ESTIMATING TRAVEL TIME RELIABILITY AND THE IMPACTS OF OPERATIONS AND SAFETY IMPROVEMENTS ON THE 2045 NETWORK

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1.0 Introduction

This memo describes the methodology to be used to estimate congestion management performance measures for alternative investment plans in the 2045 Long Range Transportation Plan (LRTP) update. The methodology is based on work done for the Strategic Highway Research Program 2 (SHRP 2) under Project C11, *Development of Improved Economic Impact Analysis Tools*.[1] In that project, several modules were developed to estimate the economic impact of transportation investments on factors not usually accounted for in transportation analyses: market access, connectivity, and travel time reliability. It is the reliability module that forms the basis for the current reliability and safety work.

A spreadsheet was developed in the original SHRP 2 Project C11 to estimate the reliability impacts of highway investments, but it is not being used in the current work. Rather, its basic procedures were extended and built into a separate tool that post-processes the loaded network file from the Tampa Bay Regional Planning Model (TBRPM), henceforth known as the "C11 Post-Processor." At the request of the Hillsborough MPO, the ability to estimate safety impacts was added. The C11 Post-Processor was previously used in the 2040 LRTP update.

2.0 Technical Approach

2.1 Modeling Structure

For input, the scripts read the loaded network file as well as a list of safety improvements. The analysis is conducted at the corridor level, using corridors defined by the MPO and structured into four large groups:

1. Freeways;
2. Divided arterials;
3. Undivided arterials; and
4. Other roadways (collectors and local roads combined).

2.2 Performance Measures

<u>Reliability</u>

- Planning Time Index (95th percentile travel time/free flow travel time)
- Reliability Index (80th percentile travel time/free flow travel time)

<u>Congestion</u>

- Mean Travel Time Index (mean travel time/free flow travel time)

<u>Safety</u>

- Crashes by severity: fatal, injury, property damage only
- Crashes for special user types: pedestrian and bicycle

[1] http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2350

2.3 Methodology

Predicting Travel Time Reliability

The method in the original C11 tool was adapted as follows.

Assign Free Flow Speed (FFS)

= 60 when Highway Type = 'Freeway'
= 45 when Highway Type = 'Divided Arterial'
= 40 when Highway Type = 'Undivided Arterial'
= 35 when Highway Type = 'Collector'
= 30 when Highway Type = 'Other'

Calculate Speed Due to Recurring Conditions Only

The travel time function proposed by Davidson (1966, 1978) for transport planning purposes has been subject to much discussion and efforts of calibration and improvement including some controversy over the meaning of its parameters. A new travel time function was proposed by Akçelik[2] as an alternative to Davidson's function to overcome the conceptual and calibration problems

In *Development of Speed Models for Improving Travel Forecasting and Highway Performance Evaluation*, Moses et al. presented a piecewise modified Davidson volume-delay function for use in a study of SR-9 and I-95 in Pompano Beach, Florida.[3]

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

Where:

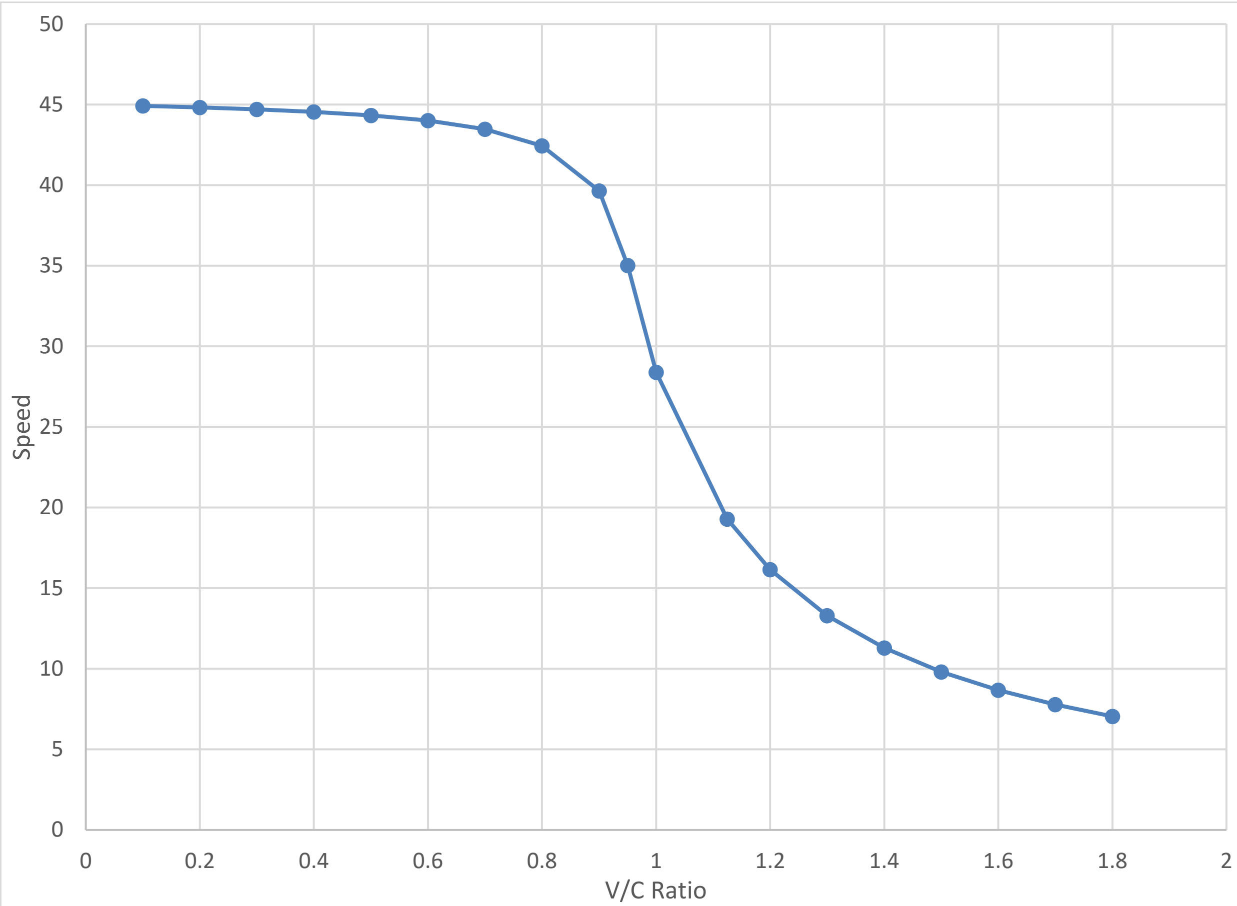
S	= predicted travel speed (mph)
S_o	= free-flow speed (mph)
J_D	= a delay parameter,
V	= volume (veh/h)
C	= capacity (veh/h)
μ	= saturation threshold parameter

[2] Akcelik, *Travel time functions for transport planning purposes: Davidson's function, its time-dependent form and an alternative travel time function*, December 2000.

[3] Moses, Ren and Enock, Mtoi, *Development of Speed Models for Improving Travel Forecasting and Highway Performance Evaluation*, FDOT Project No. BDK83, December 2013

This piecewise modified Davison equation is used in the C11 tool. Figure 1 shows how the function behaves over a range of volume-to-capacity ratios, assuming a free speed of 45 mph.

Figure 1. Volume-Delay Function in the C11 Tool



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

RecurringDelayRate = (1/Speed) – (1/FFS)

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

The lookup tables from the IDAS User Manual[4] are used to calculate incident delay. This requires the v/c ratio, number of lanes, and length and type of the period being studied, which is set at 3-hours. Equations were fit to these tables as follows:

- Number of lanes <= 2: Du = -0.0111/(1 -1471 * exp(-6.8498 * v/c))
- Number of lanes = 3: Du = -0.0085/(1 -1872 * exp(-7.1381 * v/c))

[4] IDAS User's Manual, Appendix B, Tables B.2.14 – B.2.18, http://idas.camsys.com/documentation.htm

- Number of lanes >= 4: Du = -0.0068/(1 -1827 * exp(-7.1090 * v/c))

Where: Du = Base incident delay rate

v/c = volume-to-capacity ratio

Calculate Delay (vehicle-hours)

- RecurringDelay = RecurringDelayRate * VMT
- IncidentDelay = Du * VMT
- TotalDelay = RecurringDelay + IncidentDelay

Calculate the Mean Travel Time Index (MTTI)

MTTI = 1 + (FFS * (RecurringDelayRate + Du))

Calculate Reliability Measures

Apply the equations developed below to derive the reliability measures

Assess the Impacts of Improvements

The above procedures are repeated with the impact factors from Table 4 applied as appropriate.

If incident management programs have been added as a strategy **or** if a strategy lowers the incident rate (frequency of occurrence), then the "after" delay is calculated as follows:

$$D_a = D_u * (1-R_f) * (1-R_d)^2$$

Where:

D_a = Adjusted delay (hours of delay per mile)

D_u = Unadjusted (base)delay (hours of delay per mile)

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).

Because the data on which the reliability metric predictive functions do not include extremely high values of TTI_m, it is recommended that TTI_m be capped at a value of 6.0, which roughly corresponds to an average speed of 10 mph. Even though the data included highway sections that were considered to be severely congested, an overall annual average speed of 10 mph for a peak period was never observed. At TTI_m = 6.0, the reliability prediction equations are still internally consistent.

Develop Custom Equations for Predicting Reliability Metrics

Instead of relying on the C11 tool's equations, developed from data from several cities, it was decided to recalibrate them using data from Florida. The National Performance Management Research Data Set (NPMRDS) for 2014 and 2015 was obtained for the purpose of developing reliability prediction equations for Florida. As specified in the original SHRP 2 C11 project, these relationships predict reliability measures as a function of the mean travel time index (MTTI) for a segment. For this analysis, segments were defined as Traffic Message Channels (TMCs), the basic geographic reporting unit (link) in the NPMRDS data.

The equations that were fit from the data follow. Figures 2 through 7 show the equations superimposed on the original data.

Freeway Relationships

In the following equations: X = Mean Travel Time Index (TTI)
TTI_{50} = 50th percentile TTI
TTI_{80} = 80th percentile TTI
TTI_{95} = 95th percentile TTI

$$TTI_{50} = 10.4910 - 9.5867 \times e^{(-0.0142 \times X^{2.2367})} \quad for\ X > 1.07$$
$$= 0.963X + 0.037 \quad otherwise$$
$$TTI_{80} = 7.3567 - 6.9965 \times e^{(-0.0910 \times X^{2.0185})} \quad for\ X > 1.03$$
$$= 1.0 \ otherwise$$

$$TTI_{95} = 11.7933 - 16.2178 \times e^{(-0.3855 \times X^{1.0336})} \quad for\ X > 1.08$$
$$= 1.3737X - 0.3737 \quad otherwise$$

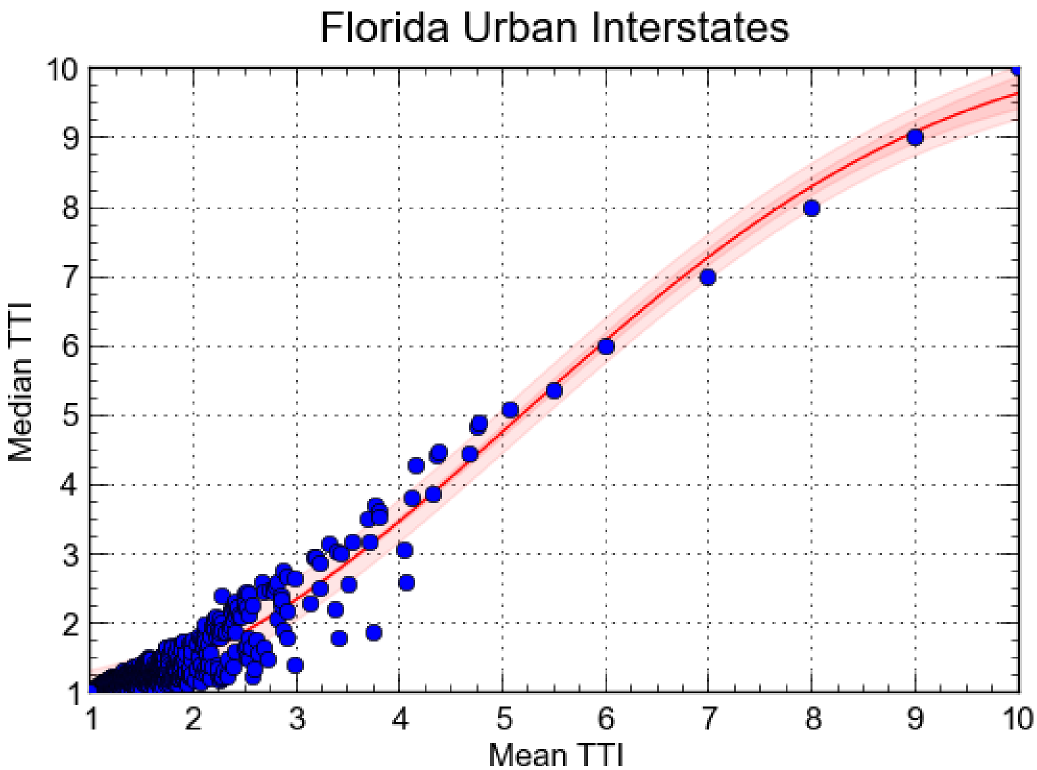
Signalized Arterial Relationships

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

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

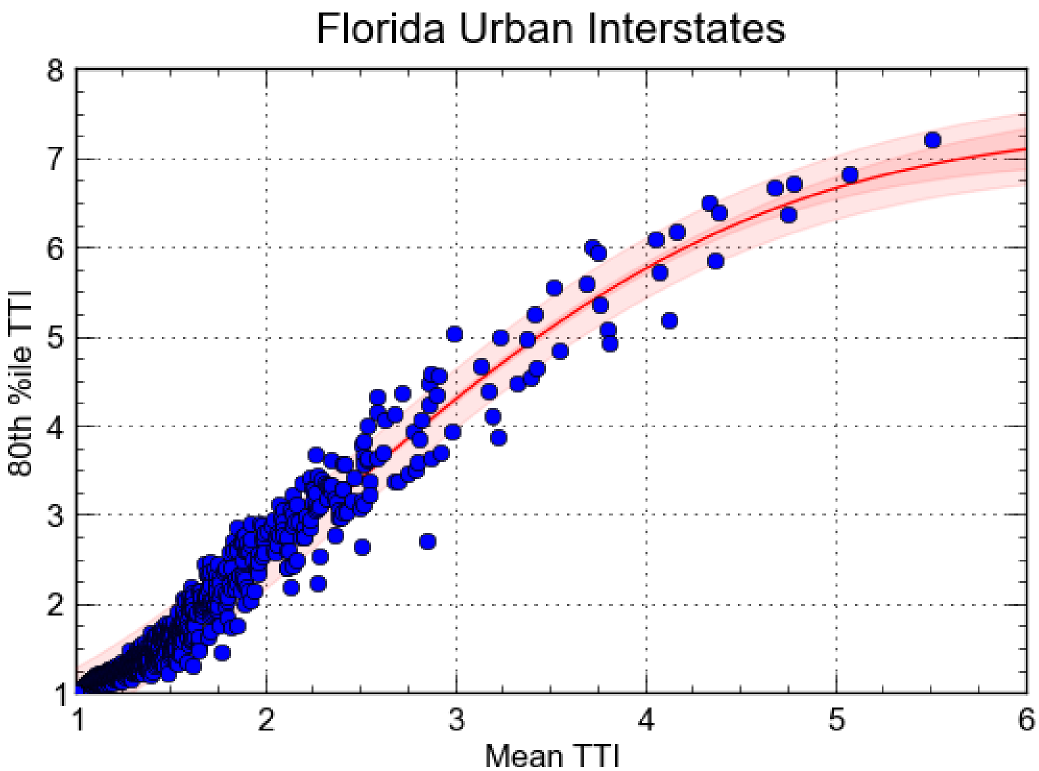
$$TTI_{95} = 21.1669 \times e^{-\frac{2.9506}{X}}$$

Figure 2.



Florida Urban Interstates
10
9
8
7
6
5
4
3
2
1
Median TTI
1
2
3
4
5
6
7
8
9
10
Mean TTI

Figure 3.



Florida Urban Interstates
80th %ile TTI
Mean TTI
1
2
3
4
5
6
7
8
1
2
3
4
5
6

Figure 4.

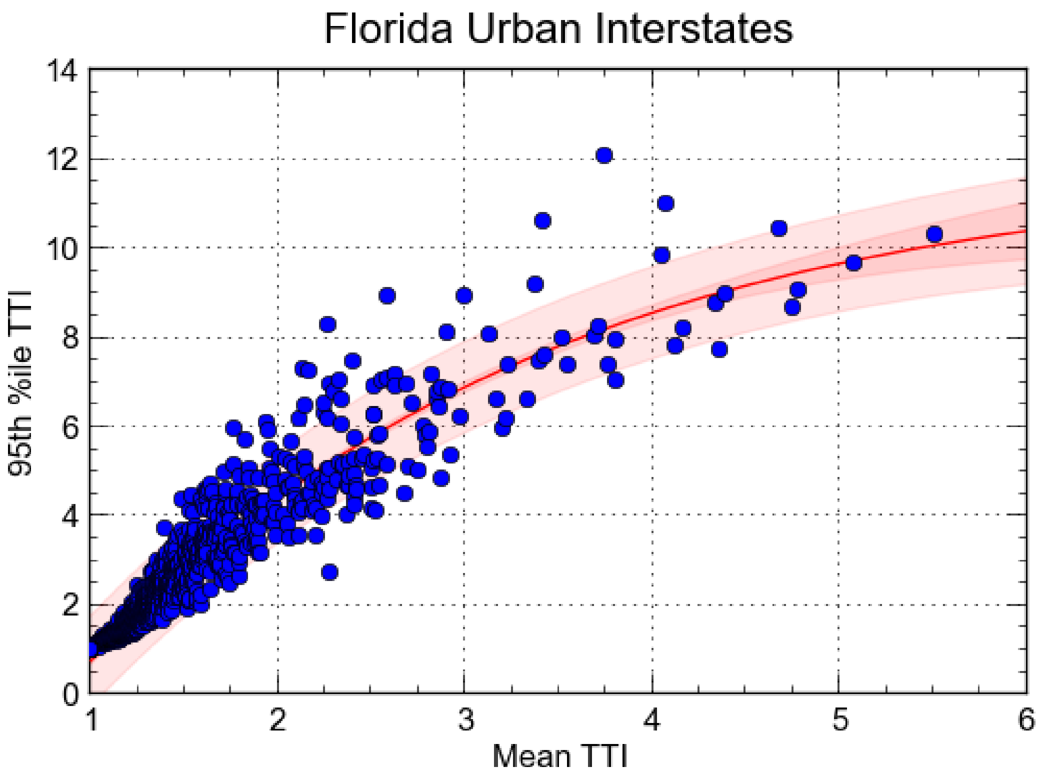

Florida Urban Interstates
95th %ile TTI
Mean TTI
0
2
4
6
8
10
12
14
1
2
3
4
5
6

Figure 5.

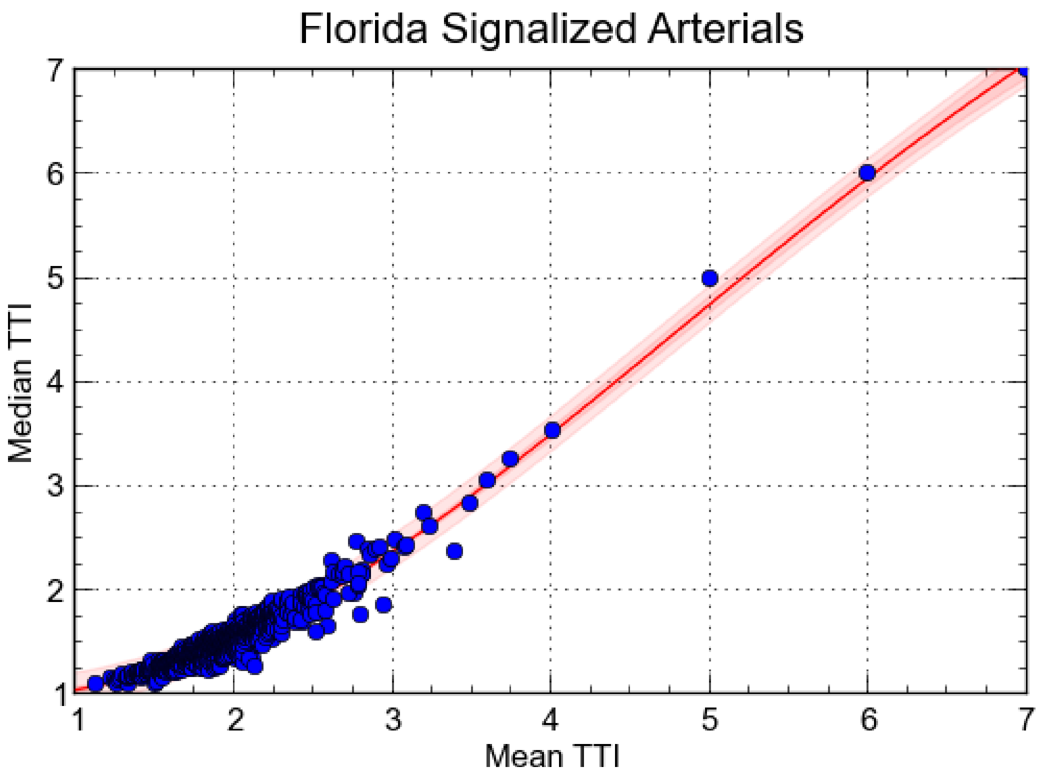

Florida Signalized Arterials
7
6
5
4
3
2
1
Median TTI
1
2
3
4
5
6
7
Mean TTI

Figure 6.

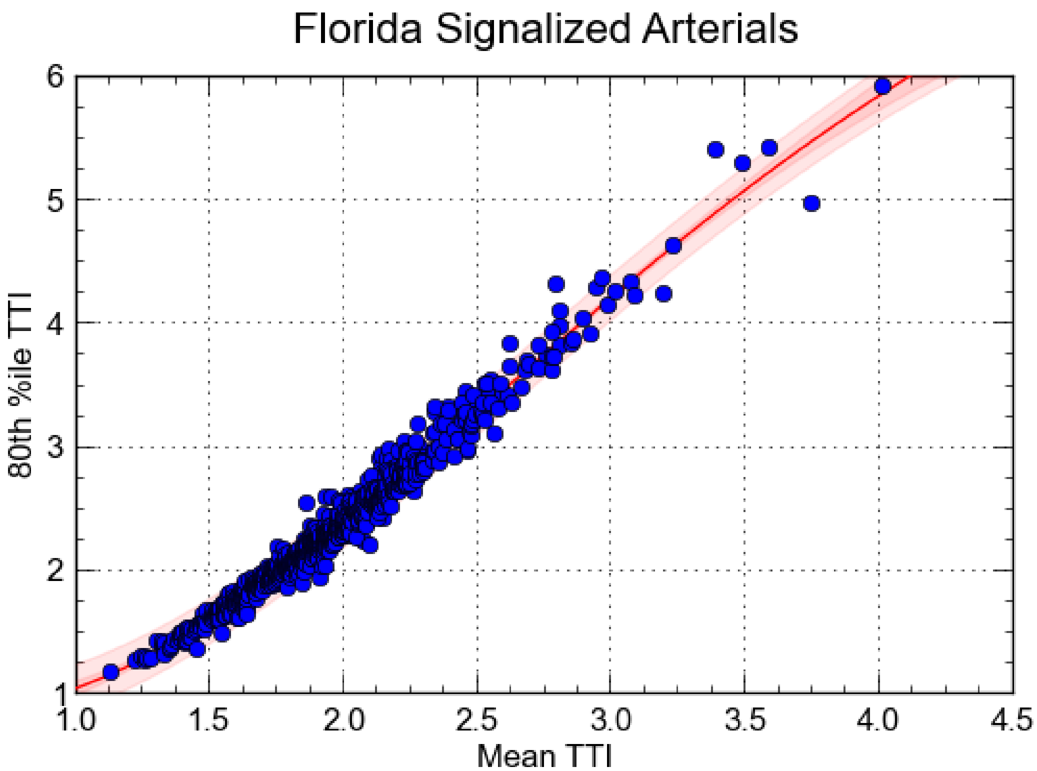
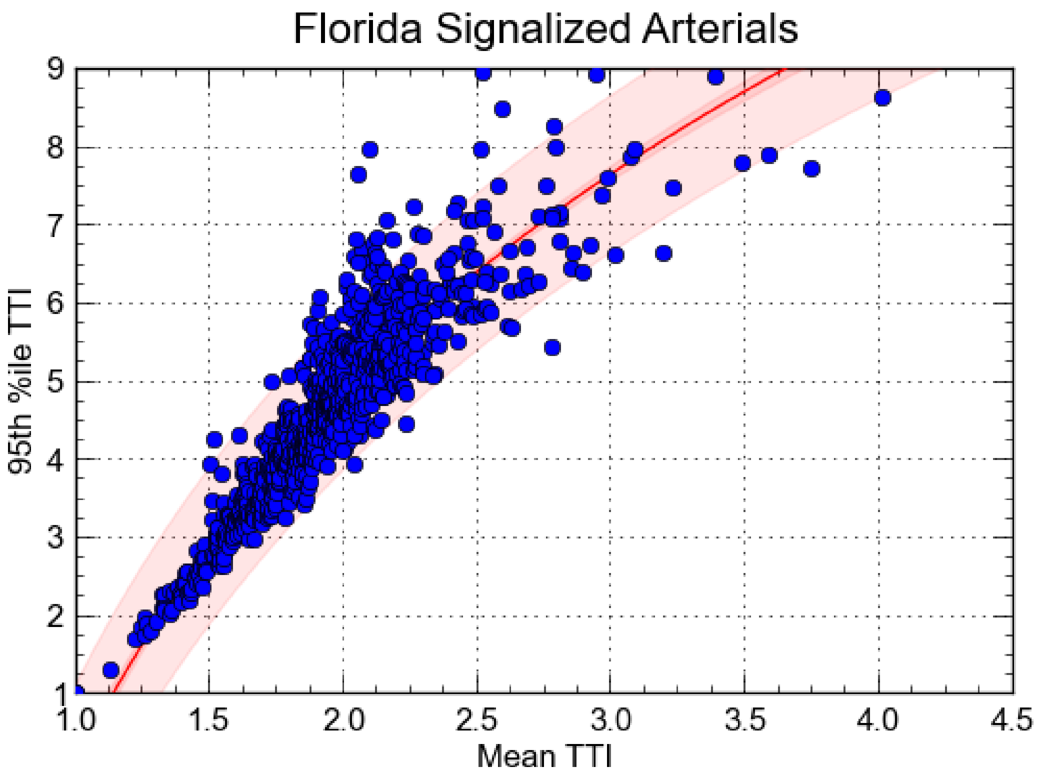

Florida Signalized Arterials
80th %ile TTI
Mean TTI
1
2
3
4
5
6
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5

Figure 7.



Safety Analysis

Safety Performance Functions (SPFs)

The SPFs used in the earlier 2040 Update were taken directly from the *Highway Safety Manual* (HSM).[5] These SPFs are national defaults and the HSM strongly recommends that local SPFs be developed. Fortunately, FDOT had funded other efforts with University of Central Florida (UCF) to do just that. Previously, UCF produced SPFs based on the major function classes of roads.[6] They are considered to be SPFs for "average" conditions as opposed to "base" (close to ideal) conditions. In the HSM, Base SPFs are used in conjunction with CMFs to predict crashes for a particular highway segment. For example, the Base SPF might be for roadways with 12-foot lanes – CMFs are used to account for a roadway with less than 12 foot lanes. However, for long range planning, data on geometric and highway environment conditions are not available so average SPFs are appropriate.

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[5] American Association of State Highway and Transportation Officials, *Highway Safety Manual*, ISBN: 978-1-56051-477-0, 2010.

[6] Abdel-Aty, Mohamed et al., Two Level Approach to Safety Planning Incorporating the Highway Safety Manual (HSM) Network Screening, FDOT Project Report BDK78 977-13, Florida Department of Transportation, 2014.

UCF recently updated the SPFs and these are the ones used in the updated C11 tool for the 2045 analysis, as shown in Tables 1 and 2 below.[7]

Table 1. Individual SPFs Developed by UCF and Used in the C11 Tool: Highway Segments

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

Table 2. Individual SPFs Developed by UCF and Used in the C11 Tool: Intersections

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

[7] Abdel-Aty, Mohamed et al., Enhancing and Generalizing the Two-Level Screening Approach incorporating the Highway Safety Manual (HSM) Methods, Phase 2, FDOT Project Report BDV-24-977-06, May 2016.

Improvement Scenarios

Reliability: Operations Improvements

- Trend Investment Scenario: The Trend investment level is based on all stakeholders' current annual funding level, as identified in the respective Capital Improvement Programs. If this funding trend continues to 2045, it will result in a total budget of **$1,192,000,000** for reliability and operational projects, or nearly **$60,000,000** per year.
  - Freeways: Incident Management
  - Arterials: Incident Management; Signal Retiming
- Trend + Sales Tax Revenue Investment Scenario: The Trend + Sales Tax Revenue investment level is based on all stakeholders' current annual funding level, as identified in the respective Capital Improvement Programs, plus 14% of the projected transportation sales tax revenue. This funding scenario could result in a total budget of **$2,034,400,000** for reliability and operational projects, or **$102,000,000** per year.
  - Freeways: Incident Management, Ramp Metering, Part-Time Shoulder Use, Variable Speed Limits
  - Arterials: Incident Management, Central Signal Control

Safety Improvements

- Trend Investment Scenario: The Trend investment level is based on all stakeholders' current annual funding level, as identified in the respective Capital Improvement Programs. If this funding trend continues to 2045, it will result in a total budget of **$364,000,000** for safety projects, or $18,000,000 per year.
  - Arterials and Collectors: Bike Lanes, Pedestrian Cross-Walks and Beacons, convert TWLTL to raised median (undivided only), Reduce Driveway Density, Speed Control/Enforcement, Traffic Calming
- Trend + Sales Tax Investment Scenario: The Trend + Sales Tax Revenue investment level is based on all stakeholders' current annual funding level, as identified in the respective Capital Improvement Programs, plus 14.58% of the projected transportation sales tax revenue. This funding scenario could result in a total budget of **$1,238,800,000**, or **$62,000,000** per year.
  - Arterials and Collectors: Bike Lanes, Pedestrian Cross-Walks and Beacons, convert TWLTL to raised median (undivided only), Reduce Driveway Density, Speed Control/Enforcement, Traffic Calming

For both investment scenarios, unlit corridors and missing sidewalks & gaps were addressed first. Using a GIS, we were able to identify 1,398 miles of missing sidewalk & gaps and 508 miles of roads within the Urban Service Area which do not have streetlights. Both scenarios prioritized these needs first and the remaining funds were invested in "Complete Streets" style safety projects, as identified above.

Impact Factors

Operations Improvements

- Ramp meters – capacity increase of +8%
- Part-time shoulder use – capacity increase of 1,600 vehicle per hour
- Incident management

    - Reduction in incident duration of 40%
    - Reduction in incident frequency of 3%
- Signal retiming – capacity increase of 4%
- Central signal control – capacity increase of 12%

Safety Improvements

The following crash modification factors (CMFs), obtained from reviewing the studies summarized in the CMF Clearinghouse,[8] were used. The factors were applied multiplicatively.

- Bike lanes – 0.95 (i.e., a 5% reduction in crashes)
- Pedestrian crosswalks and beacons – 0.90
- Convert TWLTL to raised median – 0.80
- Reduce driveways from an average of 20 per mile to 10 per mile – see equation:

$$CMF_{driveway} = e^{(0.0152 \times (20-10))}$$

- Traffic calming – 0.89
- 10% reduction in mean speed (speed control) – 0.85

Project Costs

All of the costs identified in this section were increased by 20 percent to account for typical contingencies and/or future cost fluctuations.

Operations Improvements

The current version of the FHWA Tool for Operations Benefit/Cost (TOPS-BC) was used to derive costs.[9] TOPS-BC is a sketch-planning level decision support tool developed by the FHWA Office of Operations. For operations, these include costs for both basic infrastructure and incremental costs (Table 3). These 2010 costs were updated to 2018 dollars in the script to account for inflation using a multiplicative factor of 1.149. The Bureau of Labor Statistics Consumer Price Index was used for this purpose.[10]

The safety and operational treatments shown in Table 3 are consistent with the Florida Strategic Highway Safety Plan (SHSP), in particular, the four Es of traffic safety: engineering, education, enforcement, and emergency services. The benefits of implementing these treatments will be to not only reduce crashes, but to improve travel time reliability and provide a more efficient and mobile transportation system, as described in the Florida Transportation Plan.

[8] http://www.cmfclearinghouse.org/
[9] https://ops.fhwa.dot.gov/publications/fhwahop12028/
[10] https://www.bls.gov/cpi/

Table 3. Operation Improvement Unit Costs (2010 $)

	Annualized Costs	
	Basic	
Improvement	Infrastructure	Incremental
Ramp Metering	$296,500	$6,740
Loop Detection	$40,000	$5,750
CCTV	$40,000	$11,125
Part-Time Shoulder Use	$136,500	$20,765
Incident Management	$236,388	$127,425
Central Signal Control	$592,850	$14,254
Signal Retiming	$3,850	$7,404

Safety Improvements (Cost per Mile)

- Bike lanes – $55,000
- Pedestrian crosswalks and beacons – $544,000
- Convert TWLTL to raised median – $90,000
- Traffic calming – $200,000
- 10% reduction in mean speed (speed control) – $400,000
- Streetlights - $700,000
- Sidewalks - $200,000

3.0 Results of Operations and Safety Improvements

Tables 4 and 5 show the results of applying the C11 tool to the 2045 forecasted network. Priorities for spending funds on operations improvements were based on sorting first by highway type. In priority order: freeways, arterials, and collectors. Within each highway type, the sections were sorted from highest to lowest based on their mean TTI, and only sections with a mean TTI of 1.1 received and improvement. For safety improvements, sections were also sorted first by highway type, then by the highest to lowest predicted crashes per mile. Only sections with 15 or more crashes per mile received safety improvements.

Table 4. Results of Making Operations Improvements

TREND									
	Mean TTI		**80th %ile TTI**		**95th %ile TTI**		**Daily Delay (veh-hrs)**		**Improved**
Highway Type	**Base**	**Improved**	**Base**	**Improved**	**Base**	**Improved**	**Base**	**Improved**	**Mileage**
Divided Arterial	1.290	1.156	1.416	1.214	2.135	1.660	20,814	11,195	57.5
Undivided Arterial	1.313	1.163	1.450	1.224	2.217	1.689	6,427	3,354	34.3
Freeway	1.654	1.287	2.019	1.395	2.958	1.910	13,390	5,883	21.4
Other	1.656	1.656	2.001	2.001	3.329	3.329	31,521	31,521	0.0
TOTAL	5.912	5.263	6.887	5.834	10.638	8.588	72,152	51,953	113.1
TREND + SALES TAX									
	Mean TTI		**80th %ile TTI**		**95th %ile TTI**		**Daily Delay (veh-hrs)**		**Improved**
Highway Type	**Base**	**Improved**	**Base**	**Improved**	**Base**	**Improved**	**Base**	**Improved**	**Mileage**
Divided Arterial	1.290	1.088	1.416	1.137	2.135	1.410	20,814	6,290	110.7
Undivided Arterial	1.313	1.089	1.450	1.138	2.217	1.416	6,427	1,827	60.5
Freeway	1.654	1.055	2.019	1.040	2.958	1.113	13,390	1,120	21.4
Other	1.656	1.656	2.001	2.001	3.329	3.329	31,521	31,521	0.0
TOTAL	5.912	4.887	6.887	5.316	10.638	7.268	72,152	40,758	192.5

Table 5. **Results of Making Safety Improvements**

TREND											
		Total Crashes		**Bike Crashes**		**Pedestrian Crashes**		**Injury Crashes**		**Fatal Crashes**	
Highway Type	**Miles Improved**	**Base**	**Improved**	**Base**	**Improved**	**Base**	**Improved**	**Base**	**Improved**	**Base**	**Improved**
Divided Arterial	127.6	20,113	14,536	375	274	1,770	1,279	5,853	4,230	121	87
Undivided Arterial	3.9	4,758	4,616	132	130	419	406	1,385	1,343	29	28
Other	0.0	9,060	9,060	265	265	797	797	2,636	2,636	54	54
TOTAL	131.6	33,931	28,212	771	669	2,986	2,483	9,874	8,210	204	169
TREND + SALES TAX											
		Total Crashes		**Bike Crashes**		**Pedestrian Crashes**		**Injury Crashes**		**Fatal Crashes**	
Highway Type	**Miles Improved**	**Base**	**Improved**	**Base**	**Improved**	**Base**	**Improved**	**Base**	**Improved**	**Base**	**Improved**
Divided Arterial	327.4	20,113	9,059	375	170	1,770	797	5,853	2,636	121	54
Undivided Arterial	39.3	4,758	3,732	132	117	419	328	1,385	1,086	29	22
Other	0.0	9,060	9,060	265	265	797	797	2,636	2,636	54	54
TOTAL	366.7	33,931	21,851	771	552	2,986	1,923	9,874	6,359	204	131

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