Addendum to Traffic Analysis Toolbox Volume V: Traffic Analysis Toolbox Case Studies—Benefits and Applications

Reliability Analysis Guidance Addendum

September 2023

U.S. Department of Transportation
Federal Highway Administration

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16. Abstract This document is an addendum to the *Traffic Analysis Toolbox Volume V: Traffic Analysis Toolbox Case Studies—Benefits and Applications* (Federal Highway Administration Report No. FHWA-HOP-06-005) and reflects up-to-date guidance on incorporating travel time reliability (TTR) in the Traffic Analysis Toolbox. “Traffic analysis tools” is a collective term used to describe a variety of software-based analytical procedures and methodologies that support different aspects of traffic and transportation analyses. Traffic analysis tools include methodologies such as sketch planning, travel demand modeling, traffic signal optimization, and traffic simulation. The purpose of this addendum is to give the reader a summary of real-world case studies that demonstrate the benefits of using traffic analysis tools for the project.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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CHAPTER 1. PURPOSE

This document is an addendum to the *Traffic Analysis Toolbox Volume V: Traffic Analysis Toolbox Case Studies—Benefits and Applications* (Federal Highway Administration Report No. FHWA-HOP-06-005) and reflects up-to-date guidance on incorporating travel time reliability (TTR) in the Traffic Analysis Toolbox V (Kittelson et al. 2004). This addendum consists of additional content to be appended to the original Toolbox volume V.

CHAPTER 2. ADDITIONAL CONTENT TO BE APPENDED TO THE TOOLBOX VOLUME

CASE STUDY SUMMARY

Case Study: I–94 Value of a Shoulder, Milwaukee, Wisconsin:

- This case study demonstrates how to perform sketch planning and segment-level evaluation, using the Second Strategic Highway Research Program (SHRP2) L07 methodology (Potts et al. 2014).
- The case study shows decisionmakers how to choose between two build alternatives on the basis of nonrecurring delay evaluation.

Case Study: I–94 Corridors of Commerce, Minnesota:

- This case study demonstrates how to perform reliability performance evaluation of a recently completed freeway expansion project using SHRP2 L07 methods (Potts et al. 2014).
- The case study illustrates the full benefits of similar project types.

Case Study: Incorporating Reliability and Safety into the Long-Range Transportation Plan (LRTP): The Hillsborough County Experience:

- This case study demonstrates how to perform forecasting of TTR conditions using SHRP2 C11 methods (Economic Development Research Group et al. 2013) in conjunction with the regional travel demand model.
- The case study shows how to prioritize projects in the LRTP.

Case Study: I–95 in Broward County, Florida:

- This case study demonstrates how to produce predictive TTR metrics using SHRP2 L08 methods (Kittelson et al. 2013) in conjunction with microsimulation.
- The case study shows how to analyze alternatives based on reliability performance measures.

Case Study: SHRP2 L04 Guidance Microsimulation Model (Mahmassani et al. 2014):

- This case study demonstrates how to perform a reliability analysis through the combined use of the scenario manager, the trajectory processor, and a microsimulation tool.
- The case study provides several methods to develop useful reliability metrics from model outputs.

CASE STUDY: I–94 VALUE OF A SHOULDER

Project Description

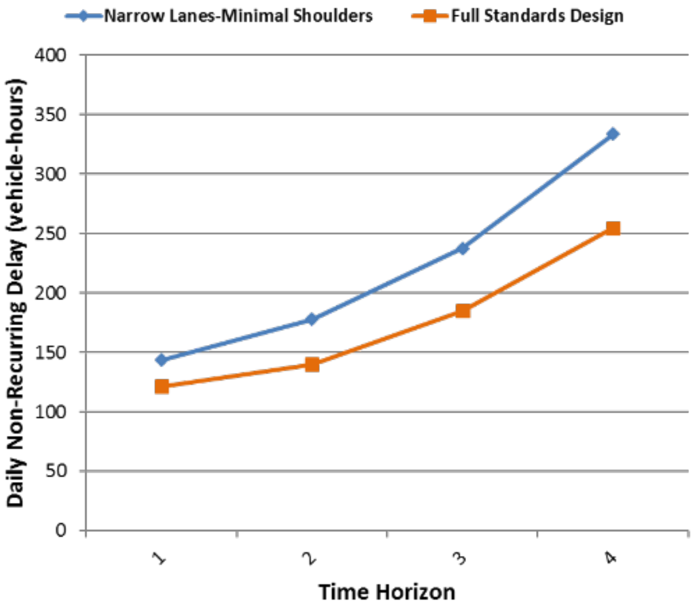
The Wisconsin Department of Transportation (WisDOT) was considering alternatives for the reconstruction of I–94, from 70th Street to 16th Street, in the City of Milwaukee. One segment of concern between Hawley Road and Mitchell Boulevard passed through a cemetery, resulting in severely limited available right-of-way. WisDOT identified two viable alternatives for reconstruction of I–94 through this segment:

- An eight-lane, at-grade alternative with 11-ft lanes and 2-ft shoulders.
- A double-deck alternative with 10 lanes, standard 12-ft lanes, and wider shoulders.

To obtain more information that could help to evaluate these two alternatives, the analysts examined nonrecurring delay for the I–94 East/West Corridor in Milwaukee.

Reliability Objective

While traditional traffic analysis methods include evaluating predictable peak-period recurring delay, nonrecurring analysis methods consider elements such as inclement weather, incidents, and event traffic demands. There are significant differences in the magnitude of infrastructure required for the construction alternatives under consideration, but from a traffic analysis and operations perspective, narrow lanes, minimal shoulders, and the number of lanes are key differences for evaluating nonrecurring delay. To evaluate these impacts, the analysts used the Project L07 tool developed as part of the Strategic Highway Research Program 2 (SHRP2) reliability focus area. Project L07 is a benefit-cost evaluation tool that considers the influences of nonrecurring conditions on travel times and delays. The purpose of this analysis was to estimate the difference in nonrecurring delay between the alternatives (Figure 1 and Figure 2).



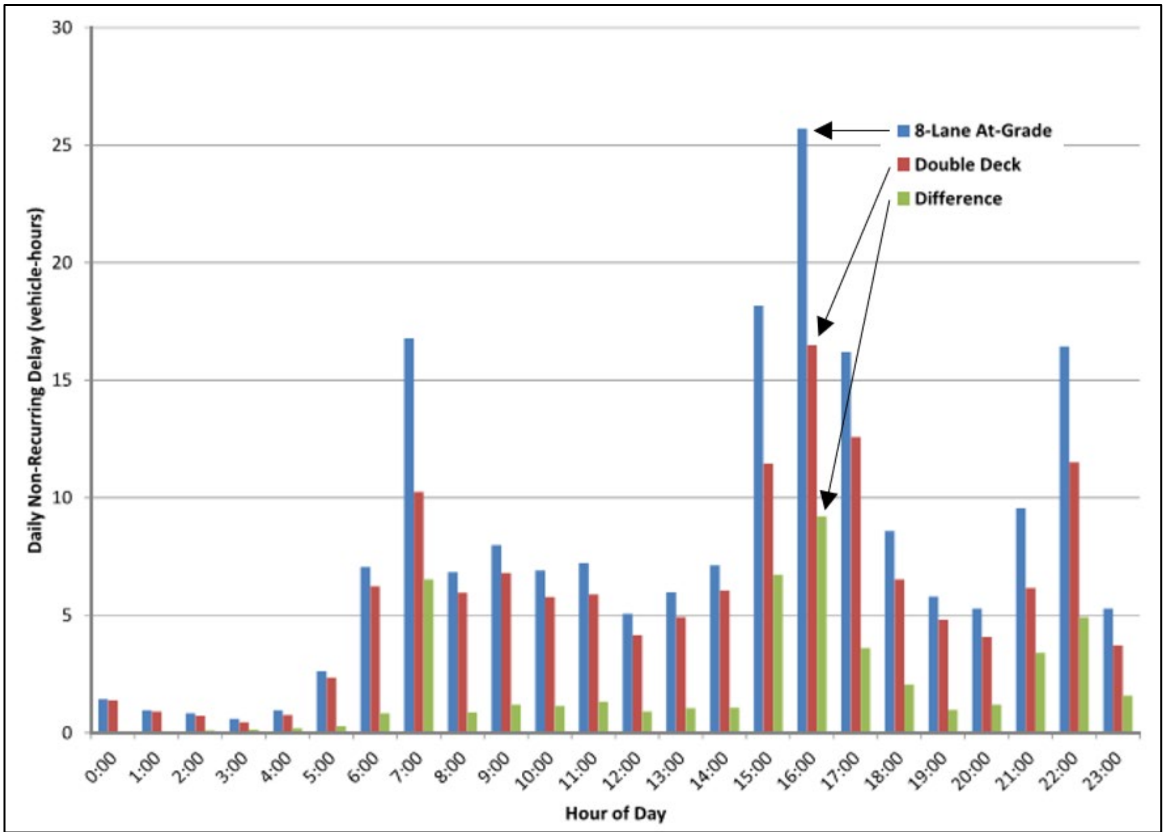
Source: Wisconsin Department of Transportation.

Figure 1. Graph. Nonrecurring delay by year.

Analysis Summary

The Project L07 tool (Potts et al. 2014) requires several data inputs to estimate the travel time impacts of nonrecurring congestion factors. These input categories include geometry, demand, incidents, weather, events, and work zones. The study referenced geometric layouts from the WisDOT design team for geometric inputs, L07 guidance, and automated traffic recorder data for demand inputs; Enhanced Interchange Safety Analyses Tool crash computations; traffic volume information during Milwaukee Brewers game days to reflect event input assumptions; and L07 defaults for regional weather and incident inputs. The team also tested two forecast growth scenarios to determine the sensitivity of each design under higher traffic volume conditions.

The study team used the underlying computational components of the L07 tool to develop a series of graphics to communicate the tradeoffs of each design to project decisionmakers.



Source: Wisconsin Department of Transportation.

Figure 2. Graph. Nonrecurring delay by time of day.

Applications to Future Work

This case study can be used as an example of how SHRP2 reliability tools can be used to help inform design decisions by incorporating nonrecurring conditions as an evaluation criterion for alternative analysis.

CASE STUDY: INTERSTATE 94 CORRIDORS OF COMMERCE

Project Description

The I–94 Corridor connects greater Minnesota and the growing northwestern suburban area to Minneapolis and St. Paul. The corridor is characterized by heavy directional peak-period flows, weekend recreational travel, and high freight volumes traveling to the western United States. As the region has grown and more development has occurred, traffic volumes have increased to the point that multiple areas in the corridor experience significant congestion each day.

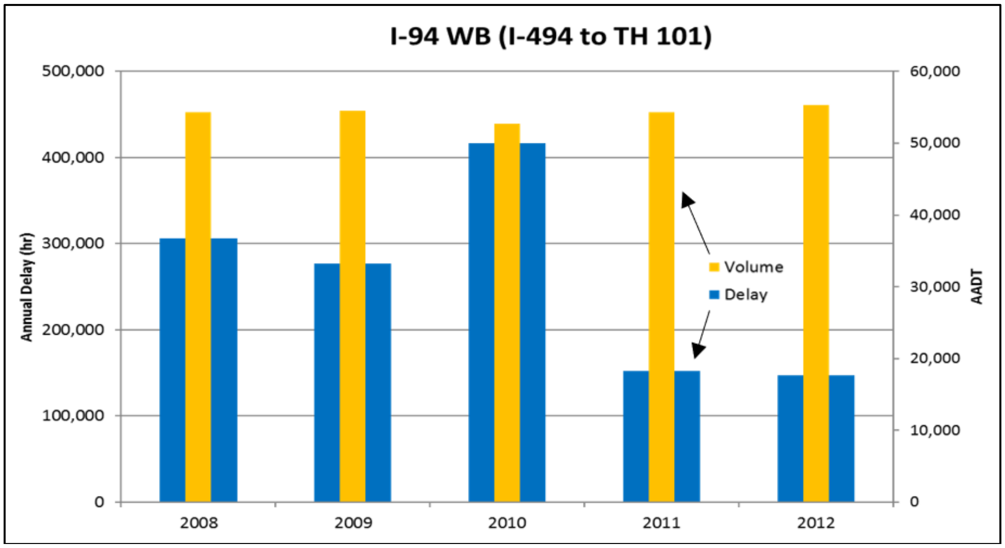
The Minnesota Department of Transportation (MnDOT) was evaluating adding capacity along the I–94 corridor. As part of this evaluation, traffic modeling was completed to evaluate the effects of providing this additional capacity. This modeling effort included an operations analysis to identify benefits and impacts that can be utilized in the upcoming environmental phase of this project.

Reliability Objectives

At the outset of the project, no TTR objectives had been established. MnDOT leveraged knowledge obtained from the SHRP2 L38 pilot testing study that was ongoing during the time of this study. The SHRP2 tools were applied to produce a series of graphics following L02 guidance to help tell the story of how previous projects completed in the corridor had benefited users (List et al. 2014). The results further illustrated how traditional modeling techniques and practice would not demonstrate the full user experience of driving on the corridor, due to the tendency to only model peak periods on a small sample of "typical" days that had no inclement weather or incidents.

Analysis Summary

The study team leveraged loop detector data in the corridor to develop year-over-year performance monitoring of the corridor (Figure 3). Significant levels of delay were observed in 2008 and 2009 before the first project was implemented in the corridor. It was shown that, while there was a significant increase in user delay during construction in 2010, delays in 2011 and 2012 were half of what they were prior to construction.



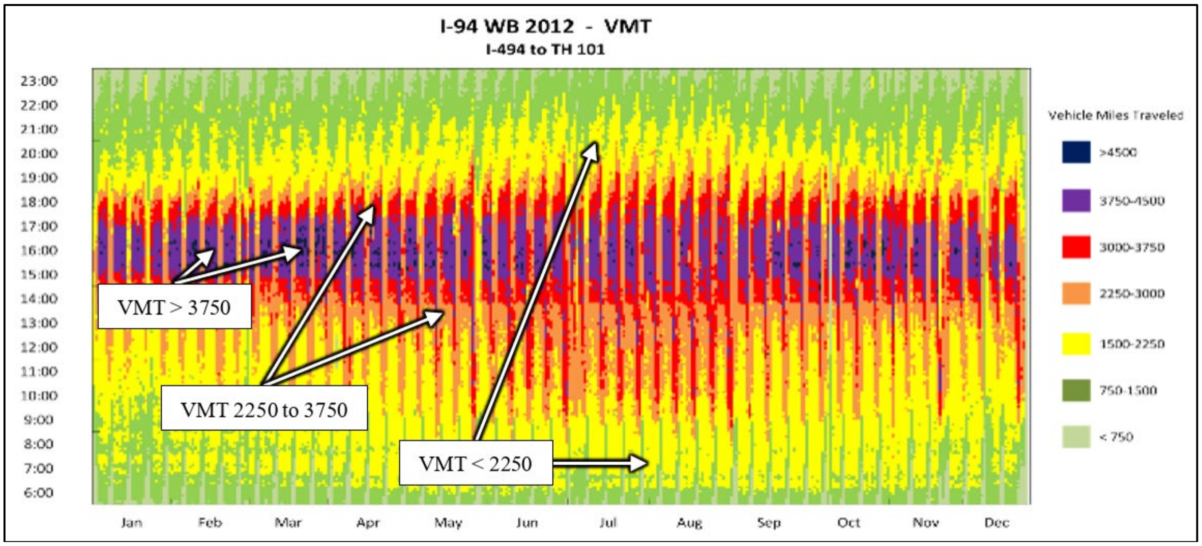
Source: Minnesota Department of Transportation.

AADT = average annual daily traffic; I– = interstate; TH = trunk highway; WB = westbound.

Figure 3. Graph. Interstate 94 delay and volume by year.

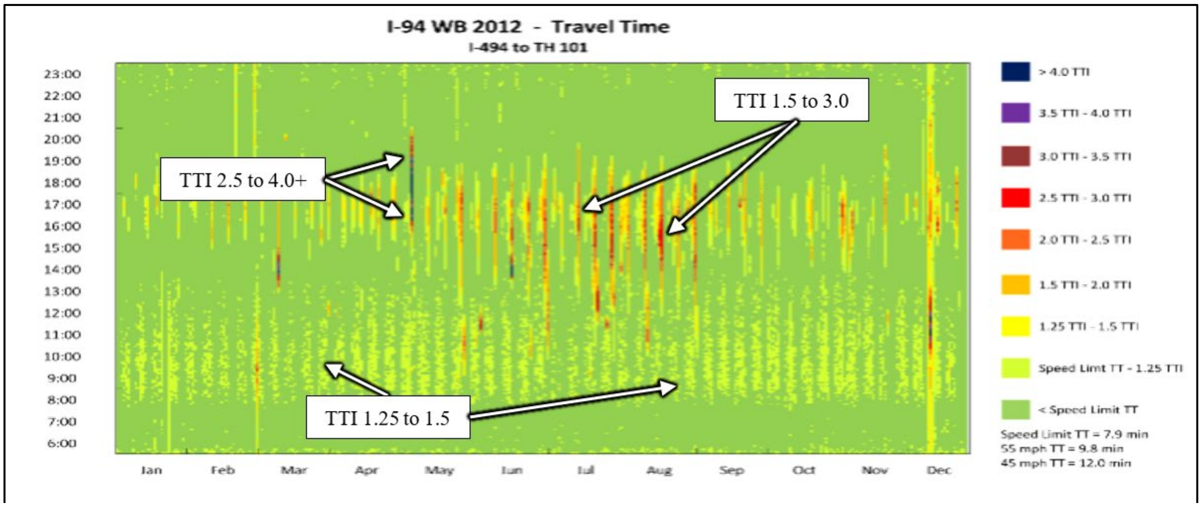
The team dug in further to show an entire year's worth of vehicle miles traveled (VMT) and travel time indices (TTI) across the corridor for existing conditions (2012) using heat map visualizations (Figure 4 and Figure 5).

The VMT heat map demonstrated that the corridor experienced a significant amount of VMT peak spreading from May through September, starting as early as 10 a.m. during the height of the summer recreational travel season. Perhaps even more significant was that datasets used for traditional modeling techniques were obtained from April or October, causing model results that were different than the experience of users traveling in the corridor during summer months.



Source: Minnesota Department of Transportation.

Figure 4. Graph. Year 2012 vehicle-miles traveled heat map.



Source: Minnesota Department of Transportation.

Figure 5. Graph. Year 2012 travel time index heat map.

Further, the team used the travel time heat map to build stakeholder consensus on the need for improvements by demonstrating the full range of conditions the facility is subject to. These conditions were communicated by calling out specific relatable incidents that caused extreme travel times, such as all-day increased travel times between January and March associated with snow events, peak travel times on Thursdays and Fridays during the summer months, and the dark blue line at the beginning of May that coincided with the State fishing opener.

Outcomes from the analysis showed that, while there was minimal congestion, delay, or variability during peak-hour travel times, there were significant demand fluctuations (increases) during the summer recreational peaks, which are not typically accounted for using traditional analysis techniques. As a result, a series of lane extension projects was constructed to accommodate these dramatic variations in travel.

Applications to Future Work

This case study illustrates the need for departments to establish regional goals, and the motivations behind those goals, such that department operations objectives can be properly defined on a project-by-project basis. It also serves as a valuable example for agencies who are new to applying reliability to project decisions but are looking for opportunities to begin applying TTR techniques to their business practices.

CASE STUDY: INCORPORATING RELIABILITY AND SAFETY INTO THE LONG-RANGE TRANSPORTATION PLAN: THE HILLSBOROUGH COUNTY EXPERIENCE

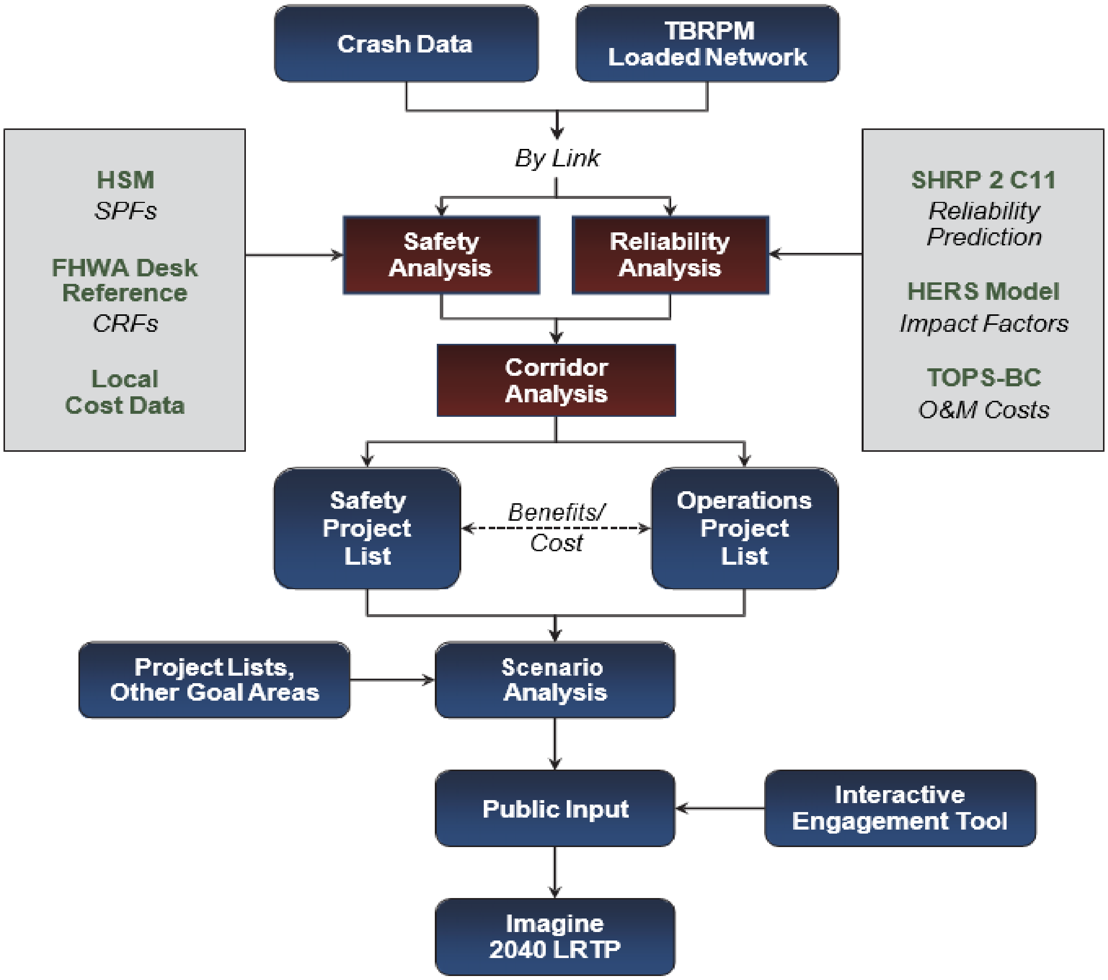
Project Description

The Hillsborough County Metropolitan Planning Organization (MPO) in Tampa, FL, identified the need to add both operations and safety projects to their LRTP update for the year 2040 (Kastrouni et al. 2015). However, the ability to forecast TTR (a major outcome of operations projects) and safety conditions in conjunction with their travel demand model did not exist. This case study documents the technical development of a postprocessor to the travel demand model that performs these tasks. The reliability component was based on the method developed for SHRP2 Project C11, and the safety component was based on methods in the Highway Safety Manual. Costs for operations and safety projects also were developed using data from the Federal Highway Administration's (FHWA) Tool for Operations Benefit Cost Analysis (TOPS-BC) (Sallman et al. 2013). The methods were adapted to work with data available from the outputs of the travel demand forecasting model. As a result, the 2040 plan update now includes both operations and safety projects, along with their estimated benefits and costs. This allows side-by-side comparison with benefits and costs of the traditional capacity, travel demand management, and transit projects that have dominated past plan updates. Once results for safety and operations projects were created, the Hillsborough MPO then used the resulting 2040 system performance forecasts as part of a public engagement program for the LRTP, asking citizens to choose their preferred level of investment and corresponding performance outcome.

The remaining sections of the case study focus on the reliability component of the travel demand model postprocessor.

Technical Approach to Reliability Forecasting for Long-Range Transportation Plan Development

Because the LRTP development depends on results from the travel demand forecasting model (the Tampa Bay Regional Planning Model (TBRPM), which is based on the Cube software), it was decided by the Tampa Bay team that the most direct way to perform reliability forecasting was to construct a postprocessor that uses the model outputs. Figure 6 shows the inputs and outputs for the postprocessor. For reliability prediction, the SHRP2 Project C11 procedure was chosen because it operates at a sketch-planning level with a minimum of data inputs. For translating the effect of operations projects into the independent variables in the C11 procedure, relationships from the Highway Economic Requirements System[1] (HERS) model were used. Capital, operating, and maintenance costs of operations projects were obtained from the TOPS-BC documentation. How these methods were adapted in the postprocessor is discussed below.



Source: Hillsborough County Metropolitan Planning Organization.
CRF = crash reduction factor; HERS = Highway Economic Requirements System; HSM = *Highway Safety Manual*; LRTP = long-range transportation plan; O&M = operations and maintenance; SPF = safety performance function; SHRP2 = second Strategic Highway Research Program; TBRPM = Tampa Bay Regional Planning Model; TOPS-BC = Tool for Operations Benefit Cost Analysis.

Figure 6. Flowchart. Hillsborough county reliability forecasting framework.

Reliability Prediction

SHRP2 Project C11, *Development of Improved Economic Impact Analysis Tools*, focused on assessing the economic benefits of transportation investments beyond the traditional elements of travel time, safety, and vehicle operating costs (Weisbrod et al. 2014). One of the impact areas identified was TTR, and an economic analysis tool called the Reliability Module was developed

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[1] https://highways.dot.gov/research/projects/hers-56-enhancements-and-analysis-25th-cp-report

to calculate reliability benefits. It is a sketch-planning corridor spreadsheet tool that estimates the benefits of improving TTR for use in benefit-cost analysis.

The purpose of the Reliability Module is to allow users to quickly assess the effects of alternative highway investments in terms of both typical travel time and TTR. The procedure is based on making estimates of recurring and nonrecurring congestion, combining them, and using predictive equations to develop reliability metrics. Its predictive equations are based on a combination of past research efforts, including the National Cooperative Highway Research Program, FHWA, and SHRP2 Project L03. The C11 model can be used as a standalone tool for doing sketch-planning-level analysis. However, a more useful application is to integrate it with a travel demand forecasting model as a postprocessor. This application allows planning agencies to assess the regional impact of LRTPs on reliability in the same way that they currently assess regional VMT and delay. It also permits reliability to enter the development and comparison of alternative improvement strategies, including operations, earlier in the LRTP development process. Finally, the technical relationships in the C11 model also are at the right scale to be incorporated into system planning tools. The C11 postprocessor is developed as a series of scripts written in the Statistical Analysis System. 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 the 192 corridors present in the TBRPM. In summary, the procedure uses the following steps:

- Estimate recurring congestion using a volume-delay function.

- Estimate incident delay using relationships from the Intelligent Transportation System Deployment Analysis System (IDAS), and then combine with recurring congestion to get the average delay.

- Use custom-developed relationships that predict reliability measures as a function of average delay (as described in the C11 procedure).

Performance Measures

- Planning time index (PTI) (95th percentile travel time/free-flow travel time)
- Reliability index (80th percentile travel time/free-flow travel time)
- Mean TTI (mean travel time/free-flow travel time)

Methodology

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

1. Assign free-flow speed (FFS):
    a. Freeways: 65 mph
    b. Arterials: 45 mph
    c. Collectors: 40 mph
    d. Ramps and local: 35 mph

2. Calculate travel time per unit distance (travel rate) using the equation in Figure 7 for the current and forecast years:

$$t = \frac{1 + (0.1225 \times X^8)}{FFS}$$

Source: Transportation Research Board.

Figure 7. Equation. Travel time per unit distance.

Where:

c = capacity (from loaded network file); *FFS* = free-flow speed; *t* = travel rate (hours per mile); *v* = volume (from loaded network file); *X* = volume/capacity, equation is only valid if $X <= 1.40$.

3. Compute the recurring delay in hours per mile according to the equation shown in Figure 8:

$$RDR = t - \left(\frac{1}{FFS}\right)$$

Source: Transportation Research Board.

Figure 8. Equation. Recurring delay rate.

Where:

FFS = free-flow speed; *RDR* = recurring delay rate; *t* = travel rate (hours per mile).

4. Compute the delay due to incidents (IncidentDelayRate) in hours per mile. The lookup tables from the IDAS user manual are used to calculate incident delay. This requires the volume-to-capacity ratio, number of lanes, and length and type of the period being studied, which is set at 1 hour (for rural two-lane highways, use number of lanes = 2). This is the base incident delay. 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 according to the equation in Figure 9:

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

Source: Transportation Research Board.

Figure 9. Equation. Adjusted delay.

Where:

D_a = adjusted delay (hours of delay per mile); D_u = unadjusted (base) delay (hours of delay per mile, from the incident rate tables); R_d = reduction in incident duration expressed as a fraction (where $R_d = 0$ means no reduction, and $R_d = .30$ means a 30-percent reduction in incident duration); R_f = reduction in incident frequency expressed as a fraction (where $R_f = 0$ means no reduction, and $R_f = .30$ means a 30-percent reduction in incident frequency).

Changes in incident frequency are most commonly affected by strategies that decrease crash rates. However, if crashes are only about 20 percent of total incidents, a 30-percent reduction in crash rates alone would reduce overall incident rates by .30 × .20 =.06.

5. Compute the overall mean TTI, which includes the effects of recurring and incident delay, using the equation in Figure 10, where IDR is either D_u or D_a:

$$TTI_m = 1 + FFS \times (RDR + IDR)$$

Source: Transportation Research Board.

Figure 10. Equation. Mean travel time index.

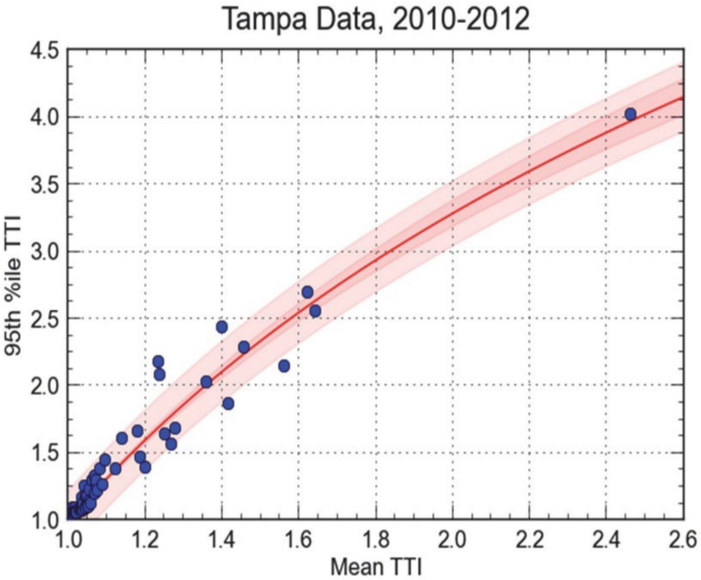
Where:

FFS = free-flow speed; IDR = incident delay rate; RDR = recurring delay rate; TTI_m = mean travel time index.

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.

6. 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 by the Tampa Bay study team to recalibrate them using data from Tampa, FL. Freeway detector data for the Tampa area for years 2010 through 2012 were obtained and analyzed for this purpose.

Figure 11 shows the relation between mean and 95th percentile TTI for local facilities. Figure 12 and Figure 13 show the equations for predicting reliability for Tampa roadways.



Source: Hillsborough County Metropolitan Planning Organization.
TTI = travel time index.

Figure 11. Graph. Relation between mean and 95th percentile Travel Time Index (TTI) values.

$$TTI_{95} = 1 + 3.3000 \times ln(TTI_m)$$

Source: Transportation Research Board.
TTI_m = mean travel time index, TTI_{95} = 95th percentile travel time index

Figure 12. Equation. 95th percentile travel time index.

$$TTI_{80} = \frac{4.2935}{1 + 20.1851 \times e^{-1.8091 \times TTI_m}}$$

Source: Transportation Research Board.
TTI_m = mean travel time index, TTI_{80} = 80th percentile travel time index.

Figure 13. Equation. 80th percentile travel time index.

7. Scheduling projects for improvements. The loaded network file that is output from the TBRPM is used as the basis for scheduling improvements. This file has the forecasted traffic volumes on the network links, along with information about the physical capacity of those links. Roadway sections are scheduled for improvement if either the a.m. or p.m. peak-period volume-to-capacity ratio is greater than or equal to 0.8. (The a.m. peak period is 2.5 hours long, and the p.m. peak period is 3 hours long.)

The impacts of making transportation improvements on the input variables (i.e., “what change in inputs does a strategy effect?”) were adapted from FHWA’s HERS model. HERS is used to estimate the national future highway needs and the impacts of improvement strategies, including operations strategies.

Postprocessor Results

Travel Time Reliability

Two types of operational improvements are considered for arterials: (1) traditional geometric treatments at intersections and (2) advanced coordinated signal control. For freeways, incident management and advanced operations treatments were used. The advanced operations treatments were defined as a bundle that includes ramp metering, variable speed limits, and lane control. The unit costs for the improvement types were compiled from FHWA's TOPS-BC tool; both capital and operating costs over the 20-year horizon are included. Table 1 shows the results for each scenario. The results were compiled on a corridor-by-corridor basis using the impact factors for each improvement type shown in the last column of Table 1. If a roadway section was scheduled for improvement, then the capacity was increased, incident impacts were reduced, or both (depending on the investment scenario). Then, the reliability metrics were calculated for the "improved" case using the same equations as for the base condition. The reliability metrics were computed separately for the a.m. and p.m. peak periods and then combined as a VMT-weighted average (Table 2).

Table 1. Operations investment scenarios.

Analysis	Scenario	Representative Improvement Types	20-Year Cost	Impact Factor
Operations/ congestion management	Low	Arterial operations improvements on priority corridors only: intersection traffic responsive control	$295M	Arterial capacity: +7 percent
	Medium	The Low scenario plus the following additions: arterial intersection geometric upgrades on priority corridors only (new signals, controllers, pedestrian signals and refuges, turn lanes/bays, crosswalks, sidewalks, lighting, curbs and gutters, shoulders). Freeway operations: incident management only	$806M	Arterial capacity: +17 percent Incident frequency: - 5 percent Incident duration: - 25 percent
	High	Same arterial improvements as the Medium scenario. Freeway operations: incident management, ramp metering, variable speed limits, lane control	$957M	Arterial capacity: +17 percent Incident frequency: -7 percent Incident duration: -25 percent Freeway capacity: +10 percent

Table 2. Reliability analysis results.

Highway Type	Mobility Measure	2040 Scenario	Investment scenario		
			Low	Medium	High
Freeways	Average TTI	Base	1.580	1.580	1.580
		With improvements	1.580	1.418	1.308
	80th percentile TTI	Base	1.891	1.891	1.891
		With improvements	1.891	1.670	1.504
	PTI	Base	2.206	2.206	2.206
		With improvements	2.206	1.944	1.744
	Centerline miles improved	NA	0	120	120
Arterials	Average TTI	Base	1.717	1.717	1.717
		With improvements	1.602	1.487	1.487
	80th percentile TTI	Base	2.065	2.065	2.065
		With improvements	1.930	1.788	1.788
	PTI	Base	2.431	2.431	2.431
		With improvements	2.254	2.074	2.074
	Centerline miles improved	NA	425	425	425
	Intersections improved	NA	650	650	650

PTI = planning time index; TTI = travel time index.

Summary and Future Enhancements

The SHRP2 Project C11 methodology for predicting TTR was successfully implemented for the Hillsborough County MPO. Rather than using the standalone spreadsheet developed by Project C11, the methodology was implemented as a postprocessor to the MPO's travel demand model. In addition, procedures in the *Highway Safety Manual* for predicting crashes were added to the C11 postprocessor. Application of the postprocessor for the 2040 update to the Hillsborough County LRTP produced project lists and associated costs for making improvements, as well as the reliability and safety impacts of those improvements. The operations and safety projects identified by the postprocessor have been included in the LRTP. Several recommendations are made to advance the use of the postprocessor, thereby encouraging that reliability and safety can be included in transportation plans:

- *Develop "user-grade" software*. The postprocessor currently in use is not deemed user-friendly and requires specific technical knowledge to operate. It would have to be improved in this capacity if it is to be operated by planning staff.

- *Apply the postprocessor to support other Florida MPOs' LRTP updates*. As all MPOs in Florida use the Cube travel demand forecasting software, the file structures are the same.

- *Adapt the C11 postprocessor for statewide planning*. While the postprocessor is set up to work with a travel demand model, it is possible to extract its reliability and safety prediction methods to improve impact analysis in the Florida Department of Transportation's (FDOT) Statewide planning.

- *Account for synergies between safety and capital expansion/operations projects*. Currently, the methodology considers safety and other projects in isolation. However, safety projects can also improve congestion conditions and operations, and capital projects aimed at congestion can also have a positive safety impact.

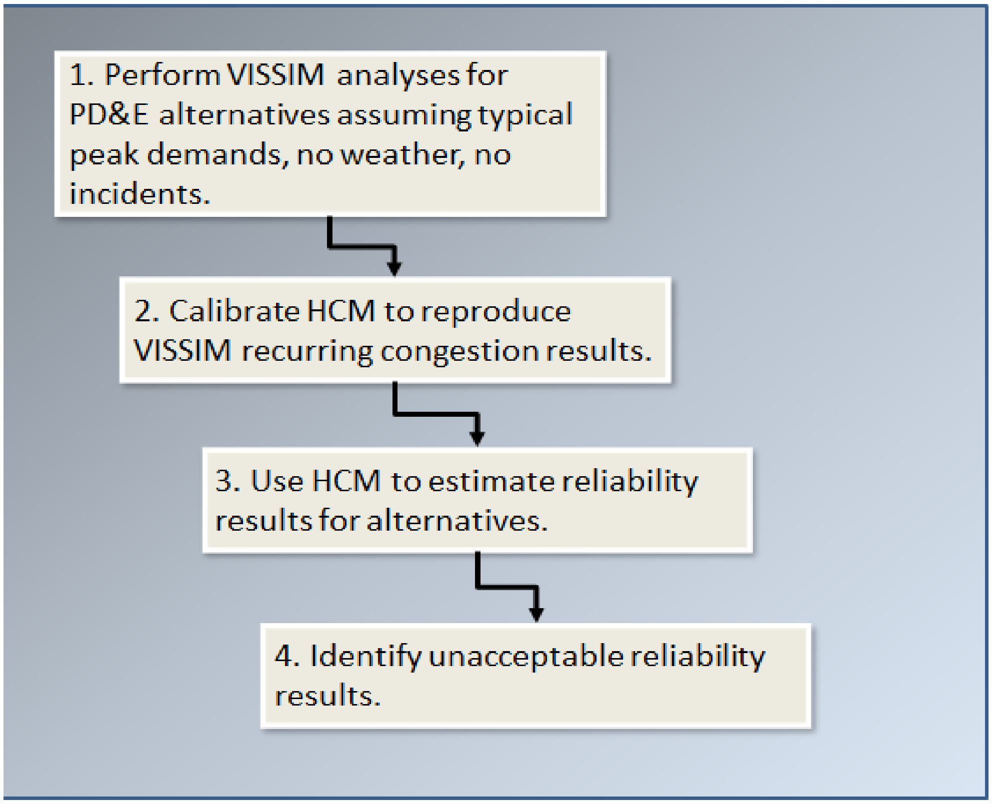
- *Consider adding demand variability to the methodology to capture reliability more completely.*

CASE STUDY: INTERSTATE 95 IN BROWARD COUNTY

TTR is an important performance measure for FDOT because it is one of the few measures that can reflect the impacts of nonrecurring congestion, such as incidents, weather, and work zones (McLeod et al. 2012). Efficient project alternatives to address the impacts of nonrecurring congestion, such as operations projects, need to be considered in FDOT's planning and design processes. The objective of this subtask was to examine the use of TTR predictive tools in FDOT's project development and environmental process (PD&E) studies and develop a methodology framework for using TTR measures as one of the operational performance measures of effectiveness in alternatives analyses conducted for PD&E studies. This task was accomplished by demonstrating how TTR analyses can be performed by traffic analysts' postprocessing results from microsimulation tools with theoretical extensions developed under SHRP2, specifically project L08, *Incorporation of Travel Time Reliability into the Highway Capacity Manual* (Zegeer et al. 2014).

The proposed methodology framework (Figure 14) for predicting the TTR for evaluating project alternatives uses results from Vissim™ analyses to calibrate a standalone *Highway Capacity Manual* (HCM) reliability model (Elefteriadou 2016). Using the calibrated model, the 6th edition HCM methods are used to predict the TTR for each alternative.

The I–95 Corridor from north of Oakland Park Boulevard (State Route 816) to South of Glades Road (State Route 808) was used as a case study in this project. Data from a completed PD&E study on this corridor were reviewed and used to calibrate the FREEVAL model.



Source: Florida Department of Transportation.
HCM = *Highway Capacity Manual*; PD&E = project development and environment process.

Figure 14. Flowchart. Reliability evaluation methodology framework.

Highway Capacity Manual Operational Analysis

The analysis was completed using the freeway facilities methodology in the HCM, as well as the HCM methodology for TTR. This methodology is implemented in several software tools, including the FREEVAL tool, which was the tool used by the Highway Capacity and Quality of Service Committee and the research team to develop and test the methods. The following sections outline the assumptions made within the HCM analysis, study location, analysis segmentation, and 15-min demand volume development.

Assumptions

The following assumptions were used:

- A combined truck percentage of 3 percent. An assumed tractor-trailer percentage of 1 percent and single-unit truck/bus percentage of 2 percent were used in the HCM analysis because the HCM now requires separate inputs for these two types of trucks.
- Three-hour analysis for the p.m. peak period (4 p.m. to 7 p.m.) with shoulder period volumes derived from 24-hr traffic counts; the actual p.m. peak hour is 5 p.m. to 6 p.m.

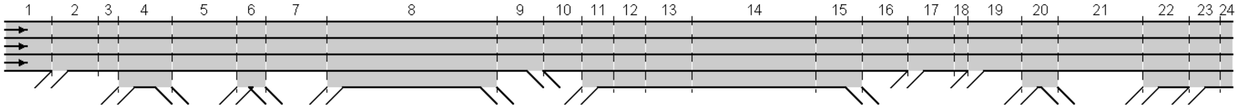
- Mainline and ramp FFSs are based on Highway Capacity System inputs included in the PD&E.

- Acceleration and deceleration lengths are based on the Highway Capacity System inputs provided in the PD&E.

- The southbound direction was selected for the facility analysis. No northbound facility analysis was completed as part of this study.

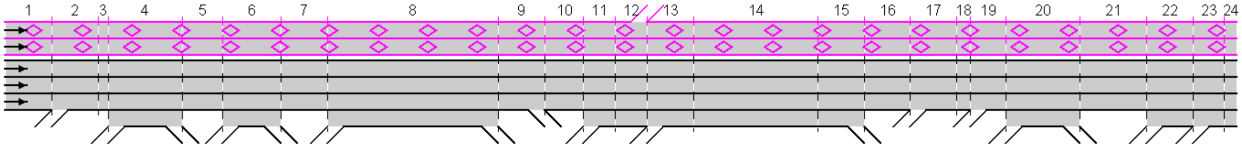
Analysis Segmentation

The segmentation for the no-build conditions (existing and future years) maintained the same number of segments as the 2040 build conditions for ease of comparison between analysis scenarios. This is important guidance for future analyses with similar differences between present-year and future-year scenarios. The more the segmentation and numbering can be maintained, the more streamlined the comparative analyses will be because of the reduced need for additional data. The no-build segmentations are shown in Figure 15, and build segmentations are shown in Figure 16.



Source: Florida Department of Transportation.

Figure 15. Diagram. Broward County existing and future year no-build segmentation.



Source: Florida Department of Transportation.

Figure 16. Diagram. Broward County future year build segmentation.

Fifteen-Minute Demand Volumes

Twenty-four-hour volume profiles were obtained from the *2015 Florida Traffic Information DVD*. The two volume profiles along I–95 were averaged to estimate a volume profile to be used along the entire study analysis facility. This profile was used in conjunction with the hourly demand volumes to further develop 15-min demand volumes for the 3-hr analysis period to provide a consistent analysis period when comparing the Vissim™ results as included in the previous study with the HCM results.

For the HCM analysis, 15-min demand volumes are necessary for the following segments:

- Initial entering mainline segment for general purpose and managed lanes
- On-ramps
- Off-ramps
- Weaving ramp-to-ramp demand volumes

Highway Capacity Manual Calibration

The FREEVAL model was calibrated based on a comparison of segment speeds with the Vissim™ output from the PD&E study.

Calibration in the HCM method is performed primarily using capacity adjustment factors. A capacity adjustment factor of 0.896 (equivalent to a capacity of 2,150 passenger car per hour per lane (pc/hr/ln)) was applied to the FREEVAL model to calibrate the FREEVAL speeds closer to the Vissim™-reported results. This adjustment to the mainline capacity is based on FDOT's capacity for urban freeway segments.

In the 2040 future no-build conditions, a capacity adjustment factor of 0.677 (equivalent to approximately 1,650 pc/hr/ln) was applied to the last, most downstream segment in the FREEVAL corridor (Segment No. 24) to replicate the congestion shown in the Vissim™ results. In a review of the Vissim™, that last segment resulted in severe congestion, which resulted in spillback upstream into the facility. With the calibrated capacity adjustment, the HCM method replicated this congestion.

The comparison of speeds between the calibrated FREEVAL network and the reported Vissim™ results is shown in Figure 17, Figure 18, and Figure 19.

The calibration results showed that the HCM method was able to mirror the Vissim™ speed results contained in the PD&E study. The HCM method reasonably approximated the Vissim™ results both across different scenarios as well as across the 3 hours of analysis within each scenario. Based on these calibration results, the team moved forward with the reliability analyses.

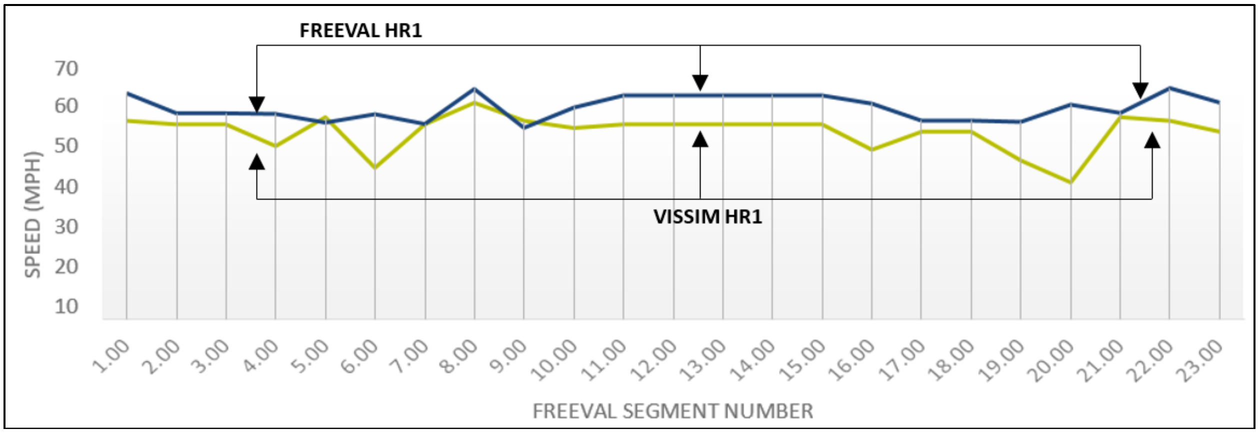
Highway Capacity Manual Operational Results

The overall summary results for each of the three analyzed scenarios are summarized in Table 3. Level of service (LOS) summary contours shown in Figure 20 illustrate how the LOS changes along the I–95 facility throughout the 3-hr peak period, by segment and by 15-min analysis periods.

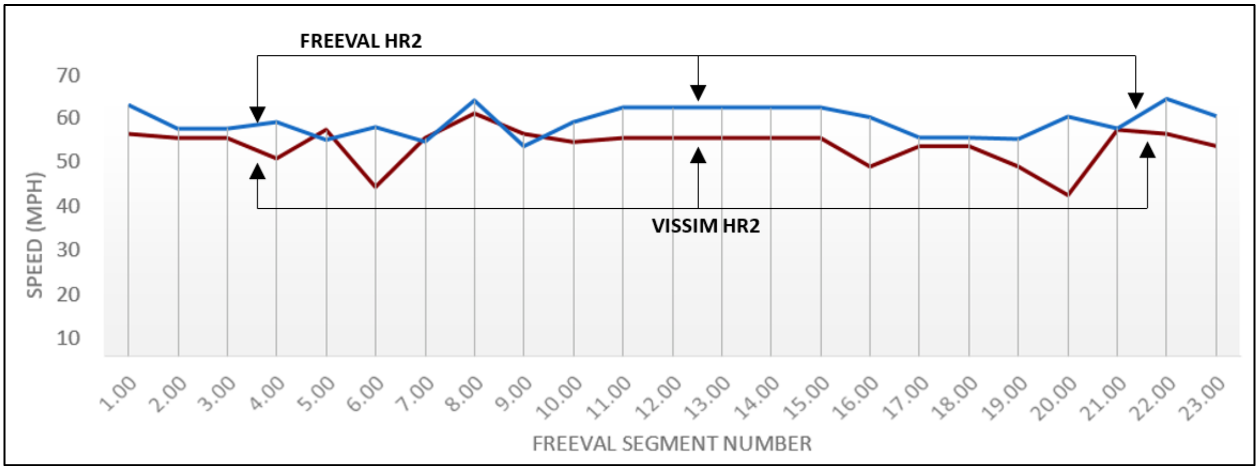
Table 3. Southbound p.m. peak period—Interstate 95 facility summary.

Performance Measure	2011	2040	
	No-Build	**No-build**	**Build**
Facility length (mi)	7.5	7.5	7.5
FFS travel time (min)	6.5	6.5	6.5
Average travel time (min)	7.7	21.3	8.0
Space mean speed (mi/h)	59.0	21.7	56.2
Average density (pc/mi/ln)	26.2	67.7	28.3
Max D/C	0.9	1.2	1.1
Max V/C	1.0	1.0	1.0
Vehicle-hours delay (hr)	395	31,152	1,623

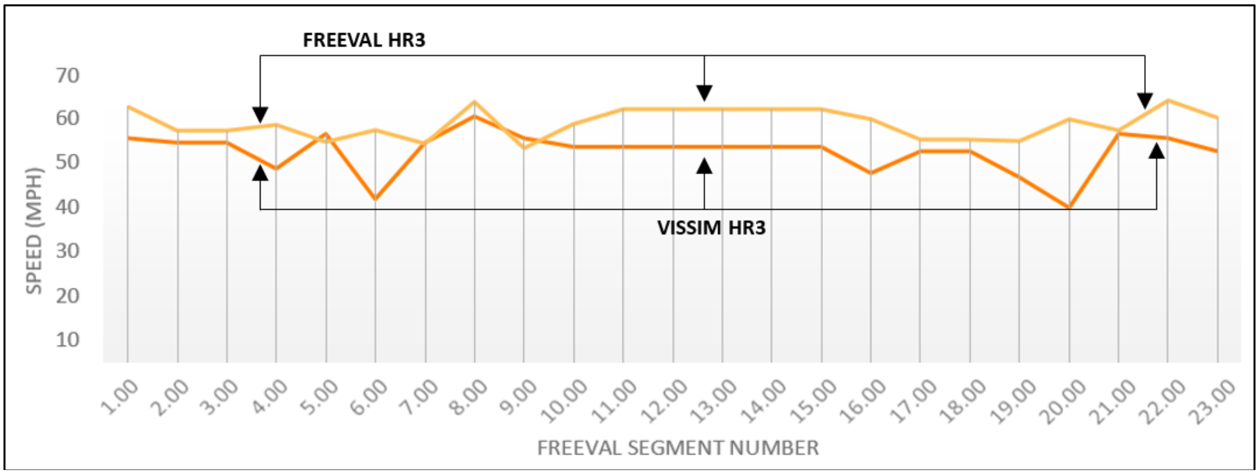
D/C = demand-to-capacity ratio; FFS = free flow speed; pc/hr/ln = passenger car per hour per lane; V/C = volume-to-capacity ratio.



a) Speeds during the first hour.



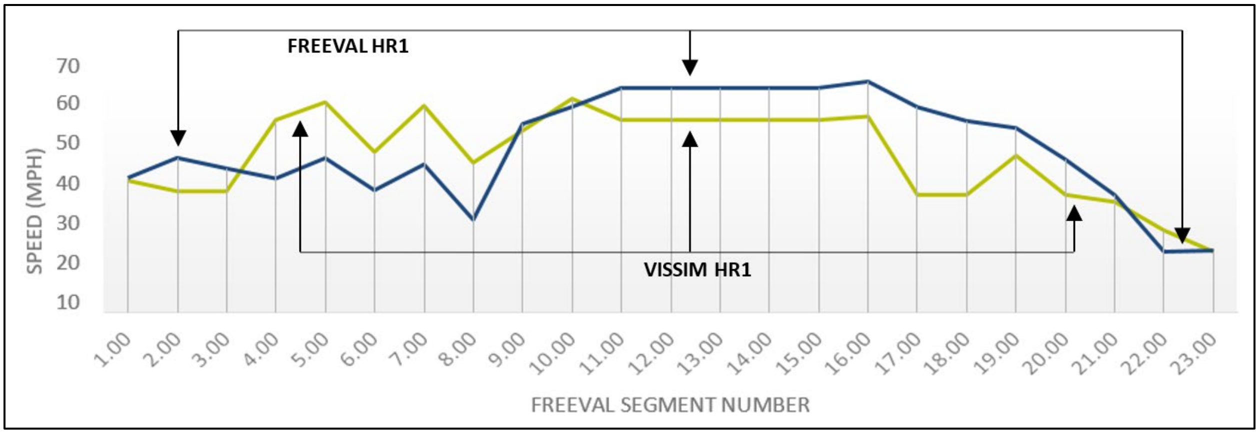
b) Speeds during the second hour.



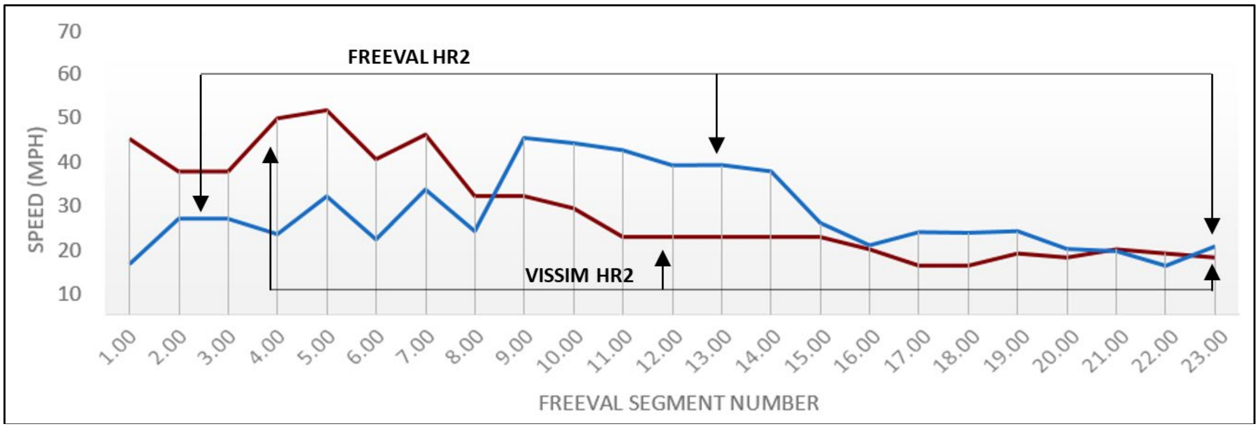
c) Speeds during the third hour.

Source: Florida Department of Transportation.

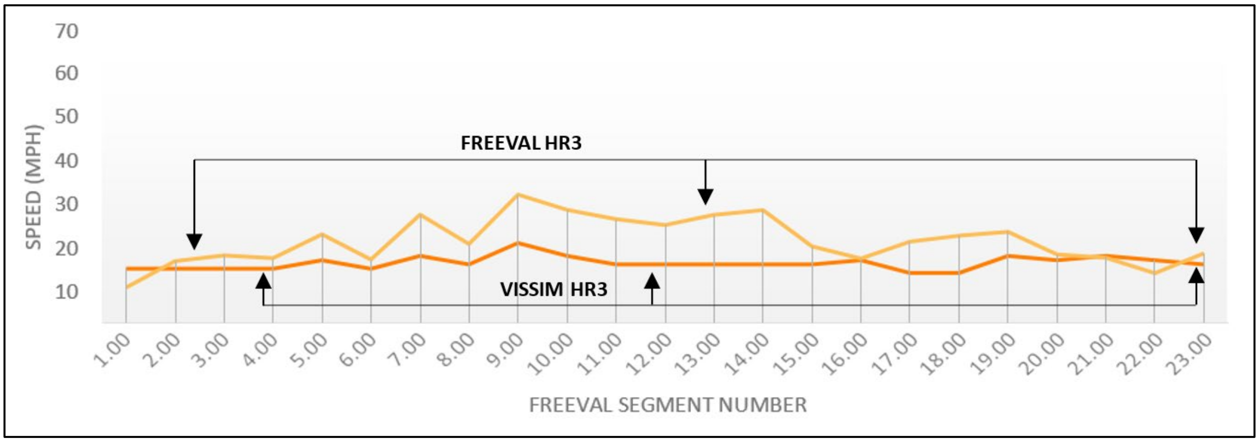
Figure 17. Graphs. 2011 existing no-build speed comparison.



a) Speeds during the first hour.



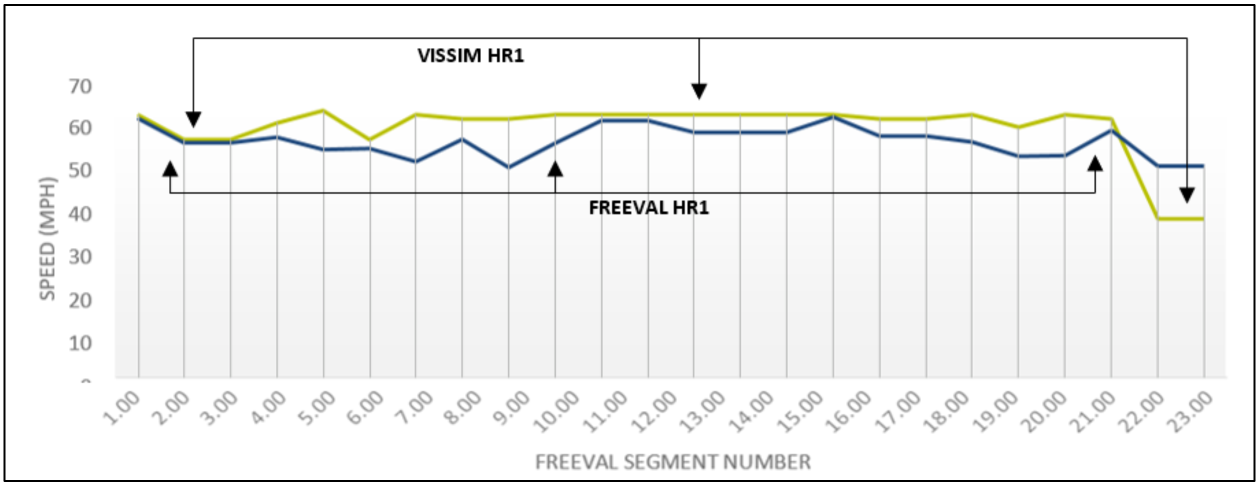
b) Speeds during the second hour.



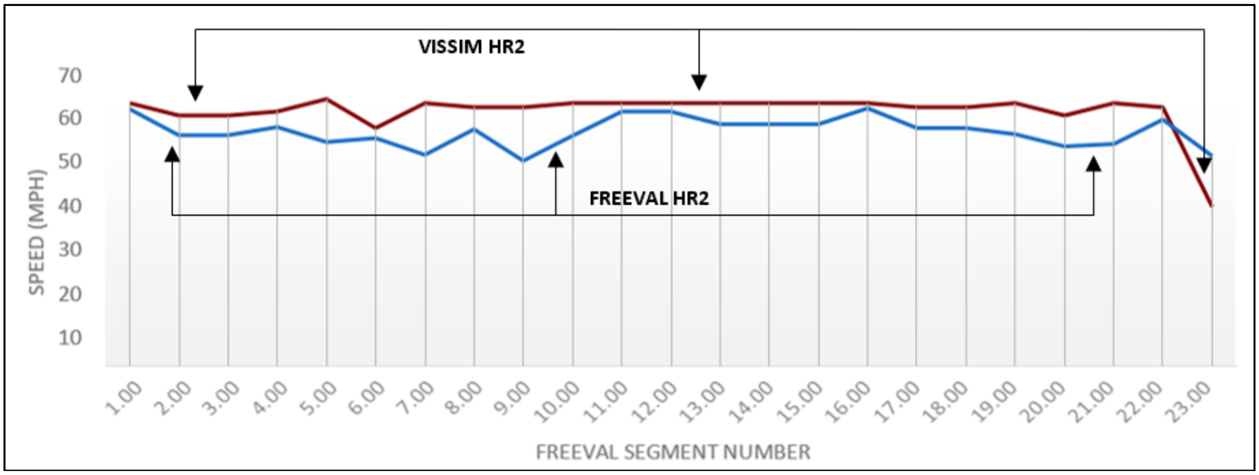
c) Speeds during the third hour.

Source: Florida Department of Transportation.

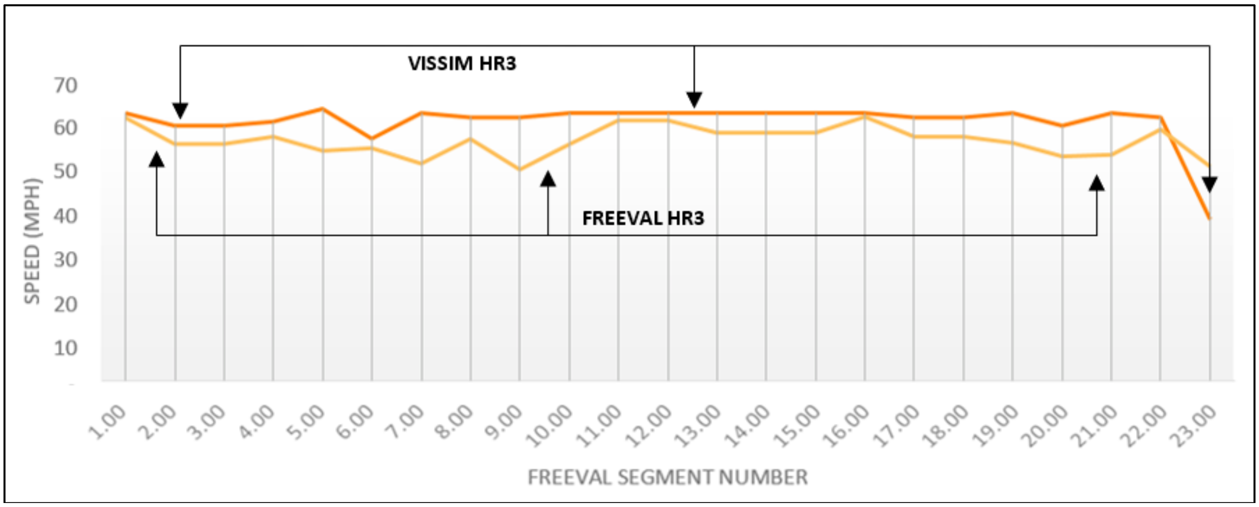
Figure 18. Graph. 2040 future year no-build speed comparison.



a) Speeds during the first hour.



b) Speeds during the second hour.



c) Speeds during the third hour.

Source: Florida Department of Transportation

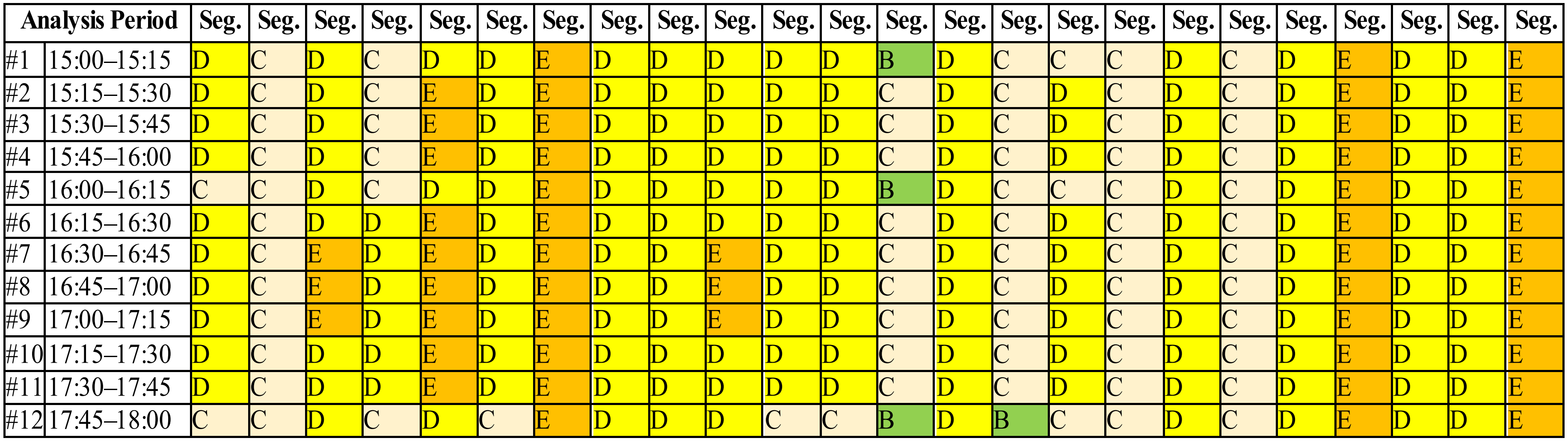
Figure 19. Graph. 2040 future year build speed comparison.

Analysis Period		Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.
#1	15:00–15:15	C	C	D	D	D	C	E	C	C	D	D	D	D	D	B	D	C	D	C	C	D	C	C	D
#2	15:15–15:30	C	C	D	C	E	C	E	C	D	D	D	D	D	D	B	D	C	D	D	C	D	C	C	D
#3	15:30–15:45	C	C	D	C	E	C	E	C	D	D	D	D	D	D	B	D	C	D	D	C	D	C	C	D
#4	15:45–16:00	C	C	D	C	E	C	E	C	D	D	D	D	D	D	B	D	C	D	D	C	D	C	C	D
#5	16:00–16:15	C	C	D	C	D	C	D	C	C	D	C	C	C	C	B	D	C	D	C	C	D	C	C	D
#6	16:15–16:30	D	C	D	C	E	C	E	C	D	D	D	D	D	D	B	D	C	E	D	C	D	C	C	D
#7	16:30–16:45	D	C	D	C	E	C	E	D	D	D	D	D	D	D	B	D	C	E	D	D	D	C	C	D
#8	16:45–17:00	D	D	D	D	E	D	E	D	D	D	D	D	D	D	B	D	C	E	D	D	D	C	C	D
#9	17:00–17:15	D	D	D	C	E	C	E	D	D	D	D	D	D	D	B	D	C	E	D	D	D	C	C	D
#10	17:15–17:30	D	C	D	C	E	C	E	D	D	D	D	D	D	D	B	D	C	E	D	D	D	C	C	D
#11	17:30–17:45	D	C	D	C	E	C	E	D	D	D	D	D	D	D	B	D	C	E	D	C	D	C	C	D
#12	17:45–18:00	C	C	D	C	D	C	D	C	C	D	C	C	C	C	B	D	C	D	C	C	D	C	C	D

a) 2011 p.m. peak hour Level of Service A through F.

Analysis Period		Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.
#1	15:00–15:15	D	D	E	E	F	F	E	F	D	D	C	C	C	C	B	C	C	D	C	C	E	F	F	D
#2	15:15–15:30	F	F	F	F	F	F	E	F	D	D	C	C	C	C	B	C	C	D	E	F	F	F	F	D
#3	15:30–15:45	F	F	F	F	F	F	F	F	D	D	C	C	C	C	E	F	F	F	F	F	F	F	F	D
#4	15:45–16:00	F	F	F	F	F	F	F	F	D	D	D	E	E	E	F	F	F	F	F	F	F	F	F	D
#5	16:00–16:15	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	D
#6	16:15–16:30	F	F	F	F	F	F	F	F	F	E	F	F	F	F	F	F	F	F	F	F	F	F	F	D
#7	16:30–16:45	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	D
#8	16:45–17:00	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	D
#9	17:00–17:15	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	D
#10	17:15–17:30	F	F	F	F	F	F	F	F	E	F	F	F	F	F	F	F	F	F	F	F	F	F	F	D
#11	17:30–17:45	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	D
#12	17:45–18:00	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	D

b) 2040 p.m. peak hour Level of Service A through F, No-Build.



Analysis Period		Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.	Seg.
#1	15:00–15:15	D	C	D	C	D	D	E	D	D	D	D	D	B	D	C	C	C	D	C	D	E	D	D	E
#2	15:15–15:30	D	C	D	C	E	D	E	D	D	D	D	D	C	D	C	D	C	D	C	D	E	D	D	E
#3	15:30–15:45	D	C	D	C	E	D	E	D	D	D	D	D	C	D	C	D	C	D	C	D	E	D	D	E
#4	15:45–16:00	D	C	D	C	E	D	E	D	D	D	D	D	C	D	C	D	C	D	C	D	E	D	D	E
#5	16:00–16:15	C	C	D	C	D	D	E	D	D	D	D	D	B	D	C	C	C	D	C	D	E	D	D	E
#6	16:15–16:30	D	C	D	D	E	D	E	D	D	D	D	D	C	D	C	D	C	D	C	D	E	D	D	E
#7	16:30–16:45	D	C	E	D	E	D	E	D	D	E	D	D	C	D	C	D	C	D	C	D	E	D	D	E
#8	16:45–17:00	D	C	E	D	E	D	E	D	D	E	D	D	C	D	C	D	C	D	C	D	E	D	D	E
#9	17:00–17:15	D	C	E	D	E	D	E	D	D	E	D	D	C	D	C	D	C	D	C	D	E	D	D	E
#10	17:15–17:30	D	C	D	D	E	D	E	D	D	D	D	D	C	D	C	D	C	D	C	D	E	D	D	E
#11	17:30–17:45	D	C	D	D	E	D	E	D	D	D	D	D	C	D	C	D	C	D	C	D	E	D	D	E
#12	17:45–18:00	C	C	D	C	D	C	E	D	D	D	C	C	B	D	B	C	C	D	C	D	E	D	D	E

c) 2040 p.m. peak hour Level of Service A through F, Build.

Source: Florida Department of Transportation.

Figure 20. Chart. Southbound Interstate 95 facility—p.m. peak period level of service contours.

2011 p.m. Peak Period

The southbound p.m. peak period analysis showed the facility operating in relatively unconstrained conditions. The average mainline travel time is 7.7 minutes, which is approximately 19 percent higher than the free-flow travel time of 6.5 minutes. Demand-to-capacity (d/c) ratios are approaching 1.0 near the off-ramp to eastbound Atlantic Boulevard with a maximum d/c ratio of 0.96. Approximately 400 hours of total vehicle delay are estimated during the p.m. peak period.

2040 p.m. No-Build

The no-build scenario is expected to experience severe congestion with a maximum d/c ratio of 1.19 experienced at the southern end of the analysis segment. The Vissim™ results also identified congestion in this area as the managed lanes come to an end, creating some turbulence along I-95. The average travel time increases to 21.29 minutes. This is more than a 200-percent increase over the free-flow travel time. The HCM analysis also identified queue spillback through the majority of the facility. Total vehicle hour delay is expected to increase to 31,152 hours.

2040 p.m. Build

With the improvements made as part of the build scenario, operations are expected to improve over the no-build scenario. Average travel times during the p.m. peak period improve to around 8 minutes. This results in a 5-percent increase over the existing (2011) travel time. A bottleneck was identified in a weaving segment (analysis segment 20) between the Andrews Avenue on-ramp and Commercial Boulevard off-ramp. The maximum d/c ratio of 1.06 occurs on this segment. Even though the demand of the weaving segment exceeds capacity, the HCM and Vissim™ both estimate that the majority of queuing takes place on the on-ramp itself, leaving the mainline lanes to operate at LOS E and a density below 43 pc/mi/ln. Overall vehicle delay is expected to decrease to approximately 1,600 hours in the build condition.

Reliability Analysis Assumptions

The reliability method in the HCM 6th Edition includes a set of national defaults that can be used in the absence of local data. There are certain data that can be obtained from Florida-specific sources, such as seasonal and daily demand variations and crash rates and input into the method to create a more realistic reliability result calibrated to local and facility-specific data. The following sections summarize the different HCM reliability analysis inputs.

Reliability Analysis Properties

A seed date of February 9, 2011 (Wednesday), was assumed for the reliability analysis. A seed date refers to the average demand levels that are evaluated in a traditional operational analysis, before considering monthly and day-of-week demand variability. The PD&E documents received for the I-95 study did not include raw counts or the data collection date. Therefore, a seed date was assumed based on the time period where the daily demand multiplier developed is equal to 1.00, which in turn represents average volumes for the entire year. The applied daily demand multipliers are described below.

The following dates from 2011 were outlier days with significantly different traffic patterns and were excluded from the reliability analysis:

- January 1—New Year's Day
- January 17—Martin Luther King Jr. Day
- February 21—Presidents Day
- May 30—Memorial Day
- July 4—Independence Day
- September 5—Labor Day
- November 24—Thanksgiving Day
- November 25—Day after Thanksgiving
- December 24—Christmas Eve
- December 25—Christmas Day

Daily Demand Multipliers

Daily demand multipliers for all months of the year were developed based on the 2015 *Volume Factor Category Summary Report for I–95 in Broward County (Category: 8695)*, included in the *2015 Florida Traffic Information DVD*. The report includes month-of-year and day-of-week factors to adjust traffic counts into average annual daily traffic. The inverse of these factors was used to develop volume demand factors for each day of the week, for each month of the analysis year. Table 4 summarizes the default HCM daily demand factors for an urban facility and the I–95 daily demand factors estimated from the FDOT data. The side-by-side comparison illustrates the importance of calibrating this reliability input to local data, as the I–95 data show a very different pattern and generally less variability than the national defaults for urban freeways.

Incidents

Default crash frequencies per 100 million VMT are provided for use in situations where actual crash rates are not available. The national default for crashes on freeways contained in the HCM is 165.4 crashes per 100 million VMT. The method then calculates incident frequencies by applying an incident-to-crash ratio to the crash rates.

To calibrate the crash and incident data to local conditions, statewide, districtwide, and countywide crash rates were obtained from FDOT's Crash Analysis Reporting System (CARS) for the most recent approved 5 years of data (2010 through 2014). Crash rates were reviewed for an urban interstate, and the average crash rate at the countywide level (Broward County) was selected for use in the HCM reliability analysis. The specific crash rates for an urban interstate are included in Table 5. The crash rates obtained from CARS are per million VMT. These crash rates were converted to crash rates per 100 million VMT before being input into the FREEVAL tool. Once input into FREEVAL, the national average incident-to-crash ratio of 4.9 was used to calculate incident frequency. Just as with demand variability, the locally calibrated crash data show clear differences with the national defaults, with the local rate being significantly lower than the HCM default.

Table 4. Daily demand factors comparison—Interstate 95.

	Default HCM factors—urban freeways					Florida data factors—I–95				
Mo.	**Mon**	**Tues**	**Wed**	**Thur**	**Fri**	**Mon**	**Tues**	**Wed**	**Thur**	**Fri**
Jan	0.822	0.822	0.839	0.864	0.965	0.996	1.016	1.027	1.038	1.072
Feb	0.849	0.849	0.866	0.892	0.996	0.970	0.990	1.000	1.011	1.043
Mar	0.921	0.921	0.939	0.967	1.080	0.964	0.984	0.994	1.004	1.037
Apr	0.976	0.976	0.995	1.025	1.145	1.003	1.023	1.034	1.045	1.079
May	0.974	0.974	0.993	1.023	1.142	1.028	1.049	1.060	1.072	1.107
June	1.022	1.022	1.043	1.074	1.199	1.040	1.062	1.073	1.084	1.120
July	1.133	1.133	1.156	1.191	1.329	1.048	1.070	1.081	1.092	1.128
Aug	1.033	1.033	1.054	1.085	1.212	1.048	1.070	1.081	1.093	1.128
Sept	1.063	1.063	1.085	1.117	1.248	1.048	1.070	1.081	1.092	1.128
Oct	0.995	0.995	1.016	1.046	1.168	1.023	1.044	1.055	1.066	1.101
Nov	0.995	0.995	1.016	1.046	1.168	1.016	1.037	1.048	1.059	1.093
Dec	0.979	0.979	0.998	1.028	1.148	1.000	1.021	1.031	1.042	1.076

Table 5. Urban interstate crash rates (Broward County, District 4, and Statewide).

Year	**Crash rate per 100 million VMT**		
	Broward County	**District**	**Statewide**
2010	74.4	72.3	70.6
2011	81.268	70.096	67.109
2012	95.0	81.1	77.1
2013	106.3	93.4	88.8
2014	104.6	94.2	90.8
Average	92.3	82.2	78.8

VMT = vehicle miles traveled.

Weather

The HCM reliability method contains historical weather patterns and weather probabilities for the 98 largest metropolitan areas in the United States, including several locations within Florida. For each, the HCM includes weather probability by type and by hour of day based on 10 years of archival regional weather data. Weather probabilities, durations, and adjustment factors based on the regional weather data are used as part of the reliability analysis. The Florida locations with regional weather data are as follows:

- Cape Coral
- Jacksonville
- Lakeland
- Miami
- North Port
- Orlando
- Palm Bay

The Miami metropolitan area data were used for the I–95 case study.

Reliability Results

The default parameters contained in the HCM can be utilized in the absence of facility-specific crash data or seasonal/daily variation data. For this case study, facility-specific and local data were available from FDOT. However, the team decided to use both the default and Florida-specific parameters in this analysis to allow for a direct comparison and to evaluate how much of a difference local data have on the reliability results. The reliability performance measures included as an output in FREEVAL are summarized in Table 6. The TTI represents the ratio of the actual travel time to free-flow travel time.

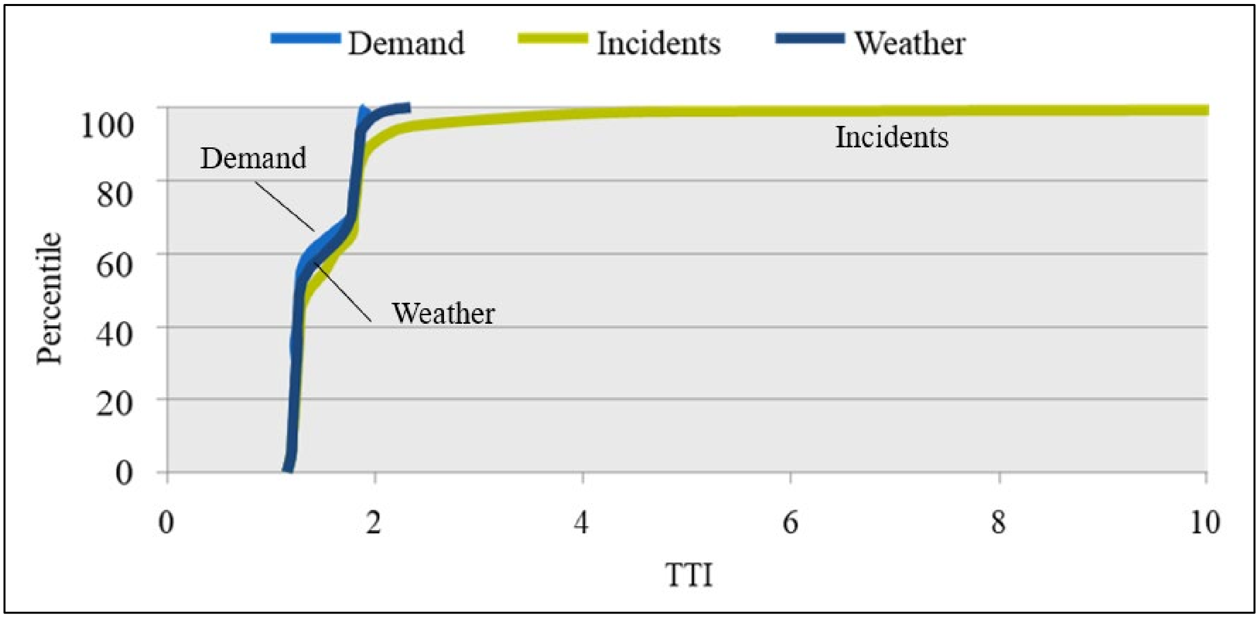
Table 6. Southbound Interstate 95 facility p.m. peak period reliability summary.

Performance measures	2011		2040 No-build		2040 Build	
	Default	Florida	Default	Florida	Default	Florida
Mean TTI	2.52	1.72	4.30	3.93	2.65	2.06
50th % TTI	1.90	1.43	4.47	4.03	2.04	1.89
80th % TTI	2.58	1.84	4.77	4.39	2.71	1.95
95th % TTI	3.49	2.37	5.13	4.69	3.69	2.60
Misery index	12.19	5.59	9.36	9.42	12.83	7.98
Semi STD	3.97	2.06	4.02	4.32	4.09	2.79

STD = standard deviation; TTI = travel time index.

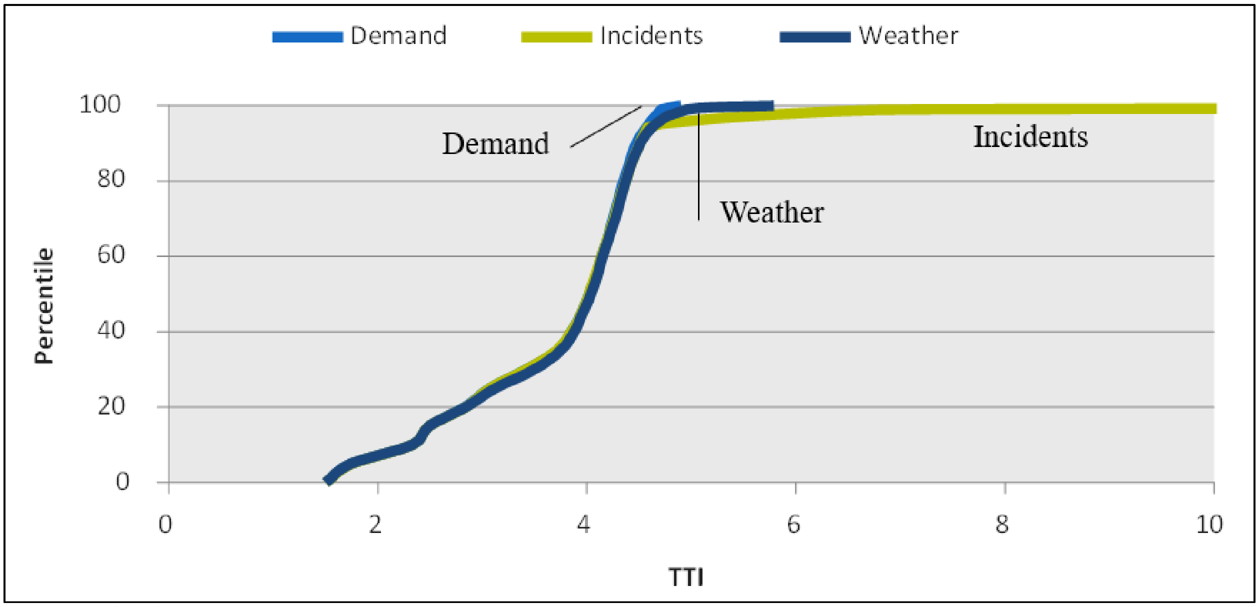
In each of the three scenarios, the TTI varies relatively little until it reaches the 95th percentile. In the no-build case, the average vehicle would be expected to experience a travel time approximately four times longer than the free-flow travel time during the p.m. peak period.

The demand, incident, and weather distributions for the 2011, 2040 no-build, and 2040 build scenarios are illustrated in Figure 21, Figure 22, and Figure 23, respectively.



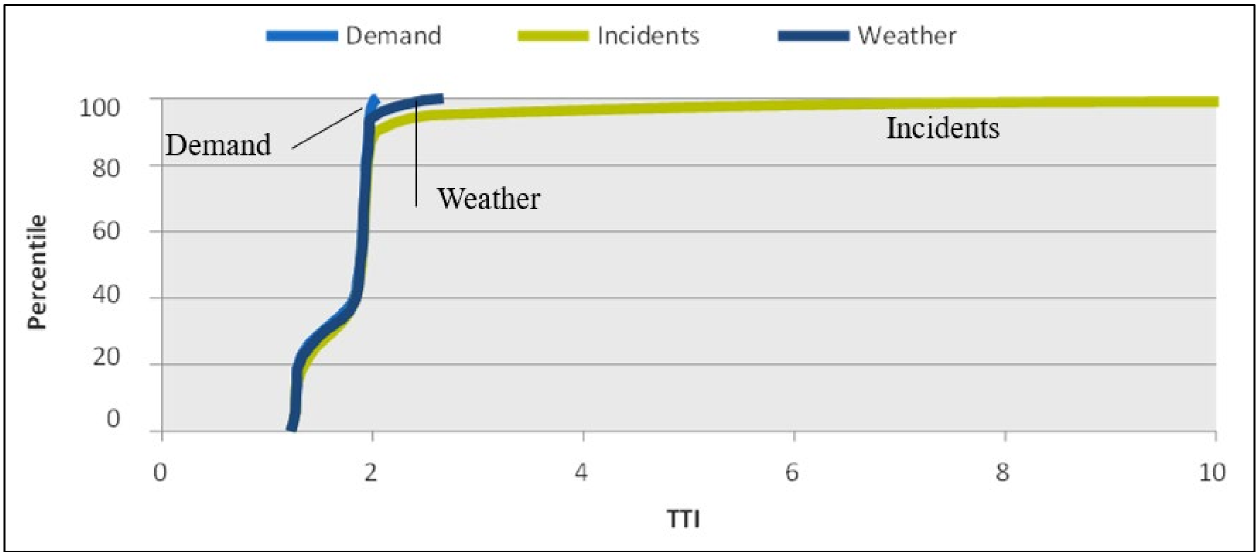
Source: Florida Department of Transportation.
TTI = travel time index.

Figure 21. Graph. 2011 p.m. (Interstate 95)—reliability variables.



Source: Florida Department of Transportation.
TTI = travel time index.

Figure 22. Graph. 2040 p.m. no-build (Interstate 95)—reliability variables.



Source: Florida Department of Transportation.
TTI = travel time index.

Figure 23. Graph. 2040 p.m. build (Interstate 95)—reliability variables.

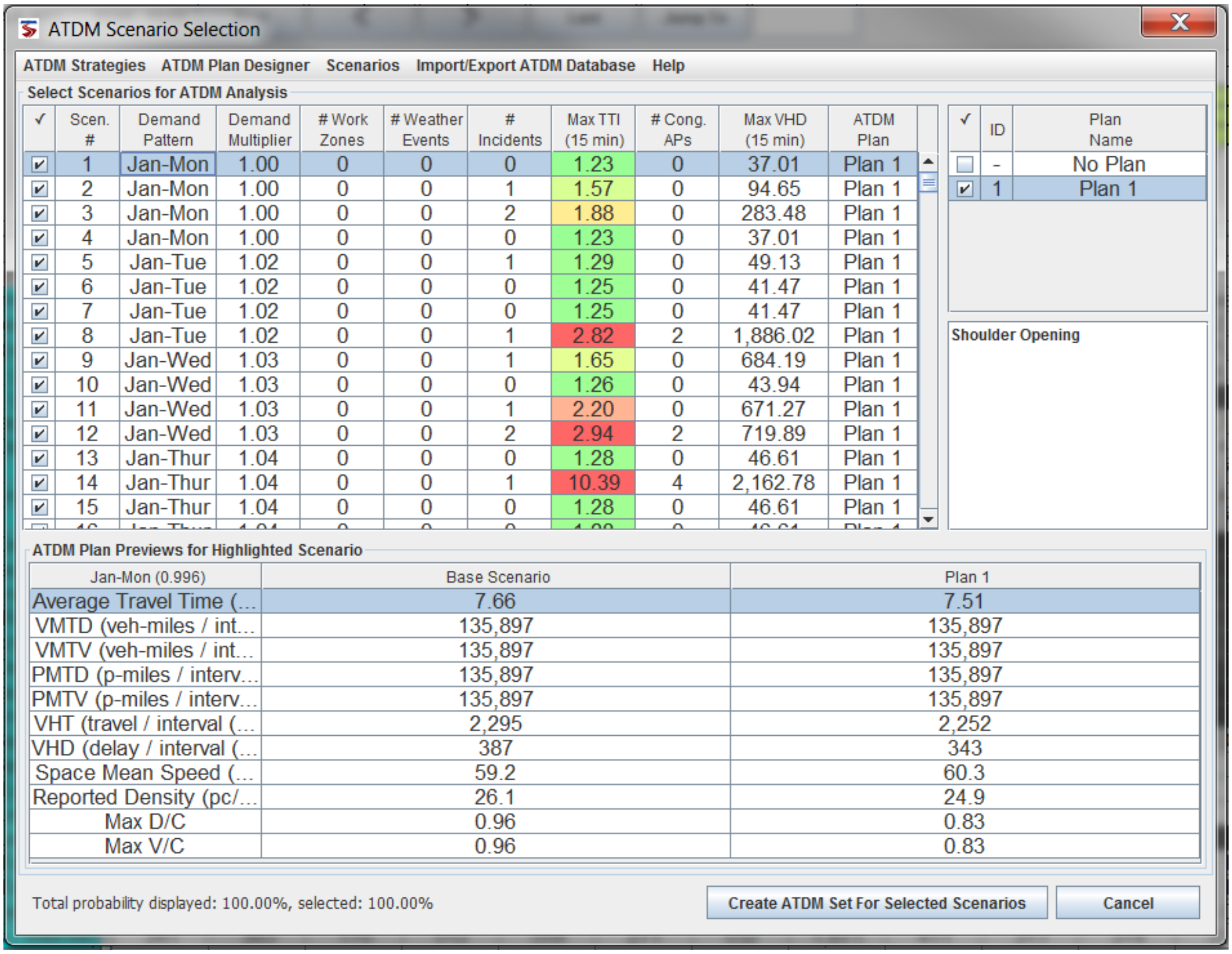
Active Traffic Demand Management Strategies

The active traffic demand management (ATDM) analysis included in the HCM 6th Edition is also implemented in the HCM-CALC and FREEVAL tools. ATDM strategies, such as demand management, weather traffic management, traffic incident management, work zone traffic management, ramp metering, and hard shoulder running (HSR), can be employed in the ATDM analysis. As part of the I–95 case study, HSR was evaluated as an ATDM strategy for each of the three analysis scenarios. The following summarizes the inputs and results from the ATDM analysis.

Hard Shoulder Running Inputs

Multiple ATDM strategies could be considered in the mitigation analysis; in this study, HSR was selected as the ATDM strategy. Once selected, the HSR strategy is configured and then further defined. The analyst can assign the HSR strategy to specific analysis segments and time periods. In this ATDM analysis, the HSR strategy was applied to all analysis segments during all 12 analysis periods (3-hr analysis). The analyst can further define the capacity of the shoulder. For the purposes of this analysis, a capacity of 75 percent of one mainline lane was used (approximately 1,500 vehicles/hour).

Once the ATDM strategy was applied to the desired segments and analysis periods and the capacity was defined, the created HSR strategy was assigned to a specific ATDM plan (Figure 24). In this case, the created strategy was applied to Plan 1. ATDM plans can be assigned to specific reliability scenarios. For example, if an ATDM plan includes incident management strategies, the overall ATDM plan can be assigned to the reliability scenarios where an incident occurred. In this analysis, the ATDM plan was assigned to all reliability scenarios.



✓	Scen. #	Demand Pattern	Demand Multiplier	# Work Zones	# Weather Events	# Incidents	Max TTI (15 min)	# Cong. APs	Max VHD (15 min)	ATDM Plan
☑	1	Jan-Mon	1.00	0	0	0	1.23	0	37.01	Plan 1
☑	2	Jan-Mon	1.00	0	0	1	1.57	0	94.65	Plan 1
☑	3	Jan-Mon	1.00	0	0	2	1.88	0	283.48	Plan 1
☑	4	Jan-Mon	1.00	0	0	0	1.23	0	37.01	Plan 1
☑	5	Jan-Tue	1.02	0	0	1	1.29	0	49.13	Plan 1
☑	6	Jan-Tue	1.02	0	0	0	1.25	0	41.47	Plan 1
☑	7	Jan-Tue	1.02	0	0	0	1.25	0	41.47	Plan 1
☑	8	Jan-Tue	1.02	0	0	1	2.82	2	1,886.02	Plan 1
☑	9	Jan-Wed	1.03	0	0	1	1.65	0	684.19	Plan 1
☑	10	Jan-Wed	1.03	0	0	0	1.26	0	43.94	Plan 1
☑	11	Jan-Wed	1.03	0	0	1	2.20	0	671.27	Plan 1
☑	12	Jan-Wed	1.03	0	0	2	2.94	2	719.89	Plan 1
☑	13	Jan-Thur	1.04	0	0	0	1.28	0	46.61	Plan 1
☑	14	Jan-Thur	1.04	0	0	1	10.39	4	2,162.78	Plan 1
☑	15	Jan-Thur	1.04	0	0	0	1.28	0	46.61	Plan 1

✓	ID	Plan Name
☐	-	No Plan
☑	1	Plan 1

Jan-Mon (0.996)	Base Scenario	Plan 1
Average Travel Time (…	7.66	7.51
VMTD (veh-miles / int…	135,897	135,897
VMTV (veh-miles / int…	135,897	135,897
PMTD (p-miles / interv…	135,897	135,897
PMTV (p-miles / interv…	135,897	135,897
VHT (travel / interval (…	2,295	2,252
VHD (delay / interval (…	387	343
Space Mean Speed (…	59.2	60.3
Reported Density (pc/…	26.1	24.9
Max D/C	0.96	0.83
Max V/C	0.96	0.83

Total probability displayed: 100.00%, selected: 100.00%

Source: Florida Department of Transportation.

Figure 24. Screenshot. Active traffic demand management plan selection.

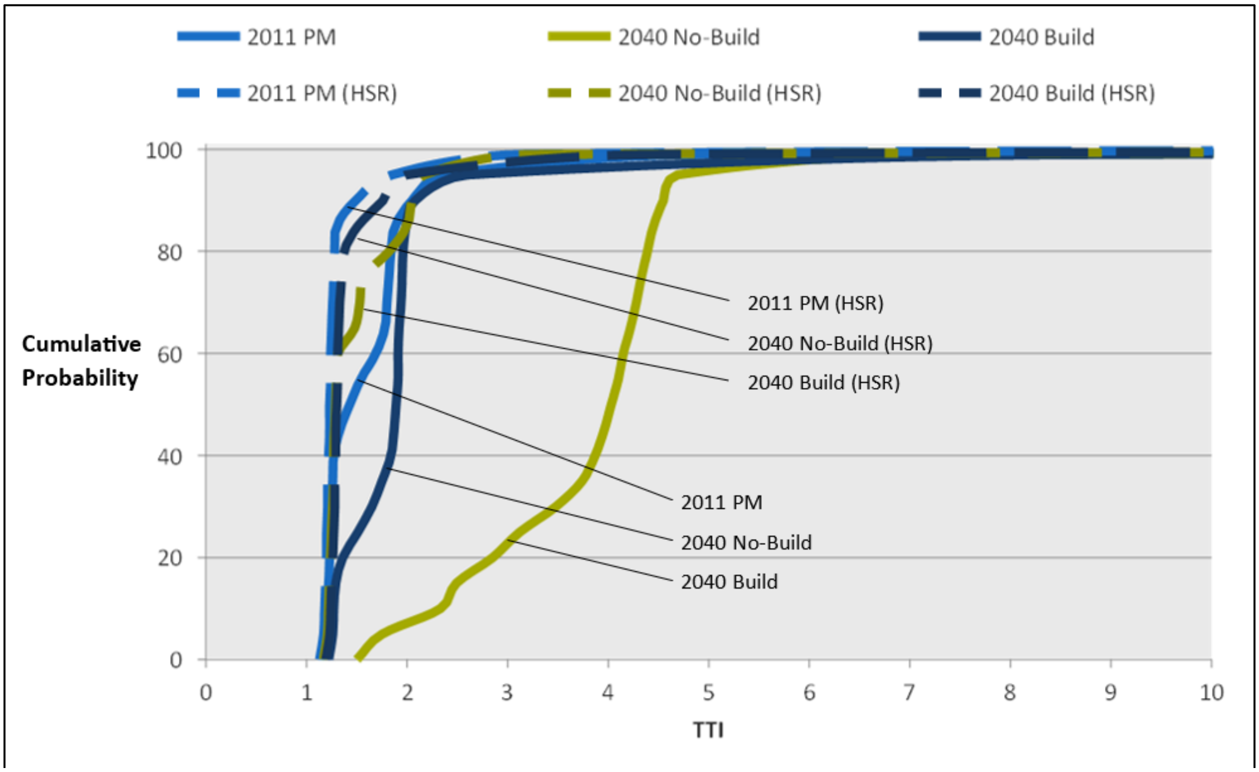
Hard Shoulder Running Results

The reliability results implementing HSR were summarized for each scenario and compared with the previous reliability results without HSR. The comparison is summarized in Table 7 and illustrated in Figure 25. As summarized in Table 7, the implementation of HSR as an ATDM strategy decreases the TTI for each of the three scenarios and improves TTR. The build scenario still offers the best reliability when compared with the no-build scenario; however, reliability was significantly improved for the no-build scenario.

Table 7. Southbound Interstate 95 facility p.m. peak period reliability summary with hard shoulder running.

Performance measures	2011		2040 No-build		2040 Build	
	No HSR	HSR	No HSR	HSR	No HSR	HSR
Mean TTI	1.7	1.4	3.9	1.6	2.1	1.5
50th % TTI	1.4	1.3	4.0	1.3	1.9	1.3
80th % TTI	1.8	1.3	4.4	1.8	2.0	1.4
95th % TTI	2.4	1.9	4.7	2.2	2.6	2.0
Misery index	5.6	3.3	9.4	4.6	8.0	4.4
Semi-STD	2.1	0.9	4.3	1.8	2.8	1.3
VMT % at TTI > 2	11.3	3.5	91.8	14.8	14.5	4.8
Reliability rating (%)	45.1	86.7	0.0	60.5	17.9	70.5

HSR = hard shoulder running; STD = standard deviation; TTI = travel time index; VMT = vehicle miles traveled.



Source: Florida Department of Transportation.
HSR = hard shoulder running; TTI = travel time index.

Figure 25. Graph. Cumulative travel time index distribution functions with hard shoulder running—Interstate 95 southbound facility.

CASE STUDY: STRATEGIC HIGHWAY RESEARCH PROGRAM 2 L04 GUIDANCE MICROSIMULATION MODEL

The purpose of this case study is to demonstrate how microsimulation tools can be used in performing reliability analyses using the framework and tools developed under SHRP2 Project L04: *Incorporating Reliability Performance Measures into Operations and Planning Modeling Tools,*[2] henceforth to be called the SHRP2 L04 guidance. The Aimsun™ simulation software was used to perform the microsimulation task.

Study Area Description

For the micromodel scenario, the study area was a section of the East Manhattan area bounded by 74th Street to the north, 48th Street to the south, 5th Avenue to the west, and York Avenue to the east. Figure 26 shows the extent of the study area considered for microsimulation purposes.

Source: Mahmassani et al. 2014.

Figure 26. Map. East Manhattan study area.

The micromodel covers an area that includes 178 lane kilometers and 217 signalized intersections. A total of 147 centroids were connected to the network to generate origin-destination (O-D) trips, including 44 gates and 103 internal centroids.

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[2] The National Academies of Sciences, Engineering, and Medicine. 2023. "Incorporating Reliability Performance Measures into Operations and Planning Modeling Tools" (web page). http://www.trb.org/Main/Blurbs/170716.aspx, last accessed January 6, 2023.

Two base models were constructed representing peak a.m. weekday and weekend conditions. The weekday a.m. peak-period model consisted of a total demand of around 155,000 vehicles over a 5-hr period from 6 to 11 a.m.

The weekend peak-period model consisted of a total demand of around 80,000 vehicles over a period of 3 hours from 2 to 5 p.m.

Microsimulation Approach and Objective

The general objective of the microsimulation tests was to determine a range of reliability measures that is characteristic of the study area for weekday and weekend traffic. The weekday and weekend scenarios were subjected to incident and demand variation events that are typical of the study area. Due to limitations with the modeling platform, the implementation of variable weather conditions was not possible as part of the microsimulation study. It was assumed that constant fair-weather conditions prevailed across all the scenarios tested for weekday and weekend.

Generating Scenarios Using the Scenario Manager

Specific scenarios under each of the four cases may be obtained either by generating random scenarios using the Scenario Manager's Monte Carlo sampling capability or by using deterministic scenarios from existing historical sources. This case study uses the former approach—a set of random scenarios is constructed using Monte Carlo sampling for each category. The factors that are considered as scenario components are weather, incident, and day-to-day demand random variation, as shown in Table 8. A detailed description for each scenario component is presented in the following subsections.

Table 8. Modeling scenario factors.

	Exogenous sources					
		Incident			**Day-to-day demand variation**	
Weekday or weekend	**Weather**	**Frequency: poisson (λ)**	**Duration: Gamma (α,β)**	**Intensity: empirical PMF**	**DMF: Normal (μ, σ)**	**Scenario case**
Weekdays	No Rain	$\lambda(\mathbf{cl}) = 0.00136$	$\alpha = 1.210$ $\beta = 31.553$	$P(0.15) = 0.4$, $P(0.30) = 0.5$, $P(0.60) = 0.1$	$\mu = 1.0$ $\sigma = 0.17$	Weekdays No Rain (wd-NR)
Weekends	No Rain	$\lambda(\mathbf{cl}) = 0.00055$			$\mu = 1.0$ $\sigma = 0.14$	Weekends No Rain (wE-NR)

Note: (w) = incident rate under weather state w (incidents/hour/lane-mile); $P(x)$ = probability that the fraction of link capacity lost due to a given incident becomes x (i.e., remaining capacity becomes $1 = x$); pMF = probability mass function; and dMF = demand multiplication factor.

Scenario Specification

Incidents

Incident properties are characterized using parametric models, as discussed in chapter 6 of the SHRP2 L04 guidance, *Implementation of Scenario Manage*r, subsection Incident Scenario. For frequency, a Poisson distribution was used to model the number of incidents for a given time period. To capture the dependency between weather and incident frequency, weather-conditional incident rates were applied. Table 8 presents the estimated rate parameters. For incident duration, a gamma distribution was identified based on model-fitting results and estimated two input parameters—shape = 1.210, and scale = 31.553. Incident intensity is expressed as the percentage capacity loss (the fraction of link capacity lost due to the incident). The empirical probability mass function (PMF) was constructed based on historical incident data, in which three levels of capacity loss (15, 30, and 60 percent) were considered in conjunction with their probabilities (0.4, 0.5, and 0.1, respectively).

Day-to-Day Demand Random Variation

To understand the day-to-day demand fluctuation pattern, Global Positioning System probe data obtained from the TomTom company were examined. The data cover 16 consecutive days from May 2 to May 17, 2010, in New York. The observed vehicle trajectories for each day were aggregated, and the variation in daily traffic volume was estimated using the demand multiplication factor (DMF) introduced in chapter 6 of the SHRP2 L04 guidance, *Implementation of Scenario Manager*, subsection Demand Scenario: Day-to-Day Random Variation. Although the available trajectory data represent only a portion of the entire travel demand in the study region, the analysis results provide insight into the characteristics of respective variations in weekday and weekend traffic levels. Based on the estimation results, the demand multiplication factor for weekdays was specified as a normally distributed random variable with mean = 1.0 and standard deviation = 0.17, and the demand multiplication factor for weekends as a normal random variable with mean = 1.0 and standard deviation = 0.14, as shown in Table 8.

Scenario Description

Based on those specified parameters for weather, incident, and demand components, 15 scenarios were generated for weekdays, and 4 scenarios were produced for weekends.

Microsimulation Travel Time Reliability Results

The input scenarios were prepared and imported into the Aimsun™ weekday and weekend models. The trajectories output for each vehicle completing trips were obtained for each scenario run and processed through the Trajectory Processor to obtain reliability metrics. The variety of reliability metrics producible from the Trajectory Processor output can be used to evaluate reliability performance at distinct levels of the system—network, O–D, and path-level.

Network-Level Results

The reliability performance across the entire network was measured using distance-normalized travel times (i.e., average travel time per mile (TTPM)) across 3 hr for the weekday and weekend peak periods. The weekday peak was for the a.m. period with time intervals spanning 7 to 8 a.m., 8 to 9 a.m., and 9 to 10 a.m. (Table 9, Table 10, and Table 11, respectively). For the weekend, peak hourly intervals were reported between 2 and 5 p.m. (Table 12, Table 13, and Table 14). The metrics reported include average TTPM, standard deviation of TTPM, and the 95th/90th/80th percentile TTPMs. The results are displayed for the 15 weekday scenarios and the 4 weekend scenarios that were modeled in Figure 27, Figure 28, and Figure 29.

Table 9. Network-level, departure time interval 7 a.m. to 8 a.m., weekday.

Scenario Name	Scenario ID	Average TTPM (min/mile)	Standard Deviation of TTPM (min/mile)	95th Percentile TTPM (min/mile)	90th Percentile TTPM (min/mile)	80th Percentile TTPM (min/mile)
4-21	1	10.55	5.46	20.63	16.63	13.47
21-29	2	9.52	4.91	18.59	15.09	12.18
25-3	3	10.26	5.12	19.55	16.25	13.20
41-7	4	9.71	5.02	19.37	15.56	12.61
44-12	5	8.45	4.31	16.12	13.28	10.85
46-39	6	7.17	4.19	14.16	11.46	9.09
48-29	7	7.71	4.18	15.00	12.27	9.81
58-10	8	8.48	4.27	16.11	13.27	10.80
61-34	9	11.55	6.41	23.71	18.78	14.78
65-22	10	10.80	5.74	21.51	17.35	13.94
72-8	11	12.14	6.78	24.65	19.85	15.69
80-26	12	7.35	4.02	14.16	11.64	9.35
85-23	13	11.64	6.86	23.78	18.64	14.87
89-4	14	8.87	4.42	17.06	13.96	11.38
90-49	15	10.32	5.19	20.33	16.60	13.30

Table 10. Network-level, departure time interval 8 a.m. to 9 a.m., weekday.

Scenario Name	Scenario ID	Average TTPM (min/mile)	Standard Deviation of TTPM (min/mile)	95th Percentile TTPM (min/mile)	90th Percentile TTPM (min/mile)	80th Percentile TTPM (min/mile)
4-21	1	13.69	8.18	26.27	21.73	17.46
21-29	2	12.26	5.82	23.45	19.15	15.64
25-3	3	13.86	9.75	26.93	22.15	17.58
41-7	4	12.90	7.77	24.59	20.19	16.25
44-12	5	11.13	5.64	21.78	17.91	14.43
46-39	6	7.77	3.96	14.87	12.09	9.81
48-29	7	8.87	4.57	17.07	13.88	11.33
58-10	8	10.24	4.87	19.62	16.00	13.11
61-34	9	16.27	11.08	31.27	25.86	20.76
65-22	10	14.81	10.03	28.14	23.36	18.63
72-8	11	19.14	17.41	40.10	31.26	23.75
80-26	12	8.08	4.06	15.26	12.58	10.21
85-23	13	18.87	13.31	39.60	31.11	24.42
89-4	14	12.47	6.83	24.33	19.89	15.92
90-49	15	13.86	7.38	26.78	22.07	17.60

Table 11. Network-level, departure time interval 9 a.m. to 10 a.m., weekday.

Scenario Name	Scenario ID	Average TTPM (min/mile)	Standard Deviation of TTPM (min/mile)	95th Percentile TTPM (min/mile)	90th Percentile TTPM (min/mile)	80th Percentile TTPM (min/mile)
4-21	1	24.27	19.55	57.60	43.62	32.97
21-29	2	15.13	8.96	28.48	23.85	19.10
25-3	3	23.03	20.54	51.08	39.40	29.81
41-7	4	15.90	11.24	30.06	24.72	19.96
44-12	5	13.87	9.25	26.51	21.89	17.52
46-39	6	8.72	3.97	15.94	13.22	10.97
48-29	7	11.02	5.21	20.91	17.41	14.15
58-10	8	12.34	5.76	22.73	19.14	15.66
61-34	9	27.32	20.56	60.12	46.01	34.94
65-22	10	26.29	29.44	61.60	46.86	33.34
72-8	11	36.23	27.44	74.87	60.43	49.66
80-26	12	10.14	4.55	18.78	15.57	12.93
85-23	13	27.10	21.02	57.57	44.75	34.62
89-4	14	16.03	11.22	31.09	25.61	20.28
90-49	15	20.68	15.67	41.46	32.95	26.61

Table 12. Network-level, departure time interval 2 p.m. to 3 p.m., weekend.

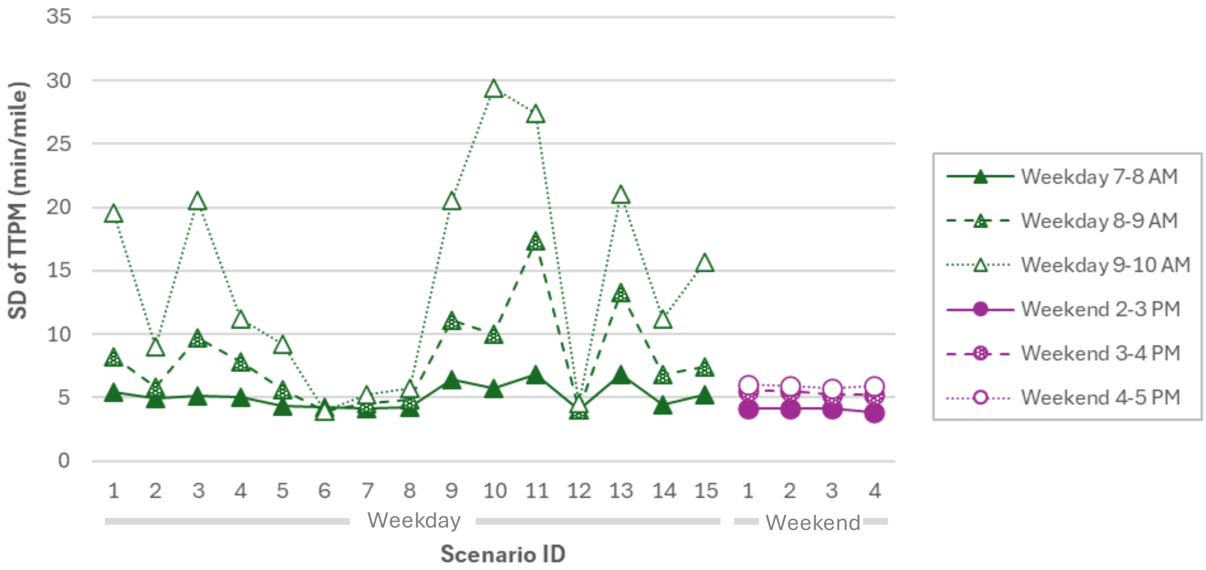
Scenario Name	Scenario ID	Average TTPM (min/mile)	Standard Deviation of TTPM (min/mile)	95th Percentile TTPM (min/mile)	90th Percentile TTPM (min/mile)	80th Percentile TTPM (min/mile)
39-4	1	7.86	4.10	15.11	12.46	10.21
56-7	2	7.86	4.10	15.11	12.46	10.21
75-5	3	7.86	4.09	15.05	12.50	10.24
94-4	4	7.64	3.87	14.35	12.00	9.91

Table 13. Network-level, departure time interval 3 p.m. to 4 p.m., weekend.

Scenario Name	Scenario ID	Average TTPM (min/mile)	Standard Deviation of TTPM (min/mile)	95th Percentile TTPM (min/mile)	90th Percentile TTPM (min/mile)	80th Percentile TTPM (min/mile)
39-4	1	9.22	5.50	19.46	15.30	11.99
56-7	2	9.23	5.51	19.46	15.35	12.01
75-5	3	9.10	5.27	18.64	14.80	11.69
94-4	4	8.88	5.21	18.44	14.45	11.41

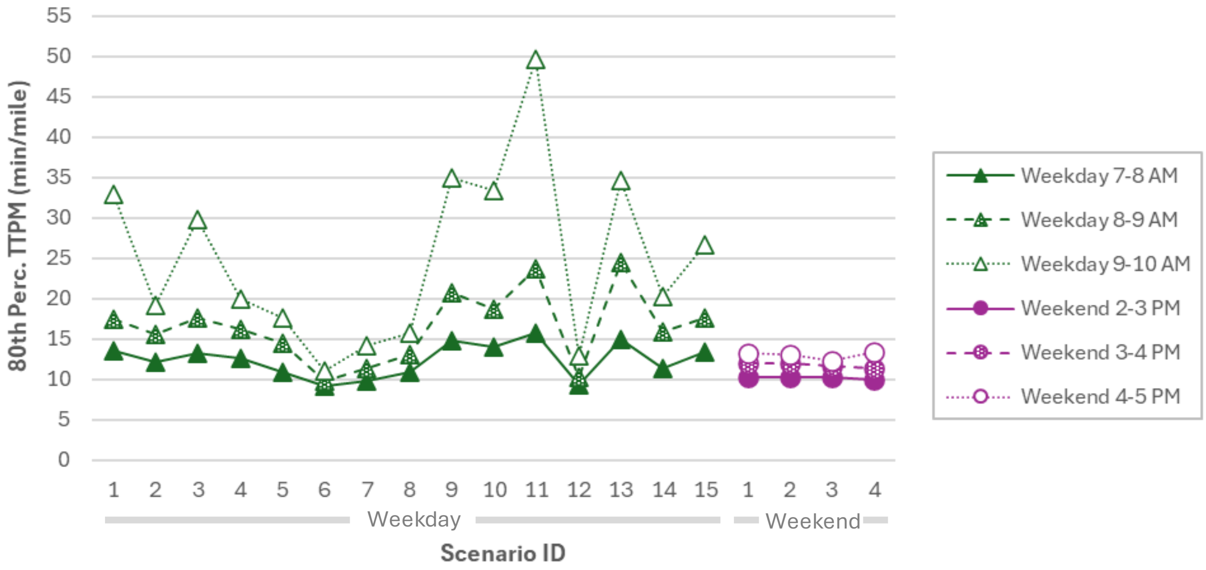
Table 14. Network-level, departure time interval 4 p.m. to 5 p.m., weekend.

Scenario Name	Scenario ID	Average TTPM (min/mile)	Standard Deviation of TTPM (min/mile)	95th Percentile TTPM (min/mile)	90th Percentile TTPM (min/mile)	80th Percentile TTPM (min/mile)
39-4	1	10.00	6.06	21.60	17.17	13.28
56-7	2	9.76	5.96	21.20	16.86	13.01
75-5	3	9.44	5.68	20.55	15.90	12.30
94-4	4	10.04	5.96	21.76	17.28	13.37



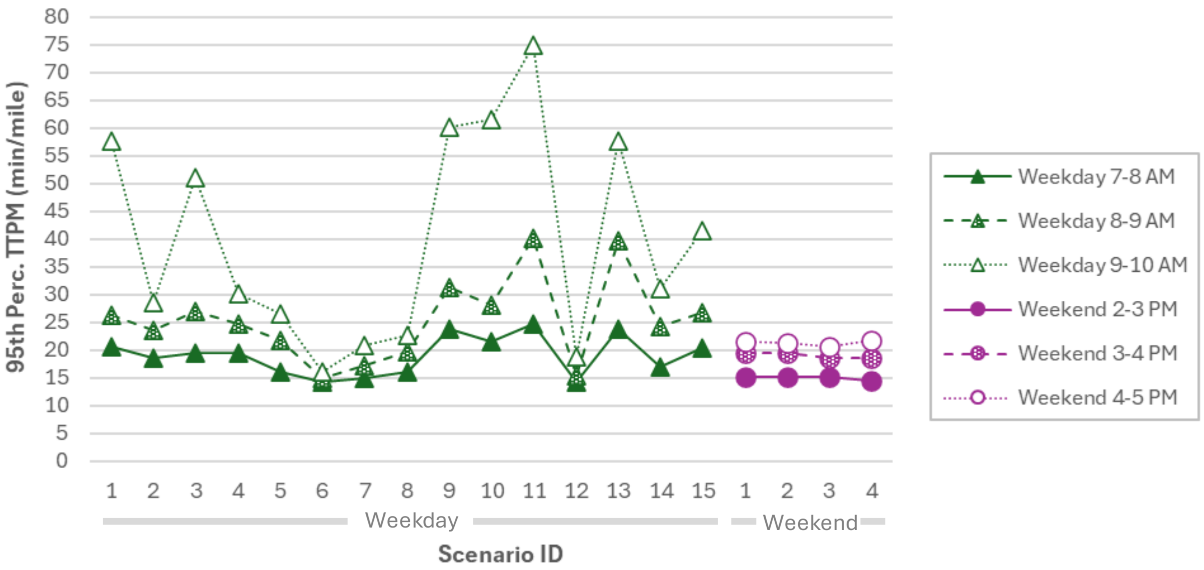
Source: Mahmassani et al. 2014.
SD = standard deviation; TTPM = travel time per mile.

Figure 27. Graph. Network level, standard deviation of travel time per mile.



Source: Mahmassani et al. 2014.
TTPM = travel time per mile.

Figure 28. Graph. Network level, 80th percentile travel time per mile.



Source: Mahmassani et al. 2014.
Perc. = percentile; TTPM = travel time per mile.

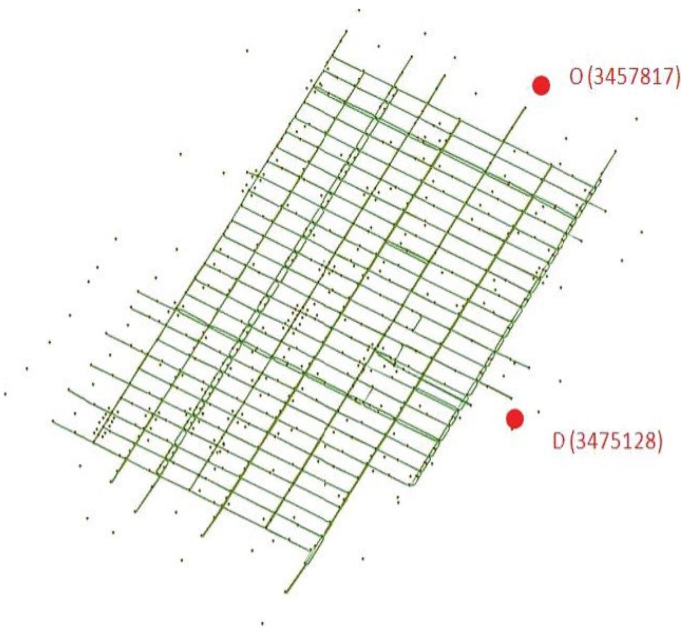
Figure 29. Graph. Network level, 95th percentile travel time per mile.

The observed trends from the data show that for the network-wide performance:

- The travel time variability is significantly less during typical weekend peak periods than weekday peaks.
- The variability by time of day is more pronounced across the hourly intervals for the weekday peaks. The travel times for the later hours in the period are characterized by more variability.
- Overall, there is a wider range of variability in travel times for the microsimulation experiment compared with the mesosimulation experiment (which can be reviewed in the SHRP2 L04 guidance mentioned above). For example, for the third weekday hour (9 to 10 a.m.), the average TTPM for Scenario 6 is 7.77 min/mile, while for Scenario 11, the value is 36.23 min/mile, resulting in a spread of 28.46 min/mile. This is much higher compared with the mesoexperiment in which the largest spread for average TTPM is around 2 min/mile. Possible reasons for this are discussed in the following section.

Origin-Destination-Level Analysis

For travel between O-D points within the network, two gate centroids were selected, as shown in Figure 30. This pair of centroids had a significant number of trips between them for all the hour intervals studied. The results for all trips between the O-D pair and for the hourly intervals between 7 a.m. and 9 a.m. for weekdays are presented in Table 15 and Table 16, and for the hourly intervals between 2 p.m. and 4 p.m. for weekends in Table 17 and Table 18.



Source: Mahmassani et al. 2014.Transportation Research Board, second Strategic Highway Research Program Report S2-L04-RR-1

Figure 30. Diagram. Origin-destination analysis modeling network layout.

The results are reported based on average nonnormalized travel times for all trips across all routes between the O-D pair. Five metrics were reported: the average travel time, standard deviation of travel time, 95th/90th/80th percentile travel times, buffer index, and skew index. Figure 31, Figure 32, Figure 33, and Figure 34 display the results that show that the interscenario variability is more significant for weekdays compared with weekends. Compared with the mesomodel results, the results for the micro experiment show a much wider range of variation.

Table 15. Origin-destination level, departure time interval 7 a.m. to 8 a.m., weekday.

Scenario Name	Scenario ID	Average travel time (min)	Standard deviation of travel time (min)	95th percentile travel time (min)	90th percentile travel time (min)	80th percentile travel time (min)	Buffer index	Skew index	Number of vehicles
4-21	1	11.66	4.10	18.66	16.93	15.12	0.60	0.98	592
21-29	2	10.44	4.37	19.70	17.26	13.53	0.89	2.10	579
25-3	3	12.27	3.84	19.04	16.89	15.22	0.55	0.90	632
41-7	4	11.26	4.55	19.95	17.54	15.11	0.77	1.66	585
44-12	5	9.92	4.20	17.33	15.73	13.68	0.75	1.16	613
46-39	6	4.72	1.40	6.86	6.52	6.01	0.45	0.84	613
48-29	7	7.73	3.23	14.21	12.46	10.35	0.84	2.07	668
58-10	8	8.85	2.90	14.20	12.20	10.93	0.60	0.79	685
61-34	9	11.81	4.51	19.61	17.67	15.46	0.66	1.42	560
65-22	10	11.58	3.82	18.08	16.68	15.12	0.56	1.04	578
72-8	11	12.31	5.22	22.99	20.30	16.75	0.87	1.74	530
80-26	12	5.85	2.16	10.48	8.81	7.26	0.79	1.93	685
85-23	13	11.57	4.74	19.26	17.14	14.31	0.66	1.26	653
89-4	14	8.76	3.52	14.90	13.12	11.70	0.70	1.50	632
90-49	15	10.81	3.86	18.31	15.74	14.12	0.69	1.35	573

Table 16. Origin-destination level, departure time interval 8 a.m. to 9 a.m., weekday.

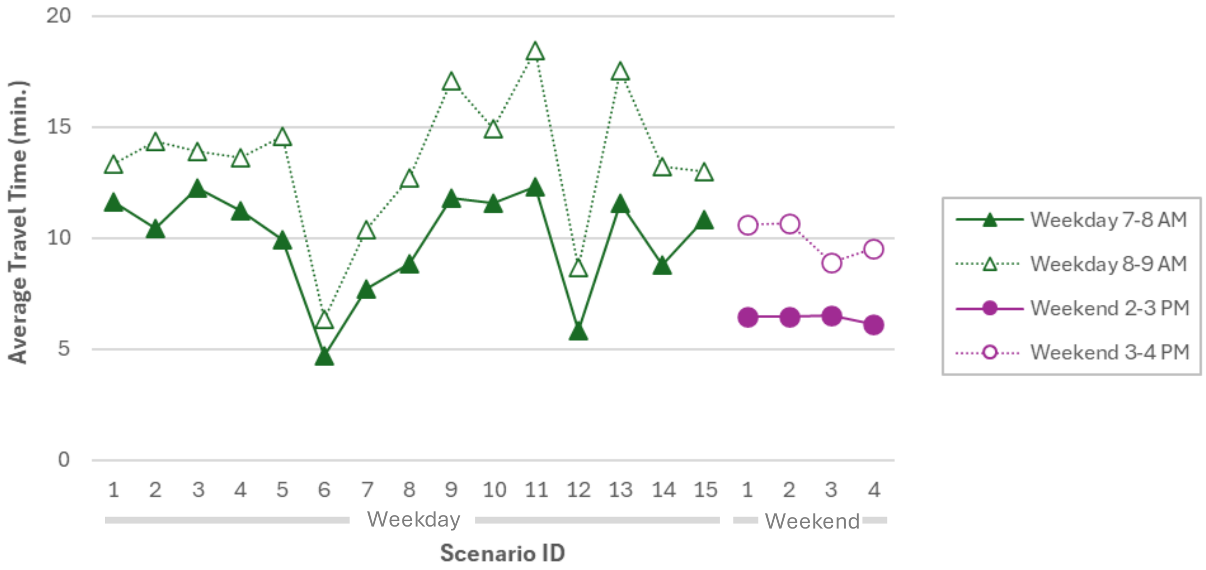
Scenario name	Scenario ID	Average travel time (min)	Standard deviation of travel time (min)	95th percentile travel time (min)	90th percentile travel time (min)	80th percentile travel time (min)	Buffer index	Skew index	Number of vehicles
4-21	1	13.36	4.89	22.15	19.69	16.86	0.66	1.07	412
21-29	2	14.37	5.05	22.40	20.37	18.41	0.56	0.72	439
25-3	3	13.93	4.71	23.16	20.12	17.31	0.66	1.39	462
41-7	4	13.61	4.74	21.87	19.02	17.03	0.61	0.97	456
44-12	5	14.60	5.31	23.53	21.09	18.59	0.61	0.81	496
46-39	6	6.32	1.21	8.34	7.85	7.22	0.32	1.34	688
48-29	7	10.36	3.03	15.98	14.50	12.60	0.54	1.27	625
58-10	8	12.71	4.11	19.86	17.88	15.80	0.56	1.02	496
61-34	9	17.11	5.75	27.41	24.79	21.25	0.60	1.45	439
65-22	10	14.91	4.74	22.95	21.51	18.39	0.54	1.29	547
72-8	11	18.46	10.82	34.00	25.77	22.28	0.84	1.84	454
80-26	12	8.69	2.64	13.70	12.67	10.71	0.58	1.75	665
85-23	13	17.53	6.60	29.94	26.61	22.10	0.71	2.50	463
89-4	14	13.21	4.13	20.66	18.21	16.18	0.56	0.97	536
90-49	15	12.98	3.65	20.33	18.10	15.40	0.57	1.59	450

Table 17. Origin-destination level, departure time interval 2 p.m. to 3 p.m., weekend.

Scenario name	Scenario ID	Average travel time (min)	Standard deviation of travel time (min)	95th percentile travel time (min)	90th percentile travel time (min)	80th percentile travel time (min)	Buffer index	Skew index	Number of vehicles
39-4	1	6.47	2.28	10.22	8.26	7.53	0.58	1.39	547
56-7	2	6.47	2.28	10.22	8.26	7.53	0.58	1.39	547
75-5	3	6.52	2.31	10.54	8.80	7.61	0.62	1.71	547
94-4	4	6.14	1.36	8.29	7.85	7.25	0.35	1.18	563

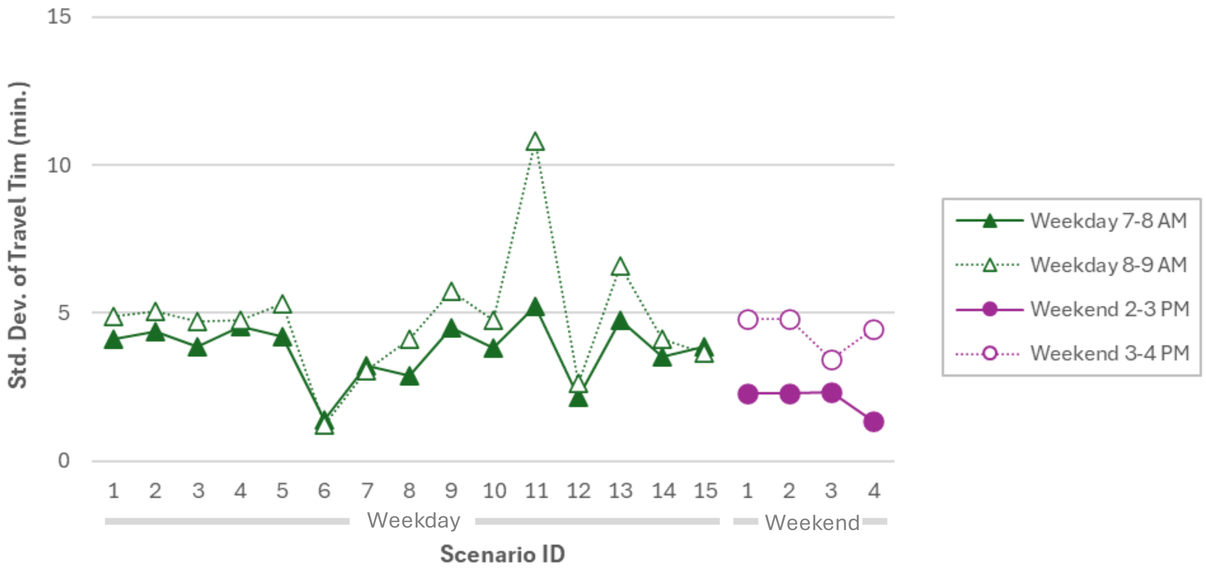
Table 18. Origin-destination level, departure time interval 3 p.m. to 4 p.m., weekend.

Scenario name	Scenario ID	Average travel time (min)	Standard deviation of travel time (min)	95th percentile travel time (min)	90th percentile travel time (min)	80th percentile travel time (min)	Buffer index	Skew index	Number of vehicles
39-4	1	10.60	4.80	19.51	17.22	14.05	0.84	1.70	576
56-7	2	10.66	4.80	19.39	17.28	14.26	0.82	1.65	576
75-5	3	8.92	3.42	15.67	12.63	10.94	0.76	1.51	575
94-4	4	9.50	4.46	18.08	15.71	12.48	0.90	2.10	586



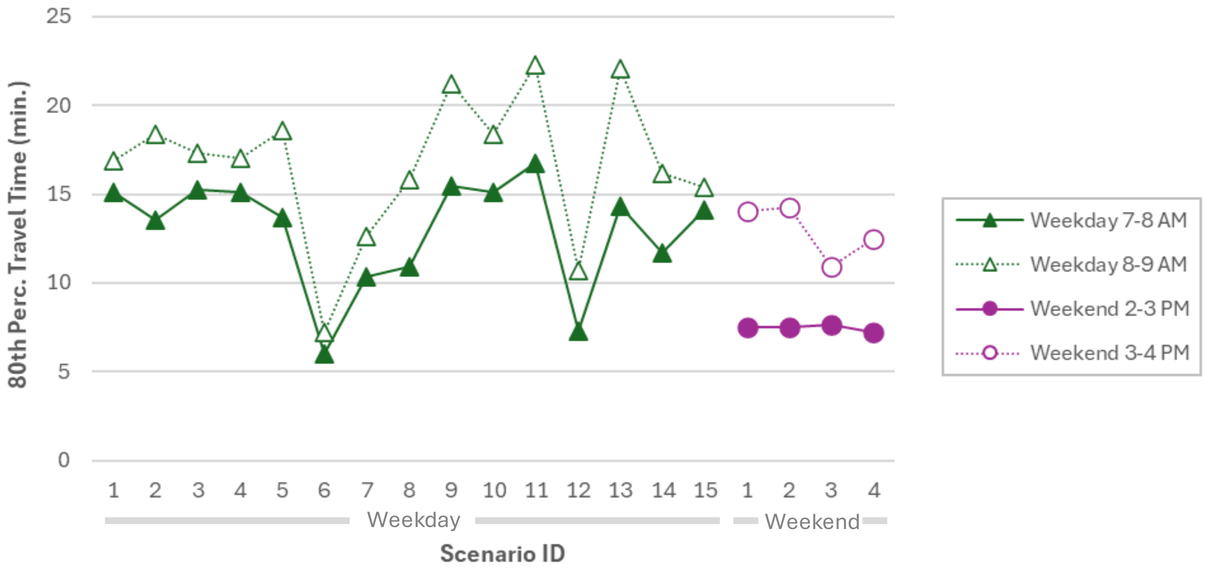
Source: Mahmassani et al. 2014.

Figure 31. Graph. Origin-destination level, average travel time.



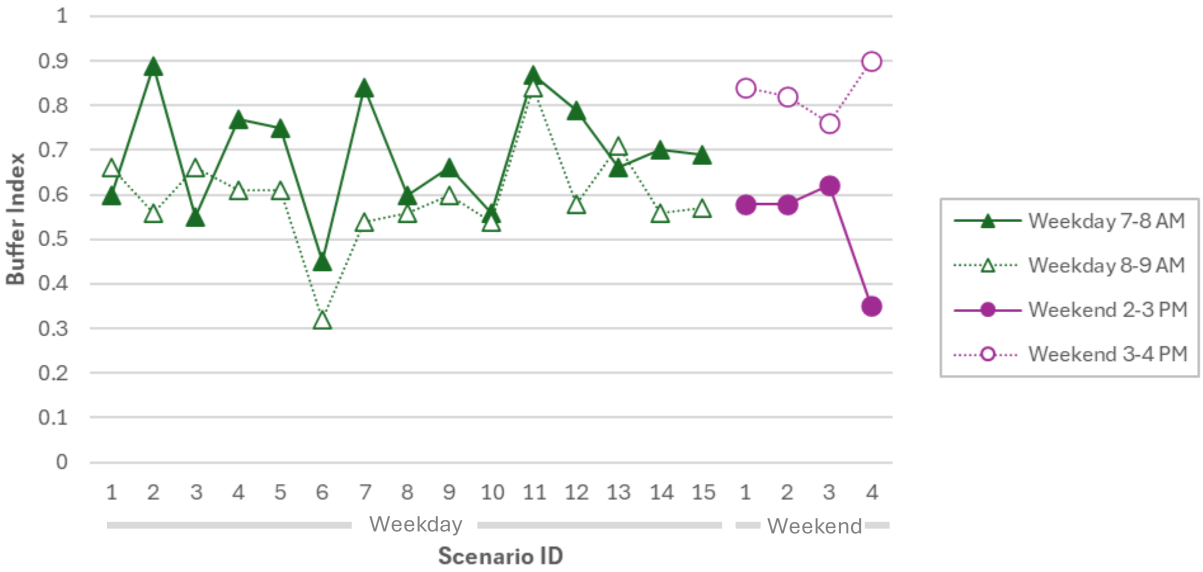
Source: Mahmassani et al. 2014.

Figure 32. Graph. Origin-destination level, standard deviation of travel times.



Source: Mahmassani et al. 2014.

Figure 33. Graph. Origin-destination level, 80th percentile travel time.

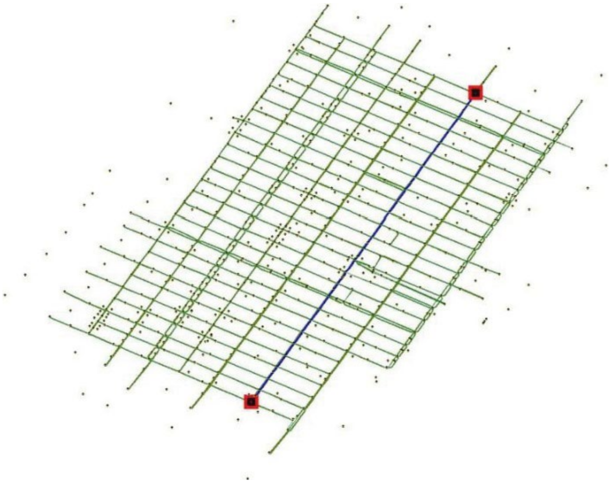


Source: Mahmassani et al. 2014.

Figure 34. Graph. Origin-destination level, buffer index.

Path-Level Analysis

Analysis of TTR can also be done at a path level for trips following a route between two points in the network. The length of the path chosen for this experiment is around 1.2 mile and is shown in Figure 35. The weekday peak was for the 7 to 8 a.m. time interval (Table 19), and the weekend peak was for the 2 p.m. to 3 p.m. interval (Table 20). The performance measures reported for the path analysis are average travel time, standard deviation, 95th/90th/80th percentile, PTI, and buffer index. The results are displayed in Figure 36, Figure 37, Figure 38, Figure 39, Figure 40, Figure 41, and Figure 42, respectively, and indicate that the travel time distribution at a path level is significantly more variable between scenarios for the weekday peak versus scenarios for the weekend peak.



Source: Mahmassani et al. 2014.

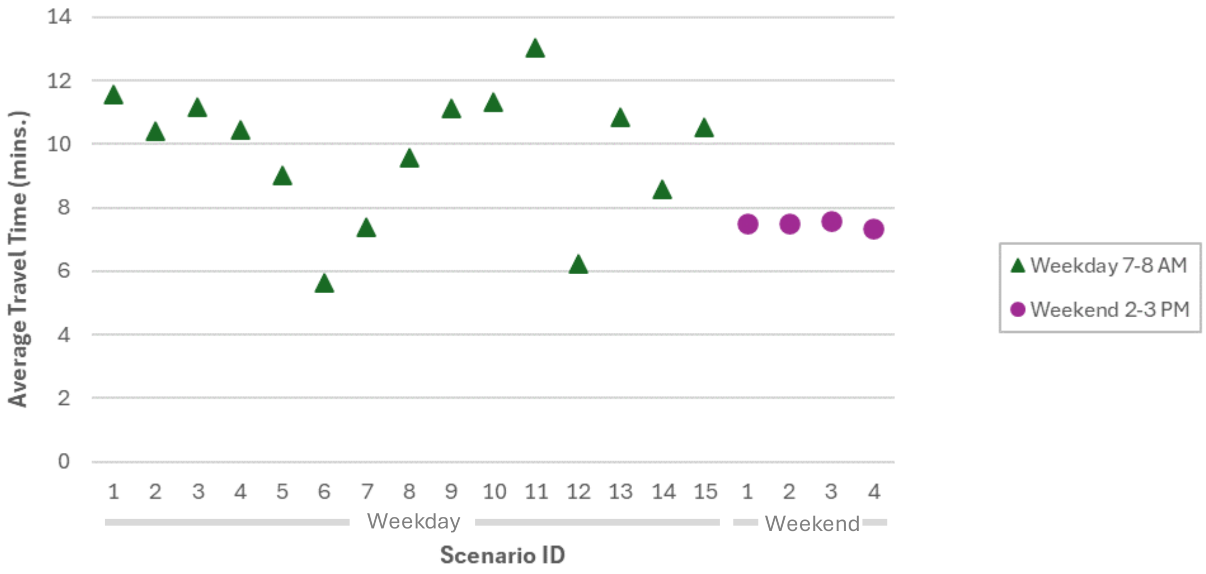
Figure 35. Diagram. Path-level analysis modeling network layout.

Table 19. Path level, departure time interval 7 a.m. to 8 a.m., weekday.

Scenario name	Scenario ID	Average travel time (min)	Standard deviation of travel time (min)	95th percentile travel time (min)	90th percentile travel time (min)	80th percentile travel time (min)	Buffer index	Planning time index
4-21	1	11.56	3.69	17.94	16.45	14.84	0.55	12.14
21-29	2	10.43	3.60	17.40	15.34	13.15	0.67	11.84
25-3	3	11.15	2.90	15.15	14.69	13.48	0.36	10.30
41-7	4	10.46	3.46	16.60	15.15	13.61	0.59	11.31
44-12	5	9.00	3.27	14.87	13.38	11.62	0.65	10.07
46-39	6	5.62	1.36	7.74	7.32	6.75	0.38	5.28
48-29	7	7.39	2.10	11.57	10.59	8.99	0.57	7.91
58-10	8	9.57	2.80	14.45	13.17	11.96	0.51	9.87
61-34	9	11.12	3.31	17.39	15.86	13.49	0.56	11.75
65-22	10	11.33	3.59	16.71	15.84	14.44	0.48	11.34
72-8	11	13.03	4.33	22.50	18.02	16.07	0.73	15.25
80-26	12	6.24	1.41	8.72	8.24	7.32	0.40	5.95
85-23	13	10.83	3.05	15.09	13.82	13.08	0.39	10.18
89-4	14	8.60	2.42	12.44	12.10	10.84	0.45	8.42
90-49	15	10.55	2.98	15.42	15.03	13.47	0.46	10.43

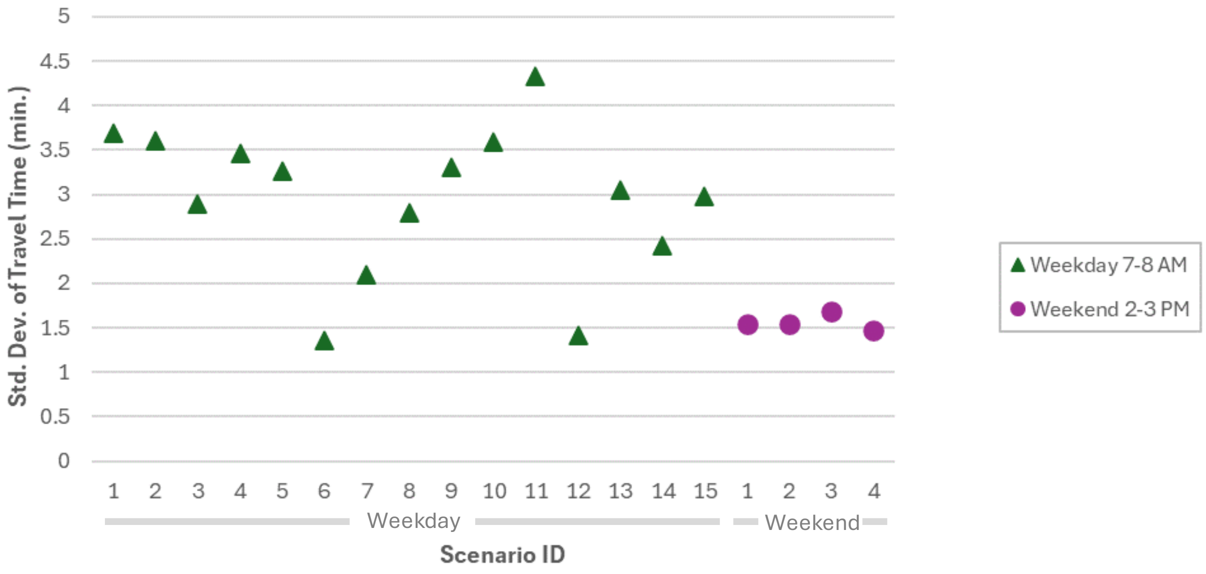
Table 20. Path level, departure time interval 2 p.m. to 3 p.m., weekend.

Scenario name	Scenario ID	Path-level analysis						
		Average travel time (min)	Standard deviation of travel time (min)	95th percentile travel time (min)	90th percentile travel time (min)	80th percentile travel time (min)	Buffer index	Planning time index
39-4	1	7.52	1.54	10.14	9.36	8.82	0.35	6.95
56-7	2	7.52	1.54	10.14	9.36	8.82	0.35	6.95
75-5	3	7.58	1.68	10.38	9.82	8.95	0.37	7.11
94-4	4	7.35	1.47	9.84	9.42	8.63	0.34	6.74



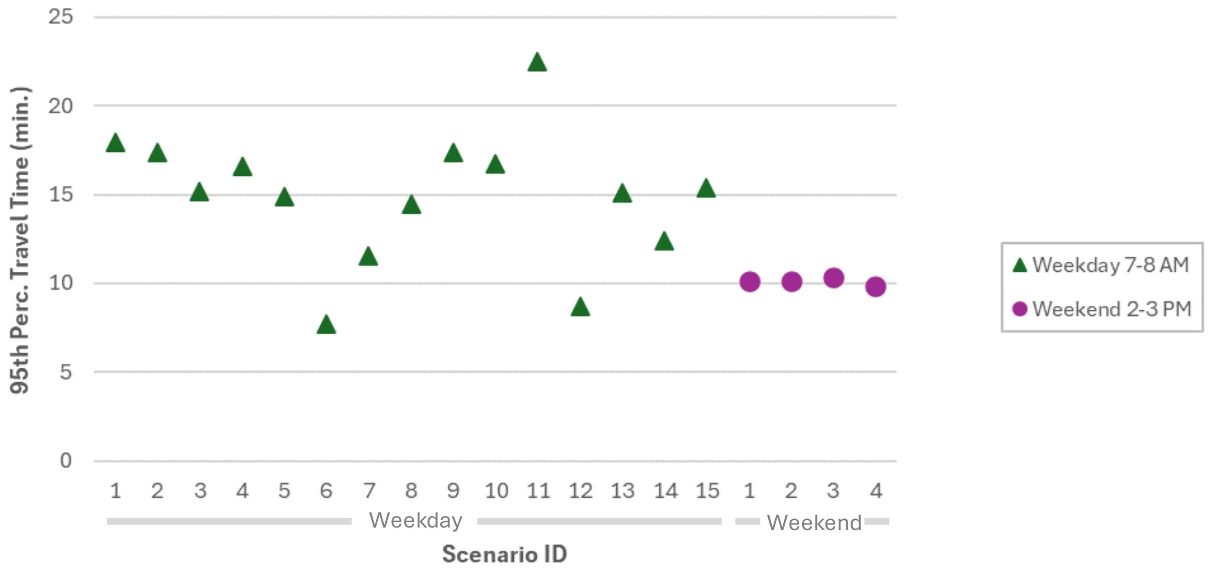
Source: Mahmassani et al. 2014.

Figure 36. Graph. Path level, average travel time.



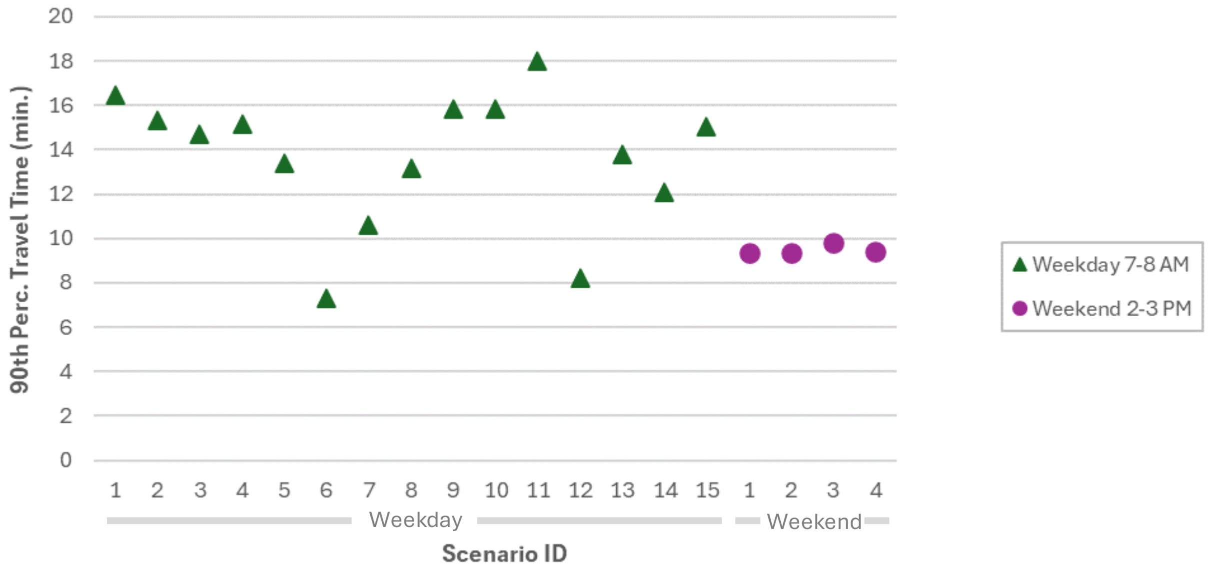
Source: Mahmassani et al. 2014.

Figure 37. Graph. Path level, standard deviation of travel time.



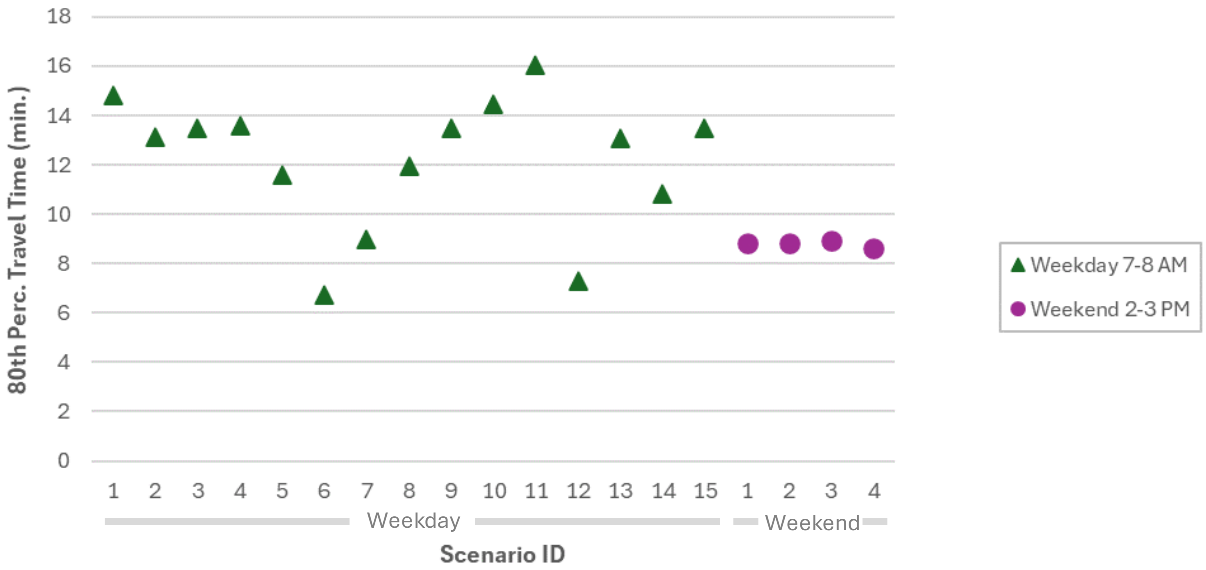
Source: Mahmassani et al. 2014.

Figure 38. Graph: Path level, 95th percentile travel time.



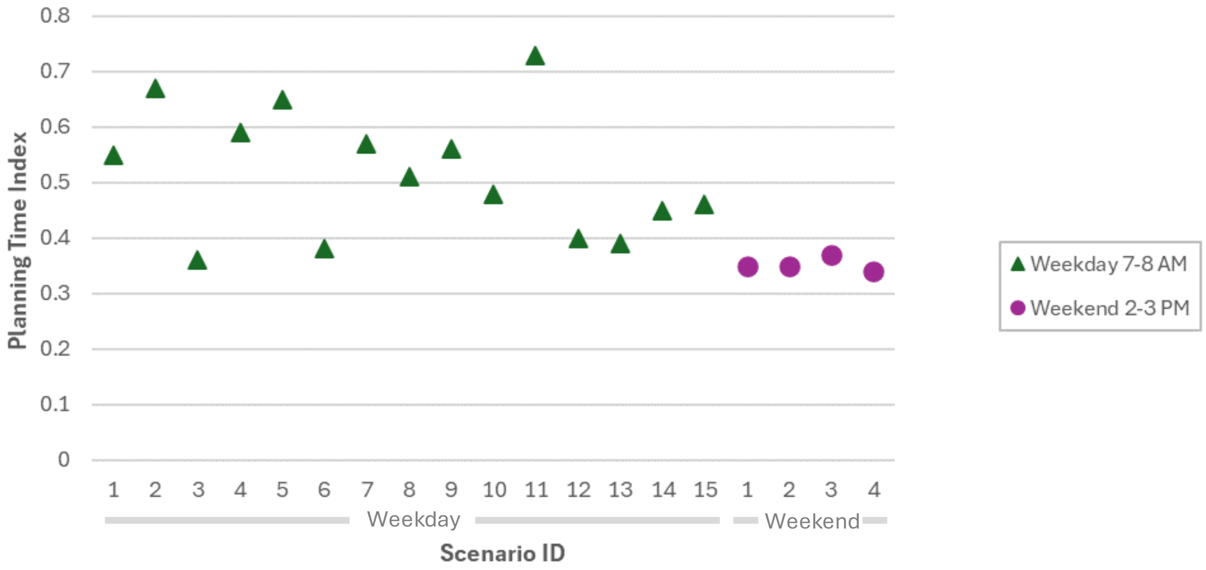
Source: Mahmassani et al. 2014.

Figure 39. Graph: Path level, 90th percentile travel time.



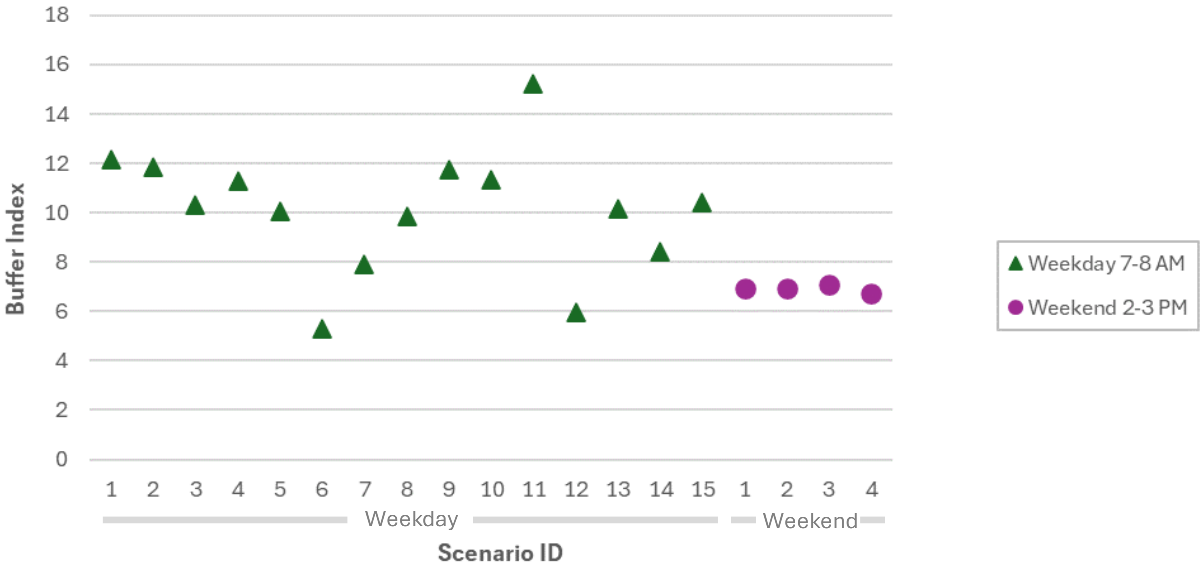
Source: Mahmassani et.al. 2014

Figure 40. Graph. Path level, 80th percentile travel time.



Source: Mahmassani et al. 2014.

Figure 41. Graph. Path level, planning time index.



Source: Mahmassani et al. 2014.

Figure 42. Graph. Path level, buffer index.

Summary of Microsimulation Experiment Findings

In summary, the findings of the microsimulation experiments across all levels of detail are characterized by the following:

- Weekday peak-period travel times are more variable than weekend peak periods.
- Variability in travel time increases as the demand increases during the simulation period.
- Compared with the mesomodel (evaluation can be reviewed in SHRP2 L04 guidance), the microsimulation travel times are much more variable for the same period of analysis. This can be attributed to:
    - *Study area size*. The much smaller study area of the micromodel does not allow for much contribution to the mean travel time by trips that are not affected by incidents. The impact of incidents is more significant in this small microsimulation context because the majority of the trips in the model are affected. Across a wider area, such as in the mesoexperiment, overall average times would not be as sensitive to local incidents because there would be many of the model trips that are far removed from the incident and that would operate under normal travel conditions.
    - *Fundamental difference in the microsimulation and mesosimulation tools*. The method in which Aimsun^{TM} does micromodeling versus the way DYNASMART does mesomodeling could be another reason for greater variability in the micromodel results. In micromodels, individual vehicles typically function separately and are tracked continuously throughout the simulation and are reported as separate trajectories. In DYNASMART, there is more of a grouping of individual vehicles in "platoons," and each vehicle output metric is influenced by the way the platoon moves through the network.

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