Task Work Order 11, Sub Task 3 Final Report

Florida DOT Reliability Model Independent Testing

Comparison of the FDOT Reliability Model with Other Reliability Prediction Methods

Submitted to

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Executive summary

Travel time reliability (TTR) is a mobility performance measure that can be interpreted by travelers and used by transportation agencies as an indicator of congestion. To report on travel time reliability agencies need tools to ascertain multiple travel time statistics. The Florida Department of Transportation (FDOT), working with University of Florida, developed a freeway travel time reliability model that can be used to report on the many travel time reliability performance measures including the percent of vehicles traveling above or below a speed threshold, the mean, 80th, and 95th travel time indices.

The main objective of this study is to conduct an independent evaluation of the FDOT model. This included an overview of the methodologies used in the model, the sensitivity of the model's outputs to it's inputs, and the accuracy of Florida DOT's model in predicting travel time reliability performance measures. This study also compares FDOT's model to other established TTR calculation methods, including the SHRP2 C11 and SHRP2 L07 models, and the use of INRIX field measured data. Methodologies for calculating TTR statistics, as well as comparison of the outputs between the 3 models and INRIX field measured data are documented.

Conclusions from this study are summarized below:

- FDOT's freeway reliability model is well suited for planning level TTR analysis and performance reporting. It was developed to account for all factors that most impact TTR.
- A sensitivity study on the major inputs confirms that FDOT's model effectively responds to major influence factors. In most cases the model follows an expected trend.
- The default parameters in FDOT's model are more suitable for Florida. In comparison to the SHRP2 C11 and SHRP2 L07 models it also has more modifiable inputs, making the model suitable for future and alternative conditions.
- FDOT's model reports TTR for both directions combined, C11 and L07 are directional models, they report TTR for a single direction.
- The FDOT model assumes the same traveling condition for the entire analysis segment, therefore it is possible the model will underestimate TTR for longer segments. The incident probability can become unreasonably high when lengths increase because the incident rate was estimated per lane mile, the longer the analysis segment the higher the probability of incidents. Results from shorter segments need to be properly aggregated to report on longer segments or facilities.

- At I-75 and I-95 testing sites:

  - I-75: while all models estimates lower TTR indices than INRIX field data, results from FDOT model are the closest to field measured data.
  - I-95: while all models estimate higher TTR indices than INRIX field data, results from SHRP2 L07 model are the closest to field measured data.

- Here are possible improvements to the model:
  - Allow for differing capacity values when presented with an odd number of lanes
  - Adjust parameters in the model with additional data.
  - Improve the model for analysis of longer segments by possibly adding impacting length instead of using segment length as the impacting length.
  - Add additional scenarios to account for the different levels of incident and work zone influence This will more accurately represent field conditions and result in more continuous and accurate speed distribution.
  - Evaluate and investigate the accuracy of the method used in aggregation.

1.0 Introduction

Florida DOT is a pioneer in evaluating travel time reliability, and created one of the earliest tools capable of predicting travel time reliability statistics. The Florida DOT freeway reliability model is used in project prioritization and for reporting travel time reliability performance measures. This report provides an independent assessment of Florida's freeway reliability model focused on the data and analytic procedures on which the model is based, it's sensitivity to key input variables, and it's ability to be used for performance reporting, tracking, and estimation.

Since the inception of Florida DOT's travel time reliability model, numerous other travel time reliability models have emerged. At the same time, more field measured travel time data has become available with multiple vendors providing trip travel times along Florida's roadways. To date no research has been conducted to compare different TTR performance measure calculation methods.

This study is motivated by the need to better understand the capabilities and limitations of existing tools, in order to select the most appropriate tool for given applications. The remainder of this report is organized as follows: section 2 describes the methodologies and inputs for existing TTR calculation methods; section 3 presents results from a sensitivity study of the FDOT model. The sensitivity analysis tests the reasonableness of outputs based on changes to input variables; section 4 provides results from different TTR calculation methods; section 5 summarizes all the findings and provides recommendations for future improvements to the FDOT TTR model.

2.0 Overview of TTR Calculation Methods

This chapter will provide an overview of existing TTR calculation methods used in FDOT's model, SHRP C11 model, and SHRP L07 model. The inputs and outputs for each method are also evaluated and compared.

2.1 FDOT Model

The freeway travel time reliability model that Florida DOT uses was developed by the University of Florida. The model uses a set of linear regression equations for predicting average hourly travel time, fitted to data from Philadelphia, Ft. Lauderdale, and Jacksonville freeways. Separate equations are applied to each of 24 possible scenarios. Different combinations of levels of congestion, incident types, weather types, and work zones define each scenario. The expected (average) travel time to traverse the full length of the freeway is computed for each scenario for each of the 24 hours in 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.

Figure 1**Error! Reference source not found.** shows the overall procedures to calculate reliability in the FDOT model. Levels of congestion, incident types, weather types, and work zones are defined as following: **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/hr), 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 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. **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 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 PM to 7 AM) and 1% for the rest of the day. These estimates were made in the absence of data on work zone probabilities. 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. Directional hourly volume was obtained by applying a fixed 0.55 D factor to peak direction, 0.45 D factor to non-peak direction, and a set of K factors based on facility and area types to segment AADT. The capacity of a scenario varies by blocking incident type and work zone type.

Two equations are used to compute section travel time rate (TR, secs/mile): If *demand*< *capacity*:

$$TR(d < c) = 3600/FFS(w) + 0.00258 \times d;$$

If *demand*> *capacity*:

$$\begin{aligned} TR(d > c) = Max\{&TR(d < c), \\ &3600/FFS(w) + 0.1238 \times d - 0.1243 \times c - 3.46 \times L + 0.67 \times T - 15.24 \\ &\times N_{cr} + 0.3964 \times d \times cr - 21.524 \times L \times cr)\} \end{aligned}$$

Where:

FFS(w) = free-flow speed (mph) adjusted by weather type
d = demand (vphpl)
c = capacity (vphpl),
L = length (miles)
T = time period (min), always set to 60 minutes in the model
N_{cr}= number of lanes when there is a capacity reduction (blocking or nonblocking incident and/or work zone), or 0 for scenarios without capacity reduction

- Average number of lanes affected by a workzone
- Ratio of non-blocking to blocking incidents is factored in calculating N_{cr}

cr = capacity reduction (%) which is a function of:

- Probability of rain
- Average incident duration
- Average incident clearance time

The model provides the entire travel time distribution for all 24 hours for both directions combined. Based on this it can predict the percent of trips or percent of hours the average speed on a facility is above or below a given speed criteria. The model can also output the "planning time index", defined as the 95th percentile travel time divided by the free-flow travel, for the facility for each hour of the day. Free flow speed is defined as travel 5 mph faster than the posted speed limit. Generally, FDOT reports the reliability results for the 5-6 PM peak weekday hour, or the 4-7 PM peak weekday period, but reliability can be reported for any hour of the day or for all 24 hours of the day.

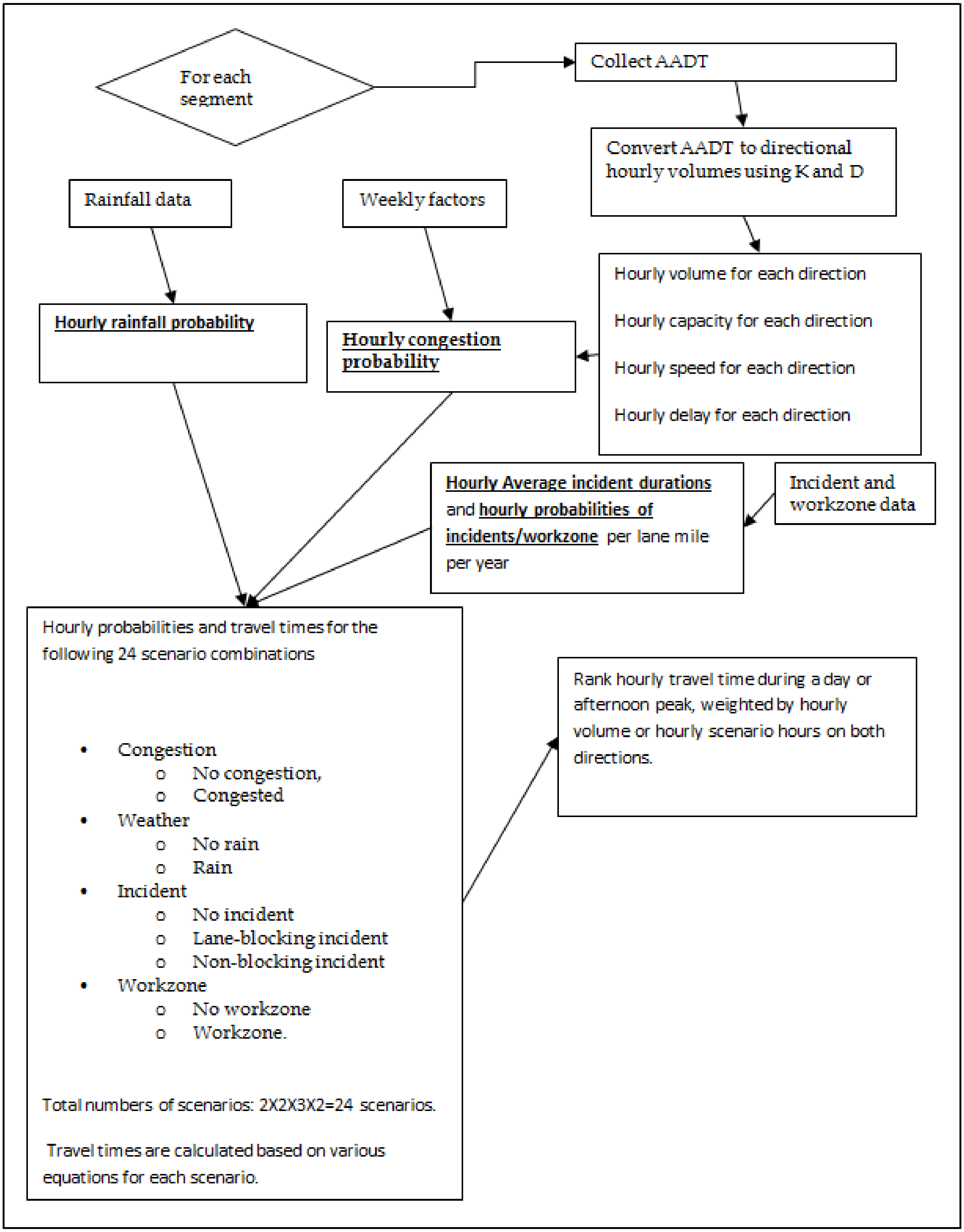

Figure 1 Reliability Methodology Flowchart

2.2 SHRP2 C11 Model

The SHRP2 C11 travel time reliability model was developed to allow users to quickly evaluate highway performance in terms of both typical travel time and travel time reliability. It was structured as a sketch planning tool that involves minimal data development and model calibration, it uses the results of other SHRP 2 projects in it's methodology as well as methods from earlier studies. The procedure is based on making estimates of recurring and non recurring congestion delay, combining them, and then using predictive equations to develop reliability matrices. If growth factors, incident reduction factors, and economic parameters are provided, the model can also be used to evaluate future TTR, effectiveness of incident reduction programs, and congestion and reliability costs. Procedures for TTR calculation are described below (reference: C11 final report)

The C11 model uses the following equation to predict segment travel rate (TR, hours/mile):

$$TR = \{1 + 0.1225 \times (v/c)^8\}/FFS\,, \qquad for\ v/c \leq 1.40$$

Where:

v = hourly volume
c = capacity (for an hour, defined above)
FFS = free flow speed
Note: v/c should be capped at 1.40

Recurring delay in hours per Mile is calculated by following equation:

$$RecurringDelayRate = TR - 1/FFS$$

Incident delay in hours per Mile is calculated by following equation:

$$IncidentDelayRate = D_u \times (1 - R_f) \times (1 - R_d)^2$$

Where:

D_u = based incident delay(hours per Mile, from lookup table in IDAS User Manual(reference: IDAS User's Manual, Appendix B, Tables B.2.14 – B.2.18, http://idas.camsys.com/documentation.htm))
R_f = Reduction in incident frequency expressed as a fraction (with R_f= 0 meaning no reduction, and R_f = .30 meaning a 30 percent reduction in incident frequency)
R_d= Reduction in incident duration expressed as a fraction (with R_d= 0 meaning no reduction, and R_d= .30 meaning a 30-percent reduction in incident duration)

Travel time reliability metrics are calculated as following:

$$TTI_m = 1 + FFS \times (RecurringDelayRate + IndidentDelayRate)$$

Following TTR performance measured are calculated using the SHRP 2 L03 "Data Poor" equations:

$$TTI_{95} = 1 + 3.67 * In(TTI_m)$$
$$TTI_{80} = 5.3746/(1 + e^{(-1.5782-0.85867\times TTI_m)})^{1/0.04953}\,; \qquad TTI_{80} \geq 1.0$$
$$TTI_{50} = 4.01224/(1 + e^{(1.7417-0.93677\times TTI_m)})^{1/0.82741}\,; \qquad TTI_{50} \geq 1.0$$
$$PercentTripsOccuringLT45mph = 1 - e^{(-1.5115\times(TTI_m-1))}$$
$$PercentTripsOccuringLT30mph = 1 - [0.333 + 0.672/(1 + e^{(5.0366\times(TTI_m-1.8256))})]$$

Where:

TTI_{95} is the 95th percentile TTI
TTI_{80} is the 80th percentile TTI
TTI_{50} is the 50th percentile TTI
PercentTripsOccuringLT45mph is the percent of trips that occur at speeds less than 45 mph
PercentTripsOccuringLT30mph is the percent of trips that occur at speeds less than 30 mph

Highway segments are the basic unit of analysis, and input data pertains to them. Segments can be of any length but it is recommended that they not be so long that the characteristics change dramatically along the segment, or too short that input is burdensome. Reasonable segment lengths would be:

- Freeways: between interchanges
- Signalized highways: between signals
- Rural highways (non freeways): 2-5 miles

Outputs are produced for the entire length of the analysis segment in tabular form; outputs are displayed for the base condition and all improvement scenarios. A variety of reliability metrics are produced to allow users wide flexibility in interpreting the results. The model also permits users to make independent estimates of the value of reliability if they so choose.

2.3 SHRP2 L07 Model

SHRP2 L07's model was developed for to evaluate the effectiveness of geometric design related treatments on reducing nonrecurrent congestions. The design treatments are evaluated based on travel time reliability indicators and delay. The analytical framework and spreadsheet-based analysis tool is derived from SHRP2 project L03 and was enhanced in project L07 to:

- Address the effects of multi-hour incidents on the traffic operational effectiveness of design treatments
- Analysis of existing data to improve the applicability of reliability models for time periods with d/c < 0.8
- Address effects of snow and ice on the traffic operation effectiveness of design treatments

Traffic operational data from Seattle and Washington were used to calibrate the L07 model. The SHRP 2 L07 reliability model equation is presented here:

$$TTI_n = \begin{cases} TTI_{NP,n} \times e^{(C_n R_{05''} + D_n S_{01''})}\ ; & for\ d/c \leq 0.8 \\ \dfrac{TTI_{NP,n}}{N_{days}} \times \left[N_{NP} + V_{FF}\left(\dfrac{R_{05''}}{c1_n V_{FF} + c2_n TTI_{NP,n}} + \dfrac{S_{01''}}{d1_n V_{FF} + d2_n TTI_{NP,n}} \right) \right]; & for\ d/c > 0.8 \end{cases}$$

Where:

TTI_n = the predicted nth percentile travel time index

$TTI_{NP,n}$ = the non-precipitation portion of $TTI_n = e^{(a_n d/c + b_n LHL)}$

LHL = lane-hours lost due to incidents and work zones

d/c = demand to capacity ratio

$R_{05''}$ = number of hours in time-slice with rain exceeding 0.05 in

$S_{01''}$ = number of hours in time-slice with snow exceeding 0.01 in

N_{days} = number of hours in time-slice

N_{NP} = number of hours in time-slice with no precipitation=Ndays-R05”-S01”

VFF = free-flow travel time on segment, mph

$a_n, b_n, c_n, d_n, c1_n, c2_n, d1_n, d2_n$ = nth-percentile coefficients

The model above was used to construct a predictive cumulative TTI curve based on four primary variables (d/c, LHL, R0.05”, and S0.01”), various reliability and delay measures are then extracted from this curve. (reference, L07 final report) In both before and after the treatment scenarios, economic analysis can be done if cost factors are provided.

A nuance, that causes complications, is the L07 spreadsheet’s inability to maintain user inputs after a file is saved. Two important inputs, number of lanes and interchanges per mile, revert back to default values whenever a file is opened. The analyst must change these values every time or they will receive erroneous results.

2.4 Model Inputs and outputs

All of the reliability models require different levels of detailed inputs. Prior to using the models, it is important to have an overall assessment of the data needed and where it’s located. Table 1 provides a side-by-side comparison of the inputs required to run each of the three models. Among the three models, C11 requires the least amount of inputs and the L07 model requires the most detailed inputs. FDOT's model was originally designed for the state of Florida. A set of default values suitable for Florida were built into the model to keep user inputs minimal, such as directional factors, K factors, capacity per lane, free flow speed (estimated from facilities posted speed limit), probabilities with/without rain, probabilities with/without work zone, reduction in incident durations with road rangers, etc. All these parameters can also be modified to make the model suitable for other regions, or for future conditions and alternative treatments. The FDOT model does not account for the impact of grade or heavy vehicles. Additionally, the FDOT model assumes the same capacity for both directions. When the number of lanes differs between two directions the FDOT model assumes an equal number on both sides.

While all of the models report TTR performance measures, the C11 tool has the most simplified reliability outputs including overall mean TTI, TTI_{95}, TTI_{80}, and percent of trips less than 45 mph and percent of trips less than 30 mph. SHRP2's L07 model constructs reliability distributions allowing for various reliability measures to be reported. Default L07 model outputs include reliability distribution graphs and tables listing major reliability measures. The FDOT model estimates travel time and probability for 24 traffic scenarios for each of the 24 hours of a day. When the travel time probabilities are combined with hourly volume, various reliability measures are output and can be customized as desired.

It is also noted that C11 and L07 are directional models, which means the travel time indices reported by C11 and L07 models are for one direction, generally the peak direction. On the other hand the FDOT model reports travel time indices for both directions of a freeway segment combined. For example, if a freeway segment has 1000 vehicles in the peak direction and 500 vehicles in the off peak direction, TTI_{95} reported by C11 and L07 models represents the 95th percentile of the 1000 vehicles going in the peak direction, but the FDOT model reports the 95th percentile of vehicles traveling in both the peak and off-peak directions combined.

Table 1: Input Comparisons

Input	FDOT Reliability Model	SHRP2 L07 Model	SHRP2 C11 Model
Volume	**User input:** AADT, model will convert to hourly and directional volume **User modifiable:** D factor and K factors	**User input:** Hourly Volume	**User input:** AADT, model will convert to hourly and directional volume using default factors
Future volume	May input future volumes	May input future volumes	**User input:** Annual traffic growth rate
Heavy vehicles	Null	**User input:** Truck and RV percent separate	**User input:** Truck percent
Capacity	**User input:** Number of lanes, **User modifiable:** capacity lookup table for different types	**User input:** Number of directional lanes, model will convert to capacity	**User input:** Number of directional lanes, model will convert to capacity
Length	**User input:** Roadway ID, Beginning and end mile point, model will calculate length, In miles	**User input:** In miles	**User input:** In miles
Free flow speed	**User modifiable:** model will find FFS through a lookup table, in Mile per hour	**User input:** Mile per hour	**User input:** Mile per hour
Terrain/Grade	Null	**User input:** percent of slope	**User input:** Flat, rolling, mountainous
Workzone lane closure	**User modifiable:** Number of lanes	**User input:** Number of lanes	**User input:** Null
Weather	**User modifiable:** In inches by number of rainy days	**User modifiable:** Hours per year that rainfall/snowfall exceeds given minimum	Null
Average incident duration	**User modifiable:** Incident duration for both blocking and non-blocking	**User input:** Incident duration for both blocking and non-blocking	IncidentDelayRate obtained from IDAS lookup table

Input	FDOT Reliability Model	SHRP2 L07 Model	SHRP2 C11 Model
Total number of incidents	**User modifiable:** For both blocking and non-blocking incidents	**User input:** For both blocking and non-blocking incidents	IncidentDelayRate obtained from IDAS lookup table
Effect of incident management strategy	**User input:** With road rangers and without	**User input:** Incident duration with treatment	**User input:** Both reduction in incident frequency and duration
Area type	**User input:** As defined in QLOS handbook	**User input:** Urban or rural	Null
Time horizon	Null	Null	**User input:** In years
Analysis period	**User modifiable:** choose any hour or hours	Null	**User input:** Morning, afternoon, and evening periods or all day
Value of reliability	Null	**User input:** Reliability*ratio	**User input:** Reliability*ratio(both personal and commercial)
Travel time unit cost	Null	**User input:** Value of time $/hr	**User input:** Personal and commercial $/hr
Facility type	**User input:** As defined in QLOS Handbook	Freeways	**User input:** Defined by 2010 HCM
Interchanges per mile	Null	**User input:** No. of interchanges	Null
Right lateral clearance	Null	**User input:** In feet	Null

User input: need input from user
User modifiable: user can choose between inputting values and using model default
Null: not a input for the model

2.5 Field Measured Data

In-vehicle cellular or GIS enabled devices have become a valuable source of data. Private vendors acquire speed and travel time data from GPS and cellular devices and use it for the calculation of travel time reliability performance measures. Traffic data, both real-time and historical, are collected on a Traffic Message Channel (TMC) network. The TMC network data has the advantage of providing space mean speeds which are more suitable for travel time calculations in comparison to time mean speed (or spot speed) usually collected by states' traffic monitoring programs' loop detectors.

INRIX speed data collected from July 1, 2010 through June 30, 2011 was provided for use in this study. The data covers 18,010 centerline miles of major roads and arterials in the sate of Florida, on 33,700 TMCs. INRIX speed data provides average travel speed for every 5 minute time interval, across all lanes

In this study, INRIX data are used as a bench mark to compare the modeling results against. TMC segment speeds were converted to travel times based on the segment lengths. The travel times were then summed over all the segments in the test facilities and divided by the estimated free-flow travel time for the entire length of all the segments to obtain the travel time index (TTI's) for each time period. Traffic volume are combined with the INRIX travel time data to derive travel time or travel speed distributions, various TTR performance measures can then be extracted.

3.0 FDOT Model Sensitivity Analysis

As part of the model evaluation process, sensitivity analyses were performed on FDOT's TTR model to assess the reasonableness of the results in response to changes in model inputs. A hypothetical 1.022 mile-long freeway section is used as the test segment. The section of freeway has similar geometric features and traffic volumes as I-95 in Broward County. It is assumed to have: 10 lanes (5 in each direction), an AADT of 300,000, free flow speed is 65 mph, capacity is 1900 vehphpl based on facility type, and the study period is from 4 to 7 pm.

3.1 Sensitivity Factors

The sensitivity test will assess the mean travel time index (TTI) and the 95th percentile TTI for the p.m. peak period, consistent with the model. The following inputs were selected for the sensitivity analysis:

- AADT – demand plus or minus 20%
- Capacity – Adding 2 lanes or removing 2 lanes, represents a 20% change in capacity
- Time period – all day calculations compared to p.m. peak
- Incident duration – plus or minus 20%
- Free flow speed reduction for rain – plus or minus 20%
- K factor –more peaking or less peaking volumes during a day. Figure 2 illustrates the base and two other different sets of the hourly to daily volume ratios used in the sensitivity analysis. "Higher Peak" is a set of K factors that has more peaking and "Lower-Peak" has less peaking.
- Segment length – 100% and 200% increase in length

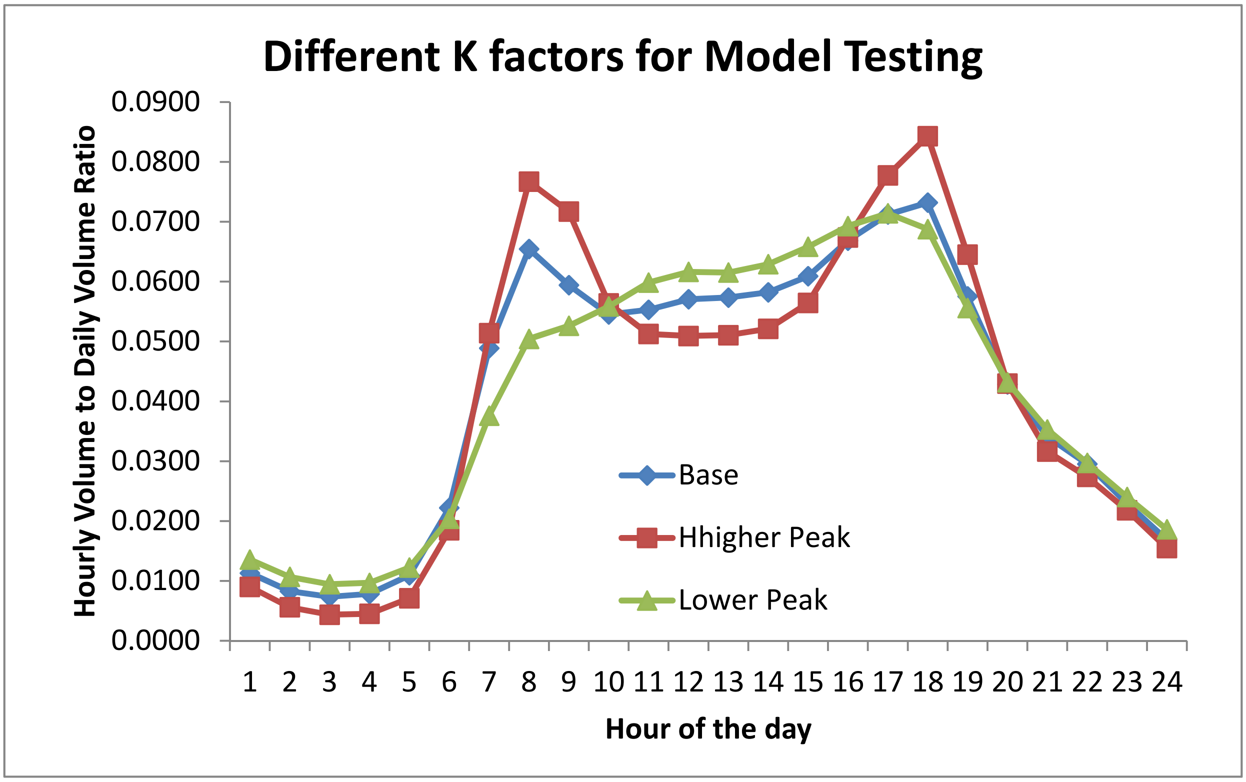

Figure 2 K Factors for testing

3.2 Sensitivity Results

Table 2 below presents the sensitivity results for selected input factors. Overall the FDOT model is able to accurately estimate changes to travel time reliability resulting from various changes to factors impacting reliability. The model showed sensitivity to capacity, demand, incident, weather, volume distributions, etc. Based on an elasticity analysis, capacity and demand have the largest impact on average travel time and length appears to have the biggest impact on travel time indices measures. More details on the results are provided below:

- Demand and capacity - demand plus or minus 20% and capacity plus or minus 20%
    - Both average travel time and Planning Time Index (PTI) increases when demand increases or capacity decreases and vice versa. This is expected as travel time would increase when congestion level increases.
- Time period – all day compared to p.m. peak(4-7pm)
    - Demand is higher during p.m. peak period, therefore it is expected that both average TTI and PTI are higher during p.m. peak compared to all day results.
- Incident duration – plus or minus 20%

  - When incident duration becomes longer, more travel will be impacted by the incidents, results in Table 2 indicates that both average TTI and PTI increased when incident duration increases, as expected.
- Free flow speed reduction for rain – plus or minus 20%
  - If drivers travel slower under severe weather condition such as heavy rain, travel time reliability is expected to be worse. The resulting reduction in free flow speed for heavy rain is as expected.
- K factor – different volume distributions throughout the day
  - When hourly to daily ratios present more peaks, a higher volume during the peak hour is expected. In these instances travel time reliability is expected to worsen during the peak hour. Results from changes to the K factors were as expected.
- Segment length – 100% and 200% increase in length
  - Results in Table 2 show both average TTI and PTI increases when segment length becomes longer. These trends continue when segment length increases.
  - In travel rate calculations used in the FDOT model, the portion of the equation representing the overall impact of congestion is $-3.46 \times L$, and the portion of the equation representing the impact of incident and weather condition is $21.524 \times L \times cr$. Both of them are length sensitive (L in the above equations represents the length of the analysis segment), and the impacts are assumed to extend to the full length of the analysis segment. Therefore the longer the analysis segment length, the model will estimate larger reduction in travel time rate, and worse the travel time reliability.
  - Because the FDOT model assumes the same travel conditions throughout the analysis segment careful attention to segment length should be given. If the length of the analysis segment is too long the FDOT model may overestimate travel time reliability indices and produce poor mobility results. When additional data becomes available, the effect of segment length on the performance of FDOT's model may be improved through calibration or possibly adding impacting length factors.

Table 2: Results of FDOT Model Sensitivity Analysis

Scenario	BMP	EMP	Length	AADT	Lanes	Free Flow TT	Avg. TT by Vol.	95% TT by Vol.	Avg. TTI	PTI	% Change in Avg TTI	% Change in PTI
Base	10.276	11.298	1.022	306,000	10	56.60	145.82	166.05	2.58	2.93		
All Day	10.276	11.298	1.022	306,000	10	56.60	97.13	168.01	1.72	2.97	-33%	1%
AADT +20%	10.276	11.298	1.022	367,200	10	56.60	210.69	234.58	3.72	4.14	44%	41%
AADT -20%	10.276	11.298	1.022	244,800	10	56.60	88.60	116.71	1.57	2.06	-39%	-30%
Capacity +20%	10.276	11.298	1.022	306,000	12	56.60	89.20	121.11	1.58	2.14	-39%	-27%
Capacity -20%	10.276	11.298	1.022	306,000	8	56.60	233.52	283.22	4.13	5.00	60%	71%
Length +100%	9.254	11.298	2.044	306,000	10	113.21	320.77	327.55	2.83	2.89	10%	-1%
Length +200%	8.232	11.298	3.066	306,000	10	169.81	542.63	1023.9	3.20	6.03	24%	106%
Higher K	10.276	11.298	1.022	306,000	10	56.60	176.61	195.56	3.12	3.45	21%	18%
Lower K	10.276	11.298	1.022	306,000	10	56.60	141.99	157.83	2.51	2.79	-3%	-5%
Incident Duration +20%	10.276	11.298	1.022	306,000	10	56.60	148.64	170.31	2.63	3.01	2%	3%
Incident Duration -20%	10.276	11.298	1.022	306,000	10	56.60	141.29	161.79	2.50	2.86	-3%	-3%
FFS reduction for rain +20%	10.276	11.298	1.022	306,000	10	56.60	145.91	167.03	2.58	2.95	< 1%	1%
FFS reduction for rain -20%	10.276	11.298	1.022	306,000	10	56.60	145.73	165.11	2.57	2.92	< 1%	-1%

4.0 Model Testing Results and Analysis

In this chapter all three travel time reliability models are used to evaluate mobility for freeway segments and facilities in Broward and Hillsborough Counties. The results from the models are analyzed and compared against each other and also compared against results from INRIX field measured data.

4.1. Testing Sites

In order to analyze and report travel time reliability, the freeway system in Florida is segmented into facilities based on following statewide criteria:

- Strategic Intermodal System (SIS) freeway to freeway interchanges;
- Non-SIS freeways are also a major consideration;
- Logical extensions of SIS freeways if a short gap of freeway is missing (This scenario occurs if a freeway terminates, and a major arterial provides connection to another freeway.);
- Nonadjacent urbanized area boundaries;
- Transitioning and rural boundaries are also considered segmentation points;
- SIS intersecting routes;
- Other special considerations;
- Major downtown core areas;
- SIS multimodel hubs;
- State boundaries; and
- Length.

The basic unit of this segmentation system is a freeway "section" that extends from one interchange to the next. Multiple sections are combined into a total of 156 facilities statewide, ranging between 9 miles and 30 miles.

Two of the 156 facilities, a 17.49 mile facility on I-95 in northern Broward County as shown in Figure 3, and a 5.18 mile facility on I-75 in east Hillsborough County as shown in Figure 4, were chosen for the testing.

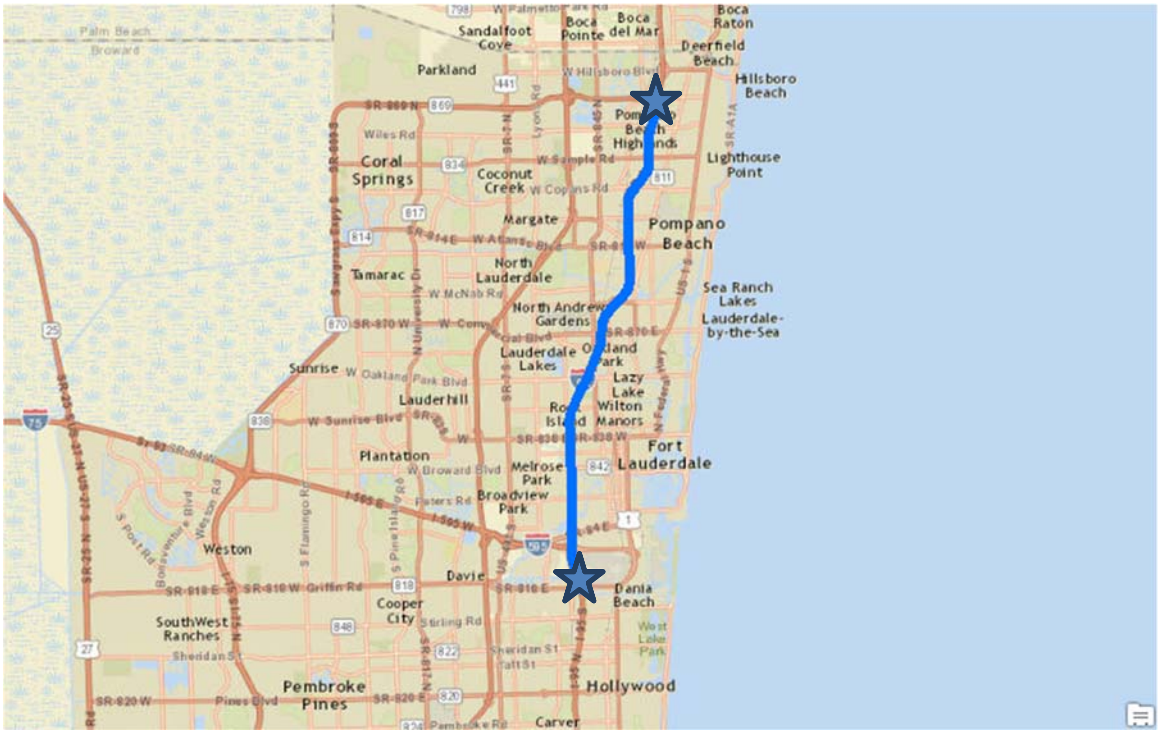

Figure 3: I-95 between I-595/SR 862 and SR 869/SW 10th St

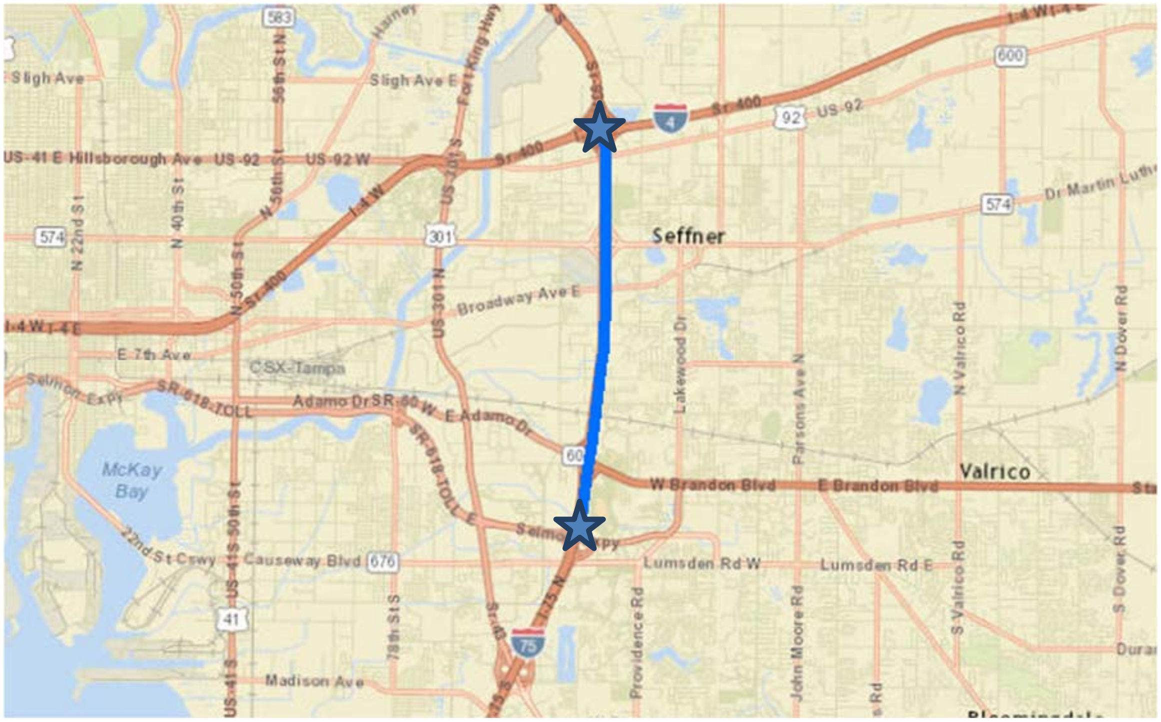

Figure 4: I-75 between SR 618 and I-4/SR 400

4.2. Model Input

Data sources for all major inputs are identified below, some are required by all models and others are only applicable to one or two of the models.

Traffic volumes are one of the most important inputs required by all models. Traffic volumes were obtained from Florida DOT permanent count stations for each hour of the day within a year. The percent of heavy vehicles is recorded and reported in Florida Traffic online. Capacity values are determined by the lookup table based on LOS E volume thresholds. The facility length is a given based on predetermined start and end points. Free flow speeds will be calculated by adding 5 mph to the posted speed limit. The number of lanes for each freeway facility will come from the roadway characteristics database. Florida is a relatively flat state, the location of both freeways being analyzed is also flat therefore the terrain will be quantified as flat.

Florida SunGuide records lane closures based on scheduled road work, this information is available for Broward and Palm Beach Counties. Similar information is produced by District 7 for Hillsborough County, and is used to report on number of lanes closed by a work zone. Incident clearance time, total number of incidents, and the average incident duration information was obtained from the District 7 ITS Office for I-75 and from SunGuide for I-95. Average rainfall is built into the FDOT model and is calculated based on what area of Florida is selected for analysis.

Both, the time horizon and analysis period are variables determined by the analyst. Similarly the facility type is a given based on the type of roadway for which travel time reliability is being evaluated. Default values will be used for the value of reliability, and travel time unit cost inputs. ARC GIS wiill be the source for tracking the number of interchanges per mile. Lastly, street-view images are used to measure the lateral clearance on the right side of the roadway. The lateral clearance can only be entered once so an analyst should report the width most representative of the entire segment.

4.3 Results and Discussion

The version of each model tool used in this study is listed below:

FDOT model: The example worksheet associated with the report "Travel Time Reliability Implementation for the Freeway SIS" was used for segment analysis. For facility reliability the 2012 peak period travel time reliability database was used;

SHRP2 C11: The December 2012 version of the reliability module for SHRP2 project C11 Economic Analysis Tools was used;

SHRP2 L07: The Project L07 tool-early Beta release V0.3 was used.

4.3.1 Segment Analysis

Freeway segments, between interchanges, are the basic analysis unit for all models. One segment from each facility is used for the segment analysis comparison.

Table 3 and Table 4 show the results of segment analysis for all of the models. Detailed inputs and model outputs can be found in appendix.

Table 3: I-75 segment analysis result

I-75 Segment	FDOT Model	SHRP2 C11	SHRP2 L07	INRIX
Mean TTI	1.37	1.28	1.16	1.52
95th TTI	2.44	1.89	1.39	3.53
80th TTI	1.15	1.4	1.19	1.55
5th Travel Speed	30.74 mph	39.68 mph	53.96 mph	21.25 mph
20th Travel Speed	65.22 mph	53.57 mph	63.03 mph	48.39 mph
% trips < 45 mph	14.17%	33.29%		18.34%
% trips < 30 mph	4.73%	4.01%		10.31%

Table 4: I-95 segment analysis result

I-95 Segment	FDOT Model	SHRP2 C11	SHRP2 L07	INRIX
Mean TTI	2.76	1.88	1.42	1.26
95th TTI	2.76	3.27	1.75	2.13
80th TTI	2.67	2.37	1.59	1.22
5th Travel Speed	27.17 mph	22.94 mph	42.86 mph	35.21 mph
20th Travel Speed	28.09 mph	31.65 mph	47.17 mph	61.48 mph
% trips < 45 mph	44.16%	71.00%		11.10%
% trips < 30 mph	26.03%	38.00%		5.27%

On I-75 segment, field measured data produced worse mobility than the mobility estimate of any models. FDOT's model is the closest to field measured data on estimating the 95th TTI and mean TTI, the SHRP2 C11 model is the closest to field measured data on estimating the 80th TTI. For the I-95 segment, travel time performance measures estimated by FDOT model and C11 model are worse than field measured data, and field measured data are better than L07 model. Overall, estimates from the L07 model are closest to field measured data on I-95.

It is also noted that while all models predict worse travel time reliability on I-95 in comparison to I-75, field measured data reports better travel time reliability on I-95.

Following is a list of observations from using the tools and data. No exact cause for these occurrences can be attributed without additional data and further investigations.

- The probability and duration of accidents, work zone, weather parameters used in this study are based on averages for District 4 and District 7, these number may not accurately represent the actual field condition of the two test sites. This may cause the models to overestimate or underestimate TTR. Obtaining facility specific data may improve the performance of the models.
- Specifically for FDOT's model:
    - Probability of non blocking incident is estimated by applying a non blocking to blocking ratio to the probability of blocking incidents. This approach might be problematic because there is no proven relationship between non blocking incidents and blocking incidents in real life. In some areas, the ratio can be really high(e.g., 20.51 for I-95), which may in turn generate unreasonably high probability for non-blocking incidents.
    - The impact of non-blocking incidents is too high for congested conditions. In real life, if speed is already very low, a non blocking incident such as a vehicle on shoulder will not greatly slow down traffic.
    - Maximum capacity in capacity lookup table is 1900 vphpl, maximum capacity in 2013 QLOS Handbook for Florida freeways is 2100 vphpl, this number should be used in the model when appropriate.
- A nuance that can cause complications is the L07 spreadsheet's inability to maintain the user inputs after a file is saved. Two important inputs, number of lanes and interchanges per mile, revert back to default values whenever a file is opened. The analyst must change these values every time or they will receive erroneous results.
- In a separate research effort, FDOT acquired travel time data using an instrumented vehicle and INRIX data. Researchers obtained data along 5 urban freeways. The travel time data included both oversaturated and undersaturated conditions. At least 5 runs were performed for each study section. Results revealed INRIX does not provide acceptable travel times during oversaturated conditions.

4.3.2 Facility Analysis

In order to report on travel time reliability measures for a facility, results for each analysis segment need to be aggregated into facility results. FDOT's travel time reliability model was used to estimate travel time for individual freeway sections. Each section's travel time is aggregated to produce facility level results. These facility level travel time reliability measures are reported in FDOT's travel time reliability database.

For C11 and L07 models, the analysis were performed on each section between interchanges. Travel time reliability performance measures for each section were weighted by VMT to get facility level results.

Results for facility analyses are shown in Table 5 and Table 6. Detailed inputs and outputs for the segments can be found in appendix.

Table 5: I-75 facility analysis result

I-75 Facility	FDOT Model	SHRP2 C11	SHRP2 L07	INRIX
Mean TTI	1.21	1.18	1.15	1.31
95th TTI	1.21	1.6	1.37	2.25
80th TTI		1.23	1.18	1.37
5th Travel Speed	61.98 mph	46.88 mph	54.74 mph	33.33 mph
20th Travel Speed		60.98 mph	63.56 mph	54.74 mph
% trips < 45 mph		23.23%		12.28%
% trips < 30 mph		2.44%		4.76%

Table 6: I-95 facility analysis result

I-95 Facility	FDOT Model	SHRP2 C11	SHRP2 L07	INRIX
Mean TTI	1.21	1.86	1.44	1.34
95th TTI	1.49	3.14	1.8	2.07
80th TTI		2.31	1.62	1.51
5th Travel Speed	50.34 mph	23.89 mph	41.67 mph	36.23 mph
20th Travel Speed		32.47 mph	46.30 mph	49.67 mph
% trips < 45 mph		64.59%		17.30%
% trips < 30 mph		32.68%		3.21%

From the results, it is clear that facility TTR indices are lower than segment results. This is because congestion is washed out by some of the not so congested segments within the facilities.

On the I-75 facility, TTIs estimated by all models are lower than the field measured results, and for I-95, only TTIs estimated by FDOT's model and the L07 model are lower than field measured data. Facility level results from the FDOT database appeared low. In addition to topics discussed in segment analysis section, the aggregation method may play a role in the accuracy of the facility level results.

5.0 Conclusions and Future Improvements on FDOT Model

This study reviewed FDOT's travel time reliability model, the SHRP2 C11 model, and SHRP2 L07 model. Analyses results from two test sites were compared against each other and INRIX field measured data. Following are a list of conclusions from this study:

- FDOT travel time reliability model is well suited for estimating reliability systemwide and reporting on the statewide freeway system.
- For the I-75 and I-95 testing sites:
    - I-75 Segment: while all models estimate lower TTR indices than INRIX field data, results from FDOT's model are the closest to field measured data.
    - I-95 Segment: while all models estimate higher TTR indices than INRIX field data, results from the SHRP2 L07 model are the closest to field measured data.
    - Field measured data may not be reliable for severely congested segments.
- The FDOT model and travel time reliability database has the following limitations:
    - Many of the parameters are based on very limited sample size.
    - The estimation of average bi-directional travel times and therefore average bi-directional reliability is washing out some of the travel time variability for the facility occurring in the peak direction.
    - The integer of average number of lanes is used, for example, for an 11-lane segment (6 lanes on one direction, 5 lanes on the other), the model uses the integer of 5.5 in calculations.
    - The capacity threshold is a single number for both directions, this is wrong for segments with unbalanced numbers of lanes.
    - Same travel conditions were assumed throughout the analysis segment. If the length of the analysis segment is too long the FDOT model may overestimate travel time reliability indices and produce poor mobility results.
    - The incident probability can become unreasonable when lengths increase because the incident rate is estimated per lane mile; and non-blocking incident rates are estimated using a ratio between blocking and non blocking incidents.
    - It is unclear from the available documentation how the facility numbers are calculated from segment results, and how the state-wide numbers are calculated from facility results.

Many of the limitations of FDOT's model can be improved with further research and data. The following are possible improvements to the FDOT model:

- Allow for differing capacity values when presented with an odd number of lanes.
- Adjust parameters in the model with additional data.
- Improve the model for analysis of longer segments by possibly adding impacting length instead of using segment length as the impacting length.
- Add additional scenarios to account for the different levels of incident and work zone influence This will more accurately represent field conditions and result in more continuous and accurate speed distribution.
- Evaluate and investigate on more accurate method for aggregation
- Recalibrate travel speeds when non-blocking incidents occur in heavy to severe congestion.
- Separate the calculation for non-peak direction and peak direction allowing the model to analyze travel time reliability solely for the peak direction.

Interchange analysis has a planning application with methodology different from operation's method.

Include the duration of the congestion for each hour then we can estimate the queue
We need a speed related reduction and not a straight reduction, slower moving traffic should not be as adversely affected by non-blocking incidents as faster moving traffic.

Reference

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3. 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.

4. Elefteriadou, L., Hongsheng Xu, FINAL REPORT to THE FLORIDA DEPARTMENT OF TRANSPORTATION SYSTEMS PLANNING OFFICE on Project "Travel Time

5. SHRP Project C11: Reliability Analysis Tool: Technical Documentation, January 2013

6. Identification and Evaluation Of The Cost-Effectiveness Of Highway Design Features To Reduce Nonrecurrent Congestion - Draft Final Report, April, 2013

7. Elefteriadou, L., A. Kondyli, and B. St. George, Comparison of Methods for Measuring Travel Time at Florida Freeways and Arterials, FDOT Contract BDV32, University of Florida, Gainesville, FL, November 2013.

Appendix

Table A-1: Inputs for I-75

Facility	I-75/SR 93A		
Segment Index	404	405	406
County	illsboroug	illsboroug	illsboroug
SFCAT	1075	1075	1075
District	7	7	7
Roadway ID	10075000	10075000	10075000
Begin MP	21.923	22.874	25.619
End MP	22.874	25.619	27.102
LOSCL	(Spacing <2)	(Spacing >=2)	(Spacing <2)
LOS Lanes	6	6	6
Directional Lanes	3	3	3
AADT	69000	130325	134500
LOS	D	F	E
2030 AADT	118300	199500	199800
LOSFT	1fwy2d	1fwy1d	1fwy2d

Table A-2: Inputs for I-95

Facility	I-95/SR 9										
Section index	699	700	701	702	703	704	705	706	707	708	709
County	Broward	Broward	Broward	Broward	Broward	Broward	Broward	Broward	Broward	Broward	Broward
SFCAT	8695	8695	8695	8695	8695	8695	8695	8695	8695	8695	8695
District	4	4	4	4	4	4	4	4	4	4	4
Roadway ID	86070000	86070000	86070000	86070000	86070000	86070000	86070000	86070000	86070000	86070000	86070000
Begin MP	6.163	7.664	8.891	10.276	11.298	13.442	15.075	16.248	18.407	20.411	21.558
End MP	7.664	8.891	10.276	11.298	13.442	15.075	16.248	18.407	20.411	21.558	23.65
LOSCL	(Spacing <2)	(Spacing <2)	(Spacing <2)	(Spacing <2)	(Spacing >=2)	(Spacing <2)	(Spacing <2)	(Spacing >=2)	(Spacing >=2)	(Spacing <2)	(Spacing >=2)
LOS Lanes	10	8	10	10	10	10	8	8	8	8	8
Directional Lanes	5	4	5	5	5	5	4	4	4	4	4
AADT	279000	301000	266000	279000	262000	264000	235000	235000	231000	219000	193478
LOS	F	F	F	F	F	F	F	F	F	F	F
2030 AADT	361000	458000	434000	434000	434000	392000	398000	398000	378000	378000	297000
LOSFT	1fwy2d	1fwy2d	1fwy2d	1fwy2d	1fwy1d	1fwy2d	1fwy2d	1fwy1d	1fwy1d	1fwy2d	1fwy1d

Table A-3: TMCs on I-75

I-75 Segment			
TMC	**Direction**	**TMC**	**Direction**
102P05169	N	102N05169	S
102+05170	N	102-05169	S
102P05170	N	102N05170	S

I-75 Facility			
TMC	**Direction**	**TMC**	**Direction**
102+05167	N	102-05166	S
102+05168	N	102-05167	S
102P05168	N	102N05168	S
102+05169	N	102-05168	S
102P05169	N	102N05169	S
102+05170	N	102-05169	S
102P05170	N	102N05170	S

Table A-4: TMCs on I-95

I-95 Segment			
TMC	**Direction**	**TMC**	**Direction**
102P04138	N	102N04139	S
102+04139	N	102-04138	S
102P04139	N	102N04138	S

I-95 Facility			
TMC	**Direction**	**TMC**	**Direction**
102P04127	N	102-04127	S
102+04128	N	102N04128	S
102P04128	N	102-04128	S
102+04129	N	102N04129	S
102P04129	N	102-04129	S
102+04130	N	102N04130	S
102P04130	N	102-04130	S
102+04131	N	102N04131	S
102P04131	N	102-04131	S
102+04132	N	102N04132	S
102P04132	N	102-04132	S
102+04133	N	102N04133	S
102P04133	N	102-04133	S
102+04134	N	102N04134	S
102P04134	N	102-04134	S
102+04135	N	102N04135	S
102P04135	N	102-04135	S
102+04136	N	102N04136	S
102P04136	N	102-04136	S
102+04137	N	102N04137	S
102P04137	N	102-04137	S
102+04138	N	102N04138	S
102P04138	N	102-04138	S
102+04139	N	102N04139	S
102P04139	N	102-04139	S
102+04140	N	102N04140	S
102P04140	N		

Table A-5: SHRP02 C11 output - I-75

C11	**I-75 404**	**I-75 405**	**I-75 406**	**I-75 Facility**
Congestion Metrics				
Overall mean TTI	1.01	1.16	1.28	1.18
TTI_{95}	1.03	1.55	1.89	1.60
TTI_{80}	1.00	1.23	1.40	1.26
Pct. trips less than 45 mph	1.12%	21.68%	33.29%	23.23%
Pct. trips less than 30 mph	0.57%	1.91%	4.01%	2.44%

Table A-6: SHRP02 L07 Results - I-75

L07	**I-75 404**	**I-75 405**	**I-75 406**	**I-75 Facility**
Congestion Metrics				
Overall mean TTI	1.11	1.16	1.16	1.15
TTI_{95}	1.25	1.38	1.39	1.37
TTI_{80}	1.13	1.19	1.19	1.18

Table A-7: SHRP02 C11 outputs - I-95

C11	**I-95 699**	**I-95 700**	**I-95 701**	**I-95 702**	**I-95 703**	**I-95 704**	**I-95 705**	**I-95 706**	**I-95 707**	**I-95 708**	**I-95 709**	**I-95 Facility**
Congestion Metrics												
Overall mean TTI	1.89	3.23	1.42	1.89	1.42	1.43	2.13	2.13	2.11	1.88	1.21	1.86
TTI_{95}	3.30	5.29	2.29	3.30	2.29	2.30	3.78	3.78	3.74	3.27	1.71	3.14
TTI_{80}	2.40	4.13	1.63	2.40	1.64	1.64	2.79	2.79	2.75	2.37	1.30	2.31
Pct. trips less than 45 mph	71.49%	96.00%	47.00%	71.00%	47.00%	47.00%	82.00%	82.00%	81.00%	71.00%	27.00%	64.59%
Pct. trips less than 30 mph	38.54%	67.00%	8.00%	39.00%	8.00%	8.00%	55.00%	55.00%	54.00%	38.00%	3.00%	32.68%

Table A-8: SHRP02 L07 Results - I-95

L07	**I-95 699**	**I-95 700**	**I-95 701**	**I-95 702**	**I-95 703**	**I-95 704**	**I-95 705**	**I-95 706**	**I-95 707**	**I-95 708**	**I-95 709**	**I-95 Facility**
Congestion Metrics												
Overall mean TTI	1.43	1.61	1.41	1.43	1.40	1.41	1.45	1.45	1.44	1.42	1.36	1.44
TTI_{95}	1.78	2.23	1.73	1.78	1.72	1.73	1.82	1.82	1.80	1.75	1.65	1.80
TTI_{80}	1.61	1.96	1.57	1.61	1.56	1.57	1.64	1.64	1.63	1.59	1.51	1.62