# Evaluation of the Draft Highway Capacity Manual Chapter 36/Travel Time Reliability Methodology on Florida PD&E Studies

*Florida DOT Statistics PDM 2012 Task Work Order 18, Final Report*

final

**report**

*prepared for*

**Florida Department of Transportation**

*prepared by*

**Cambridge Systematics, Inc.**

**Kittelson & Associates, Inc.**

*July 10, 2014*

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*report*

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July 31, 2014

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# Executive Summary

This Task Order evaluated the application of the recently adopted Highway Capacity Manual (HCM) travel time reliability estimation methods (Chapter 36) to PD&E studies in Florida and made recommendations on how travel time reliability should be analyzed for substantial freeway system capacity improvements.

The HCM Chapter 36 reliability estimation method and an alternative planning application developed by the University of Florida (UF) were both tested against INRIX travel time reliability data on two freeways that PD&Es have been recently completed. These were a ten-mile section of I-95 in Broward County, and a 13-mile section of I-75 in Hillsborough County. The conclusions of the tests are as follows:

1. The HCM method requires more data and is more analytically complex than the UF method.
2. When default values for demand variability and incidents are used in both methods, the UF method is typically more accurate at predicting travel time reliability than the HCM method.
3. When facility-specific data on demand variability and incident frequencies is provided to both methods, then the HCM method (which is more detailed than the UF method) is significantly more accurate than the UF method.
4. Both methods, UF and HCM, tend to overestimate the unreliability of the freeway facilities (predicting higher 95$^{th}$ percentile travel time indices) when compared to INRIX data. The use of defaults instead of facility specific information on incident frequencies significantly increased the amount of overestimation on both freeways using either method.
5. It should be noted that recent research in progress at the University of Florida suggests that INRIX may be biased towards lower congested travel times than those measured by floating car runs.[1] Tests on I-295 in Jacksonville found INRIX travel times to be within 5% of floating car times for the uncongested direction, and 5-38% below floating car times for the congested direction. The error appears to increase with the degree of congestion. Should this result be born out, then the accuracy of the UF method with or without defaults and the HCM with facility specific data are both within the accuracy of the INRIX data. HCM with defaults, however, is a great deal less accurate, falling outside, and on the high side of the uncertainty in the INRIX data.

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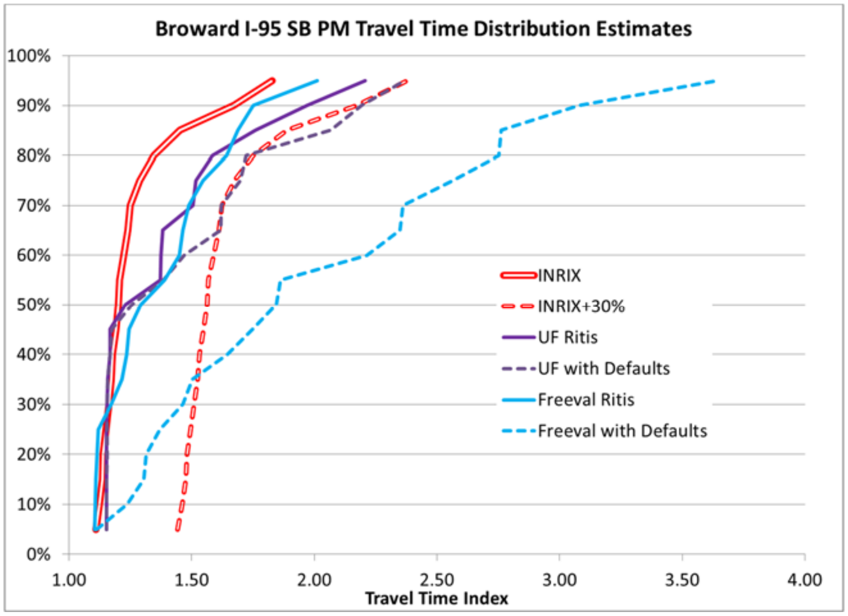
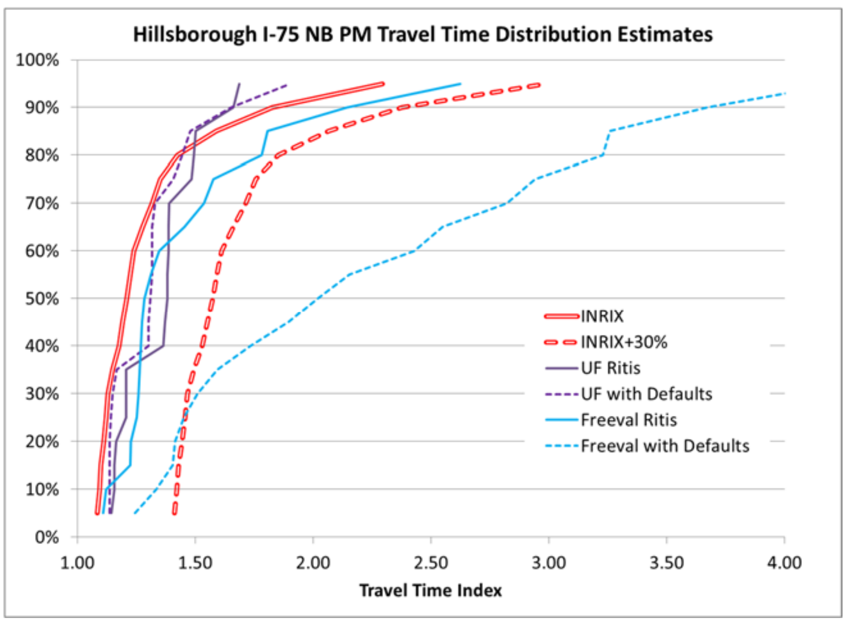
[1] Lily Elefteriadou, Alexandra Kondyli, and Bryan St. George, "Comparison of Methods for Measuring Travel Time at Florida Freeways and Arterials" FDOT Contract BDV32 TWO 977-02, Task 3: Comparison of Travel Time Data to Field Values, Transportation Research Center, The University of Florida, April 25, 2014.

## Figure 1 Broward I-95 Test Results




## Figure 2 Hillsborough I-75 Test Results




Note: The true travel time distribution probably lies between the two INRIX curves (solid and dashed).

# 1.0 Introduction

There is limited guidance in the Florida Department of Transportation (FDOT) Project Development and Environment (PD&E) Manual related to traffic analysis. Nearly all of the guidance related to traffic in support of PD&E studies comes from the Project Traffic Forecasting Handbook2. Neither of these documents mentions travel time reliability and, from the project team's experience in performing this type of work for FDOT Districts and elsewhere, the concept of travel time reliability is virtually unknown among most planning and engineering staff involved in PD&E analysis.

The Florida Department of Transportation desired that the SHRP2 L08 Draft Chapter 36 for the Highway Capacity Manual (HCM) travel time reliability prediction methodologies and performance measures be realistically tested in a typical FDOT PD&E study for two freeway corridors. The purpose of these tests was to better understand the strengths and weaknesses of these methodologies and performance measures, and to identify improvements that may be required for their real world application. This effort also provided insights into how FDOT's PD&E Manual and procedures might be improved to take advantage of the additional information on travel time reliability provided by the Chapter 36 procedures (and alternative reliability estimation methods) for the generation of project purpose and need statements and the analysis of project alternatives.

In the past, FHWA has required HCM analysis for substantial freeway system capacity improvements. It is possible that the newly developed HCM Chapter 36 will be used for PD&E analysis in the future.

This Task Order evaluated the application of Chapter 36 in PD&E studies in Florida and made recommendations on how travel time reliability should be analyzed for substantial freeway system capacity improvements. The Chapter 36 reliability estimates were tested on two freeways where PD&Es had been recently completed. The recommendations include when it is and is not appropriate to use Chapters 36 and 37 or alternative planning methods developed by the University of Florida to estimate reliability for PD&E traffic studies.

This report accomplishes the following:

1. Assesses the appropriateness of Chapter 36 travel time reliability performance measures and, as necessary, suggests alternative measures related to reliability for use in project specific PD&E alternatives generation, alternatives analysis, and selection of preferred project concept.

[2] www.dot.state.fl.us/planning/statistics/trafficdata/ptf.pdf

2. Compares the performance measures from the analysis using Chapter 36 with the performance measures used in the traditional traffic analysis to support PD&E studies.
   - Assesses the cost-effectiveness of gathering facility specific data on demands, weather, incidents, and work zones versus employing defaults for one or more of these data items.
   - Assesses the effects of the use of defaults for demand variability, weather, incidents, work zones on the accuracy of the predicted travel time reliability and variability results
3. Compares the additional demands on FDOT data collection, archiving, and analysis resources of a PD&E analysis performed using Chapter 36 travel time reliability procedures versus a conventional (no travel time reliability) analysis.
   - Identifies data demands that are different than what is used in the traditional traffic analysis to support PD&E studies.
   - Identifies possible tool improvements that might reduce the additional demands on FDOT resources.
   - Identifies possible defaults and data collection/archiving improvements to reduce additional demands of Chapter 36 methods.
4. Identifies the effects of incorporating the consideration of project specific travel time reliability, via Chapter 36 analysis methods, into PD&E tasks, such as; purpose and needs statements, generation of alternatives, analysis of alternatives, and the selection of a preferred project and facility operations and management plan.
5. Evaluates the level of service thresholds being developed in task work order 13 as they relate to the results shown in the 'traditional' traffic analysis used to support the PD&E process.

# 2.0 Current PD&E Requirements

Project Development and Environment (PD&E) studies in the State of Florida are an important step in the Florida Department of Transportation's (FDOT) highway development process and is the State's standard used for document development and processing any time FDOT prepares and processes, or assists in the processing of, an Environmental Document associated with National Environmental Policy Act (NEPA) regulations. The PD&E phase of the project development process includes scoping, environmental and engineering evaluations, and documentation.

## 2.1 Existing Guidelines For Traffic Analyses

The Project Development and Environment (PD&E) Manual, the Project Traffic Forecasting Handbook, and the Interchange Handbook are key references for preparing traffic analyses as part of a PD&E process.

Chapter 4 of the Project Development and Environment (PD&E) Manual provides engineering considerations for the project development process within a Preliminary Engineering Report (PER). The purpose of the PER is to provide technical engineering information to the Design Project Manager, Design Team, and Permit Coordinators. Chapter 4 requires a separate Traffic Report within the PER to address mobility needs through level of service evaluation. Highway capacity and level of service (LOS) analyses techniques for computing LOS at a preliminary engineering level are described in FDOT's Quality/Level of Service Handbook. The LOSPLAN software package, consisting of the program ARTPLAN, FREEPLAN, and HIGHPLAN are recommended as primary analytical tools in the project development for the auto mode. As appropriate, the LOSPLAN software may be supplemented by the Highway Capacity Software or other more detailed analytical highway capacity and LOS tools.

Interchange projects require additional operational analysis beyond FREEPLAN software. Interchange justification or modification and all PD&E studies require a Traffic Report. The Traffic Report establishes volumes and characteristics for the existing year, opening year, interim year, and design year in accordance with the Project Traffic Forecasting Handbook. Additionally, the analysis addresses traffic factors (Standard K, directional factor, truck factor, peak hour factor, etc.) for each year of interest.

## 2.2 Example PD&E Traffic Analyses

The traffic analyses performed for PD&Es vary in complexity and detail by project type. The examples below highlight the types of traffic analyses typically performed in support of PD&Es.

### I-95 Express Lanes Project (D4 - Broward, Palm Beach Co.)

The Interstate 95 Express Lanes Project (District 4) is a capacity improvement project for a 13.5 mile long section of the I-95 corridor in Broward and Palm Beach Counties involving the implementation of an express lanes system.

A macroscopic level of service (LOS) analysis of a.m. and p.m. peak hour operations was conducted of freeway segments, weaving segments, ramp merge/diverge segments, and ramp terminal intersections using HCS and Synchro for existing conditions (2011) and all forecast years. The target was to provide LOS D.

Traffic forecasts for 2020, 2030, and 2040 were produced using the Southeast Regional Planning Model.

Microsimulation was applied to the 2040 forecasts to produce an integrated, capacity constrained, facility analysis of freeway segment volumes and develop freeway segment speed profiles (separately for the HOV lanes and mixed flow lanes) over the course of the three hour morning and evening peak periods. This is as opposed to HCS and Synchro's focus on the operations of individual elements for a single peak hour. The Vissim managed lanes module was used to predict the single occupancy vehicle (SOV) usage of the express lanes. It was also used to compute "unmet demand."

The project alternatives considered in the PD&E traffic analysis included: Add a general purpose lane (rejected based on demand modeling), add a tolled express lane, and convert the existing HOV lane to tolled operation as well.

### I-75 Capacity Improvements South (D7 - Manatee, Hillsborough)

The I-75 Capacity Improvements Project South (D7 - Manatee, Hillsborough Co.) extends 24.4 miles on the I-75 freeway from Moccasin Wallow Road in Manatee County to US 301 in Hillsborough County. This section includes 4 interchanges.

HCM LOS analyses were performed using HCS software for basic freeway segments, weaving segments, ramp merge/diverge segments and ramp terminus intersections. The objective was to achieve LOS D for the Design Hour, or the best achievable LOS, if LOS D is not feasible.

Traffic forecasts for 2035 were developed using the West Central Florida Regional Planning Model. Opening year (2015) forecasts were developed by extrapolating 2007 counts.

Three improvement alternatives were evaluated in addition to the No-Build Alternative. These alternatives consisted of added general purpose or special use lanes.

### I-75 Capacity Improvements North (D7 – Hillsborough)

The I-75 Capacity Improvements Project North (D7 – Hillsborough Co.) extends 12.1 miles of the I-75 freeway from US 301, north Fletcher Avenue. This section includes 7 interchanges.

Design Hour operations analyses were performed using Vissim software to better reflect peak period capacity constraints in the corridor. Vissim delays and densities were converted to HCM LOS for basic freeway segments, weaving segments, ramp merge/diverge segments and ramp terminus intersections. The objective was to achieve LOS D for the Design Hour, or the best achievable LOS, if LOS D is not feasible.

The same traffic forecasts methods were used as for the South section of I-75, described above.

The same improvement alternatives were evaluated as for the South section of I-75, described above.

### I-95 Oslo Road Interchange (D4 – Indian River County)

I-95 Oslo Road Interchange (D4 – Indian River County) study is a preliminary assessment of a proposed new interchange on I-95.

FDOT Generalized Service Volume Tables were used to estimate LOS from the forecasted AADT's.

The Greater Treasure Coast Regional Planning Model was used to produce the 2035 demand forecasts. Interpolation between 2005 counts and the 2035 model forecasts was used to obtain 2015 and 2025 forecasts.

Interchange build and no-build alternatives were evaluated.

### SR 76 Kanner Highway (D4, Martin County)

The SR 76 Kanner Highway (D4, Martin County) project evaluated improvements to 2.4 miles of SR 76, a 2-lane to 4-lane divided urban arterial (FDOT Urban Other Principal Arterial) with 6 signalized intersections between SW Pratt Whitney Road/SW 96th Street to Cove Road.

Design Hour a.m. and p.m. LOS was computed using HCS for freeway segments, freeway ramp merge/diverge segments, arterials, and unsignalized intersections. Synchro was used for signalized intersections.

Traffic forecasts for 2013, 2020, 2030 and 2040 were produced using the Greater Treasure Coast Regional Planning Model growth rates applied to the 2008 counts.

A crash analysis and an access analysis were performed.

The study looked at lane additions plus an interchange modification. The study objective was to improve safety, capacity, truck movements, and emergency evacuation.

### FTA, North Broward Widening (D4 – Broward County)

The Florida's Turnpike, North Broward Widening PD&E Study (D4 – Broward County) evaluated widening a 7.3 mile long section of the Turnpike in North Broward County from south of Atlantic Blvd to the Sawgrass Expressway.

Design Hour a.m. and p.m. LOS was computed using HCS for freeway segments, freeway ramp merge/diverge segments, arterials, and unsignalized intersections. Synchro was used for signalized intersections.

Where HCS analysis indicated potential weaving problems, a CORSIM analysis was performed to evaluate detailed ramp design options. A C-D road option was identified as part of the CORSIM analysis.

Traffic forecasts for 2010, 2020, and 2030 were produced using the Broward County Planning Model.

The study looked at lane additions and a C-D road option.

## 2.3 Conclusions Regarding PD&Es

Traffic studies for FDOT PD&Es invariably report Highway Capacity Manual level of service (HCM LOS) for key intersections, highway segments, and freeway segments. Facility level results may be reported as well, often using a microsimulation model. These studies generally take into account recurring congestion by evaluating the peak hour operations under fair weather, non-incident conditions. Non-recurring congestion is not quantitatively addressed.

Larger magnitude projects may, in addition, evaluate congestion effects over several miles of a facility using microsimulation analysis to capture the interrelated effects of downstream bottlenecks on upstream operation. These sophisticated analyses will report facility travel time and delay measures in addition to the traditional HCM LOS results. However, these sophisticated analyses still focus on recurring congestion under peak period demand, fair weather, non-incident conditions. Non-recurring congestion is still not quantitatively addressed.

The lack of information on non-recurring congestion conditions shows in the project alternatives that are not considered in the PD&E project alternatives analyses. PD&E project alternatives typically focus on relatively expensive solutions to recurring congestion, such as add-a-lane capacity improvement projects. With a few exceptions (such as the I-95 HOT lane study described earlier), PD&Es generally do not look at operational improvements designed to reduce non-recurring congestion.

Operational improvements typically do not result in the large capacity gains typical of lane-addition projects, so it is unlikely that adding reliability analyses to PD&Es will cause FDOT to replace capacity improvement with operational improvements. However, operational improvements, when added as refinements to a capacity improvement project have the potential to stretch out the number of productive years of the capacity improvement before additional capacity is needed.

The more regular evaluation of non-recurring congestion in project PD&Es thus has the potential of improving the service lives and the overall productivity of capacity improvement projects, by refining the design of the project to provide more stable operating under non-recurring events.

# 3.0 Reliability Performance Measures

This section assesses the appropriateness of Chapter 36 travel time reliability performance measures and, as necessary, suggests alternative measures related to reliability for use in project specific PD&E alternatives generation, alternatives analysis, and selection of preferred project concept.

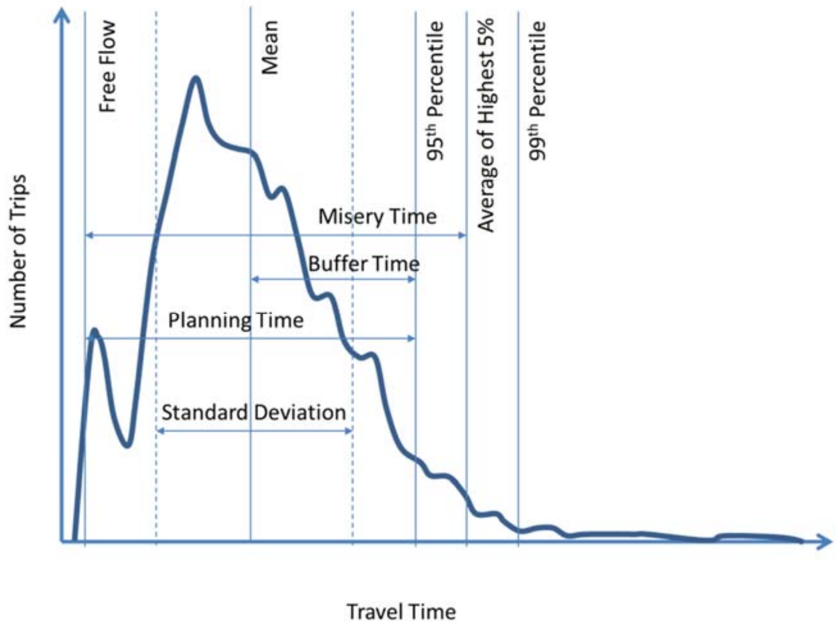
## 3.1 CURRENT PD&E PRACTICE

The design hour Highway Capacity Manual (HCM) level of service (LOS) is always one of the performance measures produced for PD&Es. Note that the standard HCS (Highway Capacity Software) segment analysis does not spot queues, only sections where densities are high. Thus some studies for the larger more complex projects will supplement a.m. and p.m. peak hour LOS with peak period and facility travel time, crash analyses, bottleneck analyses, and queuing performance measures.

## 3.2 RELIABILITY MEASUREMENT

Reliability performance measures are different ways of numerically characterizing the underlying travel time distribution. They accomplish this by selecting one or more points for measuring the reliability distribution (much like waist size and inseam characterize the pants that will normally fit a person) (see Figure 3).

**Figure 3 Characterizing the Travel Time Distribution**




## 3.3 HCM CHAPTER 36 PERFORMANCE MEASURES

Chapter 36 of the Highway Capacity Manual suggests for consideration several reliability performance measures without committing to one specific measure. These measures include some that quantify full year accumulated delay or average annual travel time, as well as several variations on the standard deviation and the percentile travel time index. Chapter 36 of the HCM introduces the concept of the "reliability rating" for the facility, the percent of vehicle trips experiencing level of service "F", oversaturated conditions over the course of a year.

These HCM measures of reliability are defined as follows:

**Measures of Cumulative Performance**

- Annual Average Travel Time
  - The annual average travel time is computed for travel between selected points on the facility for the selected time period (often a weekday peak period) for selected days of the year (holidays may be excluded).
- 50th Percentile TTI
  - The 50th percentile TTI (travel time index) is the ratio of the median (50th percentile) travel time to the free-flow travel time (for selected hours and days of the year).
- Annual delay (vehicle-hours or person-hours)

- The annual delay is the total vehicle or person-hours of delay summed over the hours and days selected for the reliability analysis.

**Indices of Reliability**

- Reliability Rating
  - The Reliability Rating is the percentage of trips experiencing TTI less than 1.33 for freeways or 2.50 for urban streets.
- 80th Percentile TTI
  - The 80$^{th}$ Percentile TTI is the 80$^{th}$ percentile highest travel time index for the facility.
- 95th Percentile TTI (The Planning Time Index)
  - The 95$^{th}$ Percentile TTI (The Planning Time Index) is the 95$^{th}$ percentile highest travel time index for the facility.
- Failure Measure
  - The Failure Measure is the percentage of trips with space mean speeds below the agency set minimum acceptable threshold speed for the facility.
- Standard Deviation of Travel Times
  - The Standard Deviation of Travel Times is the square root of the classical statistical measure of variance (the sum of the squared differences from the mean).
- Semi-Standard Deviation of Travel Times
  - Semi-Standard Deviation of Travel Times is the square root of the semi-variance, which is similar to the classical definition of variance, except that the differences for the semi-variance are measured from the free-flow travel time, rather than the mean.
- Misery Index
  - The Misery Index is the average of the highest 5% of travel times divided by the free-flow travel time.

Note that all of these measures are computed for the subset of OD pairs, times of day, and days of the year that are of interest to the agency for reliability reporting purposes.

Chapter 36 does not recommend a set of level of service thresholds for reliability results.

## 3.4 TWO 13 Reliability LOS Thresholds

FDOT Task Work Order (TWO) 13 concluded that level of service for freeways in large urbanized areas should be keyed off of the 5th percentile highest speed for the freeway (the speed that is exceeded by 95% of the trips on the freeway during non-holiday peak periods over the course of a year).

**Table 1 TWO 13 Reliability LOS Ratings**

| Level of Service | 5th PercentileSpeed Range (mph) |
|---|---|
| A | 60+ |
| B | 55-60 |
| C | 45-55 |
| D | 35-45 |
| E | 25-35 |
| F | <=25 |

Note: Table has been updated to reflect February 2014 changes to thresholds.

## 3.5 Recommendations For Testing

The HCM Chapter 36 performance measures and the TWO 13 performance measures will be tested on two freeways to determine:

1. Their suitability for use in Florida to support PD&E impact and alternatives analyses.
2. Their impact on the resources and tasks required to complete PD&Es.

# 4.0 Reliability Estimation Tools

This section describes three available tools for estimating travel time reliability that may be useful for estimating reliability for PD&E traffic studies. They are:

- The University of Florida Freeway and Arterial Reliability Models,
- The SHRP2-L07/L03 model, and
- The SHRP2-L08 (Chapter 36) reliability models.

## 4.1 University of Florida Reliability Models

FDOT and the University of Florida (UF) developed two reliability prediction models, one for freeway segments, the other for arterial streets.[3], [4], [5], [6]

### UF Freeways Reliability Model

The University of Florida (UF) freeway reliability model is a set of linear regression equations for predicting average hourly travel time, fitted to data from Philadelphia, Ft. Lauderdale, and Jacksonville freeways. Different equations are applied to each of 24 possible scenarios composed of combinations of levels of congestion, incident types, weather types and work zones. The expected (average) travel time to traverse the full length of the freeway is computed for each scenario for each of the 24 hours of a day. Reliability is then computed by applying probabilities to each of the computed travel times for each of the scenarios and hours of the day.

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[3] Elefteriadou, L, A. Li, G. Chrysikopoulos, C. Lu, L. Jin, and P. Ryus, Travel Time Reliability Implementation for the Freeway SIS, FDOT Contract BDK77-931-04, University of Florida, Gainesville, FL, December 2010.

[4] Elefteriadou, L., C. Lu, Z. Li, X. Wang, L. Jin, Multimodal Corridor Applications of Travel Time Reliability, FDOT Contract BDK77-977-10, University of Florida, Gainesville, FL, March 2012

[5] McLeod, D., L. Elefteriadou, and L. Jin, Travel Time Reliability as a Performance Measure: Applying Florida's Predictive Model to an Entire Freeway System, Submitted July 17, 2012.

[6] Elefteriadou, L., Hongsheng Xu, FINAL REPORT to THE FLORIDA DEPARTMENT OF TRANSPORTATION SYSTEMS PLANNING OFFICE on Project "Travel Time Reliability Models for Freeways and Arterials," FDOT Contract BD-545, RPWO #70 (UF Project 00060228), University of Florida, Gainesville, FL, September 30, 2007

The freeway model (composed of the travel time equations and scenario probabilities) is applied to one to two-mile long segments, and the segment results averaged to obtain facility results for stretches of the SIS freeway system ranging from 9 to 36 miles in length.

The model is designed to be applied for each hour of a 24-hour day using default K and D factors by hour of day and season of the year, applied to the AADT.

Weather is broken into two types: rain and non-rain. Non-rain includes traces of rain. Rain is further subdivided into light rain (at least 0.01 inches/hour), and heavy rain (greater than 0.5 inches per hour). Probabilities were obtained from 5-years of data (2006-2010). The state is divided into three rain regions with associated probabilities of no-rain, light rain, and heavy rain. Free-flow speeds are reduced 6 percent for light rain and 12 percent for heavy rain. There is no capacity reduction for rain.

Incidents are split into three types: lane-blocking, non-lane blocking, and no-incident. The probabilities are based on 2007 SunGuide FDOT District 4 Report, and FDOT Crash Analysis Reporting System (CARS). Separate incident probabilities are used for scenarios with: no rain/no-work zone, rain/no-work zone, no-rain/work zone, and rain/work zone. There is no free-flow speed reduction for incidents. The average number of lanes blocked by an incident is computed based on the probabilities of 1 or more lanes being blocked by the incident (Including the possibility of full facility closure).

Work zones are assumed to block the user specified number of lanes (typically one lane is assumed blocked). The capacity per lane reduction for a work zone is assumed to be the same as for a lane blocking incident. Work zones are assumed to not affect free-flow speed. The probabilities of work zones were fixed at 3% for the overnight hours (10 p.m. to 7 a.m.) and 1% for the rest of the day. These estimates were made in the absence of data on work zone probabilities.

The model provides the entire travel time distribution for all 24 hours. Based on this it predicts the probability of "on-time arrival" for each hour of the day. This is defined as the percent of trips in that one hour period that are able to complete their trip on the facility at an average speed equal to or greater than the 5 mph below the posted speed limit (Free-flow speed minus 10 mph). It also provides the probability of on-time arrival based on the number of hours that the facility operates at an average speed greater than the 5 mph below the posted speed limit.

The model also outputs the "planning time index" for the facility for each hour of the day, defined as the 95$^{th}$ percentile travel time divided by the free-flow travel (which, in turn, is defined as the travel time at the posted speed limit plus 5 mph).

The proportion of weeks in the year when a single hour falls in the congested or uncongested regimes for a given scenario is determined by comparing the hourly demands by week of the year to the capacity for the scenario. The capacity of a scenario varies by blocking incident type and work zone type.

The freeway model has the following minimum required inputs for studies conducted on South Florida freeways:

- Facility Type (by 4 area types and 2 Interchange spacing subtypes),
- AADT (total both directions),
- Through Lanes (total both directions, excludes auxiliary lanes),
- Hours and days of week when road rangers are active.
- Ratio of non-blocking to blocking incidents
- Capacity (lower number should be used in over saturated conditions)
- Free flow speed (posted speed + 5 mph)

For studies using the model outside of South Florida freeways, the analyst will want to examine and modify the following additional inputs:

1. Hourly K factors
2. Annual incident rates, average duration, clearance time with road rangers.
3. Probability of blocking incident by hour of day under different weather and work zone conditions.
4. Number of lanes blocked by work zones.

In addition, the freeway reliability model has built into it several user modifiable default values and parameters that it uses to compute reliability.

## UF Arterials Reliability Model

The UF arterial reliability model was developed by fitting two linear regression equations to travel time estimates produced for a 1.07 mile long arterial using the CORSIM microsimulator (Elefteriadou, Lu, Li, Wang, Jin)[7]. One equation is applied to uncongested scenarios; the other equation is applied to congested scenarios. The data requirements of the arterial model are as follows:

- Free-flow speed (mph)
- Incident duration (min)
- Percent lanes blocked by incidents
- Demand (vph/ln)
- Cycle length (secs)
- Number of signals per mile
- Ratio of green time to cycle length

[7] Elefteriadou, Lu, Li, Wang, Jin, Op. Cit.

- Progression quality (favorable or unfavorable).

The same basic equation but with different calibration parameters is used to predict travel times for congested and uncongested conditions. The user is warned to apply these models with caution for very low volumes (under 300 vph/lane). The user is also warned that the cycle length should be greater than 60 seconds and the green/cycle should be greater than 0.30, to apply these equations.

## 4.2 SHRP2-L03/L07 Reliability Procedure

The SHRP2-L07 project, Evaluation of the Costs and Effectiveness of Highway Design Features to Improve Travel Time Reliability, employs Richard Margiotta's SHRP2-L03 method to predict the travel time reliability distribution.[8], [9]

The L07/L03 reliability estimation model, as adapted for use in the SHRP2-L07 project, employs four variables to estimate the cumulative percentile travel time indices for demand/capacity ratios less than or equal to 80%:

$$TTI_P = exp(\propto_P * LHL + \beta_P * DC + \gamma_P * R + \delta * S) \qquad \text{(for DC <= 0.80)}$$

### Equation 1

Where:

$TTI_P$ = The cumulative percentile (P) travel time index. The ratio of the percentile travel time to the free-flow travel time

LHL = Lane-hours lost due to incidents and work zones. This value is calculated as the average number of lanes blocked per incident (or work zone) multiplied by the average duration per incident (or work zone) multiplied by the total number of incidents (or work zones) during the time slice and study period of interest.

DC = The Demand-to-capacity ratio, defined as the ratio of the 30th highest hour of the year demand to capacity.

R = Hours of rainfall exceeding 0.05 inches during the time slice and study period.

S = Hours of snowfall exceeding 0.01 inches during the time slice and study period.

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[8] MRIGlobal, Identification and Evaluation of the Cost-Effectiveness of Highway Design Features to Reduce Nonrecurrent Congestion, Draft Final Report, SHRP2-L07 Project, Transportation Research Board, Washington, DC, March 2013.

[9] Margiotta, R., Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies, Final Report S2-L03-RR-1, Transportation Research Board, Washington, DC, 2013.

$\alpha, \beta, \gamma, \delta$ = Coefficients specific to the desired TTI percentile. (see Table 2)

**Table 2 Coefficients for L07 TTI Estimation When DC <= 0.80**

| Desired Percentile TTI | α | β | γ | δ |
|---|---|---|---|---|
| 10 | 0.01400 | 0.00099 | 0.00015 | 0.00037 |
| 50 | 0.07000 | 0.00495 | 0.00075 | 0.00184 |
| 80 | 0.11214 | 0.00793 | 0.00120 | 0.00310 |
| 95 | 0.19763 | 0.01557 | 0.00197 | 0.01056 |
| 99 | 0.47282 | 0.04170 | 0.00300 | 0.02293 |

For demand/capacity ratios in excess of 80%, a more complex formula is used, as documented in the project's final report.

A procedure is provided for estimating lane-hours lost based on the incident type (crash, property damage only, minor injury, major injury/fatality, disabled vehicle) and work zone data on lanes closed and duration.

## 4.3 SHRP2-L08 (Chapter 36) Procedure

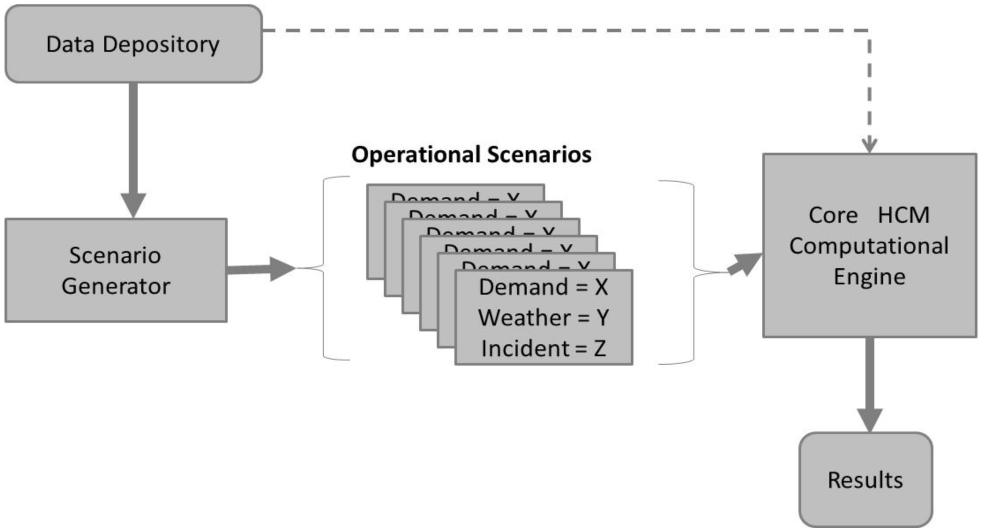
The SHRP2-L08 project was charged with developing a method for estimating travel time reliability for incorporation into the Highway Capacity Manual (HCM). As such, the SHRP2-L08 methodology, as documented in draft chapters 36 and 37 of the HCM is a macroscopic, operations analysis level approach to estimating reliability. It was not designed for preliminary screening or planning analyses. Nor is the methodology designed for application in microsimulation analyses.

Two methodologies were developed, one for freeway facilities, the other for arterial streets.

- The freeway facilities reliability estimation method is designed to be applied using the freeway operations analysis methodology described in Chapters 10-13 and 25-28 of the 2010 HCM (implemented in the Freeway Facilities Method, a derivative extension of FREEPLAN, included in HCS 2010).
- The urban streets reliability estimation method is designed to be applied using the urban streets operations analysis method described in Chapters 16-18 and 29-31 of the 2010 HCM (implemented in the Streets method included in HCS 2010).

Both methodologies involve the generation of different demand, weather, and incident scenarios and then the application of the core HCM analysis methodology specific to each facility (freeway or urban street) to each scenario (see Figure 4).

**Figure 4 Overview of SHRP2-L08 Reliability Estimation Methodology**




Source: Exhibit 36-1, SHRP2-L08

Neither reliability method has yet to be implemented within HCS, so at the time of the writing of this report, the best available software for testing the SHRP2-L08 reliability estimation methodologies is the prototype spreadsheet based computational engines developed as part of SHRP2-L08, with their consequent lack of sophisticated user interfaces and difficulty applying them to typical sized, real world study sites.

## Sensitivities

Both methodologies are sensitive to all the usual HCM operations analysis inputs: demands (and demand variations within the study period), facility geometry (cross-section, lengths, etc.), and controls (signal timing, speed limits, and ramp metering). In addition, the SHRP2-L08 methodologies are sensitive to multi-day variations in demand, weather, lane closing incidents, and work zones.

## Required Inputs

The required inputs for the reliability estimation methodologies are listed in Table 3.

### Table 3 Data Requirements of SHRP2-L08 Reliability Estimation Methodologies

| Data | Freeway | Urban Street |
|---|---|---|
| Geometry | Required – some items can be defaulted for standard facilities. | Required – some items can be defaulted for standard facilities. |
| Control | Required | Required |
| Baseline Demands | Required | Required |
| Demand Variability | Default monthly and day of week demand factors provided for Urban and Rural freeways. | Default monthly, day of week, and hourly demand factors provided for expressways, principal arterials, and minor arterials. |
| Weather Events | Default probabilities provided for 101 Metropolitan Areas of US. | Default probabilities provided for 284 locations in US. |
| Incidents | Factors provided to expand site specific crash data to incidents by severity and duration. | Factors provided to expand site specific crash data to incidents by severity and duration. |
| Work Zones | Lanes closed, frequency, and duration required if effects to be evaluated. | Lanes closed, frequency, and duration required if effects to be evaluated. |

The methodologies both require HCM operations analysis level geometric, control, and demand inputs for the study facility. Like in the original HCM methods, defaults can be used for many of the required HCM analysis inputs.

Data on demand variability is required, and both methodologies provide default demand variability factors. However, given the variation in demand variability between facilities in the same metropolitan area, it is recommended that locally, site-specific data on demand variability be used whenever feasible. The freeway methodology includes two sets of default demand variability factors, one for urban freeways, the other for rural freeways.

Data on weather events of the year is required. However, airport weather data for most major urban areas of the US is included in both of the SHRP2-L08 computational engines. The freeway methodology provides default weather event probabilities for 101 metropolitan areas of the US.

Data on crash rates for the facility is required by both methodologies. Both methodologies provide lookup tables of factors for expanding crashes to lane-closure incidents by severity and duration.

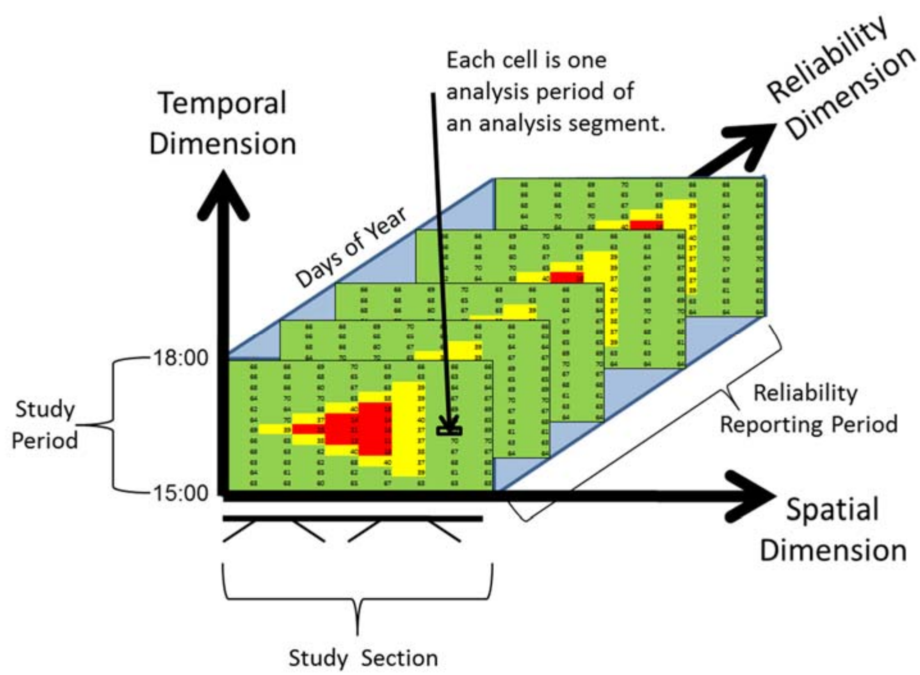
Both methodologies require that all work zones be specified in terms of lanes closed and duration if work zone impacts on reliability are to be assessed.

## Output

Both the freeway and urban street reliability methodologies predict the distribution of average travel time rates (minutes/mile) (averaged for all vehicles within the 15 minute analysis period) for traveling the length of the facility within the user selected study period over an extended period of time (often non-holiday weekday peak periods over one year) (see Figure 5 for illustration of reliability terminology used in SHRP2-L08). Figure 6 shows a typical output travel time distribution.

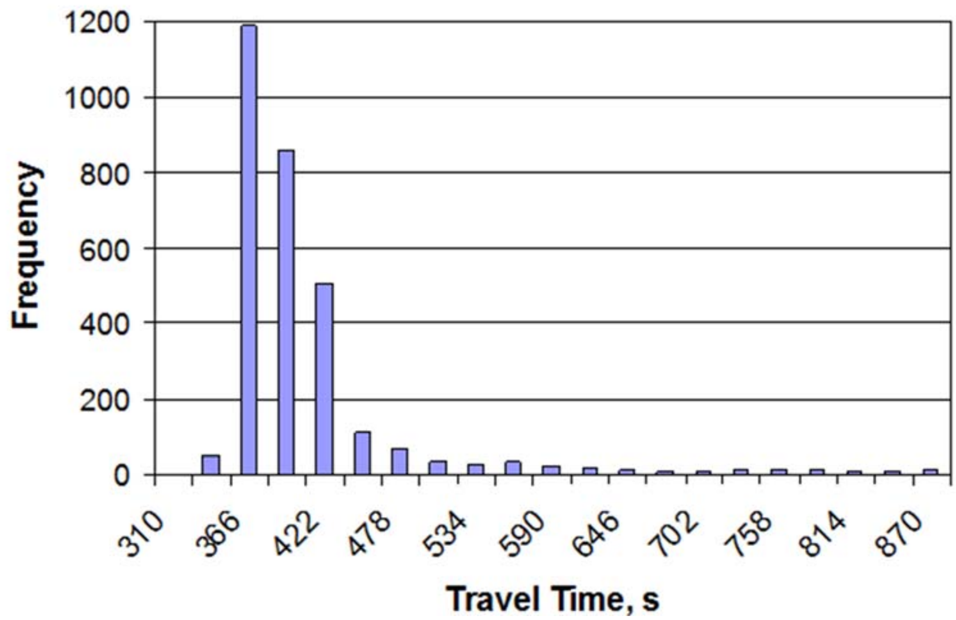
Both methodologies enable the user to post-process the scenario results to assess the proportional contributions of the different sources of unreliable facility operation. Table 4 shows one example. In this case high demand combined with incidents that close one lane accounted for 33% of the annual vehicle-hours of delay for this facility.

### Figure 5 Reliability Terminology in SHRP2-L08




Source: Exhibit 36-3, SHRP2-L08

### Figure 6 Typical Reliability Output of SHRP2-L08 Methodologies




Source: Exhibit 36-70, Draft Chapter 36, SHRP2-L08

### Table 4 Example Allocation of Annual Vehicle-Hours of Delay by Cause

| | Low Demand | | Moderate Demand | | High Demand | | |
|---|---|---|---|---|---|---|---|
| **Incidents** | **Fair Weather** | **Bad Weather** | **Fair Weather** | **Bad Weather** | **Fair Weather** | **Bad Weather** | **Total** |
| None | 596 (2%) | 407 (1%) | 818 (3%) | 362 (1%) | 6,240 (23%) | 956 (4%) | 9,379 (34%) |
| 1 lane closed | 2,363 (9%) | 92 (<1%) | 2,097 (8%) | 61 (<1%) | 9,102 (33%) | 119 (<1%) | 13,834 (51%) |
| 2 lanes closed | 194 (1%) | 13 (<1%) | 189 (1%) | 9 (<1%) | 907 (3%) | 17 (<1%) | 1,328 (5%) |
| 3 lanes closed | 621 (2%) | 40 (<1%) | 468 (2%) | 23 (<1%) | 1,510 (6%) | 32 (<1%) | 2,694 (10%) |
| Total | 3,774 (14%) | 551 (2%) | 3,572 (13%) | 456 (2%) | 17,759 (65%) | 1,124 (4%) | 27,236 (100%) |

Source: Exhibit 36-11, SHRP2-L08

## 4.4 Recommended for Testing

The University of Florida (UF) model performs much of the same functions with similar data requirements as the SHRP2-L07/L03 procedure. In addition, the UF model produces the full travel time distribution, while the L07/L02 procedure is limited to five percentile TTI values (10%, 50%, 80%, 95%, 99%). Finally, the UF model is calibrated to Florida conditions. Consequently the UF model is recommended over the L07/L03 procedure for testing.

The UF model, being more of a conceptual planning tool (requiring limited information in order to make an estimate) does not have the same sensitivity to the details of facility operation as the HCM Chapter 36 method. In addition, the UF model is limited to freeway segments, while the HCM Chapter 36 method can be applied to freeways and arterials (there is a separate procedure for each).

However, the ease of application of the UF model, and its calibration to Florida conditions suggests it could often be a cost-effective substitute for the more elaborate HCM Chapter 36 procedure.

Consequently both the UF model and the HCM Chapter 36 procedure are recommended for testing.

# 5.0 Freeway Tests

The UF and HCM Chapter 36 procedures for estimating reliability were tested on two freeway sites, the I-95 freeway in Broward County, and the I-75 freeway in Hillsborough County. The HCM Chapter 36 reliability performance measures and the TWO 13 reliability level of service measures were computed for both sites.

- I-95 Broward – This is a 9.28 mile long freeway study section extending from SW 10th street to West Oakland Park Blvd. It is a 6 to 8 multi-purpose lane freeway with 2 additional HOV lanes plus auxiliary lanes between interchanges that carries 205,000 to 267,000 AADT. The average speed in the southbound direction during the p.m. peak hour is 48 mph. More details on the site and the test can be found in **Error! Reference source not found.**.
- I-75 Hillsborough – This is a 13.45 mile long freeway study section extending from SR 60 to SR 581. It is a 4 to 6 multi-purpose lane freeway plus auxiliary lanes between interchanges that carries 95,000 to 150,000 AADT. The average speed in the northbound direction during the p.m. peak hour is 58 mph. More details on the site and the test can be found in **Error! Reference source not found.**..

## 5.1 TEST PROTOCOL

### Purpose

The purpose of the tests was to assess:

1. The amount of extra effort required to estimate reliability and the relative accuracy of the results using the HCM Chapter 36 method; and
2. The usefulness of the reliability MOE's produced by the Chapter 36 method for evaluating operating conditions, developing improvement alternatives, and evaluating their impacts.

### Site Selection

The consultant team searched the FDOT Work Program 6-year history and various district contacts to identify candidate test sites with the following desirable characteristics:

- The test sites should be freeways. This is because the purpose of the study is to evaluate the reliability methodology on freeways. Therefore, only freeway corridors were considered.

- A PD&E Study should have been recently completed for the test site so that the necessary input data for an operations analysis would be available for applying the Chapter 36 method. The team focused its efforts on PD&Es completed within the past 3 years. The PD&E traffic analysis output (LOSPLAN, HCS, Synchro, VISSIM, etc.) had to be available for use in this study.
- Reliability input (demand variation, incident logs) and output data (measured travel time reliability) should be available for about a year, so that the reliability methods could be validated and the impacts of using defaults on the accuracy of the methods could be assessed.
- Recurring congestion should be present so that a reliability analysis would have a reasonable expectation of yielding results useful for decision making.

The search was conducted primarily in Districts 4 and 7 where significant infrastructure was known to be in place for reliability monitoring. The following promising candidate test sites were identified in this search:

- **Interstate 95 Express Lanes Project** (D4 - Broward, Palm Beach Co.) – This is a capacity improvement project for a 13.5 mile long section of the I-95 corridor in Broward and Palm Beach Counties involving the implementation of an express lanes system.
- **I-75 Capacity Improvements Project South** (D7 - Manatee, Hillsborough Co.). This capacity improvement project extends 24.4 miles on the I-75 freeway from Moccasin Wallow Road in Manatee County to US 301 in Hillsborough County. This section includes 4 interchanges.
- **I-75 Capacity Improvements Project North** (D7 - Hillsborough Co.) – This capacity improvement projects extends 12.1 miles of the I-75 freeway from US 301, north Fletcher Avenue. This section includes 7 interchanges.
- **Florida's Turnpike, North Broward Widening PD&E Study** (D4 - Broward Co.) – This project is to widen a 7.3 mile long section of the Turnpike in North Broward County from south of Atlantic Blvd to the Sawgrass Expressway.
- **Wekiva Parkway** (D5 - Orange Co.) – This is a new freeway connecting SR 429 at US 441 to SR 417 at Interstate-4, completing the northwest quadrant of freeway loop around Metro Orlando. In its entirety, this project passes through Orange, Lake, and Seminole Counties.

Among these candidate test sites, I-95 in Broward County and the northern section of I-75 in Hillsborough County had the best combination of recurring congestion, readily available PD&E data sets, and an infrastructure in place of monitoring reliability.

## Data Collection

Detailed freeway operations analysis input data for the p.m. peak hour were obtained from the latest available PD&E for the Broward I-95 and Hillsborough

I-75 test sites. This generally consisted of lane geometry, free flow speeds, ramp and mainline volumes, percent trucks, distances, and other such data obtained from HCS input and output listings for the freeway LOS analyses.

Observed travel times for calibrating the Chapter 36 FREEVAL seed file (which computes the freeway travel times under average demand, fair weather, and non-incident conditions) were obtained from the PD&E report on existing traffic conditions or microsimulation model calibration for each site.

Monthly crash rates (per million VMT) were obtained from SunGuide staff for the respective TMC's for each site.

Weather data was obtained from the US airport data set built into the Chapter 36 implementation tool, FREEVAL-Reliability. There is weather data for 7 regions in Florida in the tool. The nearest appropriate airport was selected for each site.

## Data Processing

The freeways were segmented according to HCM guidelines. This had generally already been done in the PD&E LOS analyses.

The HOV volumes and the HOV lanes were treated as mixed flow traffic and mixed flow lanes for the purposes of the Chapter 36 analysis. Since HOV lanes typically have lower capacities than mixed flow lanes, a generally greater adjustment (much lower than 1.00) was applied to accurately represent the capacity of the freeway with the HOV lanes.

Hourly demands in the PD&Es were converted to four 15 minute demands using peaking factors for each freeway obtained from permanent count station data archived in RITIS.

Demand variation for the selected reliability reporting period (6 months in 2011) was obtained from the same permanent count station archives in RITIS.

The crash rates were expanded to incident rates by lane blockage type and duration using the default expansion factors built into the FREEVAL-Reliability analysis tool that implements Chapter 36.

Travel time reliability data for each test site was pulled from the INRIX dataset stored on RITIS.

More detail can be found in the appendices.

## HCM Chapter 36 Reliability Model Calibration

The PD&E traffic operations analysis results were used to generate the inputs required for the Chapter 36 analysis and to calibrate the seed file results. The seed file is the starting point for the Chapter 36 analysis, representing average peak hour demands and ideal non-incident, fair weather conditions (typically the focus of PD&E traffic operations analyses). The starting points for the seed file calibration were the default HCM capacities, same as used in the PD&E LOS analyses.

Calibration consisted of applying capacity adjustment factors to the bottleneck and other segments until the observed congestion (queues) matched those observed in the field (or in the microsimulation runs) for existing conditions, reported in the PD&Es.

## HCM Chapter 36 Reliability Computations

The Chapter 36 method was applied to the p.m. peak hour conditions identified and documented in the PD&E for each test site. For Broward I-95 the southbound direction was analyzed. For Hillsborough I-75, the northbound direction was evaluated. The Chapter 36 tool, a macro enabled spreadsheet called FREEVAL-Reliability, was used to perform the computations.

## UF Model Reliability Computations

The University of Florida reliability model was also applied to each test site, using generally the same data as was used in the HCM Chapter 36 analysis, however; at a greater level of aggregation.

Rather than using HCM segmentation, the freeway in each test site was divided into 5 to 6 segments for the UF model. Each segment was on the order of 1 to 2 miles in length.

The UF model spreadsheet was run separately on each analysis segment and the results averaged (weighted by Vehicle-Miles Traveled on each segment), to obtain the results for the entire study site.

AADT for each segment at each site was obtained from the FDOT Statewide Segmentation for Reliability. Hourly demands were obtained using the default "K" and "D" factors by hour of day built into the UF model spreadsheet.

The following incident data was obtained for each test site using the Smart SunGuide Monthly Report for each site:

- Number of non-blocking incidents
- Number of blocking incidents
- Average duration of a blocking incident
- Average duration of a non-blocking incidents
- Probabilities of lane blocking and non-lane blocking incidents by hour of day

Road rangers were assumed to be active 5 days a week from 6 a.m. to 8 p.m..

The default weather by location (Northern or Southern Florida) built into the UF model tool was used.

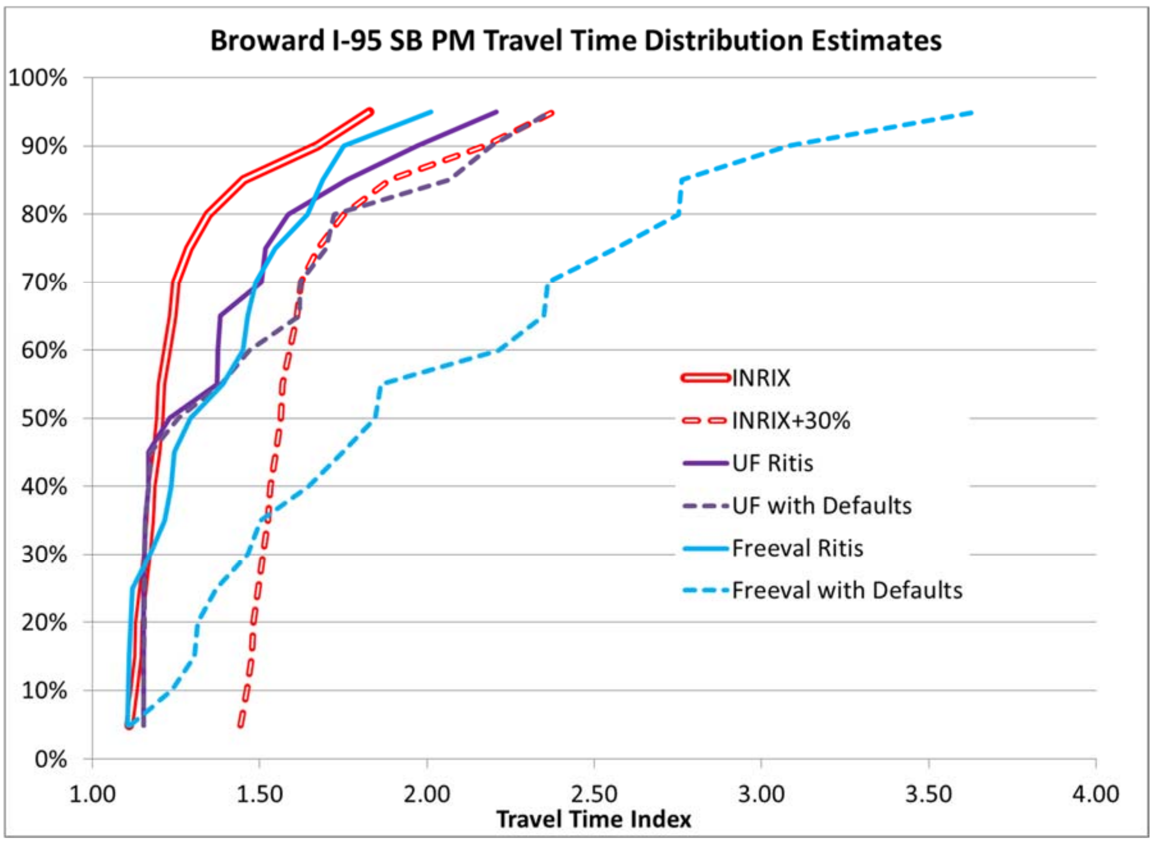
## INRIX Reliability Data

INRIX average speeds were acquired for the selected p.m. peak hour and selected direction of travel for the INRIX TMC segments at each site. The segment speeds were converted to travel times based on the segment lengths. The travel times were then summed overall the segments at the site and divided by the estimated free-flow travel time for the entire length of all the segments at the site to obtain the travel time index (TTI's) for the p.m. peak hour of each day. The percentile TTI's for each study site were then computed.

## 5.2 BROWARD I-95 TEST RESULTS

The cumulative travel time distributions produced by each method, with or without using defaults, were compared to the INRIX travel time data (see Figure 7). The Chapter 36 MOE's and TWO 13 LOS were computed using each method and the results compared as well (see Table 5)

**Figure 7 Comparison of Chapter 36 to FDOT/UF Model and INRIX on I-95**




Note: In Figure 7 "Ritis" indicates that facility specific data from RITIS was used.

### Table 5 Broward I-95 SB PM Reliability MOEs

| | INRIX | FREEVAL (RITIS) | FREEVAL (Default) | UF (RITIS) | UF (Default) |
|---|---|---|---|---|---|
| Chapter 36 MOEs | | | | | |
| Mean Travel Speed (mph) | 55.1 | 50.7 | 34.8 | 50.4 | 47.9 |
| Mean TTI | 1.27 | 1.38 | 2.01 | 1.39 | 1.46 |
| 50th % TTI | 1.20 | 1.29 | 1.84 | 1.23 | 1.26 |
| Average Delay (min/veh) | 2.12 | 2.99 | 8.01 | 3.06 | 3.69 |
| Reliability Rating | 79% | 52% | 21% | 54% | 53% |
| 80th% TTI | 1.35 | 1.64 | 2.75 | 1.59 | 1.72 |
| 95th% TTI | 1.83 | 2.01 | 3.64 | 2.21 | 2.37 |
| Failure Measure | 3% | 5% | 43% | 9% | 16% |
| Standard Deviation | 0.19 | 0.25 | 0.69 | 0.30 | 0.38 |
| Semi-Std Deviation | 0.33 | 0.45 | 1.22 | 0.49 | 0.60 |
| Misery Index | 2.09 | 2.14 | 3.92 | 2.32 | 2.46 |
| FDOT TWO 13 LOS | | | | | |
| 5th% MPH | 38.3 | 34.8 | 19.2 | 31.7 | 29.5 |
| LOS | D | E | F | E | E |

Reliability Rating =Percent of time (Non-holiday, weekday p.m. peak hours) that southbound freeway is operating at TTI 1.33 (53 mph) or better.
Failure Measure = Percent of time that freeway is operating at speeds below 35 mph (TTI of 2.00).
"RITIS" in this table indicates that facility specific incident data (from RITIS or another source) was used.

## Comparison of Reliability MOEs

The two reliability measures (the Chapter 36 reliability Rating, and the TWO 13 LOS) measure different points on the travel time distribution. This can also be said of every one of the reliability measures shown in Table 5.

Comparison between Chapter 36 reliability rating and FDOT TWO 13 reliability LOS (as well as the other MOEs) is an apple-to-oranges comparison. When the TTR LOS is poor, the reliability rating could be either high or low, which fully depends on the shape the travel time distribution. If the travel time distribution is skewed to the right, the reliability rating could be high when TTR LOS is poor; while if the travel time distribution is skewed to the left, the reliability rating could be low when TTR LOS is poor. Since the travel time distribution could vary by locations/corridors (i.e., it is a site-specific function), it is really difficult to conclude any connections between the two reliability measurement systems. They are just measuring different aspects of the travel time distribution. Figure 9 illustrates these differences.

## Comparison of Reliability Analysis Tools

The UF and Chapter 36 (FREEVAL) methods each produce travel time distributions more conservative (higher travel times) than the INRIX data. The use of default data in either method tends to produce even more conservative over estimates of travel times, especially for the higher percentiles (80% or higher).

Ongoing research by the University of Florida however suggests that INRIX travel times may be as much as 30% low for congested periods. Consequently a dashed curve has been added to the figure to show the rough confidence interval for the true travel time distribution.

Both the University of Florida and the Chapter 36 (FREEVAL) methods fall within the confidence interval for the true travel time distribution. Both methods produce results quite close to each other when facility specific data on demand variation and incidents is used in lieu of defaults.

It is apparent in the comparison that the Chapter 36 method (FREEVAL) should not be used with its built in demand variation and crash rates. The errors are too great.

The University of Florida model however is quite close, even when defaults are used in lieu of facility specific incident rates.

## Comparison of Reliability MOE Results

The Chapter 36 (FREEVAL) and UF methods produce MOE's with values similar to those computed from INRIX, when facility specific data is used (Labeled RITIS in this table).

The hazard of using default incident rates with the UF and Chapter 36 (FREEVAL) methods is highlighted by the significant differences in MOE values produced by these methods versus INRIX.

The methods using defaults rate this facility as LOS "F", while the other methods using measured data (INRIX) or facility specific data rate this facility at LOS "E", according to the TWO 13 LOS method.

The reliability rating (in essence the percent of time the facility is operating at HCM LOS E or better during non-holiday p.m. peak hours) is 52% according to Chapter 36 (FREEVAL), 53% according to the University of Florida model, and 79% when measured using INRIX.

The failure measure (the percent of time the average speed on the facility drops below 35 mph during non-holiday p.m. peak hours) is between 3% (as measured by INRIX), 5% (as estimated by the Chapter 36 method, and 9% (as estimated by the UF method).

The 5$^{th}$ percentile speed on this facility ranges from 31.7 mph (according to UF), 34.8 mph (according to Chapter 36), and 38.3 (according to INRIX).

## Diagnostic Results

Understanding the causes of reliability problems will point the analyst to possible solutions. The Chapter 36 analysis tool (FREEVAL) provides some limited information to assist the analyst (see Table 6). The percent of vehicle hours of delay (VHD) attributable to non-recurring causes (incidents, weather) are reported. In the case of I-95, the Chapter 36 method estimates that 38% of the annual VHD is attributable to incidents and weather. There is some kind of non-recurring conditions present on the facility during the p.m. peak hour 28% of the time of the year. Greater detail is possible, but the analyst must create his or her own report, compiling and categorizing the results of 800+ specific scenarios.

The University of Florida spreadsheet does not produce diagnostic reports but the analyst can apply pivot tables and other spreadsheet formulae to create a table similar to the one shown in Table 7, the shows the relative frequency of the 24 scenarios the UF model evaluates for the facility. As can be seen, I-95 is uncongested 36% of the p.m. peak hours of the year (Scenario 01), with recurring congestion accounting for 47% of the year (Scenario 09). Rain, incidents, and other non-recurring conditions that cause congestion are present in about 13% of the p.m. peak hours of the year. Unfortunately, this particular example is for only a single segment and needs to be augmented with the results from the other segments and weighted for VMT.

### Table 6 Causes of PM Peak Hour Congestion on I-95 SB

| VHD Under Condition (Veh. Hrs) | Total During Reliability Reporting Period | % VHD by Condition | %Time in Condition |
|---|---|---|---|
| Recurring | 28,359 | 61.9% | 72.0% |
| Non-Recurring | 17,445 | 38.1% | 28.0% |
| Total | 45,803 | 100.0% | 100.0% |

Note: Values reported are from FREEVAL with RITIS.

**Table 7 Frequency of Scenarios PM Peak Period on I-95 SB – UF Model**

| UF Scenario | Frequency | Description |
|---|---|---|
| Scenario 01 | 36.4% | Non-congested |
| Scenario 02 | 3.7% | Non-congested with rain |
| Scenario 03 | 0.0% | Non-congested with blocking incident |
| Scenario 03A | 0.3% | Non-congested with non-blocking incident |
| Scenario 04 | 0.0% | Non-congested with work zone |
| Scenario 05 | 0.0% | Non-congested with rain and blocking incident |
| Scenario 05A | 0.0% | Non-congested with rain and non-blocking incident |
| Scenario 06 | 0.0% | Non-congested with rain and work zone |
| Scenario 07 | 0.0% | Non-congested with blocking incident and work zone |
| Scenario 07A | 0.0% | Non-congested with non-blocking incident and work zone |
| Scenario 08 | 0.0% | Non-congested with blocking incident, work zone, and rain |
| Scenario 08A | 0.0% | Non-congested with non-blocking incident, work zone, and rain |
| Scenario 09 | 47.0% | Congested |
| Scenario 10 | 6.1% | Congested with rain |
| Scenario 11 | 1.7% | Congested with blocking incident |
| Scenario 11A | 3.4% | Congested with non-blocking incident |
| Scenario 12 | 0.8% | Congested with work zone |
| Scenario 13 | 0.2% | Congested with rain and blocking incident |
| Scenario 13A | 0.3% | Congested with rain and non-blocking incident |
| Scenario 14 | 0.1% | Congested with rain and work zone |
| Scenario 15 | 0.0% | Congested with blocking incident and work zone |
| Scenario 15A | 0.0% | Congested with non-blocking incident and work zone |
| Scenario 16 | 0.0% | Congested with blocking incident, work zone, and rain |
| Scenario 16A | 0.0% | Congested with non-blocking incident, work zone, and rain |

Note: Representative Example, Segment 705, SR 870 to W Cypress Creek Rd

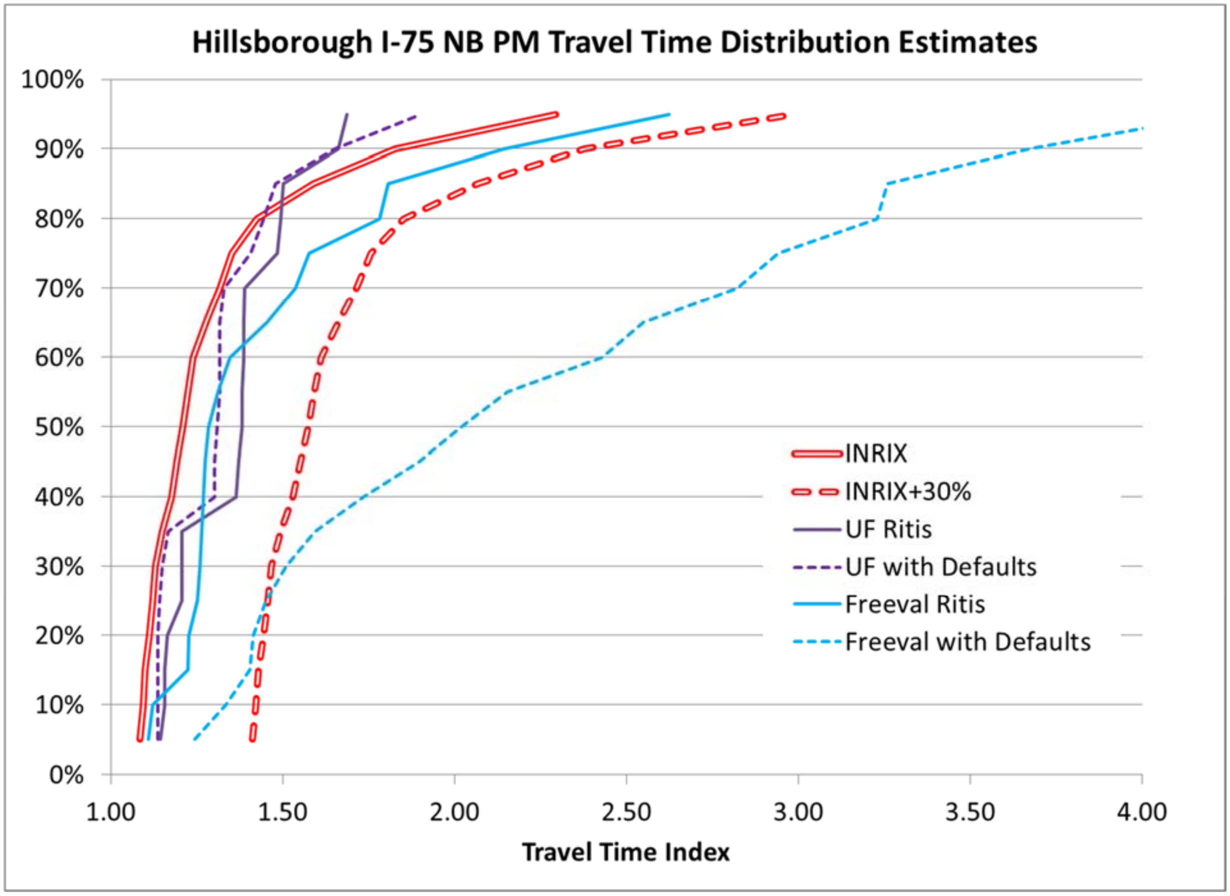
## 5.3 Hillsborough I-75 Test Results

The cumulative travel time distributions produced by each method, with or without using defaults, were compared to the INRIX travel time data (see Figure

8). The Chapter 36 MOE's and TWO 13 LOS were computed using each method and the results compared as well (see

Table 8).

**Figure 8 Hillsborough I-75 NB PM Travel Time Distributions**




Note: In the above figure, “Ritis” means that facility specific data from RITIS was used.

### Table 8 Hillsborough I-75 NB PM Reliability MOEs

| | | INRIX | FREEVAL (RITIS) | FREEVAL (Default) | UF (RITIS) | UF (Default) |
|---|---|---|---|---|---|---|
| Chapter 36 MOEs | | | | | | |
| | Mean Travel Speed (mph) | 57.3 | 51.0 | 33.2 | 55.6 | 56.8 |
| | Mean TTI | 1.31 | 1.47 | 2.26 | 1.35 | 1.32 |
| | 50th % TTI | 1.21 | 1.29 | 2.02 | 1.38 | 1.31 |
| | Avg Delay (min/veh) | 3.35 | 5.02 | 13.52 | 3.82 | 3.45 |
| | Reliability Rating | 72% | 58% | 10% | 39% | 70% |
| | 80th% TTI | 1.42 | 1.78 | 3.23 | 1.50 | 1.44 |
| | 95th% TTI | 2.30 | 2.62 | 4.23 | 1.69 | 1.90 |
| | Failure Measure | 7% | 10% | 45% | 0% | 0% |
| | Standard Deviation | 0.30 | 0.37 | 0.86 | 0.16 | 0.19 |
| | Semi-Std Deviation | 0.43 | 0.60 | 1.52 | 0.39 | 0.37 |
| | Misery Index | 2.84 | 2.86 | 4.51 | 1.70 | 2.03 |
| FDOT TWO 13 LOS | | | | | | |
| | 5th% MPH | 32.7 | 28.6 | 17.7 | 44.5 | 39.4 |
| | LOS | E | E | F | D | D |

Reliability Rating =Percent of time (Non-holiday, weekday p.m. peak hours) that freeway is operating at TTI 1.33 (56 mph in this case) or better.
Failure Measure = Percent of time that freeway is operating at speeds below 35 mph (TTI of 2.14).
"RITIS" in this table indicates that facility specific incident data (from RITIS or another source) was used.

## Comparison of Reliability MOEs

As discussed earlier for the Broward I-95 test site (see discussion following Table 5), the two reliability measures (the Chapter 36 reliability Rating, and the TWO 13 LOS) measure different points on the travel time distribution. This can also be said of every one of the reliability measures shown in.

Comparison between Chapter 36 reliability rating and FDOT TWO 13 reliability LOS (as well as the other MOEs) is an apple-to-oranges comparison. When the TTR LOS is poor, the reliability rating could be either high or low, which fully depends on the shape the travel time distribution. If the travel time distribution is skewed to the right, the reliability rating could be high when TTR LOS is poor; while if the travel time distribution is skewed to the left, the reliability rating could be low when TTR LOS is poor. Since the travel time distribution could vary by locations/corridors (i.e., it is a site-specific function), it is really difficult to conclude any connections between the two reliability measurement systems.

They are just measuring different aspects of the travel time distribution. Figure 9 illustrates these differences.

## Comparison of Reliability Analysis Tools

For the I-75 test site, the Chapter 36 (FREEVAL) method produced travel time distributions more conservative (higher travel times) than the INRIX data. The use of default data in this method tends to produce extremely conservative over estimates of travel times.

Based on ongoing research by the University of Florida a dashed curve representing a 30% increase in the INRIX points has been added to the figure to show the rough confidence interval for the true travel time distribution.

The Chapter 36 (FREEVAL) method falls within the confidence interval for the true travel time distribution only when facility specific data on demand variation and incidents is used in lieu of defaults.

It is apparent in the comparison that the Chapter 36 method (FREEVAL) should not be used with its built-in demand variation and crash rates. The errors are too great.

The University of Florida model however is quite close to INRIX data, even when defaults are used in lieu of facility specific incident rates. Above the 80th percentile, though, the UF model appears to under estimate travel times, compared to INRIX. This is a problem for the UF model regardless of whether or not default data is used.

## Comparison of Reliability MOE Results

For the I-75 test site the Chapter 36 (FREEVAL) method produces MOE's with values similar but on the conservative side (as desired) to those computed from INRIX, when facility specific data is used (Labeled RITIS in this table).

The UF model with defaults produces MOE results similar to INRIX, but on the low side, under estimating what is likely to be the true reliability problems on I-75. The use of facility specific incident rates made the UF model lower, accentuating the under estimating of travel times on this freeway by the UF model.

The UF model rates the facility at LOS D (when facility specific data is used). The Chapter 36 (FREEVAL) method rates it at LOS "F", while INRIX data suggests the freeway might be at LOS "E" when applying the FDOT TWO 13 LOS method.

The reliability rating (in essence the percent of time the facility is operating at HCM LOS E or better during non-holiday p.m. peak hours) is 58% according to Chapter 36 (FREEVAL), 39% according to the University of Florida model, and 72% when measured using INRIX.

The failure measure (the percent of time the average speed on the facility drops below 35 mph during non-holiday p.m. peak hours) is between 7% (as measured by INRIX), 10% (as estimated by the Chapter 36 method, and 0% (as estimated by the UF method).

The 5th percentile speed on this facility ranges from 44.5 mph (according to UF), 28.6 mph (according to Chapter 36), and 32.7 (according to INRIX).

## Diagnostic Results

In the case of I-75, the Chapter 36 method estimates that 15% of the annual VHD is attributable to incidents and weather (see Table 9).

The University of Florida spreadsheet does not produce diagnostic reports but the analyst can apply pivot tables and other spreadsheet formulae to create a table similar to the one shown in Table 7, the shows the relative frequency of the 24 scenarios the UF model evaluates for the facility.

The University of Florida spreadsheet estimates that I-75 is uncongested 90% of the p.m. peak hours of the year (Scenarios 01-08A), with recurring congestion accounting for 2% of the year (Scenario 09). Rain, incidents, and other non-recurring conditions that cause congestion are present in about 8% of the p.m. peak hours of the year. Unfortunately, this particular example is for only a single segment and needs to be augmented with the results from the other segments and weighted for VMT.

### Table 9 Causes of PM Peak Hour Congestion on I-75 NB

| VHD Under Condition (Veh. Hrs) | Total During Reliability Reporting Period | % VHD by Conditions | %Time in Condition |
|---|---|---|---|
| Recurring | 44,262 | 85.0% | 92.2% |
| Non-Recurring | 7,798 | 15.0% | 7.8% |
| Total | 52,060 | 100.0% | 100.0% |

Values reported are from FREEVAL with facility specific data.

### Table 10 Frequency of Scenarios PM Peak Period on I-75 SB – UF Model

| Scenario | Frequency | Description |
|---|---|---|
| Scenario 01 | 18.4% | Non-congested |
| Scenario 02 | 67.7% | Non-congested with rain |
| Scenario 03 | 0.0% | Non-congested with blocking incident |
| Scenario 03A | 2.8% | Non-congested with non-blocking incident |
| Scenario 04 | 0.0% | Non-congested with work zone |
| Scenario 05 | 0.0% | Non-congested with rain and blocking incident |
| Scenario 05A | 0.6% | Non-congested with rain and non-blocking incident |
| Scenario 06 | 0.0% | Non-congested with rain and work zone |
| Scenario 07 | 0.0% | Non-congested with blocking incident and work zone |
| Scenario 07A | 0.0% | Non-congested with non-blocking incident and work zone |
| Scenario 08 | 0.0% | Non-congested with blocking incident, work zone, and rain |
| Scenario 08A | 0.0% | Non-congested with non-blocking incident, work zone, and rain |
| Scenario 09 | 1.6% | Congested |
| Scenario 10 | 6.4% | Congested with rain |
| Scenario 11 | 1.1% | Congested with blocking incident |
| Scenario 11A | 0.2% | Congested with non-blocking incident |
| Scenario 12 | 0.2% | Congested with work zone |
| Scenario 13 | 0.3% | Congested with rain and blocking incident |
| Scenario 13A | 0.0% | Congested with rain and non-blocking incident |
| Scenario 14 | 0.7% | Congested with rain and work zone |
| Scenario 15 | 0.0% | Congested with blocking incident and work zone |
| Scenario 15A | 0.0% | Congested with non-blocking incident and work zone |
| Scenario 16 | 0.0% | Congested with blocking incident, work zone, and rain |
| Scenario 16A | 0.0% | Congested with non-blocking incident, work zone, and rain |
| | 100.0% | |

Example Segment 405, between SR 60 and MLK Jr Blvd. with facility specific data.

# 6.0 Conclusions

## 6.1 Reliability MOEs

The tests show the need for and the value of multiple measures of travel time reliability. While Hillsborough I-75 showed better average speeds and lower average delay than Broward I-95, the 95$^{th}$ percentile travel time on I-75 was significantly worse than for Broward I-95. This suggests that while breakdowns may be less frequent on Hillsborough I-75, when they do happen, they tend to be much more severe than on Broward I-95.

The FDOT TWO 13 LOS framework appears to be a good basis for assessing reliability on freeways. The LOS and 5th percentile speed were better on Broward I-95 than on Hillsborough I-75. The Failure Measure (percent below 35 mph) also showed I-75 to be worse than I-95. The Chapter 36 Reliability Rating produced mixed results, depending on whether INRIX or Chapter 36 was used to estimate the rating. I-95 is has a better Chapter 36 reliability rating if INRIX data is used. I-75 has a better Chapter 36 reliability rating if Chapter 36 method is used instead of INRIX.

### Appropriateness of Chapter 36 Performance Measures

Chapter 36 identifies several potential reliability performance measures, including some that quantify full year accumulated delay or average annual travel time, as well as several variations on the standard deviation and the percentile travel time index. The chapter introduces the concept of the "reliability rating" for the facility, the percent of vehicle trips experiencing level of service "F", oversaturated conditions over the course of a year.

It appears appropriate for FDOT to adopt some sort of cumulative, "whole year" measure of reliability performance for use in its PD&E project evaluations. The annual vehicle or person-hours of delay recommended by Chapter 36 appear to be useful measures that can also be used for cost/benefit analyses.

As far as indices of reliability, the Reliability Rating (percent of trips experiencing LOS "F" conditions), appears (based on the tests) to be among the best of the Chapter 36 recommendations.

### Evaluation of TWO 13 Reliability LOS Thresholds

TWO 13 concluded that level of service for freeways in large urbanized areas should be keyed off of the 5th percentile highest speed for the freeway (the speed that is exceeded by 95% of the trips on the freeway during non-holiday peak periods over the course of a year) (see Table 11).

### Table 11 TWO 13 Reliability LOS Ratings

| Level of Service | 5th Percentile Speed Range (mph) |
|---|---|
| A | 60+ |
| B | 55-60 |
| C | 45-55 |
| D | 35-45 |
| E | 25-35 |
| F | <=25 |

The Chapter 36 Reliability Rating does not track well with the FDOT TWO 13 Reliability LOS, with relatively high reliability ratings in excess of 70% still yielding LOS D and "E" per the TWO 13 framework (See INRIX results for both I-95 and I-75). A low reliability rating of 39% for I-75 (UF-RITIS) still had a TWO 13 LOS "D". This is because the two reliability rating systems measure different points on the speed distribution. The Chapter 36 reliability rating is based on the percent of time the freeway is operating at better than 40 to 50 mph. The TWO 13 reliability LOS is based on the speed that is exceeded 95% of the time on the freeway.

Figure 9 illustrates the application of both reliability measures to the I-95 and I-75 test sites. The reliability ratings of the two sites differ by 7 percentage points (72% vs 79%) (a 10% difference), while the 5$^{th}$ percentile speeds differ by 5.6 mph (32.7 vs 38.3 mph) (a 15% difference). The Broward I-95 with a higher Chapter 36 reliability rating than Hillsborough I-75, also has a superior TWO 13 LOS ("D" versus "E") than Hillsborough I-75.[10]

## Comparison of Reliability Performance Measures to Traditional PD&E Measures

FDOT PD&Es always report the Highway Capacity Manual Level of Service performance measures for each segment and intersection on the facility. Additional measures, such as queuing, and system measures, like vehicle-hours of delay, may be reported as well, depending on the circumstances. Reliability results taking into account weather and incidents are not reported.

Table 12 illustrates the typical PD&E LOS report for the Broward I-95 test site. Table 13 illustrates the same for the Hillsborough I-75 test site.

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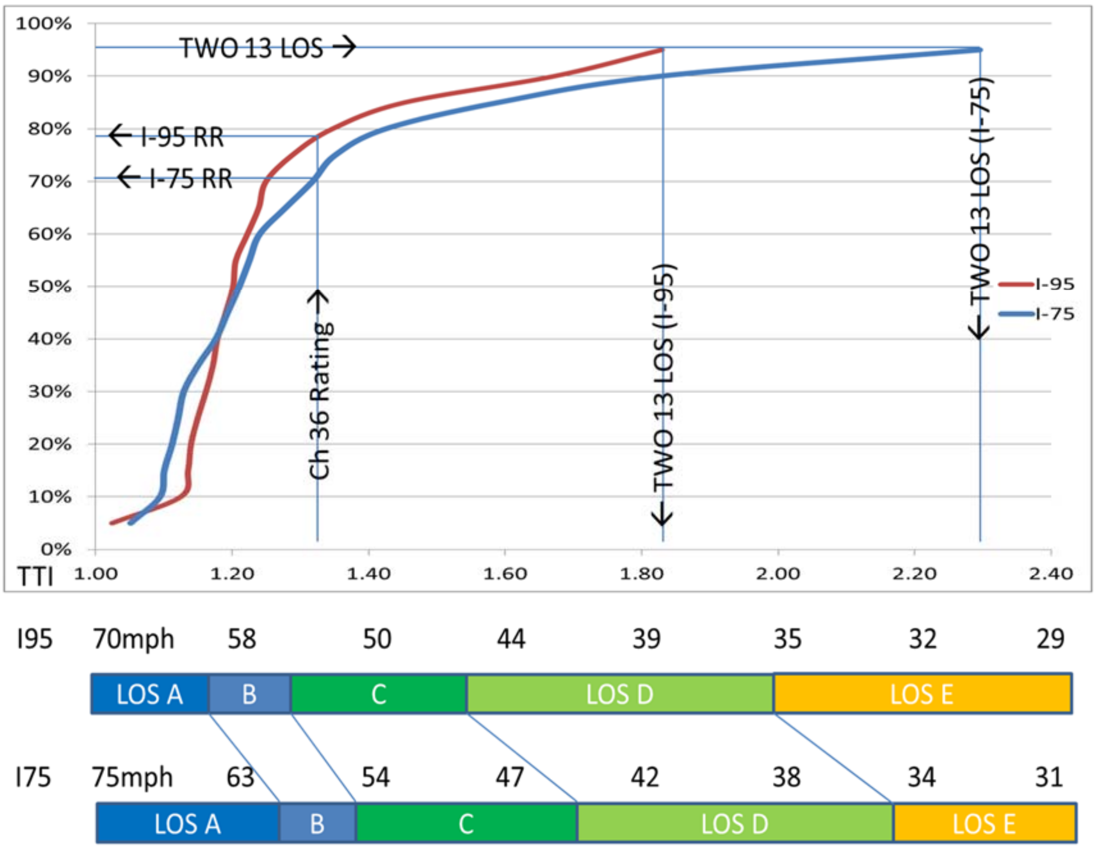
[10] Note that speed being the inverse of the TTI, it is mathematically appropriate for the speed range to stretch out at the higher values of TTI, when plotted in terms of TTI.

Note that these traditional segment based analyses can help the analyst spot geographically where the bottlenecks are. But they do not spot the queues, or how extensive they might be. These segment analyses only identify sections where densities are high. For this reason, the traditional segment based HCM analysis may be supplemented by a facility analysis using microsimulation.

**Figure 9 Chapter 36 Reliability Rating vs. TWO 13 Reliability LOS**




Note that this figure uses two speed scales (one for I-95 and the other for I-75) because of the different free-flow speeds on these facilities. The same TTI implies a different speed for each facility.

Reliability analysis requires the analysis of the entire facility, and as such, automatically produces information on bottlenecks and queues. The reliability MOE's however are facility aggregates and cannot be used to identify specific segments that contribute the most to facility reliability problems.

Although the currently available tools for reliability analysis using the Chapter 36 method or the University of Florida reliability model do not make it easy for the analyst, it is possible to parse the scenarios used in either method to identify the relative causes of reliability problems.

### Table 12 Reported PD&E Results for Broward I-95 Test Section (SB PM Peak Hour)

| Start Point | Sect # | HCM Type | Pk Demand (vph) | Density | Pk D/C | LOS |
|---|---|---|---|---|---|---|
| South of SW 10th | 1 (16) | B | 5,870 | 33.5 | 0.83 | D |
| Sample Off | 2(17) | OFR | 5,870 | 36.0 | 0.83 | E |
| | 3(18) | B | 4,900 | 26.4 | 0.69 | D |
| WB Sample On | 4(19) | ONR | 5,430 | 30.9 | 0.77 | D |
| Sample OC | 5(20) | B | 5,430 | 29.9 | 0.77 | D |
| EB Sample On | 6(21) | W | 6,030 | 25.6 | 0.68 | D |
| Copans Off | 7(1) | B | 5,630 | 31.1 | 0.79 | D |
| WB Copans On | 8(2) | W | 6,020 | 27.2 | 0.72 | C |
| EB Copans Off | 9(3) | B | 5,680 | 31.5 | 0.80 | D |
| EB Copans On | 10(4) | ONR | 6,280 | - | 0.30 | Under |
| | 11(5) | B | 6,280 | 24.9 | 0.66 | C |
| WB Atlantic Off | 12(6) | OFR | 6,280 | - | 0.39 | Under |
| | 13(7) | B | 5,510 | 30.2 | 0.78 | D |
| EB Atlantic Off | 14(8) | OFR | 5,510 | 27.9 | 0.78 | C |
| | 15(9) | B | 4,860 | 25.8 | 0.69 | C |
| Atlantic On | 16(10) | ONR | 6,050 | - | 0.60 | Under |
| | 17(11) | B | 6,050 | 23.9 | 0.64 | C |
| Cypress Off | 18(12) | OFR | 6,050 | 16.4 | - | B |
| | 19(13) | B | 4,800 | 24.9 | 0.68 | C |
| WB Cypress On | 20(14) | ONR | 5,320 | 27.3 | 0.75 | C |
| | 21(15) | B | 5,320 | 28.2 | 0.75 | D |
| PNR On | 22(16) | ONR | 5,470 | 32.2 | 0.77 | D |
| Andrews On-Commercial Off | 23(17) | ONR(W) | 6,800 | 40.5 | 0.97 | F |
| | 24(18) | B | 5,670 | 30.5 | 0.80 | D |
| EB Commercial On | 25(19) | ONR | 6,750 | - | 0.54 | Under |
| WB Commercial On | 26(20) | ONR | 7,630 | 53.1 | 0.81 | E |
| | 27(21) | B | 7,630 | 30.9 | 0.81 | D |
| Total | | | | | | |

Notes:

The D/C's and volumes shown here do not match those shown in **Table 15**. That is because **Table 15** is the calibrated FREEVAL D/C's for the selected seed day, while this table uses uncalibrated FDOT/HCM standard segment capacities using HCS with volumes for an average clear day condition.

Section numbers in parentheses are corresponding TATM HCS section #'s. "Under" means that Ramp Roadway analysis was conducted for this segment. The ramp roadway analysis procedure determines if the segment is operating under or over capacity; it does not determine Density or LOS.

Source: Table 5.1B Traffic Analysis Technical Memorandum.

### Table 13 PD&E LOS Results for Hillsborough I-75 Test Section (NB PM Peak Hour)

| Start Point | Sect # | HCM Type | Density | LOS |
|---|---|---|---|---|
| South of SR 60 | 1 | B | 18.0 | B |
| Brand/Adamo (SR 60) | 2 | ONR | 32.9 | D |
| Brand/Adamo (SR 60) | 3 | ONR | 18.8 | B |
| Mainline | 6 | B | 28.5 | D |
| E MLK Jr. Blvd (SR 574) | 7 | OFR | 34.2 | D |
| E MLK Jr. Blvd (SR 574) | 9 | OFR | 24.3 | C |
| E MLK Jr. (SR 574) | | ONR | 29.9 | D |
| Mainline | 10 | B | 23.2 | C |
| I-4 Off | 11 | W | 36.6 | E |
| I-4 On | 13 | ONR | 29.4 | D |
| I-4 On | 14 | ONR | 32.2 | D |
| Mainline | 15 | B | 28.9 | D |
| E Fowler Ave | 16 | OFR | 37.0 | E |
| E Fowler Ave | 18 | ONR | 35.0 | F (merge) |
| E Fowler Ave | 20 | ONR | 27.5 | C |
| Mainline | 21 | B | 26.2 | D |
| E Fletcher Ave | 22 | OFR | 19.9 | B |
| E Fletcher Ave | 24 | ONR | 42.6 | F |

Source: Table 2-3, Table 2-4, Design Traffic Technical Memorandum – Technical Report #1, Evaluation of Alternatives, Sep. 2009.

Table 14 compares the traditional PD&E LOS results to those produced by the Chapter 36 reliability analysis and the TWO 13 reliability LOS thresholds.

**Table 14 Comparison of PD&E and Chapter 36 Reliability Results for Both Test Sites**

| Study Corridor | Conventional PD&E Study | | Ch36 Reliability Study[2] | | |
|---|---|---|---|---|---|
| | Travel Speed (mph)[1] | Worst LOS[1] | Mean Travel Speed (mph) | 5th Percentile Travel Speed (mph) | TWO 13 Reliability LOS |
| I-95 SB | 48 | F | 49 | 35 | D |
| I-75 NB | 56 | F | 46 | 27 | E |

Notes:
The travel speed of PD&E study is based on a single-day field measurement. Note that the PD&E studies do not report an overall facility LOS, they instead identify the worst segment LOS.
The results of Ch36 reliability study are retrieved from the FREEVAL (using RITIS data wherever available)

## 6.2 Reliability Analysis Tools

### Accuracy

In the case of the Broward I-95 test, the UF model produced satisfactory results whether or not defaults were used. The UF model results were equally as good as those produce by the Chapter 36 method, when it used facility specific data.

For the Hillsborough I-75 test site, only the Chapter 36 method, using facility specific data appeared to produce satisfactory reliability estimates.

With accurate data on seasonal demand variation and crash rates on the facility, the Chapter 36 method appears to produce reasonably accurate estimates of travel time reliability, slightly superior to those produced by the UF reliability model

### Data Requirements

The UF reliability model requires no more field data than a typical HCM point and segment LOS analysis. Required data on annual average crash rates can be obtained from the appropriate FDOT source (e.g. CARS).

The Chapter 36 reliability method requires that a HCM level facility analysis be conducted. As such, the Chapter 36 method requires observations of travel times on the facility during recurring congestion conditions so that the conventional HCM facility analysis tool can be calibrated to match the observed facility travel times. This would be new data collection for the PD&E that would not otherwise perform a facility level analysis using either HCS or a microsimulation tool.

- Note that PD&Es that require only segment level HCM LOS analyses generally do not have the facility level of recurring congestion to justify a reliability analysis. Thus, if there is no significant queuing expected on the facility under the future scenarios to be evaluated, then a reliability analysis may not be necessary.

Therefore, if the PD&E was already required to perform a facility level analysis using HCS or microsimulation, then the Chapter 36 method would require no more new data collection than would ordinarily be performed for an HCS/microsimulation facility analysis.

Successful application of the Chapter 36 reliability method in Florida requires assembling archived data on facility specific seasonal demand variability and crash rates. This can usually be obtained from FDOT's RITIS system for most major facilities.

### Use of Defaults

Based on the test results it appears that the UF reliability model can usually be applied with defaults in most freeway sites in Florida. However, where possible, it is desirable to provide facility specific crash data to improve the accuracy of the reliability estimates produced by the UF reliability model.

As for the <u>Chapter 36 reliability method, it should never be applied in Florida with the current built in seasonal demand variation and incident rate defaults</u>. For weather, the airport specific weather info contained in the Chapter 36 tool is quite adequate.

### Effort Required

For people who have never used the tool before, they need to first learn the HCM facility analysis method by reading Chapters 10 and 11 of the Highway Capacity Manual. Then it may take approximately 12-16 hours for them to go through the user document/manual and get familiar with the tool and different modules. For the Chapter 36 method the estimated professional effort required (for someone who has already learned the tool and applied it once before) is:

- Collection of data and coding of data in HCS for conventional HCM segment and point analyses – Assumed to be included in typical PD&E budget.
- Coding and calibrating freeway facility analysis tool for seed day – Approximately 16-24 person-hours. (This may already be included in a typical PD&E budget, if a facility level analysis was planned.)
- Assemble and process crash and seasonable demand data from District TMC and RITIS – Approximately 4 person-hours.
- Apply Chapter 36 reliability tool, report, error check, and summarize results – Approximately 4 person-hours.

For the University of Florida Reliability Model, the estimated professional effort required to apply it (assuming they have already learned the tool and applied it once before) is:

- To obtain the facility specific crash rates and code the UF model – Approximately 8 person-hours.
- To apply the UF model tools, report, error check and summarize the results – Approximately 2 hours.

## 6.3 Feasibility of Incorporating in PD&Es

### Determining Reliability Problems

Both the UF reliability model and the Chapter 36 reliability method provide important tools for estimating and predicting travel time reliability. Neither method however identifies a threshold of acceptable and unacceptable reliability. Since all highway facilities have less than perfect reliability in the real world it is necessary to identify a point or points where less than perfect reliability is no longer acceptable.

The TWO 13 LOS framework goes a long way towards identifying this threshold of acceptability for reliability. The speed thresholds in TWO 13 however are designed for the analysis of freeway systems and will need to be adapted for arterial reliability analyses.

### Diagnosing the Sources of Reliability Problems

Both spreadsheet tools (UF and Chapter 36 FREEVAL) have the potential to be very useful for diagnosing the causes of reliability problems, however; the current implementations of these tools do not facilitate their use for diagnosis by the average user. Significant improvements to the user interface would be required. For example, a report tallying the percent of time and the percent of annual delay associated with each cause of reliability (such as described in the SHRP2-L02 Guide being evaluated under a separate task order) would be required for diagnostic purposes.

### Identifying and Evaluating Reliability Improvement Strategies

While both the UF reliability model and the Chapter 36 method are the foundation of any method for identifying and evaluating reliability improvement strategies, neither tool nor methods facilitate this at this point. The analyst must use other information sources (such as the SHRP2-L07 Guide and Tool, which are the subject of a separate task order) to identify and select improvement strategies for testing.

### Cost Effectiveness

The UF model is a cost-effective tool for performing reliability analyses, with minimal additional resource requirements for the typical PD&E. At minimal extra cost, reliability can regularly be reported in a PD&E.

The Chapter 36 method should be used to evaluate reliability when the improvement strategies to be tested exceed the level of detail and sensitivity of the UF reliability model.

### Impacts of Reliability Performance Measures on FDOT Resources

The computation of reliability for non-recurrent congestion conditions will definitely add to the data and analysis resources required by FDOT to perform traffic analyses. However, using defaults and planning applications developed by the University of Florida, it is possible to keep the extra resource requirements to a minimum.

### Impacts of Reliability Performance Measures on PD&E Tasks

#### *Project Needs and Purpose*

Reliability is already often included as a project need or purpose. For these PD&Es the application of reliability analysis tools to PD&E analyses is unlikely to change the stated project purpose and need. Instead the major effect will be on the inclusion of specific reliability performance measures and analyses in the PD&E that could not feasibly be performed before.

For example, the Preliminary Engineering Report for the I-95 Express Lanes Project in Broward County states that the project purpose is:

"The primary purpose of this project is to design a transportation system that will offer new commuting choices <u>and more reliable travel</u> during congested periods with the implementation of an express lanes system. The purpose of these express lanes is to improve mobility, relieve congestion, and provide additional travel options along the I-95 corridor."

In this case, reliability is already included in the project purpose. However, the traffic analysis (section 5.4.14 of the report) focused on average delay, density, and LOS under recurring congestion for freeway segments, and ramp termini.

Other PD&Es have more general purpose statements that do not explicitly specify reliability. For example, the Draft Project Development Summary Report for I-75 in Hillsborough County states the following project purpose and need:

"Preserving the operational integrity and regional functionality of I-75 is critical to mobility and economy, as it is a vital link in the transportation network that connects the Tampa Bay region to the remainder of the state and the nation."

Mobility implicitly includes reliability but it is not explicitly stated. The alternatives analysis focused on the recurring congestion benefits of each alternative as measured using LOS.

With the availability of reliability estimation tools, like Chapter 36 and the UF reliability model, it is now feasible to incorporate reliability explicitly into the project need and purpose, and to identify and compute reliability related performance measures.

### *Performance Measures*

The ability to directly estimate and predict reliability under adverse weather, demand, work zone, and incident conditions, as provided by the Chapter 36 and UF reliability model tools, enables the application of performance based analysis in the PD&E to directly assess the ability of the proposed project and its alternatives to meet the project purpose and needs.

Two new reliability performance measures are recommended for inclusion in PD&E analyses of reliability:

1. Whole Year Annual Delay (taking into account the effects of demand variation, weather, work zones, and incidents), and
2. Reliability Level of Service, as described and defined in TWO 13.

### *Data Collection*

The computation of reliability performance measures will add a new reliability data assembly and analysis task to the typical PD&E traffic analysis. However, the use of default values, and data already stored in Florida's Regional Integrated Transportation Information System (RITIS) will greatly simplify the added effort.

### *Design of Preferred Project*

If reliability performance measures and estimation tools had been available for the I-95 and I-75 PD&Es, they might have considered some additional design and operations features (as suggested in the SHRP2-L07 guide being evaluated under a separate task order) for the preferred project. For example, stepped up incident management programs or crash investigation sites might have been added to each project to reduce the effects of incidents and to increase the productivity and service life of each project.

### *Generation of Alternatives*

Neither reliability method or tool, the Chapter 36 method, or the UF reliability model, assists the engineer/planner in the generation of alternatives to specifically address reliability problems. The SHRP2-L07 guide, being evaluated under a separate task order, provides assistance in generating improvements that address reliability problems.

### *Alternatives Analysis*

Both the Chapter 36 method and the UF reliability model can be used to evaluate some alternatives for improving reliability, however; these methods are not ideally suited for such use in PD&E work. They require a well-trained user able to access and draw information from other published studies on the demand, capacity, and free-flow effects of various TSM&O improvements. One such source is the recently updated Chapter 35 on Active Transportation and Demand Management in the Highway Capacity Manual.

With suitable training and access to the appropriate information, a user can apply the University of Florida Reliability Model to evaluate the reliability effects of the following improvement alternatives:

1. Demand Management strategies that flatten the hourly demand during the day
2. Safety Improvements that reduce the frequency of crashes, and especially lane blocking crashes.
3. Incident Management strategies, especially Road Ranger deployments, that reduce the duration of incidents.
4. Weather Management Strategies and Pavement treatments that reduce the capacity and free-flow speed effects of rain.

With suitable training and access to the appropriate information, a user can apply the Chapter 36 method to evaluate the reliability effects of the TSM&O improvement alternatives identified above for the UF model, plus the following:

1. Weather Management Strategies and Pavement treatments for snow.
2. Incident Management strategies that reduce the relative frequencies of single, dual, triple, or quadruple lane closures, their average durations of the lane closure, and the standard deviations of those durations.
3. Incident Management strategies that divert traffic for major incidents.
4. Incident Management strategies that better preserve the original free-flow speeds in the vicinity of the incident.

# 7.0 Recommendations

Based on the evaluation test results and the conclusions identified earlier the recommendations are as follows:

1. Reliability reporting should be a regular requirement of PD&Es performed on freeways and arterials in large urban areas with regularly recurring congestion problems. At little additional analytical cost it will open up a broader range of solutions the congestion problems in the corridor and will result in improved designs of traditional capacity improvements (with TSM&O features) that will lengthen the service life of the improvements.

2. The recommended reliability MOE's are:

    a. Whole Year Annual Vehicle or Person-Hours of Delay

    b. The TWO 13 LOS (5$^{th}$ percentile speed for the facility)

    c. Reliability Rating (percent of trips experiencing traditional HCM LOS "F" conditions for the facility)

    The whole year delay provides information needed for typical cost/benefit analyses. The TWO 13 LOS framework provides an assessment of the acceptability of the reliability of the facility. The Reliability Rating provides insight into the proportion of facility travelers that are impacted by congestion due to both recurrent and non-recurrent causes.

3. The recommended reliability analysis tool is the UF Reliability Model, unless the improvement strategies to be tested exceed the sensitivities of the UF model (see Alternatives Analysis discussion on previous page for details), in which case, the Chapter 36 reliability analysis method should be used.

    a. The UF model can be used with its built in defaults for seasonal demand variation and crash rates for South Florida freeways and arterials.

    b. If the UF model is applied outside of South Florida, the analyst should input specific information on demand variation and crash rates.

    c. In call cases, if facility specific crash rates are available, they should be used with the UF Model.

    d. If the Chapter 36 reliability method is used, local seasonal demand and crash rate data MUST be entered into the tool.

4. The user interface for the UF spreadsheet must be improved. It is currently satisfactory for research purposes and must be used by a knowledgeable and experienced analyst.

5. A diagnostic feature should be added to the UF tool to assist the analyst in parsing the relative importance of the various causes of reliability problems. This feature would sum the results by scenario, weighting them accordingly, and present a pie chart or some other such summary of the relative contributions of different causes to the reliability problem.
6. The diagnostic capabilities of the Chapter 36 also need to be enhanced to facilitate their use by district and consultant personnel. Generally, more detail on the different causes of reliability problems needs to be provided to the user in a more accessible format, such as a summary report.
7. Support for alternatives analysis should be added to the UF reliability model tool and the Chapter 36 tool so that users do not need to research the necessary capacity and speed effects of different possible TSM&O improvements before applying either of the tools.
8. A guidebook and training program should be developed to train district and consultant personnel on the appropriate use and application of reliability analyses in PD&Es.

## 7.1 Specific Tool Improvements

### University of Florida Reliability Models

The possible tool improvements that would greatly facilitate incorporation of reliability and the University of Florida reliability models into FDOT PD&E traffic studies are as follows:

- Implementation of the University of Florida reliability models in LOSPLAN software
- Addition of a report and pie chart on the relative contributions of demand, incidents, weather, and work zones to the whole year annual delay.
- Development of Generalized Service Volume Tables for Reliability.
- A table of the capacity and speed effects of typical TSM&O improvements that might be considered in a PD&E for improving reliability.

### Chapter 36 Reliability Models

The possible tool improvements that would greatly facilitate incorporation of reliability and the Chapter 36 reliability method into FDOT PD&E traffic studies are as follows:

1. Implementation of the Chapter 36 models in HCS software
2. Improvement of the current report and pie chart on the causes of congestion to more precisely isolate the causes of reliability problems.
3. Development of Florida metro area specific default values for:
    a. Demand variability by day of week, month of year, and

   b. Incident frequency by lanes closure type and duration.

4. A table of the capacity and speed effects of typical TSM&O improvements that might be considered in a PD&E for improving reliability.

While a planning application of Chapter 36 is highly desirable for PD&E studies, the University of Florida reliability models can serve that purpose quite well.

# A. Broward I-95 Tests

This appendix documents the tests and the results of the evaluation of the Highway Capacity Manual Chapter 36 (SHRP2-L08) reliability analysis method for the I-95 freeway in Broward County, Florida.

## Purpose

The purpose of this evaluation is to:

1. Assess the appropriateness of Chapter 36 travel time reliability performance measures and, as necessary, suggest alternative measures related to reliability for use in project specific PD&E alternatives generation, alternatives analysis, and selection of preferred project concept.
2. Compare the performance measures from the analysis using Chapter 36 with the performance measures used in the traditional traffic analysis to support PD&E studies.
   - Assess the cost-effectiveness of gathering facility specific data on demands, weather, incidents, and work zones versus employing defaults for one or more of these data items.
   - Assess the effects of the use of defaults for demand variability, weather, incidents, work zones on the accuracy of the predicted travel time reliability and variability results.
3. Compare the additional demands on FDOT data collection, archiving, and analysis resources of a PD&E analysis performed using Chapter 36 travel time reliability procedures versus a conventional (no travel time reliability) analysis.
   - Identify data demands that are different than what is used in the traditional traffic analysis to support PD&E studies.
   - Identify possible tool improvements that might reduce the additional demands on FDOT resources.
   - Identify possible defaults and data collection/archiving improvements to reduce additional demands of Chapter 36 methods.
4. Identify the effects of incorporating the consideration of project specific travel time reliability, via Chapter 36 analysis methods, into PD&E tasks, such as; purpose and needs statements, generation of alternatives, analysis of alternatives, and the selection of a preferred project and facility operations and management plan.

5. Evaluate the level of service thresholds being developed in task work order 13 as they relate to the results shown in the 'traditional' traffic analysis used to support the PD&E process.

## A.2 APPROACH

The subtask 2 memorandum conducted a preliminary review of the HCM Chapter 36 reliability method and reached the following conclusions:

- For some planning level traffic studies, the SHRP2-L08 (Chapter 36) procedures would be inappropriate, requiring an order of magnitude greater data collection and analysis resources then currently employed for these types of studies. In such cases, a more planning oriented approach to reliability such as employed by the University of Florida (UF) reliability models or the SHRP2-L03 and SHRP2-L07 reliability models may be appropriate.
- For some preliminary engineering studies employing HCS levels of analysis, the SHRP2-L08 (Chapter 36) procedures may (or may not) be appropriate. The SHRP2-L08 procedures require the same level of demand and geometric data detail as HCS and produce similarly detailed estimates of facility performance. The question is whether the additional data requirements to estimate reliability (using SHRP2-L08) provide sufficiently improved results to warrant their use instead of the simpler UF or SHRP2-L03/L07 models.
- Finally, for those studies employing microsimulation, none of the tools under consideration (University of Florida, SHRP2-L03/L07, or SHRP2-L08) are likely to provide sufficient detail and sensitivity for use in these studies. A more detailed approach, such as used in the FHWA sponsored ICM Concept of Operations studies may be required.

The subtask 2 memorandum recommended that the following tests be performed

- The use of the University of Florida (UF) reliability models for planning level analyses should be tested in two corridors.
  - To assess the effects of the use of defaults on the model results, the corridor tests should ideally be conducted where both permanent count station data and INRIX speed data are available for one or more years to assess how the use of defaults for incidents and demand variability, in-lieu of facility specific data in the University of Florida reliability models affect the accuracy of their results
- The use of the SHRP2-L08 Chapter 36 methods for HCS level analyses of reliability should be tested in two corridors.
  - To assess the need for Florida specific defaults, the corridor tests should ideally be conducted where facility specific data on demand variability, and lane-closing incidents are available.

   - In addition, to assess the effects of the use of Florida specific or national defaults on the model results, the corridor tests should ideally be conducted where both permanent count station data and INRIX speed data are available for one or more years to assess how the use of defaults for incidents and demand variability, in-lieu of facility specific data affect the accuracy of the results

- Based on the corridor test results, the ability of the University of Florida reliability models to provide sufficient accuracy and sensitivity should be evaluated in comparison to the Chapter 36 methods to see if the more elaborate Chapter 36 methods need be employed in Florida.
- The testing of the SHRP2-L07 reliability models is not recommended at this time because the University of Florida (UF) models provide the full travel time distribution (while the L07 models produce only Percentile TTI's) and the UF models have already been calibrated to Florida conditions with Florida appropriate defaults.

In subtask 3, several corridors with recently completed PD&E studies were investigated. Two were selected for the tests recommended in the subtask 2 memorandum:

- The I-95 freeway in Broward County, a 10 mile long section between the SW 10th Street and W. Oakland Park Blvd. interchanges.
- The I-75 freeway in Hillsborough County, a 13 mile long section between SR 618 (Selmon Cross-Town Expwy) and SR 581 (Bruce Downs Blvd) interchanges.

This appendix documents the analysis and reports the results for the tests on the Broward I-95 corridor. The analysis proceeded through the following steps:

- Data Assembly
   - PD&E demand and geometric Input data for Chapter 36 (FREEVAL) seed file
   - PD&E traffic operations data for calibration of FREEVAL seed file
   - Input data for Chapter 36 (FREEVAL) reliability analysis
   - Output data (from INRIX) for assessment of accuracy of reliability results
- Coding and Calibration of FREEVAL Seed File
- Application of Chapter 36 (FREEVAL) method using:
   - Defaults for reliability analysis (Test #1)
   - Corridor specific demand variability and crash rates for reliability analysis (Test #2)
- Application of UF Reliability Model using:
   - Defaults (Test #3)

– Facility specific data on incidents and weather (Test #4)

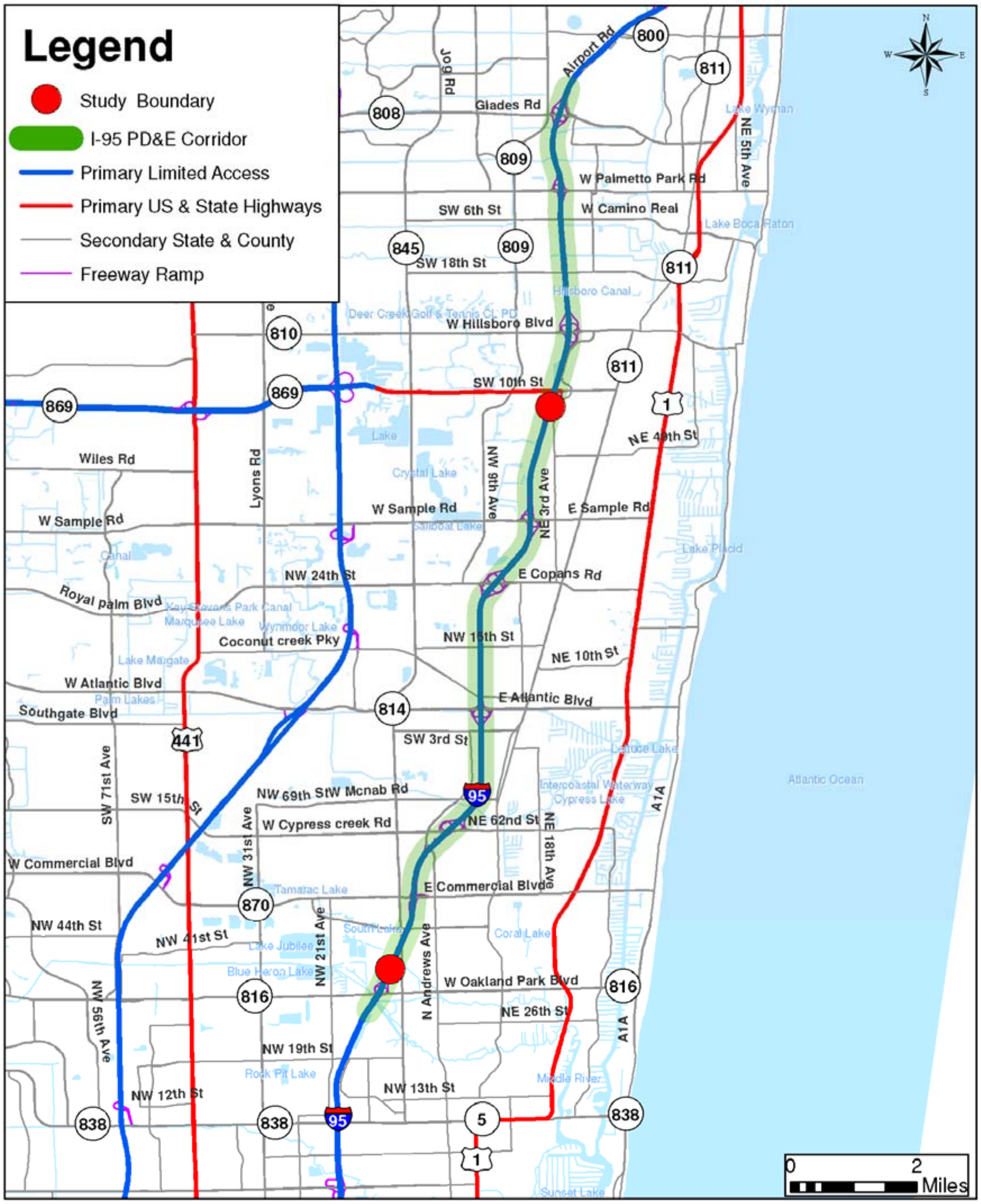
## A.3 BROWARD I-95 TEST CORRIDOR DESCRIPTION

The test section of Broward I-95 corridor selected for travel time reliability analysis extends from 1,500 feet south of the SW 10th Street to 1,500 feet north of W. Oakland Park Blvd, which is shown in Figure 10. The southbound p.m.peak period was selected for the reliability analysis.

The study section of I-95 is a 6-lane freeway plus 2 HOV lanes plus auxiliary lanes between interchanges from West Commercial Boulevard north. South of West Commercial, I-95 is an 8-lane freeway plus 2 HOV lanes. It carries 205,000 AADT at its north end, increasing to 267,000 AADT at its south end. Table 15 shows the geometry and demands for the selected study section, in the southbound direction, during the p.m. peak hour for the selected reliability analysis seed day, February, 16, 2011. The free-flow speed for the purposes of the reliability analysis was set at 70 mph.

According to the Traffic Analysis Technical Memorandum, for the I-95 PD&E, dated July 2013, the average p.m. peak hour travel time for the analysis day (02/16/2011) was 11.5 minutes for the 9.28 mile study section, an average speed of 48.4 mph, including queuing delay.

## Figure 10 I-95 SB Study Corridor Limits



### Table 15 Geometric and Demand Characteristics of Broward I-95 Test Section (SB PM Peak Hour)

| Start Point | Sect # | HCM Type | Length (ft) | Lanes | Pk Demand(vph) | Pk D/C |
|---|---|---|---|---|---|---|
| South of SW 10th | 1 | B | 4,730 | 3+HOV | 7,352 | 0.83 |
| Sample Off | 2 | OFR | 1,500 | 3+HOV | 7,352 | 0.83 |
| | 3 | B | 1,656 | 3+HOV | 6,355 | 0.71 |
| WB Sample On | 4 | ONR | 1,500 | 3+HOV | 6,900 | 0.78 |
| Sample OC | 5 | B | 335 | 3+HOV | 6,900 | 0.78 |
| EB Sample On | 6 | W | 2,717 | 4+HOV | 7,517 | 0.70 |
| Copans Off | 7 | B | 900 | 3+HOV | 7,106 | 0.80 |
| WB Copans On | 8 | W | 1,830 | 4+HOV | 7,507 | 0.71 |
| EB Copans Off | 9 | B | 1,370 | 3+HOV | 7,157 | 0.80 |
| EB Copans On | 10 | ONR | 1,500 | 4+HOV | 7,774 | 0.70 |
| | 11 | B | 3,965 | 4+HOV | 7,774 | 0.70 |
| WB Atlantic Off | 12 | OFR | 1,500 | 4+HOV | 7,774 | 0.70 |
| | 13 | B | 240 | 3+HOV | 6,982 | 0.78 |
| EB Atlantic Off | 14 | OFR | 1,500 | 3+HOV | 6,982 | 0.78 |
| | 15 | B | 1,470 | 3+HOV | 6,314 | 0.71 |
| Atlantic On | 16 | ONR | 1,500 | 4+HOV | 7,538 | 0.68 |
| | 17 | B | 4,255 | 4+HOV | 7,538 | 0.68 |
| Cypress Off | 18 | OFR | 1,500 | 4+HOV | 7,538 | 0.68 |
| | 19 | B | 1,670 | 3+HOV | 6,253 | 0.70 |
| WB Cypress On | 20 | ONR | 1,500 | 3+HOV | 6,788 | 0.76 |
| | 21 | B | 663 | 3+HOV | 6,788 | 0.76 |
| PNR On | 22 | ONR | 885 | 3+HOV | 6,942 | 0.78 |
| Andrews On | 23 | ONR | 2,348 | 3+HOV | 7,010 | 1.07 |
| Commercial Off* | XX* | XXX | XXX | 4+HOV | XXX | 0.79 |
| | 24 | B | 2,293 | 3+HOV | 7,010 | 0.73 |
| EB Commercial On | 25 | ONR | 1,390 | 4+HOV | 8,120 | 0.81 |
| WB Commercial On | 26 | ONR | 1,500 | 4+HOV | 9,025 | 0.81 |
| | 27 | B | 2,787 | 4+HOV | 9,025 | 0.83 |
| Total | | | 9.28 miles | | | |

*The Commercial Blvd. off ramp was not coded to overcome a bug in FREEVAL's queue formation algorithm that was causing queues to form on the upstream on-ramp rather than on the mainline. This bug appeared to be related to the unusual nature of the bottleneck location, occurring downstream of a lane drop for the off ramp of a weaving section.

The yellow cell in the table indicates the bottleneck. Gray shaded cells indicate extent of queue backup during p.m.PM peak hour. Demands are for February 16, 2011, p.m.PM peak hour.

## A.4 DATA ASSEMBLY

Four general sets of data were assembled for the evaluation:

- PD&E geometric Input data for Chapter 36 (FREEVAL) seed file
- PD&E demand Input data for Chapter 36 (FREEVAL) seed file
- PD&E traffic operations data for calibration of FREEVAL seed file
- Input data for Chapter 36 (FREEVAL) reliability analysis
- Output data (from INRIX) for assessment of accuracy of reliability results

### FREEVAL Seed File Data (Geometry, Demand, Operations)

The first three data sets (geometry, demand, and traffic operations) were assembled for the purpose of coding and calibrating the Chapter 36 freeway model, FREEVAL. The demands and geometry were coded into the FREEVAL seed file and the resulting predicted travel times compared to those measured in the field, as reported in the I-95 PD&E Traffic Analysis Technical Memo. Table 16 summarizes the inputs and parameters used to code the FREEVAL seed file.

**Table 16 Inputs of FREEVAL Corridor Analysis**

| Name of Input | Value of Input | Source(s) |
|---|---|---|
| Study Period Start Time | 4:45 PM | PD&E Report |
| Study Period End Time | 5:45 PM | PD&E Report |
| Seed Demand Day | 02/16/2011 | Selected by KAI |
| Number of HCM Segments | 27 | PD&E Report and Google Map |
| Length of Segments (ft) | Varies by Segments | Google Map |
| Jam Density (pc/mi/lane) | 190 | FREEVAL Default |
| Capacity Drop in the Queue Discharge Mode (%) | 5% | FREEVAL Default |
| Number of Lanes | Varies by Segments | PD&E Report and Google Map |
| Free Flow Speed (mph) | 70 | Inrix and Google Map |
| Segment Demand | Varies by Segments | PD&E Report and RITIS* |
| Length of Acceleration/Deceleration Lanes (ft) | Varies by Segments | Google Map |

As shown in Table 16, several inputs can be directly retrieved from the I-95 PD&E report, such as study period start/end time, number of HCM segments, and number of lanes. Some inputs may require manual measurement. For example, the length of each HCM segment and the length of acceleration/deceleration Lanes need be measured manually on Google map/earth. FREEVAL default values were used for jam density and capacity drop in the queue discharge mode.

## Geometry

The HOV volumes and the HOV lanes were treated as mixed flow traffic and mixed flow lanes for the purposes of this analysis. Since HOV lanes typically have lower capacities than mixed flow lanes, a generally greater adjustment (much lower than 1.00) is required to accurately represent the capacity of the freeway with the HOV lanes (see capacity calibration section below for more details).

## Seed Demand Day

Seed demand day is the date represented by the demand volumes. In this study, 02/16/2011 is selected as the seed demand day since it is a normal weekday (Wednesday) and its (15-min) demand profile is consistent with general demand trend of this study corridor in year 2011.

## FREEVAL Free Flow Speed

Model free flow speeds are set as 70 miles per hour (mph) on this study corridor based on the speed data from INRIX. The posted speed limit of the study corridor is 65 mph.

## HCM Segments

Based on the I-95 PD&E report and Google Map, there are 27 HCM segments identified for the I-95 SB study corridor. Among the 27 HCM segments, there are 13 basic freeway segments, 8 on-ramp segments, 4 off-ramp segments and 2 weaving segments.

## Demand Development

The segment demands (the demand of the first basic freeway segment and the demands of all the on-ramps and off-ramps) were developed based on the PD&E Report and the data from RITIS, which is collected by fixed detectors. The I-95 PD&E Report only provides the peak hour (4:45 p.m.PM -5:45 p.m.PM) demands for the segments; however, FREEVAL requires 15-minute demand inputs. Therefore, the peak hour demand was converted into 15-minute demand based on the factors developed from the RITIS data. The data from the RITIS were collected at the south of SW 10th St. According to the traffic counts on seed demand date (i.e., 02/16/2011), the following 15-minute factors were calculated as shown in Table 17.

### Table 17 Demand Conversion Factors

| | 16:45:00 | 17:00:00 | 17:15:00 | 17:30:00 | Total |
|---|---|---|---|---|---|
| **Traffic Counts from RITIS** | 1744 | 1897 | 1889 | 1850 | 7380 |
| **15-min Factors** | 0.236 | 0.257 | 0.256 | 0.251 | 1.000 |

Table 18 summarizes all the 15-minute demands for the first basic freeway segment and all the on-ramps and off-ramps.

### Table 18 Peaking of Ramp and Mainline In Demands

| HCM Segment | Roadway Type | 1h Demand | 16:45:00 | 17:00:00 | 17:15:00 | 17:30:00 |
|---|---|---|---|---|---|---|
| Basic | Freeway | 7150 | 6759 | 7352 | 7321 | 7169 |
| Off-ramp | Off-ramp | 970 | 917 | 997 | 993 | 973 |
| On-ramp | On-ramp | 530 | 501 | 545 | 543 | 531 |
| Weaving | On-ramp | 600 | 567 | 617 | 614 | 602 |
| | Off-ramp | 400 | 378 | 411 | 410 | 401 |
| Weaving | On-ramp | 390 | 369 | 401 | 399 | 391 |
| | Off-ramp | 340 | 321 | 350 | 348 | 341 |
| On-ramp | On-ramp | 600 | 567 | 617 | 614 | 602 |
| Off-ramp | Off-ramp | 770 | 728 | 792 | 788 | 772 |
| Off-ramp | Off-ramp | 650 | 614 | 668 | 666 | 652 |
| On-ramp | On-ramp | 1190 | 1125 | 1224 | 1218 | 1193 |
| Off-ramp | Off-ramp | 1250 | 1182 | 1285 | 1280 | 1253 |
| On-ramp | On-ramp | 520 | 492 | 535 | 532 | 521 |
| On-ramp | On-ramp | 150 | 142 | 154 | 154 | 150 |
| Weaving | On-ramp | 1330 | 1257 | 1367 | 1362 | 1334 |
| | Off-ramp | 1130 | 1068 | 1162 | 1157 | 1133 |
| On-ramp | On-ramp | 1080 | 1021 | 1110 | 1106 | 1083 |
| On-ramp | On-ramp | 880 | 832 | 905 | 901 | 882 |

## A.5 CODING AND CALIBRATION OF FREEVAL SEED FILE

The geometric and demand data was entered into the FREEVAL seed file and the model executed to compute overall travel time, delay, and queues. The initial model Test found that the default Highway Capacity Manual capacities used in FREEVAL significantly overestimated the actual capacity of the bottleneck between the Andrews on-ramp and the Commercial Blvd. off ramp on I-95. Examination of the results determined that FREEVAL was not correctly representing the mainline queuing because of the unusual location of the bottleneck, downstream of the off-ramp because of a lane drop at the end of a weaving section.

Discussions with the developer of FREEVAL determined that a "work around" would be required to solve the problem. The off-ramp at Commercial was dropped from the coded FREEVAL file and the off-ramp demand was deducted from the Andrews on-ramp. This solved the problem and FREEVAL was able to correctly identify the bottleneck and queue traffic on the mainline.

After the above described "work around", the freeway capacities were then initially computed by FREEVAL based on the free-flow speed, segment type (basic, on/off ramp and weaving), and heavy vehicles. Default settings were used where data was not available. For example, default weaving volume percentages were used for all the weaving segments.

The I-95 PD&E Traffic Analysis Technical Memo used 3% trucks in its analysis, however; a slightly more conservative 5% heavy vehicles was assumed for the purposes of the reliability analysis. Given the level terrain, the different heavy vehicle percentages are not expected to significantly affect the results.

### Bottlenecks and Segment Densities

Based on the Inrix data and the PD&E report, the bottleneck on this I-95 study corridor during p.m. peak hour is at the weaving segment between Cypress Creek Road and Commercial Blvd due to the high weaving volumes.

According to the PD&E report, the measured corridor travel time during the peak hour is 11.5 minute. The corridor travel time was used as the criterion to measure the performance of the FREEVAL model calibration.

### Capacity Adjustments

The capacities of most of the segments are estimated reasonably by FREEVAL. The average capacities of the freeway segments are about 2,200 vphpl. The capacities of the weaving segments vary by the weaving volumes. The capacity of the bottleneck (i.e., weaving segment between Cypress Creek Road and Commercial Blvd) was estimated as 2,084 vphpl, which is much higher than the demand (i.e., 1,660 vphpl). This suggests the capacity of this weaving segment is too high and this bottleneck was not activated. Based on the continuous traffic counts from RITIS immediately downstream of the bottleneck, the maximum throughput observed is a little bit less than 1,600 vphpl. Therefore, the capacity of the weaving segment between Cypress Creek Road and Commercial Blvd (segment ID in FREEVAL is **23**) was set as 1,600 vphpl. For other segments, since HOV lanes typically have lower capacities than mixed flow lanes, a 95% capacity factor (resulting in a 5% reduction in capacity) was applied throughout the study corridor.

### Corridor Statistics before and after Calibration

For the study corridor, the average corridor travel time before the capacity calibration is 9.26 minutes, which is much lower than the field measurement. After the capacity calibration, the average corridor travel time is 11.1 minutes, which is really close to the field measurement (11.5 minutes). **Table 19** summarizes the corridor statistic before and after the capacity calibration.

**Table 19 Corridor Performance Statistics Before and After Calibration**

| Performance Measures | Before Capacity Calibration | After Capacity Calibration |
|---|---|---|
| Travel time per vehicle (min)* | 9.26 | 11.1 |
| Freeway mainline delay (min) | 0.69 | 4.05 |
| System delay (min) | 0.69 | 4.05 |
| VMTD Veh-miles (Demand) | 17,326 | 17,131 |
| VMTV Veh-miles (Volume served) | 17,326 | 16,531 |
| VHT travel (hrs) | 288.71 | 342.11 |
| VHD delay (hrs) | 22.16 | 105.95 |
| Space mean speed = VMTV / VHT (mph) | 60.0 | 48.3 |
| Segment density (pc/mi/lane) | 28.0 | 33.6 |
| Density-based LOS on segment | D | D |
| Travel Time Index (TTI) | 1.08 | 1.51 |

*The average travel time is reported for the peak hour; while the rest of the performance measures are reported for the peak 15-minute during the peak hour.

## A.6 APPLICATION OF CHAPTER 36 TO BROWARD I-95 TEST CORRIDOR

In the Chapter 36 method (FREEVAL-reliability), the reliability analysis in FREEVAL is conducted by combining the seed file developed above and the scenarios generated from the FREEVAL scenario generator.

## Required Inputs in FREEVAL Scenario Generator

There are four different worksheets in the FREEVAL scenario generator to generate all different operational scenarios. They are briefly discussed as follows.

### Daily Demand Multipliers

In this step, the demand variations are provided for the study corridor. The day-to-day demand variations are generated by adjusting the demand coded in the seed file. All the multipliers are based on the ratio of the cell value to the AADT for the study corridor. If the site-specific value does not exist, the national default values for either urban or rural area can be used.

### Demand Pattern Configuration

In the demand pattern configuration table, the cells with same color represent a unique demand pattern by day of week and month of year to be analyzed as shown in **Figure 10**. The user can specify different days of the week and different months of the year to have same demand pattern. Defaults demand pattern is available in FREEVAL (also shown in **Figure 10**).

**Figure 10 Default Demand Pattern in FREEVAL**

# Demand Patterns= 9 # Days in Analysis= 129 Analysis Year= 2011

| Week # | January | Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|---|---|
| Week 1 | January | 1/3/2011 (1) | 1/4/2011 (2) | 1/5/2011 (2) | 1/6/2011 (2) | 1/7/2011 (3) |
| Week 2 | January | 1/10/2011 (1) | 1/11/2011 (2) | 1/12/2011 (2) | 1/13/2011 (2) | 1/14/2011 (3) |
| Week 3 | January | 1/17/2011 (1) | 1/18/2011 (2) | 1/19/2011 (2) | 1/20/2011 (2) | 1/21/2011 (3) |
| Week 4 | January | 1/24/2011 (1) | 1/25/2011 (2) | 1/26/2011 (2) | 1/27/2011 (2) | 1/28/2011 (3) |
| Week 5 | February | 1/31/2011 (1) | 2/1/2011 (2) | 2/2/2011 (2) | 2/3/2011 (2) | 2/4/2011 (3) |
| Week 6 | February | 2/7/2011 (1) | 2/8/2011 (2) | 2/9/2011 (2) | 2/10/2011 (2) | 2/11/2011 (3) |
| Week 7 | February | 2/14/2011 (1) | 2/15/2011 (2) | 2/16/2011 (2) | 2/17/2011 (2) | 2/18/2011 (3) |
| Week 8 | February | 2/21/2011 (1) | 2/22/2011 (2) | 2/23/2011 (2) | 2/24/2011 (2) | 2/25/2011 (3) |
| Week 9 | March | 2/28/2011 (1) | 3/1/2011 (5) | 3/2/2011 (5) | 3/3/2011 (5) | 3/4/2011 (6) |
| Week 10 | March | 3/7/2011 (4) | 3/8/2011 (5) | 3/9/2011 (5) | 3/10/2011 (5) | 3/11/2011 (6) |
| Week 11 | March | 3/14/2011 (4) | 3/15/2011 (5) | 3/16/2011 (5) | 3/17/2011 (5) | 3/18/2011 (6) |
| Week 12 | March | 3/21/2011 (4) | 3/22/2011 (5) | 3/23/2011 (5) | 3/24/2011 (5) | 3/25/2011 (6) |
| Week 13 | April | 3/28/2011 (4) | 3/29/2011 (5) | 3/30/2011 (5) | 3/31/2011 (5) | 4/1/2011 (6) |
| Week 14 | April | 4/4/2011 (4) | 4/5/2011 (5) | 4/6/2011 (5) | 4/7/2011 (5) | 4/8/2011 (6) |
| Week 15 | April | 4/11/2011 (4) | 4/12/2011 (5) | 4/13/2011 (5) | 4/14/2011 (5) | 4/15/2011 (6) |
| Week 16 | April | 4/18/2011 (4) | 4/19/2011 (5) | 4/20/2011 (5) | 4/21/2011 (5) | 4/22/2011 (6) |
| Week 17 | May | 4/25/2011 (4) | 4/26/2011 (5) | 4/27/2011 (5) | 4/28/2011 (5) | 4/29/2011 (6) |
| Week 18 | May | 5/2/2011 (4) | 5/3/2011 (5) | 5/4/2011 (5) | 5/5/2011 (5) | 5/6/2011 (6) |
| Week 19 | May | 5/9/2011 (4) | 5/10/2011 (5) | 5/11/2011 (5) | 5/12/2011 (5) | 5/13/2011 (6) |
| Week 20 | May | 5/16/2011 (4) | 5/17/2011 (5) | 5/18/2011 (5) | 5/19/2011 (5) | 5/20/2011 (6) |
| Week 21 | May | 5/23/2011 (4) | 5/24/2011 (5) | 5/25/2011 (5) | 5/26/2011 (5) | 5/27/2011 (6) |
| Week 22 | June | 5/30/2011 (4) | 5/31/2011 (5) | 6/1/2011 (8) | 6/2/2011 (8) | 6/3/2011 (9) |
| Week 23 | June | 6/6/2011 (7) | 6/7/2011 (8) | 6/8/2011 (8) | 6/9/2011 (8) | 6/10/2011 (9) |
| Week 24 | June | 6/13/2011 (7) | 6/14/2011 (8) | 6/15/2011 (8) | 6/16/2011 (8) | 6/17/2011 (9) |
| Week 25 | June | 6/20/2011 (7) | 6/21/2011 (8) | 6/22/2011 (8) | 6/23/2011 (8) | 6/24/2011 (9) |
| Week 26 | July | 6/27/2011 (7) | 6/28/2011 (8) | 6/29/2011 (8) | 6/30/2011 (8) | |
| Week 27 | July | | | | | |

## Weather Data

This worksheet is used to generate the weather events and their impacts on roadway capacities. The user can easily generate all the necessary weather information by selecting the nearest metropolitan area to the study corridor. For example, Miami, FL was selected for this I-95 SB study corridor.

## Incident data

The incident worksheet generates the incident in terms of probability of occurrence, duration and impacts on the roadway capacity. The worksheet provides two options: "data rich" environment and "data poor" environment. In the "data rich" environment, user can input facility-specific incident probability. In the "data poor" environment, user can input facility-specific incident/crash rates if data available or use HERS (2) model to estimate the incident rate.

## Facility-specific Inputs for I-95 SB Study Corridor

For this study corridor, facility-specific ***Daily Demand Multipliers*** and ***Crash Rate*** were developed.

## Facility-Specific Daily Demand Multipliers

Based on the continuous traffic counts (1/1/2011 – 6/30/2011) from RITIS at the south of SW 10th St, the daily demand multipliers were developed for this I-95 SB study corridor. **Table 20** demonstrates the daily demand multipliers from January to June.

**Table 20 Daily Demand Multipliers for Study Corridor**

| | Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|---|
| January | 1.027 | 1.035 | 1.053 | 1.072 | 1.095 |
| February | 1.065 | 1.049 | 1.074 | 1.117 | 1.156 |
| March | 1.041 | 1.072 | 1.101 | 1.105 | 1.158 |
| April | 1.029 | 1.043 | 1.068 | 1.093 | 1.073 |
| May | 0.979 | 1.001 | 1.014 | 1.033 | 1.072 |
| June | 0.970 | 0.985 | 1.009 | 1.014 | 1.056 |

Note: The corresponding AADT at the detector location is 201,000

Based on **Table 20**, Wednesday in February has a demand multiplier 1.074. This means that the demand coded in seed file are 7.4% higher than the AADT. To generate the demand volumes for Thursday in February, the demand volumes in the seed file should be multiplied by the ratio 1.117/1.074 or 1.040.

## Facility-specific Crash Rate

Based on crash reports, the facility-specific crash rate for this I-95 SB study corridor was calculated for each individual month. The crash rates of I-95 SB study corridor from January to June are:

- January: 131.8 per 100 million vehicle mile
- February: 169.0 per 100 million vehicle mile
- March: 156.1 per 100 million vehicle mile
- April: 132.6 per 100 million vehicle mile
- May: 135.3 per 100 million vehicle mile
- June: 164.9 per 100 million vehicle mile

## Summary of the Results of Reliability Studies

Two reliability tests were conducted for this I-95 SB study corridor using different amounts of default and facility specific data on demand variability and crash rates:

- Test #1: Use the built-in default values/calculations (HERS Model) in the FREEVAL scenario generator
- Test #2: Use the facility-specific daily demand multipliers and crash rate

The statistics of the corridor travel time reliability (i.e., travel time index) of Test #1, and Test #2 were then compared with the field observations calculated based on the Inrix data, as shown in Table 21.

**Table 21 Summary of Corridor Travel Time Reliability**

| Statistics of Travel Time Index | Inrix Data | FREEVAL Test #1 (All Defaults) | FREEVAL Test #2 (Min. Defaults) |
|---|---|---|---|
| Mean TTI | 1.29 | 2.06 | 1.43 |
| 50th Percentile TTI | 1.20 | 1.84 | 1.29 |
| 80th percentile TTI | 1.35 | 2.75 | 1.64 |
| 85th Percentile TTI | 1.45 | 2.76 | 1.69 |
| 95th Percentile TTI | 1.83 | 3.64 | 2.01 |

As expected, the FREEVAL reliability estimates using default values produced significantly worse estimates of unreliability than FREEVAL using actual crash, demand, and weather data for the corridor.

## A.2 Application of UF Reliability Model to Broward I-95 Test Corridor

This section presents the reliability analysis data collection efforts and results for applying the Florida Department of Transportation (FDOT) University of Florida (UF) Reliability Model.

### Data Collection

The FDOT reliability model requires input data on the facility description, LOS criteria, speed table, peak-hour factors, incidents, weather, capacity-demand, and segment specific criteria. Much of this information however can be defaulted. **Table 22** summarizes the inputs and defaults used in the FDOT/UF reliability model.

**Table 22 Inputs of FDOT Corridor Analysis**

| Name of Input | Value of Input or Default | Source |
|---|---|---|
| **Volume (AADT)** | **Varies by Segment** | **FDOT District 4** |
| Number of lanes | Varies by Segment | GoogleEarth |
| Length (miles) | Varies by Segment | ArcGIS mapping |
| Capacity within work zone (vphpl) | 1,600 | Highway Capacity Manual 2010 |
| Incident capacity reduction | Varies by lanes blocked per freeway lanes in each direction | Highway Capacity Manual 2010 |
| Avg. number of closed lanes in a work zone | 1 | FDOT Model Default |
| Avg. rainfall (inches by number of rainy days) | Varies by Hour | Weather Underground (Broward County) |
| Avg. incident blocking duration (minutes) | 43.55 | FDOT District 4 |
| Avg. incident non-blocking duration (minutes) | 19.28 | FDOT District 4 |
| Total number of blocking incidents | 5,163 | FDOT District 4 |
| Total number of non-blocking incidents | 1 ,995 | FDOT District 4 |
| Effect of incident management strategy duration w/road rangers (minutes) | 54.55 | FDOT District 4 |
| Effect of incident management duration strategy w/out road rangers (minutes) | 71.26 | FDOT District 4 |
| Free-flow speed reduction for light-rain | 6.00% | FDOT Systems Planning Office |
| Free-flow speed reduction for heavy-rain | 12.00% | FDOT Systems Planning Office |
| Area Type | Urban | As defined in QLOS handbook |
| Segment location | 1 = South Florida | FDOT Model Default |

| Name of Input | Value of Input or Default | Source |
|---|---|---|
| **Volume (AADT)** | **Varies by Segment** | **FDOT District 4** |
| Analysis Period | Peak period (4:00-7:00 p.m.) | FDOT Model Default |
| Facility Type | Freeway, Metropolitan Spacing <2 miles | As defined in QLOS handbook |

As shown in **Table 22**, several inputs must be retrieved from data available through FDOT District 4. FDOT District 4 includes Broward County and the study segments included in the analysis. The FDOT reliability model analyzes a daily and peak period travel time index (TTI). The peak period has been defined as 4:00 p.m. to 7:00 p.m.

## I-95 Corridor Study Segments

The travel time indices produced by the FDOT reliability model are most accurate for freeway segments less than two miles in length. ArcGIS was used to determine the appropriate study segments used in this model. **Table 23** summarizes each study segment and the inputs used within the model to produce a TTI for each segment. A vehicle-miles-traveled (VMT) weighted average was later applied to each segment's TTI to determine one peak period TTI for the study corridor.

### Table 23 I-95 Study Segment Input Data

| Segment Name | SORTWENS | Mile Posts | Segment Length (miles) | Lanes | AADT | VMT |
|---|---|---|---|---|---|---|
| SR 816 to SR 870 | 704 | 13.442 - 15.075 | 1.633 | 10 | 267,000 | 436,011 |
| SR 870 to W Cypress Creek Rd | 705 | 15.075 - 16.248 | 1.173 | 9 | 225,000 | 263,925 |
| W Cypress Creek Road to SR 814 | 706 | 16.248 - 18.407 | 2.159 | 10 | 221,000 | 477,139 |
| SR 814 to W Copans Road | 707 | 18.407 - 20.411 | 2.004 | 10 | 224,000 | 448,896 |
| W Copans Road to E Sample Rd | 708 | 20.411 - 21.558 | 1.147 | 8 | 217,000 | 248,899 |
| E Sample Road to SW 10th St | 709 | 21.558 - 23.650 | 2.002 | 8 | 205,000 | 410,410 |
| TOTAL | - | 13.442-23.650 | 10.118 | - | 1,359,000 | 2,285,280 |

## Weather Data

The analysis obtains the average rainfall over a year for each hour for that particular segment. Weather data was provided by county, since the entire study corridor is within Broward County limits, weather data was consistent for each study segment.

## Incident Data

The incident worksheet generates the incident in terms of probability of occurrence, duration and impacts on the roadway capacity. The model provides the users the opportunity to input facility-specific incident totals and probability. Facility specific inputs include: year to date total of blocking and non-blocking incidents, the average incident duration for both blocking and non-blocking, and the average incident clearance time with and without Road Rangers. This data was retrieved from FDOT District 4's SunGuide.

## Results

Two reliability tests were conducted for the I-95 study corridor. The result was a TTI for each segment. In order to produce a TTI for the entire study corridor, a VMT weighted average was applied to each segment's TTI. **Table 24** shows the TTI results for Test #3 and Test #4 of for the entire I-95 study corridor.

- Test #3: Uses the built-in default values/calculations throughout the FDOT Model
- Test #4: Uses the facility specific data for each segment throughout the study segment

The inputs that varied between Test #3 and Test #4 consisted of incident data, capacity demand data, and segment specific data such as length and lanes within a segment. **Table 24** summarizes the facility specific defaults used in Test #3, and the facility specific inputs used in Test #4. Weather data is also used in facility specific inputs; however, the weather data was the same for both tests, since both tests were conducted on a study corridor in Broward County, Florida.

**Table 24 Broward I-95 Facility Specific Data Inputs**

| Facility Specific Data Inputs | Test # 3 | Test #4 |
|---|---|---|
| Total number of non-blocking incidents (YTD)[1] | 7,139 | 5,163 |
| Total number of blocking incidents (YTD) | 2,191 | 1,995 |
| Ratio of non-blocking incidents | 3.26[2] | 2.59 |
| Average incident duration - blocking (minutes) | 55.15 | 43.55 |
| Average incident duration - non-blocking (minutes) | 45.00 | 19.28 |
| YTD ratio of incidents with one lane blocked | 58% | 64% |
| YTD ratio of incidents with 50% of lanes blocked | 30% | 27% |
| YTD ratio of incidents where all lanes were blocked | 12% | 9% |
| Facility type[3] | Freeway 2 | Freeway 2 |
| Begin mile post | Varies by segment | Varies by segment |
| End mile post | Varies by segment | Varies by segment |
| Lanes | Varies by segment | Varies by segment |

| Facility Specific Data Inputs | Test # 3 | Test #4 |
|---|---|---|
| Average annual daily traffic | Varies by segment | Varies by segment |
| Notes: | | |
| [1] YTD - Year to date | | |
| [2] The Florida Department of Transportation Systems Planning Office | | |
| [3] Freeway 2 - Freeway, Urbanized spacing >= 2 miles | | |

Peak period TTI results are reported for each segment of the study corridor in **Table 25**. Overall, the facility specific inputs used in Test #4 produced lower travel time indices because of the data specific to the segments along the I-95 study corridor. In order to produce a TTI for the entire study corridor, a VMT weighted average was applied to each segment's TTI.

### Table 25 Broward I-95 Segment Specific TTI Results for UF Model

| Segment Name | SORTWENS | Segment Length (miles) | AADT | VMT | Test # 3 | Test #4 |
|---|---|---|---|---|---|---|
| | | | | | Peak Period TTI | Peak Period TTI |
| SR 816 to SR 870 | 704 | 1.633 | 267,000 | 436,011 | 1.82 | 1.76 |
| SR 870 to W Cypress Creek Rd | 705 | 1.173 | 225,000 | 263,925 | 2.05 | 1.97 |
| W Cypress Creek Road to SR 814 | 706 | 2.159 | 221,000 | 477,139 | 1.36 | 1.31 |
| SR 814 to W Copans Road | 707 | 2.004 | 224,000 | 448,896 | 1.37 | 1.32 |
| W Copans Road to E Sample Road | 708 | 1.147 | 217,000 | 248,899 | 1.87 | 1.23 |
| E Sample Road to SW 10th Street | 709 | 2.002 | 205,000 | 410,410 | 1.78 | 1.69 |
| VMT Weighted Average | | | | | 1.66 | 1.53 |

Because the FDOT Model results are most reliable for study segments less than two miles in length, the aggregation of the six segments within the I-95 study corridor was necessary in order to produce the facility percentile travel indices. The equation below shows the computation.

$$\%TTI(facility) = \frac{\sum VMT(seg) * PctleSpeed(seg)}{\sum VMT(seg) * FreeFlowSpeed(seg)}$$

Where:

%TTI = percentile TTI aggregated over all the segments in the facility (for the study direction and study period)

PctleSpeed = percentile speed for segment for study segment

FreeFlowSpeed = free-flow speed for segment for study segment

VMT = vehicle-miles traveled on segment for study period of speed observation.

**Table 26** shows the TTI results for Test #3 and Test #4 of for the entire I-95 study corridor to the INRIX measured reliability results.

**Table 26 Broward I-95 Study Corridor TTI Results for UF Model**

| Statistics of Peak Period Travel Time Index | INRIX Data | FDOT/UF Test #3 | FDOT/UF Test #4 |
|---|---|---|---|
| VMT Weighted Average Peak Period TTI | 1.29 | 1.66 | 1.53 |
| 50th Percentile TTI | 1.20 | 1.30 | 1.26 |
| 80th Percentile TTI | 1.35 | 1.90 | 1.76 |
| 85th Percentile TTI | 1.45 | 2.12 | 1.91 |
| 95th Percentile TTI | 1.83 | 2.43 | 2.24 |

## A.3 REFERENCES FOR APPENDIX A

1. The Corradino Group, "State Road 9 (Interstate 95) Project Development and Environment Study", 2013.

2. Dowling Associates, Inc. and Cambridge Systematics, Inc, "SHRP2 L08 Working Paper: Incident Prediction Methodology and Data Analysis," 2011.

# B. Hillsborough I-75 Tests

This appendix documents the results of the evaluation of the Highway Capacity Manual Chapter 36 (SHRP2-L08) reliability analysis method for the I-75 freeway in Hillsborough County, Florida.

## B.1 PURPOSE

The purpose of this evaluation is to evaluate the suitability of the Chapter 36 travel time reliability method for use in Florida. See Appendix "A" for additional details.

## B.2 APPROACH

The analysis on the Hillsborough I-75 freeway proceeded through the following steps:

- Data Assembly
  - PD&E demand and geometric Input data for Chapter 36 (FREEVAL) seed file
  - PD&E traffic operations data for calibration of FREEVAL seed file
  - Input data for Chapter 36 (FREEVAL) reliability analysis
  - Output data (from INRIX) for assessment of accuracy of reliability results
- Coding and Calibration of FREEVAL Seed File
- Application of Chapter 36 (FREEVAL) method using:
  - Defaults for reliability analysis (Test #1)
  - Corridor specific demand variability and crash rates for reliability analysis (Test #2)
- Application of UF Reliability Model using:
  - Defaults (Test #3)
  - Facility specific data on incidents and weather (Test #4)

## B.3 HILLSBOROUGH I-75 DESCRIPTION

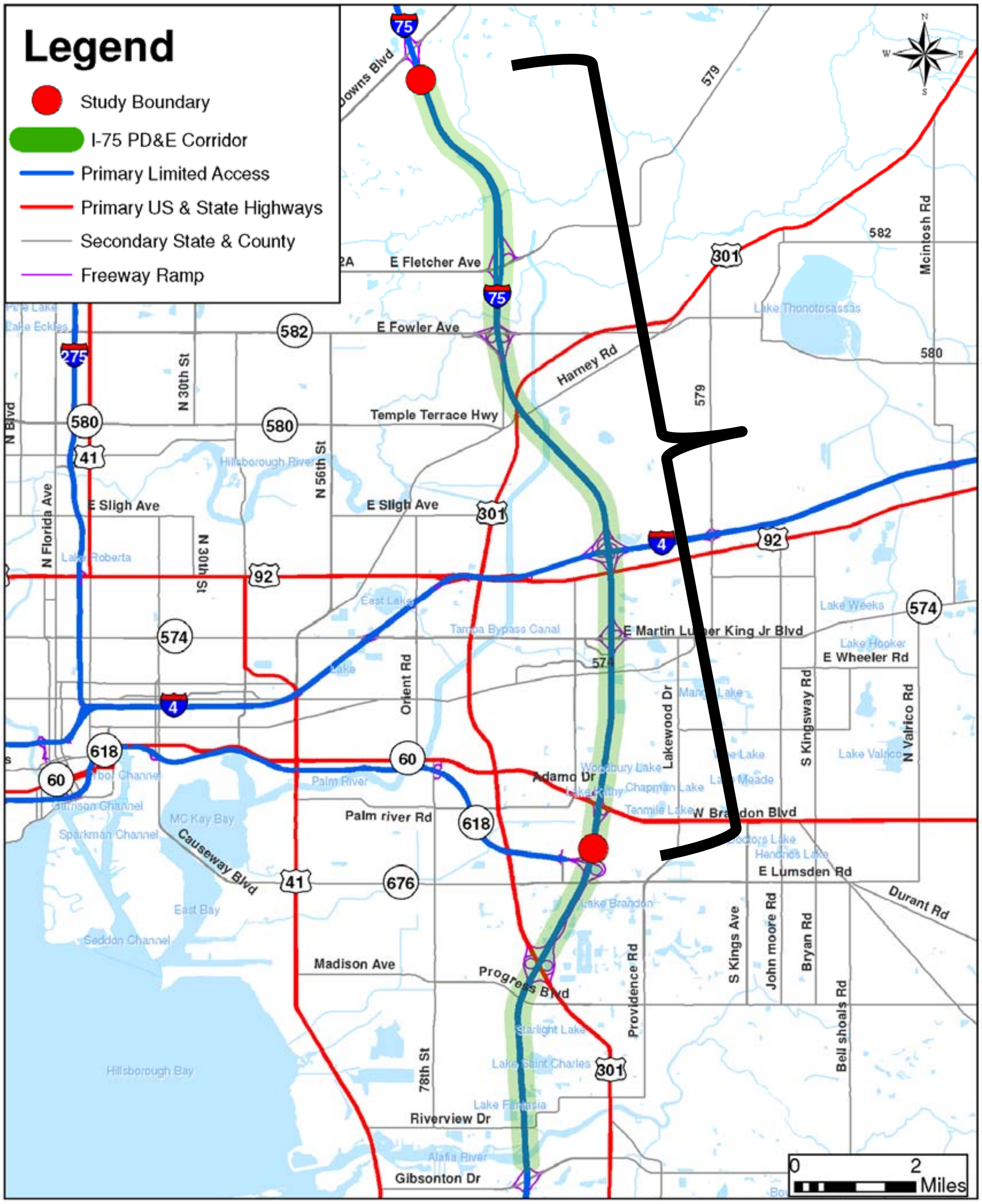
The test section of Hillsborough I-75 corridor selected for travel time reliability analysis is extends 13.45 miles from 1,500 feet north of Selmon Expressway Toll Road to 0.4 miles south of SR 581 (Bruce B. Downs Blvd.), which is shown in

**Figure 11**. The northbound p.m. peak period was selected for the reliability analysis.

The study section of I-75 is a 4/6 lane freeway plus auxiliary lanes between E Martin Luther King Jr Blvd and I-4. It carries between 95,000 and 145,000 AADT. **Table 27** shows the geometry and demands for the selected study section, in the northbound direction, during the p.m. peak hour for the selected reliability analysis seed day, January, 05, 2011. The free-flow speed for the purposes of the reliability analysis was set at 75 mph.

According to the <u>Traffic Analysis Technical Memorandum</u>, for the I-75 PD&E, dated September 2009, the average p.m. peak hour travel time collected from W Brandon Blvd and Fletcher Avenue was 11.4 minutes for the 9.41 mile study section, an average speed of 57.7 mph, including queuing delay.

## Figure 11 I-75 NB Study Corridor Limits



### Table 27 Geometric and Demand Characteristics of Hillsborough I-75 Test Section (NB PM Peak Hour)

| Start Point | Sect # | HCM Type | Length (ft) | Lanes | Pk Demand (vph) | Pk D/C |
|---|---|---|---|---|---|---|
| South of SR 60 | 1 | B | 3340 | 3 | 1,826 | 0.26 |
| Brand/Adamo (SR 60) | 2 | ONR | 1245 | 3 | 3,269 | 0.47 |
| Brand/Adamo (SR 60) | 3 | ONR | 1500 | 3 | 3,885 | 0.55 |
| | 4 | B | 990 | 3 | 3,885 | 0.55 |
| Brand/Adamo (SR 60) | 5 | ONR | 1500 | 3 | 5,274 | 0.75 |
| | 6 | B | 7635 | 3 | 5,274 | 0.75 |
| MLK Jr. Blvd (SR 574) | 7 | OFR | 1500 | 3 | 5,274 | 0.75 |
| | 8 | B | 755 | 3 | 4,734 | 0.67 |
| MLK Jr. Blvd (SR 574) | 9 | OFR | 1500 | 3 | 4,734 | 0.67 |
| | 10 | B | 1860 | 3 | 4,361 | 0.62 |
| I-4 Off | 11 | W | 2875 | 4 | 5,923 | 0.74 |
| | 12 | B | 4075 | 3 | 3,410 | 0.49 |
| I-4 On | 13 | ONR | 1160 | 3 | 4,475 | 0.64 |
| I-4 On | 14 | ONR | 1500 | 3 | 5,296 | 0.75 |
| | 15 | B | 11925 | 3 | 5,296 | 0.75 |
| E Fowler Ave | 16 | OFR | 1500 | 3 | 5,296 | 0.75 |
| | 17 | B | 3615 | 2 | 3,399 | 0.73 |
| E Fowler Ave | 18 | ONR | 1500 | 2 | 3,999 | 0.85 |
| | 19 | B | 155 | 2 | 3,999 | 0.85 |
| E Fowler Ave | 20 | ONR | 1500 | 3 | 4,750 | 0.68 |
| | 21 | B | 960 | 3 | 4,750 | 0.68 |
| E Fletcher Ave | 22 | OFR | 1500 | 3 | 4,750 | 0.68 |
| | 23 | B | 3975 | 2 | 3,804 | 0.81 |
| E Fletcher Ave | 24 | ONR | 1500 | 2 | 4,750 | 1.01 |
| | 25 | B | 11445 | 2 | 4,750 | 1.01 |
| Total | | | 13.45 miles | | | |

The yellow cell in the table indicates the bottleneck. Gray shaded cells indicate extent of queue backup during p.m. peak hour.

## B.4 DATA ASSEMBLY

Four general sets of data were assembled for the evaluation:

- PD&E geometric Input data for Chapter 36 (FREEVAL) seed file
- PD&E demand Input data for Chapter 36 (FREEVAL) seed file
- PD&E traffic operations data for calibration of FREEVAL seed file
- Input data for Chapter 36 (FREEVAL) reliability analysis

- Output data (from INRIX) for assessment of accuracy of reliability results

## FREEVAL Seed File Data (Geometry, Demand, Operations)

The first three data sets (geometry, demand, and traffic operations) were assembled for the purpose of coding and calibrating the Chapter 36 freeway model, FREEVAL. The demands and geometry were coded into the FREEVAL seed file and the resulting predicted travel times compared to those measured in the field, as reported in the I-75 PD&E Traffic Analysis Technical Memo. Table 28 summarizes the inputs and parameters used to code the FREEVAL seed file.

### Table 28 Inputs of FREEVAL Corridor Analysis

| Name of Input | Value of Input | Source(s) |
|---|---|---|
| Study Period Start Time | 4:30 PM | PD&E Report |
| Study Period End Time | 5:30 PM | PD&E Report |
| Seed Demand Day | 01/05/2011 | Selected by KAI |
| Number of HCM Segments | 25 | PD&E Report and Google Map |
| Length of Segments (ft) | Varies by Segments | Google Map |
| Jam Density (pc/mi/lane) | 190 | FREEVAL Default |
| Capacity Drop in the Queue Discharge Mode (%) | 5% | FREEVAL Default |
| Number of Lanes | Varies by Segments | PD&E Report and Google Map |
| Free Flow Speed (mph) | 75 | Inrix and Google Map |
| Segment Demand | Varies by Segments | PD&E Report and RITIS* |
| Length of Acceleration/Deceleration Lanes (ft) | Varies by Segments | Google Map |

Note: RITIS stands for Regional Integrated Transportation Information System

As shown in Table 28, several inputs can be directly retrieved from the I-75 PD&E report, such as study period start/end time, number of HCM segments, and number of lanes. Some inputs may require manual measurement. For example, the length of each HCM segment and the length of acceleration/deceleration Lanes need be measured manually on Google map/earth. FREEVAL default values were used for jam density and capacity drop in the queue discharge mode.

### *Geometry*

The bottleneck is located at the downstream of the off-ramp at E Fletcher Ave, where the number of travel lanes changes from 3 lanes to 2 lanes.

### *Seed Demand Day*

Seed demand day is the date represented by the demand volumes. In this study, 01/05/2011 is selected as the seed demand day since it is a normal weekday (Wednesday) and its (15-min) demand profile is consistent with general demand trend of this study corridor in year 2011.

### *FREEVAL Free Flow Speed*

Model free flow speeds are set as 75 miles per hour (mph) on this study corridor based on the speed data from INRIX. The posted speed limit of the study corridor is 70 mph.

### *HCM Segments*

Based on the I-75 PD&E report and Google Map, there are **25** HCM segments identified for the I-75 NB study corridor. Among the 25 HCM segments, there are **12** basic freeway segments, **8** on-ramp segments, **4** off-ramp segments and **1** weaving segments.

### *Demand Development*

The segment demands (the demand of the first basic freeway segment and the demands of all the on-ramps and off-ramps) were developed based on the PD&E Report and the data from RITIS, which is collected by fixed detectors. The I-75 PD&E Report only provides the peak hour (4:30 p.m. -5:30 p.m.) demands for the segments; however FREEVAL requires 15-minute demand inputs. Therefore, the peak hour demand was converted into 15-minute demand based on the factors developed from the RITIS data. The data from the RITIS were collected at the north of SR 618. According to the traffic counts on seed demand date (i.e., 01/05/2011), the following 15-minute factors were calculated as shown in **Table 29**. **Table 30** summarizes all the 15-minute demands for the first basic freeway segment and all the on-ramps and off-ramps.

**Table 29 Demand Conversion Factors**

| | 16:30 | 16:45 | 17:00 | 17:15 | Total |
|---|---|---|---|---|---|
| Traffic Counts from RITIS | 1908 | 1856 | 1796 | 1872 | 7432 |
| 15-min Factors | 0.257 | 0.250 | 0.242 | 0.252 | 1.000 |

**Table 30 Peaking of Ramp and Mainline In Demands**

| HCM Segment | Roadway Type | 1h Demand | 16:45 | 17:00 | 17:15 | 17:30 |
|---|---|---|---|---|---|---|
| Basic | Freeway | 1779 | 1826 | 1777 | 1719 | 1792 |
| On-ramp | On-ramp | 1405 | 1443 | 1403 | 1358 | 1416 |

| HCM Segment | Roadway Type | 1h Demand | 16:45 | 17:00 | 17:15 | 17:30 |
|---|---|---|---|---|---|---|
| On-ramp | On-ramp | 600 | 616 | 599 | 580 | 604 |
| On-ramp | On-ramp | 1352 | 1389 | 1351 | 1307 | 1363 |
| Off-ramp | Off-ramp | 526 | 540 | 526 | 509 | 530 |
| Off-ramp | Off-ramp | 363 | 373 | 363 | 351 | 366 |
| Weaving | On-ramp | 1521 | 1562 | 1519 | 1470 | 1532 |
| | Off-ramp | 2447 | 2513 | 2444 | 2365 | 2465 |
| On-ramp | On-ramp | 1037 | 1065 | 1036 | 1002 | 1044 |
| On-ramp | On-ramp | 800 | 821 | 799 | 773 | 806 |
| Off-ramp | Off-ramp | 1847 | 1897 | 1845 | 1785 | 1861 |
| On-ramp | On-ramp | 584 | 600 | 583 | 565 | 588 |
| On-ramp | On-ramp | 731 | 751 | 731 | 707 | 737 |
| Off-ramp | Off-ramp | 921 | 946 | 920 | 890 | 928 |
| On-ramp | On-ramp | 921 | 946 | 920 | 890 | 928 |

## B.1 Coding and Calibration of FREEVAL Seed File

The geometric and demand data was entered into the FREEVAL seed file and the model executed to compute overall travel time, delay, and queues.

The I-75 PD&E Traffic Analysis Technical Memo used 4% trucks in its analysis, however; a slightly more conservative 5% heavy vehicles was assumed for the purposes of the reliability analysis. Given the level terrain, the different heavy vehicle percentages are not expected to significantly affect the results.

### Bottlenecks and Corridor Statistics

Based on the Inrix data and the PD&E report, the bottleneck on this I-75 study corridor during p.m. peak hour is at the downstream of the off-ramp at E Fletcher Ave, where the number of travel lanes changes from 3 lanes to 2 lanes.

According to the PD&E report, the measured corridor travel time between W Brandon Blvd and Fletcher Avenue during the peak hour is 11.4 minute. This corridor travel time was used as the criterion to measure the performance of the FREEVAL model.

For the study corridor modeled in FREEVAL, the average corridor travel time during the peak hour is 14 minutes. However, the corridor modeled in FREEVAL is about 3.76-mile longer than the corridor with travel time measurement. The additional 3.76-mile freeway modeled in FREEVAL is between E Fletcher Ave and south of SR 581. Since this segment is just downstream of the bottleneck, the corresponding travel time should be close to the free-flow travel time, i.e., 3 minutes. Therefore, the travel time of corridor between W Brandon Blvd and Fletcher Avenue modeled in FREEVAL is about 11 minutes, which is really close to the field measurement. **Table 31** summarizes the performance statistics of the study corridor.

**Table 31 Corridor Performance Statistics**

| Performance Measures | I-75 Study Corridor |
|---|---|
| Travel time per vehicle (min)* | 14.0 |
| Freeway mainline delay (min) | 3.99 |
| System delay (min) | 3.99 |
| VMTD Veh-miles (Demand) | 15,061 |
| VMTV Veh-miles (Volume served) | 14,867 |
| VHT travel (hrs) | 268.12 |
| VHD delay (hrs) | 69.89 |
| Space mean speed = VMTV / VHT (mph) | 55.5 |
| Segment density (pc/mi/lane) | 29.8 |
| Density-based LOS on segment | D |
| Travel Time Index (TTI) | 1.37 |

*The average travel time is reported for the peak hour; while the rest of the performance measures are reported for the peak 15-minute during the peak hour.

# B.2 APPLICATION OF CHAPTER 36 TO HILLSBOROUGH I-75 TEST CORRIDOR

In the Chapter 36 method (FREEVAL-reliability), the reliability analysis in FREEVAL is conducted by combining the seed file developed above and the scenarios generated from the FREEVAL scenario generator.

## Required Inputs in FREEVAL scenario generator

There are four different worksheets in the FREEVAL scenario generator to generate all different operational scenarios. They are briefly discussed as follows.

### *Daily Demand Multipliers*

In this step, the demand variations are provided for the study corridor. The day-to-day demand variations are generated by adjusting the demand coded in the seed file. All the multipliers are based on the ratio of the cell value to the AADT for the study corridor. If the site-specific value does not exist, the national default values for either urban or rural area can be used.

## *Demand Pattern Configuration*

In the demand pattern configuration table, the cells with same color represent a unique demand pattern by day of week and month of year to be analyzed as shown in **Figure 12**. The user can specify different days of the week and different months of the year to have same demand pattern. Defaults demand pattern is available in FREEVAL (also shown in **Figure 12**).

**Figure 12  Default Demand Pattern in FREEVAL**

# Demand Patterns= 9  # Days in Analysis= 129  Analysis Year= 2011

| Week # | January | Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|---|---|
| Week 1 | January | 1/3/2011 (1) | 1/4/2011 (2) | 1/5/2011 (2) | 1/6/2011 (2) | 1/7/2011 (3) |
| Week 2 | January | 1/10/2011 (1) | 1/11/2011 (2) | 1/12/2011 (2) | 1/13/2011 (2) | 1/14/2011 (3) |
| Week 3 | January | 1/17/2011 (1) | 1/18/2011 (2) | 1/19/2011 (2) | 1/20/2011 (2) | 1/21/2011 (3) |
| Week 4 | January | 1/24/2011 (1) | 1/25/2011 (2) | 1/26/2011 (2) | 1/27/2011 (2) | 1/28/2011 (3) |
| Week 5 | February | 1/31/2011 (1) | 2/1/2011 (2) | 2/2/2011 (2) | 2/3/2011 (2) | 2/4/2011 (3) |
| Week 6 | February | 2/7/2011 (1) | 2/8/2011 (2) | 2/9/2011 (2) | 2/10/2011 (2) | 2/11/2011 (3) |
| Week 7 | February | 2/14/2011 (1) | 2/15/2011 (2) | 2/16/2011 (2) | 2/17/2011 (2) | 2/18/2011 (3) |
| Week 8 | February | 2/21/2011 (1) | 2/22/2011 (2) | 2/23/2011 (2) | 2/24/2011 (2) | 2/25/2011 (3) |
| Week 9 | March | 2/28/2011 (1) | 3/1/2011 (5) | 3/2/2011 (5) | 3/3/2011 (5) | 3/4/2011 (6) |
| Week 10 | March | 3/7/2011 (4) | 3/8/2011 (5) | 3/9/2011 (5) | 3/10/2011 (5) | 3/11/2011 (6) |
| Week 11 | March | 3/14/2011 (4) | 3/15/2011 (5) | 3/16/2011 (5) | 3/17/2011 (5) | 3/18/2011 (6) |
| Week 12 | March | 3/21/2011 (4) | 3/22/2011 (5) | 3/23/2011 (5) | 3/24/2011 (5) | 3/25/2011 (6) |
| Week 13 | April | 3/28/2011 (4) | 3/29/2011 (5) | 3/30/2011 (5) | 3/31/2011 (5) | 4/1/2011 (6) |
| Week 14 | April | 4/4/2011 (4) | 4/5/2011 (5) | 4/6/2011 (5) | 4/7/2011 (5) | 4/8/2011 (6) |
| Week 15 | April | 4/11/2011 (4) | 4/12/2011 (5) | 4/13/2011 (5) | 4/14/2011 (5) | 4/15/2011 (6) |
| Week 16 | April | 4/18/2011 (4) | 4/19/2011 (5) | 4/20/2011 (5) | 4/21/2011 (5) | 4/22/2011 (6) |
| Week 17 | May | 4/25/2011 (4) | 4/26/2011 (5) | 4/27/2011 (5) | 4/28/2011 (5) | 4/29/2011 (6) |
| Week 18 | May | 5/2/2011 (4) | 5/3/2011 (5) | 5/4/2011 (5) | 5/5/2011 (5) | 5/6/2011 (6) |
| Week 19 | May | 5/9/2011 (4) | 5/10/2011 (5) | 5/11/2011 (5) | 5/12/2011 (5) | 5/13/2011 (6) |
| Week 20 | May | 5/16/2011 (4) | 5/17/2011 (5) | 5/18/2011 (5) | 5/19/2011 (5) | 5/20/2011 (6) |
| Week 21 | May | 5/23/2011 (4) | 5/24/2011 (5) | 5/25/2011 (5) | 5/26/2011 (5) | 5/27/2011 (6) |
| Week 22 | June | 5/30/2011 (4) | 5/31/2011 (5) | 6/1/2011 (8) | 6/2/2011 (8) | 6/3/2011 (9) |
| Week 23 | June | 6/6/2011 (7) | 6/7/2011 (8) | 6/8/2011 (8) | 6/9/2011 (8) | 6/10/2011 (9) |
| Week 24 | June | 6/13/2011 (7) | 6/14/2011 (8) | 6/15/2011 (8) | 6/16/2011 (8) | 6/17/2011 (9) |
| Week 25 | June | 6/20/2011 (7) | 6/21/2011 (8) | 6/22/2011 (8) | 6/23/2011 (8) | 6/24/2011 (9) |
| Week 26 | July | 6/27/2011 (7) | 6/28/2011 (8) | 6/29/2011 (8) | 6/30/2011 (8) | |
| Week 27 | July | | | | | |

## *Weather Data*

This worksheet is used to generate the weather events and their impacts on roadway capacities. The user can easily generate all the necessary weather information by selecting the nearest metropolitan area to the study corridor. Lakeland, FL was selected for this I-75 NB study corridor.

## *Incident data*

The incident worksheet generates the incident in terms of probability of occurrence, duration and impacts on the roadway capacity. The worksheet provides two options "data rich" environment and "data poor" environment. In the "data rich" environment, user can input facility-specific incident probability. In the "data poor" environment, user can input facility-specific incident/crash rates if data available or use HERS (2) model to estimate the incident rate.

## Facility-Specific Inputs For I-75 NB Study Corridor

For this study corridor, facility-specific ***Daily Demand Multipliers*** and ***Crash Rate*** were developed.

## Facility-Specific Daily Demand Multipliers

Based on the continuous traffic counts (1/1/2011 – 6/30/2011) from RITIS at the I-75 permanent count station located south of Broadway Avenue, the daily demand multipliers were developed for this I-75 NB study corridor. **Table 32** demonstrates the daily demand multipliers from January to June.

### Table 32 Daily Demand Multipliers for Study Corridor

| | Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|---|
| **January** | 0.933 | 0.920 | 0.922 | 0.930 | 1.034 |
| **February** | 1.160 | 1.067 | 1.083 | 1.142 | 1.266 |
| **March** | 1.079 | 1.067 | 1.086 | 1.008 | 1.282 |
| **April** | 0.894 | 0.885 | 0.919 | 0.961 | 1.000 |
| **May** | 0.891 | 0.841 | 0.864 | 0.883 | 0.977 |
| **June** | 0.822 | 0.806 | 0.832 | 0.871 | 0.943 |

Note: The corresponding AADT at the detector location is 192,440

Based on **Table 32**, Wednesday in January has a demand multiplier 0.922. This means that the demand coded in seed file are 7.8% lower than the AADT. To generate the demand volumes for Thursday in February, the demand volumes in the seed file should be multiplied by the ratio 1.142/0.922 or 1.24.

## Facility-specific Crash Rate

Based on crash reports provided by Tampa Bay SunGuide RTMC, the facility-specific crash rate for this I-75 NB study corridor was calculated for each individual month. The crash rates of I-75 NB study corridor from January to June are:

- January: 34.1 per 100 million vehicle mile
- February: 49.0 per 100 million vehicle mile
- March: 37.5 per 100 million vehicle mile
- April: 49.3 per 100 million vehicle mile

- May: 40.9 per 100 million vehicle mile
- June: 31.7 per 100 million vehicle mile

### Summary of the Results of Reliability Studies

Three reliability tests were conducted for this I-75 NB study corridor using different amounts of default and facility specific data on demand variability and crash rates:

- Test #1: Use the built-in default values/calculations (HERS Model) in the FREEVAL scenario generator
- Test #2: Use the facility-specific daily demand multipliers and crash rate

The statistics of the corridor travel time reliability (i.e., travel time index) of Test #1 and Test #2 were then compared with the field observations calculated based on the Inrix data, as shown in **Table 33**.

**Table 33 Summary of Corridor Travel Time Reliability**

| Statistics of Travel Time Index | Inrix Data | FREEVAL Test #1 (All Defaults) | FREEVAL Test #2 (Min. Defaults) |
|---|---|---|---|
| Mean TTI | 1.36 | 2.36 | 1.52 |
| 50th Percentile TTI | 1.21 | 2.02 | 1.29 |
| 80th percentile TTI | 1.42 | 3.23 | 1.78 |
| 95th Percentile TTI | 2.30 | 4.23 | 2.62 |

All of the FREEVAL model's TTIs are higher than the corresponding INRIX data results. As expected, the test with facility-specific input has better performance in terms of mean TTI, $50^{th}$ percentile TTI, $80^{th}$ percentile TTI and $95^{th}$ percentile TTI than the one with built-in default values. The $50^{th}$ percentile TTI of the test with facility-specific input is really close to corresponding INRIX data, which suggests that the seed file and the facility-specific demand variation are developed appropriately.

## B.2 APPLICATION OF UF RELIABILITY MODEL TO HILLSBOROUGH I-75 TEST CORRIDOR

Similar reliability analysis data collection efforts, processing, and sources as were previously described for the Broward I-95 test site were used to apply the Florida Department of Transportation (FDOT) University of Florida (UF) Reliability Model to the Hillsborough I-75 test site.

# C. INRIX Data

This appendix describes the acquisition and processing of INRIX travel time reliability data for the two freeway test sites: The I-95 Southbound freeway in Broward County and the I-75 Northbound freeway in Hillsborough County.

## C.1 ACQUISITION OF INRIX DATA

In the INRIX system, the two corridors are divided into several TMC segments. Table 34 identifies the corresponding TMC segments of the two corridors and the corresponding link length.

**Table 34 TMC Links of Two Study Corridors**

| # | I-95 SB | | I-75 NB | |
|---|---|---|---|---|
| | TMC ID | Length (miles) | TMC ID | Length (miles) |
| 1 | 102-04139 | 1.43 | 102+05168 | 0.95 |
| 2 | 102N04139 | 0.83 | 102P05168 | 0.43 |
| 3 | 102-04138 | 0.21 | 102+05169 | 1.95 |
| 4 | 102N04138 | 0.98 | 102P05169 | 0.81 |
| 5 | 102-04137 | 1.21 | 102+05170 | 0.48 |
| 6 | 102N04137 | 0.74 | 102P05170 | 1.14 |
| 7 | 102-04136 | 1.30 | 102+05171 | 2.77 |
| 8 | 102N04136 | 0.43 | 102P05171 | 0.97 |
| 9 | 102-04135 | 0.34 | 102+05172 | 0.72 |
| 10 | 102N04135 | 0.35 | 102P05172 | 0.85 |
| 11 | 102-04134 | 0.06 | 102+05173 | 2.77 |
| 12 | 102N04134 | 0.90 | | |
| 13 | 102-04133 | 0.77 | | |

For the Broward I-95 freeway corridor the selected reliability analysis period is the non-holiday weekday p.m. peak hour between 4:45 p.m. and 5:45 p.m.. The selected direction for analysis is the southbound peak direction. For the Hillsborough I-75 freeway corridor the selected reliability analysis period is the non-holiday weekday p.m. peak hour between 4:30 p.m. and 5:30 p.m.. The selected direction for analysis is the northbound peak direction.

## C.2 TRAVEL TIME INDEX CALCULATION

### *Free Flow Travel Time*

Free flow speed is set as 70 miles per hour (mph) on I-95 SB study corridor (5 mph over the posted speed limit, i.e. 65 mph). Free flow speed is set as 75 mph on I-75 NB study corridor (5 mph over the posted speed limit, i.e. 70 mph). The free-flow travel time (length divided by the assumed free-flow speed) of I-95 SB study corridor is 8.19 minutes and the free-flow travel time of I-75 NB study corridor is 11.06 minutes.

### *Corridor Travel Time*

INRIX travel time data was obtained from FDOT. The data used for analysis was obtained for the dates 1/1/2011 to 6/30/2011. The raw data were aggregated in 5 minute interval for each TMC segment. Therefore, there are 12 speed observations for each TMC link during the peak hour on an individual day and the peak hour travel speed is calculated as the average of the 12 speed observations.

Based on the average peak-hour travel speed, the average peak-hour travel time of each TMC segment was calculated as:

$$TT_i = \frac{L_i}{V_i}$$

Where,

$TT_i$ : average peak-hour travel time of TMC segment *i*,

$L_i$ : length of TMC segment *i*,

$V_i$ : average peak-hour speed of TMC segment *i*,

The peak-hour travel time of the study corridor on an individual weekday is calculated by summing up the peak-hour travel time of corresponding TMC segments, i.e.,$\sum TT_i$. The travel time of the study corridor on individual weekday was divided by the free-flow travel time (length divided by the assumed free-flow speed) to obtain the daily travel time index (TTI) for the study corridor. The different percentiles of TTI were then calculated based on the total 129 observations (129 weekdays). The resulting percentile TTI's are shown in Table 35.

**Table 35 Observed Travel Time Index Percentiles**

| Percentile | Broward I-95 TTI<br>SB PM Peak Hour | Hillsborough I-75 TTI<br>NB AM Peak Hour |
|---|---|---|
| 50% | 1.20 | 1.21 |
| 80% | 1.35 | 1.42 |
| 85% | 1.45 | 1.59 |
| 95% | 1.83 | 2.30 |
| 99% | 2.23 | 3.11 |

Figure 13 shows the day-to-day variation in the observed non-holiday weekday p.m. peak hour TTI's for Southbound Broward I-95. Figure 15 shows the day to day variation in the observed non-holiday weekday p.m. peak hour TTI's for Northbound Hillsborough I-75.

**Figure 13 Travel Time Index by Date of Year – (Broward I-95)**

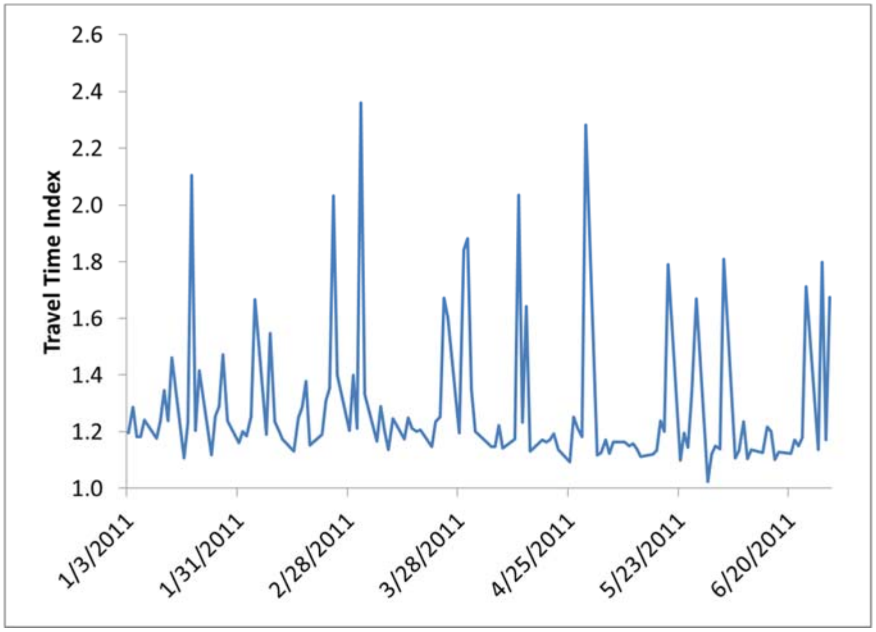



**Figure 14 Cumulative Travel Time Distribution – (Broward I-95)**

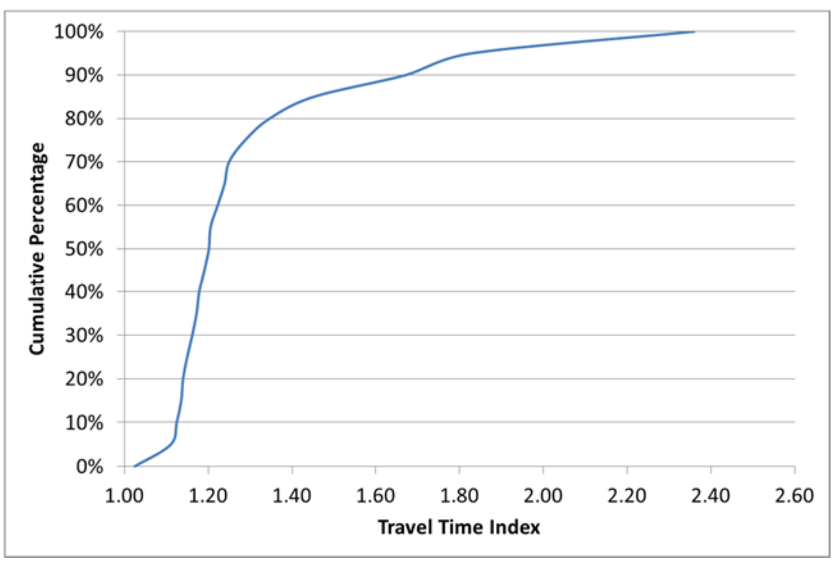


**Figure 15 Travel Time Index by Date of Year – (Hillsborough I-75)**

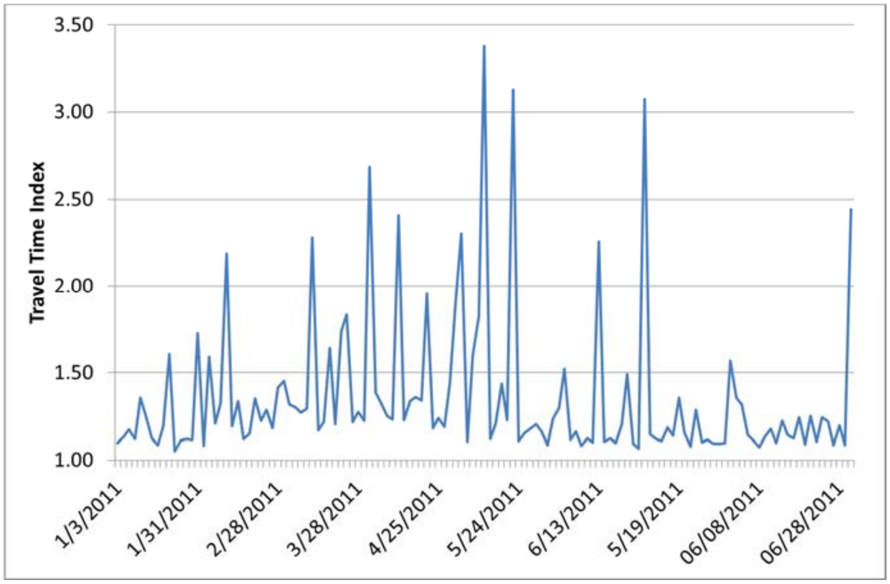



**Figure 16 Cumulative Travel Time Distribution – (Hillsborough I-75)**