CAMBRIDGE SYSTEMATICS

Express Lanes Reliability Measures

Task Work Order 19

summary

report

prepared for

Florida Department of Transportation

prepared by

Cambridge Systematics, Inc.

with

RS&H, Inc.
Kittelson and Associates, Inc.

May 23, 2014

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Executive Summary

PURPOSE

The purpose of this report is to document methods, procedures, and criteria for measuring the travel time reliability and operational effectiveness of express lane facilities in the State of Florida. Express lanes' performance is dependent on a number of factors, including travel time reliability, throughput, and customer satisfaction. The effectiveness of express lanes is one part of the overall effectiveness of the entire freeway facility. The evaluation of express lanes will assess the usage and performance of the lanes and the adjacent general-purpose (GP) lanes.

Express lanes (EL) are becoming an integral part of the freeway system in Florida. Currently, express lanes are considered as an alternative for all future capacity projects on limited access facilities. As Florida constructs new express lanes and converts existing high-occupancy vehicle (HOV) lanes into express lanes, there is a need to evaluate and monitor their effectiveness. These lanes are also a way to provide more travel reliability within a corridor while offsetting the costs of adding capacity to the system. As ELs are planned and constructed, the Florida Department of Transportation (FDOT) will benefit from a consistent way to monitor and report on their performance. The uniqueness of ELs is dynamic toll setting, and the drivers' response to toll setting is inexplicably linked to mobility outcomes. This report will address the linkage by monitoring the travel time reliability of the ELs and GP lanes.

BACKGROUND INFORMATION

The findings of this study relied on a number of different sources of information and assessments of actual data. Related sources of information included:

- **FHWA Priced Managed Lane Guide.** This guidebook provides a comprehensive explanation of the operations and design of ELs.
- **95 Express.** 95 Express is the pilot EL project for the State of Florida. The District 6 staff have operated and provided performance metrics for the project since 2008. The data and approaches were examined and compared to other reliability indices being considered in Florida.
- **Other states.** States that have been operating ELs were contacted to determine the methods being used for measuring performance and reliability. The other states were not preparing much more information than what 95 Express already produces. Other states were interested in what FDOT comes up with.

An examination of data sources was conducted and a determination of the ideal data source was identified. ELs require extensive live data (collected from freeway sensors spaced frequently along the ELs and GP lanes) to operate tolling algorithms and to monitor performance so Management Center Staff can respond immediately to changing conditions. These same collection systems provide a wealth of historical information that can in turn be used to calculate reliability.

RECOMMENDATIONS

Based on the review of practices for measuring reliability in other states, the current practices in Florida, proposed projects in Florida, and the evaluation of actual data on **95 Express**, the following recommendations are proposed.

- **Performance metrics for monitoring.** The measure recommended for monitoring the express lanes' performance is travel time/speed. This measure should be captured using volume weighted travel times for both the ELs and GP lanes.
- **Methodology for calculating speeds using freeway point detection.** Point detection should be extrapolated to represent the travel time over a short distance. The midpoint between detectors separates the travel speed observed in adjacent zones. The travel times should be weighted by volume.
- **Granularity of data.** Data is collected by freeway detection at very small increments (20 seconds or less). This data should be aggregated up to a common interval that is more intuitive and is more manageable. A 15-minute interval is recommended.
- **Time periods for evaluation.** Express Lanes may operate 24/7; however, the critical performance period is during congested periods. Congested period are typically three hours in the morning and afternoon peaks. The three-hour peak period should be the minimum and longer periods considered as congestion levels increase.
- **Segmentation.** A practical approach to segmenting ELs should be considered. The EL monitoring segments should be based on a combination of ingress and egress between major systems interchanges. For continuity, where feasible, the monitoring segments should be similar to the FDOT travel time reliability segments. The typical length of an evaluation segment based on these two criteria should be from 4 to 9 miles.
- **Revenue.** Revenue performance is not a direct measure for mobility measures. Adjusting toll rates is intended to manage performance; therefore, revenue is an outcome of this operation.
- **Performance metrics for reporting**. Key performance metrics for freeways in large urbanized areas are reliability and variability. When reporting on ELs,

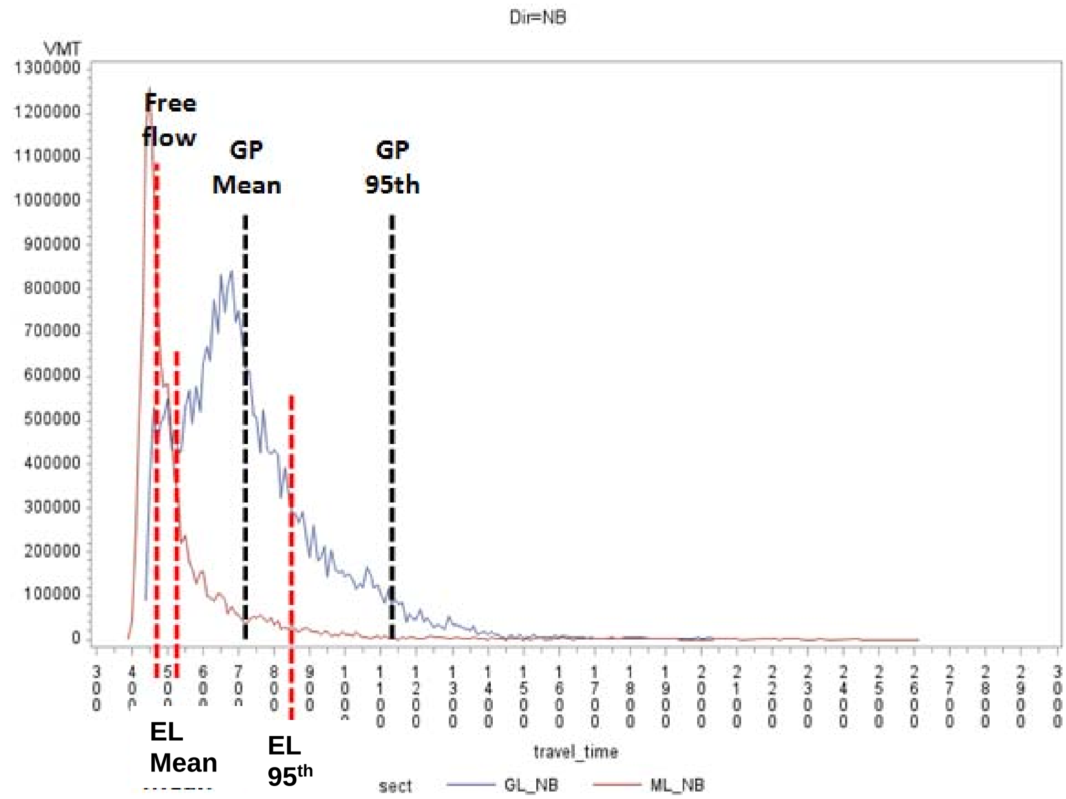
FDOT should capture the percent occurrence above the 45 mph target speed; and TTI based on the 95th percentile travel time over the average travel time.

Table ES.1 95 Express Northbound Reliability Example

	TTI	Average TTI (Minute)	P95TTI	P95_TT (Minute)	Percentage of VMT with Speed >45 mph
GP Lanes					
5-minute	1.52	12.1	2.33	18.7	
15-minute	1.52	12.2	2.33	18.7	24.72%
Hourly	1.52	12.1	2.29	18.4	
Weekday	1.14	8.8	1.77	14.2	
95 Express					
5-minute	1.15	8.9	1.73	13.8	
15-minute	1.15	8.9	1.73	13.9	97.04%
Hourly	1.15	8.9	1.63	13.1	
Weekday	1.05	7.6	1.27	10.1	
Composite					
15-minute	1.41	11.2	2.26	18.1	41.41%

TTI = Travel Time Index; and VMT = Vehicle Miles Traveled.

Figure ES.1 Northbound 95 Express Travel Time Reliability Graph



1.0 Introduction

Express lanes (EL) are becoming an integral part of the freeway system in Florida. Els will be considered as an alternative on all future capacity projects on limited access facilities. As Florida constructs new ELs and converts existing high-occupancy vehicle (HOV) lanes into ELs, there is a need to evaluate and monitor their effectiveness. These lanes are also a way to provide more travel reliability within a corridor while offsetting the costs of adding capacity to the system. As ELs are planned and constructed, the Florida Department of Transportation (FDOT) will benefit from a consistent way to monitor and report on their performance. The uniqueness of ELs is dynamic toll setting, and the drivers' response to toll setting is inexplicably linked to mobility outcomes. This report will address the linkage by monitoring the travel time reliability of the ELs and general purpose (GP) lanes.

ELs, as defined by FDOT, are priced managed lanes with limited access during long extents of the facility. The Federal Highway Administration's (FHWA) *Priced Managed Lane Guide* provides reference material, including key definitions of the various types of special-use lanes, and can be accessed at this link:

http://ops.fhwa.dot.gov/publications/fhwahop13007/fhwahop13007.pdf.

1.1 Report Purpose

The purpose of this report is to document methods, procedures, and criteria for measuring the travel time reliability and operational effectiveness of EL facilities in the State of Florida. The effectiveness of ELs is dependent on a number of factors, including travel time reliability, throughput, and customer satisfaction. The effectiveness of ELs is one part of the overall effectiveness of the entire freeway facility. The evaluation of Els will assess the usage and performance of the lanes and the adjacent GP lanes.

Travelers expect to achieve greater mobility by using ELs. ELs are meant to provide increased mobility through incentives. Unlike GP lanes, travelers using ELs should expect greater trip travel time reliability, as opposed to travelers using GP lanes. ELs by definition should have faster and more reliable trips. The reliability is promoted through setting a price that allows drivers to maintain consistent speed. In practice, as traffic volumes increase, speeds decrease, and toll prices increase. These higher tolls discourage drivers from using the ELs. The objective of this project is to determine how mobility and travel time reliability on ELs should be measured. This study was conducted as Task Work Order 19 under the FDOT's Multimodal Mobility Performance Measures contract.

1.2 REPORT STRUCTURE

The report is designed to provide relevant background material and examples of how ELs are designed and operated so that an informed recommendation on reliability measures and indices can be made. A brief overview of the chapters is provided below.

- **Chapter 2 – Express Lanes.** Within Chapter 2, the major features of ELs are described. In particular, attention to the design and operations that impact reliability is discussed.
- **Chapter 3 – Data Sources, Performance Measures, and Indices.** An overview of available data sources is provided. In addition, performance measures and reliability indices is discussed.
- **Chapter 4 – 95 Express Case Study.** This chapter documents a case study on **95 Express** in Miami, which was the first EL project in Florida. This facility is an eight-mile EL system that has been open since 2008. **95 Express** has been collecting data since inception and provides insights into reliability measures.
- **Chapter 5 – District 4 HOV Lanes Case Study.** This chapter documents a case study on the HOV lanes on freeways in District 4 that have been measured for reliability and performance for a number of years.
- **Chapter 6 – Other States.** A number of state agencies that have implemented priced-managed lanes was queried on current reporting practices and current reliability measures being used. This chapter summarizes these practices.
- **Chapter 7 – FDOT Planned Express Lanes.** More than 300 miles of ELs are in various stages of planning, design, and implementation. A basic overview of the types of facilities is discussed.
- **Chapter 8 – Recommendations.** Recommendations regarding mobility-based performance measurements and reliability are discussed.

2.0 Express Lanes

The purpose of this section is to provide information about the geometric design, operations, tolling, and safety of ELs. This information provides background and highlights the unique features of ELs that will influence the development of reliability measures. There is a draft handbook of guidelines under development for the design of express toll lanes (ETL) in Florida. The following discussion is not intended to supersede the new handbook; only to describe the main features of the EL design.

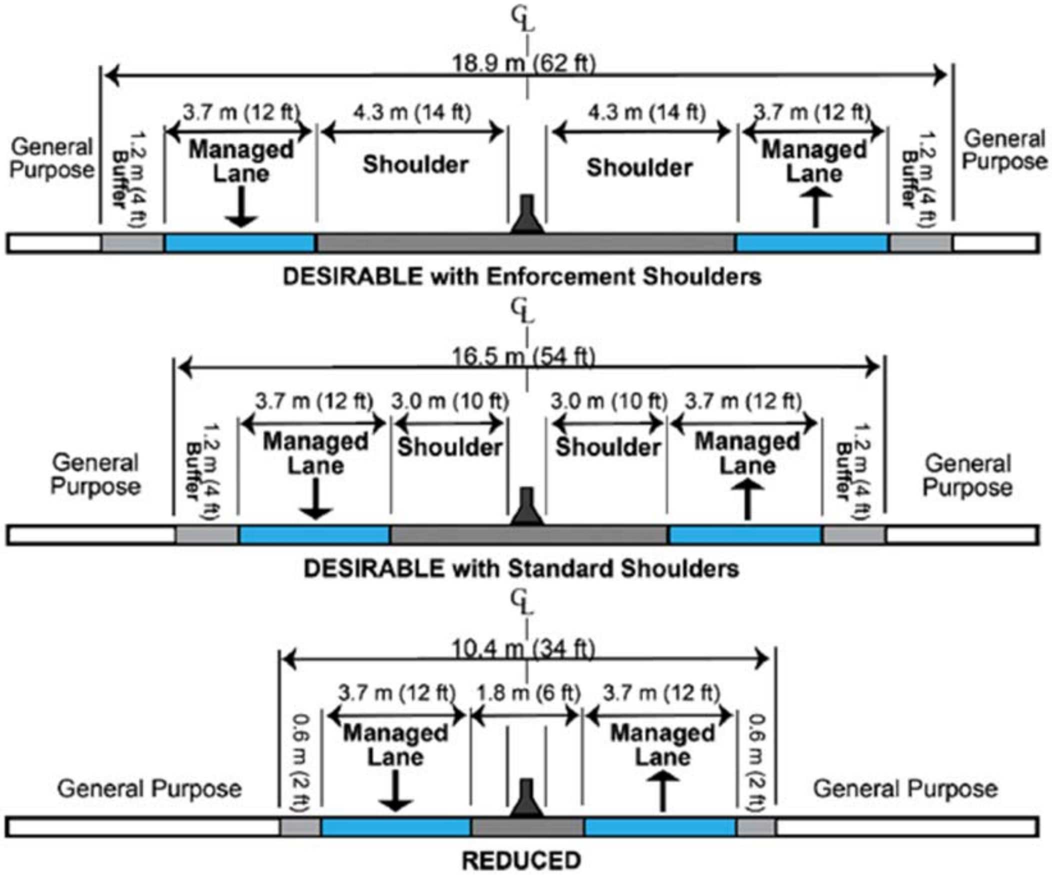
2.1 Design Features

ELs planned for the State of Florida are created by either constructing new Els or converting existing HOV lanes. Existing GP lanes are not considered for EL conversion. Heavy congestion is typically prevalent in urban areas where ELs are planned. ELs are typically built in the interior far left lane(s) and are separated from the GP lanes by either striping with a wide buffer (two to four feet) or with some type of barrier. Access to these facilities is at-grade with slip ramp openings or provided through direct access ramps. The frequency, as well as location, of ingress and egress to the ELs varies depending on the local conditions.

Typical Section

The FHWA's *Priced Managed Lane Guide* provides a number of examples of managed lane configurations. Examples of typical sections similar to the projects being considered in Florida are included in Figure 2.1 below. The buffer area between the GP lanes and the ELs may be separated by striping or with some form of physical barrier.

Figure 2.1 Sample Typical Sections



Source: FHWA-HOP-13-007 Priced Managed Lane Guide, October 2012.

Access

Access to ELs is commonly referred to as ingress and egress. Ingress is leaving the GP lanes and entering the ELs, and egress is leaving the ELs. There are two main types of ingress/egress to ELs: 1) direct access ramps (DAR) and 2) at-grade access. DARs include a physical connections to a cross road where no interaction with regular GP lanes occurs. These connections are ramps to/from a crossroad linking directly to the ELs.

At-grade ingress/egress types vary greatly. These locations are where there is a common opening between the ELs and GP lanes. These connections could be either ingress only, egress only, or both ingress and egress (although due to Type A weaving these openings are discouraged).

Locating Access

A key to the success of the usage of ELs will be the correct location of ingress and egress, as shown in Figure 2.2. Physically these locations must allow drivers to make the required lane changes, over a reasonable distance, to get either in or out of the ELs, and to get to the destination interchange. The access locations must also be located to allow for the maximum use by drivers who potentially want to use the system.

Figure 2.2 Express Lane Schematic Diagram

2.2 Operations

Operating the ELs requires a Concept of Operations and typically includes the following areas:

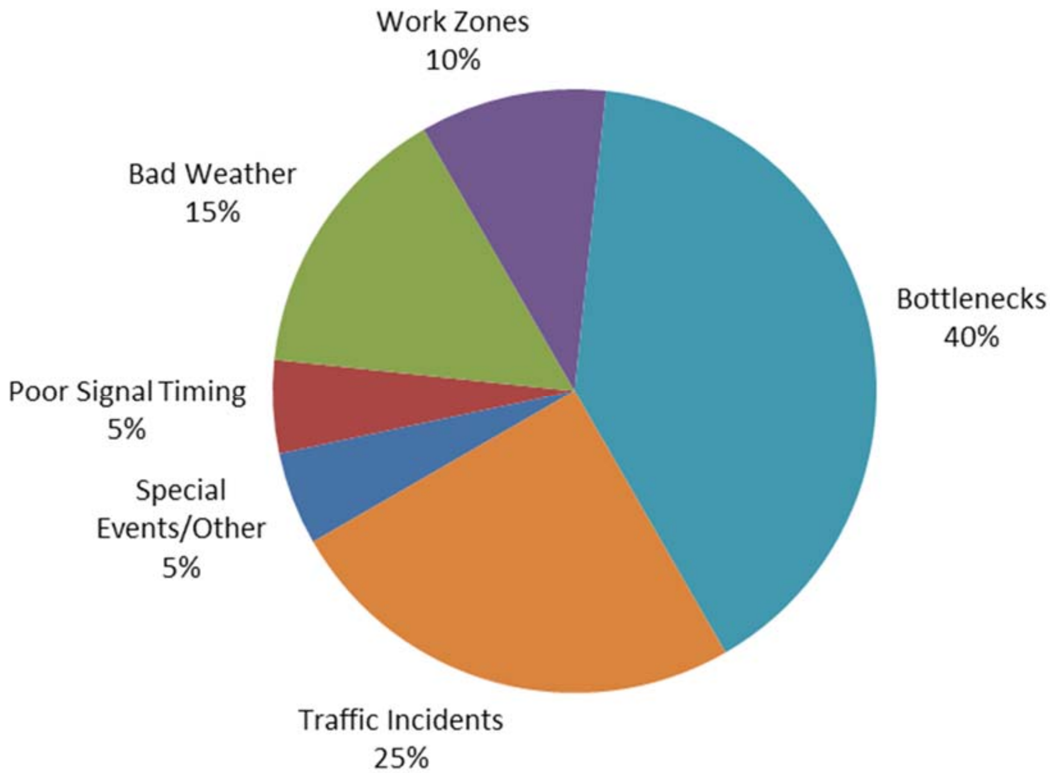
- Toll setting (dynamic pricing, mileage based, zone based, etc.);
- Vehicle exemptions (HOVs, motorcycles, hybrid vehicles);
- Vehicle Restrictions (Trucks, Trailers, etc.);
- Incident management plans; and
- Monitoring plans.
- Maintenance Plan (Delineator Replacement, Equipment Testing, Debris Cleanup, etc.)

A reliable EL facility must have these operational features addressed. Reliability of the performance depends on the day-to-day operations.

2.3 Safety

Safety performance factors heavily into the reliability of a facility. The overall observation in the State has been that approximately 40 percent of congestion are recurring and 60 percent are nonrecurring including crashes. Figure 2.3 identifies the areas and general percentages of different causes of congestion nationally.

Figure 2.3 Causes of Congestion



The conventional wisdom on freeway operations is that when more weaving is introduced and when left-hand entrances are introduced that the freeway would have higher instances of crashes. The EL project without DARs will include left-hand ramps, which tend to introduce more weaving. However, the effects of these conditions could possibly be countermanded by the improved flow attributed to the additional capacity from the ELs. Regardless, the safety performance should not be overlooked.

National Safety Observations

Nationally, ELs have not seemed to have significantly affected safety on the facilities where they have been incorporated. Overall, EL projects have been too few and do not have a long enough operating history to identify patterns, and there is not extensive research available on ELs' impact on safety. Some data and anecdotal information were available on the safety impacts of operating ELs. To understand ELs' relationship to safety, the project team acquired safety information on the ELs in Minneapolis, and Seattle.

I-35W and I-394 Express Lanes, Minneapolis Minnesota

Minnesota Department of Transportation (MnDOT) analyzed crash data three years before and after the implementation of the MnPASS ELs. The crash data along both the I-35W and I-394 EL corridors was compared to the rates shown on all interstates in metropolitan Minneapolis. This limited data set shows a reduction in serious injury crashes. Table 2.1 was provided by Brian Kary with MnDOT, and compares the Minneapolis freeways with interstates in other metropolitan areas.

Table 2.1 MnDOT Managed Lane Crash Comparison

35W MnPass	Length	ADT	K	A	B	C	PDO	TOTAL	Crash Rate	Sev Rate	Fatal Rate	
2006-2008	8.017	96,295	0	6	52	205	600	863	1	1.4	0	
2009 Change												
2010-2012	8.017	93,430	3	2	61	173	690	929	1.1	1.5	0.4	
394 MnPass	Length	ADT	K	A	B	C	PDO	TOTAL	Crash Rate	Sev Rate	Fatal Rate	
2002-2004	9.735	116,179	1	16	72	271	1,285	1,645	1.3	1.7	0.1	
2005 Change												
2006-2008	9.735	112,711	0	9	65	242	974	1,290	1.1	1.4	0	
BEFORE	**Length**	**VMT**	**K**	**A**	**B**	**C**	**PDO**	**TOTAL**	**Crash Rate**	**Sev Rate**	**Fatal Rate**	**FA Rate**
35W MnPass	8.017	845,336,731	0	6	52	205	600	863	1	1.4	0	0.7
394 MnPass	9.735	1,238,447,809	1	16	72	271	1,285	1,645	1.3	1.7	0.1	1.4
Total	17.752	2,083,784,540	1	22	124	476	1,885	2,508	1.2	1.6	0	1.1
After	**Length**	**VMT**	**K**	**A**	**B**	**C**	**PDO**	**TOTAL**	**Crash Rate**	**Sev Rate**	**Fatal Rate**	**FA Rate**
35W MnPass	8.017	820,185,999	3	2	61	173	690	929	1.1	1.5	0.4	0.6
394 MnPass	9.735	1,201,479,536	0	9	65	242	974	1,290	1.1	1.4	0	0.7
Total	17.752	2,021,665,535	3	11	126	415	1,664	2,219	1.1	1.4	0.1	0.7
	Length	**VMT**	**K**	**A**	**B**	**C**	**PDO**	**TOTAL**	**Crash Rate**	**Sev Rate**	**Fatal Rate**	**FA Rate**
35W and 394 BEFORE MnPASS	17.752	2,083,784,540	1	22	124	476	1,885	2,508	1.2	1.6	0	1.1
35W and 394 AFTER MnPASS	17.752	2,021,665,535	3	11	126	415	1,664	2,219	1.1	1.4	0.1	0.7
Metro Interstates (2010-2012)	257.7	24,202,187,604	42	100	1,592	4,525	17,228	23,487	1	1.3	0.2	0.6
Metro Interstates (2007-2009)	257.7	24,799,727,955	54	109	1,398	4,669	18,055	24,285	1	1.3	0.2	0.66
Metro Interstates (2004-2006)	257.7	24,814,788,691	73	137	1,354	5,157	19,481	26,202	1.1	1.4	0.3	0.8
Metro Interstates (2000-2002)	256.4	24,440,462,000	68	128	1,527	4,576	20,501	26,831	1.1	1.4	0.3	0.8

It should be noted that both I-35W and I-394 are highly congested corridors so one would expect to see a slightly higher crash rate than compared to other metro interstates. Having similar crash rates to the rest of the system shows the MnPASS lanes are operating safely.

In addition, in a research paper submitted to the Transportation Research Board (TRB) in 2011 (*Safety Benefits of Converting HOV Lanes to HOT Lanes: Case Study of the I-394 MnPass*, University of Minnesota, TRB 2011 Annual Meeting), the conversion from HOV to HOT along I-394 reduced the number of crashes by approximately 9.8 percent. The figures presented in Table 2.2 were calculated using Empirical-Bayes, and are based on what was expected to occur if the lane remained as an HOV versus what actually occurred as a HOT.

Table 2.2 Crashes per Year Before and After Conversion

	MnPASS				Other Highways		MnPASS		
	Average Number of Crashes				Average Number of Crashes				
Severity	Before 2005 (1)	After 2005 (2)	Reduction (3)=(1)-(2)	Percent Reduction (4)=(3)/(1)	Before 2005 (5)	After 2005 (6)	Expected Number of Crashes After 2005 (7)=(1)*(6)/(5)	Reduction (8)=(7)-(2)	Percent Reduction (9)=(8)/(7)
Fatal	1	0	1	100.0%	23	17.00	0.74	0.74	100.0%
Injury A	6.5	2.5	4	61.5%	34	33.50	6.40	3.90	61.0%
Injury B	25.25	21.5	3.75	14.9%	414.25	333.50	20.33	-1.17	-5.8%
Injury C	87.25	84	3.25	3.7%	1,272.75	1,272.00	87.20	3.20	3.7%
Property Damage	376	284.5	91.5	24.3%	5,393.75	4,603.50	320.91	36.41	11.3%
Total	496.0	392.5	103.5	20.9%	7,137.75	6,259.50	434.97	43.08	9.8%

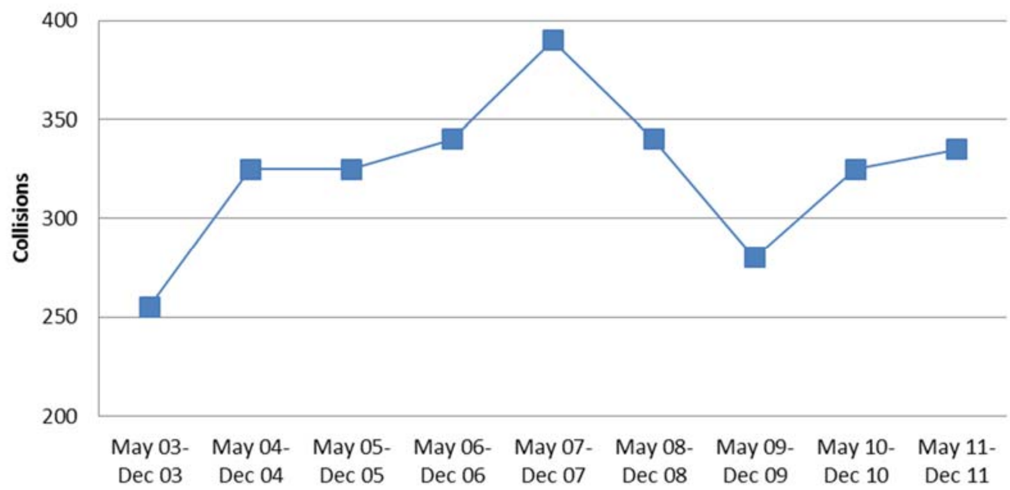
SR 167 HOT Lanes, Seattle Washington

From the 2012 SR 167 HOT Lanes Pilot Project Second Annual Performance Summary, May 2008 to April 2012

The four years of HOT lane operation data indicates that the average number of collisions is down 2 percent when compared to the five-year average prior to HOT lanes opening in 2008. The collision data timeframe begins in May and ends in December because HOT lanes began in May 2008, and December 2011 is the most recent collision data available (see Figure 2.4).

Multiple factors can affect the safety record, including the double white lines preventing erratic lane changes in and out of the HOT lanes, changing traffic volumes, reduced congestion, increasing Washington State Police enforcement, roadway surface conditions, changes in visibility, and a new law requiring the use of hands-free cellular devices. Washington State DOT (WSDOT) remains confident that HOT lanes are not adversely influencing driver safety, and engineers will continue to closely monitor safety data.

Figure 2.4 Collisions on SR 167



Source: NW Region Traffic.

2.4 REVENUE

Another area of performance measurement for ELs is revenue. Both gross and net revenue are important to the success of maintaining and possibly expanding an EL system. Each EL system has a different objective when it comes to revenue. Generally, ELs are viewed as a management tool and revenue is not the priority; although the system should garner sufficient revenue as to cover cost of operations.

Toll setting to maximize revenue may have an adverse effect on the overall system performance. If the tolls are set too high, traffic will avoid the ELs. If traffic avoids using the ELs, the travel time/speed performance may look good in the ELs, but much worse in the GP lanes. Therefore, the toll pricing objectives should be examined if ELs are not meeting the desired performance targets.

2.5 HOT LANES VS. ETLS

Within the FHWA's *Priced Managed Lane Guide*, there are a number of different terminologies used to define the types of managed lanes where pricing is used to control access and performance. The two definitions within the guide that are closest to what Florida is proposing as ELs are HOT lanes and ETLs.

HOT Lanes

HOT lanes use price, occupancy, and access restrictions to manage the number of vehicles traveling on them, thereby, maintaining free-flow traffic conditions, even during peak travel periods. Typically, qualifying HOVs may use these limited-access highway lanes for free or at a reduced cost. Motorists in vehicles that do not meet passenger occupancy requirements may choose between the GP lanes or paying for premium conditions in the HOT lanes. HOT lanes use electronic toll collection and traffic information systems that make it possible to provide variable, real-time toll pricing for non-HOV vehicles. Motorists receive information on price levels and travel conditions via variable message signs, providing potential users with information they need to decide whether to use the HOT lanes or the GP lanes.

Express Toll Lanes

ETLs are dedicated managed lanes within highway rights of way that motorists may use by paying a variably priced toll. They also are typically located next to the median to encourage travel for longer distance trips. Unlike HOT lanes, ETLs charge all vehicles – including HOVs – for passage. In some cases, they may also offer discounted passage for HOVs, but ETLs do not incentivize ride sharing to the extent that HOT lanes do. Enforcement is much simpler and less costly than HOT lanes because there is no need to enforce vehicle occupancy. ETL concepts are also attractive to transportation agencies that want to use toll revenues to cover the cost of new construction and operation.

Interstate 95 is a critical corridor serving passenger vehicles, freight, and transit in southeast Florida. This is a heavily congested corridor in Miami-Dade, where typically travelers experience peak-period travel times that are twice as long as free-flow travel times. With limited right of way, there are few options for adding capacity the traditional way through new lane construction. FDOT District 6 sought intelligent transportation systems (ITS) remedies to improve the mobility along I-95 in Miami-Dade County. The most monumental of these solutions was the creation of the ELs.

The way express lanes are being planned and constructed in Florida makes them a facility within a facility. These facilities are either a conversion of an existing lane(s) or the construction of new lane(s) on the left-hand side of the GP lanes. The ELs in Miami-Dade County were created by converting an existing HOV lane into two toll lanes. The ELs are separated from the GP lanes by plastic delineators. In order to access the ELs, traffic must weave across the GP lanes to get to or from the ELs. The exception is if a direct ramp connection to the ELs is provided. In most cases, the access connections being planned are at-grade.

The dynamic congestion pricing methodology used for **95 Express** adjusts tolls based on traffic conditions in the ELs only and not on conditions in the GP lanes. The goal is to keep traffic moving in the ELs at 45 mph 90 percent of the time during peak periods. ELs may be used free of charge by registered carpools of three or more persons; registered hybrid vehicles; registered South Florida vanpools; motorcycles; and transit, school, and Greyhound buses. Trucks are prohibited.

3.0 Data Sources, Performance Measures, and Indices

3.1 Data Sources

FDOT has acquired the National Performance Measurement Research Data Set (NPMRDS) data through a licensing agreement with the FHWA. The NPMRDS data includes travel speeds for the interstate system dating to October 2011. This data provides five-minute travel times of passenger cars, trucks, and all vehicles[1] on Traffic Message Code (TMC) links collected by probe vehicles. TMC links are a probe data vendor industry standard definition of roadway segments. Because an express lane system is a separate facility within a facility, it should also have its own TMC links. The NPMRDS data does not provide separate speed and travel time data for the ELs TMCs. Currently, the NPMRDS is not a viable data source for reporting on EL performance.

On December 5 2013, Cambridge Systematics obtained access to the historic HERE data through the FDOT ITS Office. The ITS HERE data provides more comprehensive coverage than the NPMRDS data. This data set includes all of the State Highway System (SHS), most local roads, and separate data for ELs. The EL HERE travel time and speed data is not factored in the current reporting of EL performance measures. However, if the confidence in the existing data source diminished, the ITS HERE data should be considered as a source for monitoring the performance of the ELs. This would require conflating traffic volumes to the HERE travel speed data. Conflation is a big task requiring hundreds of man hours and considerable resources.

ITS detector data is a consistently utilized source of travel speed data. ITS instruments are able to capture real-time travel speeds and report travel time data in two-minute increments. This level of granularity is sufficient for performance monitoring and reporting. Because properly functioning ITS instrumentation is critical in updating price algorithms, the EL sensors are regularly serviced. A primary reason ITS sensors are not regularly used to collect volume data is because they are not maintained. However, this is not the case for the EL sensors. They have been found to be a reliable source for both volume and speed data and should be the source for travel time data on express lanes.

[1] Travel time for all vehicles is the average travel time from all sampled probe vehicles.

Table 3.1 provides a comparison of the types of data sources that are available for use. NPMRDS, INRIX, and HERE data are current sources used by FDOT; TOM TOM data is also commercially available, but not commonly used.

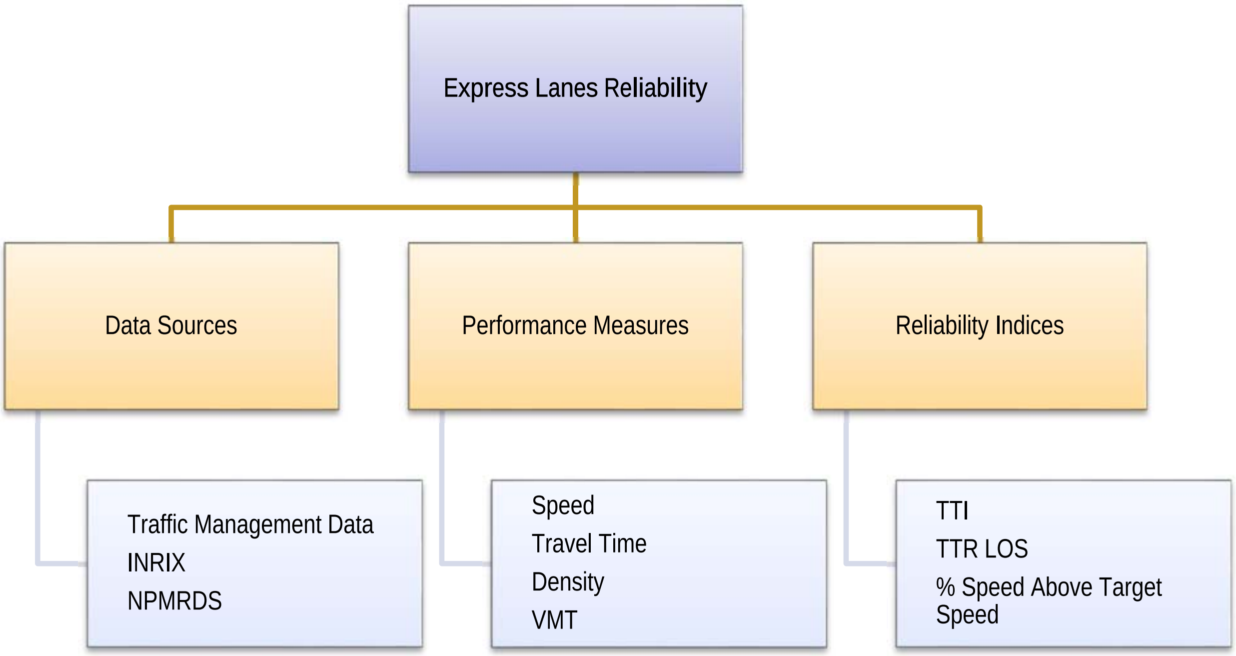
Table 3.1 Commercially Available Travel Time and Speed Data Sources

Data Set	Completeness	Granularity	Data Availability	Freight	Coverage
NPMRDS	Only uses raw data in generating speeds, where there are no observations there are gaps in the data.	5-minute speed data.	New data is reported monthly – historical data is made available.	Includes separate truck travel speeds.	Covers the entire National Highway System (NHS).
HERE	Where data is missing imputed data is used so there are no gaps.	5-minute speed data.	Real-time data can be accessed any time – historical data requires an archiving system (e.g., RITIS).	Does not include separate truck travel speeds.	Covers the entire TMC network in Florida – 20,000+ miles and provides separate TMCs for HOT lanes.
TOM TOM	Roughly 30% of overall travel speeds come from direct field measured observations.	15-minute speed data could be disaggregated to 5-minute data.	Origin/destination data is available. Travel time data can be provided monthly or annually.	Does not include separate truck travel speeds.	Provides data on a linear referencing system with smaller segment lengths than TMCs. TOM TOM likely provides the widest coverage.
INRIX	Approximately 75% of travel speeds in the peak period come from field measured observations.	Speed data can be provided in 1-minute intervals, 1-hour interval, and any interval in-between.	INRIX data downloader allows the subscriber to download any data at any time.	Captures real-time truck speeds, which can be used to create a freight profile. No truck travel speed archive.	Covers the entire TMC network in Florida – 20,000+ miles. INRIX provides additional data for minor arterials and collectors through the XD system.

3.2 Reliability Indices

Measuring the mobility performance of the ELs is essential in price setting and evaluating whether they met their overall goals. The existing service measure for freeways is vehicle density. Transportation agencies will plan and program projects based on observed densities on their freeways. Although density matters in ELs, it is not as important as travel time reliability. The purpose of the ELs is to provide a more reliable travel option to motorists on I-95 in Miami Dade. From a measurement perspective, analysts should account for speeds or travel times when evaluating the reliability of the ELs. This type of assessment can be achieved by calculating the travel time reliability for the ELs. Figure 3.1 identifies some of the typical performance measures used for freeways.

Figure 3.1 EL Reliability Overview Chart

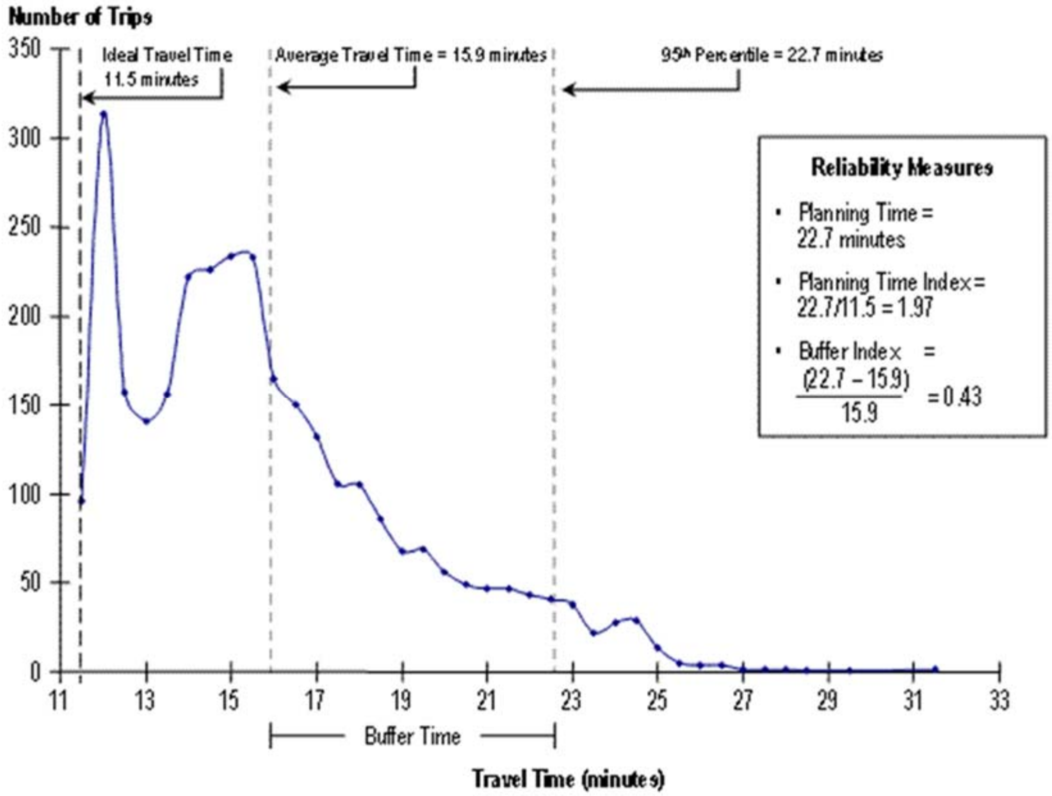


Travel time reliability is quantified from the distribution of travel times for a given facility and time period (e.g., weekday peak period), which occur over a significant span of time; one year is generally long enough to capture nearly all of the variability caused by disruptions. Figure 3.2 is an example travel time distribution. Its shape and distribution is typical of what is found on congested freeways – it is skewed toward higher travel times. The skew is reflective of the impacts of disruptions, such as incidents weather, work zones, and high demand on traffic flow. Therefore, most of the useful metrics for reliability are focused on the right one-half of the distribution; this is the region of interest for reliability.

Most reliability metrics are expressed relative to the free-flow travel time, travel time under low traffic-flow conditions, which becomes the benchmark for any reliability analysis. The degree of unreliability then becomes a relative comparison to the free-flow travel time. The free-flow speed on freeways in Florida is 5 mph over the posted speed limit.

Since the opening of the ELs, FDOT has reported on their travel time reliability. The metric FDOT uses to report on travel time reliability for the ELs is the percent of vehicles traveling above 45 mph. Forty-five miles per hour represents a constant flow of traffic; vehicles traveling at that speed can expect a reliable trip. When passenger travel goes below 45 mph, on a freeway, the travel becomes sporadic and the likelihood of achieving a reliable trip diminishes. FDOT reports on travel time reliability for both directions during the peak periods and daily.

Figure 3.2 Reliability Indices



An alternative means to capture the travel time reliability on the ELs is to measure the travel time variability on the facilities. Variability can be measured through travel time indices. These indices either report on the mean, 80th, or 95th percentile travel times. The 95th percentile TTI is known as the planning time index; this measure is an indicator of monthly facility performance. A traveler empowered with the planning time index results can expect to have an unreliable trip one day out of the month. The mean and 80th percentile measures are more volatile and attempt to predict reliability expectations on a weekly basis.

Measuring the reliability of ELs requires additional considerations over traditional all toll or GP lane facilities. ELs are a system within a system, and they require a certain level of congestion in the adjacent GP lanes so the toll price paid results in reliable travel. Inherently we should expect higher reliability from the ELs than other facilities. With that expectation, we need to explore other aspects of the ELs beyond reliability, including measuring the use of the facility. Maximum use of ELs in peak periods truly provides an overall benefit within the corridor (to both ELs and GP lanes).

The usage of an express lane facility is based on:

- Location of access (does the ingress and egress combination meet the needs of the user);
- Congestion in the adjacent GP lanes (Will the trip in the EL be a significant advantage over the "free" trip?); and
- Toll price.

In instances where the access configuration does not accommodate most users, and/or if the toll price is set too high, a "very reliable" travel time within the ELs will be observed because there are very few users of the EL. In order to cut through these issues, the reliability measures for ELs must include some measure of throughput, congestion levels in the adjacent GP lanes, and possibly the toll price setting.

Other considerations for performance measurement of the ELs include revenue, safety, and the operations of the ELs (detection, tolling algorithms, day–to-day operations). Safety is in this report, but revenue and operations are outside of the purview of the project.

3.3 TOOLS FOR ANALYZING EXPRESS LANES

Data obtained through private vendors may prove to be an acceptable source for reporting on express lane performance. HERE collects data on express lanes, separate from the general purpose lanes, in five minute bins. The suggested approach for monitoring mobility on express lanes is through analyzing the ITS data. Both the ITS and HERE data can be used to establish trend lines and interpolated for predicting future year performance. Alternatively, the Highway Capacity Manual's FREEVAL – ML software allows an analyst to assess future EL performance. FREEVAL – ML is a predictive tool requiring detailed geometric and traffic inputs. The software outputs speed, delay, and travel time indices.

In its current format, the FREEVAL –ML software is a research grade tool. Transportation agencies not already familiar with using FREEVAL will be confronted with a steep learning curve to learn FREEVAL – ML. As the software developers pursue a commercial grade software, with a friendlier user interface, it is likely the use of FREEVAL – ML will grow.

4.0 Case Study: 95 Express

95 Express in Miami-Dade County was an Urban Partnership Agreement (UPA) grant-funded project. As part of the agreement, mobility and performance monitoring were required. In order to meet the objectives, the FDOT District 6 staff ensured that the freeway detection was reliable (this was also needed for running dynamic tolling), and that software was developed that facilitated the processing of an enormous amount of data.

The **95 Express** project provides a wealth of information and insights into the performance evaluation and reliability measures of an express lane system for other districts and for the Central Office. In this section, where the data is collected, how the data is processed into both tolling algorithms and in reliability measures, and alternative methods of calculating reliability will be explored.

4.1 Data Sources

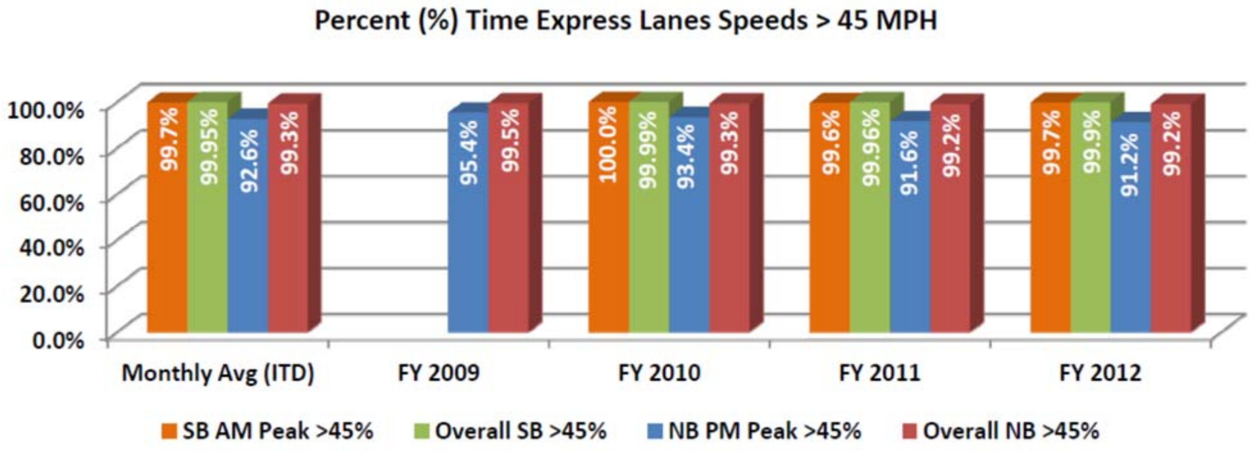
Interstate 95 and the **95 Express** have freeway microwave radar spot detection spaced approximately every one-quarter mile and in each lane. The detection area is approximately six-by-six feet; the type of data collected includes vehicles and percent occupancy (the percent of time that the detector is covered by a vehicle). From the number of vehicles crossing and the percent occupancy, speeds and densities can be derived.

This system of collection is well maintained, and the data and the redundancy of the detectors spaced every one-quarter to one-half mile provide a very data-rich source. This system provides a proper protocol for collecting data on planned express lanes. The detectors are used to run the toll algorithm that requires rigorous, reliable data that is continuously updated to ensure that the toll prices reflect the actual condition. As a result, the ability to report reliability on ELs becomes a straightforward exercise of working with the historical and robust data.

4.2 95 Express Reliability Reporting Criteria

Currently, the primary reliability metric reported for **95 Express** is the percent of traffic traveling over 45 mph (threshold speed). The target percentage is 90 percent or greater. Figure 4.1 illustrates the annual percentage of traffic traveling over 45 mph for **95 Express** and all lanes from 2009 through 2012. As observed below, from the inception of the ELs through 2012, the reliability goals were met.

Figure 4.1 95 Express Fiscal Year (FY) 2012 Reliability Graph



Source: 95 Express Annual Report covering July 1, 2011 through June 30, 2012, Project Status for UPA.

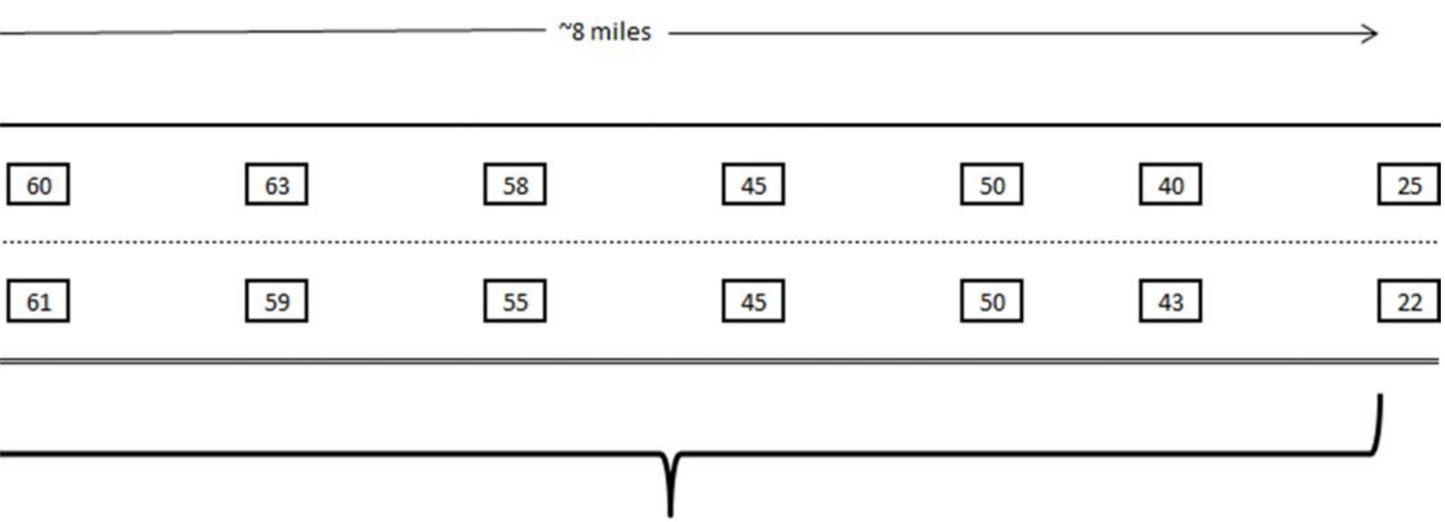
Procedure for Calculating Reliability Speeds

Discussions were held with District 6 staff and SunGuide staff in the Traffic Management Center to clarify how the data is used and how calculations are made for the reliability report. The key features of the calculations are as follows:

1. Peak period data is isolated (three hours in the a.m. and p.m. peak period);
2. 20-second detector speeds are averaged up to 15-minute intervals;
3. All the detectors within the EL are averaged together for each 15-minute interval;
4. The peak period is evaluated based on exceeding the target or not; and
5. Each day in the fiscal year is evaluated for the performance measure.

Figure 4.2 is an illustration of how the 15-minute data is averaged. The method of averaging is a surrogate for travel times; traffic volumes are not considered in the calculation.

ess 15-Minute Average Speed Calculation Procedure



Detector speeds

left	right
60	61
63	59
58	55
45	45
50	50
40	43
25	22

48.3 mph Average speed off all detectors

Other Performance Measures

In addition to the reliability measure, other performance measures and evaluations of **95 Express** include:

- ITS equipment performance;
- Volume throughput;
- Person throughput;
- Revenue and tolls;
- Composition of exemptions (HOVs, motorcycles, and hybrid vehicles);
- Availability of the ELs (percent open to traffic and not closed due to scheduled maintenance or incidents);
- Incident management; and
- Transit use.

No one performance measure tells a complete mobility story. The combination of multiple measures provides a good indicator of express lane performance. Additional performance measures were computed using 15 minute speeds and volumes for both the northbound and southbound express lanes. These observations are based on 365 days of data and 96 analysis periods per day. An analysis of the peak period, from 5 p.m. to 7 p.m. was conducted for both the northbound and southbound Express Lanes. Results for the percent of vehicles traveling at least the posted speed limit, delay, and volume are included in Table 4.1.

Table 4.1 Peak Hour Express Lanes Mobility Measures

2012	Percent Vehicles Traveling at Least PSL	Annual Hours of Delay	Average Hourly Volume in the Peak Period
95 Express	93.4%	60,574	4,240

4.3 SAFETY

The Florida Department of Highway Safety and Motor Vehicles maintains safety records for the State. The safety data is archived in the Crash Analysis Reporting System (CARS). All crashes resulting in $500 or more property damage are reported, including injuries and fatalities. Table 4.1 illustrates the statewide crash totals by type.

Table 4.2 Types of Crashes

Year	Total Crashes	PDO Crashes	PDO (Percent)	Injury Crashes	Injury (Percent)	Fatal Crashes	Fatal (Percent)
2005	268,605	117,541	43.76%	147,879	55.05%	3,185	1.19%
2006	256,200	115,834	45.21%	137,282	53.58%	3,084	1.20%
2007	256,206	117,658	45.92%	135,601	52.93%	2,947	1.15%
2008	243,342	112,416	46.20%	128,162	52.67%	2,764	1.14%
2009	235,778	107,731	45.69%	125,675	53.30%	2,372	1.01%
2010	235,461	108,353	46.02%	124,847	53.02%	2,261	0.96%
2011	228,000	107,883	47.32%	117,903	51.71%	2,214	0.97%

Source: I-95 Historic Crash Data Evaluation Report, FDOT, November 20, 2013.

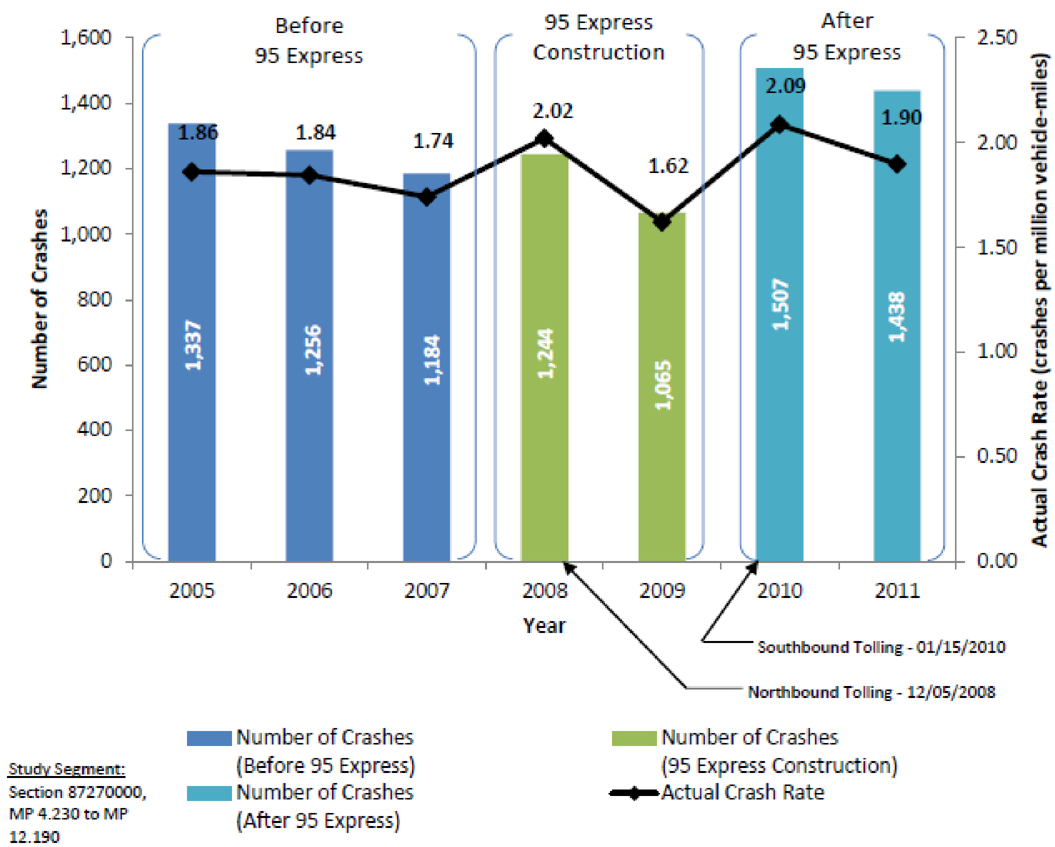
Aside from monitoring the mobility along **95 Express**, FDOT also collects crash data from CARS. Mainline crashes and crashes within ramp influence areas were evaluated separately. Of these total crashes, 4,811 were in the northbound direction and 4,220 were in the southbound direction. The statistical analyses by FDOT District 6 in Table 4.2 shows no significant difference in crash rates when comparing before the ELs opened and after they opened. This is further illustrated in Figure 4.3.

Table 4.3 Crashes by Type and Severity Before, During, and After Construction

SR 9A/I-95 within EL Limits (Mainline Only – MP 4.230 to MP 12.190)		Year						
		Before 95 Express			95 Express Construction		After 95 Express	
		2005	2006	2007	2008	2009	2010	2011
Crash Type	Rear end	826 (62%)	773 (62%)	686 (58%)	701 (56%)	593 (56%)	763 (51%)	767 (53%)
	Sideswipe	291 (22%)	273 (22%)	262 (22%)	278 (22%)	203 (19%)	338 (22%)	358 (25%)
	Fixed object	150 (11%)	139 (11%)	152 (13%)	183 (15%)	188 (18%)	271 (18%)	222 (15%)
	Other	70 (5%)	71 (5%)	52 (4%)	84 (7%)	81 (7%)	135 (9%)	91 (7%)
	Total	1,337 (100%)	1,256 (100%)	1,184 (100%)	1,244 (100%)	1,065 (100%)	1,507 (100%)	1,438 (100%)
Severity	PDO crashes	577 (43%)	612 (49%)	583 (49%)	633 (51%)	570 (54%)	792 (53%)	794 (55%)
	Fatal crashes	9 (1%)	7 (1%)	3 (0%)	5 (0%)	3 (0%)	4 (0%)	7 (0%)
	Injury crashes	751 (56%)	637 (51%)	598 (51%)	606 (49%)	492 (46%)	711 (47%)	637 (44%)
Contributing Causes	Careless driving	826 (62%)	766 (57%)	716 (54%)	738 (55%)	658 (49%)	845 (63%)	696 (52%)
	Improper lane change	235 (18%)	215 (16%)	242 (18%)	275 (21%)	221 (17%)	355 (27%)	0 (0%)
	Other	276 (21%)	275 (21%)	226 (17%)	231 (17%)	186 (14%)	307 (23%)	742 (55%)

Source: I-95 Historic Crash Data Evaluation Report, FDOT, November 20, 2013.

Figure 4.3 Total Crashes on I-95 Before, During, and After Construction

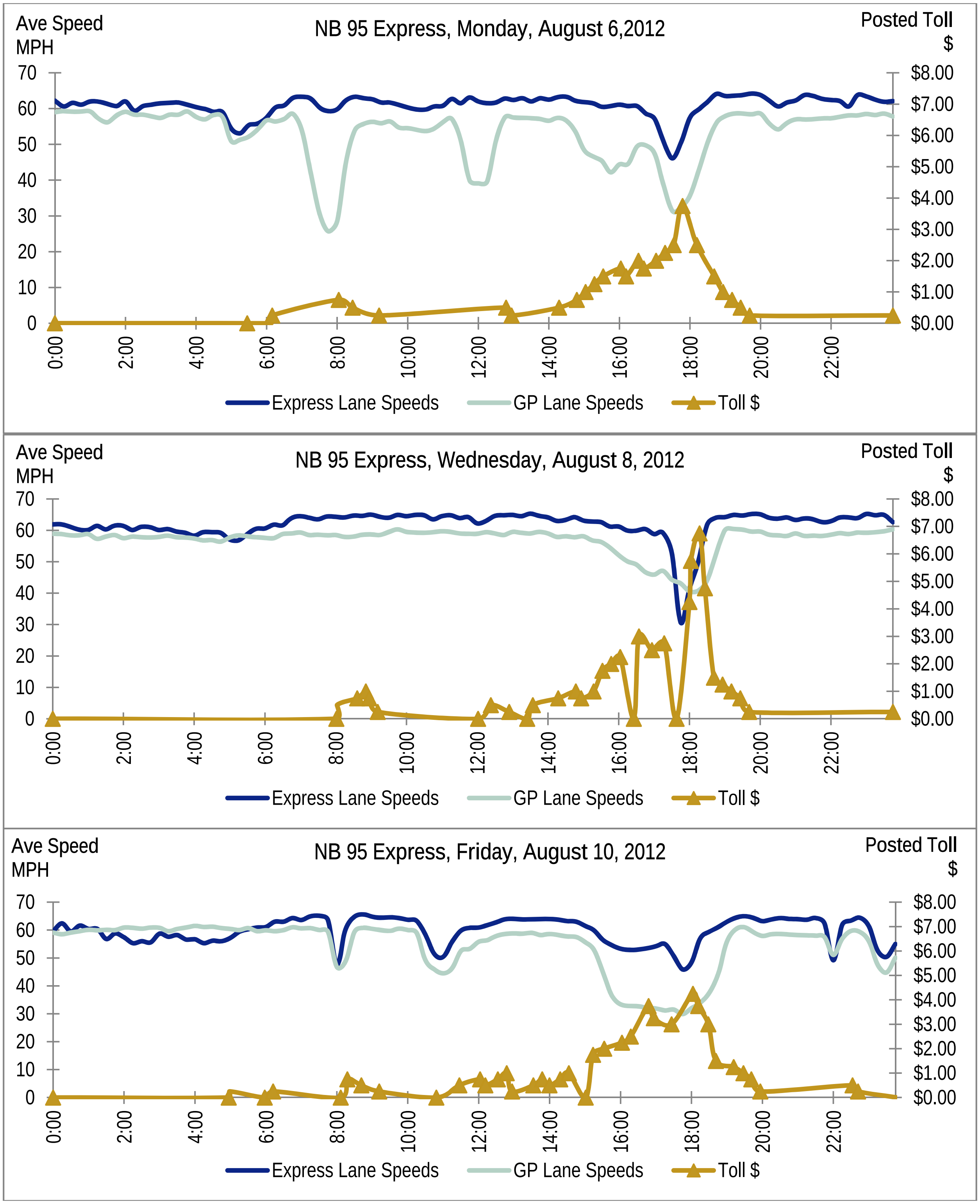


Source: I-95 Historic Crash Data Evaluation Report, FDOT, November 20, 2013.

4.4 Toll Prices and Revenue

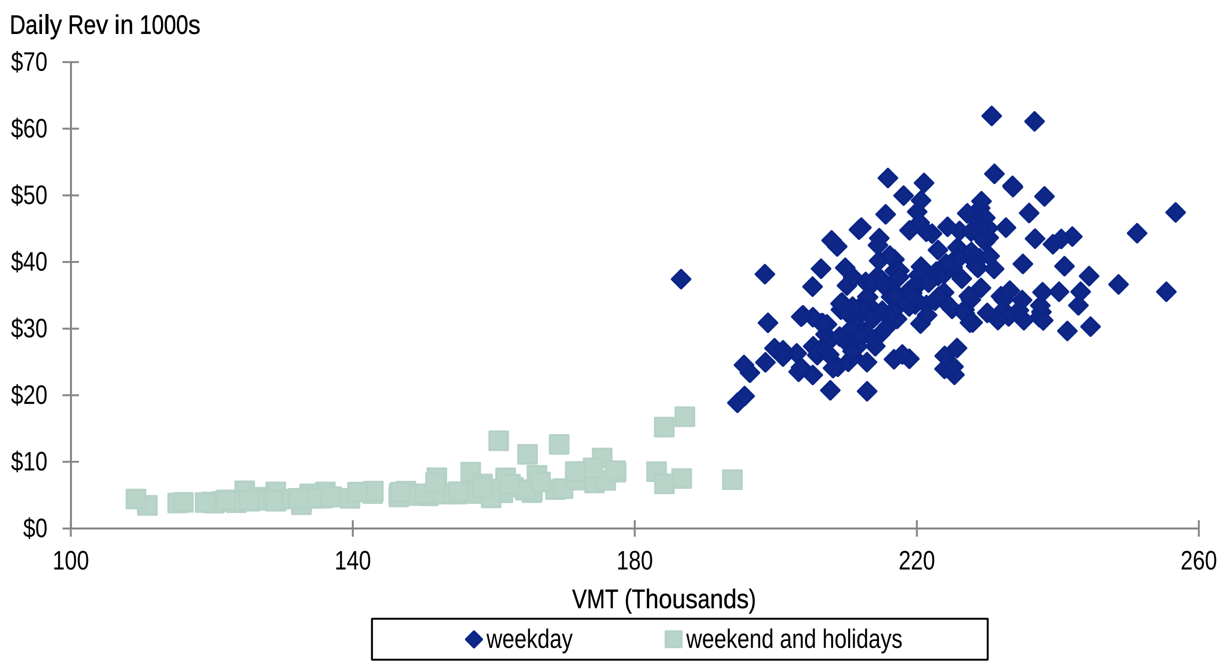
Toll price setting for dynamic tolling requires automation and operator intervention on an as-needed basis. This constant monitoring is a daily activity. Traffic patterns and performance will fluctuate enough on a daily basis to trigger different toll prices. In addition, from day-to-day people will make different choices on whether to use the ELs. Figure 4.4 illustrates toll prices and average speeds in the ELs and GP lanes for the week of August 6, 2012. Three days are shown. The toll prices show how the price responds depending on the performance in the ELs.

Figure 4.4 Northbound 95 Express Speed and Toll Price Relationships – Week of August 6, 2012



An additional expression of how the toll price and performance varies is the fluctuation of revenue on any given day. Figure 4.5 is a plot of daily revenue vs. VMT in the ELs. This shows that, under low-traffic conditions on the weekends and holidays, there is a strong correlation between revenue and traffic. However, during the weekdays there is a bigger spread between revenue and volumes. The range of revenue in the 220,000 VMT range is from $20,000 to $50,000. This spread is understandable based on how the toll prices varied by day in Figure 4.5.

Figure 4.5 95 Express 2012 Daily Revenue vs. VMT



A takeaway from examining the toll prices and revenue shows the difficulties in linking toll price and revenue to annual mobility performance measurement. If mobility performance targets are not being met, the toll pricing approach should be further examined. If the system is managed and monitored on a daily basis, it is expected that the toll prices setting is self-correcting.

It should be noted that if there are other factors affecting performance such as external bottlenecks or extreme saturation, toll price setting might not be enough. Since the start of this project, the 2013 data on **95 Express** is indicating the target is not being met. The statutory toll limit is being reached more frequently and has since been increased to allow the operators the flexibility to manage the system.

5.0 Case Study: District 4 HOV Lanes

Immediately north of the **95 Express** lanes in Miami-Dade County are HOV lanes in Broward County. HOV lanes are restricted to vehicles that have two or more occupants. These lanes are adjacent to the GP lanes and are not physically separated; HOV lane access is uncontrolled. The speed limit for the HOV lanes is 65 mph. HOV lanes on I-95 directly connect to the ELs on the southern end and travel the length of the Broward County to the Palm Beach County line on the north end. The southern portion of the Broward County HOV lanes will be converted to HOT lanes. The **95 Express** project Phase II started construction in June of 2011. Phase II will extend 14 miles north from its current terminus to Broward Boulevard. This project will connect downtown Ft. Lauderdale to downtown Miami.

The FDOT District 4 staff monitor the performance of the HOV lanes in Broward County. The methodology for monitoring the manage lane has been consistent since 1995, utilizing traffic volume counts, speed measurements, level of service (LOS), and vehicle occupancy counts for approximately 10 segments along the freeway. Cambridge Systematics also studied the travel time and costs of traveling from Palm Beach to Miami. This study was multimodal and reported on travel times and costs using Tri-Rail and Metro-Rail, Tri-Rail and express bus, managed lanes, and GP lanes. A 2012 evaluation indicated drivers using the HOV lanes for southbound direction in the a.m. peak saved 18 minutes, and those using the northbound direction for p.m. peak saved 21 minutes.[2]

There is no ITS instrumentation for the HOV lanes. Speed and travel time data is captured through the floating car method. Three runs were completed during both the p.m. and a.m. peak periods. Traffic volumes come from one-day data collection efforts at spot locations along the corridor. The heaviest volumes were south of NW 69th Street in the a.m. peak and south of Sunrise Boulevard in the p.m. peak both in the southbound direction.

Vehicle occupancy surveys conducted in eight locations during March record the number of single occupant vehicles (SOV) observed in the HOV lane. District 4 summarizes violation rates. Violation rates are defined as the percentage of total HOV lane volumes comprising SOVs. This metric is reported by location along the HOV lanes. This information is obtained by watching video feeds of the HOV lanes. Unfortunately, it is tough to capture children sitting in the back seat,

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[2] *2012 I-95 Managed Lanes Monitoring Report*, prepared by Cambridge Systematics, March 1, 2013.

and glare on the windshields often prohibits getting a good look at who is inside. Person throughput combines the vehicular volume with the average occupancy rate. FDOT's goal is to achieve the National Cooperative Highway Research Program (NCHRP)-recommended person throughput threshold for HOV lanes (400 to 800 persons per hour).

GP lane and HOV lane speeds are reported by section along I-95 in Table 5.1. Figures 5.1 and 5.2 chart the differences in average speed by direction for the a.m. and p.m. peak hours.

Table 5.1 ML and GP Lane Travel Speeds

	A.M.					P.M.			
Section	Distance (miles)	GPL Speed (mph)	HOV Lane Speed (mph)	Speed Difference (mph)	Travel Time Savings (min:sec)	GPL Speed (mph)	HOV Lane Speed (mph)	Speed Difference (mph)	Travel Time Savings (min:sec)
Northbound									
Indiantown Rd - Okeechobee Blvd	15.58	67.3	67.7	↑ 0.4	00:05	67.2	67.3	↑ 0.1	00:01
Okeechobee Blvd - Glades Rd	24.35	67.1	68.0	↑ 0.9	00:18	63.1	65.0	↑ 1.8	00:40
Glades Rd - Broward Blvd	17.68	51.4	60.2	↑ 8.8	03:01	43.2	48.8	↑ 5.7	02:51
Broward Blvd - GGI*	13.56	53.0	67.8	↑ 14.8	03:22	41.5	62.0	↑ 20.5	06:30
GGI - SR 112**	7.36	54.7	71.8	↑ 17.1	01:55	26.2	57.6	↑ 31.5	09:13
Total	78.5				08:42				20:31
Southbound									
Indiantown Rd - Okeechobee Blvd	15.58	65.7	64.7	↓ -1.1	-00:14	67.6	66.9	↓ -0.7	-00:09
Okeechobee Blvd - Glades Rd	24.35	65.5	66.6	↑ 1.2	00:24	64.9	64.6	↓ -0.3	-00:06
Glades Rd - Broward Blvd	17.68	46.3	57.3	↑ 11.0	04:23	46.6	54.9	↑ 8.3	03:27
Broward Blvd - GGI*	13.65	35.9	47.1	↑ 11.2	05:22	39.5	59.5	↑ 20.0	06:55
GGI - SR 112**	7.36	28.0	58.1	↑ 30.1	08:10	55.2	67.8	↑ 12.7	01:30
Total	78.5				18:26				11:37

* Travel time was actually between Broward Blvd and the Flyover from the Express Lane south of Miami Gardens Dr in 2012.

** Travel time was collected between GGI and EL southern terminus

Figure 5.1 I-95 Average Northbound Travel Speeds

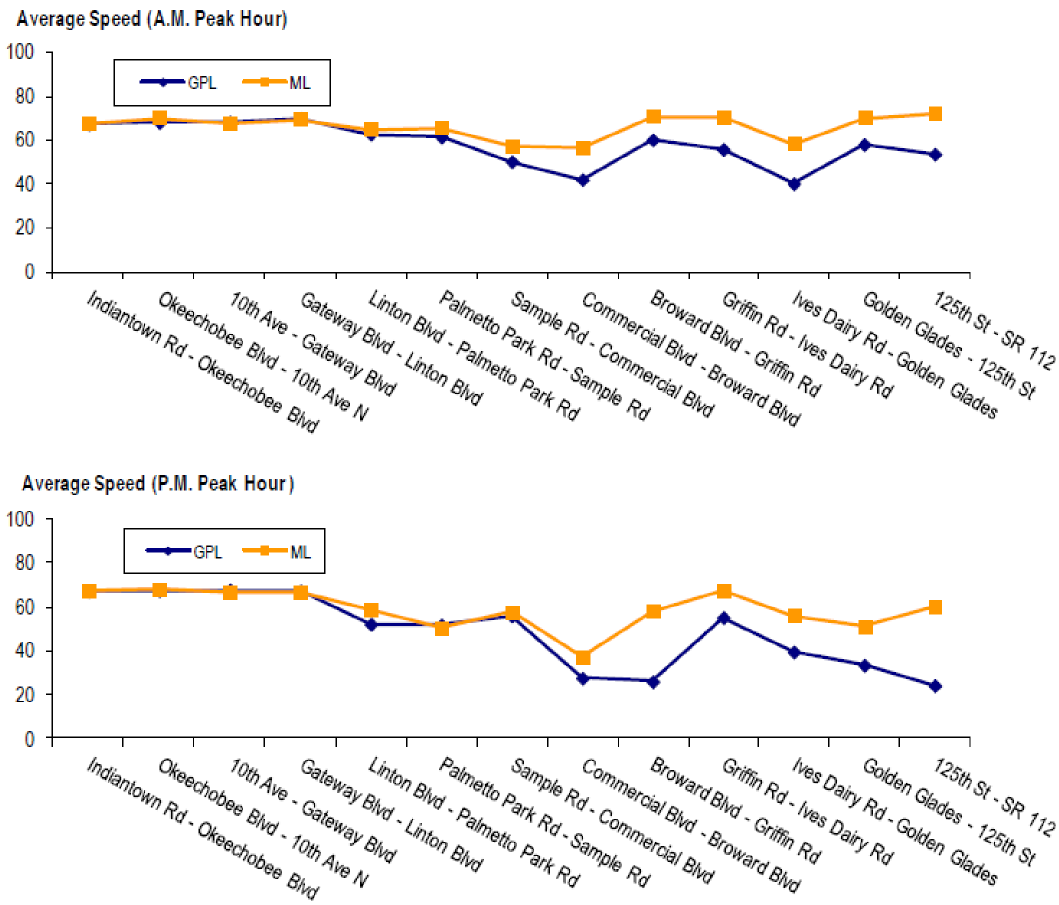
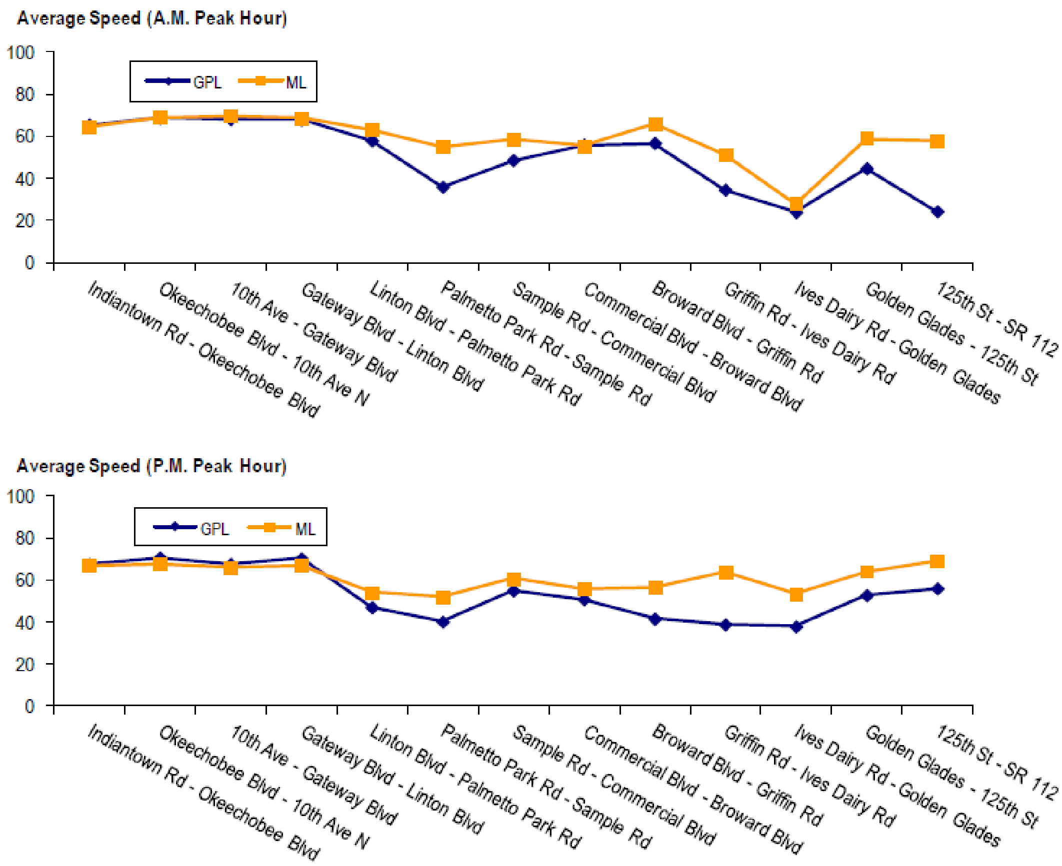


Figure 5.2 I-95 Average Southbound Travel Speeds



6.0 Other States

Agencies differ on their traffic performance goals; achieving congestion reduction can mean reducing delay, increasing person volume throughput, or improving reliability. Even reliability is not uniform across agencies as some track travel time variability and others track percent of vehicles maintaining an acceptable travel speed. Demand, geometrics, and policies are the driving forces determining which particular performance metrics are used in different projects. Regardless of the measures chosen, comprehensive baseline data documenting conditions prior to the opening of the priced managed lane facility is necessary in determining the effects of pricing when the facility becomes operational. Identifying baseline conditions allows for the comparison of the current performance on the GP lanes with the previous performance of the GP lanes.

The primary purposes for performance measures on priced managed lanes are to provide information for pricing algorithms. Secondarily, performance measures assist in monitoring traffic operations, speeds, and reliability. Another important reason performance measures are tracked is to document the performance to validate the congestion pricing to the public. Performance data should be made available to the public to avoid a political backlash, and to educate the public on the projects purpose and benefit. Some of the performance measures used to validate a project may also be used to make operational facility changes. It is critical to identify performance measures that will provide a consistent means to managing the facility operations and define when changes in toll prices are necessary. Table 6.1 lists common performance measures used to evaluate general purpose and tolled traffic performance and system performance. If the performance does not meet the standards set for the facility, then prices should be adjusted accordingly.

According to the NCHRP 694, *Evaluation and Performance Measurement of Congestion Pricing Projects*, transportation agencies should develop a performance monitoring team from different disciplines to discuss performance monitoring needs of the project. The represented disciplines should establish goals for their focus area based on existing baseline data. Candidate measures should be associated with a given goal. Performance measures selected should illustrate the goals of the priced managed lanes in the same manner those goals are presented to the traveling public. The top two reasons a traveler will consider using priced managed lanes are travel time reliability and time savings. In fact, the FHWA has mandated that states maintain an average travel speed of 45 mph for 90 percent of the time on HOT and HOV lanes.

Table 6.1 Congestion Pricing Performance Measures in Practice

Evaluation Area		Performance Measures
Traffic Performance	Speed and Travel Time	• LOS • Average speed, 95th speed • Speed differential (GP vs. HOT lanes) • Travel times • Travel time savings • Cost of delay/value of time (VOT)
	Volume	• Vehicle volume (hourly/daily/weekly/monthly) • Person volume (hourly/daily/weekly/monthly) • Tolled trips vs. untolled trips
	VMT	• VMT
	Congestion	• Delay/wait times • Congestion coefficient • Queue length
	Mode share	• Mode share (HOV, SOV, transit)
System Operations	Finance	• Total transaction • Revenue • Average toll/highest toll • Operations and maintenance (O&M) cost

Some performance measures are directly measured in the field (e.g., travel time and others are based on calculations, such as travel time reliability). Of the eight performance areas identified in the report, traffic performance is highlighted as the most important one. Since traffic performance dictates user fees, toll pricing becomes a de facto performance measure. The key traffic performance measures for priced managed lane facilities are volume and speed, because they are the most used by agencies with these types of lanes. The data can be collected on a continuous real-time basis through the use of transponders. Complications arise when not all vehicles are required to have a transponder (e.g., HOV users).

Toll system operations performance measures typically focus on revenues, average toll paid, and highest toll paid. These are indicators of whether an algorithm is responding appropriately to traffic levels without excessive lags, overcompensation, or abrupt increases or decreases. Like speed and volume, collection of toll revenues occurs through the transponders. Dynamic pricing determines the robustness, frequency, and quality of data. The data is captured continuously on a real-time basis and can be considered a must have amongst the performance evaluation measures.

No two pricing projects are alike; no single prescribed set of performance measures is the solution. This is further illustrated in the managed lanes examples provided in Table 6.2. Both Harris County (Houston) and Orange County in California have managed lane facilities with time-of-day static pricing and base the toll prices on volumes; San Diego uses dynamic toll pricing based on vehicle density; Colorado, Minnesota, and Washington State DOTs utilize dynamic pricing based on travel speed.

Table 6.2 Performance Measures in Practice for the Seven Facilities Examined

Evaluation Area	Performance Measures		Number of Facilities Using
Traffic Performance	Volume	• Vehicle volume (hourly/daily/weekly/monthly	7
System Operations	Finance	• Revenue (toll/charge)	6
Traffic Performance	Speed & Travel Time	• Speeds/average speed	5
	Mode Share	• Mode share (SOV, HOV, transit)	5
System Operations	Finance	• Average toll/highest toll	5
		• O&M cost	5
Traffic Performance	Speed & Travel Time	• LOS	4
		• Travel times	4

Performance programs should be tailored to align with project and agency goals. Revenue generation may also be a goal, especially when the objective is to pay for the project. New projects connecting managed lanes are planned for construction in the coming years. Although no managed lane networks are in existence, agencies will need to plan for performance monitoring at the regional level to evaluate managed lane networks.

Harris County Toll Road Authority (Katy Managed Lanes)

The Katy Managed Lanes are a 12-mile HOT lane facility providing two travel lanes in each direction in the median of I-10. There are seven ingress and egress points to the lanes; five from the I-10 GP lanes and two from dedicated park-and-ride transit hubs. The managed lanes have three tolling points and are separated from the GP lanes by flexible “candlestick” barriers. Tolls are collected each time a vehicle passes below one of the three tolling points. For motorists traveling the entire length of the corridor, tolls are collected three times. The three toll amounts are fixed by time of day: off-peak, shoulder, and peak-period rates.

Currently, volumes on the managed lanes are nearing the peak capacity level of 2,200 vehicles per hour per lane for peak times. Because of the high demand, the

Harris County Toll Road Authority (HCTRA) is going to modify tolling. Monitoring of the HOT lanes by HCTRA is tracked by the following measures:

- Vehicle volume (primary);
- Mode share (SOVs, HOV, transit);
- Revenue;
- O&M costs; and
- Collisions/accidents.

Orange County Transportation Authority (OCTA) SR 91 ELs

The SR 91 ELs is a four-lane express toll-lane facility in the median of SR 91, a heavily traveled eight-lane east-west freeway. SR 91 connects the SR 55 near Anaheim with Riverside County. The location of SR 91 is the optimal setting for a HOT lane. The freeway connects growing residential areas in Riverside and San Bernardino Counties with major employment centers in Orange and Los Angeles Counties. SR 91 was the first HOT lane facility in the United States. OCTA's primary goal for the 91 HOT lanes is to manage the volume of traffic using the facility at a level that allows for travel speeds of 60 to 65 mph at all times. There is one single point of access and egress along the HOT lanes.

Tolls on the 91 Express Lanes vary by direction of travel, time of day, and day of week on a fixed schedule. HOV3 motorists are allowed to use the facility free of charge, and trucks are not allowed to use the lanes at any time. The most important of the performance measure is the number of vehicles on the facility. Traffic volumes are detected automatically for both paying and nonpaying vehicles, together with the time of travel, and tolls collected. Peak tolls reached $10.25 in 2010 to maintain a constant speed flow of 60 to 65 mph. While the facility is managed to provide travel speeds of 60 to 65 mph at all times, speeds are not explicitly measured. Rather, they are inferred from the number of vehicles using the facility. If the number of vehicles across both lanes exceeds 3,200 per hour on any given day in any given direction of travel, then the toll rate for that specific period is increased by 75 cents. These decisions can only be made after reviewing 12 weeks of data, and price increases are reflected in the future tolls. Monitoring of the HOT lanes by OCTA is done by tracking the following measures:

- Speed;
- Volume (primary);
- Frequency of use;
- Origin-destination (O-D);
- Revenue;

- O&M cost; and
- Incident response time.

San Diego Association of Governments (SANDAG) I-15 ELs

The I-15 Express (HOT) Lanes are a 20-mile facility between SR 163 and SR 78. The HOT lanes feature a movable barrier allowing for three travel lanes in the predominant direction of travel during peak periods, as well as direct access to three transit centers with large park-and-ride lots. Originally, the HOT lanes were an eight-mile, reversible, managed-lane facility built as an HOV lane. SANDAG expanded the I-15 ELs by adding lanes to create a four-lane, 20-mile, barrier-separated HOT lane facility with multiple access and egress points.

SOV motorists must pay to use the HOT lanes, which feature dynamic pricing with toll rates adjusted in three-minute intervals. Tolls have been distance based since March 2009, with per-mile fees levied based on entry point. Toll levels are communicated to motorists on variable message signs located upstream of entrances to the HOT lanes, providing SOV drivers with the information. The minimum and maximum toll rates are capped at $0.50 and $8.00 per trip, respectively, with a provision for HOV-only operation if less than LOS C conditions on the lanes result even with the maximum allowable toll rate in place.

SANDAG tracks the number of vehicles entering and exiting the I-15 HOT Lanes, together with travel speeds, LOS, vehicle density, and the distribution of paid and nonpaid trips. In retrospect, staff wish they had a quantifiable, measurable approach to document the effect of pricing on such basic issues as traffic levels in the GP lanes. Data collected on the existing HOT lanes only enables them to determine the effects of congestion pricing on SOV utilization of the HOT lanes. The performance measures gathered by SANDAG are:

- LOS (primary);
- Speed;
- Volume;
- VMT;
- Mode share (SOV, HOV, transit);
- Time of departure;
- Trip length;
- Revenue; and
- O&M costs.

SANDAG stated that the term “reliable” tends to be qualitative, because customers’ expectation when driving the road goes beyond travel time. Using data obtained from Electronic Toll Collection (ETC) equipment and other detection devices installed at tolling points on the lanes, toll rates are set in real time and reflect current traffic conditions detected in three-minute intervals. Traffic densities are calculated on a zonal basis to determine if congestion is increasing. If so, an algorithm determines if other zones are experiencing congestion and sets the price accordingly to manage the flow of traffic entering the facility using per-mile toll rate adjustments.

MnDOT MnPass Lanes

MnDOT operates an 11-mile HOT lane facility on I-394, the primary travel corridor between downtown Minneapolis and the City's western suburbs. The facility provides two reversible-flow, barrier-separated HOV lanes on a three-mile section between I-94 in downtown Minneapolis and Trunk Highway 100 (TH 100), together with one nonbarrier-separated lane in each direction between TH 100 and I-494. Originally developed as an HOV system, the I-394 managed lanes were converted to HOT service in 2005. SOVs using the MnPASS lanes pay a toll, depending on congestion levels and the distance traveled, with a different rate paid based on whether motorists travel on the reversible section, the diamond lane section, or both. The facility provides inbound (east) service from 6:00 a.m. to 10:00 a.m. and outbound (west) service from 2:00 p.m. to 7:00 p.m. MnPASS provides 11 access points (five eastbound and six westbound).

When planning for managed lanes, the state legislation provided a requirement of maintaining minimal acceptable conditions. Where MnDOT converted HOV lanes to HOT lanes, traffic service levels must maintain minimum speeds of 50 to 55 miles per hour at least 95 percent of the time. Legislation required MnDOT to document the performance of any HOT lane facilities implemented in the State. The primary goal for congestion pricing is to maintain travel speeds and LOS for HOVs and carpools.

MnDOT also operates a 12-mile HOT lane facility on I-35W between downtown Minneapolis and the City's southern suburbs. Both HOT lane facilities use dynamic pricing, with the average peak-period fee varying between $1.00 and $4.00, depending on the level of congestion in the MnPASS ELs. Minimum toll rates are $0.25 per segment, but can rise to a maximum of $8.00 during periods of peak congestion. Dynamic pricing ensures that traffic in the managed lanes travels at a speed of 50 to 55 mph. Speed is the most important monitoring metric on HOT lane facilities in Minnesota. HOT lane speeds are monitored 24 hours a day by MnDOT's system operators using a series of loop detectors.

Although there is no specific measure of reliability in Minnesota, given that acceptable speeds are always maintained and the HOT lanes are always operational, they are perceived by all stakeholders as being reliable. The following measures are captured by MnDOT:

- LOS;
- Average speed (primary);

- Speed differential (primary);
- Travel times;
- Travel time savings;
- Vehicle volume (trips by hour, by day of the week);
- Mode share (SOV, HOV, transit);
- Vehicle occupancy;
- Vehicle classification;
- Vehicle make;
- Trip length;
- Trip purpose (interviews);
- O-D;
- Departure time;
- Total transactions;
- Average toll;
- Revenue;
- O&M cost;
- Traffic stops (enforcement); and
- Incident response times.

Initial experiences with the HOT lanes illustrated that rising tolls kept users away. The result was poor performing GP lanes and underutilized HOT lanes. When the HOT lanes started operating, the algorithm used to adjust prices was too sensitive to volumes and speed. Prices would rise quickly and travelers viewed these toll prices on messaging boards and chose to remain in the GP lanes.

WSDOT SR 167 HOT Lanes

A single HOT lane runs in each direction of SR 167 between Renton and Auburn in southern Kings County. The northbound lane, approximately 11 miles long, begins at 15th Street SW in Auburn and ends at I-405 in Renton, while the southbound lane, 9 miles long, begins at I-405 and ends at 15th Street NW. Carpools of two or more people, vanpools, transit vehicles, and motorcycles may use the HOT lanes at no cost. The pricing is dynamic with rates adjusted every 5 minutes based on real-time congestion levels. The State Highway Bill requires that average travel speeds during peak hours (7:00 a.m. to 8:00 a.m. and 4:00 p.m. to 5:00 p.m.) of at least 45 mph are maintained at least 90 percent of the time.

WSDOT also uses end-to-end travel times as a measure of reliability. For example, it measured that the northbound peak-hour (7:00 a.m. to 8:00 a.m.) travel time in the HOT lane was 11 minutes on average. Its data indicates that the 95th percentile travel time was also 11 minutes. This means that motorists traveling northbound during the peak hour will experience an 11-minute travel time 95 percent of the time. The southbound lane demonstrated similar travel reliability, with an average travel time of 8 minutes, for which the 95th percentile travel time is also 8 minutes. WSDOT makes a compelling case for the reliability of the HOT lane by comparing travel metrics to those on the GP lanes, where the average weekday northbound peak-hour travel time was 19 minutes, with a 95th percentile travel time of 26 minutes; and a southbound peak-hour travel time of 12 minutes, with a 95th percentile travel time of 19 minutes. WSDOT also tracks travel-time savings between the managed and GP lanes, which were found to be, on average, 8 minutes northbound in the a.m. peak and 4 minutes southbound in the p.m. peak.

Automated data on traffic volumes and speeds in both the managed and GP lanes is collected by loop detectors. WSDOT tracks volume and speed data in multiple timeframes and compares conditions in the GP lanes and managed lanes, as well as the peak and nonpeak direction of traffic. This information can be aggregated or broken down into intervals as small as 5 minutes; toll levels are adjusted every 5 minutes in order to maintain traffic service and speed levels on the HOT lanes using real-time information on travel conditions in the corridor. The algorithm adjusts toll rates based on volumes and speed data, together with the rates at which volumes and speeds were changing. Toll rates can vary between a low of $0.50 and a high of $9.00. If conditions on the SR 167 exceed the $9.00 maximum toll, the facility reverts to HOV-only operation. WSDOT tracks the following performance measures to monitor facility operation:

- Speeds (primary);
- Travel time (primary);
- Travel time savings;
- Volume;
- Vehicle make;
- O-D;
- Revenue;
- Traffic stops;
- Collisions; and
- Incident response time.

One particular challenge cited by WSDOT officials has been identifying appropriate measures of travel reliability on the SR 167 corridor. While WSDOT has done an effective job of communicating improvements in travel speeds and throughput because of the conversion, it remains to be seen whether its reliability metric of the 95th percentile end-to-end travel time carries the same impact. Communicating the meaning of the 95th percentile travel time metric to the public is challenging.

Colorado I-25 Express Lanes

The I-25 EL is a seven-mile, two-lane, reversible-flow HOT lane facility. The High Performance Transportation Enterprise (HPTE) operates the I-25 ELs between downtown Denver and U.S. 36. These lanes initially existed as HOV lanes, then were transit-only lanes, then became HOT lanes. Transit receives priority on the current HOT lanes since peak-hour tolls on the HOT lanes cannot be lower than the express bus fare.

The original performance measure on the EL facility was density-based LOS with a standard of C as prescribed by the FHWA. This criterion was difficult to measure because the managed lanes in Denver operate with single ingress and egress points. The preferred measure for the HOT lanes became travel time. The goal of the HOT lanes is to maintain a 45 mph average travel speed for all vehicles. Particular emphasis is on tracking the average on-time rate for buses operating on the I-25 HOT lanes.

The HPTE collects traffic volumes in 15-minute increments, along with enforcement statistics, incident data and response times, and various maintenance activities like snow plowing. Data collection and management on the HOT lanes are automated. The following measures are captured by the HPTE:

- LOS;
- Travel times (primary);
- Travel time savings;
- Vehicle volume;
- Mode share (SOV, HOV, transit);
- Frequency of use (hot lanes user survey);
- O-D (HOT lanes user survey);
- Trip purpose (HOT lanes user survey);
- Revenue;
- O&M costs;
- Traffic stops (enforcement);
- Collisions/accidents; and
- Transit travel time.

7.0 FDOT Planned Express Lanes

The FDOT currently is preparing an EL handbook. The *FDOT Express Lane Handbook* will include sections on feasibility assessment, vehicle eligibility, revenue potential and toll collection, operations, design, maintenance, and communications. To date the only facility in operation in the State is **95 Express** in Miami. This facility included design exceptions in order to get it constructed as part of an urban partnership agreement (UPA) grant. The **95 Express** project will be reconstructed in the near future to bring the project up to design standard.

There are 34 managed lane projects planned in the next 10 years, through which 371 miles of managed lanes will be constructed. The lengths of the planned projects range from a 1-mile connector between Interstate 4 and Selmon Expressway in Tampa to 29 miles of interstate through Polk County. The average length of a planned managed lane segment is 12 miles.

Specifics for some of the planned 34 managed lane projects have not been decided. Twenty-four of the managed lane projects will involve constructing entirely new ELs. Four projects along I-95 will convert existing GP lanes or HOV lanes to ELs. Planned projects in Miami-Dade and Pinellas Counties are studies to evaluate additional express travel lane alternatives.

The following section focuses on recommendations for monitoring mobility on planned ELs. Recommendations for methodology, procedures, and criteria will be addressed. Guidance on segmentation and reporting provides will assist future EL management efforts. This section will suggest specific measures, reporting time frames, and targets for the ELs.

8.0 Recommendations

Based on the review of practices for measuring reliability in other states, the current practices in Florida, proposed projects in Florida, and the evaluation of actual data on **95 Express,** the following areas of recommendations are proposed:

- Performance metrics for monitoring;
- Methodology for calculating speeds;
- Granularity of data;
- Time periods for evaluation;
- Segmentation;
- Revenue; and
- Performance metrics for reporting.
- Targets

Each of these areas is discussed below.

8.1 Performance Metrics

The measure recommended for monitoring the ELs' performance is travel time/speed. This measure should be captured using volume weighted travel times for both the ELs and GP lanes. A function of the ELs is to improve mobility for the entire facility, including the GP lanes.

After travel speed is captured many performance metrics monitoring the reliability and variability of travel can be reported. These include the percent of travel traveling at least 45 mph as well as the percent of travel traveling at least the posted speed limit. Variability can be reported through travel time index metrics including the planning time index which is the ratio of the 95th percentile travel time to the free flow travel time.

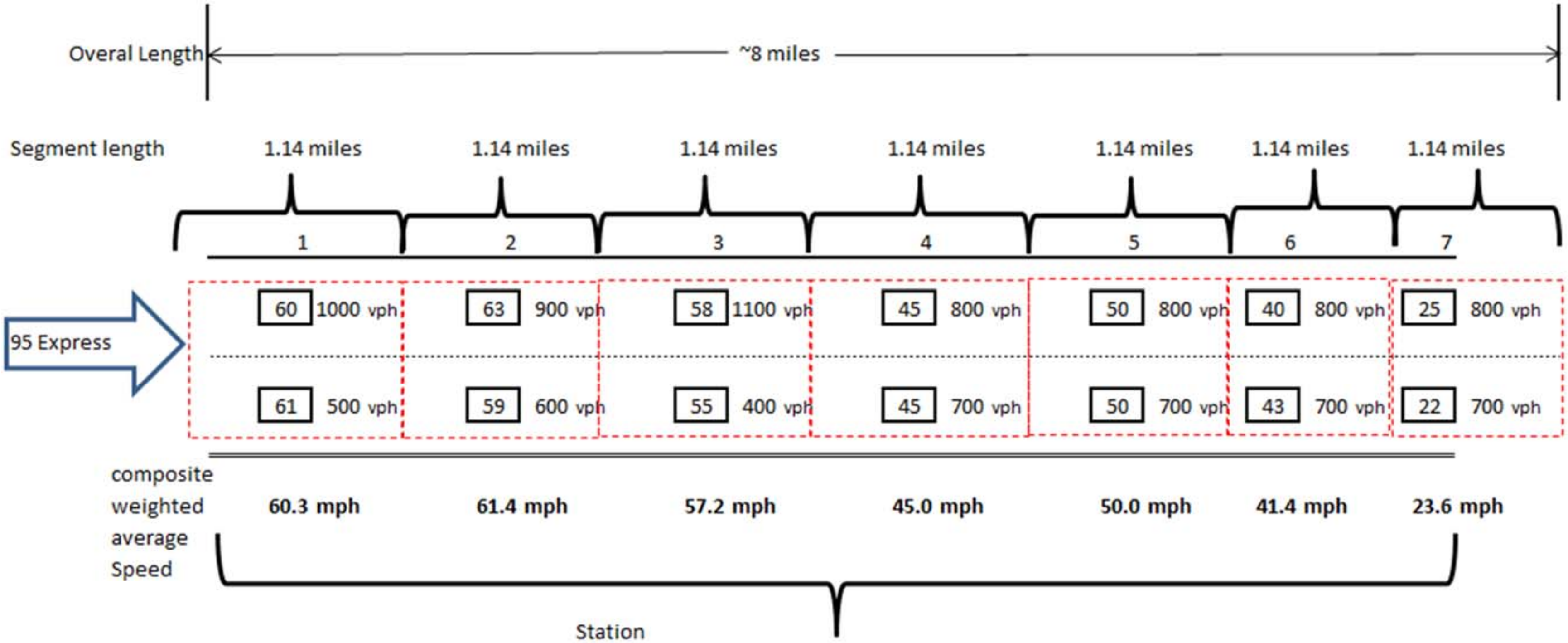
8.2 Methodology for Calculating Speeds

Since ETLs will require extensive freeway detection to run pricing algorithms and to monitor real-time performance, it will be safe to assume that all EL systems will have a data-rich environment for calculating travel speeds.

The ideal method for computing travel speeds that most closely replicate the travel experience of the motoring public is illustrated in Figure 8.1. The data used in the chart is hypothetical data and is the same hypothetical example in Section 4.0 that was used to illustrate the method that District 6 currently is using to calculate travel time reliability. The method illustrated is based on extrapolating the point detection into a travel time segment. The segment is created from midpoint to midpoint between detector groups. If the EL has two lanes, the speed for the detector station is volume weighted. The calculated average speed is converted into a travel time over the hypothetical length of the segment. The travel times of each detector group are added together, and finally the travel time over the entire length of the major length is computed and converted into an average travel speed.

The example in Figure 8.1 resulted in a travel speed over 8 miles of 44 mph, while the calculated speed from Figure 4.2 was 48.1 mph. In this comparative example, the difference in calculation methodologies resulted in not achieving the target speed of 45 mph.

Figure 8.1 Illustration of Calculating Speeds



Station

No.	Ave speed	length miles	travel time min
1	60.3	1.14	1.1
2	61.4	1.14	1.1
3	57.2	1.14	1.2
4	45.0	1.14	1.5
5	50.0	1.14	1.4
6	41.4	1.14	1.7
7	23.6	1.14	2.9
		8.0	**10.9**

44.0 mph Average Travel Speed

8.3 Data Granularity

The surveillance systems used for monitoring speed and volume data will collect and store data in increments as low as 20 seconds. This increment of data is neither practical nor intuitive for reporting performance measures. It is recommended that the practical and more intuitive granularity of data is in 15-minute increments. Tables 8.1 and 8.2 are examples of actual **95 Express** data in District 6. For illustration purposes, different granularity was calculated.

Table 8.1 95 Express Southbound Reliability Example

	TTI	Average TT (Minute)	P95 TTI	P95 TT (Minute)	Percentage of VMT with Speed >45 mph
GP Lanes					
5 minutes	1.02	8.2	1.15	9.5	
15 minutes	1.02	8.2	1.15	9.5	81.3%
Hourly	1.02	8.2	1.14	9.4	
Weekday	1.09	8.7	1.57	13.0	
95 Express					
5 minutes	1.00	7.2	1.00	7.5	
15 minutes	1.00	7.2	1.00	7.5	99.7%
Hourly	1.00	7.2	1.00	7.6	
Weekday	1.01	7.3	1.00	8.2	
Composite					
15 minutes	1.02	8.0	1.12	9.3	97.6%

Table 8-2 95 Express Northbound Reliability Example

	TTI	Average TT (Minute)	P95 TTI	P95 TT (Minute)	Percentage of VMT with Speed >45 mph
GP Lanes					
5 minutes	1.52	12.1	2.33	18.7	
15 minutes	1.52	12.2	2.33	18.7	24.72%
Hourly	1.52	12.1	2.29	18.4	
Weekday	1.14	8.8	1.77	14.2	
95 Express					
5 minutes	1.15	8.9	1.73	13.8	
15 minutes	1.15	8.9	1.73	13.9	97.04%
Hourly	1.15	8.9	1.63	13.1	
Weekday	1.05	7.6	1.27	10.1	
Composite					
15 minutes	1.41	11.2	2.26	18.1	41.41%

Express lane performance is captured every 20 seconds. The granularity of the data allows for multiple periods of reporting. Express Lane performance should be reported minute by minute, for both directions to the traffic monitoring center. Performance on the express lanes should be reported by direction monthly, bi-annually, and annually for the consumption of transportation practitioners and the traveling public. This is consistent with FDOT's current express lanes reporting practices.

8.4 Time Periods for Evaluation

ETLs are in place to provide trip reliability at a cost for the driver to avoid congestion; therefore, the important focus of measuring the reliability of the EL system is during peak periods. The challenge of identifying peak periods or set standard times statewide is that the times and duration will vary by urban area. For example, the duration of congestion in Miami is slowly increasing to four to five hours in the p.m. peak, while in Jacksonville the peaking is less than three hours. At this time, it is recommended that peak three hours in the a.m. and p.m. peaks are used for measuring reliability on the existing ELs. The a.m. peak should be from 6:00 a.m. to 9:00 a.m. and the p.m. peak should be from 4:00 p.m. to 7:00 p.m.

As stated, the peak period is not consistent across large urbanized areas. The peak period experienced in south Florida/Miami Dade is likely the longest in the state. Other large urbanized areas are likely to experience a 2 hour peak period or in some instances a peak hour. On planned express lanes the recommended monitoring period is from 7 a.m. to 9:00 a.m. and 5:00 p.m. to 7 p.m. This should be monitored as more systems are operating to determine if longer/shorter periods should be considered.

8.5 Segmentation

As discussed in Section 7.0, Florida is planning a number of EL projects. These projects are customized to fit within the characteristics of land use and access patterns within each region and between different facilities within the same region. Generally, the ELs are being planned to accommodate longer-distance trips. A practical approach to segmenting ELs should be considered. The EL monitoring segments should be based on a combination of ingress and egress between major systems interchanges. For continuity, where feasible, the monitoring segments should be similar to other FDOT monitoring segments.

To evaluate longer distance travel, typical segment length should range from 4 to 9 miles. Shorter segmentation, like one-mile segments, may not be practical for longer trips and could create skewed results. Previous FDOT research established travel time reliability segmentation for all freeways in Florida. The segmentation was based on travelers' perception of facility length. In less populated areas travelers are likely to monitor the time it takes to traverse a longer distance. In dense urban areas, with high populations, travelers are likely to monitor the time it takes to traverse shorter lengths of roadway. FDOT's travel time reliability facility segmentation reflects traveler perception and could be used to establish EL monitoring segmentation.

8.6 Revenue

Revenue goals and objectives are relatable to the mobility objectives; in that setting the toll price has an effect on the traffic using the ELs. It is the day-to-day responsibility for the traffic management center to maintain optimum performance of the ELs. If an EL at the end of a reliability evaluation is not performing, then one of the possible areas of improvement is fine tuning pricing. Each facility will be unique and require daily operation, if the daily operation is maintained the year-end reliability should be on target. If the reliability objectives are not met, then the past years data can be evaluated and used to attempt to fine tune toll pricing. However, if there is an external bottleneck issue, it may be that pricing will not be enough to manage better reliability. These factors should also be considered.

8.7 Performance Metrics for Reporting

The proposed metrics for reporting on system performance are variability and reliability. Specifically, these measures are:

- Percent occurrence above the 45 mph target speed; and
- TTI based on the 95th percentile travel time over the average travel time.

The percent occurrence above a target speed has been in use for some time and was part of older criteria for monitoring HOV lanes. This calculation can be done readily and the information can be displayed on a bar chart or report that can be easily absorbed. However, the percent measure does not tell the entire story and does not provide the dimension of the extent of the congestion. For instance, how far below does the travel time really fall, and what is the perception of how often this really occurs? The TTIs provide this dimension. Figure 8.2 is a display of the travel times for **95 Express** in the northbound peak-period direction, and it is calculated based on the total amount of VMTs that has had a particular travel time. Table 8.3 reports the TTIs for the same facility. Both the ELs and GP lanes are displayed.

Figure 8.2 Northbound 95 Express Travel Time Reliability Graph

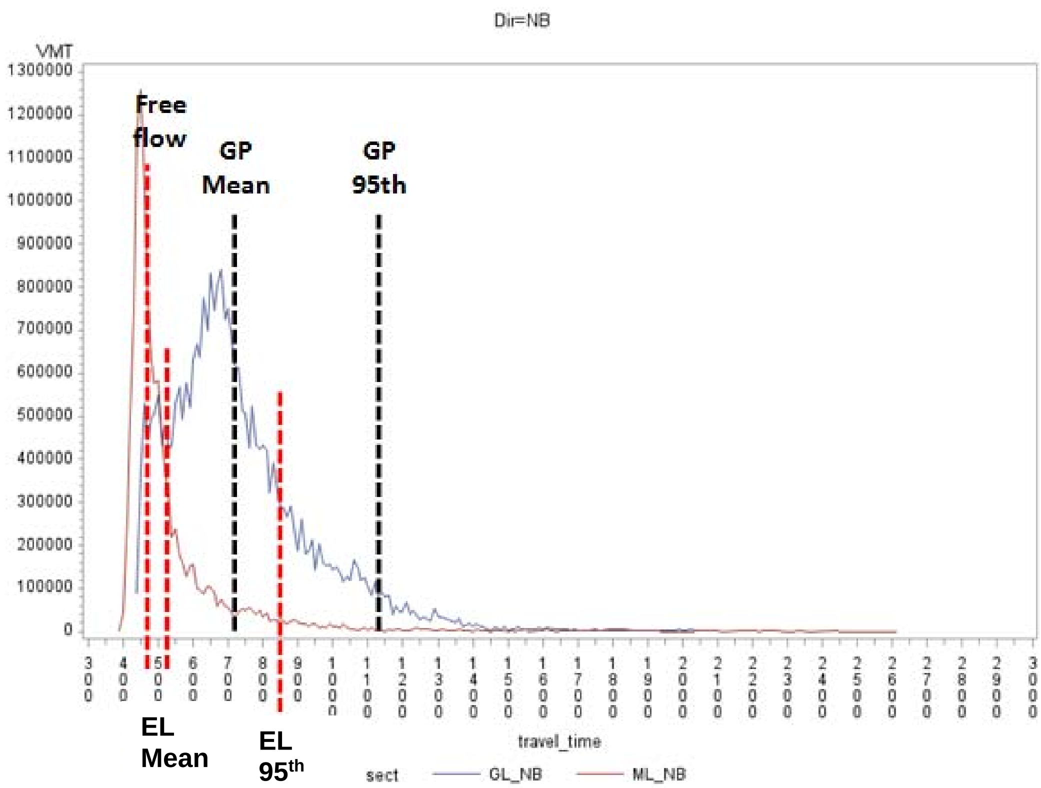


Table 8.3 Northbound 95 Express Travel Time Reliability Table

Segment	Mean TTI	Mean Travel Time (Second)	P95 TTI	P95 Travel Time (Second)
GL_NB	1.52	729	2.33	1,121
ML_NB	1.15	533	1.73	831
ALL_NB	1.41	671	2.26	1,085
Free-flow		475		475

8.8 TARGETS

The minimal requirement for EL operations is to maintain 90% of travel, during the peak period, at least 45 mph. This goal was established by FHWA and adopted by FDOT. For 3 consecutive years, from 2009 through 2012, the ELs accomplished this goal for the PM peak period. In 2013 the northbound express lane was not able to maintain 90% of the travel, in the peak period, at a travel speed of at least 45 mph. The EL operators should work with policy administers to increase the toll price. A higher toll price should exclude more traffic and allow the ELs to operate at or above the 90% target.

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