

where T is total number of reporting segments and SL_i is the segment length for segment *i*. *max* $TTTR_i$ is the maximum TTTR of five time periods for reporting segment *i*. The TTTR index is rounded to the nearest hundredth.

3.1.1.6 Performance Measures for Congestion Mitigation and Air Quality (CMAQ) Improvement Program – Traffic Congestion

Two measures are applied to evaluate traffic congestion based on the final rules in 23 CFR Part 490, including annual hours of Peak Hour Excessive Delay (PHED) per capita and percent of non-SOV travel. The matric of PHED is required to be reported by State DOT by June 15th of each year starting from 2018. In order to calculate PHED metric, a speed threshold is selected by using the value of 20 mph or 60% of the posted speed limit, and the corresponding excessive delay threshold travel time is calculated as follows.

$$Excessive\ Delay\ Threshold\ Travel\ Time_s = \left(\frac{Travel\ Time\ Segment\ Length_s}{Threshold\ Speed_s}\right) \times 3600 \qquad (3\text{-}3)$$

where s refers to a reporting segment.

The delay of a segment (i.e., Road Segment Delay, RSD) is then defined as the difference between the travel time at 15-minute intervals and the above excessive delay threshold travel time. The value of RSD is between 0 and 900 seconds as the maximum delay for a 15-minute calculation interval is 900 seconds. Converting RSD into the units of hour will produce the Excessive Delay measure. The total excessive delay for a one-year period between January 1st and December 31st can be calculated using the following equation.

$$Total\ Excessive\ Delay_s = AVO \times \sum_{d=1}^{TD}\sum_{h=1}^{TH}\sum_{b=1}^{TB}(Excessive\ Delay_{s,b,h,d} \times \left(\frac{hourly\ volume}{4}\right)_{s,h,d} \qquad (3\text{-}4)$$

where TD is total number of reporting days in one year between January 1st and December 31st . TH is total number of hour intervals in a day with only the hours within the peak periods are considered. TB is total number of 15-minute intervals. The 15-minute volume is approximated as the hourly volume divided by 4. AVO is the average vehicle occupancy, which is estimated according to Equation 3-5.

$$AVO = (p^C \times AVO^c) \times (p^B \times AVO^B) + (p^T \times AVO^T) \qquad (3\text{-}5)$$

where p refers to the percentage of share of AADT. AVO is average vehicle occupancy. The superscripts C, B, T represent cars, buses and trucks. Table 3-3 lists the latest values of the average vehicle occupancies published by FHWA (FHWA, 2018c). The annual hours of peak hour excessive delay per capita are calculated by summing the total excessive delays for all the reporting segments and divided by total population published by the U. S. Census, as shown in Equation 3-6.

$$Annual\ Hours\ of\ Peak\ Hour\ Excessive\ Delay\ per\ Capita = \frac{\sum_{s=1}^{T} Total\ Excessive\ Delay_s}{Total\ Population} \qquad (3\text{-}6)$$

Three methods can be applied to calculate the "percentage of non-SOV travel" measure. Method A relies on the American Community Survey and the percentage of non-SOV travel is calculated as 100% minus the percentage of SOV including cars, trucks, or vans. Method B is based on a local survey. Method C obtains this measure based on system use measurement by dividing the annual volume of person travel other than driving alone by the summation of annual volume of person travel while driving alone and other than driving alone. The resulted percentage of non-SOV travel is rounded to the nearest tenth of a percent.

Table 3-3 Annual Average Vehicle Occupancy Factors for Cars, Buses, and Trucks for PHED Metrics (FHWA, 2018b)

Vehicle Types	Applicable Area	Average Vehicle Occupancy Factors
Cars	All	1.7
Buses	Atlanta, GA	10.3
	Baltimore, MD	15.9
	Boston, MA-NH-RI	12.2
	Charlotte, NC-SC	8.5
	Chicago, IL-IN	10.9
	Cincinnati, OH-KY-IN	8.1
	Cleveland, OH	9.6
	Columbus, OH	5.7
	Dallas-Fort Worth-Arlington, TX	5.1
	Denver-Aurora, CO	9.2
	Detroit, MI	10.7
	Houston, TX	10.3
	Indianapolis, IN	5.8
	Las Vegas-Henderson, NV	14.5
	Los Angeles-Long Beach-Anaheim, CA	13.9
	Memphis, TN-MS-AR	7.2
	Milwaukee, WI	8.2
	Minneapolis-St. Paul, MN-WI	9.8
	New York-Newark, NY-NJ-CT	16.8
	Philadelphia, PA-NJ-DE-MD	13.3
	Phoenix-Mesa, AZ	6.8
	Pittsburgh, PA	10.8
	Portland, OR-WA	12.6
	Riverside-San Bernardino, CA	7.1
	Sacramento, CA	7.7
	Salt Lake City-West Valley City, UT	6.1
	San Diego, CA	9.5
	San Francisco-Oakland, CA	12.8
	San Jose, CA	12.2
	San Juan, PR	5.4
	Seattle, WA	14.8
	St. Louis, MO-IL	6.9
	Washington, DC-VA-MD	8.9
Trucks	All	1.0

3.1.1.7 Performance Measures for CMAQ Improvement Program – On-Road Mobile Source Emissions

Based on the final rules in 23 CFR Part 490, the performance measure to assess on-road mobile source emissions is total emissions reductions, which are calculated as the cumulative 2-year and 4-year emissions reductions for all projects funded by CMAQ funds for each pollutant of Nitrogen Oxide (NOx), Volatile Organic Compounds (VOCs), Carbon Monoxide (CO), and particulate matter (PM2.5 and PM10) with designated nonattainment or maintenance areas. The emission reduction data comes from the CMAQ Public Access System.

3.1.2 Transportation Performance Management (TPM) Guidebook

A TPM guidebook developed by FHWA provides a comprehensive view of transportation performance management principles and can be applied to assist agencies in implementing performance-based planning and programming (FHWA, 2018d). Figure 3-1 shows the ten components of TPM framework that are discussed in this guidebook, including

- Strategic direction
- Target setting
- Performance-based planning
- Performance-based programming
- Monitoring and adjustment
- Reporting and communication
- Performance management organization and culture
- External collaboration and coordination
- Data management
- Data usability and analysis

A detailed description of definitions, principles, classifying terminology, relationship to TPM components, regulatory resources, assessing risks, and implementation steps is provided to each of TPM component.

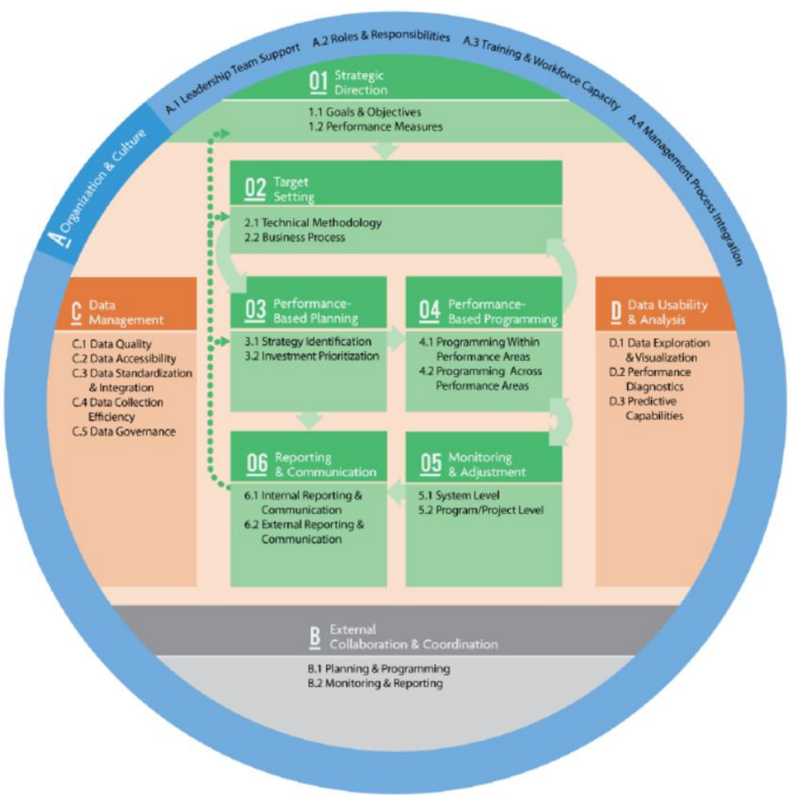


Figure 3-1 TPM Framework (Source: FHWA TPM Guidebook (FHWA, 2018d))

Chapter 2 of the TPM Guidebook provides examples of analytical tools and methods that agencies can use to forecast future performance, which is summarized in Table 3-4.

Table 3-4 Examples of Tools and Methods for Forecasting Future Performance (Source: FHWA TPM Guidebook (FHWA, 2018d))

Focus Area	Tools and Methods
Bridge	• Bridge Management software (BrM) (formerly Pontis) • Deterioration models to predict future bridge condition based on past data and bridge age • Algorithms to process National Bridge Inventory (NBI) and Element data to establish targets • Forecasting tool that combines historic performance and historical funding level then predicts expected condition using expected funding target for the bridge program • Full life cycle (75 year) analysis of bridge condition combined with revenue projections and construction inflations used to maximize the investment's impact on bridge assets • A deficit report based upon current investment and condition compared with future investment
Pavement	• Pavement Management System (PMS): model future pavement conditions on a set of criteria such as traffic levels, asset type, age of pavement, and resource constraints • GIS for data analysis and visualization • Business Intelligence and visualization tools • The graph that shows the predicted pavement performance versus age from 2012 Pavement Condition Report
Safety	• Linear regression, rolling averages, best-fit regression analysis, non-linear regression, time-series analysis • Safety trend line based on 5-year and 10-year rolling average and superimposed with safety target (for example, the safety trend line for the Washington State Department of Transportation (WSDOT) fatality forecasting through 2030)
System Performance	• Travel demand models • Highway Capacity Manual • System transportation performance management systems • Model estimating the economic benefits infrastructure improvements (e.g., Highway Economic Requirement System (HERS), Transportation Economic Development Impact System (TREDIS)) • National Emissions Inventory (NEI), Air Quality System (AQS) and Mobile 6.2

3.1.3 Performance Measures ATDM Recommended by FHWA

A set of performance measures (also referred to as measure of effectiveness) was recommended by FHWA to capture the impacts of Active Transportation and Demand Management (ATDM) strategies on travel and congestion (Dowling et al., 2013). Table 3-5 lists those performance measures and estimation methods.

Table 3-5 Performance Measures Recommended by FHWA to Quantify the Effectiveness of ATDM (FHWA, 2013)

Performance Measure	Estimation Method
VMT-Demand	The sum of the products of the vehicle trips in the input Origin-Destination (OD) table with the shortest path between each OD
VMT-Served	The sum of the product of the total link volumes and link length for the time period of interest
Vehicle-Hours Traveled	The sum of the product of the total link volumes and the average link travel times. The delay to vehicle that cannot enter the network due to traffic control such as ramp metering is added to the above Vehicle Hour Traveled (VHT) and included in the VHT total
Vehicle-Hours Delay	The difference between the VHT total and the VHT if all links are traversed at free-flow speed
Average System Speed	The sum of the VMT-served for all the scenarios divided by the sum of VHT for all the scenarios including vehicle entry delay
Vehicle-Hours Delay/Vehicle-Trip	The summation of vehicle-hours delay over all scenarios divided by the sum of the number of vehicles trips in the OD tables for all the scenarios
80^{th} Percentile Travel Time Index	80^{th} percentile travel time divided by free-flow travel time
Planning Time Index (PTI)	95^{th} percentile travel time divided by free-flow travel time

3.2 Florida Statewide Guidance and Practices

This section provides a detailed review of FDOT and MPO guidance and practice on performance measurements.

3.2.1 FDOT Annual Performance Report

The FDOT Performance Program publishes performance report each year. The latest performance report covers five areas, including safety, preservation, mobility, economy, and environment (FDOT, 2016a). Figures 3-2 to 3-6 list the FTP goal, objectives, and related performance measures for each focus area. As shown in these figures, a set of core measures as well as supporting measures are listed for each focus area. These measures are reported for a time period that spans for the past 10 years if data is available. The data sources are from different FDOT offices (for example, FDOT Safety Office, FDOT Office of Maintenance, FDOT

State Traffic Engineering Operations Office, etc.) and the previous statewide reports. The corresponding performance targets and a list of improvement strategies are also included in the performance report. The FDOT's performance report also recommends potential measures that can be included into the future performance report. Below is a brief list of these potential measures:

- Safety
  - Complete street-related safety measures
  - Transit performance-related safety measures
  - Pedestrian/bicycle related safety measures
- Preservation
  - Consideration of vehicle condition and average fleet age for transit performance measures
  - Bicycle and pedestrian facility that facilitates access to transit
  - Bicycle and pedestrian facility maintenance measures
  - Percent system at risk/retrofitted for resiliency
- Mobility
  - Measures for bicycle and pedestrian program impacts
  - Customer stratification and usage measures for bicycle/pedestrian network
  - ITS coverage of system
  - Automated vehicle technology usage measure
  - Average transit load factors
  - Transit access measures
  - Measure for extent of telecommuting over time
  - Measures for the benefits of complete streets
- Economy
  - Number of transportation technology companies located in Florida and doing business
  - Travel time by mode
  - Delivery time trends
  - Shipping cost trends
  - Transportation sector job growth
  - DEO and Florida Chamber Economic
  - Connectivity measures including cost and time savings
  - Expanded and improved Strategic Intermodal System (SIS) investments
  - Freight bottlenecks reduction
- Environment
  - Measures for community values and transportation preferences
  - Standard walkable index
  - Commuting time and costs
  - Percent of trips that are pedestrian and bicycles
  - Percent of electric vehicles and autonomous vehicles
  - Percent of people that drive alone
  - Measures for quality places in terms of transportation

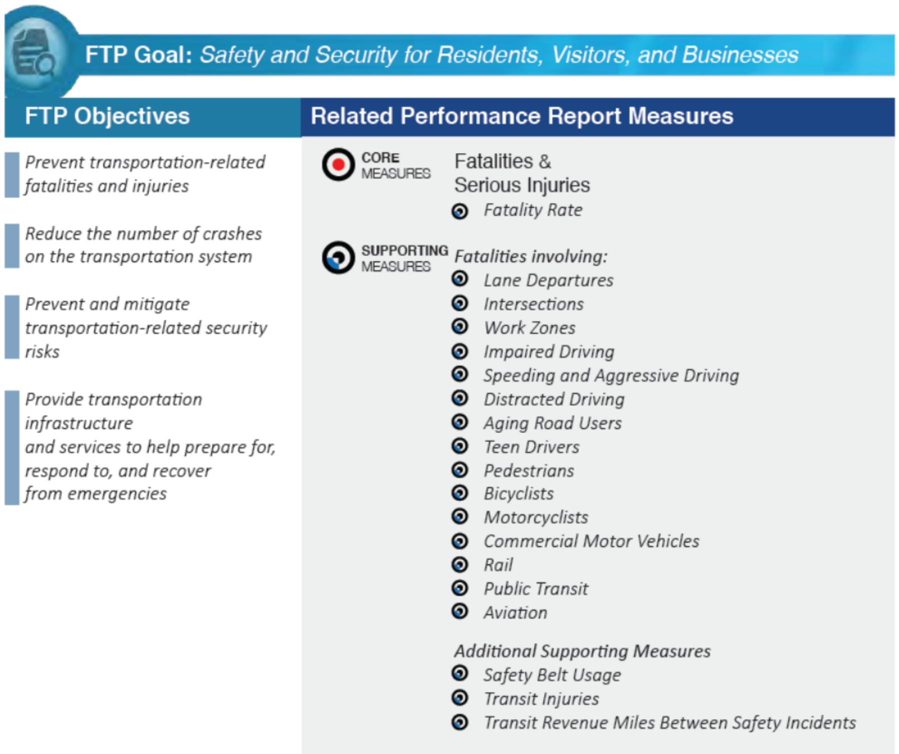


Figure 3-2 Safety-Related Performance Report Measures (Source: FDOT, 2016a)

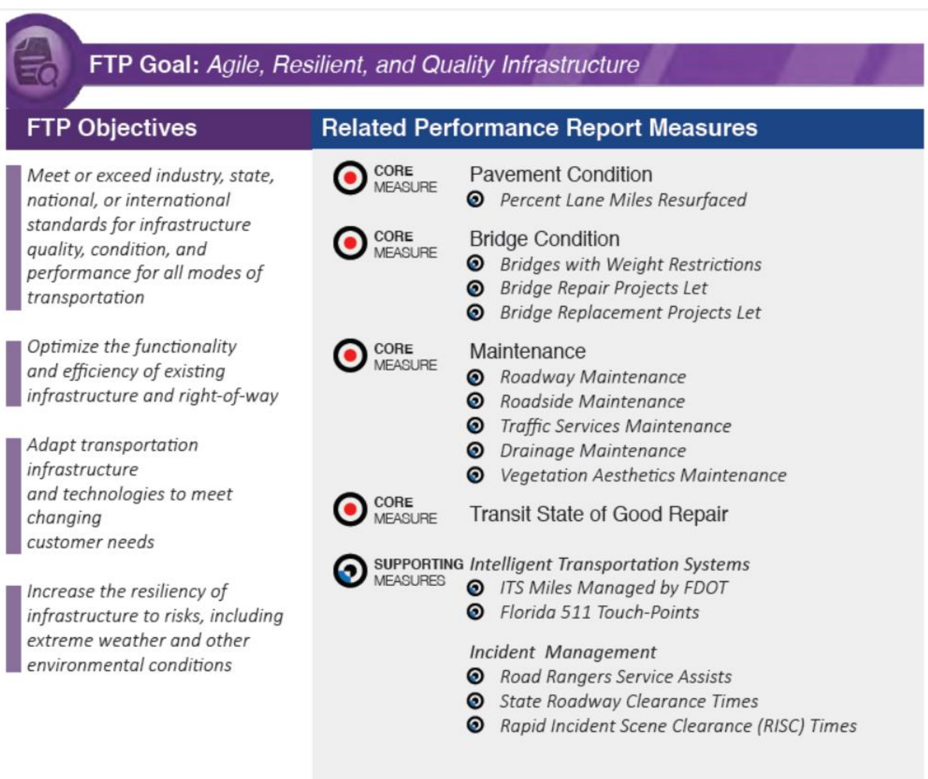
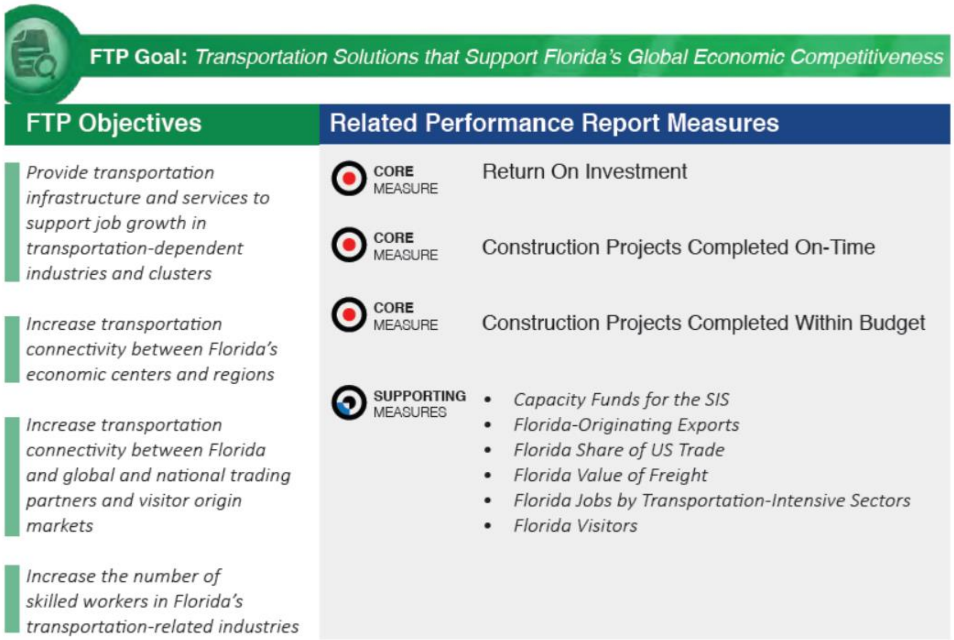


Figure 3-3 Preservation-Related Performance Report Measures (Source: FDOT, 2016a)

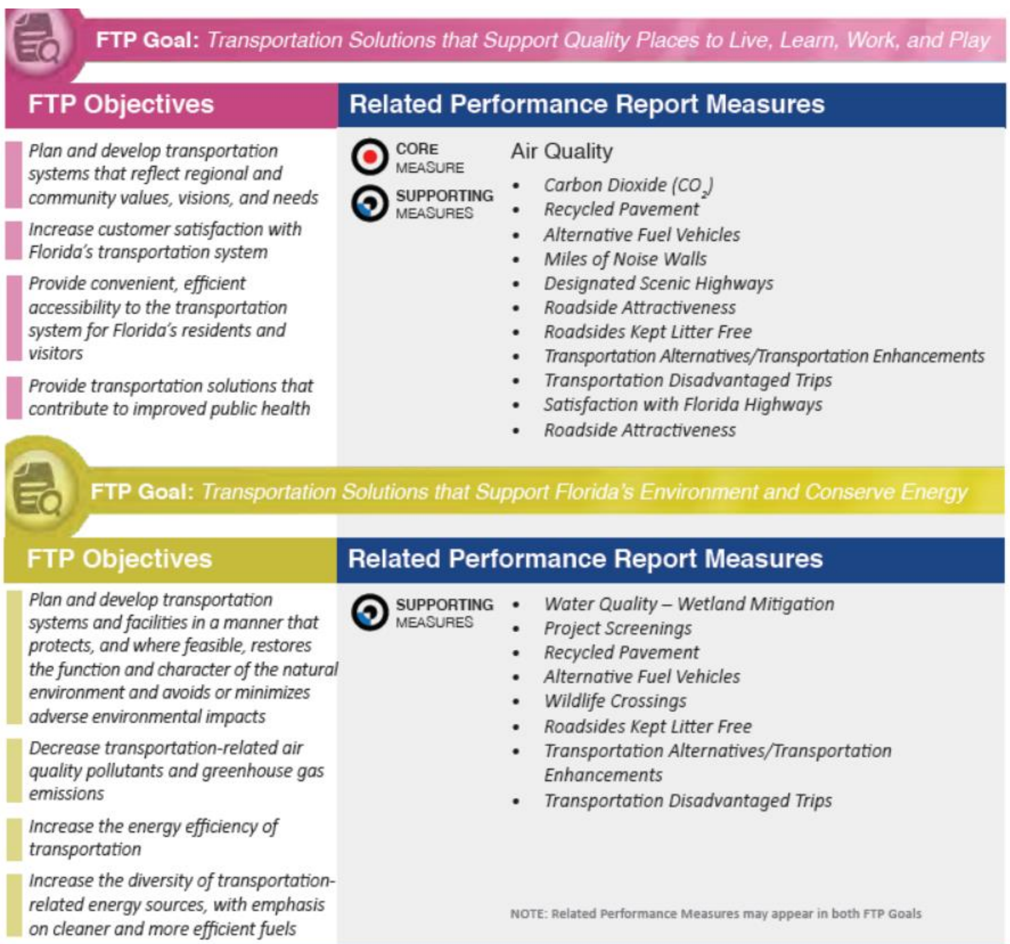
Figure 3-4 Mobility-Related Performance Report Measures (Source: FDOT, 2016a)



FTP Goal: *Transportation Solutions that Support Florida's Global Economic Competitiveness*

FTP Objectives	Related Performance Report Measures	
Provide transportation infrastructure and services to support job growth in transportation-dependent industries and clusters	CORE MEASURE	Return On Investment
Increase transportation connectivity between Florida's economic centers and regions	CORE MEASURE	Construction Projects Completed On-Time
Increase transportation connectivity between Florida and global and national trading partners and visitor origin markets	CORE MEASURE	Construction Projects Completed Within Budget
Increase the number of skilled workers in Florida's transportation-related industries	SUPPORTING MEASURES	• *Capacity Funds for the SIS* • *Florida-Originating Exports* • *Florida Share of US Trade* • *Florida Value of Freight* • *Florida Jobs by Transportation-Intensive Sectors* • *Florida Visitors*

Figure 3-5 Economy-Related Performance Report Measures (Source: FDOT, 2016a)



FTP Goal: *Transportation Solutions that Support Quality Places to Live, Learn, Work, and Play*

FTP Objectives	Related Performance Report Measures	
Plan and develop transportation systems that reflect regional and community values, visions, and needs *Increase customer satisfaction with Florida's transportation system* *Provide convenient, efficient accessibility to the transportation system for Florida's residents and visitors* *Provide transportation solutions that contribute to improved public health*	CORE MEASURE SUPPORTING MEASURES	Air Quality • *Carbon Dioxide (CO_2)* • *Recycled Pavement* • *Alternative Fuel Vehicles* • *Miles of Noise Walls* • *Designated Scenic Highways* • *Roadside Attractiveness* • *Roadsides Kept Litter Free* • *Transportation Alternatives/Transportation Enhancements* • *Transportation Disadvantaged Trips* • *Satisfaction with Florida Highways* • *Roadside Attractiveness*

FTP Goal: *Transportation Solutions that Support Florida's Environment and Conserve Energy*

FTP Objectives	Related Performance Report Measures	
Plan and develop transportation systems and facilities in a manner that protects, and where feasible, restores the function and character of the natural environment and avoids or minimizes adverse environmental impacts *Decrease transportation-related air quality pollutants and greenhouse gas emissions* *Increase the energy efficiency of transportation* *Increase the diversity of transportation-related energy sources, with emphasis on cleaner and more efficient fuels*	SUPPORTING MEASURES	• *Water Quality – Wetland Mitigation* • *Project Screenings* • *Recycled Pavement* • *Alternative Fuel Vehicles* • *Wildlife Crossings* • *Roadsides Kept Litter Free* • *Transportation Alternatives/Transportation Enhancements* • *Transportation Disadvantaged Trips*

NOTE: Related Performance Measures may appear in both FTP Goals

Figure 3-6 Environment-Related Performance Report Measures (Source: FDOT, 2016a)

3.2.2 FDOT TSM&O Strategic Plan

The 2017 FDOT Transportation Systems Management & Operations (TSM&O) Strategic Plan sets three types of TSM&O program goals. These include the goals applied to on-going operation and maintenance (O&M) performance of TSM&O system and strategies, the performance enhancement goals for the O&M of system that hasn't reached the goals, and the project performance enhancement goals for outcomes of planned and future implemented TSM&O strategies and projects. Seven goals were specified for the on-going TSM&O system performance measures covering mobility, safety, and ITS/communication networks maintenance. Table 3-6 summarizes these goals, the corresponding performance measures for each of the goals, and the associated data source. Table 3-7 lists the outcome performance metrics and goals for the planned FDOT TSM&O strategies.

Table 3-6 Goal and Performance Measures in the 2017 FDOT TSM&O Strategic Plan (FDOT, 2017a)

Goal	Application	Performance Measures	Performance Goal	Data Source
Mobility – improve travel time reliability	• Limited access roadway segments managed from the district Regional Transportation Management Center (RTMC) • Non-controlled access arterials for which the districts are using Active Arterial Management and ASCT TSM&O strategies • Other routes determined by the districts	• Perak period PTI (95th percentile) • Throughput • Delay reduction • Other metrics selected by districts to supplement PTI	• PTI ranges from 1.1 in rural areas to 4.0 or even higher in urban core areas by the end of FY 18/19	• RITIS • District probe-based travel time systems • Traffic detectors
Mobility – all lanes cleared	• Limited access roadway segments managed from the district RTMC • Other routes determined by the districts	• All lanes cleared time	• A goal of 30 to 60 minutes for all lanes cleared time for FY 19/20 and beyond	• SunGuide event log and database
Mobility – throughput increase	NA*	NA	NA	NA
Mobility – delay reduction	NA	NA	NA	NA

Goal	Application	Performance Measures	Performance Goal	Data Source
Safety – secondary crash rates	• Limited access roadway segments managed from the district RTMC • Other routes determined by the districts	• Secondary crash rate	• Determination of possible goal ranges after analyzing existing conditions	• SunGuide event log and database
ITS/communication networks maintenance – district uptime availability	• Limited access roadway segments managed from the district RTMC • Non-controlled access arterials for which the districts are using AAM, ASCT, or other TSM&O strategies • Other routes determined by the districts	• Field equipment uptime availability in percentage • RTMC equipment uptime availability in percentage • Communication infrastructure and network uptime availability in percentage	• Determination of possible goal ranges after analyzing existing conditions	• District and/or maintenance contractor network and asset management systems
ITS/communication networks maintenance – statewide uptime availability	• Statewide ITS Wide-Area Network (WAN) • Public-facing elements of FL 511 including website, phone system, and smartphone apps • Statewide data archival and analysis tools • Data Integration and Video Aggregation System (DIVAS)	• Uptime availability in percentage • Secondary metrics such as number of times and percent of time WAN was operating on a back-up communication path	• Ranged from 95% to 99% before FY 18/19	NA

Notes:
* NA means not available.

Table 3-7 Project-Performance Enhancement Goals (P-PEG) (FDOT, 2017a)

System or Strategy	Performance Metric(s)	Application	P-PEG (1)
Any TSM&O strategies where mobility is a need addressed by the strategy	Throughput, PTI, Speeds	Routes, corridors, and/or modes for which TSM&O strategies are applied	Greater than 5% improvement resulting from the TSM&O application(s)
Any TSM&O strategy where safety is a need addressed by the strategy	Crash rates, Crash Severity	Routes, corridors, and/or modes for which TSM&O strategies are applied	Minimum P-PEG thresholds will be sent in future Strategic Plan updates
Any project intended to improve performance of ITS infrastructure or communication networks supporting TSM&O strategies	Uptime availability	ITS infrastructure and communication networks supporting TSM&O strategies	Minimum P-PEG thresholds will be set in future Strategic Plan updates

Table Note (1): Districts are encouraged to set higher and/or additional P-PEG to support district and regional TSM&O strategic planning.

Appendix A of the TSM&O strategic plan provides a TSM&O strategy toolbox, which includes the definitions, performance metrics, and references for more than 50 TSM&O strategies or tools. Table 3-8 summarizes the performance metrics for the TSM&O strategies in this toolbox. As shown in this table, three categories of performance measures are commonly used to assess TSM&O strategies, that is, (1) safety measures of crash and secondary crashes; (2) mobility measures in terms of travel time, travel time reliability, and throughput; and (3) measures of system and agency efficiency.

Table 3-8 Performance Metrics Provided in FDOT TSM&O Toolbox (FDOT, 2017a)

Tool Type	Strategy/Tool	Performance Measures
Facility-Centric Safety and Congestion Tool	Freeway Management Systems (FMS)	• Safety – secondary crashes • Mobility – travel time reliability • System/agency efficiency
	Traffic Incident Management (TIM) Program	• Safety – secondary crashes • Mobility – travel time, travel time reliability • System/agency efficiency
	Ramp Metering	• Safety – crashes • Mobility – travel time, travel time reliability, throughput
	Hard Shoulder Running (HSR)	• Safety – secondary crashes • Mobility – travel time, travel time reliability, throughput
	Lane Control Signals (LCS)	• Safety – secondary crashes • Mobility –travel time reliability, throughput
	Variable Speed Limits (VSL) and Speed Harmonization	• Safety –crashes • Mobility –travel time reliability, throughput

Tool Type	Strategy/Tool	Performance Measures
	Countermeasures to Wrong Way Driving (WWD)	• Safety –crashes
	Express Lanes	• Mobility –travel time reliability, throughput
	Reversible Express Lanes	• Mobility – travel time, travel time reliability, throughput • System/agency efficiency
	Advanced Signal Control Technology (ASCT)	• Mobility – travel time, travel time reliability, throughput
	Traffic Signal Interconnect or Traffic Signal Communication	• Mobility – travel time, travel time reliability, throughput • System/agency efficiency
	Traffic Signal Coordination	• Mobility – travel time, travel time reliability, throughput
	Transportation Management Center (TMC)	• Safety – crashes, secondary crashes • Mobility – travel time, travel time reliability, throughput • System/agency efficiency
	Regional Transportation Management Center (RTMC) Operation	• Safety – crashes, secondary crashes • Mobility – travel time, travel time reliability, throughput • System/agency efficiency
	Road Ranger Service Patrol (RRSP)	• Safety – crashes, secondary crashes • Mobility – travel time, travel time reliability, throughput
	Center to Center (C2C) Communication	• Safety – crashes, secondary crashes • Mobility – travel time, travel time reliability, throughput • System/agency efficiency
	Center to Infrastructure (C2I) Communication	• Safety – crashes, secondary crashes • Mobility – travel time, travel time reliability, throughput • System/agency efficiency
	Vehicle to Infrastructure (V2I) Communication	• Safety – crashes, secondary crashes • Mobility – travel time, travel time reliability, throughput
	Intersection Collision Avoidance	• Safety – crashes, secondary crashes
	Routes of Significance (RoS)	• Mobility – travel time, travel time reliability, throughput

Tool Type	Strategy/Tool	Performance Measures
	Road Weather Information System (RWIS)	• Safety – crashes
	Intersection System Detection	• Safety – crashes, secondary crashes • Mobility – travel time, throughput
Modal-Centric Tool	Freight Advanced Traveler Information System (FRATIS)	• Safety – crashes • Mobility – travel time, travel time reliability
	Automatic Vehicle Location (AVL)	• Safety – crashes • Mobility – travel time reliability, throughput • System/agency efficiency
	Dynamic Ridesharing	• Mobility – travel time, travel time reliability
	Automated & Electronic Fare Collection (EFC)	• Mobility – travel time, travel time reliability, throughput • System/agency efficiency
	Transit Signal Priority (TSP) and Emergency Vehicle Preemption (EVP)	• Mobility – travel time, travel time reliability, throughput
	Active Parking Management	• Mobility – travel time, travel time reliability • System/agency efficiency
	Commercial Vehicle Operations (CVO)	• Safety – crashes • Mobility – travel time, travel time reliability • System/agency efficiency
	Virtual Weigh-In Motion (VWIM)	• Mobility – travel time, travel time reliability • System/agency efficiency
	Freight Tracking System	• Mobility –travel time reliability • System/agency efficiency
	Walk Smart/Bike Smart	• Safety – crashes • Mobility – travel time
	Truck Parking Availability System (TPAS)	• Safety – crashes • Mobility – travel time, travel time reliability
	Grade Crossing Notification System	• Safety – crashes • Mobility – travel time, travel time reliability
Mobility-Centric Tool	SunGuide® Software	• Safety –secondary crashes • Mobility – travel time, travel time reliability, throughput • System/agency efficiency
	Data Integration Video Aggregation System (DIVAS)	• System/agency efficiency

Tool Type	Strategy/Tool		Performance Measures
	FL511		• Safety –secondary crashes • Mobility – travel time, travel time reliability
	Dynamic Detour System (DDS)		• Mobility – travel time, travel time reliability, throughput • System/agency efficiency
	Active Arterial Management (AAM)		• Safety – crashes, secondary crashes • Mobility – travel time, travel time reliability, throughput • System/agency efficiency
	Unified Payment System (UPS)		• Mobility – travel time, travel time reliability • System/agency efficiency
	Integrated Corridor Management (ICM)		• Safety – crashes, secondary crashes • Mobility – travel time, travel time reliability, throughput • System/agency efficiency
	Signal Phase and Timing (SPaT)		• Mobility – travel time, travel time reliability, throughput
	Connected Vehicle Mobility Traffic Signals	EVP Application	• Safety – crashes, secondary crashes • Mobility – travel time, travel time reliability
		Freight Signal Priority (FSP) Application	• Safety – crashes, secondary crashes • Mobility – travel time, travel time reliability
		Intelligent Traffic Signal System (ISIG) Application	• Mobility – travel time, travel time reliability, throughput
		Pedestrian Mobility Application	• Mobility – travel time, travel time reliability
		TSP Application	• Mobility – travel time, travel time reliability
	Collision Avoidance Technology		• Safety – crashes, secondary crashes • Mobility – travel time, travel time reliability, throughput
	Access Management		• Safety – crashes • Mobility – travel time, travel time reliability
	Dynamic Pricing		• Mobility – travel time, travel time reliability • System/agency efficiency

The Regional Integrated Transportation Information System (RITIS) collects real-time point traffic detector data as well as real-time traffic data from a third party private sector vendor. It reports a set of performance measures, which are also introduced in the FDOT 2017 TSM&O strategic plan, as shown in Table 3-9.

Table 3-9 Performance Measures Used in the RITIS Performance Measurement Tools (FDOT, 2017a)

RITIS Tool	Application	RITIS Definition	Data Used
Planning Time Index	Compare routes or segments by time of day, day of week, monthly or annually.	Measure of travel time variability: PTI of 3.0 means a trip that normally takes 10 minutes will take 30 minutes 95% of the time.	Speed, Location and direction, Length, Date and time (5-minute intervals or longer).
Congestion	Compare routes or segments by time of day, day of week, monthly or annually.	Measured speed as a percentage of the free flow speed.	
Impact	Measure bottleneck duration.	Aggregation of queue length over time for congestion originating at each location in mile-minutes.	
Average Max Length	Measure bottleneck length.	Average maximum length, in miles, of queues formed by congestion originating at the location.	
Bottleneck Ranking	Rank bottleneck locations on the roadway.	Ranking of positions (impact is used by default).	

3.2.3 Florida Multimodal Mobility Performance Measures Source Book

The FDOT Transportation Statistics Office produced a multimodal mobility performance measures source book annually, which reports historical and current mobility performance measures results for state highway system including the strategic intermodal system (FDOT, 2016b). Four dimensions of mobility are considered, which are quantity, quality, accessibility, and utilization. Table 3-10 Multimodal Mobility Performance Measures Matrix (FDOT, 2016b) summarizes the performance measures included in this source book.

Table 3-10 Multimodal Mobility Performance Measures Matrix (FDOT, 2016b)

Mode		QUANTITY	Reporting Period				QUALITY	Reporting Period				ACCESSIBILITY	Reporting Period				UTILIZATION	Reporting Period			
			Peak Hour	Peak Period	Daily	Yearly		Peak Hour	Peak Period	Daily	Yearly		Peak Hour	Peak Period	Daily	Yearly		Peak Hour	Peak Period	Daily	Yearly
PEOPLE	Auto/ Truck	Vehicle Miles Traveled	X		X		% Travel Meeting LOS Criteria	X	X	X		Time Spent Commuting			X		% Travel Heavily Congested	X	X	X	
		Person Miles Traveled	X		X		% Miles Meeting LOS Criteria	X	X								Hours Heavily Congested			X	X
							Travel Time Reliability	X	X	X											
							Travel Time Variability	X	X	X											
							Vehicle Hours of Delay	X		X	X										
							Person Hours of Delay	X		X	X										
							Average Travel Speed	X	X												
	Transit	Passenger Miles Traveled				X	Average Headway	X				Weekday Span of Service *(new for 2016)*			X		Passenger Trips Per Revenue Mile *(new for 2016)*				X
		Passenger Trips				X															
	Pedestrian						Level of Service (LOS)	X				% Sidewalk Coverage				X					
	Bicycle						Level of Service (LOS)	X				% Bike Lane/Shoulder Coverage				X					
	Aviation	Passengers				X	Departure Reliability				X						Demand to Capacity Ratios				X
	Rail	Passengers				X	Departure Reliability				X										
	Seaports	Passengers				X															
PEOPLE & FREIGHT	Auto/ Truck																% Miles Heavily Congested	X	X		
																	Vehicles Per Lane Mile	X			
	Aviation											Highway Adequacy (LOS)	X								
	Rail											Highway Adequacy (LOS)	X								
	Seaports											Highway Adequacy (LOS)	X								
FREIGHT	Truck	Combination Truck Miles Traveled			X		Travel Time Reliability	X	X	X							Combination Truck Backhaul Tonnage				X
		Truck Miles Traveled			X		Travel Time Variability	X	X	X											
		Combination Truck Tonnage				X	Combination Truck Hours of Delay			X											
		Combination Truck Ton Miles Traveled				X	Combination Truck Average Travel Speed	X	X												
		Value of Freight				X	Combination Truck Cost of Delay *(new for 2016)*				X										
	Aviation	Tonnage				X															
		Value of Freight				X															
	Rail	Tonnage				X						Active Rail Access				X					
		Value of Freight				X															
	Seaports	Tonnage				X						Active Rail Access				X					
		Twenty-foot Equivalent Units				X															
		Value of Freight				X															

3.2.4 Florida MPO Handbook

One of the chapters in the FDOT MPO Handbook is performance management (FDOT, 2018b). In this chapter, a national transportation performance management framework as well as the national policies on state and MPO performance management are presented. States, MPOs, and public transportation providers must establish performance target for each performance measure identified by the final rules of the USDOT, reviewed earlier in Section 2 of this document. MPOs must include a description of the performance measures and targets in a Long Range Transportation Plan (LRTP). A system performance report is also required to be included in a LRTP to be compared with the system performance in the previous reporting period or baseline data. When MPOs develop multiple scenarios while preparing for LRTP, a system performance is also needed to demonstrate how the preferred scenario can help move toward the performance targets. Similarly, Transportation Improvement Program (TIP) is required to be designed such that when it is implemented, it can help achieve the performance targets. TIP also needs to document such anticipated impacts. In addition to the above requirement, MPOs are also required to coordinate with state and public transportation providers to ensure the MPOs' performance measures and targets are consistent with state and public transportation providers' plans. When developing LRTP and TIP, the states and MPOs need to meet the performance-based planning and programing requirements no later than two years from the effective date of each performance measure rule or two years from the publication date of planning rule on May 27, 2016.

3.2.5 MPO/TPO/TPA Practice on Performance Measures

This section discusses how performance measures are used in the business processes of metropolitan planning organization/transportation planning organization/transportation planning agency (MPO/TPO/TPA).

3.2.5.1 FDOT/MPO Pilot for National Performance Measures

As a FDOT's pilot effort to collaborate with MPO on performance measures, national performance measures for four MPOs (including Hillsborough MPO, Broward MPO, Gainesville MTPO, and India River County MPO) were calculated and added to the FDOT statewide annual performance measure report (FDOT, 2016c). The MAP 21 performance measures that have been calculated and not calculated in this pilot are shown in Figure 3-7. It is seen from this figure, the only measures that were not calculated are the ones for pavement conditions. The measure of peak hour travel reliability in this effort was calculated as the percentage of freeway trips traveling at greater than or equal to 5 mph below the posted speed limit expect that a threshold of 45 mph was used for seven counties. Since this effort was conducted in 2016, this measure is different from the measure of level of travel time reliability (defined as 80th percentile travel time index) specified in the final rules of MAP-21 performance measures. In addition, two FDOT mobility measures were also calculated for these four MPOs, including the percentage of heavily congested freeway miles at the peak hour and daily hours of vehicle delay.

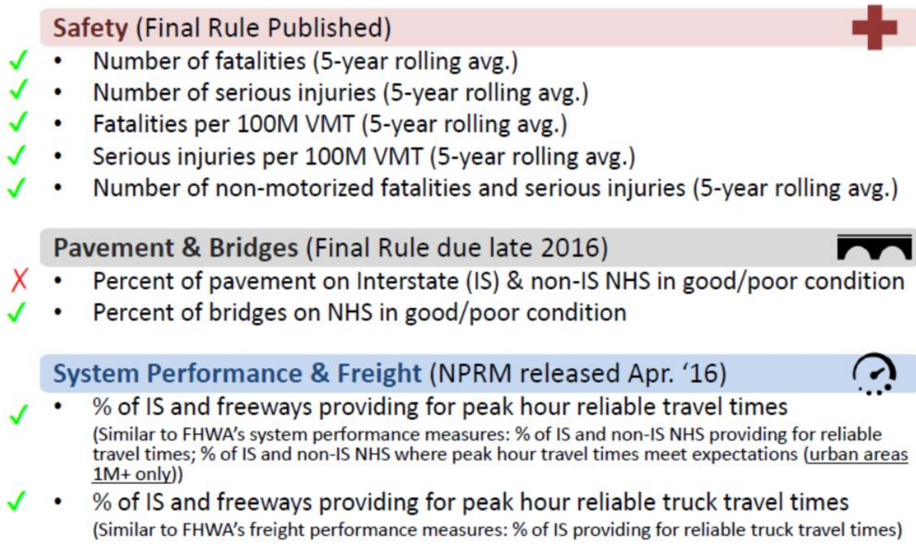


Figure 3-7 Measures in MPO Pilot (Source: FDOT, 2016c)

3.2.5.2 Miami-Dade TPO

Long Range Transportation Plan (LRTP)

Based on the national and state goals, eight goals were proposed for the Miami-Dade 2040 Long Range Transportation Plan (LRTP) to maintain the County's status as a top-100 global city, to improve the County's transportation system, and to meet the transportation service needs with the expected growth of travel demand (Gannett Fleming, Inc. et al., 2014). A weight was given to each of these goals based on the ballots collected from 15 community workshops and meetings. Below is the list of those eight goals. The number in the bracket is the corresponding weight.

- Improve system and travel (25%)
- Improve safety (8%)
- Improve security (3%)
- Support economic vitality (12%)
- Preserve environment and quality of life (14%)
- Improve connectivity (14%)
- Employ sound investment strategies (12%)
- Preserve the existing system (12%)

To achieve the eight goals, 63 objectives were developed and a total number of 89 system measures were identified correspondingly. Table 3-11 lists these goals, objectives, and performance measures.

The identified performance measures are divided into two groups based on the scope of performance measurements: system-level performance measures and project-level performance measures. System-level performance measures assess the County's transportation system as a whole and were applied to four system-level scenarios, including base year 2010, existing-pluscommitted 2019, needs plan 2040, and cost-feasible plan 2014. Project-level measures are used to prioritize improvement projects during the development of a cost feasible plan. The evaluation of each needs plan project was conducted using three steps: goal elements analysis, congestion coordination, and implementing agency coordination. In the step of goal elements analysis, the proposed improvements for each project were matched to the specific elements of the goals and objectives of the 2040 LRTP. Table 3-12 lists the goal elements and the corresponding performance measures. Two types of performance measures are included in this list. The first is geographical elements that can be assessed using buffer analysis in Geographic Information System (GIS). The second involves qualitative measures which are evaluated by scores. A weighted score was calculated for each project by summing up the scores for all the goal elements.

Table 3-11 Goals, Objectives, and Measures Identified in the Miami-Dade 2040 LRTP Plan (Gannett Fleming, Inc. et al., 2014)

Objectives	Measures
Goal 1 - Improve Transportation System and Travel	
Objective 1.1 Improve accessibility to major health care, recreation, education, employment and cultural facilities	Highway lane and centerline miles within .25 miles of major healthcare, recreation, education, employment, and cultural facilities.
	Transit service route miles within 0.25 miles of major healthcare, recreation, education, employment, and cultural facilities.
Objective 1.2 Enhance mobility for people and freight	Average Travel Time (all purposes)
	Number of daily passengers on public transit
Objective 1.3 Reduce Congestion	Hours of delay
Objective 1.4 Maximize multimodal travel options and provide travel choices	Transit service route miles
	Managed-lane miles
Objective 1.5 Fill transit service gaps	Service coverage in transit supportive areas
Objective 1.6 Promote system reliability	Total hours of delay on highway facilities with transit service
	Total hours of delay on highway facilities
Objective 1.7 Improve transportation facilities' and services' regional connectivity	Highway lane and centerline miles in corridors of regional significance
	Transit service route miles in corridors of regional significance
	Transit travel time for key travel markets
	Number of Park and Ride/multimodal facilities
Objective 1.8 Include provisions for non-motorized modes in new projects and in reconstruction	Does the plan consider non-motorized infrastructure in highway and transit improvements?
Objective 1.9 Promote non-motorized (bicycle, pedestrian, greenways) projects through new projects or reconstructions	Does the plan consider non-motorized infrastructure in highway and transit improvements?
	Does the plan consider new non-motorized facilities?
	Percentage increase in number/mileage of non-motorized facilities
	Number of bicycle trips
	Number of walking trips
Objective 1.10 Increase reverse commute opportunities for disadvantaged communities	Transit service route miles from cities and central areas in the AM Peak period (City of Hialeah, City of Homestead, City of Miami, City of Miami Beach, City of Miami Gardens, City of North Miami, City of North Miami Beach)
Objective 1.11 Promote transportation improvements that provide for the needs of the elderly and disabled	Average highway and transit travel times for areas with highest proportion of elderly population

Objectives	Measures
Goal 2 - Increase the Safety of the Transportation System for All Users	
Objective 2.1 Improve safety on facilities and in multimodal operations	Level of investment in safety projects
Objective 2.2 Reduce roadway and multi-modal crashes	Number of accidents by facility, accident type, and cost
Objective 2.3 Increase safety at transit stops and intermodal stations and connections	Does MDT address safety at transit stops and stations as part of the operation of its system?
Objective 2.4 Develop and Implement safe routes to schools	Does the county have a Safe Routes to School program?
Objective 2.5 Promote the safe mobility of aging vulnerable road users	Number of accidents involving elderly drivers
Objective 2.6 Accommodate the safe and convenient movement of non-motorized users	Number of accidents involving pedestrians
Goal 3 - Increase the Security of the Transportation System for All Users	
Objective 3.1 Enhance the capacity of evacuation corridors	Total lane miles within evacuation travel corridors
Objective 3.2 Improve transportation security for facilities and in operations	Does the plan address security as part of the operation of its system?
Objective 3.3 Ensure transportation options are available during emergency evacuations for the elderly and persons with disabilities	Transit service route miles within 0.25 miles of TAZs with a high proportion of elderly population
Objective 3.4 Ensure security at ports, airports, and major intermodal centers/terminals	Do airports, seaports, and intermodal centers address security as part of the operation of their facilities?
Goal 4 - Support Economic Vitality	
Objective 4.1 Increase access to employment sites	Average Home Base Work (HBW) travel time
Objective 4.2 Enhance tourist travel and access opportunities	Highway lane and centerline miles within .25 miles of tourist attractions
	Transit service route miles within .25 miles of tourist attractions
Objective 4.3 Increase and improve passenger and freight access to airports and seaports	Highway lane and centerline miles within .5 miles of MIA, Opa-Locka, HGAA, and Port of Miami
	Transit service route miles within 0.5 miles of MIA, Opa-Locka, Homestead General Aviation Airport (HGAA), and Port of Miami
	Number of transit patrons going to/from the airports and seaport
Objective 4.4 Augment multimodal access to major activity centers	Highway lane and centerline miles within .5 miles of major activity centers
	Transit service route miles within 0.5 miles of major activity centers
Objective 4.5 Enhance the efficient movement of freight and goods	Does the plan consider freight-specific infrastructure improvements/programs?
Objective 4.6 Implement projects that support economic development and redevelopment areas	Highway lane and centerline miles within .5 miles of redevelopment areas
	Transit service route miles within 0.5 miles of redevelopment areas
Objective 4.7 Plan and develop transportation systems to provide adequate connectivity to economically productive rural areas	Highway lane and centerline miles within .5 miles of rural activity centers
Objective 4.8 Invest in Port Miami infrastructure to further increase competitiveness for Post Panamax traffic	Percentage of funding dedicated to Port of Miami infrastructure improvements
Objective 4.9 Expand cargo-handling and related intermodal facilities to the optimum extent	Percentage of funding dedicated to intermodal access to Port of Miami and Miami International Airport

Objectives	Measures
Goal 5 - Protect and Preserve the Environment and Quality of Life and Promote Energy Conservation	
Objective 5.1 Minimize and mitigate air and water quality impacts of transportation facilities, services, and operations	Tons per day of emissions (NOx, CO, VOC)
	Surface coverage of transportation system on acres of wetlands
Objective 5.2 Reduce fossil fuels use	Vehicle Miles Traveled (VMT)
	Non fossil fuel burning daily transit service route miles
	Does the plan promote the use of alternative fuel technologies?
Objective 5.3 Promote projects that support urban infill and densification	Highway lane and centerline miles within the Urban Infill Area
	Transit service route miles within the Urban Infill Area
Objective 5.4 Minimize adverse impacts to established neighborhoods	Does the plan minimize impacts to established neighborhoods?
Objective 5.5 Promote transportation improvements that are consistent with adopted comprehensive development master plans	Is the plan consistent with adopted Comprehensive Development Master Plans?
Objective 5.6 Prioritize funding to favor intra-urban, Urban Development Boundary (UDB) improvements	Ratio of lane and highway centerline miles inside/outside UDB boundaries
	Ratio of transit service route miles inside/outside UDB boundaries
Objective 5.7 Apply transportation and land use planning techniques, such as transit-oriented development, that support intermodal connections and coordination	Number of projects which include transit oriented development or support intermodal connections and coordination.
Objective 5.8 Coordinate transportation and land use decisions to support livable rural and urban communities	Does the plan support compact, accessible, and walkable neighborhoods?
Objective 5.9 Protect historic areas	New highway lane miles within historic site/district
Objective 5.10 Coordinate transportation investments with other public and private decisions to foster livable communities	Sidewalks and trail miles per highway centerline miles
	Transit route miles per highway centerline miles
Objective 5.11 Promote the aesthetic value and character of major transportation projects and facilities in Miami-Dade County	A minimum of three significant projects (per year) will be reviewed for their aesthetic impact on the community
Goal 6 - Enhance the Integration & Connectivity of the System, Across & Between Modes, for People & Freight	
Objective 6.1 Improve connectivity to Strategic Intermodal System (SIS) and intermodal facilities	Highway centerline miles on SIS connectors
Objective 6.2 Provide multi-modal options consistent with the local government comprehensive plan	Is the plan consistent with adopted Comprehensive Development Master Plans?
Objective 6.3 Integrate modal infrastructure, technologies, and payment systems to provide seamless connectivity for passenger and freight trips from origin to destination	Does the plan address multimodal connections?
	Does the plan address integrated technologies / payment systems?
Objective 6.4 Improve goods movement by enhanced intermodal access and other infrastructure that serve major freight origins and destinations in Miami-Dade County (And Regional)	Highway lane miles within .5 miles of major freight origins and destinations
	Report truck travel times
Objective 6.5 Improve freight movement operations and reliability by promoting expedient and cooperative practices across all modes	Does the freight component of the plan address multimodal freight components?
Objective 6.6 Reinforce and transform Florida's Strategic Intermodal System facilities to provide multimodal options for moving people and freight	Percentage of funding dedicated to SIS hubs, corridors, and connectors by mode (freight rail, transit, and highway)

Objectives	Measures
Goal 7 - Optimize Sound Investment Strategies for System Improvement and Management/Operation	
Objective 7.1 Optimize benefits of capital expenditures	Capital expenditure/travel time savings benefit ratio
Objective 7.2 Optimize operations and maintenance expenses	O&M expenditure/travel time savings benefit ratio
Objective 7.3 Optimize applications of People's Transportation Plan (PTP) funding	PTP expenditures/travel time savings benefit ratio
Objective 7.4 Maximize use of State, Federal, and private sector funding sources	Dollar amount of private sector funding (as a proportion of total cost of plan)
	Dollar amount of State and Federal funding (as a proportion of total cost of plan)
Objective 7.5 Promote local improvement projects within the systems improvement context	Number of improvements on local facilities (non-State Highway System)
Objective 7.6 County will establish strong regional linkages with Southeast Florida governments to plan for infrastructure	Does the plan address regional intergovernmental coordination?
Goal 8 - Maximize and Preserve the Existing Transportation System	
Objective 8.1 Continue to examine the provision and utilization of managed lanes on the existing system	Lane miles of managed lanes as a proportion of total lane mile improvements.
	Transit route miles on managed lanes
Objective 8.2 Identify and implement the best available technologies and innovations to improve the reliability and efficiency of the transportation system	Does the plan identify and consider the latest technologies and innovations in transportation improvements?
Objective 8.3 Identify and reserve corridors and right-of-way (on roadways, railways, and waterways) for future transportation facilities and services	Does the plan identify and consider right of way acquisitions as a phase that can be planned independently?
Objective 8.4 Expand the use of Transportation Demand Management (TDM) strategies	Number of projects which utilize TDM strategies.
Objective 8.5 Achieve and maintain a state of good repair for transportation assets for all modes	Percent of funding allocated to maintenance and rehabilitation.
Objective 8.6 Reduce the vulnerability and increase the resilience of critical infrastructure to the impacts of climate trends and events.	Highway lane and centerline miles within the 100-year flood plain.
Objective 8.7 Minimize damage to infrastructure from transportation vehicles	Local centerline and lane miles of roadway with high truck volumes.
Objective 8.8 Ensure necessary supporting infrastructure (water, sewer, drainage) capacity is available for new projects and improvements.	Does the plan consider existing utilities infrastructure when planning new projects?
Objective 8.9 Repair and maintain existing infrastructure first	Does the plan prioritize repair and rehabilitation of existing infrastructure before construction of new infrastructure?
Objective 8.10 Achieve and maintain a state of good repair for evacuation corridors	Percent of funding allocated to maintenance and rehabilitation of evacuation corridors.

Table 3-12 Goal Elements and Performance Measures in the Miami-Dade 2040 LRTP Plan (Gannett Fleming, Inc. et al., 2014)

	Goal Elements	Performance Measures
Goal 1	Access to health care facilities	Proximity to health care facilities (0.25 mile)
	Access to recreational facilities	Proximity to recreational facilities (0.25 mile)
	Access to educational facilities	Proximity to educational facilities (0.25 mile)
	Access to employment facilities	Proximity to employment facilities (0.25 mile)
	Access to cultural facilities	Proximity to cultural facilities (0.25 mile)
	Disadvantaged communities	Transit improvement proximity to disadvantaged communities (0.25 mile)
	Elderly/disabled needs	Transit improvement proximity to elderly/disabled communities (0.25 mile)
	Travel options	Managed lanes or transit improvement
	Transit Service Gaps	Transit improvement outside of current service coverage area
	System reliability	Managed lanes or fixed guideway transit
	Regional Connectivity	Connection to or improvement of facility of regional signficance
Goal 2	Safety projects	Primary focus of project on safety (e.g. safe routes to school)
	Accident Locations	Project on facility with high accident rate
	Safe mobility of vulnerable users	Primary focus of project on transit or non-motorized safety
Goal 3	Evacuation needs of elderly/disabled	Evacuation facility improvement proximity to elderly/disabled communities (0.5 mile)
	Evacuation Facility Capacity	Improvement on evacuation facility
	Security projects	Primary focus of project on security (e.g. security infrastructure at transit station)
	Port, Airport, Intermodal security	Security improvements at Port, Airport, or Intermodal facility
Goal 4	Access to Tourist Destinations	Proximity to tourist destinations (0.25 mile)
	Freight Access to Airports and Seaports	Freight improvements proximity to airports/seaport (0.5 mile)
	Multimodal Access to Activity Centers	Transit improvement proximity to major employment centers (0.25 mile)
	Enhance Freight Movement	Improvement on freight facility
	Economic Development/ Redevelopment areas	Proximity to redevelopment areas (0.25 mile)
	Connectivity to Econ. Productive Rural Areas	Highway improvement proximity to agricultural areas (0.5 mile)
	Port of Miami improvements	Improvement on Port Miami infrastructure
	MIA freight improvements	Improvement on MIA freight infrastructure
Goal 5	Wetlands, Natural Areas, Habitats	Proximity to environmentally sensitive areas (0.5 mile)
	Fossil fuels use	Promotion of alternatives to single occupancy vehicle (SOV) travel
	Support Infill Development	Improvement within Urban Development Boundary
	Historic Areas	Proximity to historic bridges, cemeteries, structures, archaeological sites (0.5 mile)
Goal 6	Connectivity to SIS	Connection to SIS facility
	Multimodal options	Multimodal improvement (e.g. PnR, Intermodal facility, Transit access)
	Integrated infrastructure	Improvement on facility(ies) crossing jurisdictional regional boundaries
	Intermodal freight access to Origins/Destinations	Intermodal freight improvements proximity to freight Os and Ds (0.5 mile)
	Freight infrastructure integration across modes	Freight improvement addresses intermodal operational integration
	SIS Multimodal options	Multimodal improvement on SIS facilities (e.g. PnR, Intermodal facility, Transit access)
Goal 7	Maximize non-local funding sources	Improvement a viable candidate for P3
	Local improvements within system context	Improvement on local road with connection to regional facility
	Regional linkages	Improvement eligible for TRIP or other regional funding
Goal 8	Managed lanes on existing facilities	Managed lanes improvement
	Innovative/tech solutions	Improvement operational using technological solutions (e.g. ITS)
	Transportation Demand Management (TDM)	Improvement classified as TDM or non capital
	Repair and maintain infrastructure first	Is project operational/maintenance in nature
	State of good repair on evacuation facilities	Is project operational/maintenance in nature and on evacuation facility
	Supporting infrastructure	Water, sewer, drainage facilities in place to support improvement (0.1 mile)
	Vulnerability to climate change	Is project in flood plain and scheduled for increased routine maintenance

Performance Management Program (PMP)

The Performance Management Program (PMP) of the Miami-Dade TPO follows the performance measure requirements specified by the USDOT and the State. The highway-performance measures that are considered by the PMP are related to the seven focus areas of the MAP-21 and FAST Act. The transit performance measures used by the PMP are based on the requirement of Transit Asset Management (TAM) (49 USC 5626), which are listed below.

- Percentage of non-revenue, supporting-service and maintenance vehicles that have either met or exceeded their useful life benchmark (ULB).
- Percentage of revenue vehicles within a particular asset class that have either met or exceeded their ULB.
- Percentage of track segments with performance restrictions for rail fixed-guideway, track, signals, and systems.
- Percentage of facilities within an asset class with a rating below condition 3 on the Transit Economic Requirements Model (TERM) scale.

Bicycle/Pedestrian Plan

Five goals and 31 objectives were identified in the Miami-Dade 2040 Bicycle/Pedestrian Plan (Kimley-Horn and Associates, Inc., 2013). Bicycle Level of Service (BLOS) and Pedestrian Level of Service (PLOS) were used as main performance measures to check the performance of bicycle and pedestrian travel on a given roadway network, respectively. The methods to calculate the BLOS and PLOS are based on the FDOT Quality/Level of Service (QLOS) Handbook. The BLOS is calculated as follows.

$$BLOS = 0.507 \ln\left(\frac{Vol_{15}}{L}\right) + 0.199SP_t(1 + 10.38HV)^2 + 7.066(1/PR_5)^2 - 0.005(W_e)^2 + 0.76 \tag{3-7}$$

where Vol_{15} is motorized vehicle directional volume in the peak 15-minute time period. L is number of through lanes. HV is percentage of heavy vehicles. PR_5 is the FHWA's five-point pavement surface condition rating. W_e represents the average effective width of the outside through lane. SP_t is an effective speed factor, which is defined as

$$SP_t = 1.1199 \ln\left(SP_p - 20\right) + 0.81036 \tag{3-8}$$

where SP_p is posted speed limit as a surrogate for the average running speed.

Equation 3-9 gives the expression for the calculation of PLOS.

$$PLOS = -1.2276 \ln\left(W_{ol} + W_l + f_p \times \%OSP + f_b \times W_b + f_{SW} \times W_s\right) + 0.0091\left(\frac{Vol_{15}}{L}\right) + 0.0004SPD^2 + 06.048 \tag{3-9}$$

where W_{ol} is the width of outside lane, W_l is the width of shoulder or bicycle lane, fp is On-street parking effect coefficient with a default value of 0.20. %OSP represents the percent of segment with occupied on-street parking. f_b is the buffer area barrier coefficient. The value of f_b is 5.37 for trees spaced 20 feet on center. Wb is the buffer width in feet, which is the distance between the edge of pavement and sidewalk. fsw is sidewalk presence coefficient, which is calculated as the difference between 6 and the sidewalk width multiplied by -0.3. SPD is the average running speed of the motorized vehicles traffic.

The safety-related performance measures used in the Miami-Dade 2040 Bicycle/Pedestrian Plan include the number of bicycle-related crashes per square mile, the number of pedestrian-related cashes per square mile, and the number of pedestrian or bicyclists injuries and fatalities for the past 12 years. The time period of 12 years was used because of data availability.

3.2.5.3 Broward County MPO

LRTP

The 2040 LRTP by Broward County MPO identified six strategic areas, including bicycle/pedestrian, public transportation, car, freight, air, and sea (Broward MPO, 2013). Three goals with measurable objectives were proposed for these areas, as shown in Table 3-13 to Table 3-15. The measures in these three tables can be classified either as objective measures based on facts or subjective measures depending on opinions.

Table 3-13 Objectives and Measures of Effectiveness for the Goal of Moving People in the Broward County 2040 LRTP (Broward MPO, 2013)

Objective	How Objective is Achieved (Measures of Effectiveness)
Maintain infrastructure	• All operating and maintenance costs for existing facilities/services are fully funded through existing revenue sources (objective) for the life of the project/ service or for the duration of the cost affordable plan, whichever comes first. • All operating and maintenance costs for proposed facilities are funded through existing (objective) and/or reasonably expected future revenue sources (subjective).
Achieve LOS standards on existing infrastructure	• Maximize the proportion of facilities by mode operating at or exceeding Level-of-Service (LOS) standards weighted by the number of users or adjacent populations (objective).
Improve accessibility for all users of the transportation system	• Maximize the number of jobs within 30 minutes travel time by mode • Maximize the number of facilities that are consistent in lanes, technology and policy (such as pricing, pedestrian only, bicyclist only, etc.) across county lines.
Shorten Project Delivery	• Minimize the number of projects that need new rights-of-way (ROW) .
Maximize Transit Ridership	• Increase transit mode share by 20% (build share / baseline share) in all planning sectors • Increase transit mode share by 40% (build share / baseline share) in all areas with 20,000 or more persons per square mile • Increase transit mode share by 40% (build share / baseline share) in all areas with 10,000 or more employees per square mile

Table 3-14 Objectives and Measures of Effectiveness for the Goal of Creating Jobs in the Broward County 2040 LRTP ((Broward MPO, 2013)

Objective	How Objective is Achieved (Measures of Effectiveness)
Maintain or reduce average travel time to major economic centers of the urban area	• Average travel time to Central Business Districts (CBD's), outlying business districts and major employment centers with more than 5,000 employees/square mile (No Build Alternative – • Build Alternative) for all modes • Average in-vehicle travel time to Port Everglades (No Build Alternative – Build Alternative) • Average in-vehicle travel time to Fort Lauderdale/ Hollywood International Airport (No Build Alternative – Build Alternative)
Promote new development	• Provide newly developing areas frequent transit service (20 minute or less headway) or 95% of highway lane miles in developing areas at Level-of-Service (LOS) C or better
Minimize the overall cost of travel	• (Travel time * value of time + operating cost + maintenance cost) / (person miles of travel + truck miles of travel).
Maximize private investments in transportation service provision	• Minimize net cost of public expenditures in project development • Increase community / public involvement via innovative approaches

Table 3-15 Objectives and Measures of Effectiveness for the Goal of Strengthening Communities in the Broward County 2040 LRTP ((Broward MPO, 2013)

Objective	How Objective is Achieved (Measures of Effectiveness)
Insure transportation benefits and costs are equitably distributed throughout the region	• Maximize the number of viable transportation alternatives in all 5 of the MPO's geographic planning areas • Improve accessibility to employment opportunities in areas of the county where the majority of residents make 50% or less of the median income
Reduce accidents, injuries and fatalities	• Redesign major accident locations
Promote redevelopment and infill	• Maximize Public Private Partnership development opportunities in areas of the county where the majority of residents make 50% or less of the median income • Increase premium transit access to jobs and population
Insure projects include appropriate aesthetic considerations in their project design	• Project budget must have a line item for aesthetic improvements
Provide options for non-motorized travel	• Number of miles of sidewalk/number of roadway miles (coverage) • Number of bicycle lane miles/number of roadway miles (coverage) • Minimize the number of gaps in the sidewalk and bike lane network
Promote environmentally sensitive projects	• Reduce energy consumption measured as British Thermal Unit of Energy consumed (BTU)/person mile traveled • Produce less tons of ozone precursors and greenhouse gasses (CO2) than were produced in 1990 (pre Clean Air Act Amendments).

Unified Planning Work Program (UPWP)

Even though no specific performance measures have been mentioned in the Broward UPWP (Broward MPO, 2018a), the Broward UPWP listed the FDOT District 4 performance measurement/management-related activities in financial years 2018 to 2020, which include:

- Provide technical support to implement the performance-based planning and programming required by MAP-21 and Fast Act.
- Participate in the FDOT Mobility Performance Measures (MPM) program and maintain a district-level MPM program that address all modes.
- Focuse on the use of performance measures by performing research, sharing information, and supporting collaboration.
- Share knowledge of quality/LOS and other performance measures that agencies are currently use in their comprehensive plans.

Performance Measurement Program (PMP)

A performance measurement framework was developed by the Broward MPO in 2015 and was used to assess the baseline performances of the Broward region's transportation system (Broward MPO, 2015a). The development of such a framework considered the following factors.

- Broward MPO leadership focus
- New state and metropolitan performance-based planning requirements
- New national performance measures program
- FDOT performance measurement activities
- Industry-wide adoption of performance practices

Based on the above factors, five sets of performance measures were proposed, which correspond to the five primary performance areas: mobility, connectivity and accessibility, asset management, safety, and project delivery. A performance scorecard was also created according to those measures as illustrated in Table 3-16. As shown in this table, the performance measures focus on not only vehicles but also multimodal transportations.

Congestion Management Process/Livability Planning

Congestion management aims at developing and implementing non-road widening strategies to improve road user safety and mobility while encouraging multimode transportation usage (Broward MPO, 2015b). The congestion management corridor/area studies are part of the congestion management process. Table 3-17 illustrates the project-level objectives and performance measures for the Hollywood/Pines Corridor study. The monitoring measures were applied to reflect how the project helps achieve the goals specified in the Broward LRTP.

Table 3-16 Performance Scorecard ((Broward MPO, 2015a)

MEASURE	PREVIOUS RESULTS	CURRENT RESULTS	DESIRED TREND	STATUS
MOBILITY MEASURES				
Mode Share: Commute by SOV	79.6%	79.6%	↘	Stable
Transit Revenue Hours	1.61M	1.64M	↗	Improving
Transit Passenger Trips	43.0M	43.6M	↗	Improving
On-time Transit Trips	59.2%	60.6%	↗	Improving
On-time Rail Trips	89%	92%	↗	Improving
Per Capita Highway Hours of Delay	—	66.2	↘	TBD
CONNECTIVITY & ACCESSIBILITY MEASURES				
Transit Revenue Hours	1.61 M	1.64 M	↗	Improving
Per Capita Highway Hours of Delay	—	66.2	↘	TBD
New Bike & Pedestrian Facilities	—	19.74 miles	↗	TBD
ASSET MANAGEMENT MEASURES				
Highway Miles Meeting or Exceeding Standards*	92%	93%	↗	Improving
Highway Bridges Meeting or Exceeding Standards*	95%	95%	↗	Stable
Average Age of Transit Fleet – Bus	5.00	4.04	≤ 6 years	Sustaining
Average Age of Transit Fleet – Rail	17.13	15.95	≤ 20 years	Sustaining
SAFETY & SECURITY MEASURES				
Motor Vehicle Serious Injuries per Million VMT	6.7	6.0	↘	Improving
Motor Vehicle Fatalities per Million VMT	.56	.48	↘	Improving
Annual Bike & Pedestrian Serious Injuries	234	194	↘	Improving
Annual Bike & Pedestrian Fatalities	53	47	↘	Improving
Preventable Transit Accidents per 100K Miles of Service	116	130	↘	Not Improving

Table 3-17 Project Objectives and Performance Measures in Hollywood/Pines Corridor Project (Broward MPO, 2015b)

Project Objectives	Project Performance Measures			Monitoring Measure
1. Confirm Mobility Hub locations and typologies.	Acceptance by PAC and MPO Project Manager of Mobility Hub locations and typologies			
2. Identify potential sites for Mobility Hub infrastructure placement for each Mobility Hub area.	Acceptance by PAC and MPO Project Manager of Mobility Hub site options			
3. Recommend potential transit operational improvements at each Mobility Hub.	Reduction in walking distance from transit stops to controlled roadway crossings (signals)	Reduction of number of transit stops in Hub areas	Reduction in transit-vehicle/ automobile conflicts	Improved route headways
4. Identify Mobility Hub area intersection safety improvements for all modes.	Number of feasible recommendations identified	Reduction in pedestrian exposure	Estimated crash reduction	Reduced crash frequency and severity
5. Identify Mobility Hub area bicycle and pedestrian connectivity improvements.	Estimated increase in number of dwelling-units and employees with safe walking/biking access to Mobility Hubs			Transit ridership at Hubs
6. Identify traffic management and multimodal enhancement strategies for Johnson Street within the city of Hollywood.	Percent of Johnson Street with complete, contiguous bicycle and pedestrian facilities	Estimated crash reduction due to operational recommendations		Increased transit ridership and bicycle and pedestrian activity
7. Identify traffic operations/ congestion management strategies along Hollywood/Pines Boulevard.	Estimated reduction in vehicle delay			Improved travel time through congested sections of the roadway
8. Identify opportunities to develop the multimodal network within the study corridor.	Estimated increase in number of dwelling-units and employees with safe walking/biking access to Hollywood/Pines Boulevard	Increase in proportion of the identified network with acceptable bicycle and pedestrian facilities		Improved transit ridership throughout corridor; reduction in bicycle and pedestrian crashes
9. Identify strategies to connect existing and future centers along the project corridor to regional employment centers via mass transit.	Acceptance by PAC and MPO Project Manager of Park-and-Ride related recommendations	Estimated increase in number of Dwelling-Units and Employees with safe walking/biking access to regional transit routes with no more than one transfer		Increased boardings of regional transit (e.g., Express Bus/Tri-Rail) in the corridor
10. Provide a toolbox for urban redevelopment of Mobility Hub areas and adjacent segments of the corridor.	Acceptance by PAC and MPO Project Manager of recommended urban design tools	Extent to which Mobility Hub and corridor land use visioning is acceptable to the community	Extent to which Mobility Hub and corridor land use visioning increases transit-supportive densities/intensities in the corridor	Extent of urban infill and redevelopment related to other areas of the county; increased transit ridership

Project Objectives	Project Performance Measures			Monitoring Measure
11. Articulate the benefits of improved mobility and infill and redevelopment along Hollywood/Pines Boulevard to lower-density neighborhoods along the corridor.	Extent to which the Mobility Hub and corridor land use and transportation strategies are acceptable to the community			Increase in property values of property in the corridor related to other areas of the county
12. Recommend strategies to enhance bicycle and pedestrian safety throughout the project corridor.	Number of feasible best-practices recommendations identified	Estimated crash reduction due to recommendations related to established high-crash locations		Reduction in bike/pedestrian crashes
13. Identify, evaluate, and recommend countermeasures for high-crash locations.	Estimated crash reduction due to recommendations related to established high-crash locations			Reduction in crashes at high-crash locations
14. Identify urban design strategies to develop mixed-use, "24 hour" neighborhoods and implement CPTED (Crime Prevention Through Environmental Design) principles along the corridor.	Acceptance by PAC and MPO Project Manager of recommended strategies			Reduced crime in the corridor
15. Provide an "Urban Design Toolbox" that promotes development forms that make efficient use of land, water, and energy resources and promotes alternative travel modes.	Extent to which recommended tools promote higher floor-area-ratios and are acceptable to the community			Average floor-area-ratio of future development in the corridor
16. Identify cost-effective public engagement approaches.	Workshop attendance	Website sign-ups and comments, ZIP code monitoring	Community meeting attendance	Public Involvement Plan
17. Identify "place-making" opportunities through planning of Mobility Hubs and other infrastructure consistent with community character.	Acceptance by PAC and MPO Project Manager of recommended strategies	Extent to which Mobility Hub and corridor land use visioning is acceptable to the community		Increase in property values of property in the corridor related to other areas of the county
18. Consider longer-term operations and maintenance costs of recommended transportation strategies.	Acceptance by PAC and MPO Project Manager of recommended strategies			Cost per passenger for transit service in the corridor

Mobility Hub Program

An evaluation framework was developed for mobility hub programs in the Broward 2035 LRTP. However, in the Broward 2040 LRTP, the mobility hub initiatives were not directly addressed but indirectly related to the goals (Broward MPO, 2018b). To reflect the current priorities of the Broward MPO for mobility hubs, a new methodology was developed by the Broward MPO, which is shown in Table 3-18.

Table 3-18 Mobility Hub Market and Network Readiness Criteria (Broward MPO, 2018b)

Prioritization Criterion	Measure	2040 LRTP Goal	Description
MARKET READINESS			
Existing trip generation	Trip Producers	Move People	Auto and transit trip origins within one-half mile
	Trip Attractors	Move People	Auto and transit trip destinations within one-half mile
Potential trip generation	Trip Producers	Strengthen Communities	Residential development probability, expected dwelling units, ITE trip generation rate, buildout timing (discount trips by 0-5 years, 5-10 years, >10 years)
	Trip Attractors	Strengthen Communities	Retail/office/industrial development probability, retail/office/industrial expected gross floor area, retail/office/industrial ITE trip generation rate, buildout timing (discount trips by 0-5 years, 5-10 years, >10 years)
NETWORK READINESS			
Existing transit ridership	Trips (stop level or route)	Move People	Existing transit lines serving location in route to line terminal, existing ridership by line
Existing transit availability	Frequency	Strengthen Communities	Number of vehicles serving a location in peak hour

Complete Streets

Complete streets have been one of the most important focus areas for the Broward MPO. An evaluation framework as well as a toolkit were developed to assist the assessment of complete streets initiatives (Broward MPO, 2015c). The evaluation of complete streets can be conducted at two levels, corridor-level and program-level. Tables 3-19 and 3-20 present the goals, objectives, metrics, performance measures, and corresponding tools for corridor-level and program-level evaluation of complete streets, respectively.

Table 3-19 Corridor-Level Complete Streets Evaluation Framework (Broward MPO, 2015c)

Goals	Objectives	Metrics	Performance Measures	Tools
1. Balanced Mobility	1.1 Increase the incidence of bicycling and walking by X% at X months post-baseline.	Mode Share	Change in Bicycle Counts	Pedestrian and Bicyclist Counts Field Data Collection and Worksheet Tools
			Change in Pedestrian Count	
	1.2 Increase the number of transit users by X% at X months post-baseline.	Transit Ridership	Boarding and alighting transit activity along the Corridor	Automatic Passenger Counter Worksheet Tool
	1.3 Provide X% new facilities for bicyclists and pedestrians that improves the roadway environment for all users at X months post-baseline.	Multimodal Facilities	Percentage of Sidewalks and Bicycle Lanes/Paths Facilities	Multimodal Facility Coverage Worksheet Tool
			Multimodal Level of Service (MMLOS)	MMLOS Worksheet Tool
2. Safety	2.1 Decrease crash injury and mortality rates for bicyclists and pedestrians by X% at X months post-baseline.	Crashes and Severity	Number of Crash Injuries and Mortalities	Crash Injury and Mortality Worksheet Tools
	2.2 Implement safe design countermeasures to calm traffic and reduce crashes by X% at X months post-baseline.	Vehicle Speeds	Change in Actual Automobile Speeds	Vehicle Speeds Worksheet Tool
		Safer Facilities	Number and Value of Crash Modification Factors (CMFs) and Crash Reduction Factors (CRFs) from Design Countermeasures	CMFs Inventory Worksheet Tool
3. Health and Sustainability	3.1 Reduce vehicle emissions by X% and fuel consumption by X% through increased bicycle/pedestrian activity at X months post-baseline.	Environmental Impacts	Pounds of Carbon Dioxide Car Emissions Reduction from Bicycle and Pedestrian Usage	Conserve by Bicycle and Pedestrian Study Benefits Worksheet Tools
			Gallons of Fuel Savings	
	3.2 Increase physical activity by X% at X months post-baseline.	Physical Activity	Number of Walking and Biking Trips	Pedestrian and Bicyclist Counts Field Data Collection and Worksheet Tool
	3.3 Incorporate natural design elements throughout the corridor by X% at X months post-baseline.	Environmental Infrastructure	Percentage Tree Canopy Coverage	Tree Canopy Field Data Collection and Worksheet Tools
			Green Infrastructure for Water and Drainage	National Stormwater Calculator Field Data Collection and Worksheet Tools
	3.4 Increase community support and satisfaction by X% at X months post-baseline.	User Satisfaction	Self-Reported User Satisfaction	Complete Streets User Satisfaction Survey and Worksheet Tools
4. Economic Vitality	4.1 Increase property values and business sales along the corridor by X% at X months post-baseline.	Property Values	Commercial and Residential Property Values	Property Values Worksheet Tool
		Retail Activity	Business Sales Volume	Sales Volume Worksheet Tool
	4.2 Reduce the number of parcel/business vacancies along the corridor by X%/$X at X months post-baseline.	Vacancies	Number of Vacant Parcels	Vacant Parcels Worksheet Tool
	4.3 Reduce healthcare costs by X%/$X at X months post-baseline.	Healthcare Costs	Dollars of Healthcare Cost Savings from Bicycle and Pedestrian Usage	Conserve by Bicycle and Pedestrian Study Benefits Worksheet Tools

Table 3-20 Program-Level Complete Streets Evaluation Framework (Broward MPO, 2015c)

Goals	Objectives	Metrics	Performance Measures	Tools
1. Balanced Mobility	1.1 Increase the incidence of bicycling and walking by X% at X months post-baseline.	Mode Share	Change in Bicycle Counts	Pedestrian and Bicyclist Counts Field Data Collection and Worksheet Tools
			Change in Pedestrian Count	
	1.2 Increase the number of transit users by X% at X months post-baseline.	Transit Ridership	Boarding and alighting transit activity along the Corridor	Automatic Passenger Counter Worksheet Tool
	1.3 Provide X% new facilities for bicyclists and pedestrians that improves the roadway environment for all users at X months post-baseline.	Multimodal Facilities	Percentage of Sidewalks and Bicycle Lanes/Paths Facilities	Multimodal Facility Coverage Worksheet Tool
			Multimodal Level of Service (MMLOS)	MMLOS Worksheet Tool
	1.4 Decrease in traffic volume by X% at X months post-baseline.	Traffic Volume	Number of Annual Average Daily Traffic (AADTs)	
			Number of Vehicle Miles Traveled (VMTs)	
	1.5 Increase network connectivity by X% at X months post-baseline.	Equitable Network Connectivity	Equitable Multimodal Network Connectivity	Connectivity Worksheet Tool
2. Safety	2.1 Decrease crash injury and mortality rates for bicyclists and pedestrians by X% at X months post-baseline.	Crashes and Severity	Number of Crash Injuries and Mortalities	Crash Injury and Mortality Worksheet Tool
	2.2 Implement safe design countermeasures to calm traffic and reduce crashes by X% at X months post-baseline.	Vehicle Speeds	Change in Actual Automobile Speeds	Vehicle Speeds Worksheet Tool
		Safer Facilities	Number and Value of Crash Modification Factors (CMFs) and Crash Reduction Factors (CRFs) from Design Countermeasures	CMFs Inventory Worksheet Tool
3. Health and Sustainability	3.1 Reduce vehicle emissions by X% and fuel consumption by X% through increased bicycle/pedestrian activity at X months post-baseline.	Environmental Impacts	Pounds of Carbon Dioxide Car Emissions Reduction from Bicycle and Pedestrian Usage	Conserve by Bicycle and Pedestrian Study Benefits Worksheet Tools
			Gallons of Fuel Savings	
	3.2 Increase physical activity by X% at X months post-baseline.	Physical Activity	Number of Walking and Biking Trips	Pedestrian and Bicyclist Counts Field Data Collection and Worksheet Tools
	3.3 Incorporate natural design elements in the program area by X% at X months post-baseline.	Environmental Infrastructure	Percentage Tree Canopy Coverage	Tree Canopy Field Data Collection and Worksheet Tools
			Green Infrastructure for Water and Drainage	National Stormwater Calculator Survey and Worksheet Tools
	3.4 Increase community support and satisfaction by X% at X months post-baseline.	User Satisfaction	Self-Reported User Satisfaction	Complete Streets User Satisfaction Survey and Worksheet Tools
4. Economic Vitality	4.1 Increase property values and business sales volume in the program area by X% at X months post-baseline.	Property Values	Commercial and Residential Property Values	Property Values Inventory Worksheet Tool
		Retail Activity	Business Sales Volume	Sales Volume Worksheet Tool
	4.2 Reduce the number of vacant parcels in the program area by X%/$X at X months post-baseline.	Vacancies	Number of Vacant Parcels	Vacant Parcels Inventory Worksheet Tool
	4.3 Reduce healthcare costs by X%/$X at X months post-baseline.	Healthcare Costs	Dollars of Healthcare Cost Savings from Bicycle and Pedestrian Usage	Conserve by Bicycle and Pedestrian Study Benefits Worksheet Tools

3.2.5.4 Palm Beach County MPO

LRTP

Five goals and nineteen objectives were created in the Palm Beach 2040 LRTP (Palm Beach MPO, 2017a). The performance measures are included as a part of the objectives of the Palm Beach 2040 LRTP, as shown in Table 3-21. It can also be seen in this table that the goals focus on multimodal transportations. The current values of those performance measures and the target values for year 2025 and 2040 are also clearly specified in this table. Based on the values in Table 3-16, a scoring procedure was developed to prioritize the desired projects listed in the 2040 LRTP, which is shown in Table 3-22.

In the Palm Beach 2040 LRTP, the future population in year 2040 was forecasted based on the controlled total population retrieved from the Bureau of Economic and Business Research (BEBR). A tool, Population Allocation Model, was used to distribute the controlled total population to each individual traffic analysis zone. The growth rate of population was then applied to employment data to predict the employment in year 2040 with the consideration of land use. The predicted values of population and employment were used as the input values to travel demand model to study the impacts of improvements.

The details of how the performance measures listed in Table 3-21 are calculated and the associated data sources can be found in the document of Palm Beach MPO Congestion Management Process (CMP) (Palm Beach MPO, 2016a). Figure 3-8 shows an example of the Palm Beach MPO CMP annual reporting card.

Table 3-21 Palm Beach 2040 LRTP Goal, Objectives, and Targets (Palm Beach MPO, 2017a)

Goal	OBJECTIVE	DESCRIPTION	CURRENT VALUE	2025 TARGET	2040 TARGET
		Goal 1: Provide an efficient and reliable vehicular transportation system			
1	1.1	Reduce the number of thoroughfare intersections with critical sum > 1400	40	30	25
1	1.2	Increase the percentage of traffic signals connected to the central control system by fiber optic network	78%	85%	90%
1	1.3	Increase the percentage of principal arterials covered by closed circuit TV cameras	55%	65%	75%
1	1.4	Increase the percentage of traffic signals with operable vehicle detection	75%	85%	95%
1	1.5	Increase the percentage of facilities that accommodate two feet sea level rise For the SIS network For the non-SIS thoroughfare network	 99% 99%	 90% 75%	 90% 75%
		Goal 2: Prioritize an efficient and interconnected mass transit system			
2	2.1	Increase the percentage of transit commuter mode choice	1.6%	3%	5%
2	2.2	Increase passenger trips per revenue mile For Tri-Rail service For Palm Tran fixed route service	 1.36 1.61	 1.5 2.0	 2.0 2.5
2	2.3	Increase the number of park-n-ride spaces	2,196	3,000	4,000
2	2.4	Reduce the average ratio of transit travel time to auto travel time for Palm Tran fixed route system	2.87	2.50	2.00
		Goal 3: Prioritize a safe and convenient non-motorized transportation network			
3	3.1	Increase the percentage of Pedestrian commuter mode choice Bicycling commuter mode choice	 1.7 % 0.5%	 3.5 % 1.5%	 5 % 3%
3	3.2	Increase centerline mileage of Buffered bike lanes 10-ft or wider shared use pathways Designated bike lanes Priority bike network operating at LOS C or better	 8 25 125 140	 50 75 250 350	 100 125 500 500
3	3.3	Increase percentage of thoroughfare mileage near transit hubs That provides dedicated bicycle facilities (within 3 miles) That provides dedicated pedestrian facilities (within 1 mile)	 10% 85%	 20% 100%	 40% 100%
		Goal 4: Maximize the efficient movement of freight through the region			
4	4.1	Decrease the percentage of SIS facilities, SIS connectors, and non-SIS designated truck routes that exceed capacity (v/c > 1.1)	3.3%	2.5%	1.5%
4	4.2	Increase the annual tonnage of freight through The Port of Palm Beach Palm Beach International Airport	 2.14 M 22K	 2.5 M 25K	 3.0 M 35K
		Goal 5: Preserve and Enhance Social and Environmental Resources			
5	5.1	Decrease per capita daily fuel use (gallons/person)	1.54	1.25	1.00
5	5.2	Decrease per capita daily NOx emissions (grams/person)	50	35	25
5	5.3	Decrease per capita daily Hydrocarbon emissions (grams/person)	30	20	10
5	5.4	Decrease per capita daily Carbon Monoxide emissions (grams/person)	400	300	250
5	5.5	Decrease per capita daily Vehicles Miles Travelled (VMT/person)	25	21	20

Table 3-22 Priority Scoring Procedure Used in the Palm Beach 2040 LRTP (Palm Beach MPO, 2017a)

Priority Scoring Procedure for Review of Major 2040 Desires Plan Transportation Projects						
Value	Category	Max	Criteria	Value	Scoring	
					Near RA/UC	Non RA/UC
1 & 6	Safety, Security and Complete Streets	15	Project improves non-motorized safety by providing:	buffered bike lanes - 2	8	4
				10'+ shared-use pathways - 1.5	6	3
				designated bike lanes - 1	4	2
				new sidewalks - 0.5	2	1
			Project improves vehicular safety (project must demonstrate)		5	
		5	Project improves performance of hurricane evacuation route		3	
			Project mitigates impacts of sea level rise		2	
2	Maintenance	10	Project improves infrastructure in unacceptable condition with widespread advanced signs of deterioration; potential imminent failure		10	
			Project improves infrastructure in poor condition and mostly below standard, approaching the end of its service life, exhibiting significant deterioration and of strong risk of failure		8	
			Owner/operator provides commitment to fund O&M of capacity expansion		5	
3	TSM&O / TDM	10	Non-capacity project implements TSM strategies		7	
			Non-capacity project implements TDM strategies		3	
			Capacity project improves Thoroughfare intersection(s) where critical sum > 1400		5	
			Capacity project expands fiber optic traffic signal network		3	
			Capacity project expands CCTV camera coverage area on principal arterials		2	
4	Project Benefit and Leveraged Funds	2	Project fills in missing link in transportation system		2	
		4	Benefit/Cost Ratio or Return on Investment	>4	4	
				3-4	3	
				2-3	2	
				1-2	1	
		4	Other public or private cash funds in project	50%	4	
				25%	2	
5	Equity	5	Median income of benefit area vs PBC median income ($52,806)	< 60%	5	
				60 - <80%	3	
				80% - <100%	1	
		5	Traditionally underserved population percentage in benefit area	>80%	5	
				>60 - 80%	4	
				>40% -60%	3	
				>20% - 40%	2	
				5-20%	1	
7	Econ Dev/ Envir. Steward	10	Project is consistent with all applicable local comprehensive plans		5	
			Project is likely to be a NEPA categorical exclusion or EA FONSI		5	
8	Regional Freight	5	Project improves capacity on congested SIS facility/connector or non-SIS truck route	v/c > 1.2	5	
				v/c > 1.1	3	
				v/c > 1	1	
		5	Project improves efficient movement of freight in region		5	
9	Non-motorized Connectors	10	Project improves non-motorized facilities at an interchange, bridge, or railroad crossing		6	
			Project improves non-motorized facilities on Thoroughfare within 2 miles of a transit hub		4	
10	Efficient Transit	10	Project improves service at a transit hub		6	
			Project reduces transit travel time between transit hubs		4	

lote: The procedure was utilized for the *Directions 2040 Plan*. It is not an adopted procedure and it may be updated regularly as part of the MPO's annual revenue allocation proce

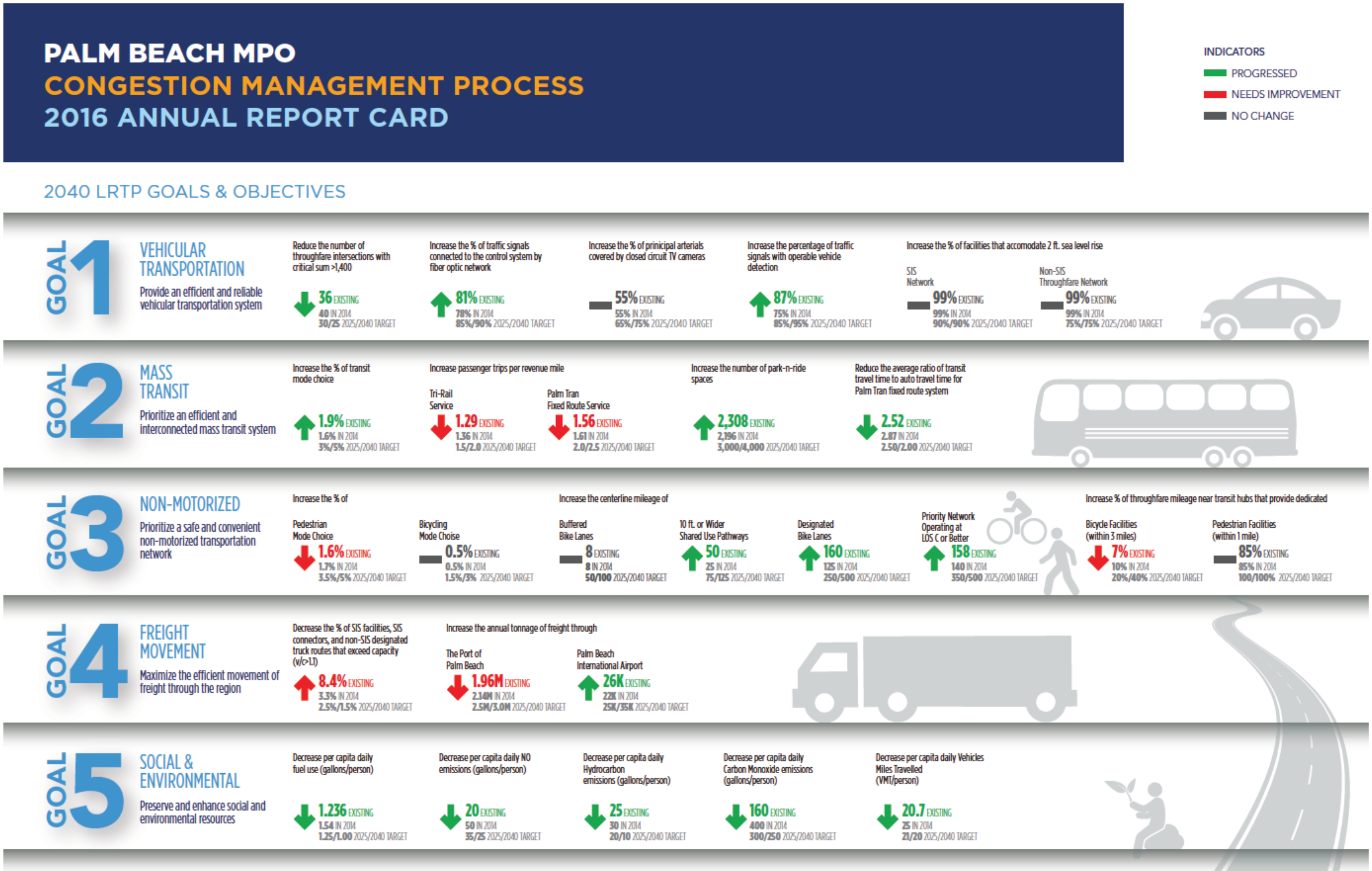


Figure 3-8 Example of Palm Beach Congestion Management Process Annual Report Card (Source: Palm Beach County MPO, 2016b)

5-Year Strategic Plan

A 5-year strategic plan has been established by the Palm Beach MPO to be used as a guide toward achieving long-term vision and missions (Palm Beach MPO, 2017b). Aligned with the Unified Planning Work Program (UPWP), six goals were formed in this strategic plan, including:

- Administer the agency
- Engage the public
- Plan the system
- Prioritize funding
- Improve the experience
- Collaborate with partners

The associated objectives and performance measures were identified for each goal. It should be pointed out that targets were also specified for each performance measure. An annual report card was developed to monitor the progress to achieve the goals. Figure 3-9 shows an example of such an annual report card.

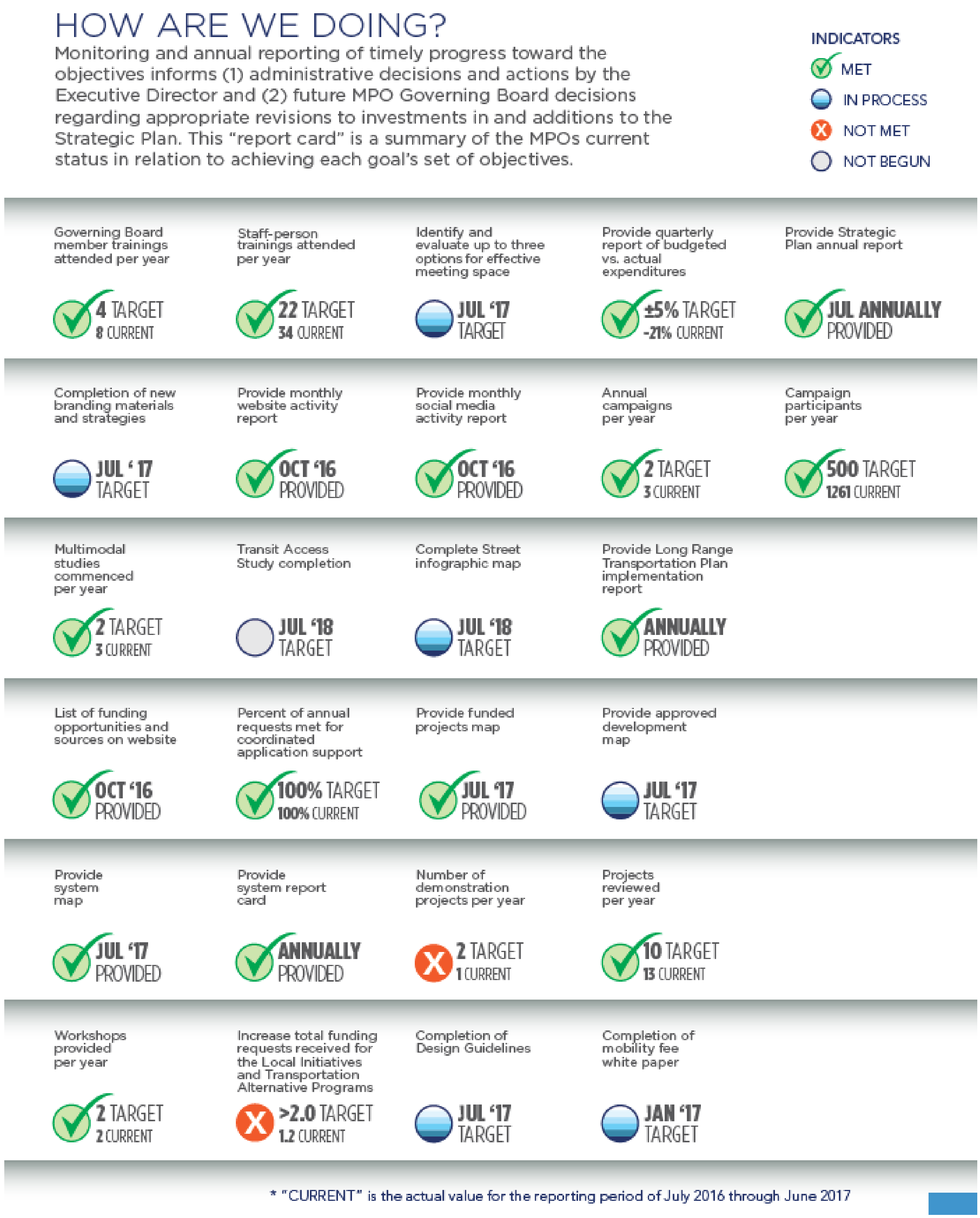


Figure 3-9 Example of Palm Beach MPO Strategic Plan Annual Report Card (Source: Palm Beach County MPO, 2017b)

Pedestrian and Bicycle Safety Study

The Palm Beach MPO Pedestrian and Bicycle Safety Study provides a list of countermeasures to reduce pedestrian and bicycle-related crashes (Kimley-Horn and Associates, Inc. 2017). In this document, the data sources for safety analysis include:

- Strava for pedestrian and cyclist information
- Florida Department of Health's (FDOH) Florida Injury Surveillance Data System
- Florida Department of Highway Safety and Motor Vehicles (DHSMV) Traffic Crash Facts Annual Report
- Palm Beach County crash system data
- Florida Department of Transportation (FDOT) Unified Basemap Repository (UBR) data

The performance measures used are number of pedestrian/bicyclist fatalities or injuries by different categories, for example, year, month, day of week, time of day, lighting conditions, road surface condition, weather condition, age, etc.

US-1 Multimodal Corridor Study

Different from the traditional transportation studies, the US-1 multimodal corridor study utilized a Health Impact Assessment (HIA) evaluation procedure (Palm Beach TPA, 2018). This procedure consists of six steps: screening, scoping, assessment, recommendations, reporting, and monitoring and evaluation. It considered the impacts of proposed project on the health of a population and the distribution of these impacts within the population. Table 3-23 lists the performance indicators used in the HIA evaluation process.

Table 3-23 Performance Indicators Used in the US-1 Multimodal Corridor (Palm Beach MPO, 2017a)

Indicator	Performance Measure
Access to health	Transit travel time along US-1 corridor
	Transit travel time from low health care access locations to nearest hospital /health care clusters
	Number of food desert tracts within 1 mile of corridor
Physical health	Percentage of adults with obesity (corridor-wide)
	Percentage of adults with diabetes (corridor-wide)
	Percentage of adults with hypertension (corridor-wide)
	Percentage of adults with asthma (corridor-wide)
	Percentage of adults with depression (corridor-wide)
Bicycle and pedestrian safety	Bicycle crashes (last 5 years)
	Pedestrian crashes (last 5 years)
	Bicycle and pedestrian fatalities (last 5 years)
	Bicycle and pedestrian fatalities occurring at night (last 5 years)
	Workers commuting by public transportation, walking, or biking
	Pedestrian activity
	Bicyclist activity
Economic health	US-1 corridor population density

	Average taxable land value of properties immediately adjacent to the US-1 corridor
	Average taxable land value within one (1) mile of the US-1 corridor (excluding barrier island properties)
	Number of new businesses
	Workers commuting by transit, walking, or bicycling
	Household units within inclusionary zoning boundaries or Community Land Trust

3.2.5.5 MetroPlan Orlando

LRTP

The 2040 LRTP developed by the MetroPlan Orlando (the MPO for Greater Orlando, FL) consists of seven goals, 35 objectives, and 22 performance measures (MetroPlan Orlando, 2016a). Table 3-24 lists the goals, evaluation criteria, and performance measures in the MetroPlan Orlando 2040 LRTP.

Table 3-24 Goals, Evaluation Criteria, and Performance Measures in the MetroPlan Orlando 2040 LRTP

Goal	Evaluation Criteria	Performance Measure
Safety	Evacuation capacity	Lane miles of evacuation routes per thousand people
	System safety	Crash rates (per million vehicle miles traveled)
Balanced multi-modal system	Miles of highway facilities	Lane miles
		Lane miles per thousand people
	Vehicle miles traveled per capita	Vehicle miles traveled per capita
	Vehicle hours traveled per capita	Vehicle hours traveled per capita
	Miles of transit service	Transit service miles
		Transit service miles per thousand people
	Transit hours of service	Revenue hours of service per thousand people
Integrated regional system	System resources designated for freight, goods, and services movement	Designated system lane miles/total system lane miles
	Transit system access	Percent of population within ¼ mile of transit service
	Transit access to employment	Percent of employment within ¼ mile of transit service
	Access to intermodal stations	Percent of population within five minute commute of intermodal stations

Goal	Evaluation Criteria	Performance Measure
	Access to activity centers	Percent of population within 10 -minute travel time of activity centers
	Access to international airports	Percent of total employment within 30-minute commute from international airports
Quality of life	Jobs-housing balance	Seminole (job/house ratio)
		Orange (job/house ratio)
		Osceola (job/house ratio)
	Average speed during congested times (Mile Per Hour (MPH))	Freeway congested speed
		Arterial congested speed
		Other roadways congested speed
		All roadways congested speed (MPH)
	Level of delay	Total daily hours of delay (vehicle hours)
		Daily delay per capita (min/day)
		Daily cost of delay per capita ($/day)
Efficient and cost effective	Cost effectiveness	Annual cost of congestion in billions of dollars (user costs only)
	Efficiency	Seminole (miles of roadways below standard)
		Orange (miles of roadways below standard)
		Osceola (miles of roadways below standard)
	Transit passenger miles	Total transit passenger miles per capita
	Percent single occupancy vehicle	Percent of person trips by single occupancy vehicle
	System daily VMT	Average VMT per dwelling
Energy and environmental Stewardship	Air pollutants	Total carbon monoxide (CO) emissions (kg)
		Total Hydrocarbon (HC) emissions (kg)
		Total Nitrogen Oxide (NO) emissions (kg)
	Fuel use	Daily gallons of fuel per capita
		Percentage increase from base (2009)
Economic vitality	Jobs created	Jobs created as a result of transportation investment
	Economic benefit	Economic activity generated as a result of transportation funding investment (billions of dollars)
	Cost feasible	Plan is financially feasible

An updated congestion management process was included in the MetroPlan Orlando 2040 LRTP (MetroPlan Orlando, 2016a). Figure 3-10 illustrates the steps used in the congestion management process. As shown in this figure, the process consists of eight steps and the third step is to develop multimodal performance measures. Figure 3-11 shows the relationship between CMP performance measures and the identified objectives. It can be seen from this figure that the CMP performance measures cover the areas of mobility, safety, reliability, transit ridership and performance, shared ridership, bicycle/pedestrian facilities, signal retiming benefit/cost, and so on.

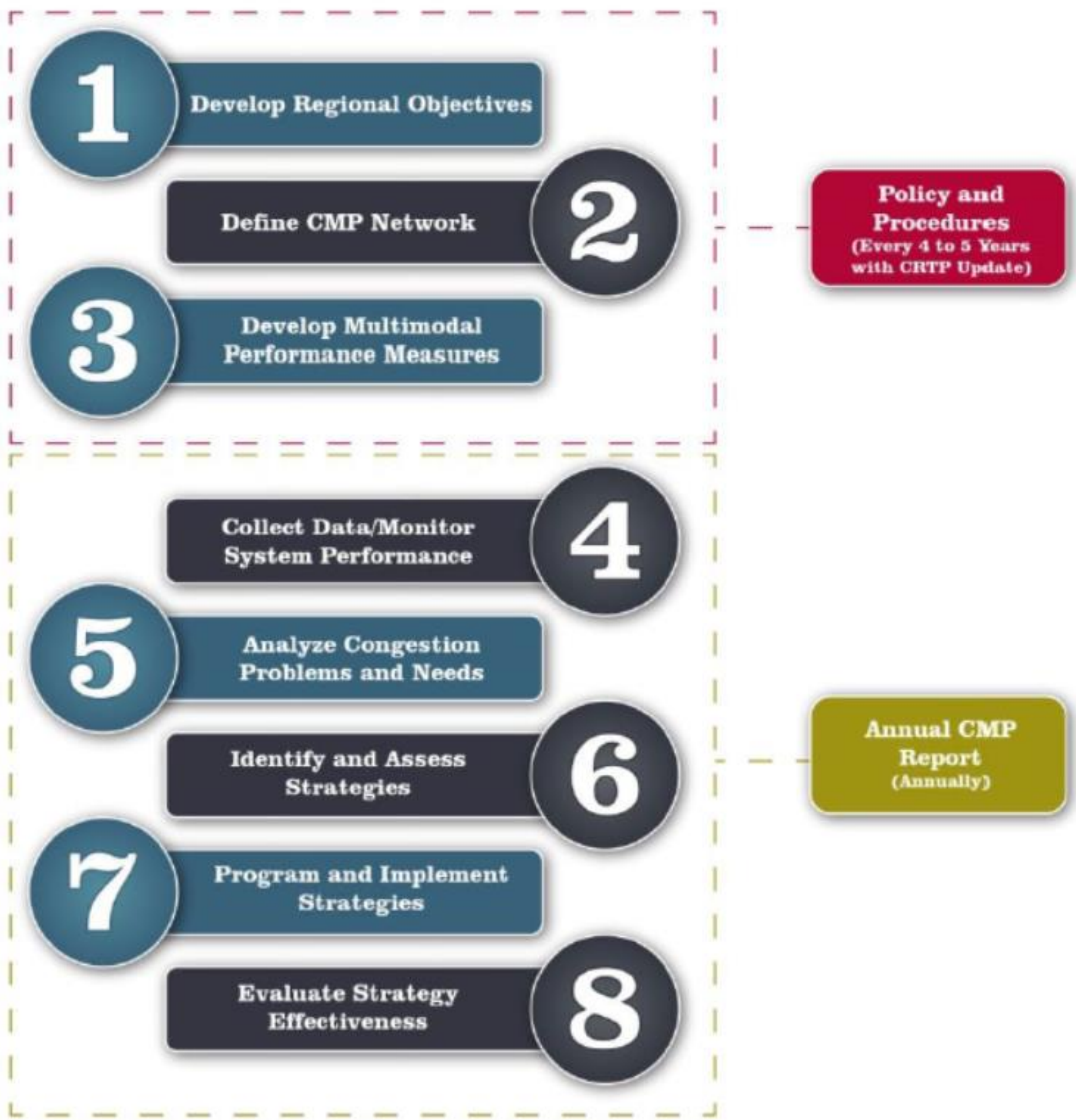


Figure 3-10 Congestion Management Process (Source: MetroPlan Orlando, 2016a)

Figure 3-11 Relationship between CMP Performance Measures and Objectives (Source: MetroPlan Orlando, 2016a)

ITS Master Plan

An ITS Master Plan was developed by the MetroPlan Orlando to identify applicable ITS strategies that improves efficiency, safety, reliability of the region's multimodal transportation system (Gannett Fleming, Inc. et al., 2017). Table 3-25 lists the goals, evaluation criteria, and performance measures used in this ITS master plan. A survey was conducted to prioritize the ITS strategies that are applicable to the MetroPlan Orlando stakeholders. Table 3-26 shows the survey results. It is seen from this table that the ITS strategies with the highest priority are traffic adaptive signals, information management, dynamic routing, and dynamic parking guidance and reservation. An ITS scoring methodology was also developed in the ITS master plan, which takes the following performance measures listed in the 2040 LRTP into consideration.

- Percent of vehicle travel in generally acceptable operating conditions (peak hour)
- Delay for vehicle
- Travel time reliability for vehicle
- Percent miles severely congested (based on Volume to Capacity (v/c) Ratio)
- Combination of truck travel time reliability
- Combination of truck delay
- Combination of truck percent miles severely congested truck
- Percent of congested roadway centerline miles with transit service transit
- On-time performance transit
- Signal retiming cost/benefit
- Incident duration

Bicycle and Pedestrian Plan

The MetroPlan Orlando Bicycle and Pedestrian Plan focuses on three areas:1) providing connectivity and completing missing gaps in the existing bicycle and pedestrian network; 2) serving areas potentially with high demand of bicycle and pedestrian; and 3) identifying improvements that could expand the bicycle/pedestrian network and make the network more user-friendly for commuter trips (MetroPlan Orlando, 2016b). To prioritize bicycle and pedestrian projects, the following measures are used as the scoring criteria:

- Non-motorized trip demand
- Type of accommodation
- Connectivity
- Intermodal
- Local match
- Local plans
- Project readiness

Among these measures, the type of accommodation and connectivity have higher weights.

Table 3-25 Goals, Evaluation Criteria, and Performance Measures in the MetroPlan Orlando ITS Master Plan (Gannett Fleming, Inc. et al., 2017)

Vision Statement: Maximize the transportation system performance by continually improving safety, efficiency, and reliability for all systems users through the application of technology.		
Goals	**Objectives**	**Measures**
A: Maximize the performance, efficiency, and reliability of the multi-modal transportation system.	**A1:** Reduce system-wide delay and travel time for automobiles, commercial vehicles, and transit.	Improve travel time and reliability
		Increased trip options/choices by mode for travelers
		Reduction in vehicle hours of delay on the system per person per day
	A2: Reduce delay and travel time on selected corridors for automobiles, commercial vehicles, transit and bicycle / pedestrian facilities using TSM&O.	Identification of priority corridors
		Percentage of corridors managed or monitored
		Improve travel time reliability on corridors during peak hours
		Reduce delay duration during peak hours
		Increased person throughput (point A to point B)
	A3: Reduce vehicle delay from incidents by implementing incident response and special event traffic management programs.	Travel times and speeds
		Reduction in response and clearance times
	A4: Monitor the service life and time in service of ITS devices used in the transportation system in order to reduce costs.	ITS devices are monitored and evaluated on a scheduled basis
	A5: Conduct on-going research regarding future ITS technologies in order to "see" into the future as to what new ITS strategies and equipment are "around the corner".	Research is routinely conducted on new ITS technologies that takes into account capital equipment, staffing and resource needs
		Pricing information, including variable pricing, is routinely evaluated
B: Integrate information, communication, and technology to empower systems users to make informed choices.	**B1:** Improve the reliability and predictability of travel by monitoring the use of the transportation system and through the collection of pertinent data.	Conduct traffic counts in real-time for vehicles, transit, bicycles, and pedestrians
		Number and percentage of roadway miles under video surveillance and monitoring
	B2: Provide real-time dynamic travel time and delay information (suggested routes, dynamically updated) to users.	Identification of locations in need of real-time dynamic travel and delay information
		Reduction in percent of locations and transit routes in need of real-time dynamic traveler information
		Increase in percent of transit routes with real-time monitoring
		Increase in percent of motorists and transit users having access to real-time travel and delay information
		Delivery of traveler information by the private sector using information developed by the public sector
		Emergency responders have access to real-time travel and delay information
	B3: Improve tourist access and mobility through the use of specialized traveler information systems.	Number and nature of 5-1-1 calls
		Number of www511 visits
		Comments to Convention and Visitor Bureau
		Increased access to GPS and other commercial traveler information real-time data sources
	B4: Improve service for special traveler needs through the use of ITS applications.	Diversity of ITS services for special populations, pedestrians, cyclists, and students is readily available
		Expanded economic opportunity and socioeconomic mobility for underserved populations (i.e., Ladders of Opportunity)
	B5: Enhance safe and efficient freight transport and delivery.	Research role and value of real-time parking information availability and truck reservation systems
		Promote responsible use of wireless inspection practices to streamline trucking operations
	B6: Promote and encourage interagency, interjurisdictional coordination and communications.	Development of regional interagency operational and communications plans and agreements (ITS regional architecture)
		Development of regional set of transportation management plans for planned major events that can be applied to planned events
		Development of list of potential ITS projects each agency could consider when developing their project priorities
		Development of detailed ITS strategies to reduce agency efforts in creating System Engineering (SE) documents

Table 3-26 Goals, Evaluation Criteria, and Performance Measures in the MetroPlan Orlando ITS Master Plan (Gannett Fleming, Inc. et al., 2017) (Con't)

		Creation of incident response and special event traffic incident management (TIM) team meetings and programs for event review and debriefing
	B7: Conduct annual surveys on customer service and seek feedback on system needs through newsletters, websites and other innovative techniques.	Development and evaluation of customer surveys and survey results
	B8: Develop a business model to demonstrate to transportation officials and elected agency leadership the benefits of continued use of ITS.	Development of a business case for MPO Board members and other officials
		Convey to elected officials and the general public the roles and benefits of video surveillance in the everyday operation and maintenance of the transportation system
C: Enhance the safety and security of the transportation system.	**C1:** Improve safety and security of the transportation system through ITS strategies and investments.	Reduction in severity of vehicle crashes (fatalities, injuries and expenditures)
		Reduction in bicycle of pedestrian accidents
		Reduction in red light violations
		Reduction in speed limit violations
		Reduction in average response and clearance times for aggressive driving crashes, intersection crashes, vulnerable road user (bicycle and pedestrian) crashes, and lane departure crashes
		Reduction in evacuation clearance times during emergency events
	C2: Monitor crash records as it relates to infrastructure improvements to quantify the benefits.	Crash rate and severity data considered during ITS procurement
	C3: Support data sharing between transit agencies and law enforcement to ensure passenger safety and security.	Share video feeds and transit vehicle location data using ITS infrastructure
D: Protect the environment and enhance the quality of life.	**D1:** Improve air quality and reduce greenhouse gas emissions.	Reduction in per capita greenhouse gas emissions from mobile sources
	D2: Reduce fuel consumption by balancing traffic volumes across the transportation network.	Reduced fuel consumption per capita
	D3: Increase in estimated number of passengers per vehicle per mode.	Increase in vehicle occupancy rates
	D4: Implement Goal 4: Quality of Life in the MetroPlan Orlando 2040 Long Range Transportation Plan.	ITS contributes to the performance of the transportation system and supports the adopted regional growth vision including context-sensitive, pedestrian scale, and community enhancing design features

Table 3-27 ITS Strategies Survey Results (Gannett Fleming, Inc. et al., 2017)

Survey Question	Response Options	Results (1-Highest to 6-Lowest)
Please select your Agency's top technology need	Additional CCTV Coverage	3
	Traffic Adaptive Signals	1
	Connected/Autonomous Vehicles	5
	Bud Rapid Transit	2
	Expanded Communication Network (Fiber Backbone)	3
	Other	4
Please rank the following technology needs for your Agency	Additional CCTV Coverage	5
	Traffic Adaptive Signals	1
	Connected/Autonomous Vehicles	4
	Bud Rapid Transit	3
	Expanded Communication Network (Fiber Backbone)	2
	Other	6
Please select your Agency's top Transportation Management need	Incident Management	3
	Traveler Information	4
	Parking Management	5
	Emergency Management	5
	Public Transit Management	2
	Information Management	1
	Other	4
Please rank the following Transportation Management needs	Incident Management	3
	Traveler Information	2
	Parking Management	6
	Emergency Management	5
	Public Transit Management	4
	Information Management	1
	Other	7

Survey Question	Response Options	Results (1-Highest to 6-Lowest)
Please prioritize the following strategies for Active Traffic Management	Dynamic Managed Lanes	2
	Dynamic Routing	1
	Dynamic Lane Use Control	3
	Adaptive Ramp Metering	5
	Hard Shoulder Running	4
	Other	6
Please prioritize the following strategies for Advanced Parking Management	Dynamic Parking Guidance & Reservation	1
	Dynamic Priced Parking	2
	Freight Parking	3
	Other	4
Please prioritize the following strategies for Public Transportation Management	Dynamic Transit Capacity Assignment	2
	Dynamic Priced Fare	4
	Transfer Connection Protection	5
	Transit Traveler Information	3
	Single Payment System with other Transit	1
	Other	6
Please rank the following barriers to implementing your ITS needs	Lack of Funding for Capital Projects	3
	Lack of Funding for Operations	1
	Interoperability between Existing Systems and/or Other Agencies	2
	Lack of Perceived Need or Benefit	4
	Other	5

3.2.5.6 Hillsborough MPO

LRTP

The Imagine 2040 LRTP was developed by the Hillsborough MPO, the MPO designated for the Tampa urbanized area (Atkins North America, 2018). A set of six goals and corresponding objectives and policies were specified in the Imagine 2040 LRTP. To achieve these goals, a list of performance measures was determined based on five categories of needs. Table 3-28 summarizes the needs categories and the corresponding performance measures listed in the Imagine 2040 LRTP.

Table 3-28 The Needs Category and Performance Measures in the Imagine 2040 LRTP

Needs Category	Subcategory	Performance Measure
Preserve the system	Pavement and bridges	• Safety – wheelpath, rutting, friction • Preservation – cracking, potholes, raveling, patching, depressions • Ride – rippling, faulting, public complaints
	Transit fleet	• Average vehicle age in fleet
Minimize traffic for drivers and shippers	Congestion management for drivers	• Reliability – consistency or dependency in commute times through a travel time index • Travel time index (mean travel time/free flow travel time)
	Freight congestion	• Percent miles of congested freight routes • Percent of freight hotspots mitigated • Planning time index • Buffer index • Cost of freight delay
Reduce crashes and vulnerability	Safety: crash reduction	• Pedestrian death index • Fatality by category • Injury/fatality rate
	Security: vulnerability reduction	• Travel time delay due to transportation network disruption • Lost trips due to transportation network disruption • Economic losses due to storm in 2014 dollars
Real choices when not driving	Transit/bus service	• Transit level of service based on number of buses per hour and wait time
	Transportation disadvantaged service	• Transportation disadvantaged living outside of bus service area

Needs Category	Subcategory	Performance Measure
	Trails and sidepaths	• The number of residents and workers with access to excellent or good pedestrian level of service and bicycle level of service
Major investments for economic growth	Key Economic Spaces (KES)	• Number of jobs served • Delay reduced
	Strategic intermodal system	NA*
	Development based on needs	NA
	Long range vision	NA

Notes:
* NA means not available.

It should be pointed out that the types of improvement considered for congestion management of vehicles are as follows.

- Geometric improvement at intersections (for example, adding or extending turn lanes)
- Advanced coordinated signal control and management
- Advanced traffic management system
- Expansion of road ranger patrols and improved incident management
- Freeway operational movement such as variable speed limit, lane control, and ramp metering

Transportation Improvement Program (TIP)

The Hillsborough MPO safety measures and targets were stated in its TIP, which are consistent with the national safety measures specified in MAP-21 and the state safety measures (Hillsborough MPO, 2018a). Table 3-29 lists these safety measures and the year 2018 targets for the State as well as the Hillsborough MPO. The safety targets for the Hillsborough MPO listed in this table were derived by using linear projection based on historical 5-year crash data on a rolling average.

Table 3-29 The Safety Measures and the Targets for the State and the Hillsborough MPO

Safety Measure	Calendar Year 2018	
	State	Hillsborough MPO
Number of Fatalities	0	184
Number of Serious Injuries	0	1,618
Nonmotorized Fatalities and Serious Injuries	0	243
Rate of Fatalities per 100M VMT	0	1.40
Rate of Serious Injuries per 100M VMT	0	12.35

In coordination with the Imagine 2040 LRTP, the TIP projects were prioritized by a list of criteria ((Hillsborough MPO, 2018a). The corresponding performance measures are as shown below.

- Preserve the system
  - Bridge repair and replacement

    - Road resurfacing
    - Transit vehicle replacement
- Reduce crashes and vulnerability
    - Total, fatal and bike/pedestrian crashes per centerline
    - Recovery time and economic impacts from flooding or major storm surge
- Manage congestion for drivers and shippers.
    - Travel time reliability on heavily congested arterials
    - Peak period V/C ratio
- Real choices when not driving
    - Density of jobs and population in 2040 within ¼ mile of proposed transit service
    - Density of jobs and population in 2040 within ¼ mile of proposed trail/sidepath
- Major infrastructure improvements
    - Key economic spaces (that is, clusters with more than 5,000 jobs)
    - 2040 jobs served per mile of improvement
    - 2040 delay reduced per mile of improvement

ITS Master Plan

An ITS Master Plan was developed by the Hillsborough MPO in 2013 (URS Inc. 2013). This plan focuses on 1) Transportation efficiency and quality; 2) Safety and security, 3) Accessibility and mobility; and 4) Reliable and coordinated operations. As a basis for future plan, the existing transportation and roadway conditions were first examined. The following performance measures were analyzed.

- Average incident duration per lane blocking incident
- Number and type of incidents
- Miles managed by ITS
- Travel time index and buffer index
- Level of service
- Percentage of transit run delays caused by congestion
- Total number of bicycle crashes
- Total number of pedestrian crashes
- Route location and associated multimodal element

A stakeholder survey was conducted to prioritize ITS needs. Based on the survey results, a number of TSM&O and ITS strategies were proposed to meet these needs, as summarized in Table 3-30. Correspondingly, 28 ITS projects were identified.

Table 3-30 Summary of the TSM&O and ITS Strategies proposed in the Hillsborough ITS Master Plan (Source: URS Inc., 2013)

Focus Area	Objectives	Strategy
Traffic management	Improve and implement strategies and technologies to mitigate congestion, improve travel flow and mobility	Provide and/or expand arterial traffic management/traffic surveillance systems.
		Enhance and/or expand real-time traveler information.
		Continued a proactive traffic signal timing optimization program
		Provide active traffic management (ATM)
	Provide and/or enhance special event management capabilities	Expand and provide ATMS capabilities along major event routes
		Provide portable Intelligent Traffic Management System
	Provide and enhance (optimize) traffic signal coordination and corridor system performance	Systematically re-time traffic signals on priority network
		Upgrade and interconnect signals on priority network
		Provide active monitoring of traffic signal systems
		Provide upgrades to signal hardware equipment
	Provide Integrated Corridor Management (ICM) strategies and support systems	Provide a regional ICM deployment plan
		Develop an inter-agency traffic control/ITS concept
	Develop and implement traffic control measures to enhance the efficiency, mobility, safety, and/or reliability of the transportation system	Evaluate a ramp metering program for interstate on-ramps
		Implement congestion pricing programs, including HOT/managed plan
		Evaluate the feasibility of implementing ATM systems along the interstates including the following techniques • Speed harmonization measures • Queue warning systems • Hard shoulder running measures along the interstates
		Develop and implement advance parking management systems at major parking facilities
		Develop and expand TSP program
		Provide and/or expand EVP systems
	Support measures to mitigate and track regional environmental impacts and EPA compliance	

	Preserve ITS/Traffic signal equipment and infrastructure investments	
Incident/Emergency management and safety	Improve Incident detection and verification times	Develop, implement and/or upgrade TMCs
		Expand and upgrade ATMS/traffic surveillance systems
		Provide the capability to share 911 and highway patrol Computer Aided Dispatch (CAD) information with City/County TMCs
	Improve incident response times	Provide and/or expand enhanced reference location signs
		Provide AVL and identification for emergency vehicles/responders
		Provide the capability to share traffic information with emergency responders
		Evaluate and provide additional interstate median crossover points
	Improve incident clearance (duration) Times	Provide freeway service patrol (road ranger) expansion and upgrades
		Develop policy and procedures to modify signal timings on detour routes and upgrade traffic controllers/field-to-center communication systems
		Identify and implement dynamic routing application for route diversions and evacuations
	Reduce crash rates and improve safety at signalized intersections (including vehicles, pedestrians, bicycles)	Provide and expand red light running programs at intersections with high crash rates
		Provide, coordinate, and/or improve pedestrian/bicycle safety solutions • Infrared Detectors • Microwave Detectors • Count-down signals • In-pavement lights • The illuminated pushbutton
	Improve mobility and reduce vehicle crash rates related to weather and other low visibility events	Develop and deploy a RWIS

	Improve safety and coordination of intermodal conflicts (highway-rail interface/crossings)	Provide crossing gate video enforcement
		Upgrade signal interconnect with traffic signals
		Provide an Active Advanced Warning System (AAWS)
		Evaluate and implement in-vehicle warning systems
	Identify and develop diversion routes and system strategies	
	Identify and provide ITS strategies to support regional emergency evacuation plans and response	Review regional evacuation plan and disaster response and recovery plan
		Expand and/or enhance the capability to provide regional emergency/traffic text alerts
Traveler information dissemination	Provide and/or enhance multi-modal information dissemination and trip planning tools that may affect roadway users and travel choices across all modes	Provide real-time parking garage/lot space availability with map of Downtown Tampa as part of the 511 mobile app
		Provide commercial truck parking lot space availability as part of the 511 mobile app
		Provide and/or expand real-time travel-time data along arterials
	Expand and/or enhance en-route traveler information systems	
Inter-agency coordination and communications	Develop regional interagency operational and communications plan(s)	Identify and enhance regional concept of operations, policies, and procedures involving transportation, emergency, and law enforcement stakeholders

Freight System Performance Measures for the Tampa Bay Region

After reviewing the national freight system performance measures as well as the existing freight-related performance measures for the Tampa Bay region, a list of potential freight performance measures were recommended by for the Tampa Bay region (FDOT District 7, 2014), as shown in Table 3-31. This table also shows the assessment of these performance measures in terms of understandability, usefulness, potential for forecasting, ease of data collection, and data quality.

Table 3-31 Recommended and Potential Freight Performance Measures and Assessment for the Tampa Bay Region (Source: FDOT District 7, 2014)

Measure (recommended in bold)	Scale (system or corridor)	Understand -able	Useful	Forecast Potential	Ease of Data Collection	Data Quality	Data Sources
Safety Measures							
Truck crashes per truck VMT	Both	Med	Med	Low	Med	Med	FDOT Data, Model
% of truck crashes involving an injury	Both	High	High	Low	High	High	FDOT Data
% of truck crashes involving a fatality	System	High	High	Low	High	High	FDOT Data
Highway/rail at-grade crashes	Both	High	Med	Low	High	High	FRA
Truck crashes	Both	High	Med	Low	High	High	FDOT Data
Truck crash injuries	Both	High	Med	Low	High	High	FDOT Data
Truck crash fatalities	Both	High	Med	Low	High	High	FDOT Data
Total rail accidents	System	High	Med	Low	High	High	FRA
% of rail accidents involving a fatality	System	High	High	Low	High	High	FRA
Highway/rail at-grade crash injuries	Both	High	Med	Low	High	High	FRA
Highway/rail at-grade crash fatalities	System	High	Med	Low	High	High	FRA
Access Measures							
Average truck delay at ports	Corridor	High	High	Med	Med	Med	ATRI GPS, Port Authorities
Truck delay on key access routes to freight activity centers	Corridor	Med	High	Med	Med	High	ATRI GPS
Volume-to-capacity ratio on freight distribution routes	Corridor	Med	Med	High	Med	Med	FDOT Data, Model
Volume-to-capacity ratio on freight activity center streets	Corridor	Med	Med	High	Med	Med	FDOT Data, Model
Mobility Measures							
Point-to-point travel times on key freight highway network segments	Corridor	High	High	Med	Med	High	ATRI GPS
Truck delay per year at top 10 highway bottlenecks	Both	Med	High	Med	Med	High	ATRI GPS, Field Observation, Model
Truck Reliability Index in AM Peak (80^{th} percentile travel time/target travel time)	Corridor	Low	High	Low	Low	High	ATRI GPS
Truck Reliability Index in PM Peak (80^{th} percentile travel time/target travel time)	Corridor	Low	High	Low	Low	High	ATRI GPS
Truck VMT	System	Med	Low	High	Med	Med	Model
Truck Travel Time Index on Interstate Highways	Corridor	Low	High	Med	Med	High	Model, ATRI GPS
Volume-to-capacity ratio on freight network	Corridor	Med	Med	High	Med	Med	FDOT Data, Model
Average Class 1 railroad speed	Both	High	Med	Low	Low	High	Railroads
Rail market share for freight tonnage	System	Med	Med	Med	Med	Med	FAF
Trucks as a percent of total traffic volume	Both	High	Med	High	Med	Med	Model, Counts
Condition Measures							
Pavement condition of freight network	Both	High	Med	Med	Med	High	HPMS
Bridge condition of freight network	Both	High	Med	Med	High	High	HPMS
Livability Measures							
Freight-related criteria pollutant emissions	System	Med	High	High	Low	Med	Model, MOVES
Freight-related greenhouse gas emissions	System	Med	Med	High	Low	Med	Model, MOVES
Economic Measures							
Freight transportation employment	System	High	Med	Med	Low	High	BLS
Tons of imports and exports by water	System	High	Med	Med	Med	High	BTS
Tons of imports and exports by air	System	High	Med	Med	Med	High	BTS
Tons of imports and exports by pipeline	System	High	Low	Med	Low	High	
Tons of imports and exports by truck	System	High	Med	Med	Med	Med	FAF
Tons of imports and exports by rail	System	High	Med	Med	Med	Med	FAF

Roadway Level of Service Report

A 2015 level of service report for the city of Tampa and a 2017 roadway level of service report for the Hillsborough COUNTY wer produced by the Hillsborough MPO to reflect the current level of service of county roadways and state roadways within the area (Hillsborough MPO, 2017; Hillsborough MPO, 2018b). Below is a list of information contained in these report for each roadway section.

- Section description
- Jurisdiction
- Strategic intermodal system
- Number of lanes per direction
- Length
- Current posted speed of the segment
- Standard level of service (that is, the level of service that shall be maintained)
- Local functional class
- Average annual daily traffic
- Peak hour peak direction volume that is calculated as the 100^{th} highest hour traffic volume
- Maximum service volume (that is, daily capacity)
- Peak hour peak direction maximum service volume
- Volume to capacity ratio
- Current level of service as determined by using FDOT generalized LOS table

State of the System Report

A 2016 State of the System Report was produced by Kimley-Horn and Associates, Inc. (2016) for the Hillsborough MPO to demonstrate how transportation system addresses community needs and satisfies the goals specified in the long range transportation plan. In this report, a number of performance measures were calculated and they are summarized in Table 3-32.

Table 3-32 Performance Measures in the 2016 State of the System Report for Hillsborough MPO

Focus Area	Goal	Performance Measure
System preservation	Maintain roadway pavement	• Safety – wheelpath, rutting, friction • Preservation – cracking, potholes, raveling, patching, depressions • Ride – rippling, faulting, public complaints • Standardized Pavement Condition Index (PCI)
	Maintain and replace bridges	• Total bridge counts and percentage of bridges in either good or poor condition
	Preserve the transit fleet	• Average age of fleet
Minimize traffic	Reliable travel time for drivers and shippers	• Peak hour travel reliability • Peak hour truck travel reliability • Travel speed, delay, and travel time index during AM and PM peak hour
Safety and security	Reduce crashes	• Total number of crashes • Total number of fatalities • Total number of injuries • Number of auto, pedestrian, bicyclist, and motorcycle fatal crashes • Injury crashes per 100 million VMT • Fatality crashes per 100 million VMT
	Improve resiliency	• Annual stormwater and flooding investment • Weeks of disruption • Economic losses of a typical category 3 storm
Real choices	People and jobs served by the bus system	• Passengers per revenue hour • On-time performance (at time periods from -1 to 5+ minutes) • Countywide population and jobs within ¼ mile of frequent and somewhat frequent transit service
		• Transportation disadvantaged living outside of bus service area
	People served by the trail network	• The miles of trails • The percentage of residents with access to trail
Major investments	Jobs served	• Number of jobs • Percentage of roads having traffic volume that is greater than capacity

3.2.5.7 North Florida TPO

LRTP

The 2040 LRTP of the North Florida TPO consists of six goals that aim at enhancing economic competitiveness, livability, safety, mobility and accessibility, equity in decision making, and system preservation. Accordingly, a number of objectives and performance measures were proposed. Tables 3-33 to 3-37 list those objectives, performance measures, and benchmarks included in the North Florida MPO LRTP.

Table 3-33 Objectives and Performance Measures to Enhance Economic Competitiveness in the North Florida TPO 2040 LRTP (Source: North Florida TPO, 2014)

Objective	Performance Measure	Benchmark
Improve travel reliability on major freight routes	Travel time reliability	Maintain or improve the reliability
Enhance access to jobs	Jobs within ½ mile of a congestion management system facility	Maintain or improve access to jobs
Maximize the return on investment	Benefit: cost ratio Return on investment	Rank benefit-to-cost ratio Rank return on investment

Table 3-34 Objectives and Performance Measures to Enhance Livability and Sustainability in the North Florida TPO 2040 LRTP (Source: North Florida TPO, 2014)

Objective	Performance Measure	Benchmark
Enhance transit accessibility	¼ mile walk accessibility to transit stops Households within 5 miles of major transit centers or park and ride lots	95% of all stops (1)
Enhance transit ridership	Annual boardings per vehicle revenue mile Annual boardings per vehicle revenue hour	(2) (2)
Enhance bicycle and pedestrian quality of service	Lane mile with bicycle and pedestrian facilities at the quality of service standard	85% of lane miles
Reduce the cost of congestion per capita	Transportation costs per capita Costs of congestion	(3)
Reduce the impacts of investments on the natural environment	Environmental screening and mitigation	Apply Efficient Decision Making Process to all projects in LRTP.
Reduce emissions from automobiles	Hydrocarbon, nitrous oxides and volatile organic compound emissions	Maintain our attainment status. (4)
Consistency with land use planning	Includes active transportation design principles in context sensitive solutions	Include walkability standards in context sensitive solutions
Supports regional evacuation needs	Reduce clearance times for evacuations	Improve clearance times by 15 minutes. (5)

Table notes

(1) This performance measure will not change significantly from year to year unless major route changes or new transit operations are deployed.
(2) Coordination with Jacksonville Transportation Authority is needed to develop the baseline and benchmark data needed.
(3) Many exogenous factors influence this performance measure including the price of fuels that are beyond the scope of a LRTP. However, this performance measure will be considered within the LRTP based on policy decisions made during the scenario development.
(4) Emissions will be determined using Florida emission factors from the FHWA Moves model.
(5) Based on modeling provide by the Northeast Florida Regional Council.

Table 3-35 Objectives and Performance Measures to Enhance Safety in the North Florida TPO 2040 LRTP (Source: North Florida TPO, 2014)

Objective	Performance Measure	Benchmark
Reduce Crashes	Number of crashes Crash rate per million vehicle miles	Reduce by 0.25% each year Reduce or maintain
Reduce Fatal crashes	Number of fatalities Crash rate per million vehicle miles	Reduce by 0.25% each year Reduce or maintain

Table 3-36 Objectives and Performance Measures to Enhance Mobility and Accessibility in the North Florida TPO 2040 LRTP (Source: North Florida TPO, 2014)

Goal	Mobility Performance Measures	Benchmark
Optimize the quantity of travel	Person-miles traveled	(2)
	Truck-miles traveled	(2)
	Vehicle-miles traveled	(2)
	Person trips	(2)
	Transit ridership	Increase transit ridership
Optimize the quality if travel (1)	Average speed	Maintain or improve the average travel speed
	Delay	Maintain or reduce the average vehicle delay
	Average trip time	Maintain or reduce the average trip time
	Reliability	Maintain or improve the reliability Achieve 95% reliability (on time arrival) on Strategic Intermodal System facilities.
	Level of service on rural facilities	Maintain the level of service standard (FDOT standard for Strategic Intermodal System facilities and local government standards for other facilities)
Improve the accessibility to mode choices	Proximity to major transportation hubs	(3)
	% miles bicycle accommodations	(3)
	% miles pedestrian accommodations	(3)
	Transit coverage	Increase the % of population served with ¼ mile
Optimize the utilization of the system	% system heavily congested	Maintain or reduce the % of system heavily congested
	% travel heavily congested	Maintain or reduce the % of travel heavily congested
	Vehicles per lane mile	Optimize the vehicles per lane mile for a desired LOS
	Duration of congestion	Maintain or reduce the duration of congestion
	Transit load factor	Optimize the transit load factor for a desired quality of service

(1) These measures may not apply on corridors not selected for context-based solutions that may intentionally lower the running speed or capacity.

(2) Generally, increases in the quantity traveled (throughout) are preferred. However, consistent with livability and sustainability goals, one objective is to reduce the amount of travel needed. Therefore, no benchmarks are proposed, but monitoring is recommended.

(3) These performance measures will not change significantly from year to year but will be evaluated in each major update to the LRTP to establish benchmark and monitor performance.

Table 3-37 Objectives and Performance Measures to Preserve the System in the North Florida TPO 2040 LRTP (Source: North Florida TPO, 2014)

Objective	Performance Measure	Benchmark
Maintain roadways	FDOT condition rating system	▪ 95% of SIS roadways in good or better condition ▪ 85% of non-SIS roadways in good or better condition
Maintain bridges	FDOT condition rating system	▪ Strengthen bridges that are either (1) structurally deficient or (2) posted for weight restriction within six years on FDOT facilities. ▪ Replace bridges that require structural repair that more cost effective to replace within nine years on FDOT facilities. ▪ Satisfy FDOT's off system bridge replacement goals.
Maintain transit system	FTA system preservation	Age of vehicles

As measures of effectiveness, the Northeast Regional Planning Model, NERPM-AB, together with other tools were used to quantify the performance measures for the Cost Feasible Plan compared to the base no-build scenario. Table 3-38 shows the measures and how these measures satisfy the benchmark requirement set by the LRTP.

Strategic Safety Plan

A strategic safety plan was developed by the HNTB Corp. for the North Florida TPO (HNTB Corp., 2015a). It set up three safety-related goals, that is,

- 5% reduction in fatality and injury crashes
- 5% reduction in crash rate
- Advance safety funding for projects located on corridors and intersections with high priority.

These three goals were addressed by a number of strategies, which are quantified by the following performance measures.

- Crash rate
- Number of first responders who have participated in Time4Safety training or National Traffic Incident Management Training
- Teen and distracted crash rate
- Vulnerable roadway users' fatal crash rate
- Red light running crash rate
- Impaired driving crash rate
- Fatal crash rate
- Lane departure crash rate
- Intersection crash rate

Table 3-38 Summary of Measure of Effectiveness for the North Florida TPO Cost Feasible Plan (Source: North Florida TPO, 2014)

Measure of Effectiveness	Change		Benchmark Met
Economic Competitiveness			
Reliability		Reliability could not be evaluated within the travel demand forecasting model.	❍
Access to jobs	254,088	additional persons with access within 1/4 mile of a Cost Feasible Plan project.	✓
Delay benefit	186,639,846	vehicle hours	✓
Maximize the return on investment	6.1%	return on investment with a benefit-to-cost ratio of 3.73.	✓
Livability			
Access to transit	58,880	additional persons with access to new transit capacity.	✓
Transit riders	17,589	more persons choose transit.	✓
Miles with bike and pedestrian accommodations	198	miles of non-Interstate projects that will include bicycle and pedestrian improvements.	✓
Reduce the cost of congestion per capita	$116	benefit of travel time saving per person per year.	✓
Reduce the impact on natural environment		A network of constrained corridors were identified and where widening would exceed six lanes on arterial roadways, context sensitive solutions were recommended. Environmental screening was performed as part of the planning projects and projects that were identified to have fatal flaws were not included in the Cost Feasible Plan.	✓
Reduce emissions from automobiles		Unable to evaluate.	❍
Safety Benefits			
Change in total crashes	17,166	crashes reduced per year.	✓
Change in fatal crashes	858	fatal crashed reduced per year.	✓
Safety benefit	$126,025,695	benefit per year in dollars.	✓
Quantity of Travel			
Person-miles traveled	1,188,246	additional persons are served.	✓
Truck-miles traveled	78,011	additional trucks served.	✓
Vehicle-miles traveled	1,188,246	additional vehicle miles traveled.	
Walk trips	(14,697)	fewer persons choose to walk - likely a result of improved access to transit.	❍
Bike trips	(2,705)	fewer persons choose to bike - likely a result of improved access to transit.	❍
Measure of Effectiveness	**Change**		**Benchmark Met**
Transit riders	17,589	more persons choose transit	✓
Quality of Travel			
Average speed	1.64	miles per hour speed improvement.	✓
Delay	33,613	vehicle hours saved.	✓
Average trip time			
Reliability		Unable to evaluate.	❍
Congestion on rural facilities	0.05%	reduction in delay on rural facilities	✓
Accessibility			
Proximity to major transit hubs		Two hubs added – Downtown and Soutel	✓
Miles of bicycle and pedestrian accommodations	198	miles of non-Interstate projects that will include bicycle and pedestrian improvements.	✓
Access to jobs	254,088	additional persons with access within 1/4 mile of a Cost Feasible Plan project.	✓
Access to persons	96,244	additional persons living in households within 1/3 of a Cost Feasible Plan project.	✓
Access to transit	58,880	additional persons with access to new transit capacity.	✓
Utilization			
System congested (miles congested)	3.07%	improvement in the percent of the system that is congested.	
Congested trips (vehicle-miles congested)	14,619,980	reduced congested trips per day.	✓
Vehicles per lane mile	144	Vehicle reduction in vehicles per lane mile	✓
Duration of congestion	0.08	minutes reduced.	✓
Lane miles added	818	lane miles added.	✓
Transit load factor		Unable to evaluate.	❍

Congestion Management Process (CMP)

The congestion management process of the North Florida TPO follows the eight elements of FHWA CMP elements (HNTB Corp., 2015b). As shown in Figure 3-12, the development of multimodal performance measures is the third step of this process after developing regional objectives and CMP network. The performance measures used in the CMP are the same as those listed in Tables 3-33 to 3-37.

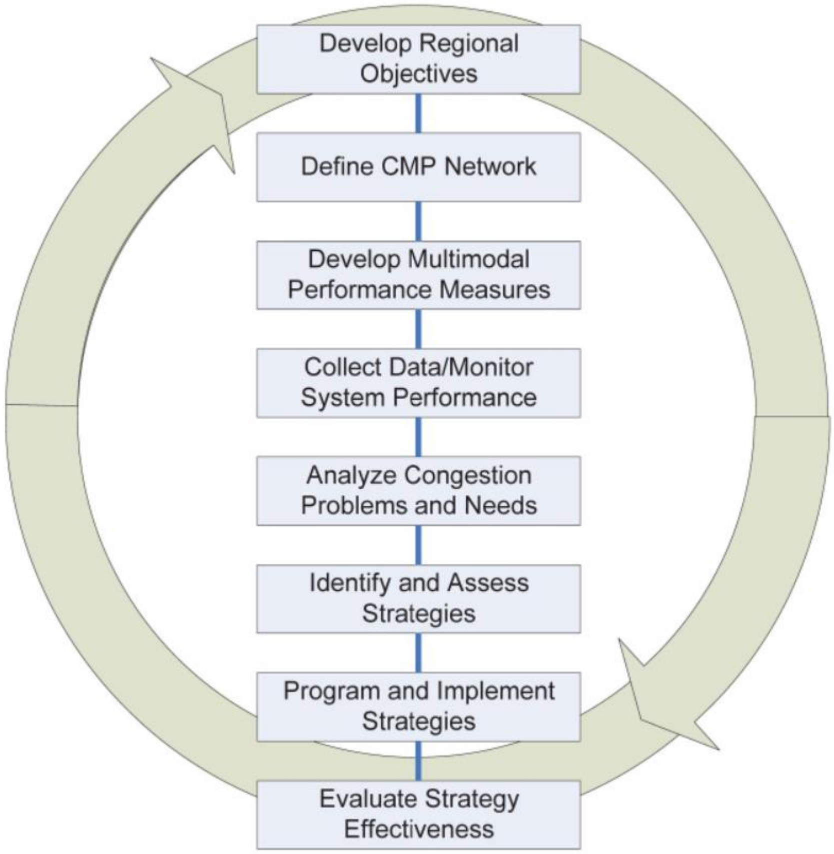


Figure 3-12 FHWA Congestion Management Process Element

To address the congestion problem, a list of strategies proposed in the CMP plan, which are as follows.

- TSM&O strategies
  - Surveillance and incident management systems
  - Access management
  - Congestion pricing
  - Integrated corridor management
  - Arterial management systems
  - Hard shoulder running
  - Reversible lanes
  - One-way streets
  - Ramp metering
  - Transit signal priority
  - Variable speed limits

  - Dynamic detours
  - Queue warning systems
  - Traveler information systems
- Traveler demand management strategies
  - High-Occupancy Vehicle (HOV) incentives
  - Park-and-ride lots
  - Multimodal transportation centers
  - Commuter assistance service programs
- Transit improvements
  - Local bus service improvements
  - Express bus service improvements
  - Bus rapid transit improvements
  - Light rail transit improvements
  - Commuter rail improvements
- Capacity improvements
- Add new lanes
- Add new managed lanes
- Intersection improvements
- Interchange improvements
- Add auxiliary lanes

It should be noted that high priority was given to TSM&O strategies and traveler demand management strategies, and less priority was assigned to capacity improvement projects.

Annual Mobility Report

An annual mobility report was produced by the North Florida TPO for year 2014 (HNTB, 2014). The mobility performance measures listed in Table 3-36 were reported on a five-year basis from 2008 to 2012 in this document. The data source is the FDOT Mobility Performance Measures database for the year 2012. The data are from the statewide telemetered traffic monitoring system (TTMS).

North Florida Regional ITS Master Plan

The North Florida MPO developed a regional ITS master plan in 2010. In this plan, the existing ITS deployments and programed ITS projects within the region were summarized. Priority corridors for ITS deployment were identified by stakeholders through a project kickoff meeting. The ITS needs and cost estimates were then developed for the existing and programmed ITS projects along the prioritized corridors. Since this ITS master plan was developed in 2010, performance measures were not considered in this plan.

3.3 Performance Measure Estimation Methods and Tools

3.3.1 Safety

3.3.1.1 Roadway Safety Data Dashboards

The office of Safety's Roadway Safety Data Dashboards under the FHWA provides a web-based application that can create safety data dashboards at national, state, regional, and MPO levels (FHWA, 2018b). It is based on the data from NHSTA's FARS database and the data has a range up to year 2015. The state and national VMT are obtained from the FHWA's Highway Statistics Series, and MPO boundaries are derived from the FHWA's HEPGIS tool. The tool allows users to select fatality type, collision type, collision location, and types of person involved in the fatal crashes. Figure 3-13 shows an example of roadway safety data dashboard produced by this tool for Miami-Dade County at the MPO level.

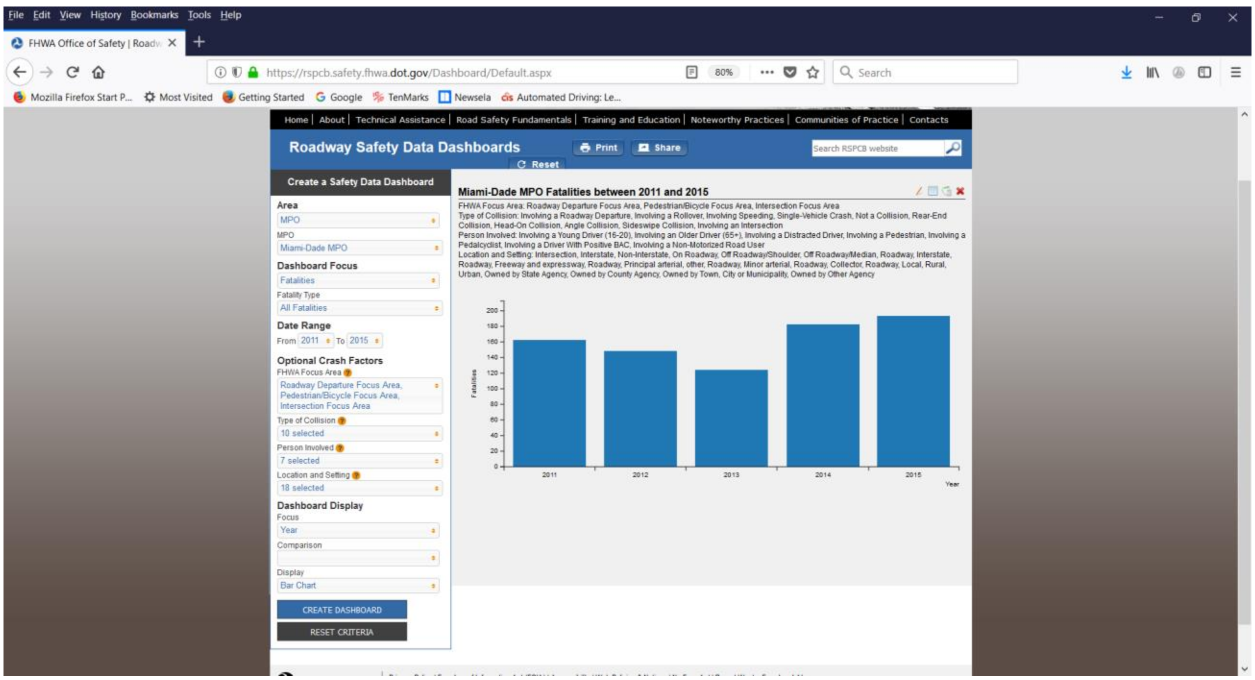


Figure 3-13 Example of FHWA Roadway Safety Data Dashboard

3.3.1.2 Florida ITS Evaluation Tool

The Florida ITS Evaluation (FITSEVAL) is a sketch-planning tool that evaluates the benefits of ITS in the FSUTMS/Cube Environment (Hadi et al., 2008). The tool uses a predictive method to estimate crash rates similar to the one used in the ITS Deployment Analysis System (IDAS) Tool. Table 3-39 shows the crash rates of property damage only (PDO), injury and fatality for freeway and arterial segments used in FITSEVAL as a function of Volume to Capacity (V/C) ratio. The total number of crashes is then estimated by multiplying the crash rate with Million Vehicle Miles Traveled (MVMT). The safety impacts of ITS strategies are studied by applying a corresponding crash modification factors.

Table 3-39 Crash Rates Table Used in FITSEVAL

<table>
<tr><th rowspan="2">V/C</th><th colspan="2">Fatality</th><th colspan="2">Injury</th><th colspan="2">PDO</th></tr>
<tr><th>Freeway</th><th>Arterial</th><th>Freeway</th><th>Arterial</th><th>Freeway</th><th>Arterial</th></tr>
<tr><td>0.09</td><td rowspan="11">0.0004</td><td rowspan="11">0.0072</td><td rowspan="5">0.5156</td><td rowspan="11">0.5757</td><td rowspan="7">0.8551</td><td rowspan="11">2.394</td></tr>
<tr><td>0.19</td></tr>
<tr><td>0.29</td></tr>
<tr><td>0.39</td></tr>
<tr><td>0.49</td></tr>
<tr><td>0.59</td><td rowspan="4">0.5757</td></tr>
<tr><td>0.69</td></tr>
<tr><td>0.79</td><td rowspan="2">0.9953</td></tr>
<tr><td>0.89</td></tr>
<tr><td>0.99</td><td>0.7392</td><td>1.1591</td></tr>
<tr><td>1.00</td><td>0.7329</td><td>1.2737</td></tr>
</table>

3.3.1.3 Florida Specific Safety Performance Function

Safety measures for past years can be directly calculated from historical crash data. However, for the future years, as data is not available, safety measures have to be estimated either from a crash rate look up table as describe in the previous section or from a safety performance function (SPF). SPF is defined in the Highway Safety Manual (HSM) as a regression model that can be applied to predict the average number of crashes on a roadway segment or at an intersection. Alluri et al. (2016) developed calibrated SPFs specifically for Florida based on roadway inventory data and crash data. Equation 3-10 presents the general form of an SPF function for a roadway segment and ramps.

$$N_{predicted} = e^{a} \times AADT^{b} \tag{3-10}$$

where $N_{predicted}$ is the number of predicted crashes per mile per year and AADT represents average annual daily traffic. a and b are regression coefficients.

Equation 3-11 presents the SPF functional form for an intersection.

$$N_{predicted} = e^{a} \times {AADT_{major}}^{b} \times {AADT_{minor}}^{c} \tag{3-11}$$

where $AADT_{major}$ and $AADT_{minor}$ represent the average annual daily traffic for the major and minor approaches of an intersection, respectively. Symbols a, b, and c are regression coefficients.

Alluri et al. (2016) also calibrated the default SPFs used in Safety Analyst, an advanced safety analysis tool, by application a calibration factor C for Florida. Tables 3-40 to 3-43 summarize the results of this calibration for arterial streets, freeways, intersections, and ramps, respectively.

Table 3-40 Florida-Specific SPFs for Arterial Streets (Alluri et al., 2016)

Category	Severity	Coefficient				k	R^2_{FT}
		a		b			
		Estimate	p-value	Estimate	p-value		
Rural Two-lane Roads	Total	-8.810	<0.001	1.096	<0.001	1.537	0.656
	F+I	-9.954	<0.001	1.148	<0.001	1.460	0.692
Rural Multilane Undivided Roads	Total	-16.159	<0.001	1.936	<0.001	1.356	0.685
	F+I	-18.401	<0.001	2.083	<0.001	1.628	0.652
Rural Multilane Divided Roads	Total	-9.749	<0.001	1.195	<0.001	1.154	0.711
	F+I	-10.703	<0.001	1.215	<0.001	0.949	0.771
Urban Two-lane Arterials	Total	-7.269	<0.001	1.037	<0.001	2.554	0.419
	F+I	-7.173	<0.001	0.925	<0.001	2.310	0.543
Urban Multilane Undivided Arterials	Total	-8.704	<0.001	1.198	<0.001	1.132	0.733
	F+I	-7.971	<0.001	1.029	<0.001	0.914	0.775
Urban Multilane Divided Arterials	Total	-10.651	<0.001	1.348	<0.001	1.143	0.691
	F+I	-10.631	<0.001	1.262	<0.001	0.979	0.734
Urban One-way Arterials[1]	Total	-3.530	NA	0.600	NA	1.380	0.041
	F+I	-5.150	NA	0.650	NA	1.450	0.111

Table 3-41 Florida-Specific SPFs for Freeway Segments (Alluri et al., 2016)

Category	Severity	Coefficient				k	R^2_{FT}
		a		b			
		Estimate	p-value	Estimate	p-value		
Rural Freeways with 4 Lanes							
Basic Freeway Segments	Total	-13.340	<0.001	1.433	<0.0001	0.126	0.965
	F+I	-13.990	<0.001	1.415	<0.0001	0.103	0.959
Segments within Interchange Influence Area	Total	-12.362	<0.001	1.377	<0.0001	0.267	0.917
	F+I	-12.742	<0.001	1.331	<0.0001	0.255	0.899
Rural Freeways with 6+ Lanes							
Basic Freeway Segments	Total	-10.287	<0.0001	1.126	<0.0001	0.171	0.966
	F+I	-10.826	<0.0001	1.090	<0.0001	0.127	0.960
Segments within Interchange Influence Area	Total	-12.207	<0.0001	1.338	<0.0001	0.208	0.945
	F+I	-12.800	<0.0001	1.310	<0.0001	0.137	0.944
Urban Freeways with 4 Lanes							
Basic Freeway Segments	Total	-10.734	<0.001	1.235	<0.001	0.938	0.827
	F+I	-13.463	<0.001	1.394	<0.001	0.628	0.871
Segments within Interchange Influence Area	Total	-16.872	<0.001	1.800	<0.001	0.446	0.916
	F+I	-17.088	<0.001	1.724	<0.001	0.307	0.916
Urban Freeways with 6 Lanes							
Basic Freeway Segments	Total	-15.040	<0.0001	1.608	<0.001	0.750	0.858
	F+I	-16.242	<0.0001	1.625	<0.001	0.552	0.889
Segments within Interchange Influence Area	Total	-15.249	<0.0001	1.626	<0.001	0.361	0.919
	F+I	-16.045	<0.0001	1.610	<0.001	0.270	0.928
Urban Freeways with 8+ Lanes							
Basic Freeway Segments	Total	-14.518	<0.0001	1.553	<0.001	0.824	0.855
	F+I	-14.502	<0.0001	1.467	<0.001	0.702	0.877
Segments within Interchange Influence Area	Total	-17.507	<0.0001	1.809	<0.001	0.459	0.928
	F+I	-19.1512	<0.0001	1.867	<0.001	0.402	0.934

Table 3-42 Florida-Specific SPFs for Intersections (Alluri et al., 2016)

Category	Severity	Coefficient						k	R^2_{FT}
		a		b		c			
		Estimate	p-value	Estimate	p-value	Estimate	p-value		
Signalized Intersections									
Rural Three-leg[1]	Total	-6.570	NA	0.660	NA	0.200	NA	0.330	0.260
	F+I	-7.830	NA	0.750	NA	0.140	NA	0.500	0.215
Rural Four-leg	Total	-6.839	<0.001	-0.019	0.950	0.883	<0.001	1.040	0.730
	F+I	-6.561	0.003	-0.126	0.732	0.893	0.003	1.461	0.699
Urban Three-leg	Total	-10.382	<0.001	0.736	<0.001	0.329	<0.001	2.090	0.623
	F+I	-9.681	<0.001	0.679	<0.001	0.239	0.004	2.074	0.641
Urban Four-leg	Total	-9.786	<0.001	0.734	<0.001	0.339	<0.001	2.093	0.659
	F+I	-9.711	<0.001	0.698	<0.001	0.291	<0.001	1.900	0.671
Unsignalized Intersections[2]									
Rural Three-leg	Total	-6.685	<0.001	0.155	0.531	0.515	0.002	2.579	0.674
	F+I	-9.179	<0.001	0.502	0.069	0.382	0.034	2.603	0.665
Rural Four-leg	Total	-4.258	0.152	0.312	0.379	0.077	0.813	3.463	0.589
	F+I	-5.039	0.121	0.410	0.290	0.029	0.935	4.015	0.593
Urban Three-leg	Total	-11.768	<0.001	0.791	<0.001	0.388	<0.001	3.397	0.537
	F+I	-11.195	<0.001	0.720	<0.001	0.323	<0.001	3.511	0.607
Urban Four-leg	Total	-9.758	<0.001	0.824	<0.001	0.127	0.320	3.189	0.583
	F+I	-10.264	<0.001	0.837	<0.001	0.098	0.478	3.3378	0.625

Table 3-43 Florida-Specific SPFs for Ramps (Alluri et al., 2016)

Category	Severity	Coefficient				k	R^2_{FT}
		a		b			
		Estimate	p-value	Estimate	p-value		
Rural Diamond Off-ramp	Total	-8.528	<0.0001	1.212	<0.0001	0.646	0.825
	F+I	-8.623	<0.0001	1.118	<0.0001	0.754	0.795
Rural Diamond On-ramp	Total	-8.323	<0.0001	1.092	<0.0001	0.767	0.801
	F+I	-9.993	<0.0001	1.183	<0.0001	0.270	0.831
Rural Parclo Loop Off-ramp	Total	-4.769	0.0001	0.836	<0.0001	0.723	0.785
	F+I	-5.874	<0.0001	0.831	<0.0001	0.751	0.714
Rural Parclo Loop On-ramp	Total	-6.313	<0.0001	0.896	<0.0001	0.359	0.837
	F+I	-6.525	0.0002	0.819	0.0002	0.998	0.714
Urban Diamond Off-ramp	Total	-4.967	<0.0001	0.826	<0.0001	0.712	0.800
	F+I	-5.392	<0.0001	0.765	<0.0001	0.723	0.794
Urban Diamond On-ramp	Total	-5.506	<0.0001	0.815	<0.0001	0.774	0.822
	F+I	-6.362	<0.0001	0.803	<0.0001	0.779	0.802
Urban Partial Diamond Off-ramp	Total	-2.463	0.0009	0.530	<0.0001	1.316	0.655
	F+I	-3.769	<0.0001	0.556	<0.0001	1.072	0.703
Urban Partial Diamond On-ramp	Total	-1.160	0.1178	0.327	0.0001	1.160	0.729
	F+I	-1.777	0.0338	0.273	0.0049	1.168	0.729
Urban Trumpet Off-ramp	Total	-3.356	<0.0001	0.604	<0.0001	0.775	0.819
	F+I	-5.004	<0.0001	0.671	<0.0001	0.763	0.815
Urban Trumpet On-ramp	Total	-5.484	<0.0001	0.795	<0.0001	0.881	0.799
	F+I	-5.785	<0.0001	0.706	<0.0001	0.714	0.823
Urban Parclo Loop Off-ramp	Total	-3.821	<0.0001	0.671	<0.0001	0.786	0.755
	F+I	-4.232	<0.0001	0.612	<0.0001	0.758	0.758
Urban Parclo Loop On-ramp	Total	-6.349	<0.0001	0.909	<0.0001	0.648	0.832
	F+I	-6.782	<0.0001	0.853	<0.0001	0.692	0.810

3.3.1.4 Safety Performance Functions and Crash Modification Factors Used in the SHRP2 C11 Post-Processor Tool

The SHRP2 C11 post-processor tool was developed by Cambridge Systematics, Inc. (2016) to produce travel time reliability measures and safety measures for future years. This tool was produced as part of an effort funded by a grant awarded to FDOT for the reliability data and analysis tools proof of concept pilot study under the fourth round of the SHRP2 implementation assistance program in November 2014. The SPF functions used in this tool was originally developed by the University of Central Florida (UCF). Table 3-44 presents the SPFs for highway segments, while the equations in Table 3-45 lists the SPFs for intersections. The SHRP2 C11 tool uses crash modifications factors to consider the impacts of safety improvements. Table 3-46 shows the values of the crash modification factors used in this tool. These factors were determined based on FHWA references and other literature.

Table 3-44 SPFs Developed by UCF and Used in the C11 Tool for Highway Segments (Cambridge Systematics, Inc., 2016)

Highway Type	SPF Equation (annual segment crashes)
2-lane undivided	exp[-4.2842 + 0.5933 * ln(AADT) + ln(Segment Length)]
Multi-lane undivided	exp[-2.8471 + 0.5292 * ln(AADT) + ln(Segment Length)]
Multi-lane divided	exp[-6.1612 + 0.8374 * ln(AADT) + ln(Segment Length)]
4-lane freeway	exp[-11.9299 + 1.3092 * ln(AADT) + ln(Segment Length)]
6-lane-freeway	exp[-7.9867 + 0.9627 * ln(AADT) + ln(Segment Length)]
8+lane freeway	exp[-9.4829 + 1.1258 * ln(AADT) + ln(Segment Length)]

Table 3-45 SPFs Developed by UCF and Used in the C11 Tool for Intersections (Cambridge Systematics, Inc., 2016)

Intersection Type	SPF Equation (annual intersection crashes)
Signalized	NO_SIGNALS * exp[-10.3764 + 0.8138 * ln(MEAN_AADT) + 0.2606 * ln(MEAN_AADT/2)]
Other types	OTHER_INTERSECTION_COUNT * exp[-8.3872 + 0.5690 * ln(MEAN_AADT) + 0.2189 * ln(MEAN_AADT/2)] Where: OTHER_INTERSECTION_COUNT = NO_LINKS/2 – NO_SIGNALS

Table 3-46 Crash Modifications for Safety Improvements (Cambridge Systematics, Inc., 2016)

Improvement Type	CMF	Relevant Crash Types for Applying CMFs
Bike lanes	0.99	Segment/Signal/Other Intersection
Delineation	0.97	Segment/Signal/Other Intersection
Lighting	0.93	Segment/Signal/Other Intersection
Stop conversion to roundabout	0.65	Segment/Signal/Other Intersection
Parking prohibition	0.90	Segment/Signal/Other Intersection
Pedestrian crosswalks	0.96	Segment/Signal/Other Intersection

Improvement Type	CMF	Relevant Crash Types for Applying CMFs
Pedestrian crosswalks + beacons	0.94	Segment/Signal/Other Intersection
Add raised median	0.70	Segment/Signal/Other Intersection
Road diet	0.80	Segment/Signal/Other Intersection
Add turn lanes	0.75	Signal
Complete Streets	0.50	Segment/Signal/Other Intersection
Ramp Metering	0.80	Segment
Dynamic Ramp Metering	0.80	Segment
Dynamic message signs		Segment
Variable Speed Limits	0.85	Segment
Incident Management (FSP, CCTV, detection)	0.04	Segment
Convert TWLTL to raised median	0.53	Segment/Signal/Other Intersection

3.3.2 Travel Time

3.3.2.1 Traffic Flow Models

A number of traffic flow models (TFMs) have been used in the planning studies to estimate travel time based on demand and capacity. Below is a description of the most commonly used TFMs.

Bureau of Public Roads (BPR) Curve

The BPR curve has been widely used in travel demand models to calculate link travel time. Equation 3-12 shows the expression of the BPR curve.

$$\boldsymbol{t_i = t_0\left[1 + \alpha\left(\frac{v}{c}\right)^{\beta}\right]} \qquad \textbf{(3-12)}$$

where t_i is congested travel time and t_0 is free-flow travel time for link i. v refers to traffic volume on link i and c is link capacity. α and β are the BPR coefficient and the BPR exponential coefficient, respectively, whose values vary with the function class of links and are usually calibrated for local conditions.

Akcelik Equation

The expression for Akcelik equation is shown in Equation 3-13.

$$t_i = t_0 \left[\frac{1}{v_0} + (g_{pb} \times g_T \times ((\frac{v}{c} + g_{AkcelikOffset} - 1) + \sqrt{\left(\frac{v}{c} + g_{AkcelikOffset} - 1\right)^2 + (g_{pa} \times g_P \times \left(\frac{\frac{v}{c} + g_{AkcelikOffset}}{c \times g_T}\right)))} \right] / (\frac{1}{v_0})$$

(3-13)

where v_0 is free-flow speed in mph. g_{pb} and g_{pa} are facility specific parameters. g_T is the length of the time period in hours. $g_{AkcelikOffset}$ is an Akcelik offset parameter, which contributes to the shape of the volume delay curve by shifting the base of the curve from a travel time ratio of 1.0. Akcelik equation has been used in the Express Lanes Time of Day (ELToD) model, a tool developed by the Florida Turnpike Enterprise (2012) to evaluate a tolled corridor at a sketch planning level.

Modified Greenshields Model

Modified Greenshields model has been applied in a number of Dynamic Traffic Assignment (DTA) simulation tools including DynaSmart and DynusT. A single-regime modified Greenshields model is used for arterials, which is express as follows.

$$s - s_0 = (v_f - s_0)(1 - \frac{k}{k_j})^{\alpha} \quad \textbf{(3-14)}$$

where s is the speed. k symbolized the density and k_j is the jam density. s_0 represents the minimum speed, v_f denotes the speed-intercept, and α is a coefficient in this model. For freeways, a dual-regime modified Greenshields model is used in DTA tools. The expression for the dual-regime modified Greenshields model is listed below:

$$\begin{aligned} s &= s_f \qquad 0 \le k \le k_{bp} \\ s - s_0 &= (v_f - s_0)(1 - \frac{k}{k_j})^{\alpha} \quad k > k_{bp} \end{aligned} \quad \textbf{(3-15)}$$

where k_{bp} is the density at the breakpoint for two modeling regimes, and s_f is the free-flow speed. The other variables are as defined above. The speed given by the modified Greenshields model can be converted into travel time by using the segment length divided by the calculated speed.

A Piecewise Modified Davison Volume-Delay Function

A piecewise modified Daidson volume-delay function has been developed by Moses et al. (2013) in a study of SR 9/I-95 in Pompano Beach, Florida. This function was further used in the SHRP2 C11 post-processor tools (Cambridge Systematics, 2016). Equation 3-16 shows this volume-delay function.

$$S = \begin{cases} \dfrac{S_0}{1+\dfrac{J_D\left(\frac{V}{C}\right)}{1-\frac{V}{C}}} & for\ \dfrac{V}{C} \leq \mu \\ \dfrac{S_0}{1+\dfrac{J_D \times \mu}{1-\mu}+\dfrac{J_D\left(\frac{V}{C}-\mu\right)}{(1-\mu)^2}} & for\ \dfrac{V}{C} > \mu \end{cases} \tag{3-16}$$

where s is speed and s_0 is free-flow speed. J_D is a delay parameter. μ is saturation threshold parameter.

3.3.2.2 Highway Capacity Manual Computational Engine

Procedures have been included in the Highway Capacity Manual (HCM) to calculate the time-dependent traffic conditions along freeway facilities and arterial streets. The corresponding computational engines are called FREEVAL (for freeways) and STREETVAL (for urban streets), respectively, in addition to the commercially available Highway Capacity software (HCS). In freeway facility analysis, a freeway facility is divided into four types of segments, including basic, merge, diverge, and weaving segments. When traffic is under congestion, segments are analyzed independently. Depending on segment type, the corresponding HCM procedure is applied to calculate segment speed. When traffic is oversaturated, freeway facility is analyzed as a node-link system and a cell transmission model is utilized to track queue formulation and dissipation over multiple time periods and segments. The output performance measures include travel time, speed, delay, queue length, VMT, VHT, and LOS for each individual segment.

In urban streets analysis, urban street facilities are coded as segments with boundary nodes that represent signalized or unsignalized intersections. The automobile mode performance of segments is determined by first analyzing the segment running time and through movement delay based on control type and segment free-flow speed, and then calculating the segment travel speed, stop rate, and level of service. The level of service of a signalized intersection is determined by control delay, which is a function of adjusted saturation flow and percentage of vehicles arriving on green. The travel time along a segment can be derived from segment travel speed.

3.3.2.3 Macro-, Meso-, and Microsimulation Models

Macro-, meso-, and micro-level simulation models can be applied to obtain travel time along a segment or a route. However, these models vary in terms of the details of network and driving behaviors. Macroscopic models (for example, regional travel demand models) consider vehicles as a whole and utilize traffic flow model to determine the traffic condition on a link or section. Microscopic simulation provides a detailed modeling of road network. Individual vehicle movements are governed by car-following, lane changing, and gap acceptance behaviors. However, microscopic modeling requires significantly more efforts to calibrate. Examples of microscopic models are VISSIM, CORSIM, PARAMICS, AIMSUN, and TransModeler. Mesoscopic simulation models are in between macroscopic and microscopic simulations. In mesoscopic model, vehicles are modelled either individually or as packets of a small number of vehicles. However, the movements of vehicles or packets of vehicles are determined by the macroscopic traffic flow models. The queuing and queue spillback are usually captured by considering the constraints of capacity and link storage. Compared to microscopic simulation, mescopic simulation requires less effort to calibrate and has a faster running time. Examples of mesoscopic simulations are Dynasmart, DynusT, Direct, Cube Avenue, AIMSUN, VISSIM meso, and Dynameq.

3.3.3 Travel Time Reliability

3.3.3.1 SHRP 2 L02 Method

The SHRP2 L02 project provides a data-based travel time reliability estimation method (Institute for Transportation Research and Education et al., 2012). This method consists of three modules, that is, a data manager, a computational engine, and a report generator. The data manager assembles data from traffic sensors, weather data feeds, and incident reporting systems, and organizes them in a database. The computational engine classifies traffic into different regimes based on demand, incident, and weather. The probability density function (PDF) and cumulative density function (CDF) distributions of travel time rate for each regime are calculated from the collected and cleaned data. These two distributions allow the visualization and comparison of travel time reliability under various traffic conditions as well as the identification of contributing factors to unreliability. The report generator presents results based on user requests.

3.3.3.2 Highway Capacity Manual Computational Engine

FREEVAL-RL, STREETVAL-RL, and HCS reliability procedures apply modeling methods developed to estimate travel time reliability for freeway facilities and urban street facilities, as part of the SHRP 2 Reliability L08 project. These tools have a scenario generator, which takes the input of demand, weather, incident, and work zone data, and generates a set of scenarios that represent different traffic conditions that are expected to occur within one year along the study facility. The impacts of incident, weather, and work zone events on capacity and speed are adjusted by using adjustment factors recommended by HCM. The conventional HCM computational engine for freeway or urban street facility is then utilized to calculate the travel time for each scenario. The measures of travel time reliability, including standard statistical measures (e.g., standard deviation, kurtosis), percentile-based measures (e.g., 80th and 95th percentile travel time, buffer index), on-time measures (e.g., percent of trips completed within a travel time threshold), and failure measures (e.g., percent of trips that exceed a travel time threshold), are calculated from the resulted distribution of travel time.

3.3.3.3 SHRP2 L07 Method

The SHRP2 L07 project developed a sketch planning-level tool for assessing the impacts of highway design treatments on travel time reliability (Potts et al., 2014). The method used in the L07 project was originally developed in the SHRP2 L03 project and updated in the L07 project to account for the effects of snow and ice. Equation 3-17 presents the general functional form developed in the SHRP2 L03.

$$\boldsymbol{TTI_{n\%} = e^{(j_n LHL + k_n dc_{crit} + l_n R_{0.05"})}} \quad \textbf{(3-17)}$$

where $TTI_{n\%}$ is nth percentile travel time index. Depending on the coefficients used in Equation 4-8, different percentile of travel time index can be estimated. LHL is the lane hour lost due to incidents and work zone. This value is calculated as the average number of lanes blocked per incident or work zone multiplied by the average duration of incident or work zone and the total number of incidents/work zones within the study time period and study time slice. dc_{crit} represents the critical demand-to-capacity ratio. Two methods were recommended to calculate demand. In the first method, when there is no congestion, the 30th-highest volume count during one-year weekdays is used as the demand. However, as traffic detectors measure volume counts instead of demand during the congested periods, a demand has to be either estimated by using a cumulative volume-based method proposed by the L03 project or by adding a field-observed number of vehicles in queue for congested periods. When there is only a single-day or multiple-day collection of volume counts, these limited volume counts are converted to the counts in the peak month using a seasonal factor and a weekday adjustment factor.

Table 3-47 Coefficients Used in SHRP2 L03 Project (Cambridge Systematics, Inc., 2016)

N (percentile)	j_n	k_n	l_n
10	0.07643	0.00405	0.00000
50	0.29097	0.01380	0.00000
80	0.52013	0.01544	0.00000
95	0.63071	0.01219	0.04744
99	1.13062	0.01242	0.00000
Mean	0.27886	0.01089	0.02935

The parameter $R_{0.05"}$ in Equation 3-17 is the hours of rainfall with a precipitation greater than 0.05 inch during the time slice and study period. The remaining variables in Equation 3-17 are regression coefficients, whose values are listed in Table 3-47.

A study by Jia et al. (2014) found that the TTI produced by the above equations are more sensitive to the number of incidents and incident duration than other factors such as demand and weather. The predicted TTI value using Equation 3-17 also has a large difference from that calculated based on real-world data. Therefore, a similar regression procedure was utilized by Jia et al. (2014) to derive expressions for travel time indices based on data for I-95 in Miami, FL. Equation 3-18 shows the final expressions and the parameters in this equation are listed in Table 3-48.

$$TTI_{n\%} = e^{b1*dc_{crit}+b2*LHL+b3*Rain+b4*Length+b5} + b6 \quad (3\text{-}18)$$

Table 3-48 Coefficients Developed by Jia et al. (2014)

Percentile	R-square	b1	b2	b3	b4	b5	b6
10	0.581	0.500	0.000	0.013	-0.075	-1.555	0.749
50	0.864	17.445	0.000	0.000	-2.457	-15.568	1.071
80	0.825	14.865	0.000	0.000	-0.658	-13.912	1.072
95	0.827	10.477	0.029	0.000	-0.832	-9.139	1.105
99	0.814	5.481	0.049	0.000	-0.894	-3.758	1.105
Mean	0.884	14.020	0.000	0.000	-0.619	-13.470	1.058

3.3.3.4 SHRP2 C11 Method

The SHRP2 C11 post-processor was developed to provide the capability to estimate the impacts of different strategies on travel time reliability and crashes (Cambridge Systematics, Inc., 2016), as mentioned earlier. In this post-processor, travel time reliability measures are calculated as a function of the mean travel time index, as shown below.

For freeways,

$$TTI_{50} = \begin{cases} 10.4910 - 9.5867 \times e^{(-0.0142 \times X^{2.2367})} & for\ X > 1.07 \\ 0.963X + 0.037 & otherwise \end{cases} \tag{3-19}$$

$$TTI_{80} = \begin{cases} 7.3567 - 6.9965 \times e^{(-0.0910 \times X^{2.0185})} & for\ X > 1.03 \\ 1.0 & otherwise \end{cases} \tag{3-20}$$

$$TTI_{95} = \begin{cases} 11.7933 - 16.2178 \times e^{(-0.3855 \times X^{1.0336})} & for\ X > 1.08 \\ 1.3737X - 0.3737 & otherwise \end{cases} \tag{3-21}$$

where X is mean travel time index. TTI_{50}, TTI_{80}, and TTI_{95} are the 50th, 80th, and 95th travel time index, respectively.

For arterials,

$$TTI_{50} = \begin{cases} \frac{0.9333 \times 101.7049 + 12.887 \times X^{2.403}}{101.7049 + X^{2.403}} & for\ X < 1.07 \\ X & otherwise \end{cases} \tag{3-22}$$

$$TTI_{80} = \frac{0.7266 \times 26.26 + 9.6702 \times X^{2.5698}}{26.26 + X^{2.5698}} \tag{3-23}$$

$$TTI_{95} = 21.1669 \times e^{-\frac{2.9506}{X}} \tag{3-24}$$

Equations 3-19 to 3-24 were obtained by using regression analysis for the freeways and arterials in a number of counties in Florida based on the National Performance Management Research Data Set (NPMRDS) for years 2014 and 2015.

The expression for the calculation of the mean travel time index is given in Equation 3-25.

$$X = 1 + (FFS * (RecurringDelayRate + Du)) \tag{3-25}$$

where FFS is free-flow speed. RecurringDelayRate is the recurring delay rate in hours per vehicle-mile, which is estimated as follows.

$$\text{RecurringDelayRate} = (1/\text{Speed}) - (1/\text{FFS}) \tag{3-26}$$

where Speed is the calculated link or segment speed based on the piecewise modified Davison equation.

Du is base nonrecurrent delay rate due to incidents. The following regression equations are applied to calculate Du.

$$Du = -\frac{0.0111}{1 - 1471 * exp\left(-6.8498 * \frac{v}{c}\right)} \text{ when number of lanes} \leq 2 \quad (4\text{-}20)$$

$$Du = -\frac{0.0085}{1 - 1872 * exp\left(-7.1381 * \frac{v}{c}\right)} \text{ when number of lanes} = 3 \quad (4\text{-}21)$$

$$Du = -\frac{0.0068}{1 - 1827 * exp\left(-7.1090 * \frac{v}{c}\right)} \text{ when number of lanes} \geq 4 \quad (4\text{-}22)$$

The implementation of an incident management strategy may reduce incident rate or duration, which results in a lower incident delay. The new incident delay rate Da is calculated as follows.

$$Da = Du \times (1 - R_f) \times (1 - R_d) \quad (4\text{-}23)$$

where R_f and R_d are the reductions in incident frequency and incident duration in fractions, respectively.

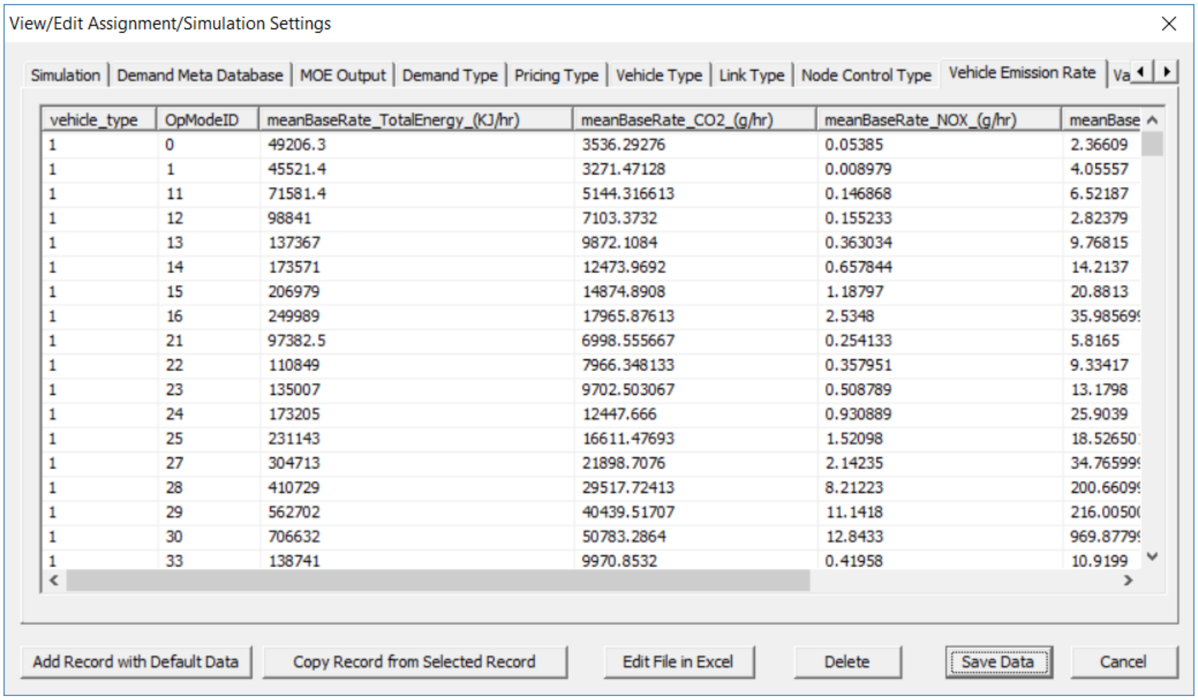
3.3.4 Energy Consumption and Emissions

3.3.4.1 MOVES

The Motor Vehicle Emission Simulator (MOVES) is an emission estimation tool released by the Environmental Protection Agency (EPA). The MOVES model can estimate emissions at three different scales: national, county, and project levels (U.S. Environmental Protection Agency, 2015). The national and county scales are usually used for a large or medium area while the project scale analysis is targeted for small to medium network. The project level is the finest level of vehicle emission estimation in MOVES. It includes three different estimation methods: the average speed approach, the drive schedule approach, and the operating mode distribution approach. The average speed approach is the simplest methods of the three approaches. It estimates emissions based on average speed and vehicle mile travelled by vehicle type. This approach can be integrated with various levels of modelling tools to estimate emission by using the link-based performance measures exported from these models as input. The drive schedule method estimates emissions based on second-by-second speed profiles of vehicles. However, this method only allows the input of one representative speed profile from traffic models. The operating mode distribution approach is a detailed emission estimation approach that requires the input of the distribution of each operating mode. Operating modes are defined based on Vehicle-Specific Power (VSP), vehicle speed, and vehicle acceleration. These information can be generated from mesoscopic or microscopic simulation outputs.

3.3.4.2 MOVES Lite

As MOVES is a computational intensive emission estimation model requiring a large number of data input, Liu and Frey (2013) developed a simplified and light version of MOVES called MOVES Lite. In MOVES Lite, input parameters, such as temperature, humidity, air conditioning load, fuel properties, and so on, are considered to be constant as modeling and simulation scenarios usually represent a short period of time on a typical day. Such an assumption greatly reduces the computation effort required by the full version of MOVES and leads to a simplified estimation of cycle average emission rates for different operating modes. MOVES Lite has been implemented in the dynamic traffic assignment tool, DTALite. Figure 3-14 illustrates the vehicle emission rates used in DTALite.



vehicle_type	OpModeID	meanBaseRate_TotalEnergy_(KJ/hr)	meanBaseRate_CO2_(g/hr)	meanBaseRate_NOX_(g/hr)	meanBase
1	0	49206.3	3536.29276	0.05385	2.36609
1	1	45521.4	3271.47128	0.008979	4.05557
1	11	71581.4	5144.316613	0.146868	6.52187
1	12	98841	7103.3732	0.155233	2.82379
1	13	137367	9872.1084	0.363034	9.76815
1	14	173571	12473.9692	0.657844	14.2137
1	15	206979	14874.8908	1.18797	20.8813
1	16	249989	17965.87613	2.5348	35.98569
1	21	97382.5	6998.555667	0.254133	5.8165
1	22	110849	7966.348133	0.357951	9.33417
1	23	135007	9702.503067	0.508789	13.1798
1	24	173205	12447.666	0.930889	25.9039
1	25	231143	16611.47693	1.52098	18.52650
1	27	304713	21898.7076	2.14235	34.76599
1	28	410729	29517.72413	8.21223	200.6609
1	29	562702	40439.51707	11.1418	216.0050
1	30	706632	50783.2864	12.8433	969.8779
1	33	138741	9970.8532	0.41958	10.9199

Figure 3-14 Snapshot of Vehicle Emission Rates Used in DTALite

3.4 Summary

This section provides a summary of performance measures that have been reviewed in this document. Tables 3-49 to 3-55 summarize these performance measures based on the categories of mobility, reliability, safety and security, fuel consumption and environment, system preservation, freight, and livability and sustainability, which correspond to the seven focus areas of MAP-21. Note that a large number of performance measures listed in these tables are reported by the State and MPOs, however, no detailed calculation methods or data sources are explained. When available, the methods used in the calculation of the measures are reported.

Table 3-49 Summary of Mobility Performance Measures

Performance Measures	Source(s) Identified the Measure	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Annual hours of peak hour excessive delay (PHED) per capita	• National (MAP-21)	System	• The excess delay is calculated as the difference between travel time and a travel time threshold defined using a value of 20 mph or 60% of the post speed limit as speed threshold. • The excessive delay for vehicles is then converted to personal excess delay by multiplying by the average vehicle occupancy. • The accumulated excessive delay over all segments and time periods is divided by total population to generate PHED per capita. • The data sources are National Performance Management Research Data Set (NPMRDS) or equivalent data set	• Demand model/sketch planning • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Percent of non-SOV travel	• National (MAP-21) • State (FDOT Multimodal Mobility Performance Measure Source Book)	Both	• Method A: 100% minus percentage of SOV including cars, trucks, or vans • Method B: local survey • Method C: annual volume of person travel other than driving alone divided by the total number of persons • The data source is survey.	• Demand model
Percent of commute by SOV	• MPO (Broward MPO PMP)	Both	NA	• Demand model
Percent of person trips by SOV	• MPO (MetroPlan Orlando LRTP)	Both	NA	• Demand model
Number of registered carpools or vanpools	• MPO (MetroPlan Orlando CMP)	System	NA	• Demand model

Performance Measures	Source(s) Identified the Measure	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
VMT-demand	• National (FHWA ATDM Guide)	System	• The sum of the products of the vehicle trips in the input origin-destination (OD) table by the length of the shortest path between each OD	• Demand model • Mesoscopic simulation
VMT-served	• National (MAP-21 and FHWA ATDM Guide) • State (FTP and FDOT Multimodal Mobility Performance Measure Source Book) • MPO (Miami-Dade TPO LRTP, Palm Beach MPO LRTP, MetroPlan Orlando CMP, North Florida TPO LRTP, and North Florida TPO Cost Feasible Plan MOE)	Both	• The sum of the product of the total link volumes and link length for the time period of interest	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Vehicle miles traveled per capita	• State (FTP) • MPO (MetroPlan Orlando LRTP)	System	• The sum of the product of the total link volumes and link length for the time period of interest divided by total population	• Demand model • Mesoscopic simulation
Average VMT per dwelling	• MPO (MetroPlan Orlando LRTP)	System	• The sum of the product of the total link volumes and link length for the time period of interest divided by total number of houses	• Demand model
Person-miles traveled	• State (FDOT Multimodal Mobility Performance Measure Source Book) • MPO (North Florida TPO LRTP, and North Florida TPO Cost Feasible Plan MOE)	Both	• Person miles traveled is determined by using vehicle traffic volume, segment length, and average vehicle occupancy for highway motor vehicles	• Demand model

Performance Measures	Source(s) Identified the Measure	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Vehicles per lane mile	• State/MPO	Both	• The total number of vehicles divided by length	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Vehicle-hours traveled	• National (FHWA ATDM Guide)	Both	• The sum of the product of the total link volumes and the average link travel times. The delay to vehicle that cannot enter the network due to traffic control such as ramp metering is added to the above VHT and included in the VHT total	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Vehicle-hours delay	• National (FHWA ATDM Guide) • State (FTP and FDOT Multimodal Mobility Performance Measure Source Book) • MPO (Miami-Dade TPO LRTP, and North Florida TPO Cost Feasible Plan*)	Both	• The difference between the VHT total and the VHT if all links are traversed at free-flow speed (FHWA ATDM Guide) • Delay is the product of directional hourly volume and the difference between travel time at "threshold" speeds and travel time at the average speed. The thresholds are based on LOS B as defined by FDOT (FDOT Multimodal Mobility Performance Measure Source Book)	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Person hours of delay	• State (FDOT Multimodal Mobility Performance Measure Source Book) • MPO (Miami-Dade TPO LRTP and MetroPlan Orlando ITS Master Plan)	Both	• Person hours of delay is calculated as the product of directional hourly volume, average vehicle occupancy and the difference between travel time at "threshold" speeds and travel time at the average speed. The thresholds are based on LOS B as defined by FDOT	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Total daily hours of delay (vehicle hours)	• MPO (MetroPlan Orlando LRTP)	System	NA	• Demand model

Performance Measures	Source(s) Identified the Measure	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Delay per capita	• MPO (Broward MPO PMP and MetroPlan Orlando LRTP and ITS Master Plan)	System	NA	• Demand model
Average vehicle delay	• MPO (Hillsborough MPO System Report, and North Florida TPO LRTP)	Both	NA	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Delay reduction per mile of improvement	• MPO (Hillsborough MPO TIP)	Both	• The summation of delay divided by the total number of miles of improvement	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Average speed	• National (FHWA ATDM Guide) • State (FDOT Multimodal Mobility Performance Measure Source Book) • MPO (MetroPlan Orlando ITS Master Plan, Hillsborough MPO System Report, North Florida TPO LRTP, and North Florida TPO Cost Feasible Plan MOE)	Both	• The sum of the VMT-served for all the scenarios divided by the sum of VHT for all the scenarios including vehicle entry delay (FHWA ATDM Guide) • Travel speeds are attained form a private vendor. Speeds are provided in 15-minute increments and gathered from fleet vehicles, Bluetooth signals, and navigational devices (FDOT Multimodal Mobility Performance Measure Source Book)	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Peak-hour travel speed	• MPO (MetroPlan Orlando CMP)	Corridor	• Average speed during peak hour	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation

Performance Measures	Source(s) Identified the Measure	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Average speed during congested times for freeways	• MPO (MetroPlan Orlando LRTP)	Corridor	• Average speed when speed is less than a given threshold for freeways	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Average speed during congested times for arterials	• MPO (MetroPlan Orlando LRTP)	Corridor	• Average speed when speed is less than a given threshold for arterials	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Average speed during congested times for roadways other than freeway and arterials	• MPO (MetroPlan Orlando LRTP)	Corridor	• Average speed when speed is less than a given threshold for roadways other than freeway and arterials	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Average speed during congested times	• MPO (MetroPlan Orlando LRTP)	Corridor	• Average speed when speed is less than a given threshold	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Average travel time	• State (FDOT TSM&O Toolbox) • MPO (Miami-Dade TPO LRTP, Broward MPO LRTP, and MetroPlan Orlando ITS Master Plan)	Corridor	• Average travel time	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Average Home Base Work travel time	• MPO (Miami-Dade TPO LRTP)	System	• Average travel time for home-based work trip	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation

Performance Measures	Source(s) Identified the Measure	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Vehicle-hours delay/vehicle-trip	• National (FHWA ATDM Guide)	System	• The summation of vehicle-hours delay over all scenarios divided by the sum of the number of vehicles trips in the OD tables for all the scenarios	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Total hours of delay on highway facilities with transit service	• MPO (Miami-Dade TPO LRTP)	System	• The product of volumes and the difference between travel and free-flow travel time for highway facilities with transit service	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Hours heavily congested	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	• The vehicle hours heavily congested is the total number of hours during which a segment operates at LOS E and F, weighted by lane-miles	• Demand model • Mesoscopic simulation
Total hours of delay on highway facilities	• MPO (Miami-Dade TPO LRTP)	System	Sensor data or third part data	• Demand model • Mesoscopic simulation
Delay on rural facilities	• MPO (North Florida TPO Cost Feasible Plan MOE)	System	Sensor data or third party vendor	• Demand model • Mesoscopic simulation
Number of 511 calls	• MPO (MetroPlan Orlando ITS Master Plan)	Both	• 511 data	NA
Number of www511 visits	• MPO (MetroPlan Orlando ITS Master Plan)	Both	• 511 data	NA
Person trips	• MPO (North Florida TPO LRTP)	System	NA	• Demand model • Mesoscopic simulation
Average trip time	• MPO (North Florida TPO LRTP Cost Feasible Plan MOE)	System	May be estimated based on sensor data	• Demand model • Mesoscopic simulation

Performance Measures	Source(s) Identified the Measure	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Level of service	• State (FTP) • MPO (Hillsborough MPO ITS Master Plan and Level of Service Report)	Corridor	• Calculation based on highway capacity manual LOS definitions	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Level of service on rural facilities	• MPO (North Florida TPO LRTP)	Corridor	• Calculation based on highway capacity manual LOS definitions	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
% travel meeting LOS criteria	• State (FDOT Multimodal Mobility Performance Measure Source Book)	Both	• Summing the VMT on roadways operating acceptably and then diving by the total system VMT. • The term "acceptabley" is defined as LOS D (two-hour peak) for the urbanized areas of the 7 largest MPOs, LOS D (one-hour peak) for other urbanized areas, and LOS C (one-hour peak) everywhere else.	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
% system heavily congested	• MPO (North Florida TPO LRTP and Cost Feasible Plan)	System	Sensor data or third party vendor	• Demand model • Mesoscopic simulation
Percent miles severely congested	• State (FTP and FDOT Multimodal Mobility Performance Measure Source Book) • MPO (MetroPlan Orlando CMP and ITS Master Plan)	System	• The percentage of miles heavily congested is determined by summing the miles of roadway operating at LOS E and F in the peak hour/peak period and then dividing by the total highway miles	• Demand model • Mesoscopic simulation

Performance Measures	Source(s) Identified the Measure	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
% travel heavily congested	• State (FTP and FDOT Multimodal Mobility Performance Measure Source Book) • MPO (North Florida TPO LRTP and Cost Feasible Plan MOE)	System	• The percentage of travel heavily congested is determined by summing the VMT on roadways operating at LOS E and F and then dividing it by the total system VMT	• Demand model
Vehicles per lane mile	• State (FDOT Multimodal Mobility Performance Measure Source Book) • MPO (North Florida TPO LRTP and Cost Feasible Plan MOE)	Both	• The vehicles on a road segment divided by the number of lane miles on that segment	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Duration of congestion	• MPO (North Florida TPO LRTP and North Florida TPO Cost Feasible Plan MOE)	Both	Sensor data or third party vendor	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Number of thoroughfare intersections with critical sum>1400	• MPO (Palm Beach MPO LRTP)	Both	Sensor data or third party vendor	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Average incident duration per lane blocking incident	• MPO (Hillsborough MPO ITS Master Plan)	Both	• Average of incident duration for lane blocking incident	NA
Number of incidents by type	• MPO (Hillsborough MPO ITS Master Plan)	Both	• Incident data	NA

Performance Measures	Source(s) Identified the Measure	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Peak period v/c ratio	• MPO (Hillsborough MPO TIP)	Corridor	• The ratio of volume to capacity for peak period	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Vehicle hours traveled per capita	• MPO (MetroPlan Orlando LRTP)	System	• The sum of the product of the total link volumes and link travel time for the time period of interest divided by total population	• Demand model • Mesoscopic simulation
Percent of vehicle travel in generally acceptable operating conditions during peak hour	• MPO (MetroPlan Orlando CMP and ITS Master Plan)	System	Sensor data	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Person throughput	• State (FDOT TSM&O Strategic Plan and FDOT TSM&O Toolbox) • MPO (MetroPlan Orlando ITS Master Plan)	Both	NA	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Increase in vehicle occupancy rate	• MPO (MetroPlan Orlando ITS Master Plan)	Both	NA	NA
Transit travel time	• MPO (Miami-Dade TPO LRTP and Palm Beach MPO)	Both	• Transit travel time data	• Demand model
Transit travel time for key travel markets	• MPO (Miami-Dade TPO LRTP)	Both	• Transit travel time data	• Demand model

Notes:
*NA: not available **MOE: measure of effectiveness

Table 3-50 Summary of Reliability Performance Measures

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
% of reliable person-miles traveled on the interstate	• National (MAP-21) • MPO (Hillsborough MPO System Report)	Both	• The level of travel time reliability (LOTTR) is calculated as the 80th percentile travel time divided by the normal travel time (i.e. 50th percentile travel time) • The travel time reliability measure is calculated as the ratio of segments with LOTTR is less than 1.5 for all four time periods to the all segments in terms of multiplications of segment length, segment volume, and average occupancy • The data sources are NPMRDS or equivalent data set	• SHRP 2 L03, L07, C11 products • HCM-based reliability analysis procedure (SHRP 2 L08-based) • Simulation-based SHRP 2 L04
% of reliable person-miles traveled on the non-interstate NHS	• National (MAP-21)	Both	• The level of travel time reliability (LOTTR) is calculated as the 80th percentile travel time divided by the normal travel time (i.e. 50th percentile travel time) • The travel time reliability measure is calculated as the ratio of segments with LOTTR is less than 1.5 for all four time periods to the all segments in terms of multiplications of segment length, segment volume, and average occupancy • The data sources are NPMRDS or equivalent data set	• SHRP 2 L03, L07, C11 products • HCM-based reliability analysis procedure (SHRP 2 L08-based) • Simulation-based SHRP 2 L04
80th percentile travel time index	• National (FHWA ATDM Guide)	Corridor	• 80th percentile travel time divided by free-flow travel time	• As in the above

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Planning time index (PTI) (95% Travel Time Index)	• National (FHWA ATDM Guide) • State (FDOT TSM&O Strategic Plan) • State (FDOT Multimodal Mobility Performance Measure Source Book)	Corridor	• 95th percentile travel time divided by free-flow travel time	• As in the above
Mean travel time index	• MPO (Hillsborough MPO LRTP)	Corridor	• Mean travel time/free flow travel time	• HCM-based reliability analysis procedure • Demand model • Mesoscopic simulation • Microscopic simulation
Buffer index	• MPO (Hillsborough MPO ITS Master Plan)	Corridor	• The difference between the 95th percentile travel time and the average travel time, normalized by the average travel time	• HCM-based reliability analysis procedure
On-time arrival	• State (FDOT Multimodal Mobility Performance Measure Source Book) • MPO (Miami-Dade TPO LRTP)	Corridor	• For the urbanized areas of the 7 largest MPOs, on-time arrival is defined as the percentage of freeway trips traveling at least 45 mph. • For all others, on-time arrival is defined as the percentage of freeway trips traveling at greater than or equal to 5 mph below the posted speed limit.	• HCM-based reliability analysis procedure

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Travel time reliability	• State (FTP and FDOT TSM&O Strategic Plan and FDOT Multimodal Mobility Performance Measure Source Book) • MPO (MetroPlan Orlando CMP and ITS Master Plan, Hillsborough MPO LRTP, TIP, and System Report, and North Florida TPO LRTP and Cost Feasible Plan MOE)	Corridor	NA	• SHRP 2 L03, L07, C11 products • HCM-based reliability analysis procedure (SHRP 2 L08-based) • Simulation-based SHRP 2 L04
Percentage of interstate and freeways providing for peak hour reliable travel times	• MPO (FDOT/MPO Pilot)	System	NA	• SHRP 2 L03, L07, C11 products • HCM-based reliability analysis procedure (SHRP 2 L08-based) • Simulation-based SHRP 2 L04

Notes:
*NA: not available **MOE: measure of effectiveness.

Table 3-51 Summary of Safety and Security Performance Measures

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Number of fatalities	• National (MAP-21) • MPO (FDOT/MPO Pilot, Miami-Dade TPO LRTP, MetroPlan Orlando CMP and ITS Master Plan, Hillsborough MPO LRTP, TIP, and System Report, and North Florida TPO Strategic Safety Plan and Cost Feasible Plan MOE)	Both	• 5-year rolling average (The data sources are Final Fatality Analysis Reporting System (FARS) data and FARS Annual Report File (ARF))	• Safety performance function • Lookup table used in FITSEVAL
Number of serious injuries	• National (MAP-21) • MPO (FDOT/MPO Pilot, Miami-Dade TPO LRTP, MetroPlan Orlando CMP and ITS Master Plan, Hillsborough MPO LRTP, TIP, and System Report, and North Florida TPO Strategic Safety Plan)	Both	• 5-year rolling average (The data sources are Final Fatality Analysis Reporting System (FARS) data and FARS Annual Report File (ARF))	• Safety performance function • Lookup table used in FITSEVAL
Rate of fatalities per 100 million VMT	• National (MAP-21) • State (FTP) • MPO (FDOT/MPO Pilot, Broward MPO PMP, and Hillsborough MPO LRTP, TIP, and System Report)	Both	• Average of 5-year fatality rate (The data sources are Final Fatality Analysis Reporting System (FARS) data, FARS Annual Report File (ARF), Highway Performance Monitoring System (HPMS), and MPO VMT)	• Safety performance function • Lookup table used in FITSEVAL

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Rate of serious injuries per 100 million VMT	• National (MAP-21) • State (FTP) • MPO (FDOT/MPO Pilot, Broward MPO PMP, and Hillsborough MPO LRTP and TIP)	Both	• Average of 5-year serious injury rate (The data sources are Final Fatality Analysis Reporting System (FARS) data, FARS Annual Report File (ARF), Highway Performance Monitoring System (HPMS), and MPO VMT)	• Safety performance function • Lookup table used in FITSEVAL
Number of combined nonmotorized fatalities and nonmotorized serious injuries	• National (MAP-21) • MPO (FDOT/MPO Pilot and Hillsborough MPO TIP)	Both	• 5-year rolling average (The data sources are Final Fatality Analysis Reporting System (FARS) data and FARS Annual Report File (ARF))	NA
Number of fatalities involving lane departures	• State (FTP)	Both	Crash databases	Based on review of historical proportions
Number of fatalities involving intersections	• State (FTP)	Both	Crash databases	Safety performance functions
Number of fatalities involving work zones	• State (FTP)	Both	• 5-year rolling average over FARS data	Safety performance function combined with historical proportions
Number of fatalities involving impaired driving	• State (FTP)	Both	Crash databases	Safety performance function combined with historical proportions
Number of fatalities involving speeding and aggressive driving	• State (FTP)	Both	• 5-year rolling average over FARS data	Safety performance function combined with historical proportions

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Number of fatalities involving distracted driving	• State (FTP) • MPO	Both	• 5-year rolling average over FARS data	Safety performance function combined with historical proportions
Number of fatalities involving aging road users	• State (FTP)	Both	NA	Safety performance function combined with historical proportions
Number of fatalities involving teen drivers	• State (FTP) • MPO	Both	• 5-year rolling average over FARS data	Safety performance function combined with historical proportions
Number of fatalities involving pedestrians	• State (FTP) • MPO (Miami-Dade TPO Bicycle/Pedestrian Plan, Broward MPO PMP and Hillsborough MPO System Report)	Both	• 5-year rolling average over FARS data	Safety performance function combined with historical proportions
Number of fatalities involving bicyclists	• State (FTP) • MPO (Miami-Dade TPO Bicycle/Pedestrian Plan, Broward MPO PMP and Hillsborough MPO System Report)	Both	• 5-year rolling average over FARS data	Safety performance function combined with historical proportions
Number of fatalities involving motorcyclists	• State (FTP) • MPO (Hillsborough MPO System Report)	Both	• 5-year rolling average over FARS data	Safety performance function combined with historical proportions
Number of fatalities involving commercial motor vehicles	• State (FTP)	Both	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Number of fatalities involving rail	• State (FTP)	Both	Crash databases	Safety performance function combined with historical proportions
Number of fatalities involving public transit	• State (FTP)	Both	Crash databases	Safety performance function combined with historical proportions
Number of fatalities involving aviation	• State (FTP)	Both	Crash databases	NA
Safety belt usage	• State (FTP)	Both	• Based on state survey	Safety performance function combined with historical proportions
Transit injuries	• State (FTP)	Both	NA	Safety performance function combined with historical proportions
Transit accident per 100k miles of service	• MPO (Broward MPO PMP)	Both	• The total number of transit-related accidents divided by 100,000 miles of service	Safety performance function combined with historical proportions
Transit revenue miles between safety incidents	• State (FTP)	Both	• Number of total annual revenue miles divided by the number of revenue vehicle system failures. It is an indicator of the average frequency of delays because of a problem with the equipment	• Demand model combined with the information of transit incidents.
Number of crashes	• State (FDOT TSM&O Toolbox) • MPO (Hillsborough MPO System Report and North Florida TPO LRTP and North Florida TPO Cost Feasible Plan MOE)	Both	Crash databases	• Safety performance function Lookup table used in FITSEVAL

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Total crashes per centerline	• MPO (Hillsborough MPO TIP)	Both	Crash databases	As above
Number of crashes per centerline	• MPO (Hillsborough MPO TIP)	Both	Crash databases	As above
Number of crashes involving heavy vehicles	• MPO (MetroPlan Orlando CMP)	Both	Crash databases	Based on safety performance functions and historical proportions
Number of accidents involving elderly drivers	• MPO (Miami-Dade TPO LRTP)	Both	• 5-year rolling average over FARS data	As above
Crash rate per million vehicle miles	• MPO (MetroPlan Orlando LRTP and ITS Master Plan, North Florida TPO LRTP, and North Florida TPO Strategic Safety Plan)	Both	Crash databases	Safety performance function Lookup table used in FITSEVAL
Number of first responders who have participated in Times4Safety training or National Traffic Incident Management Training	• MPO (North Florida TPO Strategic Safety Plan)	System	NA	NA
Vulnerable roadway users' fatal crash rate	• MPO (North Florida TPO Strategic Safety Plan)	Both	NA	NA
Red light running crash rate	• MPO (North Florida TPO Strategic Safety Plan)	Both	Crash database	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Red light running	• MPO (MetroPlan Orlando ITS Master Plan)		Crash database	NA
Impaired driving crash rate	• MPO (North Florida TPO Strategic Safety Plan)	Both	Crash database	Historical data
Lane departure crash rate	• MPO (North Florida TPO Strategic Safety Plan)	Both	Crash databases	Safety performance function combined with historical proportions
Intersection crash rate	• MPO (North Florida TPO Strategic Safety Plan)	Both	Crash databases	Safety performance function combined with historical proportions
Pedestrian death index	• MPO (Hillsborough MPO LRTP)	System	Calculated based on the rate of pedestrian deaths relative to the number of people driving to work in a given region	NA
Number of bicycle crashes	• MPO (Hillsborough MPO ITS Master Plan and MetroPlan Orlando ITS Master Plan)	Both	Crash database	Historical data
Number of bicycle crashes per centerline	• MPO (Hillsborough MPO TIP)	Both	Crash database	Historical data
Number of pedestrian crashes	• MPO (Miami-Dade TPO LRTP, MetroPlan Orlando ITS Master Plan, and Hillsborough MPO ITS Master Plan)	Both	Crash database	Historical data
Number of pedestrian crashes per centerline	• MPO (Hillsborough MPO TIP)	Both	Crash database	Historical data

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Number of bike and pedestrian serious injuries	• MPO (Miami-Dade TPO LRTP)	Both	Crash database	Historical data
Number of bike and pedestrian fatalities	• MPO (Miami-Dade TPO Bicycle/Pedestrian Plan, and Broward MPO LRTP)	Both	Crash database	Historical data
Average response time and clearance time for crashes	• MPO (MetroPlan Orlando ITS Master Plan)	Both	Crash database	Historical data
Speed limit violation	• MPO (MetroPlan Orlando ITS Master Plan)	Both	Crash database	Historical data
Preventable transit accidents per 100k miles of service	• MPO (Broward MPO)	System	Crash database	Historical data
Secondary crashes	• State (FDOT TSM&O Strategic Plan and FDOT TSM&O Toolbox)	Both	Crash database	Historical data and models

Table 3-52 Summary of Fuel Consumption and Environmental Performance Measures

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Total emission reductions	• National (MAP-21)	Both	• Calculated as the cumulative 2-year and 4-year emissions reductions for all projects funded by CMAQ funds for each pollutant of NOx, VOCs, CO, and particulate matter (PM2.5 and PM10) with designated nonattainment or maintenance areas. • The data source is CMAQ Public Access System	• MOVES • MOVES Lite
Emissions of HC	• MPO (Palm Beach MPO LRTP, MetroPlan Orlando LRTP, and North Florida TPO LRTP)	Both	NA	• MOVES • MOVES Lite
Emissions of NOx	• MPO (Miami-Dade TPO LRTP and Palm Beach MPO LRTP)	Both	NA	• MOVES • MOVES Lite
Emissions of VOCx	• MPO (Miami-Dade TPO LRTP and North Florida TPO LRTP)	Both	NA	• MOVES • MOVES Lite
Emissions of CO	• MPO (Miami-Dade TPO LRTP, Palm Beach MPO LRTP, and MetroPlan Orlando MPO (MetroPlan Orlando LRTP)	Both	NA	• MOVES • MOVES Lite
Emissions of CO_2	• State (FTP)	Both	• State carbon dioxide emission data	• MOVES • MOVES Lite
Emissions of NO	• MPO (North Florida TPO LRTP, MetroPlan Orlando LRTP)	Both	Based on roadside or mobile (on-board sensors)	• MOVES • MOVES Lite
Percentage of fuel use from base year	• MPO (MetroPlan Orlando LRTP)	Both	Based on mobile (on-board sensors)	• MOVES • MOVES Lite

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Fuel consumption per capita	• MPO (Palm Beach MPO LRTP, and MetroPlan Orlando LRTP and ITS Master Plan)	System	Based on mobile (on-board sensors)	• MOVES combined with demand model • MOVES Lite combined with demand model
Capita greenhouse gas emission from mobile sources	• MPO (MetroPlan Orlando ITS Master Plan)	System	NA	• MOVES combined with demand model • MOVES Lite combined with demand model
Tons of ozone precursors and CO_2 produced that are less than those produced in 1990	• MPO (Broward MPO LRTP)	Both	NA	NA
Recycled pavement	• State (FTP)	System	NA	NA
Alternative fuel vehicles	• State (FTP)	Both	NA	NA
Miles of noise walls	• State (FTP)	System	NA	NA
Designated scenic highways	• State (FTP)	System	NA	NA
Roadside attractiveness	• State (FTP)	System	NA	NA
Roadside kept litter free	• State (FTP)	System	NA	NA
Water quality – wetland mitigation	• State (FTP)	System	NA	NA
Wildlife crossings	• State (FTP)	System	NA	NA
Transportation alternatives/transpo rtation enhancement	• State (FTP)	System	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Transportation disadvantage trips	• State (FTP)	System	NA	NA
Surface coverage of transportation system on acres of wetlands	• State (FTP) • MPO (Miami-Dade TPO LRTP)	System	NA	NA

Table 3-53 Summary of System Preservation Performance Measures

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Pavement Conditions				
% of interstate pavements in Good condition	• National (MAP-21)	System	• Based on the combination of condition metrics, International Roughness Index (IRI), rutting, faulting, and Crasking_Percent, or Present Serviceability Rating depending on speed limit • The data is collected by state DOT	• Pavement Management System (PMS)
% of interstate pavements in Poor condition	• National (MAP-21)	System	• Based on the combination of condition metrics, International Roughness Index (IRI), rutting, faulting, and Crasking_Percent, or Present Serviceability Rating depending on speed limit • The data is collected by state DOT	• Pavement Management System (PMS)
% of non-interstate NHS pavements in Good condition	• National (MAP-21)	System	• Based on the combination of condition metrics, International Roughness Index (IRI), rutting, faulting, and Crasking_Percent, or Present Serviceability Rating depending on speed limit • The data is collected by state DOT	• Pavement Management System (PMS)
% of non-interstate NHS pavements in Poor condition	• National (MAP-21)	System	• Based on the combination of condition metrics, International Roughness Index (IRI), rutting, faulting, and Crasking_Percent, or Present Serviceability Rating depending on speed limit • The data is collected by state DOT	• Pavement Management System (PMS)
Percent lane miles resurfaced	• State (FTP)	System	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
% of SIS roadway in good or better condition	• MPO (North Florida TPO LRTP)	System	• The data is from FDOT condition rating system	NA
% of non-SIS roadways in good or better condition	• MPO (North Florida TPO LRTP)	System	• The data is from FDOT condition rating system	NA
Standardized pavement condition index	• MPO (Hillsborough MPO System Report)	System	NA	NA
Percentage of highway miles meeting or exceeding standards	• MPO (Broward MPO LRTP and PMP)	System	NA	NA
Bridge Conditions				
Percentage of bridges in good conditions	• National (MAP-21) • MPO (FDOT/MPO Pilot and Hillsborough MPO System Report)	System	• Calculated from the National Bridge Inventory (NBI) Items including 58 – Deck, 59 – Superstructure, and 60 – Substructure or the NBI Item 62 – Culverts • The data source is NBI	• Bridge Management software (BrM) (formerly Pontis) • Deterioration models
Percentage of bridges in poor conditions	• National (MAP-21) • MPO (FDOT/MPO Pilot and Hillsborough MPO System Report)	System	• Calculated from the National Bridge Inventory (NBI) Items including 58 – Deck, 59 – Superstructure, and 60 – Substructure or the NBI Item 62 – Culverts • The data source is NBI	• Bridge Management software (BrM) (formerly Pontis) • Deterioration models
Bridges with weight restriction	• State (FTP) • MPO (North Florida TPO LRTP)	System	NA	NA
Bridge that needs repair	• State (FTP) • MPO (Hillsborough MPO TIP)	System	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Bridge that needs replacement	• State (FTP) • MPO (Hillsborough MPO TIP and North Florida TPO LRTP)	System	NA	NA
Total bridge counts	• MPO (Hillsborough MPO System Report)	System	NA	NA
Percentage of highway bridges meeting or exceeding standards	• MPO (Broward MPO PMP)	System	NA	NA
Maintenance				
Roadway maintenance	• State (FTP)	System	NA	NA
Roadside maintenance	• State (FTP)	System	NA	NA
Traffic service maintenance	• State (FTP)	System	NA	NA
Drainage maintenance	• State (FTP)	System	NA	NA
Vegetation aesthetics maintenance	• State (FTP)	System	NA	NA
Transit System				
Average fleet age	• State • MPO (Hillsborough MPO LRTP and System Report, and North Florida TPO LRTP)	System	NA	NA
Average age of transit fleet -bus	• MPO (Broward MPO PMP)	System	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Average age of transit fleet -rail	• MPO (Broward MPO PMP)	System	NA	NA
Transit state of good repair	• State (FTP)	System	NA	NA
Percentage of non-revenue, supporting-service and maintenance vehicles that have either met or exceeded their useful life benchmark (ULB)	• MPO (Miami-Dade TPO PMP)	System	NA	NA
Percentage of revenue vehicles with a particular asset class that have either met or exceeded their useful life benchmark	• MPO (Miami-Dade TPO PMP)	System	NA	NA
Percentage of track segments with performance restrictions for rail fixed-guideway, track, signals, and systems	• MPO (Miami-Dade TPO PMP)	System	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Percentage of facilities within an asset class with a rating below condition 3 on the Transit Economic Requirements Model (TERM) scale	• MPO (Miami-Dade TPO PMP)	System	NA	NA
Transit vehicle replacement	• MPO (Hillsborough MPO TIP)	System	NA	NA
Intelligent Transportation System				
Miles managed by ITS	• State (FTP) • MPO (Hillsborough MPO ITS Master Plan)	System	NA	NA
Florida 511 touch-points	• State (FTP)	System	• 511 Data	NA
Road rangers service assists	• State (FTP)	Both	NA	• Lookup table for the number of road ranger service assists per VMT
State roadway clearance times	• State (FTP)	Both	NA	NA
Rapid incident scene clearance (RISC) times	• State (FTP)	Both	NA	NA
Incident duration	• MPO (MetroPlan Orlando CMP and ITS Master Plan)	Both	NA	NA
Incident response and clearance time	• MPO	Both	NA	NA
All lanes cleared time	• State (FDOT TSM&O Strategic Plan)	Both	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Percentage of traffic signals connected to the central control system by fiber optic network	• MPO (Palm Beach MPO)	System	NA	NA
Percentage of principal arterials covered by closed circuit TV cameras	• MPO (Palm Beach MPO LRTP)	System	NA	• Demand model
Percentage of traffic signals with operable vehicle detection	• MPO (Palm Beach MPO LRTP)	System	NA	• NA
Managed lane miles	• MPO (Miami-Dade TPO LRTP)	System	• The total number of managed lane miles	• Demand model
Managed lane miles as a proportion of total lane mile improvement	• MPO (Miami-Dade TPO LRTP)	System	• The total number of managed lane miles divided by the total lane miles for improvement	• Demand model combined with signal optimization tool • Mesoscopic simulation combined with signal optimization tool
Signal retiming cost/benefit	• MPO (MetroPlan Orlando CMP and ITS Master Plan)	Both	NA	• Demand model combined with signal optimization tool • Highway capacity manual • Mesoscopic simulation combined with signal optimization tool • Microscopic simulation combined with signal optimization tool

Table 3-54 Summary of Freight Performance Measures

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Truck travel time reliability index	• National (MAP-21)	Both	• Truck travel time reliability is defined as 95th percentile travel time divided by normal truck travel time (that is, 50th percentile travel time). • Truck travel time reliability index is maximum of truck travel time reliability for four time periods weighted by segment length • The data sources are NPMRDS or equivalent data set	• SHRP 2 reliability procedures • Highway capacity manual reliability procedure
Percentage of reliable trucks travels during peak hour	• MPO (Hillsborough MPO System Report)	Both	NA	• SHRP 2 reliability procedures • Highway capacity manual reliability procedure
Combination truck travel time reliability	• MPO (MetroPlan Orlando ITS Master Plan)	Both	NA	• Highway capacity manual reliability procedure • SHRP 2 reliability procedures
Truck percent miles heavily congested	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	• The percentage of miles heavily congested is determined by summing the miles of roadway operating at LOS E and F in the peak hour and then dividing it by the total highway miles.	• Demand model • Mesoscopic simulation
Truck vehicles per lane mile	• State (FDOT Multimodal Mobility Performance Measure Source Book)	Both	• The vehicles on a road segment divided by the number of lane miles on that segment	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Designated system lane miles for freight, goods, and service movements/total system lane miles	• MPO (MetroPlan Orlando LRTP)	System	Real-World data	NA
Percent miles of congested freight routes	• MPO (Hillsborough MPO LRTP)	System	Real-World data	• Demand model • Mesoscopic simulation
Planning time index	• State (FDOT Multimodal Mobility Performance Measure Source Book) • MPO (Hillsborough MPO LRTP)	Corridor	• 95th percentile travel time divided by free-flow travel time	• SHRP 2 procedure • Highway capacity manual reliability procedures
Buffer index	• MPO (Hillsborough MPO LRTP)	Corridor	• The difference between the 95th percentile travel time and the average travel time, normalized by the average travel time	• SHRP 2 procedure • HCM-based reliability analysis procedure
Percentage of facilities designated truck routes that exceed capacity (v/c>1)	• MPO (Palm Beach MPO LRTP)	System	• Based on v/c ratio	• Demand model • Mesoscopic simulation
Percentage of funding dedicated to SIS hubs, corridors, and connection by mode	• MPO (Miami-Dade TPO LRTP)	System	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Combination truck miles traveled	• State (FTP and FDOT Multimodal Mobility Performance Measure Source Book) • MPO (MetroPlan Orlando CMP)	System	• The product of combination truck traffic volume and segment length	• Demand model • Mesoscopic simulation
Truck miles traveled	• State (FDOT Multimodal Mobility Performance Measure Source Book) • MPO (North Florida TPO LRTP, and North Florida TPO Cost Feasible Plan MOE)	Both	• The product of a road's VMT and the percentage of vehicles that are truck.	• Demand model • Mesoscopic simulation
Truck tonnage	• State (FDOT Multimodal Mobility Performance Measure Source Book)	Both	• Freight tonnage carried by trucks. • The Freight Analysis Framework (FAF) tonnage data is interpolated using a combination truck miles traveled factor and an average truck load factor to calculate truck tonnage.	• Demand model combined with truck load factor and cargo value data
Freight tonnage	• MPO (Palm Beach MPO LRTP)	Both	NA	NA
Truck value of freight	• State (FDOT Multimodal Mobility Performance Measure Source Book)	Both	• The value of truck freight in dollar amount is obtained from the Freight Analysis Framework cargo value data, truck tonnage, and annual factors for CTMT and average truck load.	• Demand model combined with truck load factor and cargo value data
Combination truck ton miles traveled	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	• The product of CTMT and average weight of the load	• Demand model combined with truck load factor

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Travel time reliability	• State (FDOT Multimodal Mobility Performance Measure Source Book) • MPO (Hillsborough MPO)	Corridor	• For the urbanized areas of the 7 largest MPOs, on-time arrival is defined as the percentage of freeway trips traveling at least 45 mph. • For all others, on-time arrival is defined as the percentage of freeway trips traveling at greater than or equal to 5 mph below the posted speed limit.	• Demand model
Combination truck hours of delay	• State (FTP and FDOT Multimodal Mobility Performance Measure Source Book) • MPO (MetroPlan Orlando ITS Master Plan)	Both	• Delay is as calculated as the product of directional hourly volume and the difference between travel time at "threshold" speeds (at LOS B) and travel time at the average speed	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Combination truck average travel speed	• State (FDOT Multimodal Mobility Performance Measure Source Book)	Corridor	• Travel speeds are attained form a private vendor. Speeds are provided in 15-minute increments and gathered from fleet vehicles, Bluetooth signals, and navigational devices. The free-flow speed is assumed to be lower than that for passenger vehicles.	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation
Combination truck cost of delay	• State (FDOT Multimodal Mobility Performance Measure Source Book)	Both	• The monetization of combination truck cost of delay is based on combination truck hours of delay and the marginal cost of truck labor per hour.	• Demand model • Highway capacity manual • Mesoscopic simulation • Microscopic simulation

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Truck empty backhaul tonnage	• State (FDOT Multimodal Mobility Performance Measure Source Book)	Both	• The Freight Analysis Framework tonnage data is interpolated using combination truck miles traveled data to calculate incoming and outgoing truck freight tonnage. An average capacity to average load ratio is calculated and applied to the difference between incoming and outgoing truck tonnage.	• Freight/Demand model
Combination truck percent miles severely congested	• MPO (MetroPlan MPO CMP and ITS Master Plan)	System	Real-world data	• Various modeling tools
Percentage of interstate and freeways providing for peak hour reliable truck travel times	• MPO (FDOT/MPO Pilot)	System	Real-world data	Various modeling tools
Cost of freight delay	• MPO (Hillsborough MPO LRTP)	System	NA	Various modeling tools
Aviation tonnage	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	• All air cargo handled by weight at public airports	Freight modeling
Aviation value of freight	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	• Values of air cargo are extracted from Freight Analysis Framework	Freight modeling
Rail tonnage	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	• Tons of freight carried by rail mode originated or terminated in Florida	Freight modeling

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Rail Active rail access	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	• Active rail access accounts for active rail serving intermodal logistic centers and seaports	Freight modeling
Seaport tonnage	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	• International and domestic waterborne tons of cargo handled at both public and private terminals in port areas of Florida	Freight modeling
Seaport twenty-foot equivalent units	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	• International and domestic waterborne cargo handled at both public and private terminals in port areas of Florida, expressed as twenty-foot equivalent units	Freight modeling
Seaport value of freight	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	• Value of international and domestic waterborne cargo handled at both public and private terminals in port areas of Florida	Freight modeling
Seaport active rail access	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	• Seaport rail access accounts for the percentage of seaports served by an active railroad. An active railroad is determined by the presence of trains operating on the facility	Freight modeling
Local centerline and lane miles of roadways with high truck volumes	• MPO (Miami-Dade TPO LRTP)	System	• Real-world data	transportation system models

Table 3-55 Summary of Livability and Sustainability Performance Measures

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Jobs				
Jobs within ½ mile of a congestion management system facility	• MPO (North Florida TPO LRTP)	Corridor	NA	NA
Number of jobs served	• MPO (Hillsborough MPO LRTP and System Report)	System	NA	NA
Jobs served per mile of improvement	• MPO (Hillsborough MPO TIP)	System	NA	NA
Job/house ratio	• MPO (MetroPlan Orlando LRTP)	System	NA	NA
Number of jobs within 30 minutes travel time by mode	• MPO (Broward MPO LRTP)	System	NA	NA
Number of jobs	• MPO (Hillsborough MPO LRTP and MetroPlan Orlando LRTP)	System	NA	NA
Job Accessibility	• State (FDOT Multimodal Mobility Performance Measure Source Book) • MPO (North Florida TPO Cost Feasible Plan MOE)	System	• Job accessibility reflects the total amount of jobs reachable by auto within a 30-minute travel time threshold. • It is calculated for each census block and the results are aggregated to provide a statewide average. • The calculation assumes a departure time of 8:00 am in order to represent job accessibility during the morning peak period.	• Demand model

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Transit				
¼ mile walk accessibility to transit stops	• MPO (North Florida TPO LRTP)	Both	NA	• Demand model
Households within 5 miles of major transit centers or park and ride lots	• MPO (North Florida TPO LRTP)	Both	NA	NA
Annual boarding per vehicle revenue mile	• MPO (North Florida TPO LRTP)	Both	NA	• Demand model
Annual boarding per vehicle revenue hour	• MPO (Hillsborough MPO System Report and North Florida TPO LRTP)	Both	NA	• Demand model
Passenger trips per revenue hour	• MPO (MetroPlan Orlando CMP)	Both	NA	• Demand model
Passenger trips per revenue mile	• State (FTP and FDOT Multimodal Mobility Performance Measure Source Book) • MPO (Palm Beach MPO LRTP, and MetroPlan Orlando)	Both	• The ratio of annual transit passenger trips to total annual transit revenue miles of service	• Demand model
Transit ridership	• MPO (Miami-Dade TPO LRTP, MetroPlan Orlando CMP, North Florida TPO LRTP, and North Florida TPO Cost Feasible Plan MOE)	Both	NA	• Demand model
Percentage of transit run delays caused by congestion	• MPO (Hillsborough MPO ITS Master Plan)	System	NA	• Demand model

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Percentage of transportation disadvantaged living outside of bus service area	• MPO (Hillsborough MPO LRTP and System Report)	System	NA	NA
The number of residents and workers with access to excellent or good pedestrian level of service and bicycle level of service	• MPO (Hillsborough MPO LRTP)	System	NA	NA
Density of jobs within ¼ mile of transit service	• MPO (Hillsborough MPO TIP)	System	NA	NA
Density of population within ¼ mile of transit service	• MPO (MetroPlan Orlando and Hillsborough MPO TIP)	System	NA	NA
Percent of population within ¼ mile of transit service	• MPO (MetroPlan Orlando LRTP)	System	NA	NA
Percent of employment within ¼ mile of transit service	• MPO (MetroPlan Orlando LRTP)	System	NA	• Demand model
Percent of population within five minute commute of intermodal stations	• MPO (MetroPlan Orlando LRTP)	System	NA	NA
Percent of population within 10 -minute travel time of activity centers	• MPO (MetroPlan Orlando LRTP)	System	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Percent of total employment within 30-minute commute from international airports	• MPO (MetroPlan Orlando LRTP)	System	NA	NA
Transit coverage	• MPO (North Florida TPO LRTP)	System	NA	NA
Transit load factor	• MPO (North Florida TPO LRTP and North Florida TPO Cost Feasible Plan MOE)	Both	NA	NA
Transit on-time performance	• MPO (MetroPlan Orlando CMP and ITS Master Plan, and Hillsborough MPO System Report)	both	• Defined as time periods from -1 to 5+ minutes	• Demand model
On-time transit trips	• MPO (Broward MPO PMP)	both	NA	• Demand model
On-time rail trips	• MPO (Broward MPO PMP)	both	NA	NA
Transit level of service	• MPO (Hillsborough MPO LRTP)	Both	• Based on number of buses per hour and wait time	• Demand model
Transit service miles	• MPO (Miami-Dade TPO LRTP and MetroPlan Orlando LRTP)	System	NA	• Demand model
Transit service miles per thousand people	• MPO (MetroPlan Orlando)	System	NA	• Demand model
Transit passenger miles per capita	• MPO (MetroPlan Orlando LRTP)	System	NA	• Demand model
Percentage of transit commuter mode choice	• MPO (Palm Beach MPO LRTP)	System	NA	• Demand model

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Number of park-n-ride spaces/multimodal facilities	• MPO (Miami-Dade TPO LRTP)	System	NA	• Demand model
Number of park-n-ride spaces	• MPO (Palm Beach MPO LRTP)	System	NA	• Demand model
Average ratio of transit travel time to auto travel time for fixed route system	• MPO (Palm Beach MPO LRTP)	System	NA	• Demand model
Transit revenue hours	• MPO (Broward MPO PMP)	Both	NA	• Demand model
Transit revenue hours of service per thousand people	• MPO (MetroPlan Orlando LRTP)	Both	NA	NA
Transit headway	• State (FDOT Multimodal Mobility Performance Measure Source Book) • MPO (Broward MPO LRTP)	Corridor	• Calculated based on transit schedule	• Demand model
Average peak service frequency	• MPO (MetroPlan Orlando CMP)	Both	• Calculated based on transit schedule	• Demand model
Transit service route miles within ¼ miles of major healthcare, reaction, education, employment, and cultural facilities	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Transit service route miles in corridors of regional significance	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Transit service route miles within ¼ miles of tourist attractions	• MPO (Miami-Dade TPO LRTP)	System	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Transit service route miles within 0.5 miles of redevelopment areas	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Transit service route miles within 0.5 miles of major activity center	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Transit service route miles within the urban infill area	• MPO (Miami-Dade TPO)	System	NA	NA
Non fossil fuel burning daily transit service route miles	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Transit route miles per highway centerline miles	• MPO (Miami-Dade TPO LRTP)	System	NA	• Demand model
Percent of congested roadway centerline with transit service	• MPO (MetroPlan Orlando CMP)	System	NA	• Demand model
Weekday span of service	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	• It is determined by computing the number of hours between the time service begins and the time service ends for an average weekday.	• Demand model
Passenger miles traveled	• State (FDOT Multimodal Mobility Performance Measure Source Book)	Both	NA	• Demand model

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Transit passenger trips	• State (FTP and FDOT Multimodal Mobility Performance Measure Source Book) • MPO (Broward MPO PMP)	Both	• Annual number of passenger trips on the transit vehicles. A trip is counted each time a passenger boards a transit vehicle. If a passenger has to transfer between buses to reach a destination, the passenger is counted as making two passenger trips.	• Demand model
Access to transit	• MPO (North Florida TPO Cost Feasible Plan MOE)	System	• The percentage of the population within a half-mile of fixed route transit	• Demand model
Fixed route major transit incidents	• MPO (MetroPlan Orlando CMP)	System	NA	NA
Bicycle and Pedestrian				
Lane mile with bicycle and pedestrian facilities at the quality of service standard	• MPO (North Florida TPO LRTP)	System	NA	NA
% miles bicycle accommodations	• MPO (North Florida TPO LRTP and North Florida TPO Cost Feasible Plan MOE)	System	NA	NA
% miles pedestrian accommodations	• MPO (North Florida TPO LRTP and North Florida TPO Cost Feasible Plan MOE)	System	NA	NA
Percentage of pedestrian commuter mode choice	• MPO (Palm Beach MPO LRTP)	System	NA	NA
Percentage of bicycle commuter mode choice	• MPO (Palm Beach MPO LRTP)	System	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Centerline mileage of buffered bike lanes	• MPO (Palm Beach MPO LRTP)	System	NA	NA
Centerline mileage of 10-ft or wider shared use pathways	• MPO (Palm Beach MPO LRTP)	System	NA	NA
Centerline mileage of designated bike lanes	• MPO (Palm Beach MPO LRTP)	System	NA	NA
Centerline mileage of priority bike network operating at LOS C or better	• MPO (Palm Beach MPO LRTP)	System	NA	NA
Percentage of thoroughfare mileage near transit hubs that provides dedicated bicycle facilities (within 3 miles)	• MPO (Palm Beach MPO LRTP)	System	NA	NA
Percentage of thoroughfare mileage near transit hubs that provides dedicated pedestrian facilities (within 1 mile)	• MPO (Palm Beach MPO LRTP)	System	NA	NA
Miles of new bike and pedestrian facilities	• MPO (Broward MPO PMP)	System	NA	NA
Changes in bicycle counts	• MPO (Broward MPO Complete Street Evaluation)	System	• Pedestrian and Bicyclist Counts Field Data Collection and Worksheet Tools	NA
Changes in pedestrian count	• MPO (Broward MPO Complete Street Evaluation)	System	• Pedestrian and Bicyclist Counts Field Data Collection and Worksheet Tools	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Bicycle level of service	• State (FTP) • MPO (Miami-Dade TPO Bicycle/Pedestrian Plan)	Corridor	• The summation of miles of each LOS letter grade	• Demand model integrated with the calculation method of bicycle LOS.
Pedestrian level of service	• State (FTP and FDOT Multimodal Mobility Performance Measure Source Book) • MPO (Miami-Dade TPO Bicycle/Pedestrian Plan)	Corridor	• The summation of miles of each pedestrian LOS letter grade	• Demand model integrated with the calculation method of pedestrian LOS.
Bicycle and pedestrian facilities	• State (FTP and FDOT Multimodal Mobility Performance Measure Source Book)	System	NA	NA
Multimodal level of service	• MPO (Broward MPO Complete Street Evaluation)	Both	NA	• MMLOS Worksheet Tool
Number of walking and biking trips	• MPO (Broward MPO Complete Street Evaluation)	Both	• Pedestrian and Bicyclist Counts Field Data Collection and Worksheet Tools	NA
Number of bicycle trips	• MPO (Miami-Dade TPO LRTP and North Florida TPO Cost Feasible Plan MOE)	Both	NA	NA
Number of walking trips	• MPO (Miami-Dade TPO LRTP and North Florida TPO Cost Feasible Plan MOE)	Both	NA	NA
Number of gaps in the sidewalk and bike lane network	• MPO (Broward MPO LRTP)	System	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Number of bicycle lane miles/number of roadway miles	• MPO (Broward MPO LRTP)	System	NA	NA
Number of miles of sidewalk miles/number of roadway miles	• MPO (Broward MPO LRTP)	System	NA	NA
Number of non-motorized facilities	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Miles of non-motorized facilities	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Percentage of population within 1 mile of bike lane and shared-use path	• State (FDOT Multimodal Mobility Performance Measure Source Book) • MPO (Miami-Dade TPO)	Both	• Ratio of population within one mile of bike lanes and shared-use paths to Florida's total population. The bike lane and shared-use path miles include those on the SHS and a limited number of non-SHS miles deemed of interest to FDOT	• Demand model updated with information of bike lane and shared-use path
Percentage of sidewalk coverage	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	NA	NA
Percentage of bike lane and shoulder coverage	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	NA	NA
Percent of congested roadway centerline miles with pedestrian facilities	• MPO (MetroPlan Orlando CMP)	System	NA	NA
Percent of congested roadway centerline with bicycle facilities	• MPO (MetroPlan Orlando CMP)	System	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Trail and Sidepath				
Density of jobs within ¼ mile of trail/sidepath	• MPO (Hillsborough MPO TIP)	System	NA	NA
Density of population within ¼ mile of trail/sidepath	• MPO (Hillsborough MPO TIP)	System	NA	NA
The percentage of residents with access to trail	• MPO (Hillsborough MPO System Report)	System	NA	NA
The miles of trails	• MPO (Hillsborough MPO System Report)	System	NA	NA
Sidewalks and trail miles per highway centerline miles	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Aviation				
Aviation passenger boardings	• State (FTP and FDOT Multimodal Mobility Performance Measure Source Book)	System	• The total number of revenue passengers who board an aircraft at a Florida Airport. If a passenger has to transfer between planes to reach a destination, the passenger is counted as making two passenger boardings.	NA
Departure reliability	• State (FTP and FDOT Multimodal Mobility Performance Measure Source Book)	System	• Departure is deemed reliable if the flight departs within 15 minutes after the scheduled time shown in the carrier's Computerized Reservation Systems (CRS).	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Demand to capacity ratio	• State (FTP and FDOT Multimodal Mobility Performance Measure Source Book)	System	• The ratio of the annual operational demand to annual service volume. Annual service volume is determined by the quantity of airports' runwasy and taxiways.	NA
Highway adequacy (LOS)	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	• The ratio of the annual operational demand to annual service volume. Annual service volume is determined by the quantity of airports' runwasy and taxiways.	NA
Rail				
Rail passenger trips	• State (FTP and FDOT Multimodal Mobility Performance Measure Source Book)	System	• Annual number of revenue paying rail passengers. Rail passengers include those riding on Amtrack, SunRail, and Tri-Rail.	NA
Departure reliability	• State (FTP and FDOT Multimodal Mobility Performance Measure Source Book)	System	• A train is considered on-time if arrival at endpoint is within a specified threshold timeframe of scheduled arrival time. The threshold timeframe varies based on the trip length.	NA
Highway adequacy (LOS)	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	NA	NA
Seaports				
Seaport passenger trips	• State (FTP)	System	• Annual number of passengers embarking on cruise ships at Florida's seven cruise ports.	
Highway adequacy (LOS)	• State (FDOT Multimodal Mobility Performance Measure Source Book)	System	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Congestion Costs and Highway System				
Transportation costs per capita	• MPO (North Florida TPO LRTP)	System	NA	• Demand model • Mesoscopic model
Overall cost of travel	• MPO (Broward MPO LRTP)	System	• Travel time * value of time+operating cost+maintenance cost)/(person miles of travel +truck miles of travel)	• Demand model • Mesoscopic model
Cost of congestion	• MPO (North Florida TPO LRTP and North Florida TPO Cost Feasible Plan MOE)	Both	NA	NA
Delay reduced per mile of improvement	• MPO (Hillsborough MPO)	System	NA	NA
Percent of corridors managed and monitored	• MPO (MetroPlan Orlando ITS Master Plan)	System	NA	NA
Percentage of roads having traffic volume that is greater than capacity	• MPO (Hillsborough MPO System Report)	System	NA	• Demand model • Mesoscopic model
Travel time delay due to transportation disruption	• MPO (Hillsborough MPO LRTP)	System	NA	NA
Daily cost of delay per capita	• MPO (MetroPlan Orlando LRTP)	System	NA	• Demand model • Mesoscopic model
Annual cost of congestion	• MPO (MetroPlan Orlando LRTP)	System	NA	• Demand model • Mesoscopic model
Lost trips due to transportation network disruption	• MPO (Hillsborough MPO LRTP)	System	NA	NA
Proximity to major transportation hubs	• MPO (North Florida TPO LRTP and Cost Feasible Plan MOE)	System	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Highway lane miles	• MPO (MetroPlan Orlando LRTP and North Florida TPO Cost Feasible Plan MOE)	System	NA	• Demand model
Highway lane miles per thousand people	• MPO (MetroPlan Orlando LRTP)	System	NA	NA
Highway centerline miles on SIS connectors	• MPO (Miami-Dade TPO LRTP)	System	NA	• Demand model
Miles of roadway below standard	• MPO (MetroPlan Orlando LRTP)	System	NA	• Demand model • Mesoscopic model
Highway lane and center line miles within ¼ miles of major healthcare, recreation, education, employment, and cultural facilities	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Highway lane and center line miles in corridors of regional significance	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Highway lane and center line miles within 0.5 miles of major activity centers	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Highway lane and center line miles within 0.5 miles of redevelopment areas	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Highway lane and center line miles within 0.5 miles of rural activity centers	• MPO (Miami-Dade TPO LRTP)	System	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Highway lane miles within 1/4 miles of tourist attractions	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Highway lane and center miles within the urban infill area	• MPO (Miami-Dade TPO)	System	NA	NA
New highway lane miles within historic site/district	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Highway lane miles within 0.5 miles of major freight origins and destinations	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Highway lane and centerline miles within the 100-year flood plain	• MPO (Miami-Dade TPO LRTP)	System	NA	NA
Time spent commuting	• State (FDOT Multimodal Mobility Performance Measure Source Book)	Both	• The percentage of auto commuters with drive time less than 30 minutes • Data source: U.S. Census Bureau – American Community Survey	• Demand model
Commuting times greater than 30 minutes	• State (FTP)	Both	• The percentage of auto commuters with drive time greater than 30 minutes • Data source: U.S. Census Bureau – American Community Survey	• Demand model
Percentage of facilities that accommodate two feet sea level rise	• MPO (Palm Beach MPO LRTP)	System	NA	NA
Field equipment uptime availability in percentage	• State (FDOT TSM&O Strategic Plan)	Both	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
RTMC equipment uptime availability in percentage	• State (FDOT TSM&O Strategic Plan)	System	NA	NA
Communication infrastructure and network uptime availability in percentage	• State (FDOT TSM&O Strategic Plan)	System	NA	NA
Number of times WAN was operating on a back-up communication path	• State (FDOT TSM&O Strategic Plan)	System	NA	NA
Percent of times WAN was operating on a back-up communication path	• State (FDOT TSM&O Strategic Plan)	System	NA	NA
Global Economic Competitiveness				
Return on investment	• State (FTP) • MPO (North Florida TPO LRTP and North Florida TPO Cost Feasible Plan MOE)	System	NA	NA
Construction projects completed on-time	• State (FTP)	System	NA	NA
Capacity funds for the SIS	• State (FTP)	System	NA	NA
Florida-originating exports	• State (FTP)	System	NA	NA
Florida share of US trade	• State (FTP)	System	NA	NA
Florida value of freight	• State (FTP)	System	NA	NA

Performance Measures	Sources	Scale (System or Corridor)	Calculation Method Based on Data	Potential Modeling Method
Florida jobs by transportation-intensive sectors	• State (FTP)	System	NA	NA
Florida visitors	• State (FTP)	System	NA	NA
System/agency efficiency	• State (FDOT TSM&O Toolbox)	System	NA	NA
Special Events				
Economic losses due to storm in 2014 dollars	• MPO (Hillsborough MPO LRTP)	System	NA	NA
Weeks of disruption due to storm water and flooding	• MPO (Hillsborough MPO System Report)	System	NA	NA
Economic loss due to a typical category 3 storm	• MPO (Hillsborough MPO System Report)	System	NA	NA
Lane miles of evacuation routes per thousand people	• MPO (MetroPlan Orlando LRTP)	System	NA	• Demand model
Reduction in clearance times for evacuations	• MPO (North Florida TPO LRTP)	System	NA	NA
Reduction in evacuation clearance times during emergency events	• MPO (MetroPlan Orlando ITS Master Plan)	System	NA	NA
Total lane miles within evacuation travel corridors	• MPO (Miami-Dade TPO LRTP)	System	NA	• Demand model
Percentage of funding allocated to maintenance and rehabilitation of evacuation corridors	• MPO (Miami-Dade TPO LRTP)	System	NA	NA

3.5 Conclusions and Recommendations

Based on the literature review presented in this chapter, it can be concluded that there are a large number of metrics that have been identified and utilized at the national level, by FDOT departments, and by various MPO/TPO/TPA in Florida, as listed in Table 3-49 to 3-55. Some of these measures will be calculated in the initial version of the updated FITSEVAL. Others, will be calculated in future versions as needed. Specifically, the following can be concluded:

- A wide range of performance measures have been selected, calculated, and reported by different FDOT departments for different purposes. These measures will be considered to be calculated by the developed tool. Examples of the measures are those identified in the FDOT Florida Transportation Plan (FTP), FDOT TSM&O Strategic Plan, and FDOT Multimodal Mobility Performance Measure Source Book)
- Metropolitan planning organization/transportation planning organization/transportation planning agency (MPO/TPO/TPA) in Florida have included performance management into their planning process. The performance measures used by MPOs/TPOs/TPAs vary with their specific goals and objectives. The safety performance measures are more consistent among MPO/TPO/PTAs, while there is a large variation in other performance measures. There is no standard regarding what performance measures should be reported. A number of MPOs/TPOs/TPAs have set up targets according to the required national performance measures.
- The final rule of the Moving Ahead for Progress in the 21st Century Act (MAP-21) MAP-21 have clearly specified the national performance measures in seven focus areas that need to be calculated by state and MPOs. The calculation method, data source, and reporting date for those performance measures are also provided in detail.
- As MPOs/TPOs/TPAs place more emphasis on multimodal transportation system, it is recommended not only to calculate automobile-related performance measures, but also multimodal performance measures that are related to transit, trucks, pedestrians, and bicycles. The developed tool should be updated to allow the calculation of multimodal performance measures based on modeling, where possible.
- A number of methods have been identified to calculate safety, mobility, reliability, and emission performance measures. These methods can be either data-based or model-based.

4. PERFORMANCE MEASURE ESTIMATION FOR BASE CONDITION

Different methods are reviewed in this study for potential use in FITSEVAL to estimate the mobility, reliability, and safety performance for the base conditions before implementing advanced technologies. The estimation can be based on real-world data, utilizing different analytical models or simulation. Methods to estimate travel time and travel time reliability are assessed in this study by comparing the resulting estimates from applying these methods to those estimated based on real-world data.

4.1 Mobility Performance Measure Estimation

Mobility is the most important widely used performance measurement category considered in planning studies. Examples of mobility performance measures include annual hours of peak hour excessive delay (PHED) per capita and the percent of non-SOV travel as specified by MAP-21 (FHWA, 2017), vehicle mile traveled (VMT), vehicle hour traveled (VHT), average speed, average travel time, throughput, level of service, and so on. Many of the mobility measures can be derived based on travel time and volume estimates. A complete set of mobility performance measures was presented in Chapter 2. This section provides a detailed review of how mobility measures can be forecasted for future years.

4.1.1 Estimation of Mobility Performance Measures based on Data

This section presents a review the definition of the measures and methods of commonly used to estimate the mobility measures for the existing conditions based on data before moving onto the forecasting of these measures. Table 4-1 presents this review.

Table 4-1: Mobility Measure Estimation Methods based on Data

Mobility Measure	Calculation Method	Data Requirement
Annual hours of peak hour excessive delay (PHED) per capita	**MAP-21(FHWA, 2017):** • Annual hours of PHED is calculated as the total excessive delay divided by the total population. • The total excessive delay is the summation of each 15-minute excessive delay multiplied by the average vehicle occupancy. • Excessive delay is defined as the difference between the travel time at 15-minute intervals and the excessive delay thresholds travel time. • The threshold for excessive delay will be based on the travel time at 20 miles per hour or 60% of the posted speed limit travel time, whichever is greater, and will be measured in 15-minute intervals.	• 15-minute travel time • Population
Vehicle hours delay	**Multimodal Mobility Performance Measure Source Book (FDOT, 2017b):** • Delay is the product of directional hourly volume and the difference between travel time at "threshold" speeds and travel time at the average speed. The thresholds are based on Level of Service (LOS) B as defined by FDOT. **FHWA ATDM Guide (Dowling et al., 2013):** • The difference between the VHT total and the VHT if all links are traversed at free-flow speed	• Hourly directional volume • Travel time
Vehicle hour traveled (VHT)	**FHWA ATDM Guide (Dowling et al., 2013):** • The sum of the product of the total link volumes and the average link travel times. • The delay of vehicles that cannot enter the network due to traffic control such as ramp metering is added to the above VHT and included in the VHT total	• Volume • Travel time
Vehicle mile traveled (VMT)	**FHWA ATDM Guide (Dowling et al., 2013) and Multimodal Mobility Performance Measure Source Book (FDOT, 2017b):** • The sum of the product of the total link volumes and link length for the time period of interest	• Volume • Road segment length

Mobility Measure	Calculation Method	Data Requirement
Percentage of non-SOV travel	**MAP-21(FHWA, 2017):** • Method A: 100% minus the percentage of Single Occupancy Vehicle (SOV) including cars, trucks, or vans • Method B: a local survey • Method C: annual volume of person travel other than driving alone divided by the total number of persons **Multimodal Mobility Performance Measure Source Book (FDOT, 2017b):** • Non-SOV travel including travel via carpool, van, public transportation, commuter rail, walking or bicycling as well as telecommuting divided by total travel within Florida using the data from U.S. Census Bureau-American Community Survey	• Non-SOV travels and total travels
Person Trips	• Number of persons traveled	• Number of person trips
Average speed	**Multimodal Mobility Performance Measure Source Book (FDOT, 2017b):** • Speeds are provided in 15-minute increments and gathered from private sector vendor based on fleet vehicles, Bluetooth readers, and other probe data. **FHWA ATDM Guide (Dowling et al., 2013):** • The sum of the VMT-served for all the scenarios divided by the sum of VHT for all the scenarios including vehicle entry delay.	• Speed • Travel time • volume
Average travel time	Average travel time	• Travel time
Level of service	Calculated based on the highway capacity manual LOS definitions	• Density for freeways • Speed or travel time for arterials

4.1.2 Forecasting Mobility Performance Measures

This section provides a detailed review of methods that have been used for forecasting travel time in the literature.

4.1.2.1 Traffic Flow Models

As shown in Table 4-1, all the mobility performance measures listed in this table are derived from the travel time or speed values, which are usually obtained based on a traffic flow model (TFM) in travel demand models. A number of TFMs have been used in the planning studies to estimate travel time based on demand and capacity. Below is a description of the most commonly used TFMs.

Bureau of Public Roads (BPR) Curve

As part of the 1965 Highway Capacity Manual (HCM), the Bureau of Public Roads (BPR) developed a relationship between speed and flow commonly referred to as the BPR curve. This relationship has been widely used in travel demand models, including those in Florida, as a link capacity-based Volume-Delay Function (VDF). The curve suggests that if volume (or flow) increases relative to the capacity, the speed would decrease (or the travel time would increase). By definition, the BPR curve defines delay as a function of link length instead of the number of vehicles in the queue (NCHRP, 1999). Thus, the shorter is the coded link with the high volume/capacity (V/C) ratio, the lower is the delay. No spillback of congestion is projected to upstream links. In addition, the model allows inputting v/c ratios higher than 1.0. These are major deficiencies in the BPR curve and similar VDF relationships.

In Florida, the BPR curve is widely used in the FSUTMS (Florida Standard Urban Transportation Model Structure) models to produce the congested time (or speed) in a capacity restraint route choice assignment. Although the BPR curves are very popular in static route choice assignment as part of demand forecasting, it is often criticized for underperforming in congested traffic conditions where demand exceeds capacity. For instances, the Treasure Coast Regional Planning Model (TCRPM) used BPR curve to determine average travel speed (FDOT, 2014). Researchers and practitioners often raised questioned on this kind of application as there are no situations where V/C is higher than 1.0 in the real world. Queue forms in the real world when demand exceeds capacity, while the passing volume on the congested link does not exceed the queue discharge rate, which is lower than capacity.

Equation 4-1 shows the expression of the standard BPR curve.

$$t_i = t_0\left[1 + \alpha\left(\frac{v}{c}\right)^{\beta}\right] \tag{4-1}$$

where t_i is congested travel time and t_0 is free-flow travel time for link i. v refers to traffic volume on link i and c is practical capacity. α and β are the BPR coefficient and the BPR exponential coefficient, respectively, whose values vary with the function class of links and are usually calibrated for local conditions. The traditional value for α and β are 0.15 and 4 (Martin, 1998). However, the value of α could vary from 0.1 to 1.0 and value of β could vary from 4 to 11 (Dowling, 1997). Different studies have calibrated BPR equation for various conditions and found different sets of values for the parameters (Dowling, 1997; Martin, 1998; Moses et al., 2013; and Horowitz et al. 2014). Also it should be noted that, the practical capacity in equation (2-1) that is used in the demand model is often defined as 80% of the link capacity and the free-flow travel time is often assumed to equal 1.15 times the speed at the practical capacity

(Dowling, 1997). In this study the base α and β parameter values were obtained from a well-calibrated regional model in Florida (e.g. the South East Regional Planning Model (SERPM)).

Modified Davison Function

Davidson (1966) developed a flow-travel time relationship based on the queuing theory concept. It was a widely accepted model in the late 1970s and the 1980s. The main drawback of the Davidson model was that it does not work for oversaturated condition. Therefore, Akcelik (1978) has proposed a Modified Davidson Function, as shown in Equation 4-2.

$$S = \begin{cases} \dfrac{S_0}{1+\dfrac{J_D\left(\frac{V}{C}\right)}{1-\frac{V}{C}}} & for\ \dfrac{V}{C} \le \mu \\ \dfrac{S_0}{1+\dfrac{J_D \times \mu}{1-\mu}+\dfrac{J_D\left(\frac{V}{C}-\mu\right)}{(1-\mu)^2}} & for\ \dfrac{V}{C} > \mu \end{cases} \quad (4\text{-}2)$$

where s is speed and s_0 is free-flow speed. J_D is a delay parameter and μ is saturation threshold parameter. Note that, these parameters are location specific. Proper calibration need to be performed before using it for a local condition. The Modified Davidson function was also further used in the SHRP2 C11 post-processor tools (Cambridge Systematics, 2016).

Akcelik's Equation

Akcelik (1991,1996) further modified Davidson's function as mentioned earlier and proposed a new equation is shown in Equation 4-3.

$$t = t_0\left\{1 + 0.25\frac{T}{t_0}\left[(x-1) + \sqrt{(x-1)^2 + \frac{8J_A}{cT}}\right]\right\} \quad (4\text{-}3)$$

where, t and t_0 are the average and free-flow travel time per unit distance, T is the flow period (typically 1 hour), x is the degree of saturation (v/c ratio), c is the capacity and J_A is the delay parameter.

Akcelik equation has been adopted by Florida Turnpike Enterprise (2012) as the traffic flow model used in the Express Lanes Time of Day (ELToD) model. ELToD is used to evaluate a tolled corridor at a sketch planning level. It is also used to estimate travel time for freeway oversaturated conditions in the FDOT Multimodal Mobility Measures Source Book (FDOT, 2017b). The modified form of Akcelik equation that has been used in ELToD is show in Equation (4-4)

$$t_i = t_0\left[\frac{1}{v_0} + (g_{pb} \times g_T \times (\left(\frac{v}{c} + g_{AkcelikOffset} - 1\right) + \sqrt{\left(\frac{v}{c} + g_{AkcelikOffset} - 1\right)^2 + (8 \times g_P \times \left(\frac{\frac{v}{c}+g_{AkcelikOffset}}{c \times g_T}\right)))}\right] / (\frac{1}{v_0}) \quad (4\text{-}4)$$

where v_0 is free-flow speed in mph, g_T is the Akcelik T, g_{pb} is the constant multiplied by the Akcelik T value to calibrate the curve to observed traffic condition, g_P is the facility specific parameter, v/c is the volume to capacity ratio, and $g_{AkcelikOffset}$ contributes to the shape of the volume delay curve by shifting the base of the curve from a travel time ratio of 1.

Conical Delay Function

The Conical Delay function was developed by Spiess (1990) focusing on overcoming the inherent drawbacks of the BPR function. A typical form of Conical delay function is shown in Equation 4-5.

$$t = t_0\left(2 + \sqrt{b^2 * (1-x)^2 + a^2} - b * (1-x) - a\right) \quad (4\text{-}5)$$

Where t is the travel time, t0 is the free flow travel time, a is a calibration parameter (< 1), x is the v/c ratio, and a = (2b-1)/(2b-2). The Conical Delay function is computationally efficient and overcome the limitation of BPR curve (Dowling, 1997).

4.1.2.2 Calibrated Models for Florida

As part of a FDOT research project conducted by Florida State University (FSU) (Moses et al., 2013), different volume delay function has been calibrated in order to better utilize the travel forecasting models. Four different volume delay functions (VDFs), namely the Modified BPR, Modified Davidson, Akcelik, and Conical functions were calibrated for three different area types (rural, urban, and residential) of two different facilities (uninterrupted and interrupted flow facilities). For the uninterrupted facility type (freeways), the study selected a location on SR-9/I-95 in Pompano Beach, FL. However, for the interrupted facility type, the study estimated the parameters based on simulated data, as none of the permanent detector data could provide the full range of v/c values. The model results show that for the freeways, the Modified BPR function fits the data the best, followed by the Modified Davidson, conical and Akcelik functions. For arterial, the Akcelik function and the BPR function fitted the data the best, followed by the modified Davidson and the conical functions. The calibrated models of FSU are presented in Table 4-2.

Table 4-2: Summary of different Traffic Flow models

Facility Type	**Area Type**	**Fitted BPR**		**Conical**		**Modified Davidson**		**Akcelik**
		α	***β***	***b***	***a***	**J**	**μ**	**J**
Freeway	Urban	0.263	6.869	18.390	1.029	0.009	0.950	0.100
	Residential	0.286	5.091	18.390	1.029	0.009	0.949	0. 101
	Rural	0.150	5.610	15.064	1.036	0.010	0.951	0.099
Toll Road	Urban	0.162	6.340	18.390	1.029	0.008	0.940	0.110
	Residential	0.250	7.900	15.064	1.036	0.010	0.952	0.098
	Rural	0.320	6.710	15.064	1.036	0.010	0.940	0.097
HOV/HOT	Residential	0.320	8.400	18.550	1.028	0.009	0.950	0.090
	Urban	0.330	8.600	18.700	1.028	0.009	0.947	0.080
Divided Arterial - Signalized, <35 MPH	Residential	0.215	8.135	1.029	18.390	0.008	0.945	0.105
	Urban	0.240	7.895	1.033	16.599	0.010	0.951	0.099

Divided Arterial - Signalized, >40MPH	Residential	0.250	8.460	1.028	18.550	0.009	0.950	0.090
	Urban	0.260	8.650	1.028	18.700	0.009	0.947	0.080
Undivided Arterial - Signalized, <35 MPH	Residential	0.215	8.135	1.029	18.390	0.008	0.945	0.105
	Urban	0.240	7.895	1.033	16.599	0.010	0.951	0.099
Undivided Arterial - Signalized, >40MPH	Residential	0.250	8.460	1.028	18.550	0.009	0.950	0.090
	Urban	0.260	8.650	1.028	18.700	0.009	0.947	0.080

4.1.2.3 Highway Capacity Manual Procedures

Procedures have been included in the Highway Capacity Manual (HCM) to calculate the time-dependent traffic conditions along freeway facilities and arterial streets. Examples of the corresponding computational engines are called FREEVAL (for freeways) and STREETVAL (for urban streets), respectively, in addition to the commercially available Highway Capacity Software (HCS), which has procedures for both types of facilities. In freeway facility analysis, a freeway facility is divided into four types of segments; including basic, merge, diverge, and weaving segments. When traffic is under congestion, segments are analyzed independently. Depending on the segment type, the corresponding HCM procedure is applied to calculate segment speed. When traffic is oversaturated, the freeway facility is analyzed as a node-link system and a cell transmission model is utilized to track queue formulation and dissipation over multiple time periods and segments. The output performance measures include travel time, speed, delay, queue length, VMT, VHT, and LOS for each individual segment.

In urban streets analysis, urban street facilities are coded as segments with boundary nodes that represent signalized or unsignalized intersections. The performance of segments is determined by first analyzing the segment running time and through movement delay based on the signal control information and segment free-flow speed, and then calculating the segment travel speed, stop rate, and level of service. The level of service of a signalized intersection is determined based on the control delay. The travel time along a segment can be derived from segment travel speed.

4.1.2.4 Simulation Modeling

Macro-, meso-, and micro-level simulation models can be applied to obtain travel time along a segment or a route. However, these models vary in terms of the details of network and driving behaviors, data requirements, and the effort required to develop and more importantly to calibrate the models. Macroscopic models (for example, regional travel demand models) consider vehicles as a whole and utilize traffic flow model to determine the traffic condition on a link or section. Microscopic simulation provides a detailed modeling of road network. Individual vehicle movements are governed by car-following, lane changing, and gap acceptance behaviors. However, microscopic modeling requires significantly more efforts to calibrate. Examples of microscopic models are VISSIM, CORSIM, PARAMICS, AIMSUN, and TransModeler. Mesoscopic simulation models are in between macroscopic and microscopic simulations. In mesoscopic model, vehicles are modelled either individually or as packets of a small number of vehicles. However, the movements of vehicles or packets of vehicles are determined by the macroscopic traffic flow models. The queuing and queue spillback are usually captured by considering the constraints of capacity and link storage. Compared to microscopic simulation, mescopic simulation requires less effort to calibrate and has a faster running time. Examples of mesoscopic simulations are Dynasmart, DynusT, Direct, Cube Avenue, AIMSUN, VISSIM meso, and Dynameq.

4.1.2.5 Queuing Theory

Queuing occurred when the number of arriving vehicle (e.g. demand flow rate) becomes greater than the roadway segment capacity within a particular time period. Queuing measures such as queue lengths and associated delays can be estimated using analytical models such as queuing theory based on the cumulative volume and shockwave theory. When comparing queuing and shock wave analysis, queuing analysis is used more widely to identify congestion impacts due to its simplicity. A study by Rakha and Zhang (2005) demonstrated the consistency in delay estimates based on queuing theory and shock-wave analyses and pointed out that queuing theory provides a simple and accurate technique for estimating delays and queue lengths at bottlenecks. Thus, this study will investigate the use of queuing theory to calculate the delay at locations when the volume exceeds capacity.

The number of vehicles in queue can be estimated using Equation 4-6.

$$N_{qi} = V_{ai} - V_{di} + N_{q(i-1)} \tag{4-6}$$

where N_{qi} is the number of queued vehicles at the end of period i. V_{ai} is the number of arriving vehicles during period i. V_{di} is the roadway segment capacity, and $N_{q(i-1)}$ is the number of vehicles queued at the end of period (i-1).

To estimate the queuing delay, there is a need to estimate the difference between demand and capacity for each time period where queue exists. Next, the average vehicle delay for each time period can be identified from the ratio between the area formed by cumulative demand vs. cumulative capacity curve and actual volume for that time period (a simple example is shown in Figure 4-1). Finally, the queuing delay can be accounted for to estimate actual travel time (or speed) for each time period.

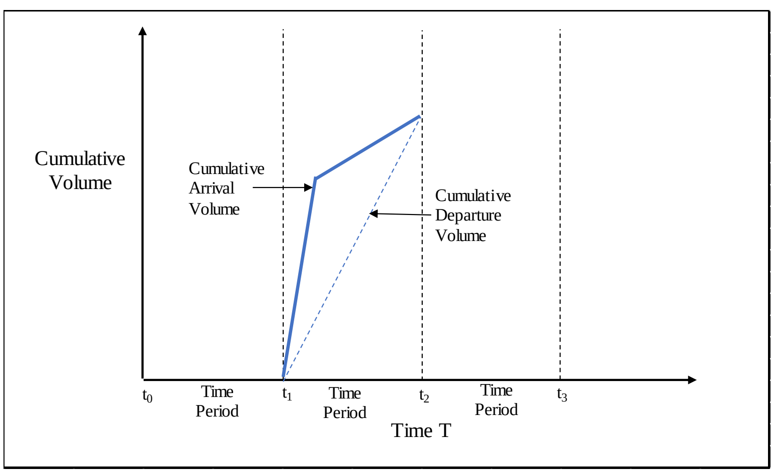


Figure 4-1: Queuing Delay Estimation Approach

4.1.3 Comparison of Traffic Flow Models for Travel Time Estimation

Different methods to estimate travel time and travel time reliability were assessed by comparing the resulting estimates from applying these methods to those estimated based on real-world data. Two corridors were used as case studies for assessing the accuracy of the estimates for freeways and urban arterial streets, respectively, as follows:

- I-95 northbound between NW 32nd Street and NW 103rd Street in Miami-Dade County, FL (used as a freeway case study)
- Sunrise Blvd. between US 441 and US 1 in Broward County, FL (used as an urban street case study)

4.1.3.1 The Freeway Case Study

A 4.73 mile (24,977 feet) long freeway roadway segment along the I-95 Northbound (NB) was selected for use as a freeway case study. This segment is instrumented with six microwave point detection stations, starting from NW 32nd Street to NW 103rd Street, as shown in Figure 4-2. Prior studies suggest that NW 103rd Street on-ramp merge is a bottleneck to the I-95 NB traffic. Thus, this location was selected as the downstream capacity constrained location. The study corridor was selected such that the detector on the upstream end remains uncongested during the study period to ensure that all queues and demands are accounted for as much as possible. When the volume exceeds the estimated capacity of the segment, the demand at the queuing location was estimated by adding the queue length increment in a period to the volume in that period, since the volume by itself is constrained by the capacity and does not represent the demand in congested conditions. Figure 4-2 shows the detector number (green color) and the distance covered by each detector. As shown in the figure, Detector No. 2876 is located near NW 103rd Street and Detector No. 3016 is located near NW 32nd Street. The traffic flow direction is from NW 32nd Street (Detector No. 3016) northbound to NW 103rd Street (Detector No. 2876).

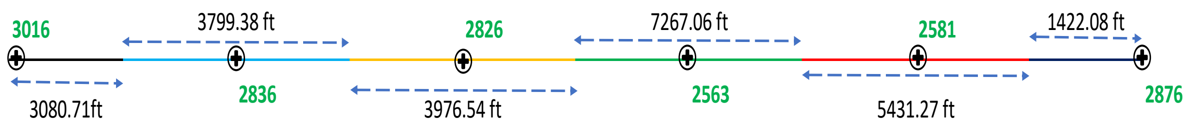


Figure 4-2 Detector Locations and Coverage Along the I-95 NB (Freeway Corridor)

4.1.3.2 The Arterial Street Case Study

Sunrise Blvd. from US 441 up to US 1 in the Eastbound (EB) direction was selected as the arterial case study. The length of this segment is around 5.3 miles and includes seven detection stations that provide volume and speed measurements. Figure 4-3 shows the detector number (green color) and the distance covered by each detector. As shown in the figure, Detector No. 9 is located near US 441 and Detector No. 15 is located near US 1. The traffic flow direction is eastbound, from US 441 to US 1. Bluetooth readers are also installed on this segment to derive travel time measurements.

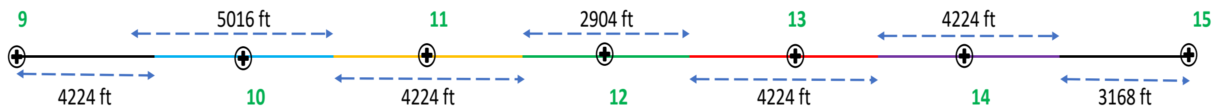


Figure 4-3: Detector Location and Coverage Along the Sunrise Blvd. (Arterial Corridor)

4.1.3.3 Data Collection and Preparation

This study performed extensive data analysis to measure mobility and reliability based on real-world data for comparison with the different utilized methods. To do that, one-year worth of volume and speed/travel time data were gathered for both the freeway and arterial facilities. Traffic incident and weather condition data for the corresponding year were also obtained for both facilities.

Overview of Freeway Data

Three important freeway parameters were required for this study to estimate the mobility measures based on data for the freeway case study, as follows:

- Traffic parameters (volume and speed data),
- weather data, and
- incident data.

Volume data was needed for this study to measure demand, while speed data was required to estimate travel time. This study gathered volume and speed data from the RITIS data warehouse (Regional Integrated Transportation Information System) website. The weather data (rainfall intensity) was used in the estimation of reliability based on modeling. The rainfall intensity information was collected from NOAA (National Oceanic and Atmospheric Administration).

This study also obtained incident data for utilization in the estimation of reliability. Detail incident data were collected from the FDOT District Six database to calculate the number of incidents during a time slice, average number of lane blockage per incident, and average duration of each incident.

For this study locations, three different time periods have been included in the analysis:

- AM Peak (07:00 AM – 09:30 AM),
- Mid-Day (12:00 PM– 02:30 PM), and
- PM Peak (02:30 PM – 04:30 PM)

Overview of Arterial Street Data

To estimate different mobility measures, the following traffic measurements were obtained in this study:

- Volume data from microwave point detectors (MVDS),
- Travel time data based on Bluetooth readers installed by FDOT District 4 and two private sector vendors (Inrix and HERE),

- Turning movement counts from a previously well calibrated VISSIM network for use as inputs to the HCM procedure,
- Traffic signal timing data from the well-calibrated network, and
- Incident data.

Similar to the freeway, this study also estimated reliability utilizing incident data. Detail incident data were collected from the FDOT District 4 SunGuide system to determine the number of incident during a time slice, average number of lane blockage per incident, and average duration of each incident. The incident data was used as an input to the HCM procedure and to estimate the LHL required for SHRP2 L03 and SHRP2 L07 projects.

Three different time period has been also considered for arterial corridor analysis:

- AM Peak (07:00 AM – 09:00 AM),
- Mid-Day (11:00 AM – 01:00 PM), and
- PM Peak (04:00 PM – 07:00 PM)

Volume and Speed/Travel Time Data

Volume and Speed/travel time data were collected from the RITIS website for the selected freeway corridor. For the freeway segment, the downloaded RITIS data includes volume, speed, and occupancy measurements using point detectors and travel time using HERE data. For the arterial segment, travel time data from Bluetooth readers and two private sector data vendors (HERE and Inrix), in addition to volumes from microwave detectors, were also downloaded from RITIS.

The investigation of forecasting travel times using different models was based on data for the period between January 1st, 2017 and December 31st, 2017. On the freeways (I-95 NB), only measurements based on the detectors on general-purpose lane and nly weekdays were used in the analysis. Data for incident days was also collected but removed from the database when estimating mobility for recurrent conditions. Incident day comparison was also conducted later. For the analysis purpose, this study aggregated the downloaded 5-minute data into three-time periods; the AM, Mid-Day, and PM periods. To better understand the model performance, the mobility comparison was performed for ten randomly selected days, instead of averaging the days over the full year.

For reliability estimation on the freeway, the speed and volume data were gathered for the same freeway corridor from an earlier period (1st January 2012 – 31st December 2012) SHRP2 pilot test project and also for the Year 2017. The reason for selecting the earlier period is that it was used for a detailed investigation of reliability estimation as part of a SHRP2 project conducted by the authors. Like mobility, only weekday data was considered for reliability estimation. Incident day data was also included in the reliability analysis, as the incident is a key contributing factor in a reliability study.

Weather Condition Data

This study requires weather condition data (e.g. rainfall intensity) to measure reliability. Rainfall intensity information was obtained from NOAA for the year 2012 as this study utilized 2012 data for reliability estimation and also for 2017.

Traffic Incident Data

Traffic incident data is also required in this study to estimate reliability. Since this study measured reliability for both freeway and arterial segments, incident data were collected for both facilities.

Traffic incident data for the I-95 NB facility was collected from the FDOT District Six and RITIS website. The traffic incident data for the arterial segment (Sunrise Blvd.) was collected from the FDOT District 4 SunGuide system database. Incident data was gathered for the same periods as those, for which the traffic and weather data were collected. The FDOT traffic incident data provides detailed incident information for every incident. From the incident database, the following information was extracted and utilized in this study.

- Number of incidents
- Average number of lanes blocked per incident
- Average duration of incidents

Since this study analyzed data in 3 specific time slices (AM, Mid-Day, and PM), each of the above information was estimated for each time slice.

Traffic Signal and Capacity Data

This study estimated mobility and reliability on arterial for which traffic signal timing and capacity data were needed. A previously well-calibrated VISSIM network for Sunrise Blvd. was utilized in this study to obtain turning movement volume and traffic signal timing information (offset, green time, and cycle length). Traffic signal timing information for each of the intersection along the EB Sunrise Blvd. corridor was extracted from the VISSIM network. The cycle length was found to be 180 sec. for all intersections. The effective green times for the EB main street through movement on individual intersections vary from intersection to intersection between 93 seconds and 145 seconds. The timing information was used as an input to the Urban Street module of the Highway Capacity Software (HCS) and also to calculate the capacity for use in traffic flow equation calculation of travel time on arterial streets. The effective green time and cycle length information were utilized to derive arterial roadway capacity using Equation 4-7.

$$Capacity = \frac{\text{Effectice Green Time}}{\text{Cycle Length}} \text{ x } 1700 \tag{4-7}$$

Five different capacity was used in the traffic flow functions (BPR curve, Akcelic equation, etc.) as follows:

- 900 vehicles per hour per lane – this is the value used in the SERPM demand model for the Sunrise Blvd.

- 880 vehicles per hour per lane - This value was obtained from Equation (4-7) by taking the minimum value of the effective green time to cycle length ratio among all the intersections along the EB direction of Sunrise Blvd.
- 1,120 vehicles per hour per lane – This value was obtained from the Equation (4-7) by taking the average value of the effective green time to cycle length ratio among all the intersections along the EB direction of Sunrise Blvd.
- 1,370 vehicles per hour per lane - This value was obtained from the Equation (4-7) by taking the maximum value of the effective green time to cycle length ratio among all the intersections along the EB direction of Sunrise Blvd.

4.1.3.4 Freeway Recurrent Conditions Analysis Results

The accuracy of the following functions to estimate speed/travel time were assessed based on comparison with data-based estimates of travel time:

- Bureau of Public Road (BPR) Curve with the parameters extracted from SERPM
- Akcelik Equation with the parameters extracted from the ELTOD software developed for managed lane toll assessment
- BPR Curve with the parameters calibrated in a study conducted by Florida State University (FSU)
- Akcelik Equation with the parameters calibrated in a study conducted by FSU
- Modified Davidson Equation with the parameters calibrated in a study conducted by FSU
- Conical Equation with the parameters calibrated in a study conducted by FSU
- Freeway and urban street Highway Capacity Manual (HCM) procedures

Figures 4-4 to 4-6 present the speed estimates for the AM Peak period, which is a non-congested peak since the northbound traffic is the non-peak direction. The figures provide a comparison between the estimates obtained using different mobility estimation methods compared to real-world measurements using detector data (referred to as Detector Speed in the figures) and HERE data (referred to as Prob Speed in the figures). Please, note that a disadvantage with the probe data is that it does not differentiate between general purpose and managed lane speed. Estimates from only three of the ten selected days since this is sufficient to discuss the findings. The days were selected to represent different seasons of the year 2017; early year (February 7, 2017), mid-year (June 22, 2017), and end of the year (December 12, 2017). Tables 4-3 and 4-4 present goodness of fit statistics to illustrate the performance of different methods. Based on the comparison, it appears that several methods predicted speeds reasonably well compared to real-world mobility measures for the uncongested NB direction of the freeway in the AM Peak period. The Conical model did not perform well showing higher percentage error. The methods with the highest accuracy were FSU-calibrated Modified Davidson FSU-Calibrated and ELTOD Akcelik function, highway capacity procedure utilizing FREEVAL, and FSU calibrated BPR curve. It should be mentioned that for uncongested conditions, it is expected that the estimation accuracy improves by better estimation of free flow speed. The free flow speed used as input to the models was calculated as the posted speed limit (55 mph) plus 5 mph.

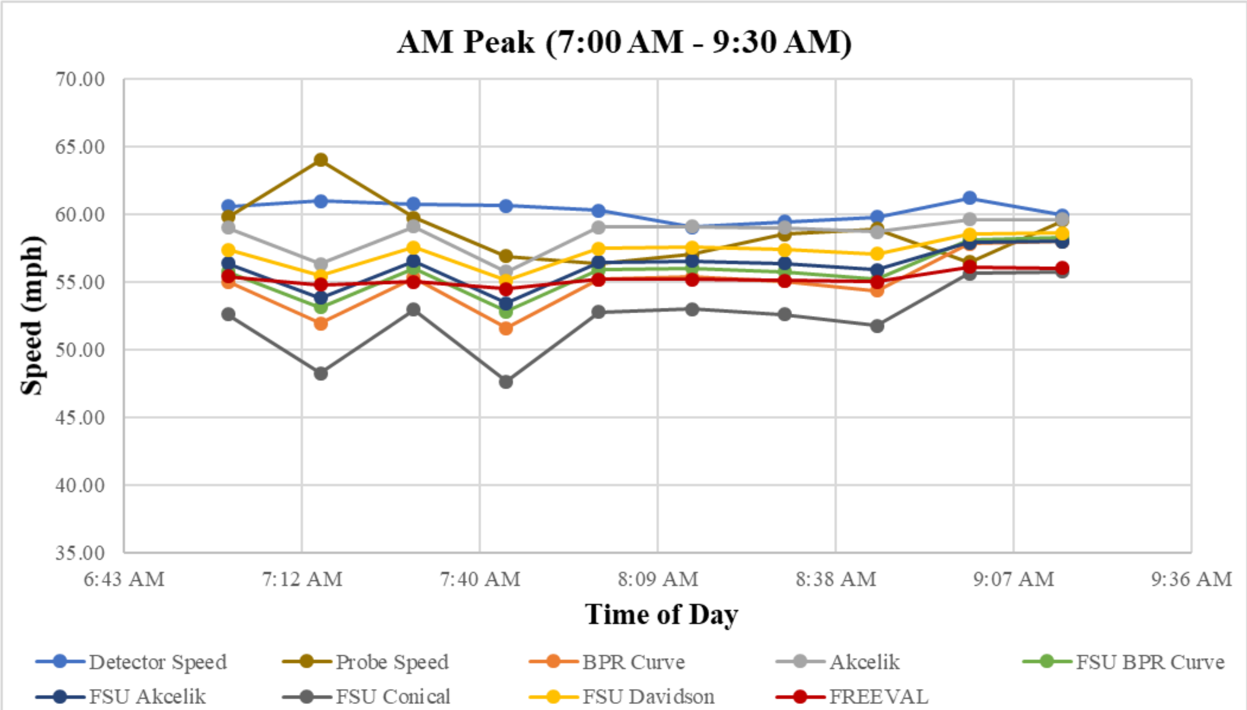


Figure 4-4: Predictive Ability of Different Mobility Estimation Methods - Travel Speed (Freeway, AM Peak, Day 01)

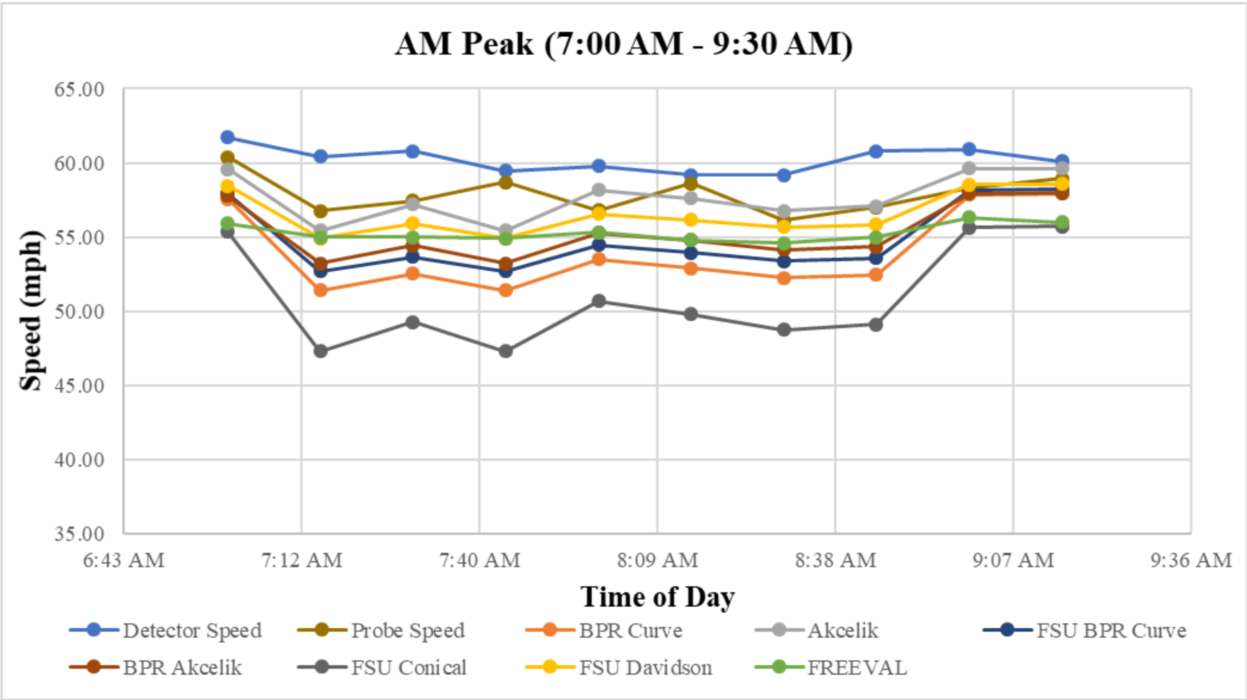


Figure 4-5: Predictive Ability of Different Mobility Estimation Methods - Travel Speed (Freeway, AM Peak, Day 02)

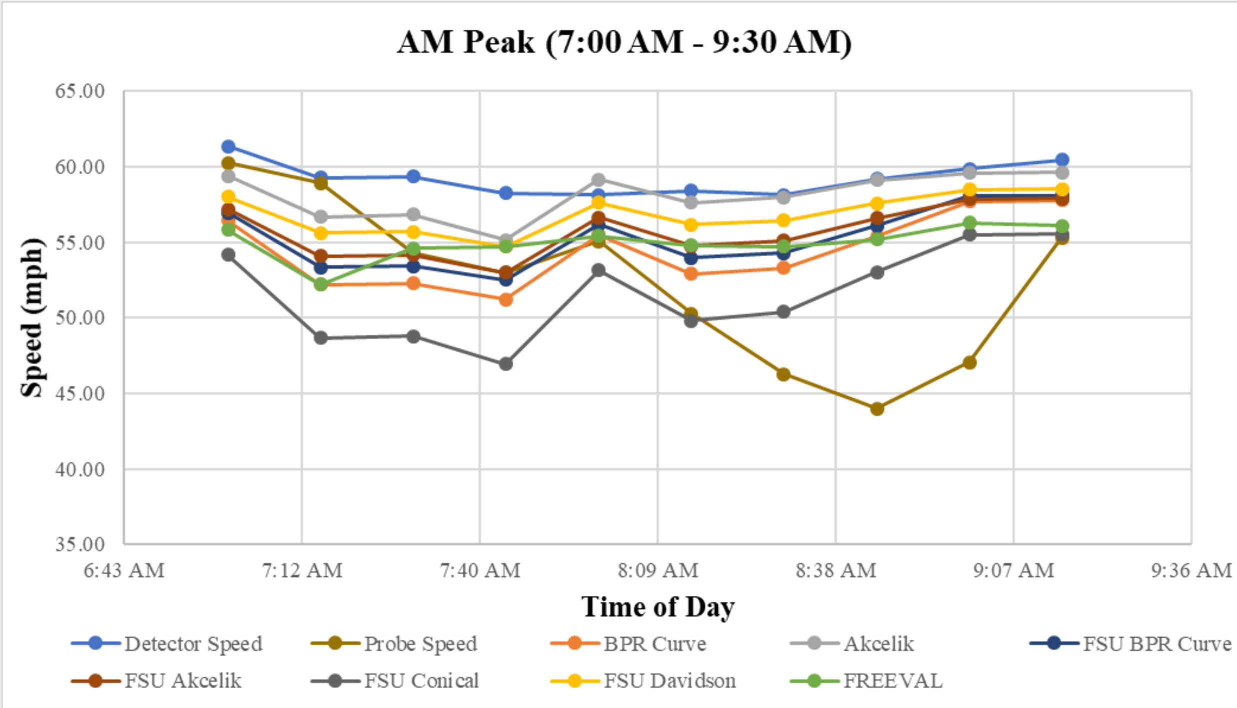


Figure 4-6: Predictive Ability of Different Mobility Estimation Methods - Travel Speed (Freeway, AM Peak, Day 03)

Table 4-3: Speed Estimation Accuracy with Different Methods (Freeway, AM Peak) Compared to Detector Data

	MAE (mph)							MAPE							RMSE (mph)						
	BPR Curve	**Akcelik**	**FSU BPR Curve**	**FSU Akcelik**	**FSU Conical Delay**	**FSU Modified Davidson**	**FREEVAL**	**BPR Curve**	**Akcelik**	**FSU BPR Curve**	**FSU Akcelik**	**FSU Conical Delay**	**FSU Modified Davidson**	**FREEVAL**	**BPR Curve**	**Akcelik**	**FSU BPR Curve**	**FSU Akcelik**	**FSU Conical Delay**	**FSU Modified Davidson**	**FREEVAL**
19th January	3.43	3.43	3.13	3.05	6.23	3.18	3.61	0.06	0.07	0.06	0.06	0.11	0.06	0.07	4.51	4.35	4.13	4.17	7.38	4.12	4.51
7thFebruary	5.30	1.74	4.56	4.13	7.96	3.06	5.03	0.09	0.03	0.08	0.07	0.13	0.05	0.08	5.72	2.37	4.93	4.45	8.41	3.36	5.09
30th March	8.64	5.41	7.64	7.48	12.41	6.11	6.94	0.14	0.09	0.12	0.12	0.20	0.10	0.11	8.94	5.81	7.87	7.73	12.94	6.28	6.96
10th April	7.52	3.99	6.79	6.38	10.19	5.32	7.23	0.12	0.06	0.11	0.10	0.16	0.08	0.12	7.77	4.31	7.00	6.57	10.51	5.48	7.26
9th May	6.58	3.06	5.61	5.33	10.12	3.99	4.93	0.11	0.05	0.09	0.09	0.17	0.07	0.08	6.93	3.67	5.88	5.65	10.67	4.26	4.98
22nd_June	6.25	2.58	5.37	4.92	9.35	3.68	4.95	0.10	0.04	0.09	0.08	0.16	0.06	0.08	6.65	2.92	5.69	5.16	9.78	3.87	4.99
20th July	5.37	1.69	4.54	4.07	8.27	2.90	4.36	0.09	0.03	0.08	0.07	0.14	0.05	0.07	5.65	2.00	4.77	4.25	8.61	3.04	4.41
17th august	4.30	1.59	3.54	3.21	7.12	2.29	3.61	0.07	0.03	0.06	0.05	0.12	0.04	0.06	4.78	1.93	3.98	3.61	7.64	2.54	3.79
6th December	4.98	1.33	4.18	3.74	7.82	2.61	4.24	0.08	0.02	0.07	0.06	0.13	0.04	0.07	5.28	1.97	4.42	3.98	8.22	2.81	4.26
12th December	4.77	1.33	3.96	3.51	7.64	2.36	4.26	0.08	0.02	0.07	0.06	0.13	0.04	0.07	5.10	1.70	4.24	3.75	8.02	2.58	4.42
Average	***5.71***	***2.61***	***4.93***	***4.58***	***8.71***	***3.55***	***4.92***	***0.10***	***0.04***	***0.08***	***0.08***	***0.15***	***0.06***	***0.08***	***6.28***	***3.37***	***5.43***	***5.09***	***9.36***	***4.01***	***5.18***

Table 4-4: Speed Estimation Accuracy with Different Methods (Freeway, AM Peak) Compared to Probe Data

	MAE (mph)							MAPE							RMSE (mph)						
	BPR Curve	Akcelik	FSU BPR Curve	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson	FREEVAL	BPR Curve	Akcelik	FSU BPR Curve	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson	FREEVAL	BPR Curve	Akcelik	FSU BPR Curve	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson	FREEVAL
19th January	4.27	5.26	4.28	4.40	5.52	4.79	4.53	0.08	0.10	0.08	0.08	0.10	0.09	0.09	5.18	6.44	5.08	5.39	7.31	5.68	5.09
7thFebruary	4.03	1.90	3.35	2.90	6.42	2.27	3.49	0.07	0.03	0.06	0.05	0.11	0.04	0.06	5.07	2.89	4.38	3.95	7.49	3.15	4.20
30th March	3.75	5.41	7.64	7.48	12.41	6.11	6.94	0.06	0.09	0.12	0.12	0.20	0.10	0.11	4.08	5.81	7.87	7.73	12.94	6.28	6.96
10th April	4.11	3.99	6.79	6.38	10.19	5.32	7.23	0.07	0.06	0.11	0.10	0.16	0.08	0.12	4.45	4.31	7.00	6.57	10.51	5.48	7.26
9th May	3.05	1.83	2.14	1.89	6.49	1.30	1.40	0.05	0.03	0.04	0.03	0.12	0.02	0.02	3.57	2.17	2.61	2.56	7.24	1.71	1.83
22nd_June	3.93	1.07	3.04	2.60	7.02	1.40	2.63	0.07	0.02	0.05	0.04	0.12	0.02	0.05	4.40	1.35	3.47	2.96	7.49	1.77	2.82
20th July	3.00	1.01	2.17	1.71	5.91	0.71	2.08	0.05	0.02	0.04	0.03	0.10	0.01	0.04	3.39	1.08	2.54	2.01	6.24	1.07	2.37
17th august	2.71	2.85	2.31	2.28	4.53	2.09	1.94	0.05	0.05	0.04	0.04	0.08	0.04	0.03	3.49	3.26	2.94	2.77	5.88	2.51	2.24
6th December	3.27	2.76	2.67	2.20	5.44	1.91	2.07	0.06	0.05	0.05	0.04	0.09	0.03	0.04	4.04	3.03	3.41	3.08	6.46	2.63	2.88
12th December	4.89	6.29	4.88	4.89	5.21	5.55	4.78	0.10	0.13	0.10	0.10	0.10	0.11	0.10	6.11	7.93	6.29	6.44	6.18	7.00	6.09
Average	***4.53***	***3.24***	***3.93***	***3.67***	***6.91***	***3.15***	***3.71***	***0.08***	***0.06***	***0.07***	***0.06***	***0.12***	***0.06***	***0.06***	***5.50***	***4.39***	***4.91***	***4.75***	***8.06***	***4.26***	***4.60***

Figures 4-7 to 4-9 present the speed estimation accuracy for the mid-day period, which is uncongested period. As with the AM period, the figures present the results for three days of the selected 10 days. Tables 4-5 and 4-6 present goodness of fit statistics to illustrate the performance of different methods. The accuracy analysis results in the mid-day appear to be very similar to that in the AM period, with most function perform relatively well. The Conical model did not perform well. The FSU-calibrated Modified Davidson, the default Akcelik used in ELTOD, highway capacity procedure in FREEVAL, and FSU calibrated BPR curve performed the best, as in the AM peak.

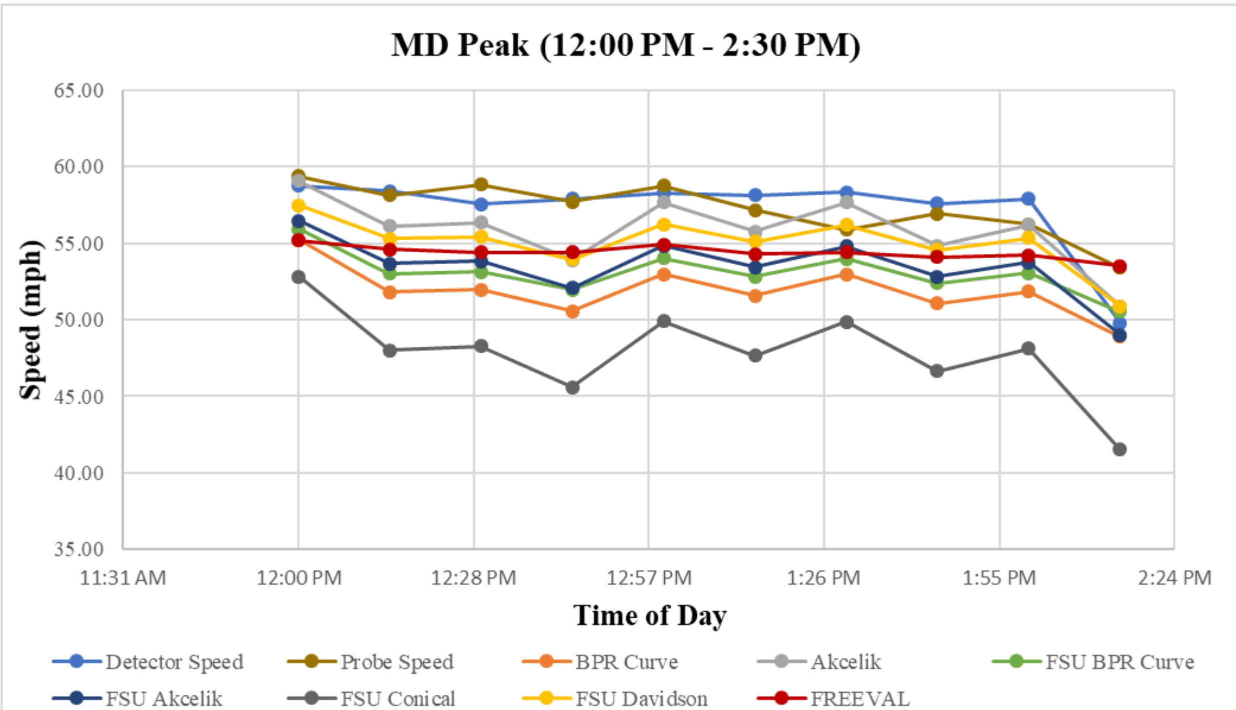


Figure 4-7: Predictive Ability of Different Mobility Estimation Methods -Travel Speed (Freeway, Mid-Day, Day 01)

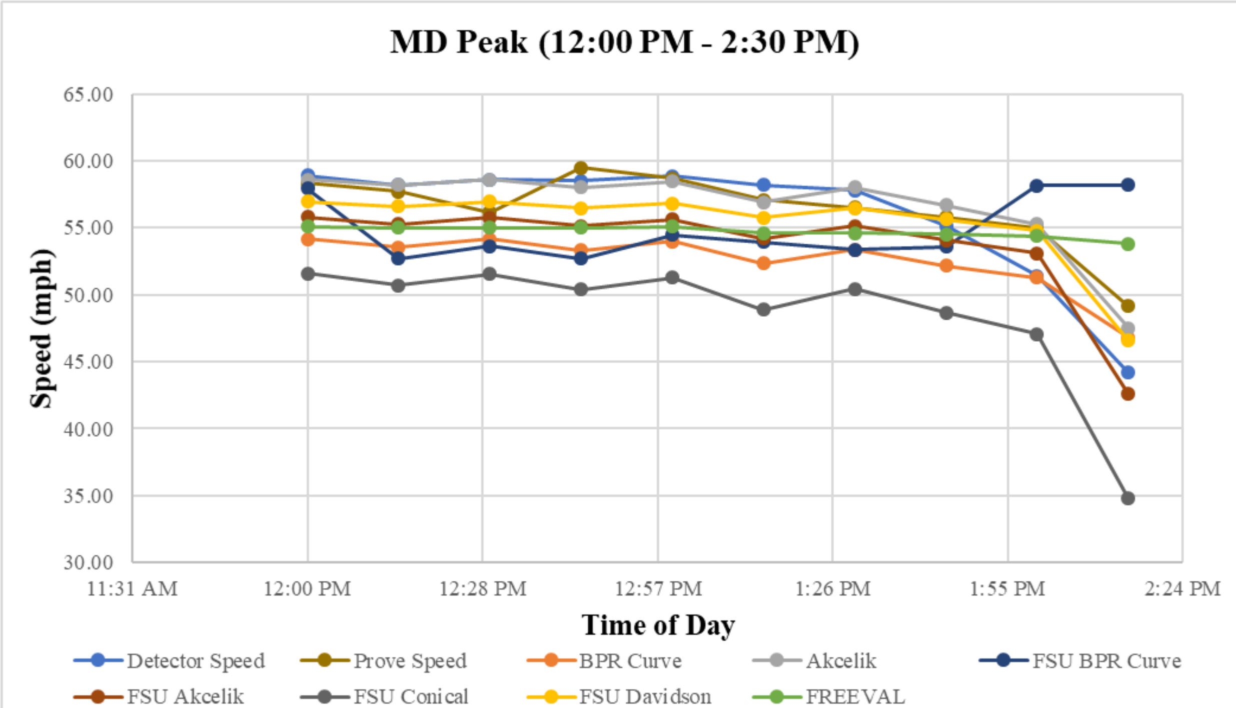


Figure 4-8: Predictive Ability of Different Mobility Estimation Methods -Travel Speed (Freeway, Mid-Day, Day 02)

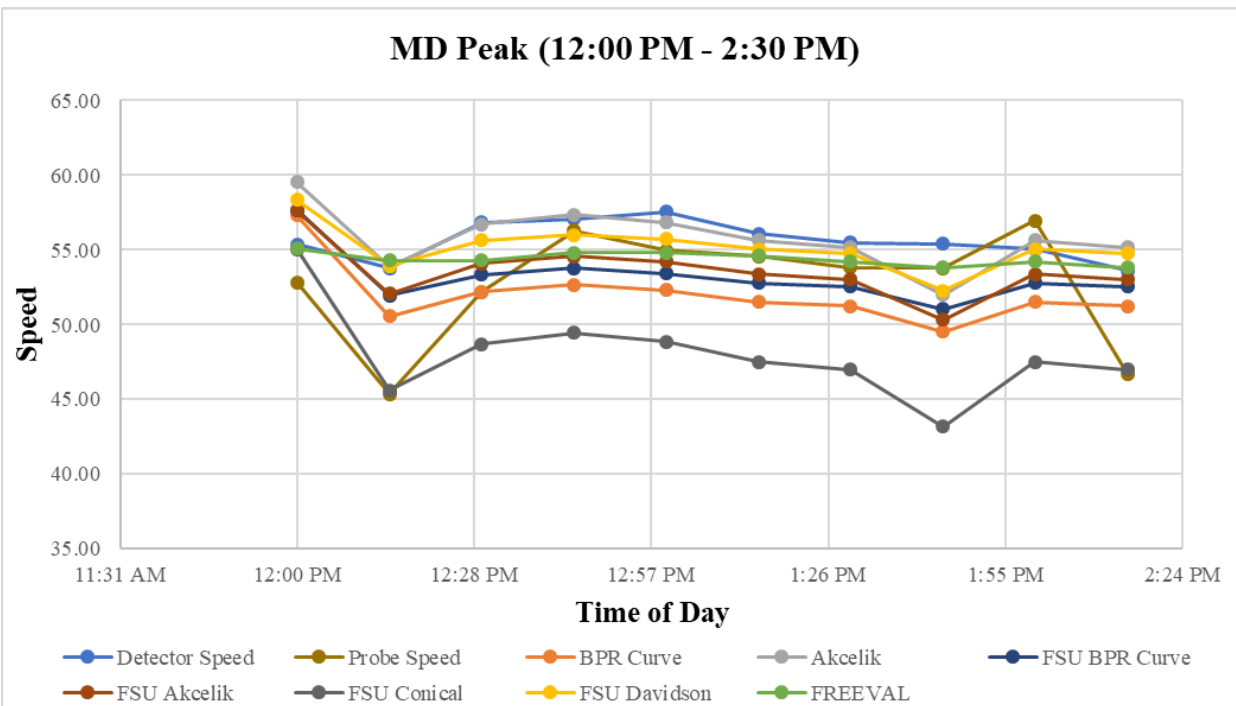


Figure 4-9: Predictive Ability of Different Mobility Estimation Methods -Travel Speed (Freeway, Mid-Day, Day 03)

Table 4-5: Speed Estimation Accuracy with Different Methods (Freeway, Mid-day) Compared to Detector Data

	MAE (mph)							MAPE							RMSE (mph)						
	BPR Curve	Akcelik	FSU BPR Curve	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson	FREEVAL	BPR Curve	Akcelik	FSU BPR Curve	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson	FREEVAL	BPR Curve	Akcelik	FSU BPR Curve	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson	FREEVAL
19th January	5.68	2.17	4.35	4.30	10.56	2.56	2.98	0.09	0.06	0.08	0.14	0.21	0.07	0.10	5.89	2.55	4.63	4.44	10.65	2.77	3.16
7thFebruary	5.38	1.70	4.33	3.79	9.43	2.44	3.61	0.10	0.04	0.08	0.08	0.19	0.04	0.05	5.67	2.02	4.56	4.03	9.58	2.58	3.61
30th March	3.90	5.90	4.60	12.49	11.23	5.25	6.31	0.09	0.03	0.07	0.07	0.16	0.04	0.06	4.27	7.00	5.18	15.08	15.71	6.37	6.94
10th April	7.88	4.47	6.56	8.12	13.72	5.18	4.82	0.09	0.13	0.11	0.32	0.30	0.12	0.15	8.02	5.17	6.66	10.33	15.08	5.76	4.85
9th May	4.94	2.74	3.96	5.35	10.33	2.78	2.86	0.13	0.08	0.11	0.14	0.24	0.09	0.08	6.06	3.62	4.78	10.01	12.80	4.01	3.67
22nd_June	3.99	1.15	3.51	2.64	7.44	1.94	3.79	0.10	0.06	0.08	0.12	0.22	0.06	0.06	4.30	1.75	3.67	2.78	7.57	2.07	4.35
20th July	2.83	4.20	3.09	12.79	14.62	3.76	17.67	0.07	0.02	0.06	0.05	0.13	0.04	0.07	3.76	4.89	3.73	16.84	18.72	4.96	20.07
17th august	4.90	3.17	4.03	6.25	9.20	3.51	3.95	0.06	0.09	0.07	0.32	0.36	0.08	0.36	5.08	4.65	4.53	9.21	11.54	4.64	4.74
6th December	4.06	2.53	3.82	4.36	7.38	2.30	3.84	0.09	0.07	0.08	0.14	0.19	0.07	0.08	4.21	4.00	4.23	6.24	8.75	3.70	4.63
12th December	4.00	1.17	2.90	2.50	7.63	1.33	1.37	0.08	0.06	0.08	0.10	0.15	0.05	0.08	4.17	1.81	3.06	2.74	8.14	1.66	1.63
Average	***4.76***	***2.92***	***4.11***	***6.26***	***10.16***	***3.25***	***5.12***	***0.07***	***0.02***	***0.05***	***0.04***	***0.14***	***0.02***	***0.02***	***5.29***	***4.09***	***4.60***	***9.45***	***12.36***	***4.75***	***7.59***

Table 4-6: Speed Estimation Accuracy with Different Methods (Freeway, Mid-day Peak) Compared to Probe Data

	MAE (mph)							MAPE							RMSE (mph)						
	BPR Curve	Akcelik	FSU BPR Curve	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson	FREEVAL	BPR Curve	Akcelik	FSU BPR Curve	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson	FREEVAL	BPR Curve	Akcelik	FSU BPR Curve	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson	FREEVAL
19th January	5.81	2.43	4.48	4.43	10.69	2.69	2.74	0.09	0.07	0.08	0.14	0.21	0.06	0.10	5.95	2.80	4.65	4.61	10.86	2.91	2.89
7thFebruary	5.36	1.76	4.17	3.78	9.41	2.27	2.87	0.10	0.04	0.08	0.08	0.19	0.05	0.05	5.51	2.05	4.34	3.98	9.61	2.48	3.14
30th March	1.61	5.90	4.60	12.49	11.23	5.25	6.31	0.09	0.03	0.07	0.07	0.16	0.04	0.05	2.06	7.00	5.18	15.08	15.71	6.37	6.94
10th April	3.04	4.47	6.56	8.12	13.72	5.18	4.82	0.04	0.13	0.11	0.32	0.30	0.12	0.15	3.34	5.17	6.66	10.33	15.08	5.76	4.85
9th May	7.21	4.67	5.79	7.90	13.11	4.79	3.81	0.05	0.08	0.11	0.14	0.24	0.09	0.08	10.50	8.11	9.05	15.17	17.78	8.86	6.44
22nd_June	3.89	0.93	2.79	2.73	7.86	1.25	2.62	0.13	0.09	0.11	0.15	0.24	0.09	0.07	4.06	1.19	3.08	3.17	8.24	1.58	2.94
20th July	2.60	4.73	2.75	13.03	14.43	4.44	18.69	0.07	0.02	0.05	0.05	0.14	0.02	0.05	3.57	5.13	3.52	17.03	18.81	5.09	20.07
17th august	3.98	2.91	3.12	5.41	9.19	2.81	2.07	0.06	0.10	0.07	0.32	0.35	0.10	0.39	4.72	4.23	3.59	10.69	12.82	4.56	2.64
6th December	3.29	2.33	2.29	4.31	8.79	2.14	1.92	0.08	0.06	0.06	0.11	0.18	0.06	0.04	3.76	2.88	2.64	8.61	11.33	3.05	2.29
12th December	3.58	3.67	3.24	3.12	5.31	3.14	2.52	0.06	0.04	0.04	0.09	0.17	0.04	0.03	3.88	4.72	3.75	3.77	6.32	4.33	3.86
Average	***4.75***	***3.38***	***3.98***	***6.53***	***10.38***	***3.29***	***4.84***	***0.07***	***0.07***	***0.06***	***0.06***	***0.10***	***0.06***	***0.05***	***5.82***	***4.79***	***4.99***	***10.51***	***13.25***	***4.45***	***7.55***

Figures 4-10 to 4-12 present the speed estimation accuracy for the PM peak period, which is a congested period. As with the AM period, the figures present the results for three days of the selected 10 days. Tables 4-7 and 4-8 present goodness of fit statistics to illustrate the performance of different methods. The figures and tables indicate that it is more difficult to predict the travel time accurately in the PM congested period. Some of the tested functions produced high errors. The functions that produced the best results are the FSU-calibrated Modified Davidson, the Akcelik function used in ELTOD, the default BPR curve used in SERPM, and the FREEVAL (freeway facility HCM-based facility procedure).

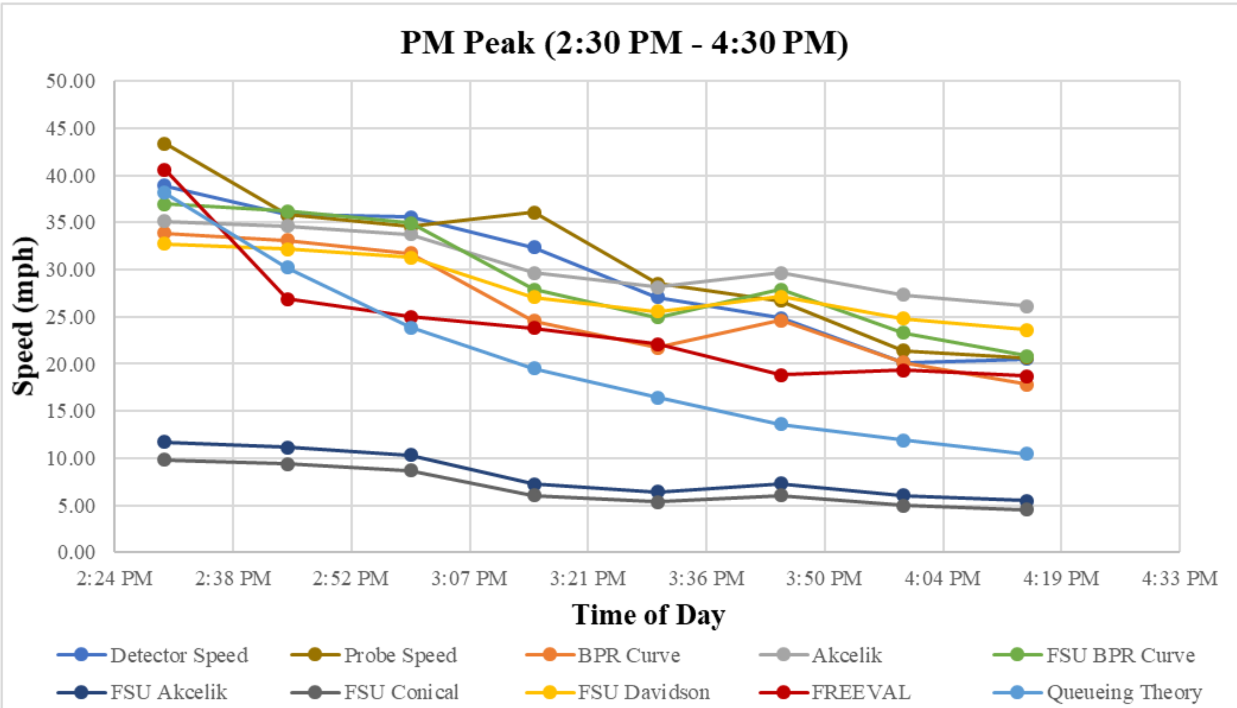


Figure 4-10: Predictive Ability of Different Mobility Estimation Methods -Travel Speed (Freeway, PM Peak, Day 01)

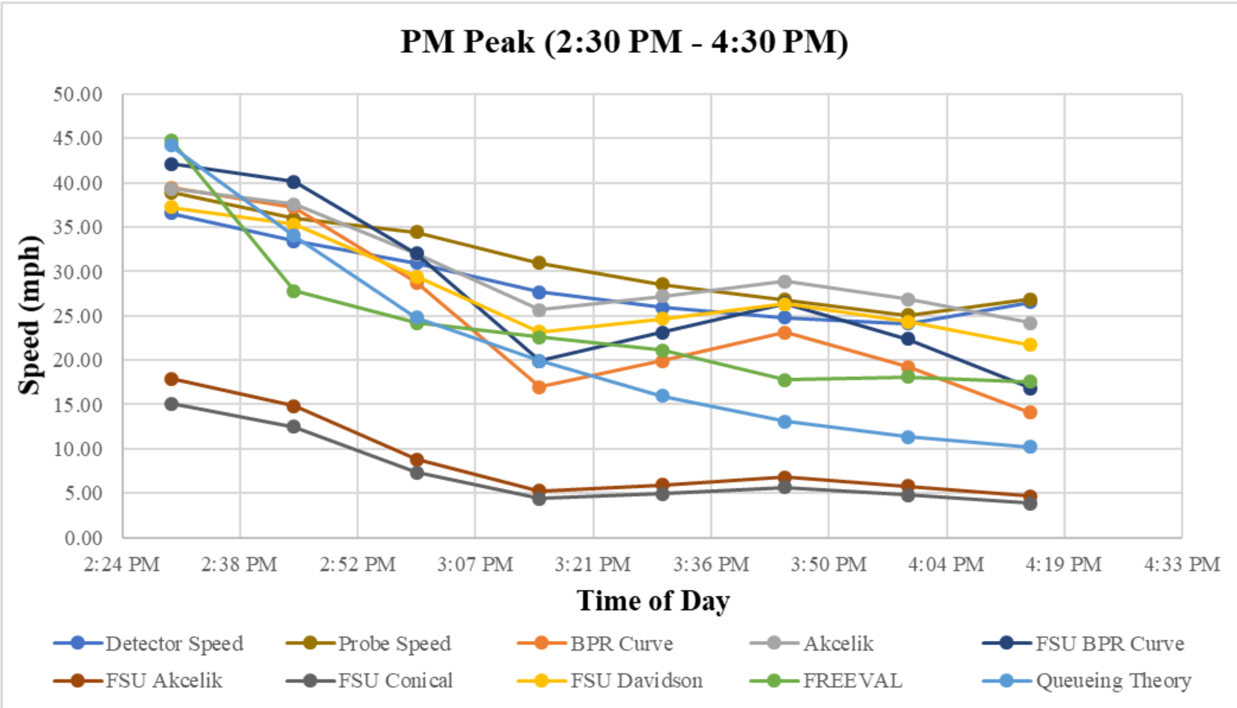


Figure 4-11: Predictive Ability of Different Mobility Estimation Methods -Travel Speed (Freeway, PM Peak, Day 02)

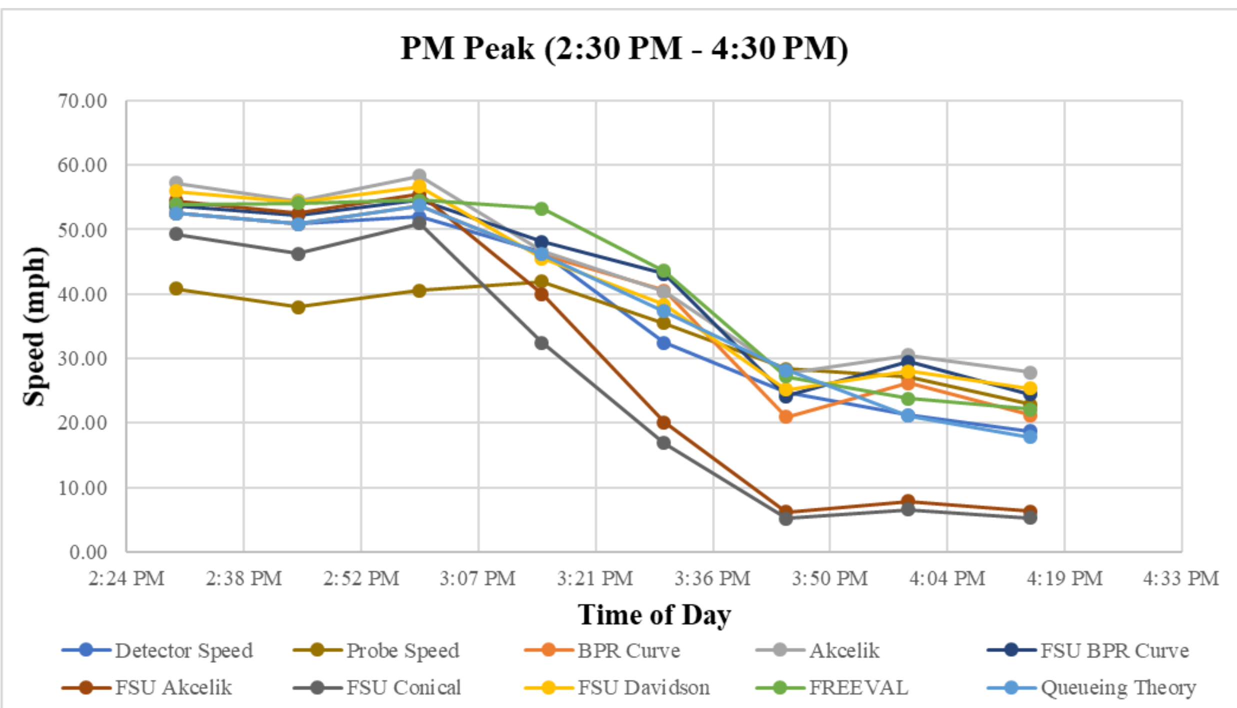


Figure 4-12: Predictive Ability of Different Mobility Estimation Methods -Travel Speed (Freeway, PM Peak, Day 03)

Table 4-7: Speed Estimation Accuracy with Different Methods (Freeway, PM Period) Compared to Detector Data

	MAE (mph)								MAPE								RMSE (mph)							
	BPR Curve	Akcelik	FSU BPR Curve	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson	FREEVAL	Queueing Theory	BPR Curve	Akcelik	FSU BPR Curve	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson	FREEVAL	Queueing Theory	BPR Curve	Akcelik	FSU BPR Curve	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson	FREEVAL	Queueing Theory
19th January	4.83	5.34	4.36	12.27	13.45	4.17	2.61	4.86	0.24	0.22	0.24	0.63	0.68	0.31	0.18	0.31	5.65	6.49	5.43	14.47	15.25	5.57	4.10	5.39
7thFebruary	3.47	3.52	2.03	21.20	22.55	3.85	5.43	8.90	0.16	0.20	0.15	0.49	0.52	0.15	0.08	0.18	4.25	4.09	2.47	21.73	23.11	4.12	6.45	9.65
30th March	8.14	10.04	10.50	12.77	14.46	7.62	3.32	6.84	0.11	0.14	0.07	0.72	0.77	0.13	0.18	0.33	10.31	11.39	12.65	13.78	15.24	9.38	4.16	7.58
10th April	5.39	2.35	3.59	20.08	21.95	3.27	7.06	7.85	0.38	0.46	0.49	0.53	0.61	0.36	0.14	0.29	6.34	3.12	4.30	20.41	22.28	3.73	7.69	9.08
9th May	6.73	4.78	5.17	20.73	22.01	4.68	8.19	10.42	0.20	0.08	0.14	0.68	0.73	0.10	0.23	0.30	9.20	5.73	7.90	21.45	22.75	6.04	9.96	11.29
22nd_June	5.60	2.54	4.62	20.00	21.43	2.06	6.57	9.13	0.24	0.18	0.18	0.74	0.78	0.16	0.26	0.40	6.73	2.76	5.54	20.07	21.49	2.62	6.71	10.16
20th July	10.64	5.89	8.51	22.26	22.44	6.98	7.69	12.04	0.20	0.09	0.16	0.71	0.76	0.07	0.23	0.34	12.49	7.17	10.77	23.17	23.91	8.29	8.72	13.47
17th august	8.51	5.51	8.45	19.20	20.33	6.02	5.43	10.06	0.34	0.17	0.27	0.72	0.74	0.21	0.25	0.41	9.99	6.80	9.31	19.94	21.01	6.45	6.38	10.76
6th December	7.35	8.26	9.11	16.18	17.36	6.99	2.58	8.61	0.33	0.25	0.35	0.73	0.77	0.25	0.20	0.42	8.98	8.88	9.67	17.17	18.24	7.50	3.60	9.06
12th December	2.70	5.51	4.03	8.80	10.79	4.04	4.20	1.45	0.31	0.40	0.41	0.68	0.73	0.33	0.10	0.38	3.80	6.29	5.36	10.56	12.52	4.63	5.17	2.24
Average	***6.34***	***5.37***	***6.04***	***17.35***	***18.68***	***4.97***	***5.31***	***8.02***	***0.25***	***0.22***	***0.25***	***0.66***	***0.71***	***0.21***	***0.18***	***0.34***	***7.77***	***6.27***	***7.34***	***18.28***	***19.58***	***5.83***	***6.29***	***8.87***
Std. Deviation	***2.42***	***2.39***	***2.85***	***4.59***	***4.35***	***1.84***	***2.07***	***3.04***	***0.09***	***0.12***	***0.13***	***0.09***	***0.08***	***0.10***	***0.06***	***0.07***	***2.85***	***2.61***	***3.22***	***4.11***	***3.99***	***2.13***	***2.09***	***3.17***

Table 4-8: Speed Estimation Accuracy with Different Methods (Freeway, AM Peak) Compared to Probe Data

	MAE (mph)								MAPE								RMSE (mph)							
	BPR Curve	Akcelik	FSU BPR Curve	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson	FREEVAL	Queueing Theory	BPR Curve	Akcelik	FSU BPR Curve	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson	FREEVAL	Queueing Theory	BPR Curve	Akcelik	FSU BPR Curve	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson	FREEVAL	Queueing Theory
19th January	5.21	6.90	5.53	11.67	12.87	5.63	3.43	4.28	0.27	0.23	0.25	0.66	0.70	0.32	0.24	0.36	6.80	7.80	6.81	14.63	15.31	6.93	4.44	4.77
7thFebruary	4.94	3.93	2.79	22.68	24.02	4.52	6.48	10.37	0.18	0.28	0.22	0.47	0.51	0.22	0.12	0.16	6.10	4.81	3.97	23.34	24.71	5.54	7.42	10.95
30th March	2.19	10.04	10.50	12.77	14.46	7.62	3.32	6.84	0.15	0.14	0.08	0.73	0.78	0.14	0.21	0.36	2.63	11.39	12.65	13.78	15.24	9.38	4.16	7.58
10th April	2.04	2.35	3.59	20.08	21.95	3.27	7.06	7.85	0.09	0.46	0.49	0.53	0.61	0.36	0.14	0.29	2.26	3.12	4.30	20.41	22.28	3.73	7.69	9.08
9th May	9.95	7.74	8.27	23.68	24.96	8.17	11.14	12.89	0.08	0.08	0.14	0.68	0.73	0.10	0.23	0.30	12.23	8.61	10.52	25.05	26.37	9.57	13.73	13.33
22nd_June	6.56	2.21	4.92	22.18	23.62	3.18	8.17	10.58	0.30	0.26	0.26	0.75	0.79	0.25	0.31	0.45	8.03	2.59	6.05	22.30	23.72	4.06	8.27	11.51
20th July	12.60	7.20	10.25	24.22	24.41	8.63	9.59	14.00	0.23	0.07	0.16	0.73	0.77	0.10	0.27	0.37	14.08	8.00	11.98	25.52	26.39	9.66	9.90	15.12
17th august	9.55	6.47	9.00	20.48	21.61	7.06	6.71	11.34	0.38	0.20	0.31	0.73	0.74	0.24	0.29	0.45	11.03	7.31	10.03	21.46	22.53	7.43	7.93	11.70
6th December	12.63	8.87	11.11	26.78	27.96	10.13	12.13	19.21	0.35	0.27	0.36	0.74	0.78	0.28	0.22	0.45	15.22	10.13	13.33	27.93	29.03	11.55	13.36	19.66
12th December	7.16	8.68	7.93	14.81	14.58	7.60	8.49	6.89	0.34	0.26	0.32	0.77	0.81	0.29	0.34	0.57	8.53	10.84	9.30	15.81	15.65	9.98	10.22	8.37
Average	***7.28***	***6.44***	***7.39***	***19.94***	***21.04***	***6.58***	***7.65***	***10.43***	***0.24***	***0.23***	***0.26***	***0.68***	***0.72***	***0.23***	***0.24***	***0.38***	***8.69***	***7.46***	***8.89***	***21.02***	***22.12***	***7.78***	***8.71***	***11.21***
Std. Deviation	***3.84***	***2.73***	***2.99***	***5.14***	***5.20***	***2.34***	***2.91***	***4.30***	***0.11***	***0.11***	***0.12***	***0.10***	***0.09***	***0.09***	***0.07***	***0.11***	***4.45***	***3.08***	***3.42***	***4.86***	***5.05***	***2.68***	***3.21***	***4.20***

Based on the results presented in this section, the functions that produced the best results for all three periods for the ten days are the FSU-calibrated Modified Davidson model, the Akcelik function used in ELTOD, and the HCM-based freeway facility procedure. The SERPM BPR relationship worked well for congested conditions but was somewhat less accurate than other methods for uncongested conditions. The other tested models were less accurate. In general, the estimation is much more accurate for less congested conditions for all tested methods.

4.1.3.5 Calculation of Other Mobility Measures based on Travel Time Estimates (Freeway)

Mobility measurements listed in Table 4-1, as required by national and state guidance and procedures can be calculated based on travel time estimates calculated as described above combined with demand model output. Table 4-9 provides a summary of such measurements for the I-95 corridor segment used as a freeway case study segment in this project.

Table 4-9: Additional Mobility Measures Estimated for the Freeway Case Study Segment

Mobility Measure	AM Period Value	MD Period Value	PM Period Value
Annual hours of peak hour excessive delay (PHED) per capita	0.00	0.00	0.00
Vehicle hours delay	0.12	0.43	2.98
Vehicle hour traveled (VHT)	38.94	81.71	131.76
Vehicle mile traveled (VMT)	112,870	224,281	206,068
Percentage of non-SOV travel	79.81	74.60	80.31
Person trips	15,947	32,406	29,508
Average speed	45.25	42.79	24.85
Average travel time	9.26	9.79	16.87

4.1.3.6 Freeway Incident Conditions Analysis Results

This study further investigated the predictive ability of the different methods in presence of an incident during the AM peak, which is uncongested in the NB direction of the freeway study segment during recurrent conditions. A real-world incident that occurred on March between 08:00 AM to 08:30 AM near NW 103rd Street was used in the comparison. The capacity due to the incident was adjusted accordingly based on the HCM procedure. Table 4-10 presents the performance summary of mobility estimation methods during incident.

Table 4-10: Performance Summary of Mobility Methods during an Incident

	MAE (mph)	MAPE (%)	RMSE (mph)
BPR Curve	8.86	22	12.75
Akcelik	5.06	12	7.15
FSU BPR Curve	8.04	20	11.83
FSU Akcelik	9.08	23	14.33
FSU Conical	12.50	29	16.05
FSU Davidson	5.74	14	8.02
FREEVAL	10.63	20	13.73
Queueing Theory	12.65	26	15.58

According to the Table 4-10, the lowest error was observed when using the ELTOD Akcelik model and the FSU-Calibrated Davidson model. The HCM procedure predicted higher travel time compared with the real-world measures. This model performs well for the PM congested conditions. Further examination indicates that the traffic in the HCM-based procedure takes longer time to recover from congestion caused by the incident. This could be due to not considering diverted traffic in the analysis.

It should be noted her that all models, except the Queueing Analysis and HCM-based procedure show that the delay occurs during the incident lane blockage duration and do not include the additional delay during queue dissipation (recovery) after incident lane-blockage clearance (see Figure 4-13). However, both the Queueing Analysis and HCM-based procedure overestimates the time it takes for the queue to recover. This may be due to underestimation of the queue discharge rate or an error in the incident duration estimation. This issue is being investigated.

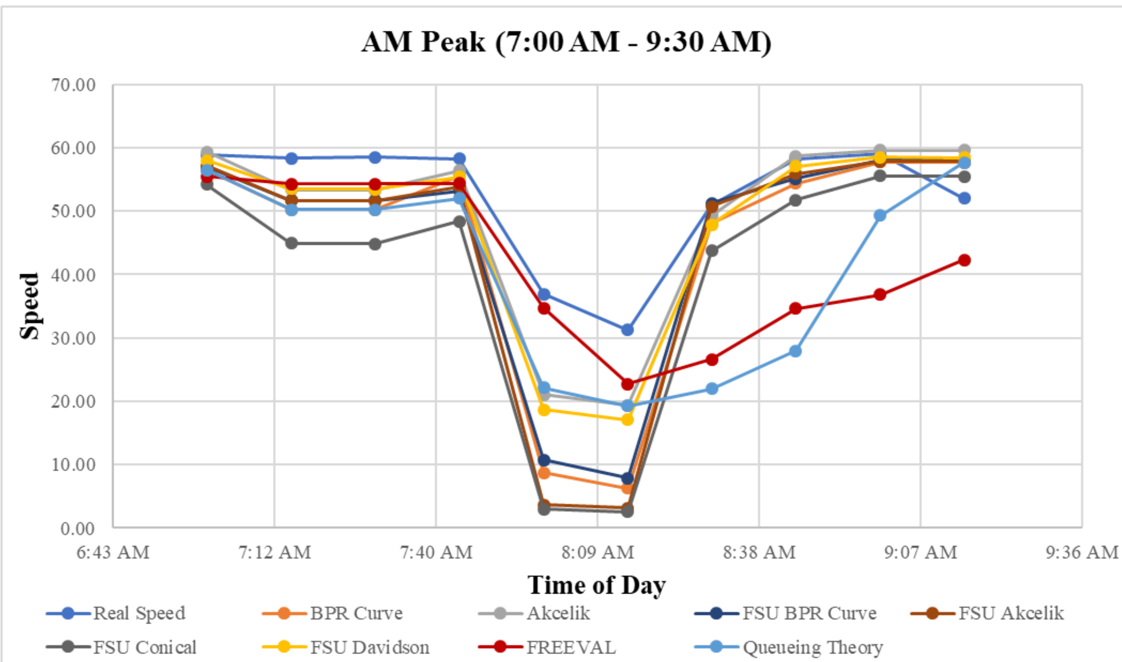


Figure 4-13: Incident Impact on Predictive Ability of Different Mobility Estimation Methods (Near 103rd Street)

4.1.3.7 Arterial Recurrent Conditions Analysis Results

For arterial recurrent condition analysis, the eastbound direction of Sunrise Blvd. in Broward County from I-95 intersection to US1 was used as a case study location for the analysis. A year worth of traffic data was utilized to generate the results. Real-world travel time data from a private sector data provider (HERE) was used as the ground truth for evaluating the estimation performance of different predictive models.

The free flow speed (S_f) for an entire corridor was calculated following the procedure mentioned by Dowling, R. (1997). The free flow speed (S_f) is a function of length of the analysis segment (L), posted speed limit (S_p), Number of signalized intersections along the corridor (N), and total signal delay per vehicle (D).

$$S_f = \frac{L}{\frac{L}{S_{mb}} + N*(\frac{D}{3600})} \quad (4\text{-}8)$$

$$S_{mb} = 0.79 * S_p + 12 \quad (4\text{-}9)$$

$$D = DF * 0.5 * C(1 - g/C)^2 \quad (4\text{-}10)$$

where, C is the cycle length, g/C is the critical effective green time, cycle length ratio with a default value of 0.45, and DF is the delay adjustment factor (DF) which has the following default values:

Uncoordinated traffic with actuated signals = 0.9
Uncoordinated traffic with fixed time signal = 1.0
Coordinated traffic with unfavorable progression = 1.2
Coordinated traffic with favorable progression = 0.9
Coordinated traffic with highly favorable progression = 0.6

The capacity is calculated using following equation:

$$\text{Capacity (vph)} = \text{Ideal Sat} *N*F_w*F_{HV}*PHF*F_{park}*F_{ba}*F_{CBD}*g/C*F_c \quad (4\text{-}11)$$

$$F_{HV} = 1/(1+HV) \quad (4\text{-}12)$$

where, Ideal Sat is the ideal saturation flow rate. Dowling R. (1997) recommended a value of 1900 for urban interrupted flow facilities. N is the total number of lanes. Fw is lane width factor which has a value of 0.93 for lanes width less than 12 ft otherwise 1. F_{HV} is heavy vehicle adjustment factor, HV is the percentage of heavy vehicle, PHF is the peak hour factor with a default value of 0.9. Fpark is the adjustment factor (0.9) for on-street parking presence, Fbay is the adjust factor (1.1) for excusive left turn lane presence, FCBD is the adjustment factor (0.9) for CBD, Fc is the user specific calibration factor to match the estimated capacity to the observed capacity with a default value of 1.

For this study location, the corridor has posted speed limit of 45 mph, length of the corridor is 1.8 mile and the traffic is coordinated with unfavorable progression. It has three through lanes with a lane width of 11ft, no presence of on-street parking and exclusive left turning lanes. Therefore, the equations provide a free flow speed of 28.3 mph and capacity of 662.6 vphpl. This is lower than the default capacity used in the SERPM model, which was 900 vphpl.

Figures 4-14 to 4-16 presents the travel time estimates for the AM Peak. Mid-Day, and PM Peak period for the urban street case study used in this project. Table 4-11 presents the goodness of fit statistics that illustrate the performance of different methods. The figures and tables suggest that for the arterial street segment, the FSU-calibrated Modified Davidson model produced the most accurate results for the AM and PM peak periods. However, the BPR function in the SERPM model works better for the Mid-Day period. Overall, it appears that, for the arterial segment, the FSU-calibrated Davidson model performed the best, followed by the FSU calibrated BPR curve, and ELTOD Akcelik equation.

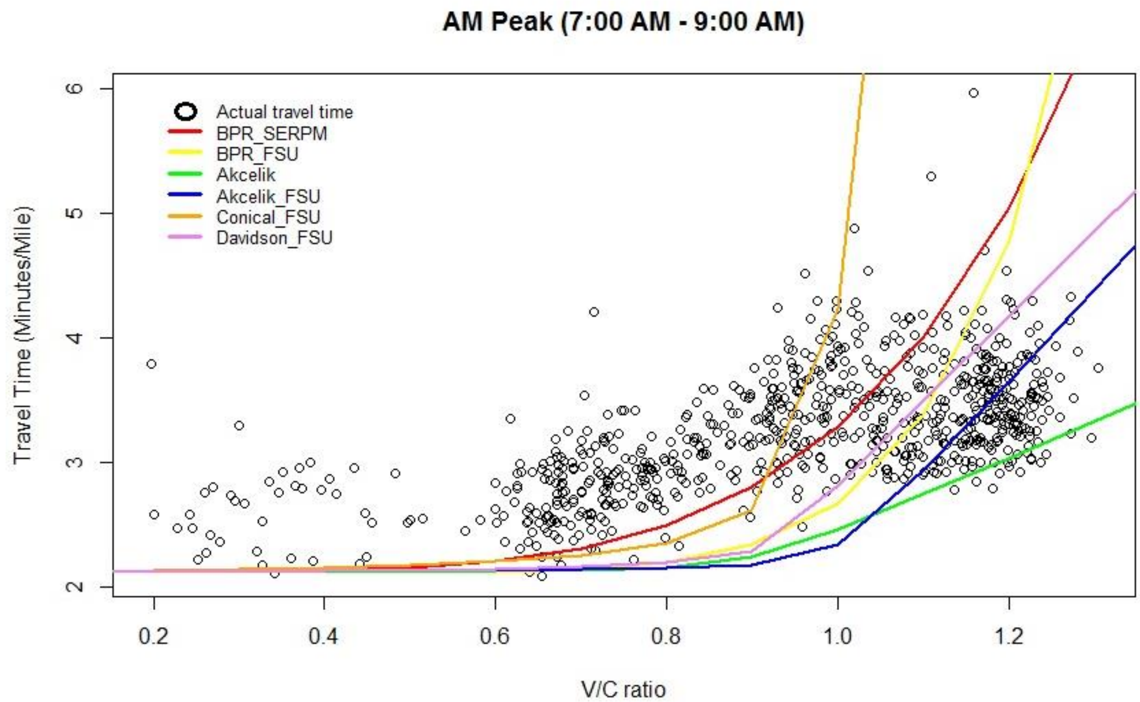


Figure 4-14: Predictive Ability of Different Mobility Estimation Methods -Travel Time (Arterial, AM Peak, Capacity 662 vphpl)

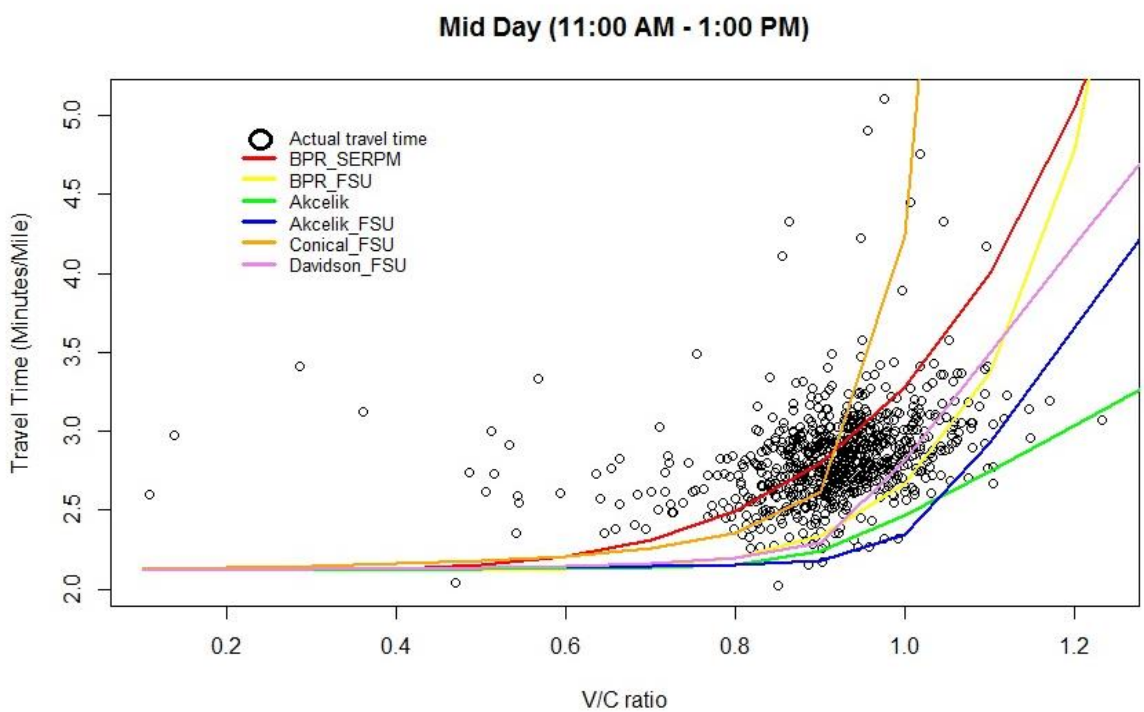


Figure 4-15: Predictive Ability of Different Mobility Estimation Methods -Travel Time (Arterial, Mid-Day, Capacity 662 vphpl)

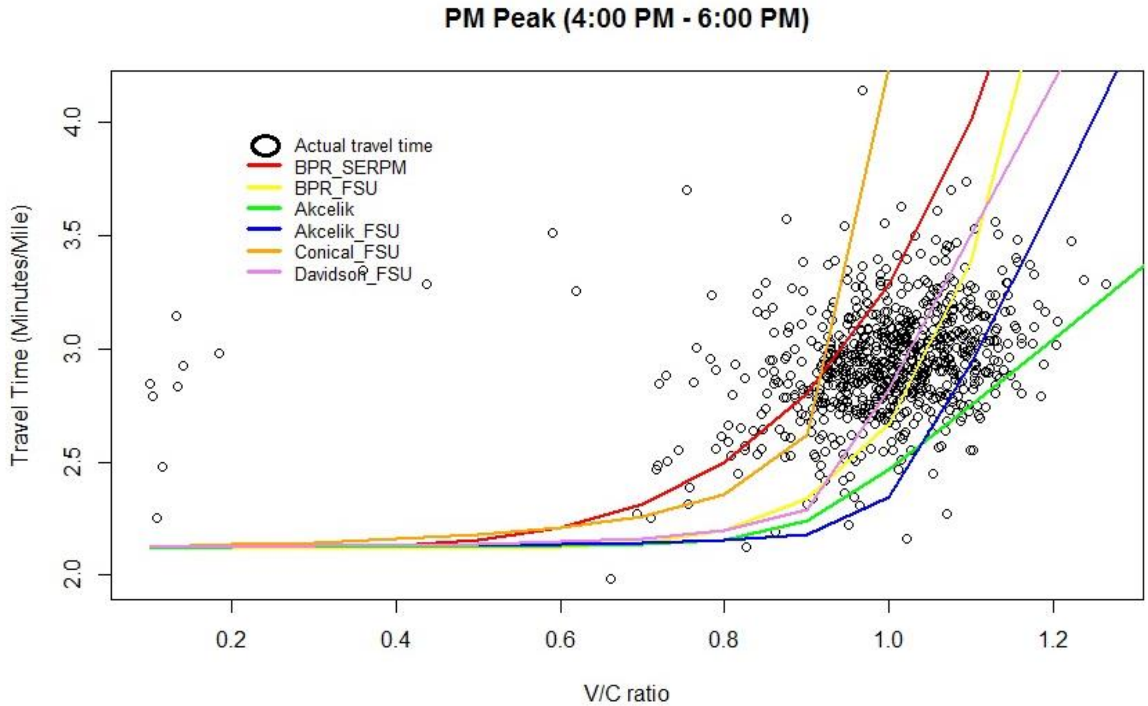


Figure 4-16: Predictive Ability of Different Mobility Estimation Methods - Travel Time (Arterial, PM Peak, Capacity 662 vphpl)

Table 4-11: Accuracy of Different Travel Time Estimation Methods

		SERPM BPR Curve	FSU BPR Curve	ELTOD Akcelik	FSU Akcelik	FSU Conical Delay	FSU Modified Davidson
AM Peak	MAPE (x100)	0.230	0.252	0.225	0.215	1.495	0.202
	MAE (min)	0.759	0.836	0.756	0.714	5.129	0.662
	RMSE (min)	0.953	1.002	0.870	0.859	7.926	0.761
Mid-Day	MAPE (x100)	0.101	0.142	0.194	0.216	0.276	0.145
	MAE (min)	0.288	0.419	0.569	0.630	0.817	0.424
	MAPE	0.400	0.510	0.637	0.696	1.808	0.511
PM Peak	MAPE (x100)	0.178	0.131	0.163	0.184	0.987	0.129
	MAE (min)	0.522	0.391	0.491	0.549	2.959	0.382
	RMSE (min)	0.668	0.503	0.556	0.621	4.498	0.472

The estimated capacity (662 vphpl) is much lower than value used as default in the SERPM model (900 vphpl). Therefore, the above procedure was repeated utilizing the capacity of 900 vphpl. Figure 4-17 to 4-19 shows the actual travel time and model estimation travel time for the AM, PM, and Mid-Day periods. All the figures show that the use of 900 vphpl capacity under-estimate the travel time especially during congestion. This appears to be mostly true when the corridor is long with multiple signalized intersection within it. The use of lower capacity accounts for the arrival on red. Thus, the use of the lower capacity value of 662 vphpl is recommended.

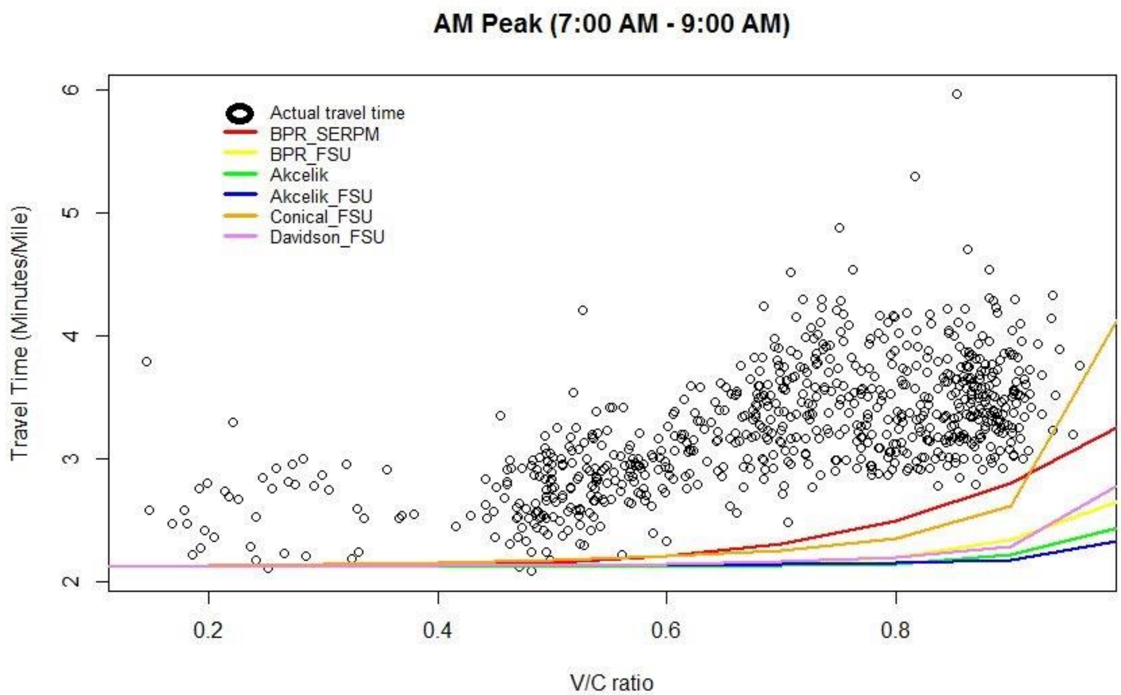


Figure 4-17: Predictive Ability of Different Mobility Estimation Methods -Travel Time (Arterial, AM Peak, Capacity 900 vphpl)

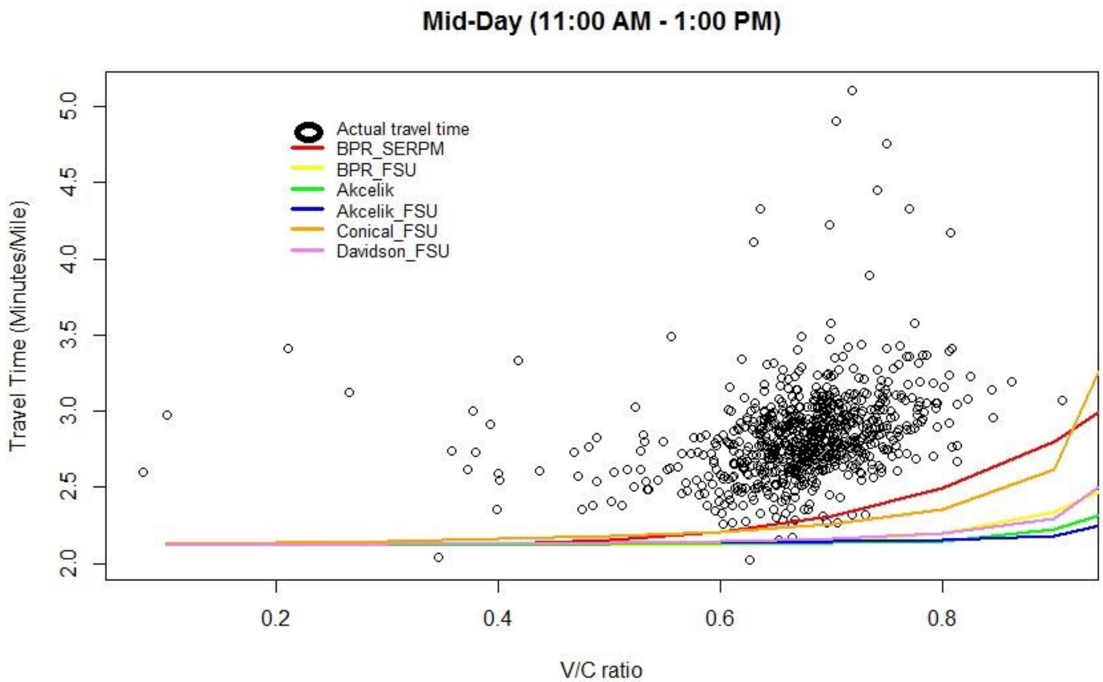


Figure 4-18: Predictive Ability of Different Mobility Estimation Methods -Travel Time (Arterial, Mid-Day, Capacity 900 vphpl)

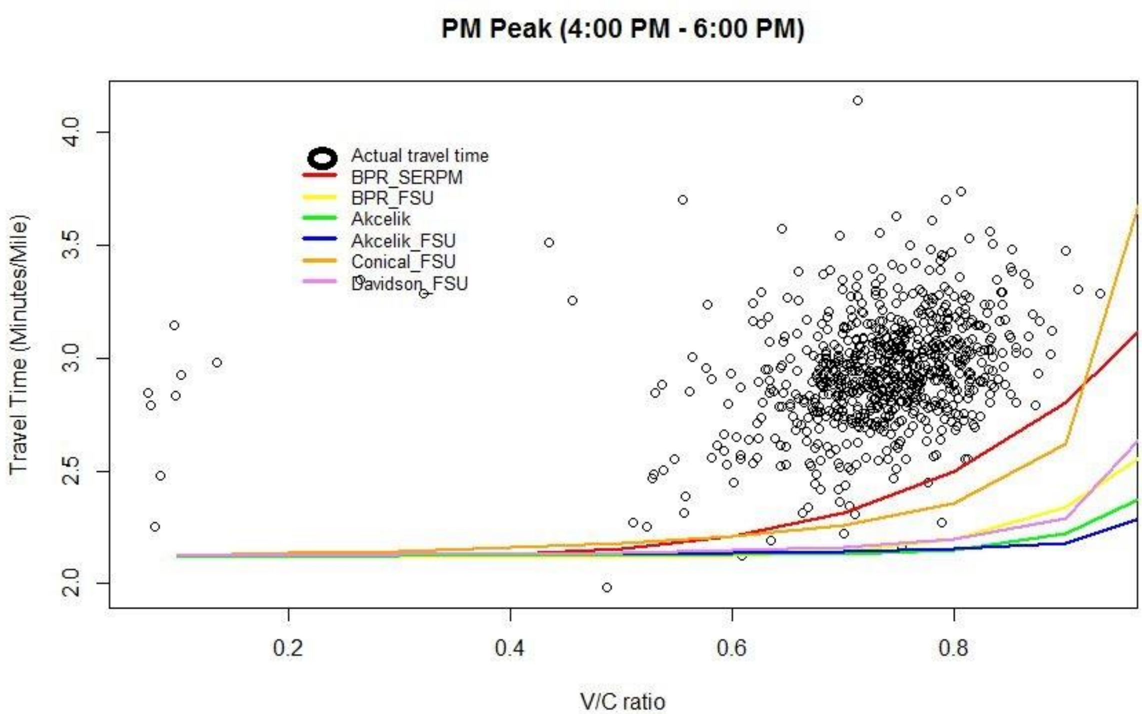


Figure 4-19: Predictive Ability of Different Mobility Estimation Methods - Travel Time (Arterial, PM Peak, Capacity 900 vphpl)

4.1.3.8 Calculation of Other Mobility Measures based on Travel Time Estimates (Arterial)

Mobility measurements listed in Table 4-1, as required by national and state guidance and procedures can be calculated based on travel time estimates calculated as described above combined with demand model output. Table 4-12 provides a summary of such measurements for the Sunrise Blvd. segment used as an urban street case study segment in this project.

Table 4-12: Summary of Mobility Measures from Demand Model (Arterial, AM Peak)

Mobility Measure	AM Peak Value	MD Peak Value	PM Peak Value
Annual hours of peak hour excessive delay (PHED) per capita	0.00	0.00	0.00
Vehicle hours delay	0.20	0.06	0.1
Vehicle hour traveled (VHT)	15.74	16.76	13.84
Vehicle mile traveled (VMT)	23,857	31,732	24,231
Percentage of non-SOV travel	83	74.78	76.6
Person trips	7,374	10,280	9,714
Average speed	25.35	31.38	29.02
Average travel time	8.86	7.15	7.68

4.2 Reliability Performance Measure

The travel time reliability measures reflect day-to-day variation in congestion levels due to contributing factors such as demand and capacity stochasticity, incidents, adverse weather, and work zones. This section describes different reliability measures, the methods utilized to estimate them, and presents a comparison of these method accuracy based on the project case study data.

Table 4-13 presents the commonly used reliability measures. These measures are estimated based on travel time data. The data should be for at least one-year period. The contributing factors to the unreliability of the system requires the collection of volume, incident, weather, and work zone data. Reliability can also be estimated based on models that range from simple equations to HCM-based procedures to simulation-based procedures. The methods to estimate reliability based on data and models are described next.

Table 4-13: Reliability Measure Calculation Methods

Reliability Measure	Calculation Method	Data Requirement
Level of travel time reliability (LOTTR)	• 80th percentile travel time divided by 50th percentile travel time	• Travel time
80th percentile travel time index	• 80th percentile travel time divided by free-flow travel time	• Travel time
Planning time index (PTI) (95% Travel Time Index)	• 95th percentile travel time divided by free-flow travel time	• Travel time
Mean travel time index	• Mean travel time/free flow travel time	• Travel time
Buffer index	• The difference between the 95th percentile travel time and the average travel time, normalized by the average travel time	• Travel time
On time Arrival	• Percentage of freeway trips travelling at least 45 mph	• Travel time

In this study, the forecasting of reliability measures was compared with reliability estimations for both the freeway case study (I-95 in Miami-Dade County) and the arterial segment (Sunrise Blvd. in Broward County) based on real-world data from Bluetooth vendors and two data vendors (HERE and INRIX). The followings are the tested reliability forecasting methods in this project, all of which developed as part of the Reliability Program of the Strategic Highway Research Program 2 (SHRP2**):**

- SHRP2 L03 Project Data-Poor Procedure
- SHRP2 L03 Project Data-Rich Procedure
- SHRP2 L07 Project Procedure with Default Parameters
- SHRP2 L07 Project Procedure Calibrated for Miami by Florida International University as part of the SHRP2 L38 project

- SHRP2 C11 Project Procedure
- SHRP2 C11 Project Procedure Calibrated for the Tampa Bay Region as part of a federal grant
- SHRP 2 L08 procedures as adopted in the HCM and implemented in FREEVAL and HCS.

4.2.1 Forecasting of Reliability Performance Measures

4.2.1.1 SHRP 2 L02 Method

The Strategic Highway Research Program 2 (*SHRP2*) SHRP2 L02 project provides a framework and guidance for a data-based travel time reliability estimation method (Institute for Transportation Research and Education et al., 2012). The framework consists of three components, that is, a data manager, a computational engine, and a report generator. The data manager assembles data from traffic sensors, weather data feeds, and incident reporting systems, and organizes them in a database. The computational engine classifies traffic into different regimes based on demand, incident, and weather. The probability density function (PDF) and cumulative density function (CDF) distributions of travel time rate for each regime are calculated from the collected and cleaned data. These two distributions allow the visualization and comparison of travel time reliability under various traffic conditions as well as the identification of contributing factors to unreliability. The report generator presents results based on user requests.

4.2.1.2 Highway Capacity Manual Procedure

The SHRP 2 Project L08 developed reliability assessment methods and tools based on the *Highway Capacity Manual* (*HCM*) freeway and urban street facility procedures and computational engines (Kittleson & Associates et al. 2012). These procedures were used a basis for reliability estimation in the latest version of the HCM. The FREEVAL-RL, STREETVAL-RL, and Highway Capacity Software (HCS) apply the above mentioned developed procedures to estimate travel time reliability. These tools have a scenario generator, which takes the input of demand, weather, incident, and work zone data, and generates a set of scenarios that represent different traffic conditions that are expected to occur within one year along the study facility. The impacts of incident, weather, and work zone events on capacity and speed are adjusted by using adjustment factors recommended by HCM. The conventional HCM computational engine for freeway or urban street facility is then utilized to calculate the travel time for each scenario. The measures of travel time reliability, including standard statistical measures (e.g., standard deviation, kurtosis), percentile-based measures (e.g., 80th and 95th percentile travel time, buffer index), on-time measures (e.g., percent of trips completed within a travel time threshold), and failure measures (e.g., percent of trips that exceed a travel time threshold), are calculated from the resulted distribution of travel time.

4.2.1.3 SHRP2 L03 Method

As a foundational study, the product of the SHRP2 L03 project defined reliability, presented recommended reliability measures derived from travel time distributions, highlighted the causes of congestion, explained how to build a database for estimating reliability prediction models, conducted before and after studies of operations and capacity improvements, and developed two sets of prediction models based on empirical data from numerous metropolitan areas (Cambridge Systematics et al., 2013). SHRP2 L03 gathered a year worth of readily available real-world detector-based travel time data from transportation agencies/private sectors for different regions of the United States. The study adopted a before-after study approach to build the relationship between highway improvements and travel time reliability. SHRP2 L03 developed two cross-sectional statistical predictive models to capture the relationship in context of highway improvements; 'data-poor model' and 'data-rich model'.

<u>Data-Poor Model</u>

The SHRP2 L03 produced a highly practical set of relationships to predict reliability, known as 'data-poor' model. The data-poor model is a simpler model that can be applied in an environment with limited data. The calculation equations are provided below.

$$\text{Overall mean TTI} = 1.0274 * \text{RecurringMeanTTI}^{1.2204} \quad (4\text{-}13)$$

$$\text{95th Percentile TTI} = \text{mean TTI}^{1.8834} \quad (4\text{-}14)$$

$$\text{90th Percentile TTI} = \text{mean TTI}^{1.6424} \quad (4\text{-}15)$$

$$\text{80th Percentile TTI} = \text{mean TTI}^{1.365} \quad (4\text{-}16)$$

$$\text{Median TTI} = \text{mean TTI}^{0.8601} \quad (4\text{-}17)$$

$$\text{10th Percentile TTI} = \text{mean TTI}^{0.1524} \quad (4\text{-}18)$$

The above equations work when the mean TTI is less than 2. However, in many cases, the mean TTI may exceed 2. Equation 4-19 to Equation 4-21 should be used for mean TTI greater than 2.

$$\text{95th percentile TTI} = 1+3.6700 * \ln(\text{Mean TTI}) \quad (4\text{–}19)$$

$$\text{90th percentile TTI} = 1+2.7809 * \ln(\text{Mean TTI}) \quad (4\text{–}20)$$

$$\text{80th percentile TTI} = 1+2.1406 * \ln(\text{Mean TTI}) \quad (4\text{–}21)$$

<u>Data-Rich Model</u>

The project L03 quantifies the impact of incidents and work zones on reliability with respect to three key variables; a) lane hours lost, b) critical demand-to-capacity ratio, and c) hours of rainfall exceeding 0.05 inch. The relationship is provided below.

$$\boldsymbol{TTI_{n\%} = e^{(j_n dc_{crit} + k_n LHL + l_n R_{0.05''})}} \quad \textbf{(4-22)}$$

where $TTI_{n\%}$ is nth percentile travel time index. Depending on the coefficients used in Equation 4-22, different percentile of travel time index can be estimated. LHL is the lane hour lost due to incidents and work zone. This value is calculated as the average number of lanes blocked per incident or work zone multiplied by the average duration of incident or work zone and the total number of incidents/work zones within the study time period and study time slice. dc_{crit} represents the critical demand-to-capacity ratio. Two methods were recommended to calculate demand. In the first method, when there is no congestion, the 30th-highest volume count during one-year weekdays is used as the demand. However, as traffic detectors measure volume counts instead of demand during the congested periods, a demand has to be either estimated by using a cumulative volume-based method proposed by the L03 project or by adding a field-observed number of vehicles in queue for congested periods. When there is only a single-day or multiple-day collection of volume counts, these limited volume counts are converted to the counts in the peak month using a seasonal factor and a weekday adjustment factor.

The parameter $R_{0.05"}$ in Equation 4-22 is the hours of rainfall with a precipitation greater than 0.05 inch during the time slice and study period. The remaining variables in Equation 4-22 are regression coefficients, whose values are listed in Table 4-14.

Table 4-14 Coefficients Used in SHRP2 L03 Project (Cambridge Systematics, Inc., 2013)

N (percentile)	j_n	k_n	l_n
For Peak Hour			
10	0.07643	0.00405	0.00000
50	0.29097	0.01380	0.00000
80	0.52013	0.01544	0.00000
95	0.63071	0.01219	0.04744
99	1.13062	0.01242	0.00000
Mean	0.27886	0.01089	0.02935
For Peak Period			
10	0.01180	0.00145	0.00000
50	0.09335	0.00932	0.00000
80	0.13992	0.01118	0.01271
95	0.23233	0.01222	0.01777
99	0.33477	0.01235	0.02531
Mean	0.09677	0.00862	0.00904

4.2.1.4 SHRP2 L07 Method

The SHRP2 L07 project developed a sketch planning-level tool for assessing the impacts of highway design treatments on travel time reliability (Potts et al., 2014). The product of the SHRP 2 L07 is a design guide, consisting of a compendium of design treatments likely to affect non-recurring congestion plus an Excel-based tool that designers can use to evaluate the effects of such treatments on delay, safety, travel time reliability, and lifecycle benefits and costs (Potts et al., 2014). As stated earlier. SHRP2 L03 developed models for predicting a travel time index (TTI) at five percentiles (10th, 50th, 80th, 95th, and 99th) along the TTI distribution, but only for certain peak periods (e.g. AM Peak, PM Peak). The SHRP2 L07 research team adapted a modification to the SHRP2 L03 data-rich models for use for one-hour time-slices, so that the TTI distribution could be predicted for each hour of the day. The coefficients corresponding to the Equation 4-23 are presented in the Table 4-15.

$$TTI_n = \begin{cases} TTI_{NP,n} * e^{(c_n R_{05"} + d_n S_{01"})} & for\ d/c \leq 0.8 \\ \frac{TTI_{NP,n}}{N_{days}} * \left[N_{NP} + V_{FF}\left(\frac{R_{05"}}{c1_n V_{FF} + c2_n TTI_{NP,n}} + \frac{S_{01"}}{d1_n V_{FF} + d2_n TTI_{NP,n}}\right)\right] & for\ d/c > 0.8 \end{cases} \tag{4-23}$$

Table 4-15: Default co-efficient for L07 data-rich model

	d/c < 0.8				d/c > 0.8					
N (percentile)	a_n	b_n	c_n	d_n	a_n	b_n	$c1_n$	$c2_n$	$d1_n$	$d2_n$
10	0.014	0.00099	0.00015	0.00037	0.07643	0.00405	1.364	-28.34	0.178	15.55
50	0.07	0.00495	0.00075	0.00184	0.29097	0.0138	0.966	-6.74	0.345	3.27
80	0.11214	0.00793	0.0012	0.0031	0.52013	0.01544	0.63	6.89	0.233	5.24
95	0.19763	0.01557	0.00197	0.01056	0.63071	0.01219	0.639	5.04	0.286	1.67
99	0.47282	0.0417	0.003	0.02293	1.13062	0.01242	0.607	5.27	0.341	-0.55

A study by Jia et al. (2014) found that the Travel Time Index (TTI) produced by the above equations are more sensitive to the number of incidents and incident duration than other factors such as demand and weather. The predicted TTI value using Equation 4-23 also has a large difference from that calculated based on real-world data. Therefore, a similar regression procedure was utilized by Jia et al. (2014) to derive expressions for travel time indices based on data for I-95 in Miami, FL. Equation 4-24 shows the final expressions and the parameters in this equation are listed in Table 4-16.

$$TTI_{n\%} = e^{b1*dc_{crit}+b2*LHL+b3*Rain+b4*Length+b5} + b6 \tag{4-24}$$

Table 4-16 Coefficients Developed by Jia et al. (2014)

Percentile	R-square	b1	b2	b3	b4	b5	b6
10	0.581	0.500	0.000	0.013	-0.075	-1.555	0.749
50	0.864	17.445	0.000	0.000	-2.457	-15.568	1.071
80	0.825	14.865	0.000	0.000	-0.658	-13.912	1.072
95	0.827	10.477	0.029	0.000	-0.832	-9.139	1.105
99	0.814	5.481	0.049	0.000	-0.894	-3.758	1.105
Mean	0.884	14.020	0.000	0.000	-0.619	-13.470	1.058

4.2.1.5 SHRP2 C11 Method

The SHRP2 C11 aimed at improving the state of the practice in assessing the wider economic benefits of transportation capacity projects. Three classes of project benefits were addressed in project C11; a) travel time reliability benefits, b) intermodal connectivity benefits, and c) market access benefits. The travel time reliability benefits were estimated in the SHRP2 C11 using the following steps:

Step 01: Free Flow Speed Estimation

For freeways and rural two-lane highways,

$$\boldsymbol{Free\ Flow\ Speed = (0.88 * Speed\ Limit) + 14} \tag{4-25}$$

For signalized highways,

$$\boldsymbol{Free\ Flow\ Speed} = (\mathbf{0.79} * \boldsymbol{Speed\ Limit}) + \mathbf{12} \quad (4\text{-}26)$$

<u>Step 02: Travel Time per Unit Distance (Travel Rate) for the Current and Forecast Years</u>

$$\boldsymbol{t} = \{\left(\mathbf{1} + \left(\mathbf{0.1225} * \left(\boldsymbol{v/c}\right)^{\mathbf{8}}\right)\right)\}/\boldsymbol{Free\ Flow\ Speed},, \boldsymbol{for\ v/c} \leq \mathbf{1.40} \quad (4\text{-}27)$$

where, t is the travel rate (hours per mile), v is hourly volume; and c is the capacity. Please not that, the v/c value is capped at 1.4.

<u>Step 03: Delay Due to Incidents (Incident Delay Rate) in Hours per Mile</u>

$$D_a - D_u * \left(1 - R_f\right) * (1 - R_d)^2 \quad (4\text{-}28)$$

where, D_a is the Adjusted delay (hours of delay per mile); D_u is Unadjusted (base) delay (hours of delay per mile, from the incident rate tables); R_f is Reduction in incident frequency expressed as a fraction (with R_f = 0 meaning no reduction, and R_f =0.30 meaning a 30% reduction in incident frequency), R_d is Reduction in incident duration expressed as a fraction (with R_d = 0 meaning no reduction, and R_d = 0.30 meaning a 30% reduction in incident duration).

<u>Step 04: Compute the Overall Mean Travel Time Index (TTI_m)</u>

$$TTI_m = 1 + FFS * (Recurring\ Delay\ Rate + Incident\ Delay\ Rate) \quad (4\text{-}29)$$

$$\boldsymbol{TTI_{95}} = \mathbf{1} + \mathbf{3.6700} * \mathbf{ln}(\boldsymbol{TTI_m}) \quad (4\text{-}30)$$

$$\boldsymbol{TTI_{50}} = \mathbf{4.01224}/\{(\mathbf{1} + \boldsymbol{e}^{(\mathbf{1.7417} - \mathbf{0.93677} * \boldsymbol{TTI_m})})^{(\mathbf{1/0.82741})}\} \quad (4\text{-}31)$$

$$\boldsymbol{TTI_{80}} = \mathbf{5.3746}/\{(\mathbf{1} + \boldsymbol{e}^{(-\mathbf{1.5782} - \mathbf{0.85867} * \boldsymbol{TTI_m})})^{(\mathbf{1/0.04953})}\} \quad (4\text{-}32)$$

The SHRP2 C11 Project reliability models predicts reliability measures as a function of the Mean Travel Time Index (MTTI) for a segment.

Later, a SHRP2 C11 Post-Processor tool was developed under a Florida Department of Transportation (FDOT) (Cambridge Systematics, Inc., 2016) contract in conjunction with the Hillsborough County MPO in Tampa, Florida. To develop reliability prediction equations for Florida, the C11 Post-Processor tool mentioned above obtained travel data for the Tampa region from the National Performance Management Research Data Set (NPMRDS) for 2014 and 2015. In the analysis, the segments were defined based on the Traffic Message Channels (TMCs) location referencing scheme, which is the basic geographic reporting unit (link) in the NPMRDS data.

The following equations were derived for Travel Time Index (TTI) for freeways:

$$TTI_{50} = 10.4910 - 9.5867 \times e^{(-0.0142 \times X^{2.2367})} \; for\ X > 1.07$$

$$= 0.963X + 0.037 \ \ otherwise \tag{4-33}$$

$$TTI_{80} = 7.3567 - 6.9965 \times e^{(-0.0910 \times X^{2.0185})} \ \ for\, X > 1.03$$

$$= 1.0 \ otherwise \tag{4-34}$$

$$TTI_{95} = 11.7933 - 16.2178 \times e^{(-0.3855 \times X^{1.0336})} \ \ for\, X > 1.08$$

$$= 1.3737X - 0.3737 \ \ otherwise \tag{4-35}$$

where, X is Mean Travel Time Index (MTTI); TTI_{50} TTI_{80}, and TTI_{95} are 50th percentile, 80^{th} percentile, and 95^{th} percentile TTI respectively.

The following equations were used to derive TTI for signalized arterials:

$$TTI_{50} = \frac{0.9333 \times 101.7049 + 12.887 \times X^{2.403}}{101.7049 + X^{2.403}} \ \ for\, X < 1.07$$

$$= X \ \ otherwise \tag{4-36}$$

$$TTI_{80} = \frac{0.7266 \times 26.26 + 9.6702 \times X^{2.5698}}{26.26 + X^{2.5698}} \tag{4-37}$$

$$TTI_{95} = 21.1669 \times e^{-\frac{2.9506}{X}} \tag{4-38}$$

The following steps were used to calculate the MTTI:

<u>Step 01: Assign Free Flow Speed (FFS)</u>

Free Flow Speed (FFS) for freeway in Tampa was set at 60 mph, for arterial streets at 45 mph, for collectors at 35 mph, and for other types of road at 30mph.

<u>Step 02: Calculate the Recurring Delay Rate (hours per vehicle-mile)</u>

Recurring Delay Rate = (1/Speed) – (1/FFS) (4-39)

<u>Step 03: Calculate the Base Incident-Related Delay Rate (hours per vehicle-mile)</u>

Number of lanes <= 2:

$$Du = -0.0111/(1 - 1471 * \exp^{(-6.8498 * v/c)}) \tag{4-40}$$

Number of lanes = 3:

$$Du = -0.0085/(1 - 1872 * \exp^{(-7.1381 * v/c)}) \tag{4-41}$$

Number of lanes >= 4:

$$Du = -0.0068/(1 - 1827 * \exp^{(-7.1090 * v/c)}) \tag{4-42}$$

Where, Du is the base incident delay rate and v/c = volume-to-capacity ratio.

Step 04: Calculate the MTTI

$$MTTI = 1 + (FFS * (Recurring\ Delay\ Rate + Du)) \quad (4\text{-}43)$$

4.2.2 Comparison of Reliability Measure Calculation Methods

This section provides the results of the application of the SHRP2 products (L03, L07, C11, and HCM-based procedure) to estimate reliability measures (e.g. travel time index) for both freeway and arterial facilities. The study considered three forms of the travel time index as reliability measures: the 80th percentile, the 90th percentile, and 95th percentile travel time indexes. This section also includes a comparison of these estimated reliability measures and the reliability measures estimated based on real-world. Please note that the HCM-based analysis is on-going. Thus, only partial results from applying this procedure are presented in this memorandum. Additional details will be presented in a future deliverable.

4.2.2.1 Freeway Reliability

Figures 4-20 to 4-22 and Table 4-17 present the reliability measures (e.g. travel time index) for the freeway case study corridor during the AM Peak, Mid-Day, and PM Peak periods. As mentioned before, the study estimated three set of reliability measures (the 50^{th} percentile TTI, 80^{th} Percentile TTI, and 95^{th} percentile TTI) and compared the estimated measures with real-world measures, as shown in the figures. As presented in the figures, the estimated reliability measures were found to be very close to the real-world measures for the AM Peak and Mid-Day periods. However, the estimated reliability measures were different than the real-world measures during the more congested PM Peak for all three indices (50th percentile TTI, 80th Percentile TTI, and 95th percentile TTI). When considering the three peaks, the models that produced the best forecasts of reliability compared to data-based reliability estimation for the freeway segment is the SHRP2 C11 model calibrated for the Tampa Bay Area and the SHRP2 L03 Data Poor Model. Please note that the Akcelic Equation was used to generate the mean recurrent travel time for the models that require the estimation of this value.

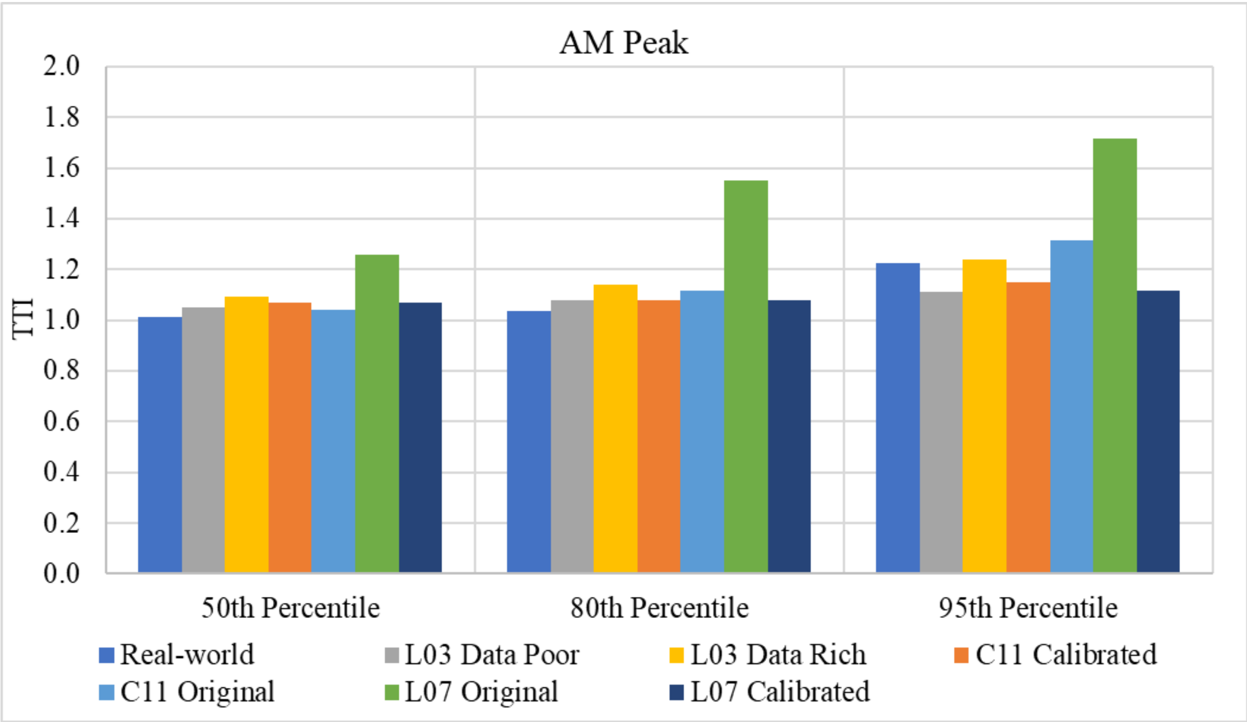


Figure 4-20: Reliability Measures on Freeways for AM Peak

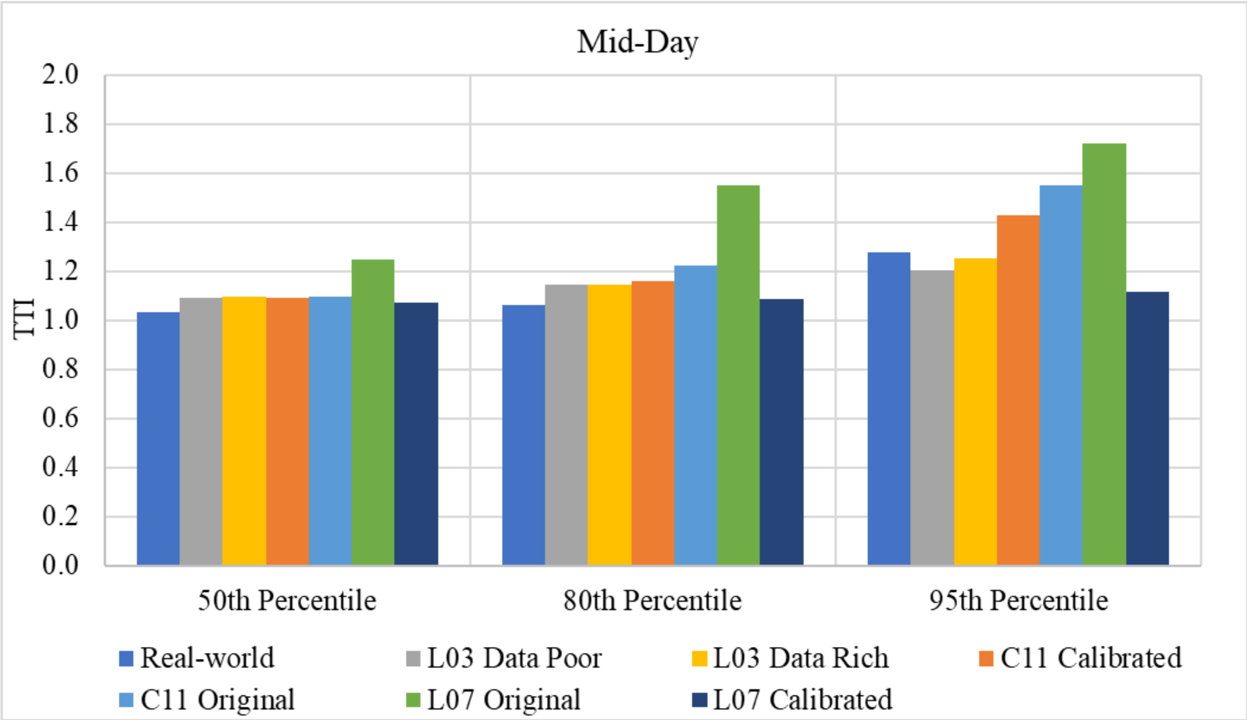


Figure 4-21: Reliability Measures on Freeways for Mid-Day

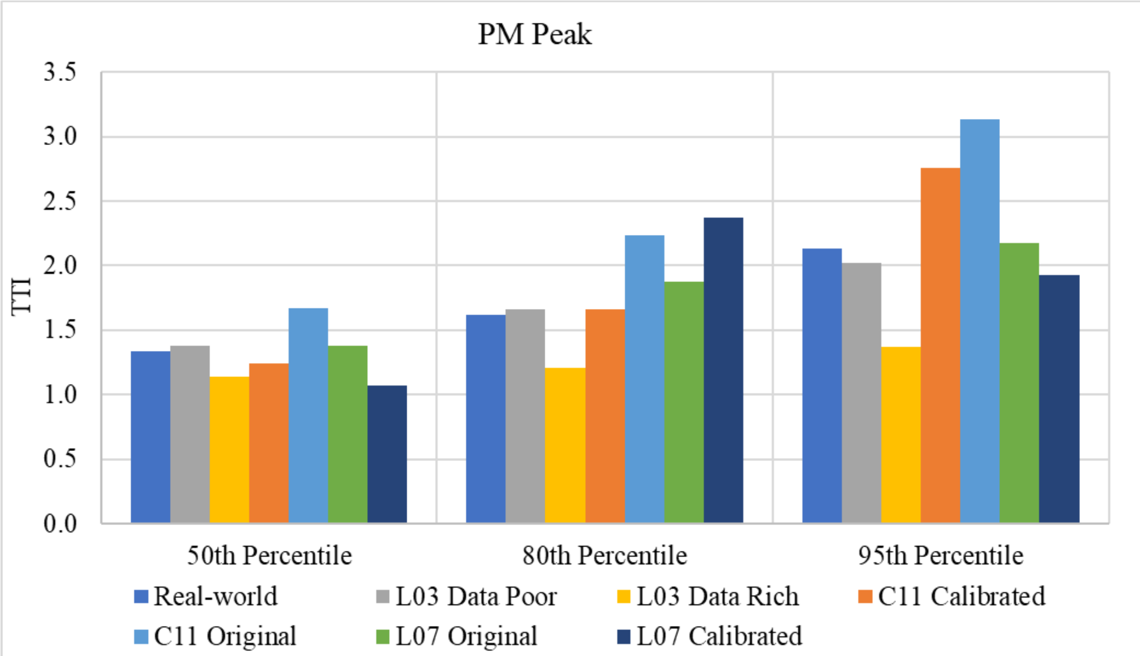


Figure 4-22: Reliability Measures on Freeways for PM Peak

Table 4-17: Comparison of Reliability Forecasts of the Freeway Case Study Using Different Methods and Estimates Based on Real-World Data

	AM Peak			Mid-Day			PM Peak		
	TTI50	TTI80	TTI95	TTI50	TTI80	TTI95	TTI50	TTI80	TTI95
C11 Calibrated	1.07	1.08	1.15	1.09	1.16	1.43	1.24	1.66	2.76
C11 Original	1.04	1.12	1.31	1.10	1.22	1.55	1.67	2.24	3.14
L03 Data Poor	1.05	1.08	1.11	1.09	1.14	1.21	1.38	1.66	2.02
L03 Data Rich	1.09	1.14	1.24	1.09	1.15	1.25	1.14	1.21	1.37
L07 Original	1.26	1.55	1.72	1.25	1.55	1.72	1.38	1.87	2.18
L07 Calibrated	1.07	1.08	1.11	1.07	1.09	1.12	1.07	2.37	1.93
Real-world	1.01	1.04	1.22	1.03	1.06	1.28	1.33	1.62	2.13

4.2.2.2 Arterial Reliability

Figures 4-23 to 4-25 and Table 4-18 present the reliability measures (e.g. travel time index) for the arterial street case study corridor during the AM Peak, Mid-Day, and PM Peak periods. As with the freeway case study, the study estimated three set of reliability measures (the 50th percentile TTI, 80th Percentile TTI, and 95th percentile TTI) and compared the estimated measures with real-world measures, as shown in the figures. When considering the three peaks, the model that produced the best forecasts of reliability compared to data-based reliability estimation for the urban arterial study segment The model that produced the best forecasts of reliability compared to data-based reliability estimation for the urban arterial study segment is the L07 original model followed by the SHRP2 L03 data poor and L03 data rich model.

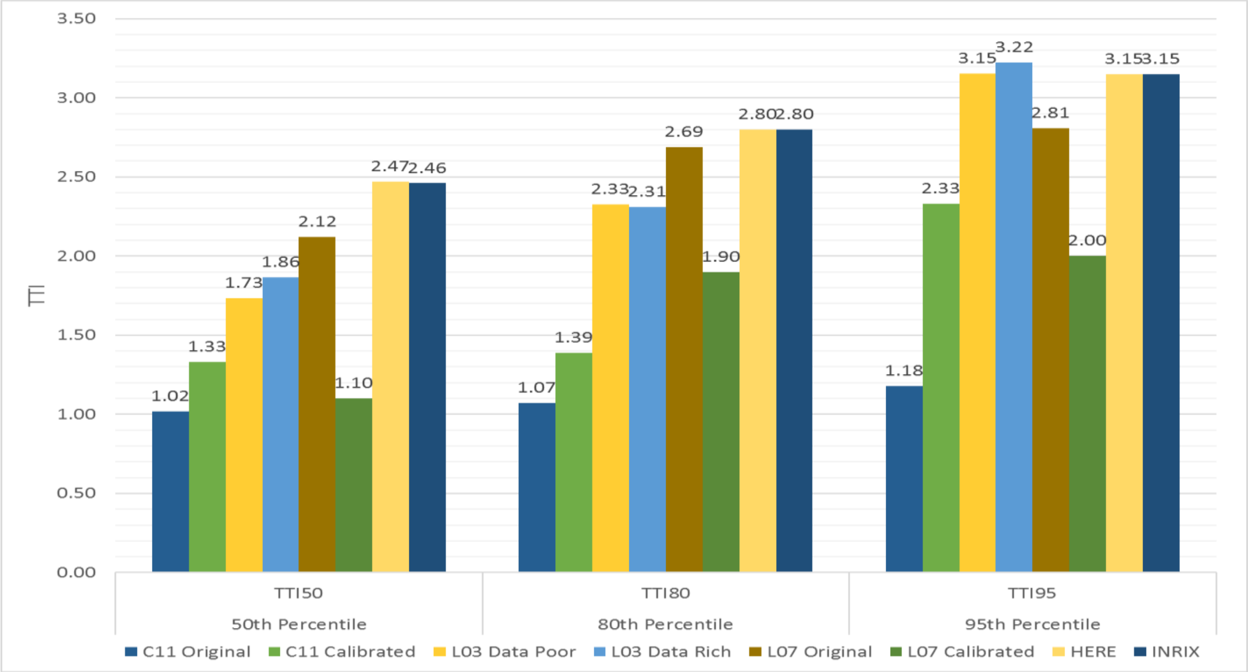


Figure 4-23: Reliability Measures on Arterial for AM Peak

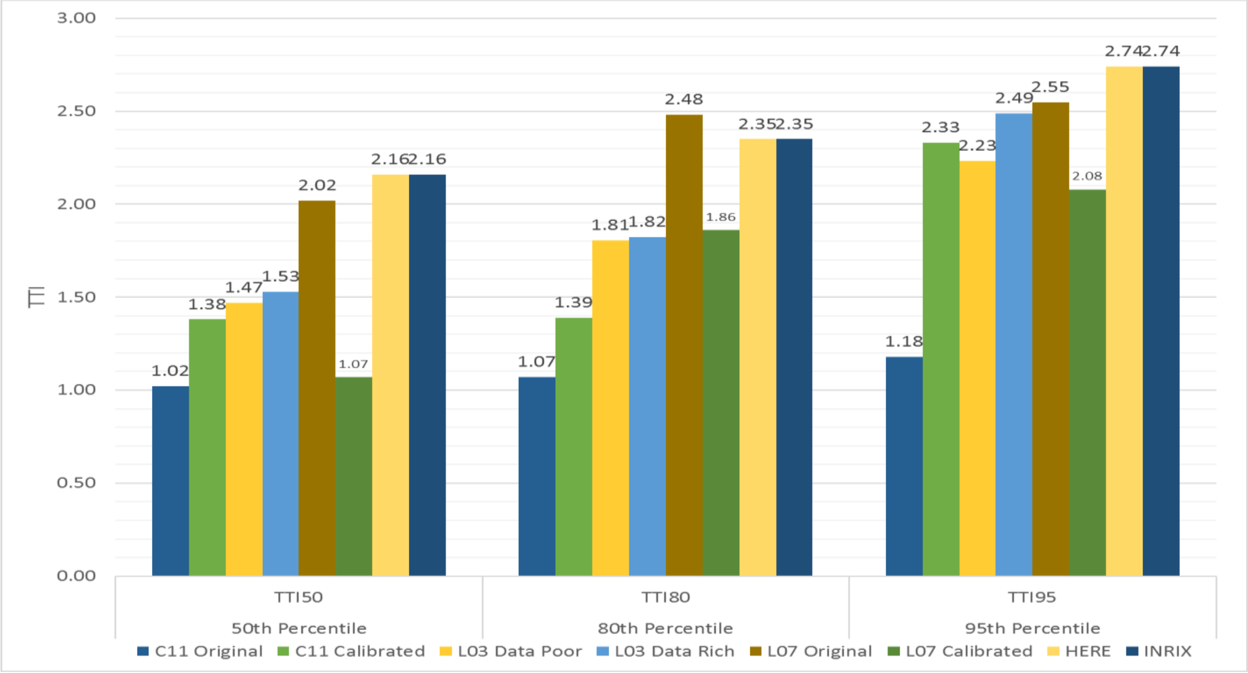


Figure 4-24: Reliability Measures on Arterial for Mid-Day

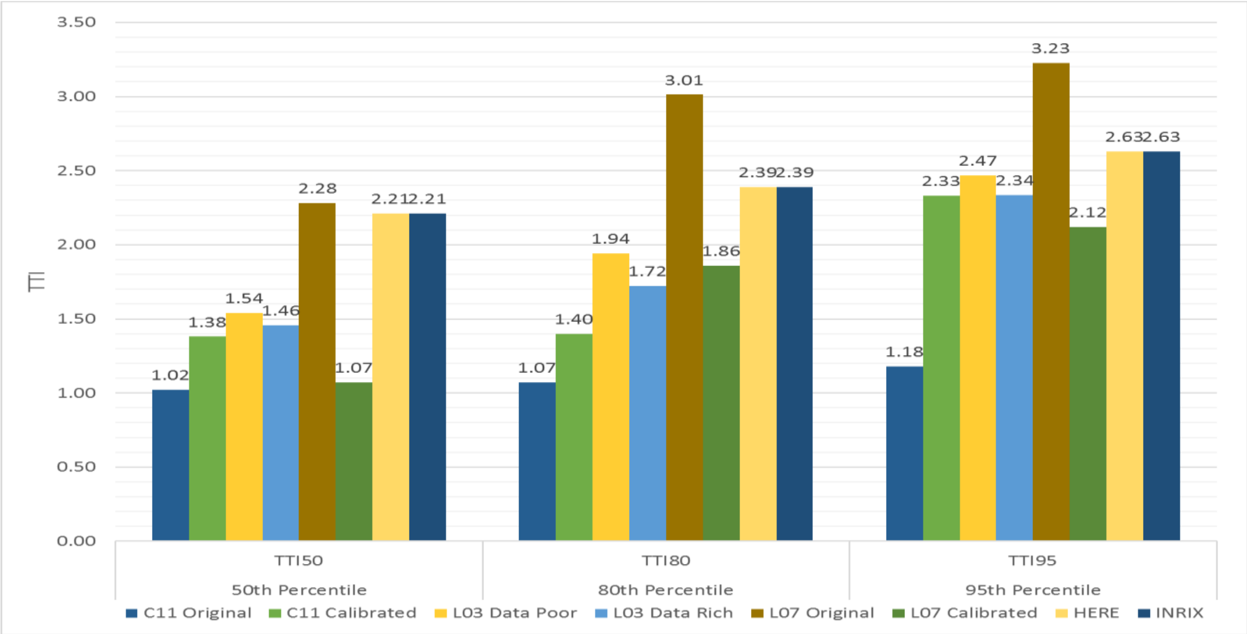


Figure 4-25: Reliability Measures on Arterial for PM Peak

Table 4-18: Comparison of Reliability Forecasts of the Arterial Case Study Using Different Methods and Estimates Based on Real-World Data

	AM Peak			MD Period			PM Peak		
	TTI50	TTI80	TTI95	TTI50	TTI80	TTI95	TTI50	TTI80	TTI95
C11 Calibrated	1.33	1.39	2.33	1.38	1.39	2.33	1.38	1.40	2.33
C11 Original	1.02	1.07	1.18	1.02	1.07	1.18	1.02	1.07	1.18
L03 Data Poor	1.73	2.33	3.15	1.47	1.81	2.23	1.54	1.94	2.47
L03 Data Rich	1.86	2.31	3.22	1.53	1.82	2.49	1.46	1.72	2.34
L07 Original	2.12	2.69	2.81	2.02	2.48	2.55	2.28	3.01	3.23
L07 Calibrated	1.10	1.90	2.00	1.07	1.86	2.08	1.07	1.86	2.12
HERE	2.47	2.80	3.15	2.16	2.35	2.74	2.21	2.39	2.63
INRIX	2.46	2.80	3.15	2.16	2.35	2.74	2.21	2.39	2.63

4.3 Safety Performance Measure Estimation

Two methods can be used to estimate the safety performance for the base conditions: the Lookup Table method and the Florida Safety Performance Functions (SPF). As described later in this document, the updated version of FITSEVAL allows the user to estimate the safety for the base conditions using one of these two methods or based on real-world crash data.

4.3.1 Lookup Table

The first method to predict the number of crashes is the Lookup Table along a corridor method, which is based on the same method used in the original version of FITSEVAL (Hadi et al., 2008). Table 4-19 shows the crash rates per Million Vehicle Miles Traveled (MVMT) of property damage only (PDO), injury, and fatality for freeway and arterial segments as a function of Volume to Capacity (V/C) ratio, utilized in the method. The total number of crashes is then estimated by multiplying the crash rate by the MVMT (which is a multiplication of segment volume and length). The advantage of this method is that it can be directly applied to any period in the day as long as we know the average V/C ratio, the segment length, and the volume for the period. The disadvantage is that these relationships have not been fully and formally calibrated for Florida.

Table 4-19: Crash Rates per MVMT Used in FITSEVAL

<table>
<tr><th rowspan="2">V/C</th><th colspan="2">Fatality</th><th colspan="2">Injury</th><th colspan="2">PDO</th></tr>
<tr><th>Freeway</th><th>Arterial</th><th>Freeway</th><th>Arterial</th><th>Freeway</th><th>Arterial</th></tr>
<tr><td>0.09</td><td rowspan="11">0.0004</td><td rowspan="11">0.0072</td><td rowspan="5">0.5156</td><td rowspan="11">0.5757</td><td rowspan="7">0.8551</td><td rowspan="11">2.394</td></tr>
<tr><td>0.19</td></tr>
<tr><td>0.29</td></tr>
<tr><td>0.39</td></tr>
<tr><td>0.49</td></tr>
<tr><td>0.59</td><td rowspan="4">0.5757</td></tr>
<tr><td>0.69</td></tr>
<tr><td>0.79</td><td rowspan="2">0.9953</td></tr>
<tr><td>0.89</td></tr>
<tr><td>0.99</td><td>0.7392</td><td>1.1591</td></tr>
<tr><td>1.00</td><td>0.7329</td><td>1.2737</td></tr>
</table>

4.3.2 Florida Safety Performance Function

The second method utilizes calibrated SPFs developed for Florida based on roadway inventory data and crash data (Alluri et al., 2016). Equation 4-44 presents the general form of the SPF function used for roadway segments and ramps.

$$N_{predicted} = e^{a} \times AADT^{b} \quad (4\text{-}44)$$

where $N_{predicted}$ is the number of predicted crashes per mile per year and AADT represents average annual daily traffic. a and b are regression coefficients.

Equation 4-45 presents the SPF functional form for intersections.

$$N_{predicted} = e^{a} \times {AADT_{major}}^{b} \times {AADT_{minor}}^{c} \quad (4\text{-}45)$$

where $AADT_{major}$ and $AADT_{minor}$ represent the average annual daily traffic for the major and minor approaches of an intersection, respectively. Symbols a, b, and c are regression coefficients.

Tables 4-20 to 4-23 present the coefficients of the calibrated SPF functions to estimate the total number of crashes and to estimate fatal plus injury crashes (F+I) for arterial streets, freeways, intersections, and ramps, respectively. The actual number of crashes are calculated by multiplying the results with crash modification factors that account for various segment or intersection attributes. The advantage of this method is that i is that these relationship have been fully and formally calibrated for Florida. The disadvantage is that the SPFs are functions of the AADT and thus does not account for the vriations in volumes during the day. In the FITSEVAL application, a method was used to caculate the AADT based on the hourly volumes to allow the use of the SPFs as decribed next. Please note that in the first version of FITSEVAL produced as part of this project, the SPFs are applied without utilizing location specific crah modification factors to account for the attributes of the facility since this will add a complexity that cannot be accomodated with this project resources. This can be incorporated in a future update to the tool.

Table 4-20: Florida-Specific SPFs for Arterial Streets (Alluri et al., 2016)

Category	Severity	Coefficient				k	R^2_{FT}
		a		b			
		Estimate	p-value	Estimate	p-value		
Rural Two-lane Roads	Total	-8.810	<0.001	1.096	<0.001	1.537	0.656
	F+I	-9.954	<0.001	1.148	<0.001	1.460	0.692
Rural Multilane Undivided Roads	Total	-16.159	<0.001	1.936	<0.001	1.356	0.685
	F+I	-18.401	<0.001	2.083	<0.001	1.628	0.652
Rural Multilane Divided Roads	Total	-9.749	<0.001	1.195	<0.001	1.154	0.711
	F+I	-10.703	<0.001	1.215	<0.001	0.949	0.771
Urban Two-lane Arterials	Total	-7.269	<0.001	1.037	<0.001	2.554	0.419
	F+I	-7.173	<0.001	0.925	<0.001	2.310	0.543
Urban Multilane Undivided Arterials	Total	-8.704	<0.001	1.198	<0.001	1.132	0.733
	F+I	-7.971	<0.001	1.029	<0.001	0.914	0.775
Urban Multilane Divided Arterials	Total	-10.651	<0.001	1.348	<0.001	1.143	0.691
	F+I	-10.631	<0.001	1.262	<0.001	0.979	0.734
Urban One-way Arterials[1]	Total	-3.530	NA	0.600	NA	1.380	0.041
	F+I	-5.150	NA	0.650	NA	1.450	0.111

Table 4-21: Florida-Specific SPFs for Freeway Segments (Alluri et al., 2016)

Category	Severity	Coefficient				k	R^2_{FT}
		a		b			
		Estimate	p-value	Estimate	p-value		
Rural Freeways with 4 Lanes							
Basic Freeway Segments	Total	-13.340	<0.001	1.433	<0.0001	0.126	0.965
	F+I	-13.990	<0.001	1.415	<0.0001	0.103	0.959
Segments within Interchange Influence Area	Total	-12.362	<0.001	1.377	<0.0001	0.267	0.917
	F+I	-12.742	<0.001	1.331	<0.0001	0.255	0.899
Rural Freeways with 6+ Lanes							
Basic Freeway Segments	Total	-10.287	<0.0001	1.126	<0.0001	0.171	0.966
	F+I	-10.826	<0.0001	1.090	<0.0001	0.127	0.960
Segments within Interchange Influence Area	Total	-12.207	<0.0001	1.338	<0.0001	0.208	0.945
	F+I	-12.800	<0.0001	1.310	<0.0001	0.137	0.944
Urban Freeways with 4 Lanes							
Basic Freeway Segments	Total	-10.734	<0.001	1.235	<0.001	0.938	0.827
	F+I	-13.463	<0.001	1.394	<0.001	0.628	0.871
Segments within Interchange Influence Area	Total	-16.872	<0.001	1.800	<0.001	0.446	0.916
	F+I	-17.088	<0.001	1.724	<0.001	0.307	0.916
Urban Freeways with 6 Lanes							
Basic Freeway Segments	Total	-15.040	<0.0001	1.608	<0.001	0.750	0.858
	F+I	-16.242	<0.0001	1.625	<0.001	0.552	0.889
Segments within Interchange Influence Area	Total	-15.249	<0.0001	1.626	<0.001	0.361	0.919
	F+I	-16.045	<0.0001	1.610	<0.001	0.270	0.928
Urban Freeways with 8+ Lanes							
Basic Freeway Segments	Total	-14.518	<0.0001	1.553	<0.001	0.824	0.855
	F+I	-14.502	<0.0001	1.467	<0.001	0.702	0.877
Segments within Interchange Influence Area	Total	-17.507	<0.0001	1.809	<0.001	0.459	0.928
	F+I	-19.1512	<0.0001	1.867	<0.001	0.402	0.934

Table 4-22: Florida-Specific SPFs for Intersections (Alluri et al., 2016)

Category	Severity	Coefficient						k	R^2_{FT}
		a		b		c			
		Estimate	p-value	Estimate	p-value	Estimate	p-value		
Signalized Intersections									
Rural Three-leg[1]	Total	-6.570	NA	0.660	NA	0.200	NA	0.330	0.260
	F+I	-7.830	NA	0.750	NA	0.140	NA	0.500	0.215
Rural Four-leg	Total	-6.839	<0.001	-0.019	0.950	0.883	<0.001	1.040	0.730
	F+I	-6.561	0.003	-0.126	0.732	0.893	0.003	1.461	0.699
Urban Three-leg	Total	-10.382	<0.001	0.736	<0.001	0.329	<0.001	2.090	0.623
	F+I	-9.681	<0.001	0.679	<0.001	0.239	0.004	2.074	0.641
Urban Four-leg	Total	-9.786	<0.001	0.734	<0.001	0.339	<0.001	2.093	0.659
	F+I	-9.711	<0.001	0.698	<0.001	0.291	<0.001	1.900	0.671
Unsignalized Intersections[2]									
Rural Three-leg	Total	-6.685	<0.001	0.155	0.531	0.515	0.002	2.579	0.674
	F+I	-9.179	<0.001	0.502	0.069	0.382	0.034	2.603	0.665
Rural Four-leg	Total	-4.258	0.152	0.312	0.379	0.077	0.813	3.463	0.589
	F+I	-5.039	0.121	0.410	0.290	0.029	0.935	4.015	0.593
Urban Three-leg	Total	-11.768	<0.001	0.791	<0.001	0.388	<0.001	3.397	0.537
	F+I	-11.195	<0.001	0.720	<0.001	0.323	<0.001	3.511	0.607
Urban Four-leg	Total	-9.758	<0.001	0.824	<0.001	0.127	0.320	3.189	0.583
	F+I	-10.264	<0.001	0.837	<0.001	0.098	0.478	3.3378	0.625

Table 4-23: Florida-Specific SPFs for Ramps (Alluri et al., 2016)

Category	Severity	Coefficient				k	R^2_{FT}
		a		b			
		Estimate	p-value	Estimate	p-value		
Rural Diamond Off-ramp	Total	-8.528	<0.0001	1.212	<0.0001	0.646	0.825
	F+I	-8.623	<0.0001	1.118	<0.0001	0.754	0.795
Rural Diamond On-ramp	Total	-8.323	<0.0001	1.092	<0.0001	0.767	0.801
	F+I	-9.993	<0.0001	1.183	<0.0001	0.270	0.831
Rural Parclo Loop Off-ramp	Total	-4.769	0.0001	0.836	<0.0001	0.723	0.785
	F+I	-5.874	<0.0001	0.831	<0.0001	0.751	0.714
Rural Parclo Loop On-ramp	Total	-6.313	<0.0001	0.896	<0.0001	0.359	0.837
	F+I	-6.525	0.0002	0.819	0.0002	0.998	0.714
Urban Diamond Off-ramp	Total	-4.967	<0.0001	0.826	<0.0001	0.712	0.800
	F+I	-5.392	<0.0001	0.765	<0.0001	0.723	0.794
Urban Diamond On-ramp	Total	-5.506	<0.0001	0.815	<0.0001	0.774	0.822
	F+I	-6.362	<0.0001	0.803	<0.0001	0.779	0.802
Urban Partial Diamond Off-ramp	Total	-2.463	0.0009	0.530	<0.0001	1.316	0.655
	F+I	-3.769	<0.0001	0.556	<0.0001	1.072	0.703
Urban Partial Diamond On-ramp	Total	-1.160	0.1178	0.327	0.0001	1.160	0.729
	F+I	-1.777	0.0338	0.273	0.0049	1.168	0.729
Urban Trumpet Off-ramp	Total	-3.356	<0.0001	0.604	<0.0001	0.775	0.819
	F+I	-5.004	<0.0001	0.671	<0.0001	0.763	0.815
Urban Trumpet On-ramp	Total	-5.484	<0.0001	0.795	<0.0001	0.881	0.799
	F+I	-5.785	<0.0001	0.706	<0.0001	0.714	0.823
Urban Parclo Loop Off-ramp	Total	-3.821	<0.0001	0.671	<0.0001	0.786	0.755
	F+I	-4.232	<0.0001	0.612	<0.0001	0.758	0.758
Urban Parclo Loop On-ramp	Total	-6.349	<0.0001	0.909	<0.0001	0.648	0.832
	F+I	-6.782	<0.0001	0.853	<0.0001	0.692	0.810

To be able to use Equation 4-44, the AADT needs to be calculated from the link traffic hourly volume before utilizing the SPF equation. The user will have to provide a ratio of the analysis hour volume to the AADT ($R_{volume/AADT}$) and directional factor (D), which is the ratio of traffic in the peak direction as inputs. The AADT is then calculated from the link volume using Equation 4-41.

$$AADT = \frac{Volume}{(R_{volume/AADT})*D} \quad (4\text{-}46)$$

The number of crashes on the intersections along the corridor is calculated using Equation 4-45. Since cross street volumes are difficult to obtain based on Cube outputs, the updated version of FITSEVAL has defaults for the cross street AADT as percentages of the main street AADT. These defaults can be overridden by the user to calculate intersection crashes. The following are the required variables:

Total number of major signalized intersections on the segment (two major streets intersecting each other's)	=	$I_{major\text{-}sig}$
Total number of minor signalized intersections on the segment (one major street intersecting a minor street)	=	$I_{minor\text{-}sig}$
Total number of un-signalized intersections	=	I_{unsig}
Percentage of Cross Street AADT to Main Street AADT for the Major Intersections (default 40%)	=	$AADT\_Ratio_{major\text{-}signalized}$
Percentage of Cross Street AADT to Main Street AADT for the Minor Intersections (default 20%)	=	$AADT\_Ratio_{minor\text{-}signalized}$
Percentage of Cross Street AADT to Main Street AADT for the Minor Intersections (default 10%)	=	$AAD\text{-}Ratio_{unsignalized}$

$N_{predict\_major\_sig}$, $N_{predict\_minor\_sig}$, and $N_{predict-unsig}$ are the predicted number of crashes for the three types of intersections calculated using Equation 4-45. Finally, the total number of crashes along the corridor is calculated utilizing Equation 4-47.

$$N_{predict-cor} = \sum_{i=1}^{k} N_{predict\_link} + I_{major\_sig} * N_{predict_{major_{sig}}} + I_{minor-sig} * N_{predict_{\_minor\_sig}} + I_{unsig} * N_{predict-unsig} \quad (4\text{-}47)$$

The predicted number of crashes from the SPFs is for the whole day and both direction. Therefore, the peak hour directional crush number is calculated using Equation 4-48.

$$No\ of\ crush\ in\ the\ peak\ hour = N_{predict-cor} * R_{volume/AADT} * D \quad (4\text{-}48)$$

4.4 Summary

Different methods to estimate travel time and travel time reliability were assessed in this by comparing the resulting estimates from applying these methods to those estimated based on real-world data. Two corridors were used as case studies for assessing the accuracy of the estimates for freeways and urban arterial streets, respectively, as follows:

- I-95 northbound between NW 32nd Street and NW 103rd Street in Miami-Dade County, FL (used as a freeway case study)
- Sunrise Blvd. between US 441 and US 1 in Broward County, FL (used as an urban street case study)

The accuracy of the following functions to forecast speed/travel time were assessed based on comparison with data-based estimates of travel time:

- Bureau of Public Road (BPR) Curve with the parameters extracted from SERPM
- Akcelik Equation with the parameters extracted from the ELTOD software developed for managed lane toll assessment
- BPR Curve with the parameters calibrated in a study conducted by Florida State University (FSU)
- Akcelik Equation with the parameters calibrated in a study conducted by FSU
- Modified Davidson Equation with the parameters calibrated in a study conducted by FSU
- Conical Equation with the parameters calibrated in a study conducted by FSU
- Freeway and urban street Highway Capacity Manual (HCM) procedures

Based on the results presented in this study, the functions that produced the best results for all three periods are the FSU-calibrated Modified Davidson model, the Akcelik function used in ELTOD, and the HCM-based freeway facility procedure. The SERPM BPR relationship worked well for congested conditions but was somewhat less accurate than other methods for uncongested conditions. The other tested models were less accurate. In general, the estimation is much more accurate for less congested conditions for all tested methods.

The functions were also tested to estimate travel times during an incident condition. The lowest error again was observed when using the ELTOD Akcelik model and the FSU-Calibrated Davidson model. The HCM procedure predicted higher travel time compared to the real-world measures. This model, however, performs well for the PM congested conditions, which raises questions on why this high delay is estimated during incident conditions. Further examination indicates that the traffic in the HCM-based procedure takes longer time to recover from congestion caused by the incident. An investigation is being done to determine the impact of reducing the capacity drop and/or increasing the queue discharge rate on improving the HCM-based procedure. It should be noted her that all models, except the Queueing Analysis and HCM-based procedure show that the delay occurs during the incident lane blockage duration and do not include the additional delay during queue dissipation (recovery) after incident lane-blockage clearance.

The findings from this chapter suggest that the travel time forecasting methods are able to forecast travel time more accurately for freeways compared to arterial street facilities and for less congested periods, as reflected by the MAPE values. For the arterial street segment, the FSU-calibrated Modified Davidson model produced the most accurate results for the AM and PM peak periods. However, the BPR function in the SERPM model works better for the Mid-Day period. Overall, it appears that, for the arterial segment, the FSU-calibrated Davidson model performed the best, followed by the SERPM default BPR curve, followed by the ELTOD Akcelik equation.

The HCM procedures have the advantage of considering the temporal and spatial impacts of congestion since they consider the spillbacks between the roadway segments including ramps and the extended queue from one period to the next. However, these procedures require more time to prepare and fine-tune the model and the use of a software like FREEVAL, STREETVAL, or Highway Capacity Software (HCS).

Reliability Forecasting

In this study, the forecasted reliability measures were compared with reliability estimated for both the freeway case study (I-95 in Miami-Dade County) and the arterial segment (Sunrise Blvd. in Broward County) based on real-world data. The followings are the tested reliability forecasting methods in this project, all of which were developed as part of the Reliability Program of the Strategic Highway Research Program 2 **(**SHRP2**):**

- SHRP2 L03 Project Data-Poor Procedure
- SHRP2 L03 Project Data-Rich Procedure
- SHRP2 L07 Project Procedure with Default Parameters
- SHRP2 L07 Project Procedure Calibrated for Miami by Florida International University as part of the SHRP2 L38 project
- SHRP2 C11 Project Procedure
- SHRP2 C11 Project Procedure Calibrated for the Tampa Bay Region as part of a federal grant
- SHRP 2 L08 procedures as adopted in the HCM and implemented in FREEVAL and HCS.

When considering the three peaks, the models that produced the best forecasts of reliability compared to data-based reliability estimation for the freeway segment is the SHRP2 C11 model calibrated for the Tampa Bay Area and the SHRP2 L03 Data Poor Model. The model that produced the best forecasts of reliability compared to data-based reliability estimation for the urban arterial study segment is the SHRP2 L03 Data Rich model. It should be noted that the overall reliability of the arterial test corridor appears to be relatively good, which did not allow testing the model under congested conditions. The performance under more congested conditions is being considered now.

5. ASSESSING THE IMPACTS OF ADVANCED TECHNOLOGIES

This chapter describes methods to estimate the impacts of the transportation system management and operations (TSM&O) and intelligent transportation systems (ITS) applications that are implemented in the updated version of the FITSEVAL tool, produced as part of this project. These applications include adaptive signal control, transit signal priority, freight signal priority, Connected Vehicles (CV)-based support of speed adjustment to support arrival on green, CV-based support of signalized safety, CV-based support of unsignalized intersection safety, CV-based hazard warning, and the effect of automation. Please, note that there many other applications that could have been included. The above applications were selected for the initial implementation. Additional applications will be added in the future as needed. This chapter also presents an overview of the updated version of the FITSEVAL tool.

5.1 Evaluation of Advanced Applications

ITS evaluation tools require three types of parameters: 1) Outcome Performance Modification Parameters, 2) cost parameters, and 3) benefit dollar values. The original FITSEVAL development effort as part of the original FDOT research project that resulted in the development of FITSEVAL (Hadi et al. 2008) identified methods to evaluate different ITS applications, based on an extensive review of literature. Default benefit, cost, and dollar value parameters were identified for use in the conjunction with the developed methods. The ITS applications that can be evaluated in the original version of FITSEVAL are:

- Incident management
- Ramp metering
- Advanced traveler information systems
- Smart work zones
- Road weather information systems
- Managed lanes
- Signal control
- Emergency vehicle signal preemption
- Transit vehicle signal priority
- Advanced public transit system
- Highway advisory radio (HAR) and dynamic message signs (DMS)
- Transit information system
- Transit security systems
- Transit electronic payment systems

As stated earlier, a different set of ITS implementations are included in the updated version of FITSEVAL to focus the development effort as it is implemented in a new platform. A strong focus in the updated version is on the impacts of connected vehicles (CV) and automated vehicles (AV). However, the assessment of additional applications can be added to the tool as needed. The following are the applications evaluated in the new version:

- Adaptive signal control with and without connected vehicle (CV) support
- Transit signal priority with and without CV support
- Freight Signal priority with and without CV support
- Speed adjustment of CV to support arrival on green
- CV applications to support of signalized intersection safety
- CV applications to support unsignalized intersection safety
- CV applications to support hazard warning
- Vehicle automation

Please, note that the above list should be considered as an initial list and other applications can be included by the FDOT in future efforts.

5.1.1 Outcome Performance Modification Parameters

Where applicable, the benefit parameters used in the original version of FITSEVAL are used as a starting point in this project. These parameters were updated in this document based on the following resources:

- A review of CV-based application benefits for arterials streets has been conducted, as part of an on-going research project conducted for the FDOT by the research team. The review conducted as part of that project (Project BDV29 977-41, entitled "Connected Vehicle to Vehicle-to-Infrastructure Support of Active Traffic Management") provides additional important inputs regarding the benefits of the ITS applications.
- The benefit data reported in the United States Department of Transportation (USDOT) Joint Program Office (JPO) benefit database (USDOT, 2019).
- The benefit data utilized in the TOPS-BC tool developed by the FHWA (Sallman et al., 2013)
- The parameters reported as part of FDOT District 5 FITSEVAL Phase 2 Effort (FDOT, 2016)

Gaps in the available information was identified and additional review is conducted as part of this project with focus on AV applications since the impacts of the CV-based arterial applications has already been reviewed as part of the project mentioned above and AV applications.

The parameters needed to assess the impacts of TSM&O/ITS application on mobility and reliability measures are required to modify the values calculated for the base conditions with no ITS applications. These parameters are referred to as mobility modification factors (MMF) and reliability modification factors (RMF) and obtained based on the resources mentioned earlier. In general, these parameters can be classified into:

- Modification factors that are the proportion improvements in the mobility and reliability outcome measures. The impacts of ITS in this case are calculated as the multiplication of the factors and the values of performance measures calculated using the procedures discussed in Chapter 3 including using speed-flow relationships, highway capacity procedure, reliability estimation equations, real-world data, and possibly simulation modeling.

- Modification factors that are applied to the inputs of the analytical models that allow calculating the outcome measures rather than to the calculated the measures themselves. Examples of these measures can be the reduction in incident duration, percentage capacity drop due to incidents and work zones, lane-hour lost due to incidents, and capacity increase due to automated vehicles. This type of factors is preferred, if information is available to support it.

With regard to safety, the crash modification factors (CMF) of ITS applications are also obtained based on the resources mentioned above. These factors multiply the crash frequency for the highway segment with the base conditions assuming no ITS to obtain the crash frequency with ITS. As described earlier, the crash frequency with no ITS can be calculated using based on real-world data, safety performance functions, or the look-up table. It should be noted that, depending on ITS applications, the CMF may be applicable to all crashes, crashes of specific type (rear-end, sideswipe, pedestrian, left-turn, etc.), severity (fatal, injury, or property damage only (PDO)), or specific conditions (e.g., under incident or rainy conditions). Thus, the crash frequency has to be calculated first for the affected crash category and the result is multiplied by the CMF to account for the ITS impacts.

The ITS impact modification factors discussed in this document and as implemented in the updated version of FITSEVAL should be considered as initial values and should be updated when additional information become available. An on-going FDOT research center project is expected to provide recommendations for mobility and crash modification factors for TSM&O/ITS. The ITS impact parameters reported in previous evaluation studies, the benefit data reported in the USDOT JPO benefit database, and the results of field deployments should be continuously monitored to determine the most appropriate factors. The users shall be able to change the default parameters to reflect their reviews, judgment, and local conditions. The default and user input values for the ITS impact parameters shall include minimum and maximum values to allow conducting sensitivity or risk analysis.

The modification factors of different ITS applications as recommended in different sources and the values recommended for use as default in the new version of FITSEVAL are presented in the individual ITS Application sections, later in this document. Please, note all default values can be overridden by the user if better information is available.

5.1.2 Cost Parameters

Cost estimation is another required component of benefit-cost analysis. The cost estimation must consider the number and types of equipment required for each type of evaluated ITS deployment. FITSEVAL includes initial cost, operation and maintenance cost, estimated interest rate, and equipment life-time. The cost information also includes low, high, and average values for each item.

The study team reviewed the following cost data sources:

- The cost data reported in the United States Department of Transportation (USDOT) Joint Program Office (JPO) benefit database (USDOT, 2019).
- The cost data utilized in the TOPS-BC tool developed by the FHWA (Sallman et al., 2013).

- The parameters reported as part of FDOT District 5 FITSEVAL Phase 2 Effort (FDOT, 2016).
- The CV deployment cost used in the Near-Term V2I Transition and Phasing Analysis Life Cycle Cost Model tool (USDOT, 2015).
- Other data sources

The cost values of different ITS applications as recommended in different sources are presented in the individual ITS Application sections in this document. It should be pointed out that there is a lot of uncertainty in the cost of emerging technologies like those associated with CV and automated vehicle (AV)-based applications. Thus, the provided values should be considered as a starting point and further information should be used if more accurate costs can be estimated.

5.1.3 Conversion to Dollar Values

An important component of benefit-cost analysis is to convert ITS impacts to dollar values. The original version of FITSEVAL has default parameters to convert the mobility, safety, emission, and fuel consumption to dollar values. The FDOT District 5 FITSEVAL effort recommended updates to these parameters. The transportation Benefit-Cost Analysis wiki (B-C Wiki) that is sponsored by the TRB Committee on Transportation Economics (http://bca.transportationeconomics.org/) presents a detailed set of recommended values.

In addition to travel time cost, measures of reliability or variability has been used some times as part of the benefit dollar values. The standard deviation of travel time and other measures such as the differences of percentiles. The difference between the 80th percentile and median is used in this study. Previous research has estimated the ratio of the dollar value of travel time reliability to the dollar value of travel time referred to as travel time reliability value ratio to be between 0.8 and 1.3 based on stated preference surveys (B-C wiki, 2019). However, the decision to include this measure in the benefit-cost evaluation is left to the analyst since there may be a concern about double counting the benefits if both the travel time and travel time reliability values are included in the analysis.

Table 5-1 shows the dollar values of mobility, reliability, and safety; recommended in different sources and the values recommended for use as defaults in the new version of FITSEVAL.

Table 5-1: Dollar Values of Mobility, Reliability, and Safety

Parameter	Source	General Traffic ($/person-hr)	Freight Traffic ($/veh-hr)
Travel Time	FITSEVAL	13.45	71.05
	TOPS-BC	14	28
	2015 Urban Mobility Report (Schrank et al., 2015)	17.67	94.04
	District 5 Update (Based on Urban Mobility Report)	17.67	94.04
	Default Values for the C11 reliability tool	19.86	36.05
	TRB B-C Wiki	According to Litman (2009) unit time value for commuters are calculated as 50% of average wage under level-of-service (LOS) A-C, but increase to 67% at LOS D, 84% at LOS E and 100% at LOS F. For non-commuters, San Francisco planning analysis use 0.32 of wage rate	Various studies reported different values ranging from $36 to $196
	Utilized Values	17.67 More detailed values can be derived locally based on the method presented in the TRB-BC Wiki	$94
Reliability	TRB B-C Wiki	Travel time reliability value ratio between 0.8 and 1.3 (B-C wiki, 2019)	Travel time reliability value ratio between 0.8 and 1.3 (B-C wiki, 2019)
	Utilized Values	0.8 multiplying the difference between the 80th percentile and median	0.8 multiplying the difference between the 80th percentile and median
Safety	FITSEVAL	Urban Street Fatal $2,771,48, Injury $66,397, PDO $1,776 Urban freeway $3,079,351, $73,390, $1,776	
	District 5 Update	1 Fatal [K] $10,230,000 2 Incapacitating [A] $580,320 3 Non-Incapacitating [B] $157,170 4 Possible or Minor [C] $97,650 5 Property Damage Only [O] $7,600	

	TOPS-BC	Fatality Cost - $6,500,00 Injury Cost - $67,000 PDO - $2,300
	TRB B-C Wiki	Blincoe, et al. state that the value of a fatality lies in the range of $2-7 million, and assign a “working value” of $3,366,388. This suggests that a reasonable range is from about 40% lower to about 200% higher than their assigned values, at least for crashes involving significant non-market (quality of life) damages
	Highway Safety Manual	1 Fatal [K] $4,008,900 2 Disabling Injury [A] $216,000 3 Evident Injury [B] $79,000 4 Fatal/Injury [K/A/B] $158,200 5 Possible Injury [C] $44,900 6 Property Damage Only [O] $7,400
	Utilized Values	$3,300,000, $75,000, $3,000 for fatal, injury, and PDO crashes; respectively

5.1.4 Considering Uncertainty

Benefit–cost analyses of ITS alternatives produce point estimates of the return on investment of ITS deployments. These analyses used default or user input values of the cost, benefit, and dollar values of the benefits. However, there is a great amount of uncertainty associated with these parameters. The values of the parameters as reported in previous evaluation studies vary widely. Decision makers may not be willing to accept an alternative that has an acceptable average or median benefit–cost ratio but has a 25% probability of having a low benefit–cost ratio or if there is a relatively high probability that the budget of the project will be high. The uncertainty is even higher when dealing with connected and automated vehicle technologies. To account for the uncertainty, two approaches can be used:

Sensitivity analyses: This type of analysis involves separately varying the individual values of key input parameters of the return-on-investment analyses. This approach, however, does not allow the analyst to identify confidence limits and probabilities for the results of the analysis. To apply this approach, a range is established for each input variable based on previous studies. The high, low, and most likely values are identified. The next step is to calculate the benefit-cost measures using the most likely values of all variables. Then, for each variable, the benefit-cost measures are calculated with the high and low values of the variable, while fixing the other variable values at the most likely values. This will allow the identification of the range of the benefit-cost measure and how sensitive is the measure to the value of each variable.

Risk analyses: Risk analyses have been used to account for uncertainty in return on investment by expressing the input parameters as probability distributions rather than as fixed values. Usually, Monte Carlo simulation procedure is used as part of the risk analysis to vary the input parameters and identify probability distributions for each resulting performance measure such as the benefit-cost ratio or net worth value. An issue with this approach is that the distributions is that the distributions of the variables themselves are uncertain. The lognormal distribution has been used in estimating the evaluation of the benefits and costs in the project decision-making process. In a previous study conducted by the FIU research team (Yang et al., 2007), a general procedure was used to perform risk analysis in the evaluation of ITS benefits and costs. The procedure utilized lognormal distribution as part of Monte Carlo simulation process to describe the random variations in the input parameter values. The parameters of the lognormal distributions were estimated based on the highest and lowest values of the benefits reported in the literature. The method used to estimate these parameters are estimated in that paper (Yang et al., 2007).

The method recommended for the updated version of FITSEVAL is based on the risk analysis method described in Yang et al. (2007) paper. The first version of FITSEVAL does not include this feature but this will be included in a future effort.

5.2 Adaptive Signal Control with and without CV Support

Adaptive Traffic Signal Control (ATSC) allows better control of the intersection allowing green time adjustment based on the arrival traffic pattern. Due to stochastic nature of traffic arrival, the green time needs to be adjusted from cycle to cycle. ATSC will be able to make this adjustment, providing improvement in system performance. ATSC is one of the focus area for FDOT Statewide Arterial Management Program (STAMP) and the FDOT Transportation System Management and Operations (TSM&O) program.

There are some limitations with existing ATSC systems. In addition to the additional needs for sensors, these systems utilize aggregate traffic data from point detectors such as volumes and occupancies. Existing adaptive systems and associated algorithms are still constrained by the low fidelity of data available from current point detection technologies. These constraints limit the system awareness of the state of the traffic, which reduces the performance of adaptive signal control. Thus additional benefits are expected to be realized due to the application of adaptive signal control system that is supported by CV technology.

The following is a brief description of the method used to estimate the benefits of ATSC.

Mobility: A MMF is selected for the reduction in travel time and multiplied by the travel time estimated based on flow-speed relationship, HCM-based method, simulation, or real-world data. The MMF utilized previously and used in the updated version of FITSEVAL are shown in Table 5-2. Please, note that it assumes that the ATSC systems will provide more improvements in understated conditions. Also, please note that it is assumed that the benefits of adaptive signal control increases linearly with the increase in the market penetration of CV, if CV-based information are used to improve the control system. The market penetration growth rate that is a user input determines the number of connected vehicles for each year in the future but a default growth rate is used in the tool based on Iqbal et al. (2018).

Reliability: The reliability is calculated utilizing SHRP 2 L03 data poor model. This is because the SHRP 2 L03 data poor model is a function of the recurring mean travel time that is estimated with and without ATSC when estimating the mobility impacts. Therefore, the L03 model allows direct estimation of the reliability impact of the ATSC.

Safety: 17% reduction in property damage only crashes based on a previous study as shown in Table 5-2. This benefit is assumed to increase linearly to 27%, as the market penetration of CV increases from 0% to 100%, if CV-based information is used to improve the control system.

Table 5-2: The Benefit Parameters of ATSC

Outcome Measure	***Source***	***Congested Conditions***	***Uncongested Conditions***
Mobility	Existing FITSEVAL	10%	
	On-Going FDOT Project Recommendation (BDV28 TWO 977-41)	-5% without CV. -15% with 100% CV MP -Linear interpolation between 5% and 15% for lower market penetration	-10% without CV -25% with 100% CV MP. -Linear interpolation between 10% and 25% for lower market penetration
	10th Street Corridor in Greeley, Colorado Evaluation (Sprague and Archambeau 2012)	9% improvement in travel time	
	HCM Urban STREET ATDM Procedure Document (Hale et al., 2017)	5.1% to 13.5% increase in speed on the major road (average 10.2 mph) 1.2% to 5.4% increase in speed on minor road (average 4%)	
	Utilized Values	Same as BDV28 TWO 977-41	Same as BDV28 TWO 977-41
Safety	Fontaine et al. (2015)	17 percent reduction in total intersection crashes, although no significant change in fatal or injury crashes occurred.	
	Utilized Values	17 percent of PDO crashes	

Table 5-3 shows the cost parameters of ATSC in previous studies and what is utilized in the updated version of FITSEVAL.

Table 5-3: The Cost Parameters of ATSC

Source	***Estimated Cost (Dollars) per intersection***	
	Capital	***O&M per year***
Existing FITSEVAL	38,000	6,000
TOPS-BC	78,770	12,540
USDOT Cost Database	8,000 – 60,000 based on system (Curtis E., 2011)	-
Utilized value	\$75,000 per intersection without CV \$100,000 per intersection with CV	\$12,000 per intersection without CV \$20,000 per intersection with CV

5.3 Transit and Freight Signal Priority with and without CV Support

Transit Signal Priority (TSP) and Freight Signal Priority (FSP) uses technology to realize approaching high priority vehicles and alter signal timings to provide priority control to transit/freight vehicles. The priority provisions are classified into two categories: conditional and unconditional. To get conditional priority, when detected, the transit/freight vehicle must meet the specified conditions, such as the number of passengers, freight category, route schedule adherence, or the time since last priority is awarded. Utilized priority strategies include green extension, early green, and to lesser extents actuated transit phase, phase insertion, and phase rotation. The priority requests can be made at the central level through center-to-center communication such as between the traffic management center with the transit management center and/or the freight management center/Intermodal terminal. It can also be made using a distributed (local) priority architecture.

CV-equipped vehicles can be tracked at a relatively long distance upstream of the intersection. This allows downstream signals to recognize the need to provide the priority earlier than what can be done with existing distributed priority implementations. This allows the controller to better prepare for the priority such as serves the phases with non-priority calls to reduce the delays for the vehicles served by these faces. Another example of the benefits of CV-based priority application is that it allows transit vehicles making a left-turn that are blocked by either a short left-turn pocket or long queue for the through movement which blocks the access of the left-turning bus to the left-turn pocket. When such a condition is detected, the system grants priority for the through movement to clear the queue to allow the transit vehicle to access the left-turn pocket sooner and grant priority for the left-turn movement to reduce delay of the transit vehicle. In addition, on-board CV units can be used to inform priority vehicle drivers that their priority requests will be met. Another challenge that faces existing TSP implementations that is uncertainty of dwell time associated with nearside bus stops. The nearside stop issue can be addressed by including bus door open/close status in the priority request messages combined with location information on the nearside stop. The queue between the bus and the nearside stop can be also considered.

The following is a brief description of the method used to estimate the benefits of TSP and FSP.

Mobility: MMF of the impacts of signal priority on transit or fright vehicles is multiplied by the travel time estimated based on flow-speed relationship, HCM-based method, simulation, or real-time data. Additional delay is added to the cross street vehicles, as indicated in Table 5-4. The agency may decide not to implement priority on all intersections. In addition, the agency may decide to implement conditional priority (such as schedule adherence, number of bus passengers, type of freight shipment, and/or weight-to-power ratio of the truck). If the priority is conditional, the benefits are only calculated for the buses that meet the conditions (default 60%). Thus, the benefits will be calculated as follows:

$$T_{with-TSP} = T_{without-TSP} * (1 - \%\, reduction\ in\ priority\ vehicle\ TT * \%vehicles\ that\ meet\ conditions * percentage\ of\ intersections\ that\ can\ be\ equipped) \quad (5\text{-}1)$$

For TSP, the saving in travel time is converted to passenger hour saving per year based on the number of passengers per bus. For freight, the saving in travel time is converted to truck-hour savings per year and then converted to dollar values considering the higher values of truck delays.

Reliability: The reliability is calculated utilizing SHRP 2 L03 data poor model. This is because the SHRP 2 L03 data poor model is a function of the recurring mean travel time that is estimated with and without TSP when estimating the mobility impacts. Therefore, the L03 model allows direct estimation of the reliability impact of the TSP.

Safety: CMF is applied to transit PDO crashes based on a previous study, as shown in Table 5-4.

Table 5-5 shows the cost parameters of priority implementation in previous studies and what is utilized in the updated version of FITSEVAL.

Table 5-4: Benefit Parameters of Priority Implementation

Outcome Measure	***Source***	***Without CV***	***With CV***
Mobility	Existing FITSEVAL	12% reduction in travel time applied to buses that are not on time. Increase in cross street delay by 6-15 seconds per vehicle depending on congestion levels	
	On-Going FDOT Project (BDV28 TWO 977-41)	12% decrease in bus travel time with increase in cross street delay by 6-15 seconds per vehicle depending on congestion levels	15% to 25% decrease in bus travel time depending on CV market penetration. Increase in cross street delay by 6-15 seconds per vehicle depending on congestion levels
	Utilized Values	Same as BDV28 TWO 977-41	Same as BDV28 TWO 977-41
Safety	Song and Noyce Study (2019)	Reduction in property-damage-only crashes of 10.0 percent	
	Utilized Values	10% reduction in transit PDO crashes	

Table 5-5: Cost Parameters of Priority Implementation

Source	***Estimated Cost per intersection***	
	Capital	***O&M per year***
Existing FITSEVAL	7,000	2,800
TOPS-BC	$33,000	$1,800
District 5 Study	$20,000 per intersection	$7,000
Utilized Values	Infrastructure Unit $25,000 per intersection. On-Board Unit 7,000 per bus or truck	$7,000

5.4 Speed Adjustment to Support Arrival on Green

Green Light Optimal Speed Advisory (GLOSA) is a CV-based application that involves providing information and guidance to drivers as they approach traffic signals to allow them to adjust their speeds to reduce the probability of stopping at downstream intersection. The speeds are calculated based on the vehicle's location and Signal Phase and Timing (SPaT) messages and communicated to the vehicle using dedicated short-range communication (DSRC) or cellular communications. A more advanced application, referred to as Glide Path, automatically adjusts the speeds of the vehicles to allow them to arrive on green. An extension of this application is to combine adaptive signal control with GLOSA optimize the signal control.

The following is a brief description of the method used to estimate the benefits of GLOSA and Glide Path

Mobility: The travel time of connected vehicles is multiplied by a MMF factor that reflect the impact of the specific application (GLOSA or Glide Path), as shown in Table 5-6. The market penetration growth rate that is a user input determines the number of connected vehicles for each year in the future. A default growth rate is included in the tool based on Iqbal et al. (2018).

Reliability: The reliability is calculated utilizing SHRP 2 L03 data poor model. This is because the SHRP 2 L03 data poor model is a function of the recurring mean travel time that is estimated with and without the GLOSA and Glide Path applications when estimating the mobility impacts. Therefore, the L03 model allows direct estimation of the reliability impact of the GLOSA and Glide Path.

Safety: It is assumed that the PDO of CV with this application is reduced by the same proportion of the improvement in mobility.

Table 5-6: The Benefit Parameters of GLOSA and Glide Path

Outcome Measure	Source	GLOSA	Glide Path
Mobility	On-Going FDOT Project (BDV28 TWO 977-41)	5% of CV travel time	15% of CV travel time
	Utilized Values	3%-10% of CV travel time	10%-20% of CV travel time

Table 5-7 shows the cost parameters of GLOSA and Glide Path utilized in the updated version of FITSEVAL.

Table 5-7: The Cost Parameters of GLOSA and Glide Path

Source	***Application***	***Estimated Cost per intersection***	
		Capital ($)	***O&M per year ($)***
Utilized Values		Infrastructure Unit $40,000 per intersection. On-Board Unit 7,000 per bus or truck	$7,000

5.5 CV Application Support of Signalized Intersection Safety

CV-based applications have been proposed to provide solutions to address transportation safety concerns. A number of these applications have been suggested to support signalized intersection safety including Signalized Left Turn Assist (SLTA), Red Light Violation Warning (RLVW), and Pedestrian in Signalized Crosswalk Warning (PCW).

The benefits of these applications are calculated as follows:

Mobility: Some safety applications, particularly the non-CV solutions may have adverse impacts on mobility. For example, protecting a left turn to increase its safety will result in increase in intersection delay. This adverse impacts can be calculated based on HCM-based or simulation-based analysis.

Reliability: The reduction in crashes will increase the reliability of the traffic stream due to the reduction of non-recurrent delay. The SHRP 2 L03 model cannot account for this since it does not account for the reduction in non-recurrent delay. Thus, the SHRP 2 C11 model reliability model that estimate travel time reliability based on AADT and non-recurrent delay will be used. The non-recurrent delay in this model accounts for the reduction in the number of incidents due the safety applications.

Safety: The base number of crashes for the evaluated intersection without the application is calculated based on actual real-world data, utilizing the table look-up method, or the Florida SPF functions. CMF were estimated for CV-based solutions and non-CV based solutions to the safety issues based on a review of what is available in the literature. The base crash frequency is then multiplied by these CMF the predicted number of crashes with different safety applications. A summary of the identified CMF are presented in Table 5-8. Depending on the application, the modification factors may be only applied to specific types of crashes such as pedestrian or rear-end crashes or specific severity such as injury or PDO.

Table 5-8: Summary of the Identified CMF for Safety Applications to Signalized Intersections

Function	Application		CRF (%)	Crash Type
Left Turn Assist	Without CV	Change from permissive only to flashing yellow arrow permissive only (Simpson and Troy, 2015)	10.8 - 31.1	All
			50.2 - 65.1	Left turn
		Change from permissive only to protected with permissive (Simpson and Troy, 2015)	6.50 - 34.6	All
			40.2 - 40.8	Left turn
		Change from permitted or permitted-protected to protected on major approach (Davis and Aul, 2007)	99	Angle
			42	All
		Change permissive left-turn phasing to protected only	55	All
			51	Rear end

		(Chen et al., 2015)		77	Left turn
				64	HO/SS
	With CV	Signalized Left Turn Assist (SLTA) (BDV28 TWO 977-41)		36 - 70	All
Utilized Values		***Without CV***		***10- 35***	***All***
		With CV		***36 - 70***	***All***
Right Turn Assist	Without CV	Prohibit right-turn-on-red (HSM, 2010)		2	All
		Install offset right turn lane (Maze et al., 2010)		6.15	All
	With CV	Signalized Right Turn Assist (SRTA) (BDV28 TWO 977-41)		25 - 50	All
Utilized Values		***Without CV***		***2 - 5***	***All***
		With CV		***25- 50***	***All***
Red Light Violation	Without CV	Implement automated red light running enforcement cameras	Hallmark et al., 2010; Haque et al., 2010; Persaud et al., 2005	20 - 40	All
			Persaud et al., 2005; Shin and Washington, 2007	-24 to -45	Rear end
			Walden, 2011	24	Angle
		Installation of fixed combined speed and red light cameras (De Pauw et al., 2014)		14 - 28	All
				11	Angle/left turn
	With CV	Red-Light Violation Warning (RLVW) (BDV28 TWO 977-41)		25 - 50	All
Utilized Values		***Without CV***		***15- 40***	***All***
		With CV		***25 - 50***	***All***
Pedestrian Support	Without CV	Rectangular Rapid Flash Beacon (RRFB) (Monsere et al., 2018)		7	All
		Install pedestrian countdown timer (Kitali et al., 2017)		4.8 – 8.8	All
				70	Veh/pedestrian
		Implement Barnes Dance (Chen et al., 2012)		-10	All
		Install a pedestrian hybrid beacon (PHB or HAWK) (Fitzpatrick and Park, 2010)		15- 29	All
		Increase cycle length for pedestrian crossing (Chen et al., 2012)		45	All
	With CV	Pedestrian in Signalized Crosswalk (PSCW) (BDV28 TWO 977-41)		50 - 100	All
Utilized Values		***Without CV***		***5- 45***	***All***
		With CV		***50 - 100***	***All***

The cost parameters of the safety applications to signalized intersection are presented in Table 5-9.

Table 5-9: Summary of the Cost Parameters of the Safety Applications to Signalized Intersections

Source	***Application***	***Estimated Cost per intersection***	
		Capital ($)	***O&M per year ($)***
Life Cycle Cost Model (LCCM)	Red Light Violation Warning - DSRC (RLVW)	$85,000 including RSU and integration	$5,500
	Pedestrian in Signalized Crosswalk Warning - DSRC (PSCWT)	$240,000 including pedestrian detection and integration	$20,000
Utilized Values		Based on the above	

5.6 CV Application Support of Unsignalized Intersection Safety

There are non-CV applications that can be used to increase the safety of un-signalized intersection safety. For example, flashing beacons can be used to warn drivers of a stop sign ahead. Another example is the modification of unsignalized intersection to J-turn intersection to increase the intersection safety.

Reliability: The reduction in crashes will increase the reliability of the traffic stream due to the reduction of non-recurrent delay. The SHRP 2 L03 model cannot account for this since it does not account for the reduction in non-recurrent delay. Thus, the SHRP 2 C11 model reliability model that estimate travel time reliability based on AADT and non-recurrent delay will be used. The non-recurrent delay in this model accounts for the reduction in the number of incidents due the safety applications.

Safety: The introduction of CV technology can provide safety benefits for unsignalized intersections. Two such applications have been suggested: Stop Sign Violation Warning (SSVW), and Stop Sign Gap Assistance (SSGA). SSVW warns the vehicle driver if the vehicle is predicted to violate a stop sign. This application will reduce crashes with the cross-street traffic and may also reduce the number of rear-end. The SSGA provides advisory information to cross-street drivers at a stop-sign controlled intersection to support their gap selections at the intersection. To estimate the benefits, the base number of crashes without unsignalized intersection applications is calculated based on real-world data or utilizing the table lookup method or the Florida SPF curve. CMF, identified based on the literature, are then multiplied by the base number of crashes to predict the number of crashes with the unsignalized intersection applications. A summary of the identified CMF are presented in Table 5-10.

The cost parameters of the safety applications to unsignalized intersection are presented in Table 5-11.

Table 5-10: Summary of the Identified CMF for Safety Applications to Unignalized Intersections

Function	Application		CRF (%)
Stop Sign Violation Warning	Without CV	Add centerline and STOP bar, replace 24-inch with 30-inch stop signs (ITE, 1993)	67
		Increase retro reflectivity of STOP signs (Persaud et al., 2007)	9.4
		Install double stop signs (ITE, 1993)	55
		Provide flashing beacons at stop controlled intersections (Srinivasan et al., 2008)	13
		flashing LED stop sign (Xiong and Davis, 2012)	41.1
	With CV	Stop Sign Violation Warning (SSVW) (BDV28 TWO 977-41)	50 - 100
Utilized Values		***Without CV***	***10- 60***
		With CV	***50- 100***
Stop Sign Gap Assist	Without CV	-	-
	With CV	Stop Sign Gap Assist (SSGA) (BDV28 TWO 977-41)	28
Utilized Values		***Without CV***	-
		With CV	***28***

Table 5-11: Summary of the Cost Parameters of the Safety Applications to Unsignalized Intersections

Source	***Application***	***Estimated Cost per intersection***	
		Capital ($)	***O&M per year ($)***
Life Cycle Cost Model (LCCM)	Stop Sign Gap Assist - DSRC (SSGA)	$260,000 including detection, integration, RSU, and DMS	$15,000
	Stop Sign Violation Warning - DSRC (SSVW)	$160,000 including road weather detection, small DMS, roadside unit and integration	$9,000
Utilized Values		Based on the above	

5.7 Hazard Warning

Existing safety solutions that assist drivers along a roadway segment includes warning drivers of unsafe speeds/ unsafe speeds on curves, warnings drivers of oversize vehicles, warning drivers of bad weather and pavement conditions, and railroad crossing warning. Different CV applications that assist driver on hazard warning are Reduced Speed Zone Warning (RSZW), Curve Speed Warning (CSW), Oversize Vehicle Warning (OVW), Spot Weather Information Warning (SWIW), and Railroad Crossing Violation Warning (RCVW).

Reliability: The reduction in crashes will increase the reliability of the traffic stream due to the reduction of non-recurrent delay. The SHRP 2 L03 model cannot account for this since it does not account for the reduction in non-recurrent delay. Thus, the SHRP 2 C11 model reliability model that estimate travel time reliability based on AADT and non-recurrent delay will be used. The non-recurrent delay in this model accounts for the reduction in the number of incidents due the safety applications.

Safety: The number of crashes without hazard warning is calculated based on real-world, utilizing the table lookup method or the Florida SPF functions. CMFs are then multiplied by these numbers to predict the number of crashes with hazard warning. The identified CMF for the hazard warning applications are shown in Table 5-12.

The cost parameters of the safety applications to unsignalized intersection are presented in Table 5-13.

Table 5-12: Summary of the Identified CMF for Safety Applications for Hazard Warning

Function	Application		CRF (%)
Speed Warning	Without CV	Implement automated speed enforcement cameras (HSM, 2010)	17
		Individual changeable speed warning signs (Elvik and Vaa, 2004)	41
		Install Variable Speed Limits (Pu et al., 2017)	29
		Install dynamic speed feedback sign (Hallmark et al., 2015)	5
		Implement mobile automated speed enforcement system (Li et al., 2015)	14.5
	With CV	Reduced Speed Zone Warning (RSZW) (BDV28 TWO 977-41)	50
Utilized Values		***Without CV***	***5- 40***
		With CV	***50***
Curve Speed Warning	Without CV	Changeable Curve Speed Warning signs (Tribbett et al., 2000)	2
	With CV	Curve Speed Warning (CSW) (BDV28 TWO 977-41)	20-30
Utilized Values		***Without CV***	***2***
		With CV	***20-30***

Oversize Vehicles Warning	Without CV	Oversize Load signs	-
	With CV	Oversize Vehicle Warning (OVW) (BDV28 TWO 977-41)	75-90
Utilized Values		***Without CV***	-
		With CV	***75-90***
Spot Weather Information Warning	Without CV	Improving Roadway Condition (Zeng et al., 2014)	15
	With CV	Spot Weather Information Warning (SWIW) (BDV28 TWO 977-41)	50
Utilized Values		***Without CV***	***15***
		With CV	***50***
Railroad Crossing Warning	Without CV	Install flashing lights and sound signals (Elvik and Vaa, 2004)	50
		Automatic gates (Elvik and Vaa, 2004)	45
	With CV	Railroad Crossing Violation Warning (RCVW) (BDV28 TWO 977-41)	50
Utilized Values		***Without CV***	***45 - 50***
		With CV	***50***

Table 5-13: Summary of the Cost Parameters of the Safety Applications to Unsignalized Intersections

Source	***Application***	***Estimated Cost per intersection***	
		Capital	***O&M per year***
Use the values from the FHWA Life Cycle Cost Model (LCCM) tool as a basis)	Curve Speed Warning - DSRC (CSW)	$200,000 including Road weather information sensor, small dynamic message sign (DMS), RSU, and software integration	$10,000
	Oversize Vehicle Warning - DSRC (OVW)	$150,000 including small DMS, RSU, and software integration	$7,000
	Spot Weather Impact Warning - DSRC (SWIW)	$200,000	$10,000
	Reduced Speed-Work Zone Warning - DSRC (RSWZW)	$200,000	$10,000
Utilized Values		Based on the above	

5.8 Effect of Automation

Automated Vehicle (AV) will play an important role both for increasing mobility and safety of the roadway. The updated version of FITSEVAL also incorporates the effect of automation on roadway as part of FITSEVAL tool. The introduction of different levels of automation will allow the reduction of crashes and the severity of injuries and will improve mobility, reliability, and accessibility of the transportation systems. In this study, we have reviewed the reported mobility and safety impacts for these levels of automation that are capable to target different percentages of crash population depends on the level of automation or combined levels of automation.

A technical report (Smith et. al., 2015) published by the USDOT titled "Benefits Estimation Framework for Automated Vehicle Operations" summarized a list of the following autonomous vehicle applications as shown in Table 5-14.

Table 5-14: List of Automated Vehicle Applications (Source: Smith et al. 2015)

Automation level	AV function
Level 0	Forward Collision Warning (FCW), Intersection Movement Assist (IMA), Blind Spot Warning (BSW) / Lane Change Warning (LCW)/ Blind Spot Monitoring (BSM), Road Departure Crash Warning (RDCW), Alcohol Detection Technology, Backup Assistant Systems (BAS), Lane Departure Warning (LDW), Pre-Crash Brake Assist (PBA), Pre-Crash Braking (PB);
Level 1	Automated Roadwork Assistance 1 Automatic Parking 1 Pedestrian Crash Avoidance and Mitigation Adaptive Cruise Control (ACC) Electronic Stability Control (ESC) Automated Emergency Braking (AEB)/ Emergency Braking System (EBS)
Level 2	Automated Roadwork Assistance 2 Automatic Parking 2 Traffic Jam Assist Lane keep/change/merge
Level 3	Automatic Parking 3 Platooning Emergency Stopping Assist
Level 4	Automatic Parking 4 Automated taxi/shuttle

Reliability: The reduction in crashes will increase the reliability of the traffic stream due to the reduction of non-recurrent delay. The SHRP 2 L03 model cannot account for this since it does not account for the reduction in non-recurrent delay. Thus, the SHRP 2 C11 model reliability model that estimate travel time reliability based on AADT and non-recurrent delay will be used. The non-recurrent delay in this model accounts for the reduction in the number of incidents due the safety applications.

Safety: CMF was identified based on reviewing previous studies as shown in Table 5-15. Such CMF can be used to multiply the base crash frequency estimated based on the real-world, lookup table, or SPF functions. Cooperative automated vehicles will also impact on the roadway capacity. A summary of the capacity improvement with different autonomous vehicle application is provided in Table 5-16.

Table 5-15: Safety Benefits of Vehicle Automation

Level of Automation	Application	CRF (%) /Safety Benefits
Level 0	BSM (Jermakian, 2012)	22,000 tractor-trailer crashes annually
	IIHS (2010)	33% of annual crashes
	LDW (Kusano et al. (2014))	29.4 % of all road departure crashes
	LDW (Blower 2014)	11 – 13 % Fatal and 2 – 9% Injury
	FCW (Kusano et. al., 2012)	3.2%
	FCW in heavy vehicles (Fitch et. al., 2008)	21 % of rear-end crashes
	FCW (Anderson et. al., 2012)	20 – 40 % of all fatal crashes 30 – 50 % of all injury crashes
	LWD (Penmetsa et. al., 2018)	2.7% of all lane departure crashes by (2020) and 16.4% by (2045)
	FCW + LDW (Kuehn et al., 2009)	25% of all crashes
	BSW/LCW + FCW (Jermakian,2011)	395,000 and 1.2 million crashes annually
Utilized Values		Based on the above
Level 1	IIHS (2010)	33% of annual crashes
	ESC (Blower, 2013)	7% in all crashes
	FCW + PBA (Kusano et. al., 2012)	3.6%
	ESC (Farmer, 2010)	33 – 20 % of all fatal multiple Vehicle crashes, 49% for single vehicle crashes, 35% for SUVs, 30% for cars
	Speed Harmonization (Dowling et. al., 2016)	Reduced the 95th percentile highest speed difference up to 30 – 50 %
	FCW + AEB (Sugimoto et al., 2005))	44% of fatal rear-end collisions
	FCW + AEB, Adaptive headlights (Moore et al., 2007)	10 - 14 % reduction in claims
	EBS (Cicchino, 2016)	41 % of rear-end crashes
Utilized Values		Based on the above

Level 2	FCW + PBA + PB (Kusano et. al., 2012)	7.7% of all rear-end crashes
	FCW, ACC, and AEB (Batelle, 2007)	23–28 percent of rear-end crashes
Utilized Values		Based on the above
Level 3	Banerjee et al., 2018	20 to 4000 times worse
Utilized Values		Based on the above
Level 4	Morando et al., 2018	20% to 65% (Signalized Intersections) 29% to 64% (roundabouts)
Utilized Values		***20% - 65%***
Level 5	NHTSA (nde)	94%
Utilized Values		***94%***

Table 5-16: Capacity Benefits of Vehicle Automation

Author	Automated Application	Capacity Benefits
Shladover et al., 2012	Cooperative Adaptive Cruise Control (CACC)	50% and 80% increase in capacity at 80% and 100% market penetration, respectively
Tientrakool et al., 2018	FCW	43% at 100% market penetration
	FCW + V2V Communication	273% at 100% market penetration
Oila et al., 2018	CACC	300% at 100% market penetration
Wang et al., 2017	CACC	150% at 70% market penetration
Utilized Values		Based on the above

5.9 FITSEVAL Update

The original version of FITSEVAL was produced utilizing the Script language of Cube. It works only as a processor to cube provided input and output files, in addition to analyst supplied parameters utilizing the user interface. The new version of FITSEVAL is a standalone desktop tool that reads files from multiple sources as long as it is provided in an acceptable format. The currently acceptable format are Cube files and Highway Capacity Software (HCS) file format. The source of the data can be any model or real-world data as long as it is converted to one of these two formats. The software itself is coded in the C# language. The user does not need to use the C# language to utilize the tool since it is compiled and used in an executable form. The final product is an executable file which could be run on any windows platform. Thus, the user only needs to interface with the tool through the graphical user interface (GUI), input files, and output files.

Figure 5-1 shows the assessment of the base condition mobility based on demand model outputs (FSUTMS model). The user has the option to utilize the travel time estimated by the demand model or to override the travel times utilizing previously calibrated travel time-volume/capacity equations that were found in this study to perform well compared to other equations. The volume and capacity used in these equation will be based on the demand model outputs. The individual link performance is presented in tabulator format at the lower half of the screen. The performance of the overall analyzed network is presented in the gauges at the upper half of the screen. The metrics estimated based on the demand model outputs are:

- Speed
- Excess delay
- Vehicle-mile traveled
- Vehicle-hour traveled
- Vehicle-hour delayed
- Vehicles per lane-mile
- Vehicle occupancy
- Percentage of Non-SOV
- Person-Trips
- Person-miles traveled

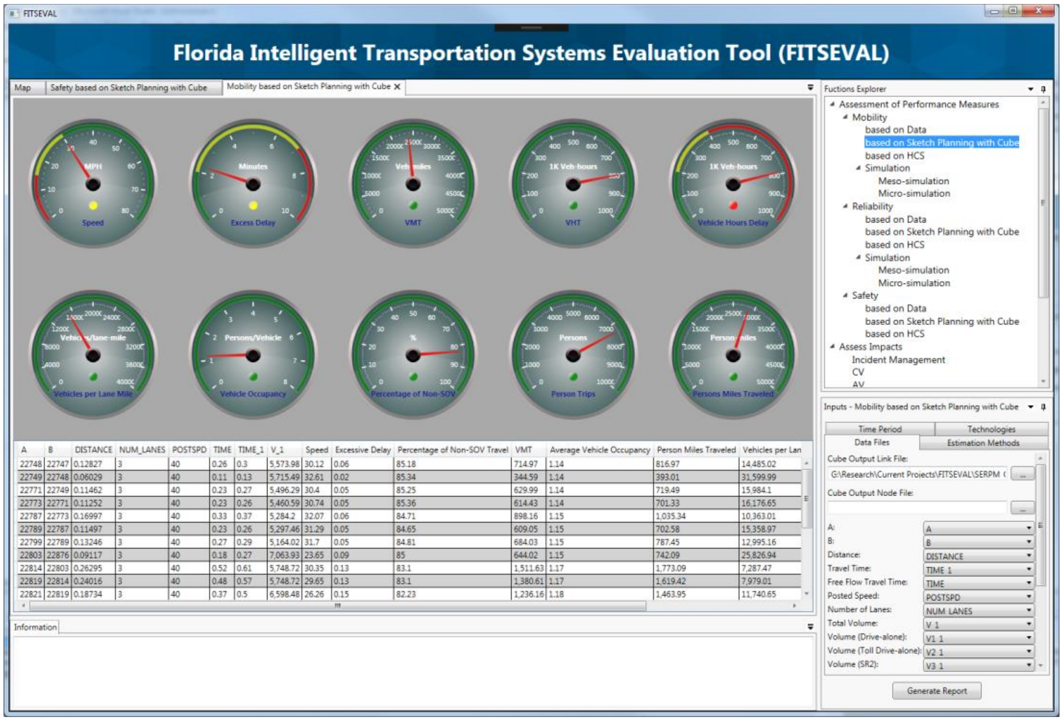


Figure 5-1: Mobility Performance Metric Estimation based on Demand Forecasting Models

Figure 5-2 shows the same type of assessment but based on the HCS outputs. Somewhat different metrics are calculated based on the outputs from the HCS model due to the availability of different types of information, as shown in Figure 5-2. The metrics estimated based on the demand model outputs are:

- Speed
- Excess delay
- Vehicle-mile traveled
- Vehicle-hour traveled
- Vehicle-hour delayed
- Vehicles per lane-mile
- Through Delay
- Stop rate
- Running Time

A powerful feature is that the user can put two or more different assessments side-by-side for comparison purpose. For example, in Figure 5-3, the mobility performance based on the HCS and that based on the demand model are compared. If the mobility assessment is also dome based on real-world data, the comparison can also be made with this assessment. Figure 5-4 shows a comparison of the assessment of mobility with and without CV-based adaptive signal control. Figures 5-5 and 5-6 show the reliability estimation based on the demand model outputs and HCS, respectively. Figures 5-7 and 5-8 show the safety estimation based on the demand model outputs and HCS, respectively.

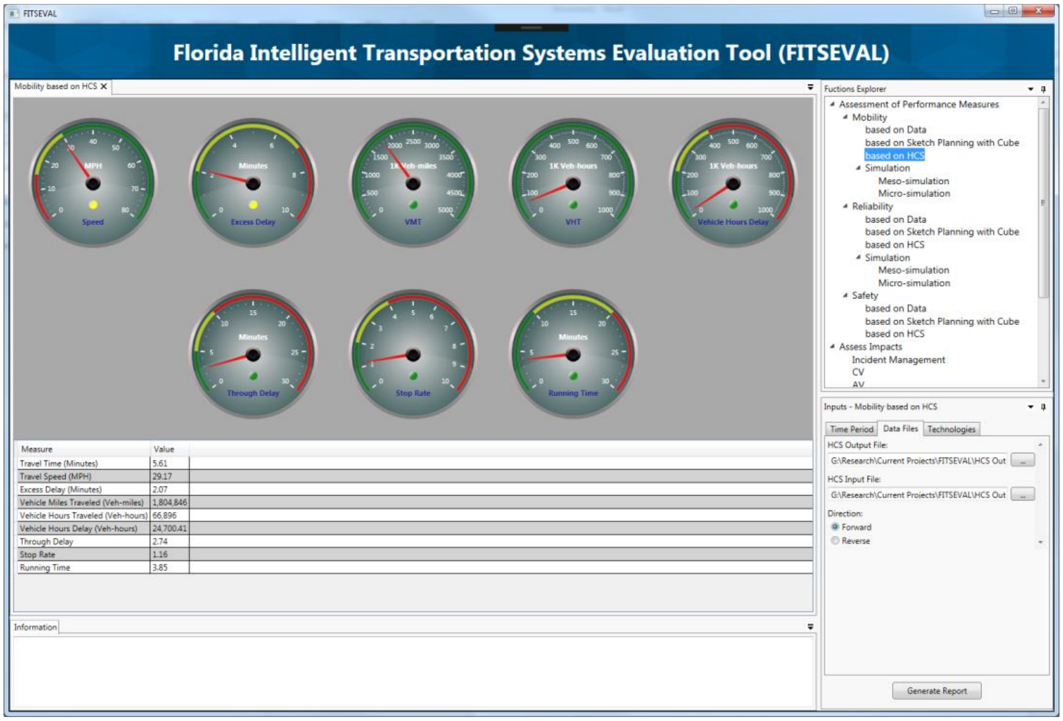


Figure 5-2: Mobility Performance Metric Estimation based on the Highway Capacity Software (HCS)

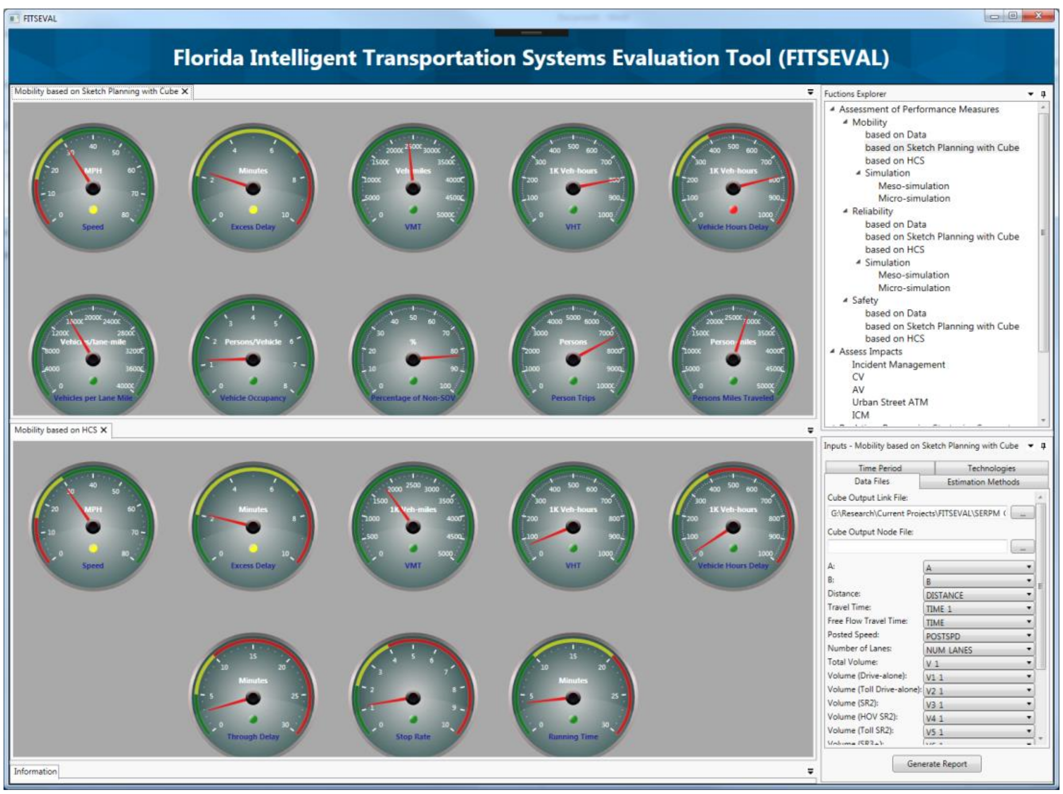


Figure 5-3: Comparison of Mobility Assessment based on Demand Model and HCS

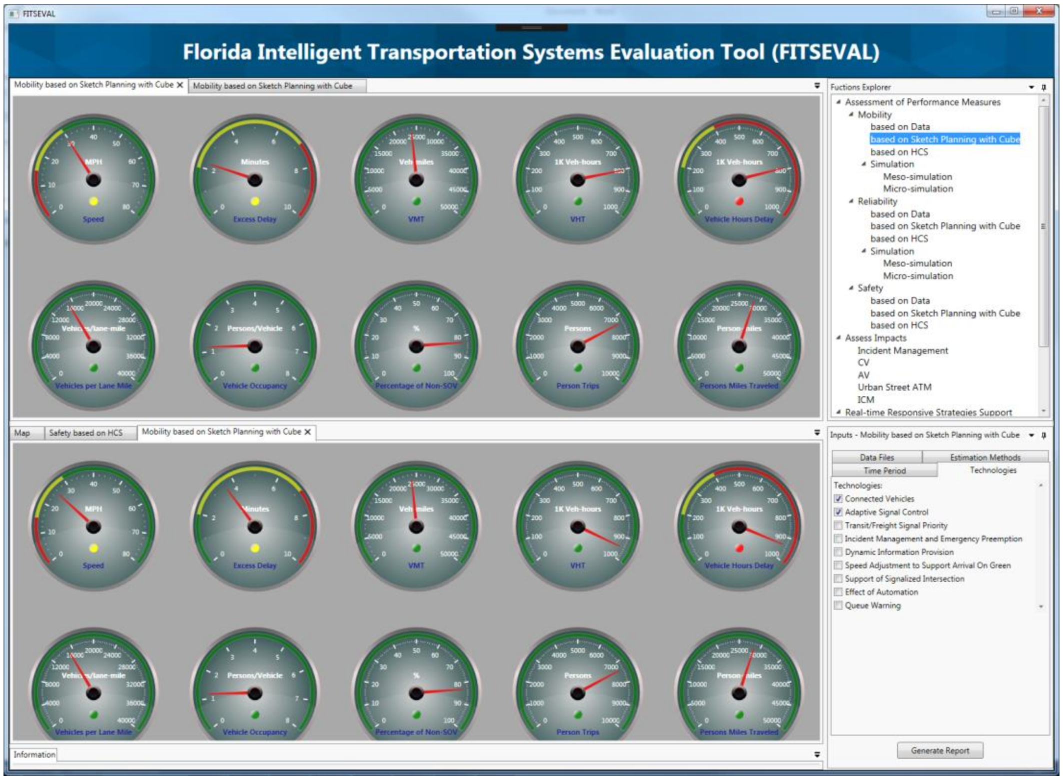


Figure 5-4: Comparison of Mobility with and without CV –based Adaptive Signal Control

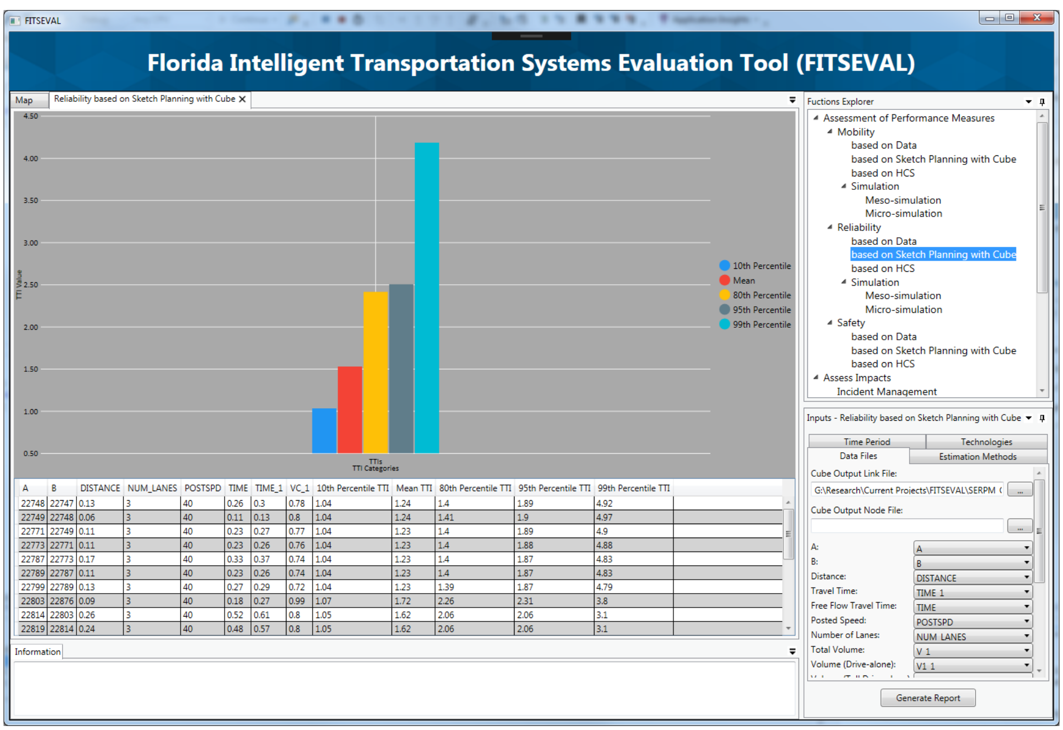


Figure 5-5: Reliability Estimation based on Demand Model Output

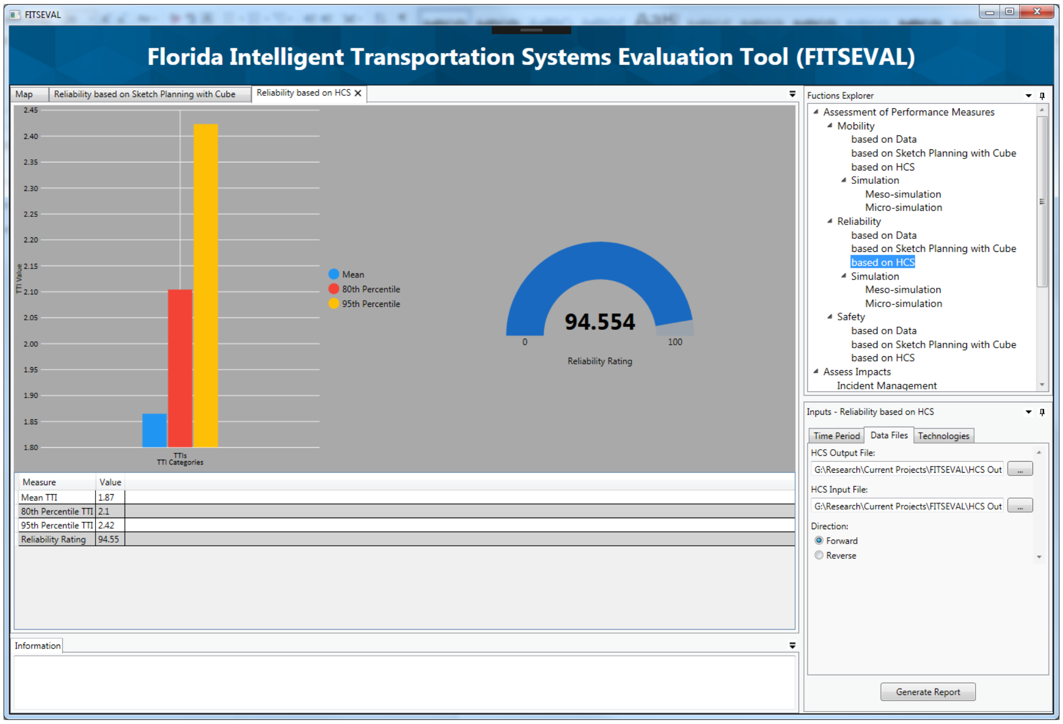


Figure 5-6: Reliability Estimation based on HCS Output

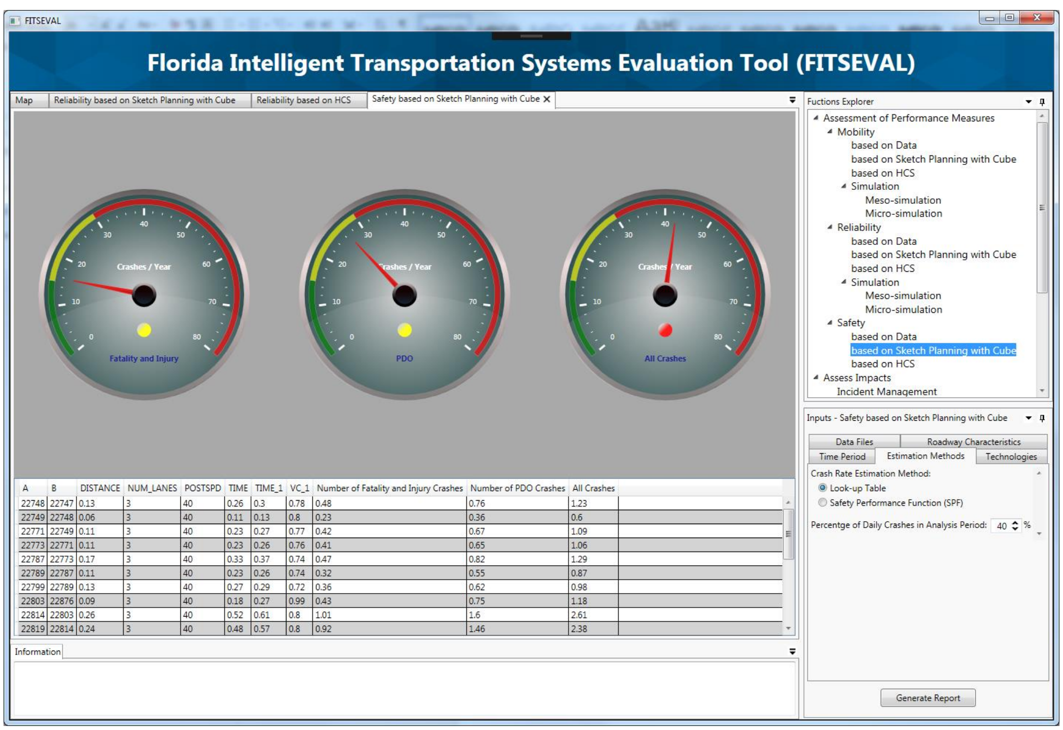


Figure 5-7: Safety Estimation based on Demand Model Output

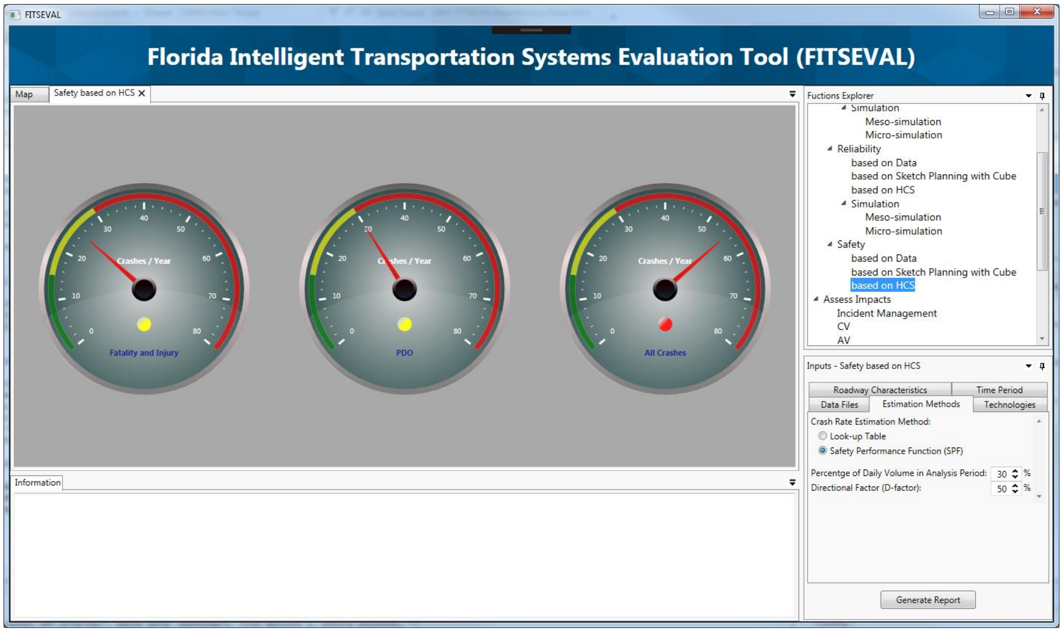


Figure 5-8: Safety Estimation Based on HCS Output

REFERENCES

Akcelik, R. (1978). A new look at Davidson's travel time function. *Traffic Engineering & Control*, 19 (N10).

Akçelik, R. (1991). Travel Time Functions for Transport Planning Purposes: Davidson's Function, Its Time Dependent Form and an Alternative Travel Time Function. *Australian Road Research*, 21(3), pg. 49-59.

Akçelik, R. (1996). Relating Flow, Density, Speed and Travel Time Models for Uninterrupted and Interrupted Traffic, *Traffic Engineering and Control*, 1996.

Alluri, P., Liu, K., Gan, A., Saha, D. (2016). *Generation of 2011-2014 Input Data for Safety Analyst*, State Safety Office, Florida Department of Transportation, Tallahassee, Fl.

Atkins North America. (2018). *Imagine 2040: Hillsborough Long Range Transportation Plan Summary Report*. Prepared for Hillsborough County Metropolitan Planning Organization for Transportation.

Anderson, R., Doecke, S., Mackenzie, J. R., Ponte, G., Paine, D., & Paine, M. (2012). Potential benefits of forward collision avoidance technology. *Injury*, 44(15), 24.

Battelle. (2001). *Evaluation Plan for the Volvo Intelligent Vehicle Initiative Field Operational Test*: *Draft Version 1.3*, (No. DTFH61-96-C-00077). U.S. Department of Transportation, Washington D.C.

Batelle, (2007). *Final Report Evaluation of the Volvo Intelligent Vehicle Initiative Field Operational Test Version 1.3* (Report No. FHWA-JPO-07-016). US Department of Transportation, Washington, DC.

Banerjee, S. S., Jha, S., Cyriac, J., Kalbarczyk, Z. T., and Iyer, R. K. (2018). Hands Off the Wheel in Autonomous Vehicles? A Systems Perspective on over a Million Miles of Field Data. *In 2018 48th Annual IEEE/IFIP International Conference on Dependable Systems and Networks (DSN)*, pp. 586-597. IEEE.

B-C Wiki. (2019). Transportation Benefit-Cost Analysis, Retrieved January 22, 2019, from http://bca.transportationeconomics.org/

Blower, D. (2014). *Assessment of the effectiveness of advanced collision avoidance technologies* (No UMTRI-2014-3). The University of Michigan.

Broward Metropolitan Planning Organization (Broward MPO). (2013). Commitment 2040 Goals, Objectives, and Measures. Retrieved on May 26, 2018 from http://www.browardmpo.org/images/WhatWeDo/LRTP/Report-2040LRTP-GoalsObjectives.pdf,.

Broward Metropolitan Planning Organization (Broward MPO). (2015a). Baseline Performance Reference Guide. Retrieved on May 26, 2018 from http://archive.browardmpo.org/userfiles/files/Report-BrowardMPO-BaselinePerformance-v12.pdf.

Broward Metropolitan Planning Organization (Broward MPO). (2015b). Hollywood/Pines Corridor Project Performance Measures. Retrieved on May 26, 2018 from http://www.browardmpo.org/images/WhatWeDo/CongestionManagement/HPperformance-measures.pdf.

Broward Metropolitan Planning Organization (Broward MPO). (2015c). Broward Complete Streets Evaluation Toolkits User Manual. Retrieved on May 26, 2018 from http://www.browardmpo.org/images/WhatWeDo/completestreetsinitiative/EvaluationToolkit.pdf

Broward Metropolitan Planning Organization (Broward MPO). (2018a). Unified Planning Work Program (UPWP) and Budget: July 1, 2018 – June 30, 2020. Retrieved on May 26, 2018 from http://www.browardmpo.org/images/WhatWeDo/UPWP/20180510-upwp.PDF.

Broward Metropolitan Planning Organization (Broward MPO). (2018b). Revisit & Update Mobility Hubs Program: Assess Current Methodology. Technical Memorandum. Retrieved on May 26, 2018 from http://www.browardmpo.org/images/WhatWeDo/Mobility_Hubs/TM1-Mobility_Hubs_Revisit-Assess_Current_Methodology-January_2018_FINAL.pdf.

Cambridge Systematics, et al. (2013). Analytical procedures for determining the impacts of reliability mitigation strategies. *Transportation Research Board Annual Meeting*, Washington D.C.

Cambridge Systematics, Inc. (2016). *SHRP2 C11 Post-Processor Tool: Technical Manual*. Prepared for the Florida Department of Transportation. Tallahassee, Florida.

Cicchino, J. B. (2016). Effectiveness of Volvo's City Safety low-speed autonomous emergency braking system in reducing police-reported crash rates. Insurance Institute for Highway Safety, Arlington, VA. Retrieved from https://cdn2.vox-cdn.com/uploads/chorus_asset/file/5970433/FCP_City_safety_effectiveness.0.pdf

Chen, L., Chen, C., & Ewing, R. (2012). The relative effectiveness of pedestrian safety countermeasures at urban intersections - Lessons from a New York City experience. *In Transportation Research Board (TRB) 91st Annual Meeting*, Washington, DC.

Chen, L., Chen, C., & Ewing, R. (2015). Left-turn phase: Permissive, protected, or both? A quasi-experimental design in New York City. *Accident Analysis & Prevention*, 76, 102-109.

Cornell Law School. (2018). 23 CFR Part 490 – National Performance Management Measures. Retrieved on April 28, 2018 from https://www.law.cornell.edu/cfr/text/23/part-490.

Curtis, E. (2011). *Adaptive Signal Control Technology Overview*. United States Department of Transportation, Federal Highway Administration, Washington, DC. Retrieved from https://www.itscosts.its.dot.gov/ITS/benecost.nsf/ID/0C2F309992BEB5C185257DF200634F56?OpenDocument&Query=CApp

Davidson, K. B. (1966). A flow travel time relationship for use in transportation planning. *In Australian Road Research Board (ARRB) Conference*, 3rd, 1966, Sydney (Vol. 3, No. 1).

Davis, G. A., & Aul, N. (2007). *Safety effects of left-turn phasing schemes at high-speed intersections* (No. MN/RC-2007-03). Minnesota Department of Transportation.

De Pauw, E., Daniels, S., Brijs, T., Hermans, E., & Wets, G. (2014). To brake or to accelerate? Safety effects of combined speed and red light cameras. *Journal of safety research*, 50, 59-65.

Dowling, R. (1997). *Planning techniques to estimate speeds and service volumes for planning applications.* Transportation Research Board, NCHRP Report No. 387.

Dowling, R., Margiotta, R., Cohen, H., & Skabardonis, A. (2013). *Guide for highway capacity and operations analysis of active transportation and demand management strategies*. No. FHWA-HOP-13-042.

Dowling, R., Nevers, B., Jia, A., Skabardonis, A., Krause, C., & Vasudevan, M. (2016). Performance benefits of connected vehicles for implementing speed harmonization. *Transportation research procedia*, 15, 459-470

Edara, P., Sun, C., & Breslow, S. (2013). *Evaluation of j-turn intersection design performance in Missouri* (No. cmr 14-005). Missouri. Dept. of Transportation. Organizational Results.

Elvik, R. and Vaa, T. (2004). *Handbook of Road Safety Measures*. Oxford, United Kingdom, Elsevier.

Farmer C. M. (2010). Effects of electronic stability control on fatal crash risk. *Insurance Institute for Highway Safety.*

FDOT System Planning Office. (2014). *Traffic Analysis Handbook: A Reference for Planning and Operations*. Florida Department of Transportation.

FDOT (2014b). Source Book Calculations Documentation. Prepared for Florida Department of Transportation, Retrieved October 2018 from http://www.fdot.gov/planning/FTO/mobility/Task4-Documentation.pdf

FDOT. (2016). Florida Intelligent Transportation Systems Evaluation (FITSEVAL) Phase 2 Efforts FDOT District Five Technical Memorandum: Benefit Development Refinement. Florida Department of Transportation: District 5, Broward, Fl.

FDOT. (2016a). 2016 Performance Report. Florida Department of Transportation, Retrieved April 28, 2018, from http://www.fdot.gov/planning/performance/2016/2016PerformanceReport.pdf.

FDOT. (2016b). Florida Multimodal Mobility Performance Measures Source Book. Florida Department of Transportation, Retrieved April 28, 2018, from http://www.fdot.gov/planning/statistics/sourcebook/2016MPM.pdf.

FDOT. (2016c). Florida/MPO Pilot National Performance Measures. Florida Department of Transportation, Retrieved April 28, 2018, from http://www.fdot.gov/planning/performance/StatewideWorkshop-092816-ALL.pdf.

FDOT. (2016d). Planning for Travel Time Reliability Guide. Florida Department of Transportation.

FDOT. (2017a). Transportation Systems Management & Operations (TSM&O) 2017 Strategic Plan. Florida Department of Transportation, Retrieved April 28, 2018, from http://www.fdot.gov/traffic/Doc_Library/PDF/2017%20TSM&O%20Strat%20Plan%20Aug%2024%202017%20FINAL.pdf.

FDOT. (2017b). Multimodal Mobility Performance Measure Source Book, Florida Department of Transportation Forecasting and Trends Office.

FDOT. (2018a). Traffic Engineering and Operations Office. Florida Department of Transportation , Retrieved March 1, 2018 from *http://www.fdot.gov/traffic/Mission_Vision.shtm*.

FDOT. (2018b). MPO Program Management Handbook. Florida Department of Transportation, Retrieved April 28, 2018, from http://www.fdot.gov/planning/Policy/metrosupport/Resources/FDOT%20MPO%20Handbook.pdf.

FDOT District 7. (2014). Freight System Performance Measures for the Tampa Bay Region. Tampa Bay Regional Goods Movement Study. Florida Department of Transportation, Retrieved April 28, 2018, from http://tampabayfreight.com/wp-content/uploads/FreightWhitePaper_PerformanceMeasures.pdf.

Florida Turnpike Enterprise. (2012). *Annual Customer Service Satisfaction Survey*, Retrieved 28, 2018,http://www.floridastrnpike.com/downloads/CustomerSurveys/2005custsat_web.pdf.

Fitch, G. M., Rakha, H. A., Arafeh, M., Blanco, M., Gupta, S. K., Zimmermann, R. P., & Hanowski, R. J. (2008). *Safety benefit evaluation of a forward collision warning system: final report. NHTSA*, US Department of Transportation, HS, 810(910), 100.

Fitzpatrick, K., & Park, E. S. (2010). *Safety effectiveness of the HAWK pedestrian crossing treatment* (No. FHWA-HRT-10-042). Federal Highway Administration. Washington DC.

FHWA. (2012). *Moving Ahead for Progress in the 21st Century Act (MAP-21): A summary of Highway Provision*. Federal Highway Administration, Office of Policy and Governmental Affairs, Washington DC. Retrieved January 30, 2019, from https://www.fhwa.dot.gov/map21/docs/map21_summary_hgwy_provisions.pdf.

FHWA. (2017). National Performance Management Measures; Assessing Performance of the National Highway System, Freight Movement on the Interstate System, and Congestion Mitigation and Air Quality Improvement Program, Federal Highway Administration, Rules and Regulations, Federal Register Volume 82, Number 11, pp. 5970-6050.

FHWA. (2017a). What is TPM? Federal Highway Administration, Office of Policy and Governmental Affairs, Washington DC, Retrieved April 28, 2018, from https://www.fhwa.dot.gov/tpm/about/tpm.cfm.

FHWA. (2017b). Safety. Federal Highway Administration, Office of Policy and Governmental Affairs, Washington DC, Retrieved April 28, 2018, from https://safety.fhwa.dot.gov/hsip/spm/conversion_tbl/.

FHWA. (2017c). National Performance Management Measures: Pavement and Bridge Condition to Assess the National Highway Performance Program. Federal Highway Administration, Office of Policy and Governmental Affairs, Washington DC, Retrieved April 28, 2018, from https://www.fhwa.dot.gov/tpm/rule/170531pm2.pdf/.

FHWA. (2018a). Safety Performance Management (Safety PM). Federal Highway Administration, Office of Policy and Governmental Affairs, Washington DC, Retrieved April 28, 2018, from https://safety.fhwa.dot.gov/hsip/spm/state_safety_targets/.

FHWA. (2018b). Roadway Safety Data Dashboards. Federal Highway Administration, Office of Policy and Governmental Affairs, Washington DC, Retrieved April 28, 2018, from https://rspcb.safety.fhwa.dot.gov/Dashboard/Default.aspx.

FHWA. (2018c). Average Vehicle Occupancy Factors for Computing Travel Time Reliability Measures and Total Peak Hour Excessive Delay Metrics. Federal Highway Administration, Office of Policy and Governmental Affairs, Washington DC, Retrieved April 28, 2018, from https://www.fhwa.dot.gov/tpm/guidance/avo_factors.pdf, Accessed April 28, 2018.

FHWA. (2018d). TPM Guidebook. Federal Highway Administration, Office of Policy and Governmental Affairs, Washington DC, Retrieved April 28, 2018, from https://www.tpmtools.org/guidebook/.

Fontaine, M.D., Ma, J. and Hu, J. (2015). *Evaluation of the Virginia Department of Transportation adaptive signal control technology* (Pilot project. No. VCTIR 15-R24). Virginia Center for Transportation Innovation and Research.

Gannett Fleming, Inc., AECOM Technical Services, Inc., Cambridge Systematics, Inc., Charesse Chester & Associates, Inc., Decisions Lens, Inc., Kittelson & Associates, Inc., Parsons Brickerhoff, and The Corradino Group. (2014). Miami-Dade 2040 Long Range Transportation

Plan. Final Report, Prepared for Metropolitan Planning Organization for the Miami Urbanized Area.

Gannett Fleming, Inc., Cambridge Systematics, Inc., Ghyabi & Associates, Inc., Kimley Horn, Inc. (2017). MetroPlan Orlando Intelligent Transportation System (ITS) Master Plan. Final. https://metroplanorlando.org/wp-content/uploads/MetroPlan_ITS-Master-Plan_Final.pdf, Accessed May 30, 2018.

Hadi, M., Y. Xiao, H. Ozen, and P. Alvarez. (2008). *Evaluation Tools to Support ITS Planning Process: Development of a Sketch Planning Tool in FSUTMS/Cube Environment* (Final Report BD015-19). Florida Department of Transportation.

Hallmark, S., Orellana, M., McDonald, T., Fitzsimmons, E., & Matulac, D. (2010). Red light running in Iowa: Automated enforcement program evaluation with Bayesian analysis. *Transportation Research Record*, 2182(1), 48-54.

Hallmark, S., Hawkins, N., & Smadi, O. (2015). *Evaluation of dynamic speed feedback signs on curves: a national demonstration* (Project No. FHWA-HRT-14-020). Federal Highway Administration.

Hale, D., Mahmassani, H. and Mittal, A. (2017). *Active Transportation and Demand Management Analytical Methods for Urban Streets* (No. FHWA-HOP-16-088). US Department of Transportation, Washington, DC.

Haque, M. M., Chin, H. C., & Huang, H. (2010). Applying Bayesian hierarchical models to examine motorcycle crashes at signalized intersections. *Accident Analysis & Prevention*, 42(1), 203-212.

Harper, C. D., Hendrickson, C. T., & Samaras, C. (2016). Cost and benefit estimates of partially-automated vehicle collision avoidance technologies. *Accident Analysis & Prevention*, 95, 104-115.

Hillsborough MPO. (2017). City of Tampa 2015 Roadway Level of Service Report. Hillsborough Metropolitan Planning Organization, Retrieved May 26, 2018, from http://www.planhillsborough.org/wp-content/uploads/2015/07/COT_2015_FINAL_LOS_Report_08302017.pdf.

Hillsborough MPO. (2018a). Transportation Improvement Program for Fiscal Years 2017/18 – 2021/22. Hillsborough Metropolitan Planning Organization, Retrieved May 26, 2018, from http://www.planhillsborough.org/wp-content/uploads/2018/05/Draft-TIP-18-19_v1.pdf.

Hillsborough MPO. (2018b). Hillsborough County 2017 Roadway Level of Service Report. Hillsborough Metropolitan Planning Organization, Retrieved May 26, 2018, from http://www.planhillsborough.org/wp-content/uploads/2015/07/2017-LOS-Report-FINAL.pdf.

HNTB Corporation (Corp.). (2014). 2014 Annual Mobility Report. Prepared for North Florida TPO.

HNTB Corporation (Corp.). (2015a). Appendix A Strategic Safety Plan. Prepared for North Florida TPO.

HNTB Corporation (Corp.). (2015b). Appendix B Congestion Management Plan. Prepared for North Florida TPO.

Horowitz, A., Creasey, T., Pendyala, R., & Chen, M. (2014*). Analytical Travel Forecasting Approaches for Project-Level Planning and Design*, NCHRP Report No. 08-83.

HSM. (2010). *Highway safety manual: part D*. American Association of State Highway and Transportation Officials.

Hummer, J., Haley, R. L., Ott, S. E., Foyle, R. S., & Cunningham, C. M. (2010). *Superstreet benefits and capacities* (Project: 2009 – 06). North Carolina Department of Transportation (NCDOT).

IIHS. (2010, May 20). New estimates of benefits of crash avoidance features on passenger vehicles Status Report, *The Insurance Institute for Highway Safety*, Vol. 45, No. 5.

INRIX. (2007). Available at http://www.inrix.com. Accessed Jan. 3, 2007.

Institute for Transportation Research and Education, et al. (2012). SHPR 2 Guidebook L02: Establishing Monitoring Programs for Travel Time Reliability. *Transportation Research Board of the National Academies*, Washington, DC.

Iqbal, M. S., Hadi, M., & Xiao, Y. (2018). Effect of Link-Level Variations of Connected Vehicles (CV) Proportions on the Accuracy and Reliability of Travel Time Estimation. *IEEE Transactions on Intelligent Transportation Systems*, (99), 1-10.

Jeannotte, K., D. Sallman, R. Margiotta, and M. Howard. (2009). *Applying Analysis Tools in Planning for Operations* (FHWA-HOP-10-001). Federal Highway Administrative, Washington D.C.

Jermakian, J. S. (2011). Crash avoidance potential of four passenger vehicle technologies. Accident Analysis & Prevention, 43(3), 732-740

Jia, J., Y. Xiao, and M. Hadi. (2014). Developing and Applying Estimation Model for Travel Time Index under Uninterrupted Condition. *In Proceedings of the 94th Annual Meeting of Transportation Research Board*, Washington, DC.

Kimley-Horn and Associates, Inc. (2013). Miami-Dade 2040 Bicycle/Pedestrian Plan. Prepared for Miami-Dade MPO. http://www.miamidadetpo.org/library/plans/miami-dade-2040-bicycle-pedestrian-plan.pdf. Accessed May 7, 2018.

Kimley-Horn and Associates, Inc. (2016). 2016 State of the System Report. Prepared for Hillsborough County Metropolitan Planning Organization for Transportation.

http://www.planhillsborough.org/wp-content/uploads/2013/02/Hillsborough-MPO-2016-SOS-Report_website-version.pdf, Accessed May 26, 2018.

Kimley-Horn and Associates, Inc. (2017). Palm Beach MPO Pedestrian and Bicycle Safety Study http://www.palmbeachtpa.org/static/sitefiles/Plans_and_Resources/Ped_Bike_Safety_Study.pdf, Accessed May 26, 2018.

Kitali, A. E., Sando, T., Castro, A., Kobelo, D., & Mwakalonge, J. (2017). *Developing Crash Modification Factors to Quantify Impacts of Pedestrian Countdown Signals to Drivers* (No. 17-05178).

Kittleson & Associates, Cambridage Systematics, ITRE, and Texas A&M Research Foundation. (2012). *SHRP 2 Draft Final Report L08: Incorporation of Travel Time Reliability into the Highway Capacity Manual*. Unpublished Report. Transportation Research Board of the National Academies, Washington, D.C., September, 2012.

Kuehn, M., Hummel, T., & Bende, J. (2009, June). Benefit estimation of advanced driver assistance systems for cars derived from real-life accidents. *In 21st International Technical Conference on the Enhanced Safety of Vehicles ESV* (Vol. 15, p. 18).

Kusano, K. D., & Gabler, H. C. (2012). Safety benefits of forward collision warning, brake assist, and autonomous braking systems in rear-end collisions. *IEEE Transactions on Intelligent Transportation Systems*, 13(4), 1546-1555

Kusano, K., Gorman, T. I., Sherony, R., & Gabler, H. C. (2014). Potential occupant injury reduction in the US vehicle fleet for lane departure warning–equipped vehicles in single-vehicle crashes. *Traffic injury prevention*, 15(sup1), S157-S164.

Leftwich Consulting Engineers, Inc. (2016a). *Florida Intelligent Transportation Systems Evaluation (FITSEVAL) Phase 1 Pilot Study – Technical Report: Phase 1 Pilot Project Summary*. Prepared for Florida Department of Transportation.

Leftwich Consulting Engineers, Inc. (2016b). *Florida Intelligent Transportation Systems Evaluation (FITSEVAL) Phase 2 Efforts – Technical Memorandum: Benefit Development Refinement*. Prepared for Florida Department of Transportation.

Leftwich Consulting Engineers, Inc. (2016c). *Florida Intelligent Transportation Systems Evaluation (FITSEVAL) Phase 2 Efforts – Technical Memorandum: Cost Development Refinement*. Prepared for Florida Department of Transportation.

Li, L., X. Chen, Z. Li, L. Zhang. (2013). Freeway Travel-Time Estimation Based on Temporal–Spatial Queueing Model. *Intelligent Transportation System, IEEE Transaction*, Vol. 14, pp.1536–1541.

Li, R., El-Basyouny, K., & Kim, A. (2015). Before-and-after empirical Bayes evaluation of automated mobile speed enforcement on urban arterial roads. *Transportation research record*, 2516(1), 44-52.

Litman T. (2008). Valuing Transit Service Quality Improvements. *Journal of Public Transportation*,11(2), 43-64. Retrieved from www.nctr.usf.edu/jpt/pdf/JPT11-2Litman.pdf

Liu, B., and H. C. Frey. (2013). Development of a Simplified Version of MOVES and Application to Iterative Case Studies. *Proceedings of 106th Annual Meeting of the Air & Waste Management Association*, Chicago, IL.

Margiotta, R., and B. Alden. (2016). Reliability and Safety Prediction for Planning. Presented at the Florida Model Task Force Meeting.

Martin, W. (1998). *Travel Estimation Techniques for Urban Planning* (NCHRP Report 365), Transportation Research Board, National Research Council, Washington, D.C.

Ma, J., and M. J. Demetsky, (2013). *Integration of Travel Demand Models with Operational Analysis Tools*. (FHWA/VCTIP 14-R5). Federal Highway Administration, Washington D.C.

MetroPlan Orlando. (2016a). 2040 Long Range Transportation Plan: Plan Overview. Final Adopted Plan. https://metroplanorlando.org/wp-content/uploads/2040-lrtp-plan-overview-1.pdf, Accessed May 26, 2018.

MetroPlan Orlando. (2016b). 2040 Long Range Transportation Plan Technical Report 6: Bicycle and Pedestrian Plan. https://metroplanorlando.org/wp-content/uploads/2040-LRTP-TR6-Bicycle-Pedestrian.pdf, https://metroplanorlando.org/wp-content/uploads/2040-lrtp-plan-overview-1.pdfAccessed May 26, 2018.

Monsere, C. M., Kothuri, S., Razmpa, A., & Figliozzi, M. A. (2018). *An Analysis of the Safety Effectiveness of Pedestrian Crossing Enhancements in Oregon* (No. 18-00737). Oregon Department of Transportation.

Moore, M., and Zuby, D. (2013). Collision Avoidance Features: Initial Results. *In 23rd International Conference on the Enhanced Safety of Vehicles*, Seoul, Korea, South.

Morando, M. M., Tian, Q., Truong, L. T., & Vu, H. L. (2018). Studying the Safety Impact of Autonomous Vehicles Using Simulation-Based Surrogate Safety Measures. *Journal of Advanced Transportation*, 2018. https://doi.org/10.1155/2018/6135183

Moses, R., Mtoi, E., Ruegg, S., & McBean, H. (2013). *Development of Speed Models for Improving Travel Forecasting and Highway Performance Evaluation*, (FDOT Project No. BDK83). Florida Department of Transportation.

Murray, D., Shackleford, S., Houser, A., (2009). *Analysis of Benefits and Costs of Forward Collision Warning Systems for the Trucking Industry* (No. FMCSA-RRT-09-021). American Transportation Research Institute, Arlington, VA.

NCHRP (1999). A Planning Applications for the Year 2000 Highway Capacity Manual. Retrieved October 2018 from http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/appxa.pdf

NHTSA (nde). National Highway Traffic Safety Administration., Retrieved on January 30, 2019 from https://www.nhtsa.gov/.

Olia, A., Razavi, S., Abdulhai, B., & Abdelgawad, H. (2018). Traffic capacity implications of automated vehicles mixed with regular vehicles. *Journal of Intelligent Transportation Systems*, 22(3), 244-262.

Palm Beach MPO. (2016a). Palm Beach MPO Congestion Management Process. Palm Beach Metropolitan Planning Organization, Retrieve May 26, 2018, from http://www.palmbeachtpa.org/static/sitefiles/MPO_Plans_and_Documents/CMP/2016_CMP_Final_Reduced.pdf.

Palm Beach MPO. (2016b). Palm Beach MPO Congestion Management Process Report Card. Palm Beach Metropolitan Planning Organization, Retrieve May 26, 2018, from http://www.palmbeachtpa.org/static/sitefiles/documents/19205_CongestionManagementProcess_ReportCardBrochure_2017.7.21.pdf.

Palm Beach MPO. (2017a). Palm Beach MPO 2040 Long Range Transportation Plan: Main Document. Palm Beach Metropolitan Planning Organization, Retrieve May 26, 2018, from http://www.palmbeachtpa.org/static/sitefiles/documents/LRTP/LRTP.pdf.

Palm Beach MPO. (2017b). Palm Beach MPO 5-Year Strategic Plan. Palm Beach Metropolitan Planning Organization, Retrieve May 26, 2018, from http://www.palmbeachtpa.org/static/sitefiles/MPO_Plans_and_Documents/StrategicPlan/StrategicPlan2017.pdf.

Palm Beach TPA. (2018). US-1 Multimodal Corridor Study. Draft Report. Palm Beach Metropolitan Planning Organization, Retrieve May 26, 2018, from http://www.palmbeachtpa.org/static/sitefiles/documents/US-1_Study/Draft_Report.pdf.

Penmtsa, P., Hudnall, M., & Nambisan, S. (2018). Potential safety benefits of lane departure prevention technology. *IATSS Research* (In Press).

Persaud, B., Council, F., Lyon, C., Eccles, K., & Griffith, M. (2005). Multijurisdictional safety evaluation of red light cameras. *Transportation Research Record: Journal of the Transportation Research Board*, (1922), 29-37.

Persaud, B. N., Lyon, C., Eccles, K., Lefler, N., & Amjadi, R. (2010). Safety evaluation of increasing retroreflectivity of STOP signs. *Accident reconstruction journal*, 20(1), 47-54.

Potts, I. B., Harwood, D. W., Hutton, J. M., Fees, C. A., Bauer, K. M., Lucas, L. M., ... & Frazier, R. J. (2014). Identification and evaluation of the cost-effectiveness of highway design features to reduce nonrecurrent congestion. Transportation Research Board of the National Academies, Washington, DC.

Pu, Z., Li, Z., Zhu, W., Cui, Z., & Wang, Y. (2017). Evaluating Safety Effects of Variable Speed Limit System using Empirical Bayesian Before-After Analysis (No. 17-05863). *In Transportation Research Board 96th Annual Meeting*. Washington DC.

Rakha, H., and Zhang, W. (2015). Consistency of Shock-Wave and Queuing Theory Procedures for Analysis of Roadway Bottlenecks. Presented at 84th Annual Meeting of the Transportation Research Board, Washington, D.C., 2005.

Sallman, D., E. Flanigan, K. Jeanotte, C. Hedden, and D. Morallos. (2012). *Operations Benefit/Cost Analysis Desk Reference* (FHWA-HOP-10-028)., Federal Highway Administration, U.S. Department of Transportation, Washington D.C.

Sallman, D, Jeannotte, K., Margiotta, R., and Strasser, J. (2013). *Operations Benefit/Cost Analysis TOPS-BC User's Manual* (FHWA-HOP-13-041). Federal Highway Administration, U.S. Department of Transportation, Washington D.C.

Sayeed, A. F. (2016). FDOT District Two Level of Service. Presented at the Florida Model Task Force Meeting.

Schrank, D., Eisele, B., Lomax, T. and Bak, J., (2015). 2015 Urban Mobility Scorecard, Texas A&M Transportation Institute, Texas.

Simpson, C. L., and Troy, S. A. (2015). Safety effectiveness of flashing yellow arrow: evaluation of 222 signalized intersections in North Carolina. *Transportation Research Record: Journal of the Transportation Research Board*, (2492), 46-56.

Shin, K., & Washington, S. (2007). The impact of red light cameras on safety in Arizona. *Accident Analysis & Prevention*, 39(6), 1212-1221.

Shladover, S. E., Su D., and Lu., X.-Y. (2012). Impacts of Cooperative Adaptive Cruise Control on Freeway Traffic Flow. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2324, pp. 63–70.

Smith, S., Bellone, J., Bransfield, S., Ingles, A., Noel, G., Reed, E. and Yanagisawa, M., (2015). *Benefits estimation framework for automated vehicle operations* (No. FHWA-JPO-16-229; DOT-VNTSC-FHWA-15-12). US Department of Transportation, Intelligent Transportation Systems Joint Program Office, Washington DC.

Song, Y. and Noyce, D. (2019). Effects of transit signal priority on traffic safety: Interrupted time series analysis of Portland, Oregon, implementations. *Accident Analysis & Prevention*, 123, 291-302.

Spiess, H. (1990). Conical volume-delay functions. *Transportation Science*, 24(2), 153-158.

Sprague, D. and Archambeau, J. (2012). *Adaptive signal timing: comparison between the Insync and QuicTrac adaptive signal systems installed in Colorado* (CDOT-2012-6). Colorado Department of Transportation, Denver.

Srinivasan, R., Carter, D., Persaud, B., Eccles, K., & Lyon, C. (2008). Safety evaluation of flashing beacons at STOP-controlled intersections. *Transportation Research Record: Journal of the Transportation Research Board*, (2056), 77-86.

Sugimoto, Y., & Sauer, C. (2005, June). Effectiveness estimation method for advanced driver assistance system and its application to collision mitigation brake system. *In Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicles* (No. 05-0148-O)

Tientrakool, P., Ya-Chi, H., and Nicolas F. M. (2011). Highway Capacity Benefits from Using Vehicle-to-Vehicle Communication and Sensors for Collision Avoidance. *Vehicular Technology Conference (VTC Fall) 2011 IEEE*, Retrieved from http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6093130.

Tribbett, L., McGowen, P., & Mounce, J. (2000, April). An evaluation of dynamic curve warning systems in Sacramento river canyon ((No. CD-013, Final Report)). California Department of Transportation.

TPO. (2010). ITS Master Plan Update for North Florida Regional ITS Master Plan. North Florida Transportation Planning Organization. https://issuu.com/northfloridatpo/docs/appendix_i_-_its___tsm_o_master_pla?e=19110718/33992697, Accessed May 26, 2018.

TPO. (2014). 2040 Long Range Transportation Plan. Final Report. North Florida Transportation Planning Organization. https://issuu.com/northfloridatpo/docs/path_forward_2040_long_range_plan_f?e=19110718/35889100, Accessed May 26, 2018.

Traf-O-Data Corp. (2016). *Florida Intelligent Transportation Systems Evaluation (FITESEVAL): A Review of the Application within FDOT District One*. Prepared for Florida Department of Transportation.

ITE (1993). *The traffic safety toolbox: A primer on traffic safety*. Institute of Transportation Engineers.

URS, Inc. (2013). Hillsborough County ITS Master Plan Update. Prepared for Hillsborough County Metropolitan Planning Organization.

U.S. Environmental Protection Agency (EPA). (2015). *Motor Vehicle Emission Simulator (MOVES) User Guide for MOVES2014*a. Washington D.C.

USDOT. (2015). The CV deployment cost used in the Near-Term V2I Transition and Phasing Analysis Life Cycle Cost Model Tool User Guide. U.S. Department of Transportation, Federal Highway Administration (FHWA) Washington, DC.

USDOT. (2019). Joint Program Office (JPO) Benefit Database, U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology, Washington D.C. Accessed online on January 30, 2019. Link: https://www.itsbenefits.its.dot.gov/its/benecost.nsf/BenefitsHome

Walden, T. (2011). Effectiveness of Red Light Cameras-Texas Statewide Evaluation. Institute of Transportation Engineers. *ITE Journal*, 81(12), 30.

Wang, Q., Li, B., Li, Z., & Li, L. (2017, October). Effect of connected automated driving on traffic capacity. *In 2017 Chinese Automation Congress (CAC)* (pp. 633-637). IEEE.

Xiao, Y., Hadi, M., & Ozen, H. (2012). Development of a Data-Based Intelligent Transportation System Evaluation Tool. Prepared for Florida Department of Transportation, Miami, Fl.

Xiong, H., & Davis, G. (2012). Crash Reduction Effects of Flashing LED Stop Signs (No. 12-3794). Minnesota Department of Transportation, MN.

Yang, S., Luou, S., and Hadi, M. (2007). Risk Analysis to Account for Uncertainty in Benefit-Cost Evaluations of Intelligent Transportation Systems. *Transportation Research Record: Journal of the Transportation Research Board*, 2035,187-194.

Yang, H., Y. Zou, Z. Wang, and B. Wu. (2018). A Hybrid Method for Short-Term Freeway Travel Time Prediction Based on Percentage Error Correction and Noise Extraction. In *Proceedings of the 97th Transportation Research Board Annual Meeting*, Washington, DC.

Zeng, H., Fontaine, M., & Smith, B. (2014). Estimation of the safety effect of pavement condition on rural, two-lane highways. *Transportation Research Record: Journal of the Transportation Research Board*, (2435), 45-52.