Washington Joint Transportation Committee

I-405 Traffic Data and Corridor Performance Analysis

Final Report

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EXECUTIVE SUMMARY

This report reflects findings from an independent and objective analysis of traffic data pertaining to performance of Washington's I-405 tolled corridor. Researchers were asked to describe where the I-405 express toll lane (ETL) facility is working and where it is underperforming by analyzing the accuracy, utility, and limitations of available and applicable traffic data. Further, researchers were asked to compare findings against relevant performance measures contained in state statute.

Data

We considered three unique data sources for analysis – loop detector data; ETL toll transaction data; and HERE/INRIX cell-phone derived data – and several important characteristics for data to be deemed useful: availability of data over an appropriate study period; content of data to include traffic density, volume, speed, travel time, lane differentiation (general purpose vs ETL), and sample rate (resolution). WSDOT loop detector and ETL toll transaction data were found to offer necessary volume, speed, and travel time data for both the general purpose lanes (GPLs) and ETLs both before and after ETL facility opening. HERE/INRIX data did not meet these characteristics and were not utilized in this study.

Statutory Performance Measures

Washington state statute RCW 47.56.880 lists several general performance measures for the I-405 ETL facility. Of these, three measures are of primary interest to this study:

a) Whether the express toll lanes generate sufficient revenue to pay for all I-405 express toll lane-related operating costs;
b) Whether the express toll lanes maintain speeds of 45 miles per hour (mph) at least 90 percent of the time during peak periods; and
c) Whether the average traffic speed changed in the general purpose lanes.

The Washington State Department of Transportation (WSDOT) reports that the ETL facility is generating sufficient revenue to pay for all I-405 express toll lane-related operating costs. As such, this study focuses on the two remaining traffic performance measures listed above due to the availability of robust traffic data capable of producing conclusive findings and due to the primary importance state statute attributes to the 45 mph ETL speed goal. In addition, the study examines overall corridor throughput in both the ETL and GPL as another important performance measure.

With respect to the statutory performance measures listed above, we determined that:

a) **Financial Performance Measure Met.** The I-405 ETL facility is achieving the first primary performance measure the WA Legislature set for the facility – to be financially self-sufficient.
b) **ETL Speed Performance Measure Not Met.** The I-405 ETL facility is not meeting the second primary performance measure the WA Legislature set for the facility – to have vehicles on the ETL averaging 45 mph at least 90 percent of the time. This study finds that on average the amount of time in peak period where ETL speed is above the 45 mph statutory goal is 85 percent in the northbound direction and 78 percent in the southbound direction (Jan 2017 – Jun 2017).
c) **GPL Speeds Showed No Significant Change.** Average GPL speeds during the peak period were not dramatically different before and after opening of the ETL facility. Improved speed was recorded immediately following opening of the paved GPL shoulder, but that improvement returned to pre-ETL levels as time passed.

Corridor Performance

Following are some of our major findings regarding the state of the I-405 corridor and its ETL facility:

i. **ETL speed performance measure not met.** On average, the percent time in peak period where ETL speed is above 45 mph is falling short of the statutory goal of 90 percent – with the performance measure being met 85 percent of the time in the northbound direction and 78 percent of the time in the southbound direction (Jan 2017 – Jun 2017).

ii. **Speed improved after transforming HOV lane to ETL.** From January 2014 to August 2015, the percent time in peak period where high occupancy vehicle (HOV) lane speed was above 45 mph was 69 percent in the northbound direction and 67 percent in the southbound direction – both considerably less than ETL performance.

iii. **ETL facility increasing corridor throughput.** Even though the ETL facility is not meeting the 45 mph speed requirement, its lanes are serving more vehicles than did the HOV lane: 59.2 percent more in the northbound direction and 94.5 percent more in the southbound direction. In other words, the corridor is carrying significantly more vehicles after ETL facility opening. This, in combination with better travel times, can be considered as overall improvements of the corridor. Tables 1 and 2 show a significant increase in total corridor vehicle miles traveled (VMT) after opening of the ETL facility. Project construction increased total corridor lane-miles by 4% in the northbound direction and 13% in the southbound direction; this increased capacity occurred primarily in the two-lane section of the ETL facility. For comparison, statewide VMT grew by an average of roughly 2.7 percent in 2016.

Table 1. Northbound average daily VMT traveled in corridor for January to June (2015 and 2017)

	GPL	HOV/ETL	Total
Jan-Jun 2015 Average	924,600	144,342	1,068,942
Jan-Jun 2017 Average	936,339	229,857	1,166,195
Percent Increase	1.3%	59.2%	9.1%

Table 2. Southbound average daily VMT traveled in corridor for January to June (2015 and 2017)

	GPL	HOV/ETL	Total
Jan-Jun 2015 Average	983,689	137,213	1,120,903
Jan-Jun 2017 Average	1,067,442	266,858	1,334,299
Percent Increase	8.5%	94.5%	19.0%

iv. **GPL Speeds Showed No Significant Change.** Average GPL speeds during the peak period were similar before and after opening of the ETL facility. Improved speed was recorded immediately following opening of the paved GPL shoulder in Spring 2017, but that improvement diminished as time passed.

v. **ETL toll rates max out during 15 percent of peak period.** The maximum toll, set in administrative rule at $10, was charged on average 15 percent of the duration of the peak period in either direction, over the last six months of the study period. Reaching the maximum toll rate is problematic from a traffic management standpoint because once the maximum is reached the lane volume can no longer be managed through pricing to ensure desired ETL speed.

vi. **Tolling algorithm is not optimally responsive and toll rate is too low as traffic volume builds.** The difference between the toll rate actually paid and the toll rate displayed at a trip's conclusion can be as high as $4. That is, a motorist might enter the ETL and lock in a toll rate that does not reflect the actual traffic volume building during their trip along the ETL corridor. Particularly during peak travel times, the toll algorithm and pricing is not controlling input traffic along the ETL effectively, which in turn can result in too many vehicles in the ETL, unmanageable congestion and ETL breakdown, and thus unacceptably low average ETL vehicle speeds.

Variables Likely Impacting I-405 Corridor Performance. Many factors are impacting the GPL speeds. Among them are population growth in the area, the change in carpool rules from 2+ HOV to 3+ HOV, opening of the 1.8-mile northbound shoulder lane, and additional ETL capacity. However, the relative impact of multiple variables on corridor performance cannot be measured without the use of more sophisticated traffic modeling – which this study could not accommodate due to time and budget considerations.

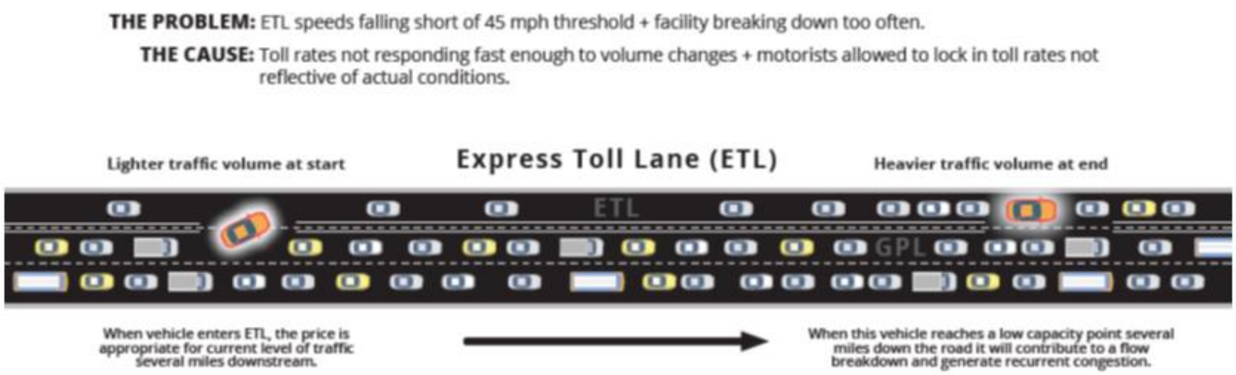
While a number of variables are impacting the performance of the corridor, significant improvements in speeds and throughput have occurred during the study period following ETL implementation.

In sum, the I-405 ETL facility is meeting the statutory performance measure related to financial sustainability, but not the performance measure related to average ETL speeds. This is due in part to overall traffic volume growth and a toll rate algorithm and pricing not adequately responsive to rapidly-increasing traffic volume during peak periods.

Even though the ETL facility is not meeting the 45 mph speed requirement, its lanes are serving more vehicles than did the HOV lane. As a result, overall corridor throughout has increased significantly. Also, average ETL speeds and travel times have improved significantly following ETF facility opening, and average GPL speeds and travel times have not changed significantly.

Key findings regarding ETL speed performance are depicted in the infographic below (Figure 1). These recommendations, as well as additional longer-term suggestions, are described in more detail in the following section.

Figure 1. ETL facility breakdown infographic



RECOMMENDATIONS

In addition to providing independent and objective analysis of traffic data and I-405 corridor performance, we were asked to provide recommendations – both short-term and long-term – for improving the ETL facility in particular and I-405 corridor generally.

Study of traffic data and research about other ETLs around the world has revealed a number of opportunities for improving the I-405 ETL facility and corridor performance. We are confident the following recommendations are both actionable and have a high likelihood of addressing challenges identified in our data analysis. However, additional study described in the corresponding section of this report would offer important detail and insight informing recommendation implementation.

Top Tier Short-Term Recommendations

The following recommendations could be implemented in the relative short term and offer the greatest promise for addressing current congestion and improving corridor performance:

1) Improve ETL speed though a more responsive dynamic toll algorithm

Our analysis reveals that the tolling algorithm is not optimally responsive. More specifically, the toll rate is too low as traffic volume builds in the ETL. In fact, the difference between the toll rate actually paid and the toll rate displayed at a trip's conclusion can be as high as $4. That is, a motorist might enter the ETL and lock in a toll rate that does not reflect the actual traffic volume building during their respective trip along the ETL corridor. Particularly during peak travel times, the toll algorithm and pricing is not adequately controlling input traffic along the ETL, which in turn can result in unmanageable ETL congestion and breakdown – and thus unacceptably low average ETL vehicle speeds.

This is a short-term recommendation. It could be implemented without new infrastructure investment. However, it may require additional study focused on the specifics of how WSDOT would make its toll algorithm more responsive to volume changes.

- Impact achievable in short term
- Additional study recommended
- $ (relatively low cost compared with other recommendations)

2) Improve ETL speed through segmented corridor tolling
WSDOT currently allows motorists to "lock in" one corridor-long toll rate upon entering the facility. This is a business rule which WSDOT enacted for simplicity and ease-of-use for motorists. However, locking in one corridor-long toll rate also has significant traffic management disadvantages. Traffic conditions and volumes can change considerably along the 17-mile tolled corridor – especially during peak periods. Applying tolls on a segment-by-segment basis, with segment-specific toll rates that are more reflective of real-time traffic conditions and volumes, will improve speeds in the ETLs and corridor performance overall.

Under this approach, an electronic dynamic pricing sign would advise motorists entering the facility of segment-specific toll rates. The toll rates for each segment would be updated every few minutes based upon the volume in each segment. Segment pricing is used in many U.S. cities, and there are many different approaches for structuring and communicating segment prices.

This recommendation also could be implemented in the short term. Although it would involve certain infrastructure enhancements, such as additional dynamic pricing signs and access points through striping, these changes would be comparable to other facility adjustments that have been made in the past. However, this change in WSDOT's business rule would require clear communication with motorists who currently expect to lock in a corridor-long toll rate.

- Impact achievable in short term
- Additional study recommended
- $$ (relatively moderate cost compared with other recommendations)

Second Tier Short-Term Recommendations

The following recommendations also could be implemented in the relative short term, and we believe they would complement those recommendations above to help address current congestion and improve corridor performance:

3) Move toward an "open access" ETL facility to smooth lane transfer
The ETL facility currently is striped to limit entrance from and exit to the GPLs. Controlling the flow of traffic between lanes has advantages, especially in situations where prevailing lane speed can contrast considerably.

However, in some cases, limiting the number of entrance and exit points can concentrate lane transfer and actually impede traffic flow and reduce speed overall. Therefore, we believe that implementing an open access strategy <u>on some parts of the ETL facility</u> could improve traffic flow and throughput. Any changes in access policy should be in concert with the corridor segment toll structure described above.

Although this recommendation can be considered short-term in nature, further study of how best to apply an open access approach may reveal corridor segments where restricted ETL access remains beneficial.

- Impact achievable in short term
- Additional study recommended
- $$ (relatively moderate cost compared with other recommendations)

4) Increase maximum toll rate to reduce ETL breakdown

Analysis reveals that the maximum toll rate was applied on average 15 percent of the time in either direction during the daily peak hours of the last six months of the study period. The maximum toll rate set in administrative rule is $10.

This is an indication of ETL breakdown. For dynamically-priced toll facilities such as the I-405 ETLs, the goal is to reach the maximum toll rate only rarely. Reaching the maximum toll rate is problematic from a traffic management standpoint, because once the maximum is reached the lane volume can no longer be managed through pricing to ensure ETL speed. This phenomenon is known as a facility breakdown. During breakdown, the travel time reliability benefits of the ETL facility are lost altogether while the resulting congestion can seriously disrupt travel for extended periods.

Although this recommendation could be implemented in the short term, it should be considered complementary to the recommendations described above. We believe that the combination of a more responsive dynamic toll algorithm and application of toll rates by segment should significantly reduce congestion in the ETL, and thus reduce the frequency the $10 maximum toll rate is charged. However, to ensure ETL speed and facility performance during the most adverse traffic conditions, an increased maximum toll rate is recommended – required, even – to produce full benefits from recommendations described above.

- Impact achievable in short term
- Additional study recommended
- $ (relatively low cost compared with other recommendations)

5) Adjust AM peak period times to increase ETL speed

Extending the AM peak period for an additional hour in order to remove 2+ HOVs during this time would improve ETL performance by reducing the frequency and/or intensity of ETL breakdown.

The AM peak period is currently defined as 5AM to 9AM, Monday through Friday. However, analysis reveals that traffic volumes along the corridor are consistent with peak period condition between 9AM and 10AM – and significantly greater between 9AM and 10AM than between 5AM and 6AM. Although ETL toll rates apply to motorists in these lanes throughout each weekday, 2+ HOV motorists are allowed into the ETL facility without paying a toll during non-peak hours. As such, the current AM peak period hours restrict free use of the ETL facility for 2+ HOV motorists at a time when the facility could support them (5-6AM), and they permit 2+ HOV motorists to use the facility for free at a time when the facility is congested, and therefore doesn't have the capacity to support them (9-10AM).

We have two alternative recommendations to address this:

a) As a recommendation that could be implemented in the short-term, expanding the AM peak period to 5AM – 10AM would provide ETL congestion relief.
b) As an alternative, adjusting the AM peak period from 5AM – 9AM to 6AM – 10AM would produce ETL congestion relief during the latter portion of the AM commute; however, shifting the peak period rather than expanding it could invite more motorists into the ETL lane as volumes begin to mount and contribute to unintended congestion early in the AM peak period.

Either approach would help alleviate AM peak period congestion in the ETL.

- Impact achievable in short term
- Additional study recommended
- $ (relatively low cost compared with other recommendations)

Long-term Recommendations

The following recommendations would require a longer period of time to implement, but nonetheless offer promise for addressing congestion and improving corridor performance:

6) Extend second full ETL in each direction to improve ETL speed

In high-growth and geographically confined traffic corridors such as the I-405 corridor, congestion pricing approaches such as the ETL facility offer the dual promise of predictable ETL drive time and increased throughput, as compared to GPL-only facilities. This is the case with the I-405 corridor. Based upon how similar facilities have performed around the country, we are confident that extending two full ETLs from 160 Street NE in Woodinville to I-5 in Lynnwood would remove current ETL bottleneck conditions and improve the flow of traffic along the ETL facility – likely producing improved ETL speeds and overall corridor traffic throughput.

This recommendation would require more time to implement than the others described above. Optimal design of the additional ETLs would require in-depth traffic modeling and scenario analysis, and construction would take additional time. Nonetheless, researchers are confident that congestion pricing has and will continue to improve traffic performance along and the I-405 corridor.

- Impact achievable in long term
- Additional study recommended
- $$$ (relatively high cost compared with other recommendations)

7) Add Capacity to Ensure Lane Continuity and Ease Bottlenecks

Bottlenecks occur in areas where traffic volumes converge – be it through lane loss, on-ramps, etc. The I-405 corridor includes a number of bottlenecks in both the GPLs and ETLs, and it may be beneficial to add lane capacity in areas with bottlenecks to improve corridor continuity. We recommend studying this issue to better inform a final decision on the question.

This is a long-term recommendation, because it would require time to study where and how GPLs should be expanded, and additional time to construct GPL expansions.

- Impact achievable in long term
- Additional study recommended
- $$$ (relatively high cost compared with other recommendations)

8) Increase transit options to improve throughput and speed

Growth in VMT along the I-405 corridor is well outpacing statewide and national averages. Therefore, regardless of the ETL changes we describe in this section, the corridor will continue to experience significant pressure from recent and projected population and motorist growth. Over time, the short-term benefits of added lane capacity will be reduced by growth in VMT. As a result, maintaining and improving long-term corridor performance requires a balanced approach of roadway infrastructure improvements and transit options. Research conducted by others has found that well-designed transit options can help move more people through a corridor in fewer vehicles. In this way, transit can help improve corridor throughput efficiency in both the ETLs and the GPLs.

Over the long term, implementation of I-405 master plan transit improvements will reduce congestion and increase passenger throughput in the high-growth corridor. These improvements include new transit centers and park and ride spaces, a bus rapid transit (BRT) system, vanpools, direct access ramps for transit and carpools, and an overall increase in transit service.

- Impact achievable in long term
- Additional study recommended
- $$ (relatively moderate cost compared with other recommendations)

CONCLUSION

The I-405 ETL facility is meeting the statutory performance measure related to financial sustainability, but not the performance measure related to average ETL speeds. This is due in part to overall traffic volume growth and a toll rate algorithm and pricing not adequately responsive to rapidly-increasing traffic volume during peak periods. Our findings suggest that a number of adjustments could be made that should lead to both of the primary statutory performance measures being met.

Even though the ETL facility is not meeting the 45 mph speed requirement, its lanes are serving more vehicles than did the HOV lane. As a result, overall corridor throughput has increased significantly. Also, average ETL speeds and travel times have improved significantly following ETL facility opening, and average GPL speeds and travel times have not changed significantly.

As time passes and conditions change, even the most sophisticated ETL facilities require regular adjustments. This is particularly true of those operating in traffic corridors like the I-405 corridor that serve rapidly growing regions. Therefore, these recommendations should be considered part of the natural evolution of the corridor, not criticisms of work that has been done in the past. We are confident that implementation of these recommendations will improve I-405 ETL performance and significantly increase throughput and efficiency along the corridor.

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1. INTRODUCTION

1.1 Background per Washington Joint Transportation Committee

Unpredictable commute times during peak hours on I-405 and increasing congestion that impeded bus transit led lawmakers in 2011 to authorize WSDOT to build a system of express toll lanes. This initial phase of ETLs spanned a 17-mile stretch between Bellevue in the south and Lynnwood in the north (Figure 2). The project included one new paved ETL in each direction from Bellevue to Bothell, and converting the old HOV lanes from Bellevue to Lynnwood. This resulted in two ETLs each direction Bellevue-Bothell, and one each way Bothell-Lynnwood.

Figure 2. I-405 corridor map

The goal was to provide drivers a choice for a faster, more reliable trip on I-405. As stated in statutory performance measures, another goal is for the ETLs to maintain speeds of 45 mph at least 90 percent of the time.

The Washington State Transportation Commission sets toll rates in Washington, and after analyzing extensive traffic, performance and population growth data, they set a minimum of 75 cents and a maximum of $10 for the I-405 facility – despite a stated WSDOT preference for a $15 maximum toll rate. Tolling in the ETLs is dynamic; electronic signs post the toll rate based on destination and automatically adjust depending on real-time traffic conditions. As more vehicles enter or exit the lanes at designated access points, toll rates adjust to try to keep traffic moving at least 45 miles per hour in the ETL. Toll rates are based on speeds and traffic volumes in the ETLs, and take into account volumes in the general-purpose lanes.

The ETLs opened to traffic on September 27, 2015. Upon opening, 3+ HOVs with a Flex Pass transponder drove for free in the ETLs at all times. In a policy change, 2+ HOVs now had to pay to drive in the ETLs during peak hours (5AM-9AM, 3PM-7PM), Monday through Friday. Solo drivers paid to drive in the ETLs at all times. The Commission changed that policy in March 2016, to allow all vehicles to drive toll-free during weekday evenings (7 PM-5AM). In addition, the lanes became toll-free for everyone on weekends and six major federal holidays.

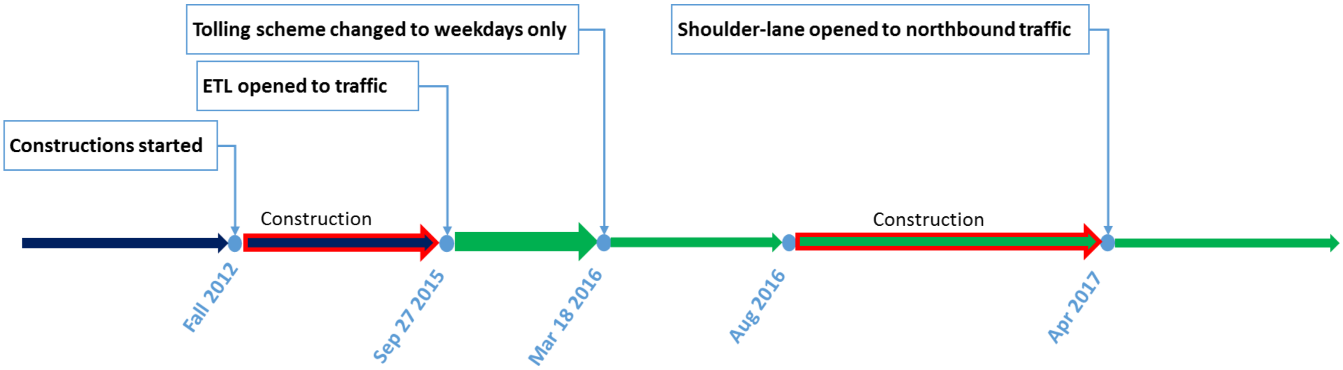
The $10 maximum toll was predicted to be rare initially, but by December of 2015, drivers paid $10 more frequently than expected. WSDOT's data showed that while traffic improved in the southern part of the corridor, it slowed in general-purpose lanes in the Bothell area and at points north of SR 522 – the area where the lone HOV was converted to ETL. WSDOT reported that the additional northbound capacity in the southern portion of the project moved some of the worst congestion north, from Kirkland to Bothell. Toll payers and buses were saving up to 14 minutes in the morning. Southbound general-purpose traffic saved time in the morning, but evening northbound traffic was delayed through Bothell.

1.2 Timeline of the I-405 Express Toll Lanes

Figure 3 shows the timeline for implementation of the ETL on the I-405 corridor. Major events are shown at the top part of the timeline. The red colors in the timeline represent periods of construction, blue colors represent before and green represents after the ETL facility opened. The width of the green parts of the timeline represents the tolling window.

In particular, the timeline notes that construction of the ETL facility began in fall 2012 and continued through September 2015. The ETL facility opened to traffic on September 27, 2015, and within months was improved through extension of access points near SR 527; during this time the tolling algorithm was adjusted to help keep ETL traffic moving. On March 18, 2016, the tolling policy was adjusted and thereafter tolls were no longer applied on weekends. In August 2016 the northbound GPL was improved through a 1.8 mile stretch of shoulder hardening, which was opened to traffic in April 2017.

Figure 3. Timeline of the I-405 ETL facility



2. DATA DESCRIPTION

This section describes the data that the study team has received from WSDOT for evaluating the performance of the I-405 ETL facility. Analyses are conducted on three datasets, namely the loop detector data, the ETL transaction data, and HERE data. A brief description of each dataset along with its contents and limitations is provided below. For purposes of this study, researchers obtained raw data from WSDOT for independent observation and analysis.

2.1 Loop Detector Data

WSDOT has embedded pairs of loop detectors in the pavement of all lanes of the I-405 corridor. Figures 4 and 5 show the conceptual and actual deployment of loop detectors, respectively. The loop detectors collect information about traffic volume and speed that is aggregated and analyzed by WSDOT.

This study relied upon simple raw data, in the basic form it was originally collected by WSDOT, for the period spanning January 2014 to June 2017. The data was collected by inductive loop detectors embedded in the pavement by WSDOT. Detectors collect the passage of vehicles by sending a signal to a controller. Then, digital information from signals are recorded in a computer database. Detectors are installed every 0.5 miles and in every lane of the corridor, collecting data in a lane-by-lane format. Thus, analysis of loop detector data can illustrate the traffic conditions on both ETLs and GPLs. The data covers both before and after the opening of the ETL facility. Thus, the analysis compares corridor performance before and after opening of the ETLs.

WSDOT employs double loop detector systems, meaning that two detectors about ten feet apart collect data as shown in Figures 4 and 5. Therefore, three types of loop detector data are available in the data set: “Loop” and “Speed Loop” (collected by the first and second detectors respectively) can provide traffic volume, density, and *estimated* speed. “Speed Trap” is the combination of the data from the two loops. This provides more reliable and consistent speed estimates than the other two types. Thus, speed and travel time analysis is conducted based on the data collected by Speed Trap. Volume analysis is conducted using the data from the first loop.

The loop detector data are aggregated in 20-second time intervals, and can be further aggregated to five-minute intervals for faster analysis without compromising the data quality.

Figure 4. Double loop detectors in theory

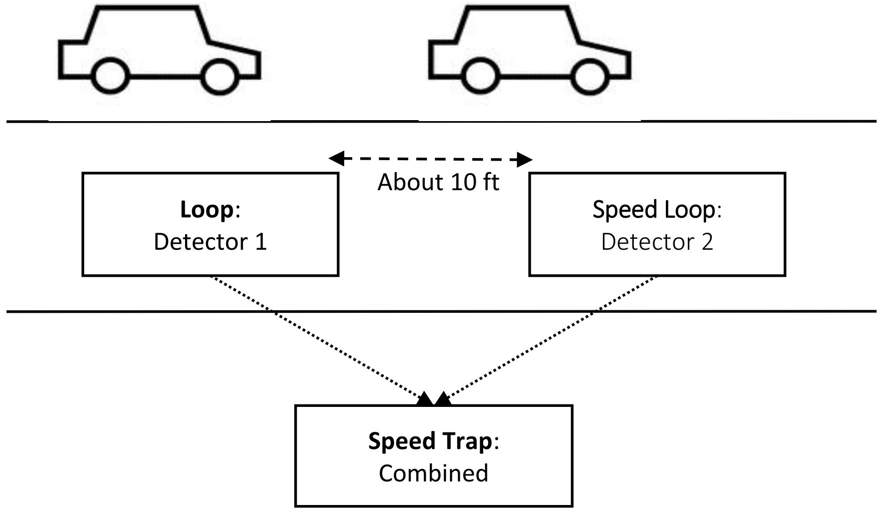
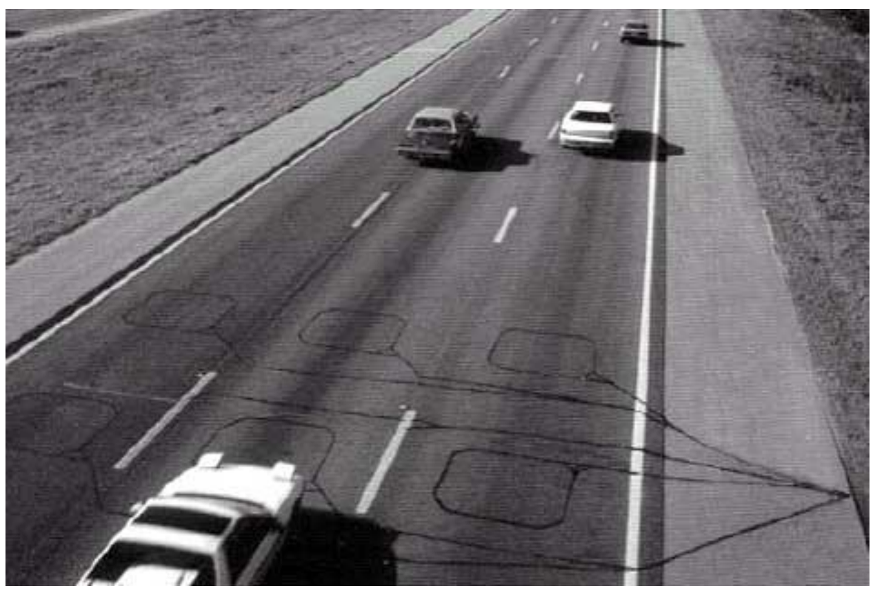


Figure 5. Double loop detectors in practice



2.2 ETL Transaction Data

Data from toll transactions on the ETL from January 2016 to June 2017 were utilized for this study. There are 10 northbound and 11 southbound gantries to detect the entry and exit of vehicles on the ETLs. Any vehicle passing through the gantries is detected and related information such as time, location, and toll amount is recorded. Particularly, each record of data contains a unique trip identification (ID), the trip start and end location, date and time, toll amount, intermediate locations and detected time, trip type (e.g. HOV, toll paid via transponder, or toll paid via mail), and some additional information.

The transaction data contain the starting and ending locations of a trip as well as intermediate points. Combining the transaction locations and transaction times, travel times and speed can be calculated for the trips and for each segment. Volume analysis can be performed on a segment-based level and on an entry-exit based level in the ETLs but not in the GPLs because there are no tolling gantries in the GPLs (and there were no tolling gantries in the HOV lanes before ETL). The toll charged for each trip using the ETL facility is also available.

In sum, an analysis of speed, travel time, volume, and toll rates can be conducted with ETL transaction data, but the outcomes are limited to the ETLs. A complete picture of the corridor requires information from GPLs and HOV lanes before ETLs were implemented, which is obtained from loop detector data.

2.3 HERE Data

WSDOT also provided a HERE dataset that includes several months of data (usually the fourth quarter) from 2013 to 2017. HERE collects the data from vehicle probes, such as GPS devices and cell phones when drivers use the company's HERE WE GO app. National highways are divided into Traffic Message Channel (TMC) codes with approximate lengths of 0.5-0.8 miles and the measured travel times are coded to the TMC locations. HERE data contains travel times for three categories of vehicles (all vehicles, passenger vehicles, and trucks) at five-minute intervals. However, the data cannot differentiate the vehicles traveling on the ETLs and GPLs. As a result, the travel times provided by HERE data are the average estimates from vehicles in all the lanes, not distinguishing between ETL and GPL travel times – even though actual travel times may vary significantly between the ETLs and the GPLs. In addition, the values are calculated from relatively small samples and therefore provide no volume information. Due to these shortcomings, the travel time can be biased and misleading; this is the major shortcoming of the HERE data, and the reason it was not used in this study.

A similar data source is INRIX, which also collects traffic data using GPS-equipped vehicles. The data provided by INRIX also comes with the TMC locations. INRIX data is known to have similar shortcomings relative to those described above for HERE data.

2.4 Data Summary and Comparison

Table 3 summarizes the content, sample characteristics, advantages, and shortcomings of the three data sets available and considered for this study.

Table 3. Data summary and comparison

Data set	**Loop Detector Data**	**ETL Transaction Data**	**HERE Data**
Available dates	Jan 2014-Jun 2017	Oct 2015-Jun 2017	Partial months from 2013 to 2017
Contents	Speed and volume, date, time, milepost and lane information	Transaction date, time, locations, toll amount, etc.	Estimated segment travel times
Sample rate	20 seconds, every 0.5 miles	Real time at 21 gantries	5 minutes, 0.5-0.8 miles
Advantages	Provides both volume and speed info; High resolution data; Provides lane usage info; Provides good coverage along the corridor	Tracks trips on ETLs, so complete trip info; Provides accurate travel time info; Provides accurate volume info	Estimated travel times for different types of vehicles
Disadvantages	Reported speeds are local, need processing for travel time	Lacks info on GPL and HOV lanes before ETL facility	No volume information; No distinction between ETL and GPL; No lane usage info; Small sample size; Potentially biased travel times
# of records*	13 million / month	4 million / month	300,000 / month

* # of records does not necessarily mean the number of sampled vehicles.

3. DATA ANALYSIS METHODOLOGY

3.1 Travel Time Analysis

Travel time analysis by loop detector data: The speeds are measured at loop detector locations approximately 0.5 miles apart. The GPLs and ETLs have separate detectors on the entire corridor. Travel times are calculated by dividing the distance between two consecutive detectors by the average speed of the two detectors. Adding up these travel times along the corridor makes up the travel time on the corridor. Similarly, travel times for the most common trips are calculated using the segment travel times.

Travel times are calculated for every five-minute interval of peak period (according to WSDOT definitions, 5AM-9AM in the southbound direction and 3PM-7PM in the northbound direction) on Tuesday, Wednesday, and Thursday of every week for each month of the study period. The reason to select these three days among five weekdays is that traffic peak in other days may be shifted due to potentially irregular work schedules of commuters on Mondays and Fridays. Travel times are calculated for non-peak hours (hours outside the peak period) as well. Finally, these travel times are aggregated to three measures of average, 90th percentile, and 10th percentile of travel time in each month. The percentile travel times represent day-to-day variability of travel time. The wider the gap between the 90th and 10th percentiles the more variable and less reliable the travel time.

Travel time analysis by ETL transaction data: A single trip on the ETL contains several segments, each with a start and end point (gantry) together with the corresponding transaction times. Travel time of each segment is the difference between the timestamps at the start and end point. The travel times are calculated for one-minute intervals for peak and off-peak hours of the three weekdays for every month with available data. The 90th percentile and 10th percentile travel times are calculated as well, representing travel time variability.

3.2 Volume Analysis

Volume by loop detector data: Loop detectors collect lane-by-lane volume data by counting vehicles on a continuous basis and recording counts in 20-second intervals. Information on how volume is distributed along the corridor in both the ETLs and GPLs can be obtained from the detector data. By observing monthly volume changes, the effect of major events in the corridor can be investigated, for example the opening of the ETLs or opening of the shoulder lane.

Volume data can be aggregated over many different time periods. Monthly volume aggregation is commonly used to illustrate changes and trends over several years. Monthly and/or weekly aggregations are also used to reveal changes around major policy or capacity-affecting events. For example, monthly aggregation of volume is used to investigate the effect on the system by the opening of the ETLs and later of the shoulder lane.

For this purpose, the vehicle-mile travelled (VMT) metric is developed. VMT is the volume from detectors multiplied by the distance between consecutive detectors, summed over all the detectors in the corridor. This is a very common metric with vehicle-mile unit, representing how many vehicles used the corridor along with the length of their trips in the corridor. The monthly VMT trend is presented herein.

Volume by ETL transaction data: Volume information on the ETLs can be obtained from the ETL transaction data. Trip records in the data set are distinguished as one of the following: 3+ HOV vehicles traveling for free; vehicles paying tolls with a transponder; or vehicles without transponders paying tolls by mail. Counting the trips by their start/end points and transaction times indicates where vehicles enter and exit the facility and how trips are distributed along the corridor.

3.3 Speed Analysis

Speed analysis by loop detector data: Loop detectors collect speeds along the corridor on both GPLs and ETLs every 0.5 miles. These data show the speed when vehicles pass over the two paired detectors, thus representing the local speed at certain points along the corridor. By arranging these location speeds in the milepost order, speed profiles along the corridor can be created for both types of lanes. The speed profiles are created every 5 minutes for the peak and off-peak hours on the weekdays. The average and percentiles of speed are calculated for the months with available data. The wider the gap between the 90^{th} and 10^{th} percentile speed, the more variable the corridor speed on different days. Moreover, by comparing the average speed with the required minimum of 45 mph, the percentage of the time in peak hours that speed is below the threshold is calculated for every month in the ETLs and GPLs.

Speed analysis by transaction data: A single trip on the ETLs is broken down into several components, each with a start and end point together with the corresponding transaction times. Based on the distance between the starting and ending points and the measured travel time, average segment speed can be calculated. Aggregating the data monthly, the speed variations are calculated.

4. RESULTS

4.1 Travel Time Analysis

Travel time analysis by loop detector data: As explained in the methodology, travel times are calculated from the loop detector data for the entire corridor in both directions, and separately for the ETL and GPL.

Results for the start-to-end of the corridor (NE 8th Street to I-5) are presented in Figure 6, which displays total corridor monthly travel times as recorded by loop detector data. The green lines show average travel time and the vertical bars show the range between the 10th percentile and the 90th percentile. The vertical dashed line shows the ETL opening month. The horizontal dashed line shows free flow travel time. A smaller vertical bar indicates greater trip reliability.

Figure 6. Monthly travel times, entire corridor (loop detector data) Jan 2014 to June 2017.

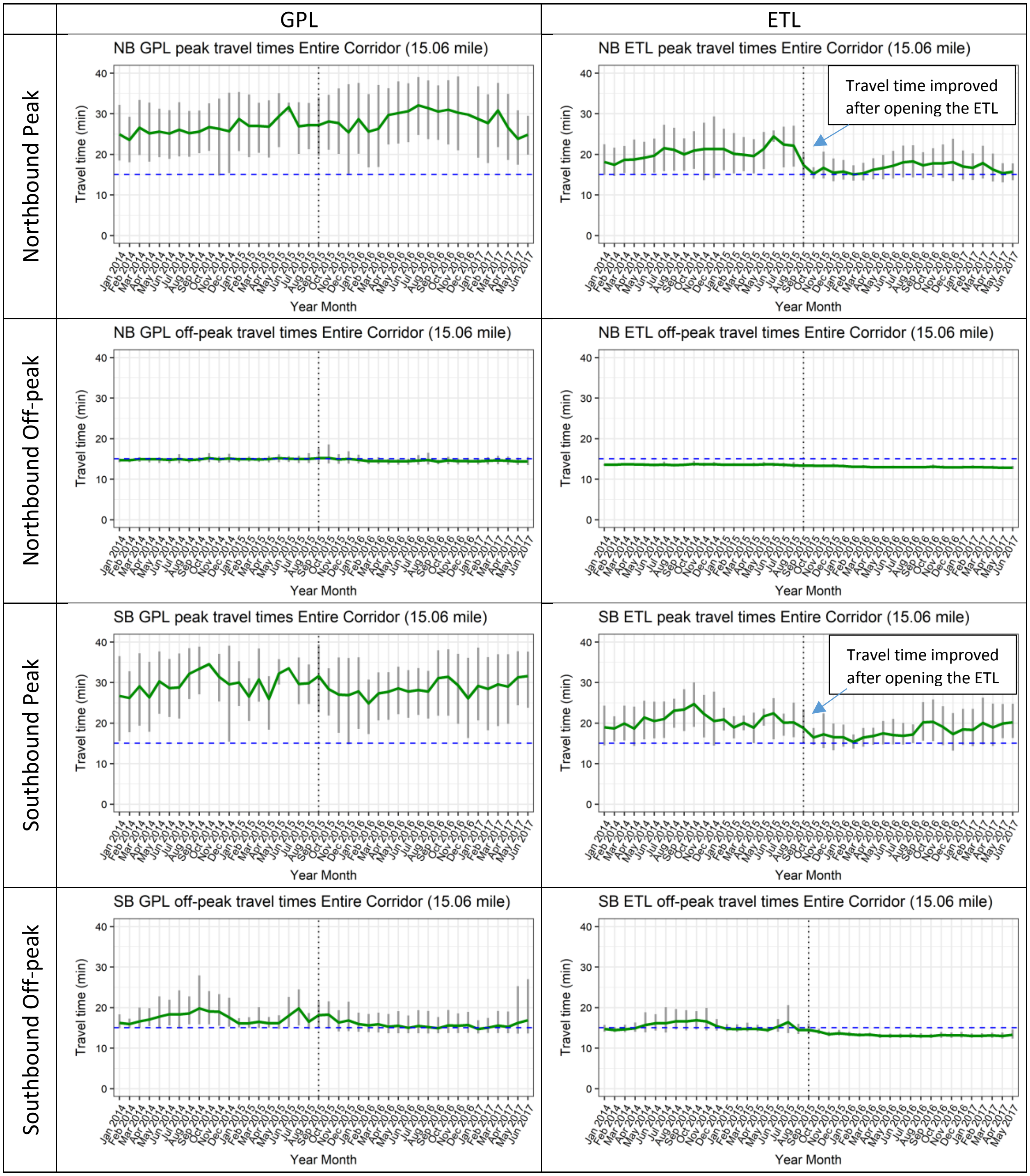


Figure 6 shows:

- Noticeable improvement in northbound ETL peak-period travel times after facility opening;
- Noticeable, but less dramatic, improvement in southbound ETL off-peak travel time; and
- Little change in northbound ETL off-peak or GPL peak-period travel time in either direction.

Figure 7 shows northbound monthly peak-period travel time averages for select common trips in the corridor. The green lines show average travel time; vertical bars show the range between the 10th and the 90th percentiles. The vertical dashed line shows the ETL opening month and the horizontal dashed line shows the free flow travel times. Observations of common northbound trips include the following:

- Noticeable improvement in ETL peak-period travel times in all depicted common-trip segments following facility opening; and
- No sustained change in GPL travel times.

Figure 7. Northbound monthly travel times, specific corridor segments (loop detector data) Jan 2014 to June 2017.

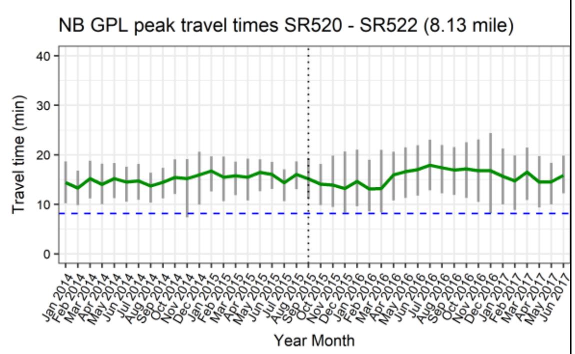
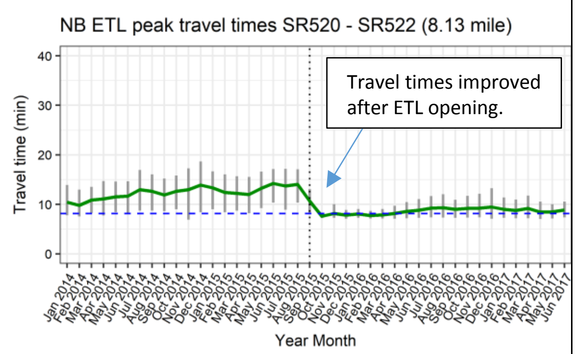
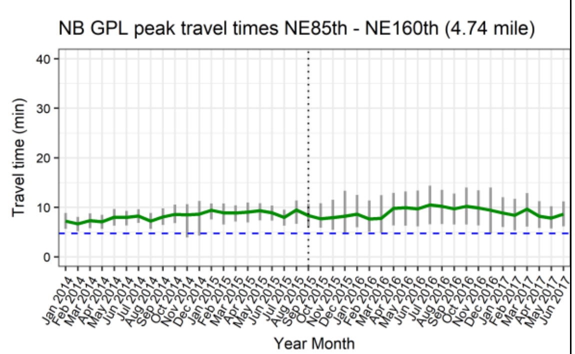
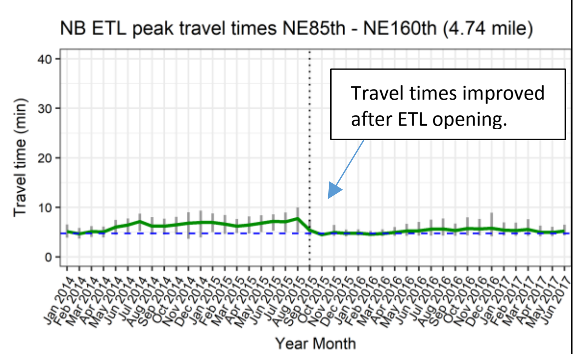
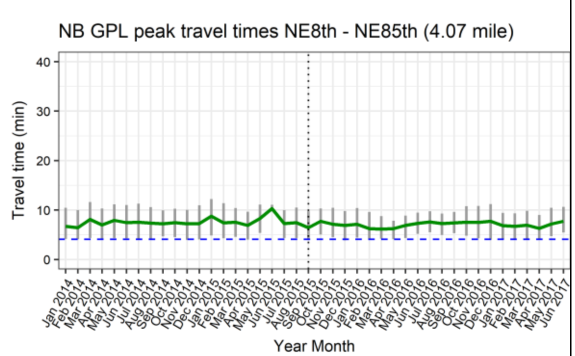
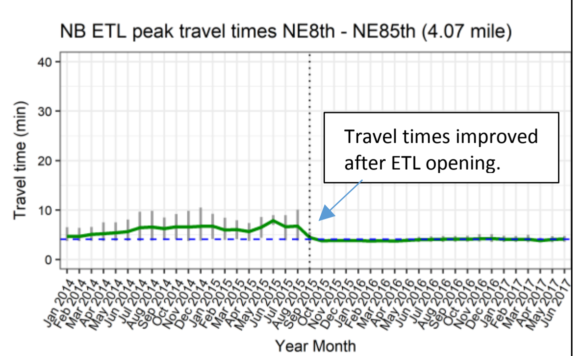
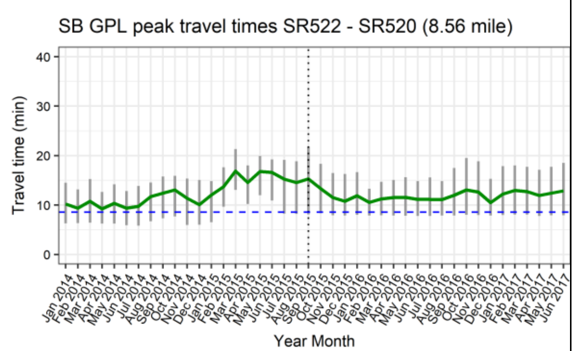
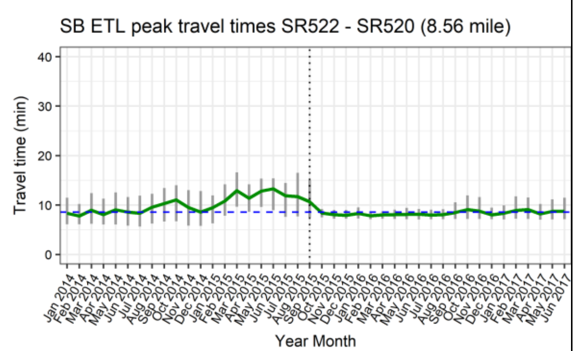
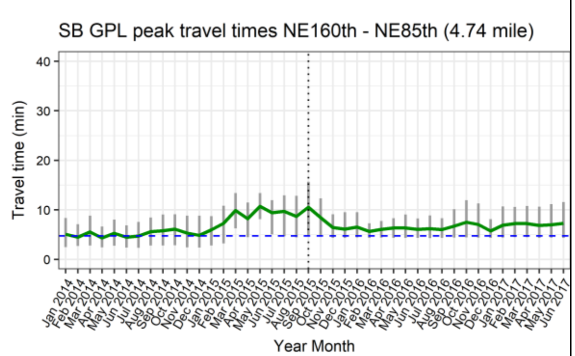
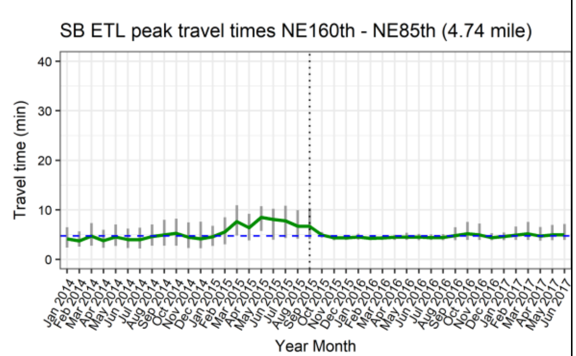
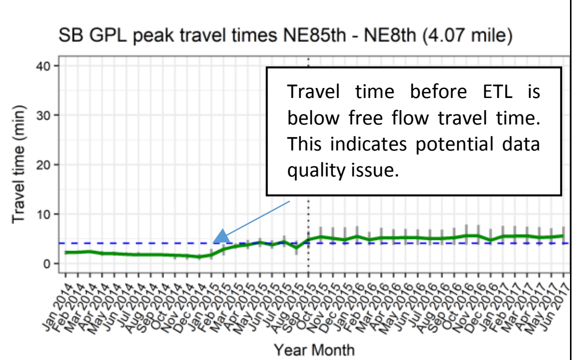
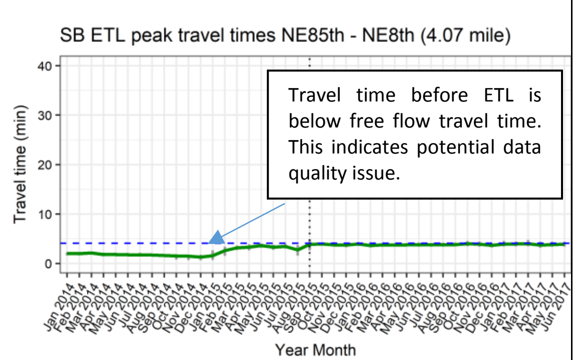
NB	GPL	ETL
SR 520 – SR 522 (8.13 mi)		
NE 85th – NE 160th (4.74 mi)		
NE 8th – NE 85th (4.07 mi)		

Figure 8 shows southbound monthly peak-period travel time averages for select common trips in the corridor. The green lines show average travel time; vertical bars show the range between the 10th and the 90th percentiles. The vertical dashed line shows the ETL opening month and the horizontal dashed line shows the free flow travel times. Observations of common southbound trips include the following:

- Travel times on all segments of the ETLs are lower and less variant compared with travel time on the HOV lanes before opening the ETLs (low travel time variation indicates higher reliability); and
- Travel times on the southbound direction of GPLs do not show noticeable changes after opening of the ETLs. However, more travel time variation (wider range in travel time) can be observed in the segments between NE 85th St to NE 160th St as well as between SR 520 to SR 522 (high travel time variability indicates lower reliability).

Figure 8. Southbound monthly travel times, specific corridor segments (loop detector data) Jan 2014 to June 2017.

<table>
<tr><th>SB</th><th>GPL</th><th>ETL</th></tr>
<tr><td>SR 522 – SR 520 (8.56 mi)</td><td>
</td><td>
</td></tr>
<tr><td>NE 160th – NE 85th (4.74 mi)</td><td>
</td><td>
</td></tr>
<tr><td>NE 85th – NE 8th (4.07 mi)</td><td>
</td><td>
</td></tr>
</table>

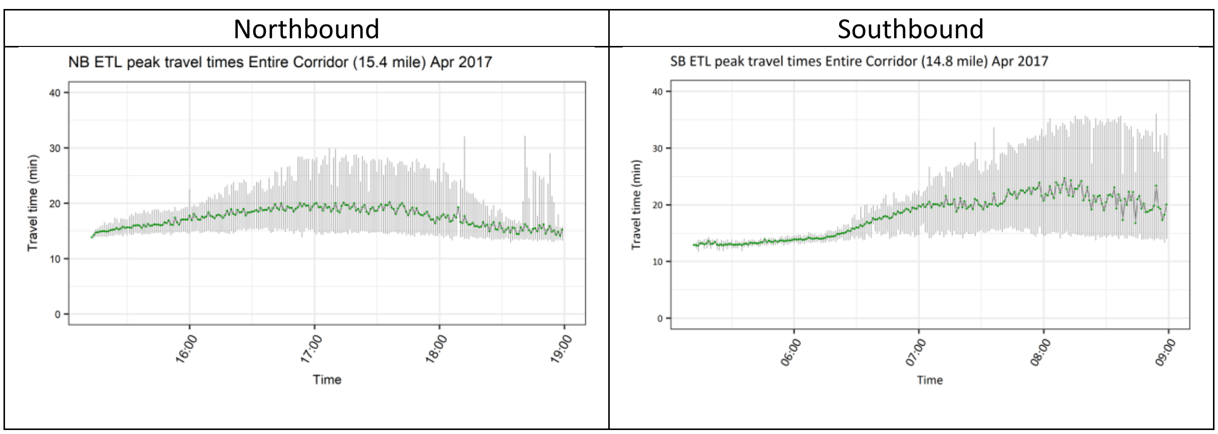
Travel time analysis by ETL transaction data: Travel times are also calculated for the ETL traffic using ETL transaction data (as explained in the methodology) and are used for validating the travel times calculated from detector data. In this case, travel times are calculated for the trips according to the nearest gantries, and for every month from January 2016 to June 2017. Comparison of average monthly travel times from transaction data and from detector data confirms that the measures calculated from detector data are reliable and the conclusions are robust. In other words, this comparison adds another level of confidence to detector data as a reliable data source.

Figure 9 shows minute-by-minute travel time profiles in the peak period for the sample month of April 2017. The green lines display average travel time and the vertical bars show the range between the 10^{th} percentile and the 90^{th} percentile travel time.

Travel time profiles in Figure 9 indicate that:

- Peak travel time in the southbound direction is more variant than in the northbound direction, meaning that travel time in the southbound direction is less reliable; and
- Peak travel time in the southbound direction starts later than the defined peak period of the direction. Indeed, while the defined peak period is from 5AM to 9AM, the actual peak travel time starts after 6AM and extends beyond 9AM.

Figure 9. Peak travel time profiles in the ETLs for April 2017.



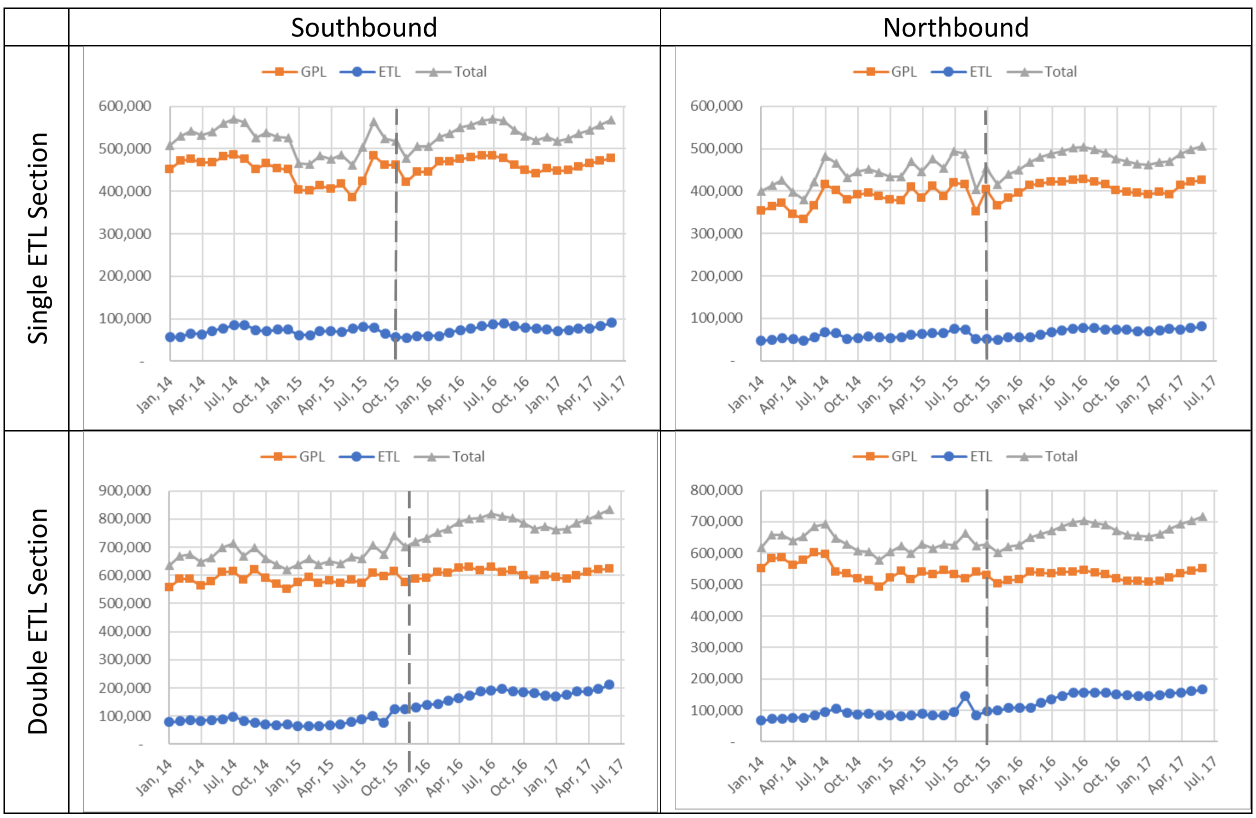
4.2 Volume Analysis

Volume by loop detector data: The volume data collected by loop detectors are analyzed in this section. The presented measure is the daily vehicle miles traveled (VMT) in the corridor, which reflects changes both in the number of trips and in the length of the trips in the corridor (shown in Figure 10).

Specifically, Figure 10 shows:

- In the single ETL section of southbound direction, VMT increased on both GPL and ETL;
- In the double ETL section of southbound direction, VMT increased on both GPL and ETL, where the increase is much higher on the ETL;
- In the single ETL section of northbound direction, VMT increased in both GPL and ETL; and
- In the double ETL section of northbound direction, VMT significantly increased in ETL, where slightly decreased in GPL.

Figure 10. Average daily VMT for the 42-month study period separated by direction, ETL sections, and lane types



Tables 4 and 5 compare average daily VMT on the GPLs and HOV/ETLs for the last six months of the study period (January 2017 – June 2017) compared with the same six months in 2015 when the ETL facility was not open. We considered several different ways to analyze this particular data and convey the results; this approach accounts for seasonal variations and temporary impacts of the ETL, and it presents an apples-to-apples comparison before and after ETL opening.

Results show that the average daily VMT increased in all lanes, leading to an overall northbound increase of 9.1 percent and an overall southbound increase of 19.0 percent. The lane-mile increase in the corridor has been 4 percent in the northbound and 13 percent in the southbound.

Table 4. Northbound average daily VMT traveled in corridor for the last six months and the same six months in 2015

	GPL	HOV/ETL	Total
Jan-Jun 2015 Avg	924,600	144,342	1,068,942
Jan-Jun 2017 Avg	936,339	229,857	1,166,195
Percent Increase	1.3%	59.2%	9.1%

Table 5. Southbound average daily VMT traveled in corridor for the last six months and the same six months in 2015

	GPL	HOV/ETL	Total
Jan-Jun 2015 Avg	983,689	137,213	1,120,903
Jan-Jun 2017 Avg	1,067,442	266,858	1,334,299
Percent Increase	8.5%	94.5%	19.0%

Growth in VMT indicates that the corridor carries significantly more vehicles after opening the ETL. This, in combination with better travel times, can be considered as overall improvements of the corridor.

For comparison, the average Washington State VMT increased in 2014 by 1.7 percent; in 2015 by 3.6 percent; and in 2016 by 2.7 percent.

As noted before, VMT must be taken into consideration when travel time or speed analysis is conducted. In a corridor with VMT well above the Washington state average, traffic volume has increased and average travel times have decreased after opening the ETLs.

Breakdown of corridor VMT in the peak period is presented in Table 6. The table shows the peak period VMT in the last six months of the study period (January 2017 – June 2017) compared with the same six months in 2015, when ETL was not open. Results show that:

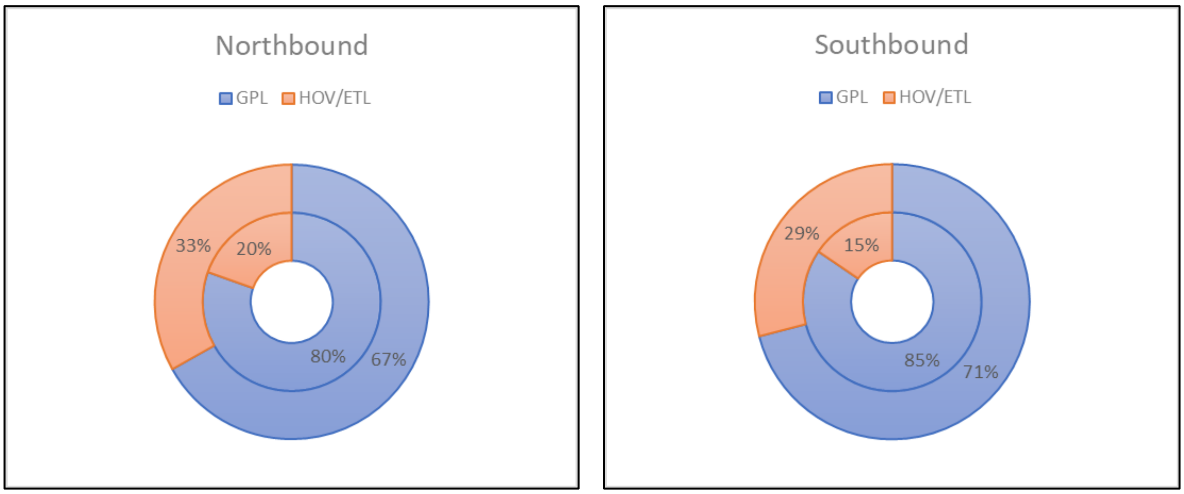
- Overall, peak period VMT has increased significantly in the corridor; that is, 19.2 percent northbound and 30.3 percent southbound.
- In the double ETL section, where the major capacity increase happened by adding a second lane, VMT increases even more than the capacity increase. VMT in the double ETL section increased by 148.4 percent northbound and 243.1 percent southbound. This indicates that the ETL, after accounting for the extra lane, is carrying more per-lane traffic than before.
- In the single ETL section, where capacity increase is negligible because no lane was added, VMT still increased significantly. VMT in the single ETL section increased by 43.3 percent northbound and 41.1 percent southbound. This indicates that ETL, even without an extra lane, is carrying more per-lane traffic than before.
- GPL VMT is consistent with statewide VMT growth

Table 6. Average peak period VMT in corridor for the last six months and the same six months in 2015

Direction	Section	Lane Type	Jan'15-Jun'15 Avg	Jan'17-Jun'17 Avg	Percent Increase
NB	Single	GPL	102,903	105,754	2.8%
		HOV/ETL	25,441	36,451	43.3%
		Total	128,344	142,205	10.8%
	Double	GPL	133,248	128,228	-3.8%
		HOV/ETL	32,039	79,584	148.4%
		Total	165,287	207,812	25.7%
	Total NB		293,632	350,017	19.2%
SB	Single	GPL	86,252	104,724	21.4%
		HOV/ETL	20,972	29,588	41.1%
		Total	107,224	134,312	25.3%
	Double	GPL	147,249	150,812	2.4%
		HOV/ETL	21,855	74,987	243.1%
		Total	169,104	225,799	33.5%
	Total SB		276,328	360,111	30.3%

As another way to consider corridor VMT, Figure 11 presents the percent share of northbound and southbound GPL and HOV/ETL peak period traffic both before and after the ETL implementation (same six month period as in Table 6). The graphs show that the ETLs carry a significantly greater share of traffic volume in the corridor compared with what the former HOV lane carried. This is the result of increased capacity by adding a second ETL and more efficient traffic flow in the ETLs due to higher speed. The internal circle represents VMT share before ETL opening and the external circle shows VMT after ETL opening.

Figure 11. Share of peak period VMT in GPL and HOV/ETL in the corridor; internal circle shows before, external circle after



Volume by ETL transaction data: Although loop detector data provide comprehensive volume information, ETL volume from transaction data can be used as an additional input to the study. To make the information more useful, the peak period ETL volume by entrance and exit points are presented in Tables 7 and 8. Each cell represents a trip by start and end points. Dark red colors show higher volume while lighter colors show lower volume.

Note that since ETL transactions are collected at the gantries only, the gantries are selected as the entrance and exit points rather than actual trip origins or destinations. Table 7 shows that:

- The highest volume in the northbound direction is destined to Rose Hill, primarily starting from NE 85th Street and NE 8th Street; and
- Other significant northbound volume is observed toward I-5 from NE 85th and NE 8th Street, as well as SR 527 gantry.

Table 7. Northbound ETL volume by entry and exit points from transaction data

	To / From	Double ETL			Single ETL			
		NB03 (NE85th)	NB04 (Rose Hill)	NB05 (NE128th)	NB07 (SR522)	NB08 (SR527)	NB09	NB10 (I-5)
Double ETL	NB01 (NE8th)	808	1671	577	407	142	40	926
	NB02 (NE8th)	229	677	352	133	33	7	330
	NB03 (NE85th)		1556	427	404	160	45	760
	NB04 (Rose Hill)			88	206	89	25	455
	NB06 (NE128th)				158	50	11	422
Single ETL	NB07 (SR522)					11	8	36
	NB08 (SR527)						33	781
	NB09							274

Table 8 shows that:

- In the southbound direction, the highest volume is observed at NE 8th Street primarily starting from SR-522 and I-5; and
- Other significant southbound volume is destined to NE 85th Street coming from SR 522 and I-5.

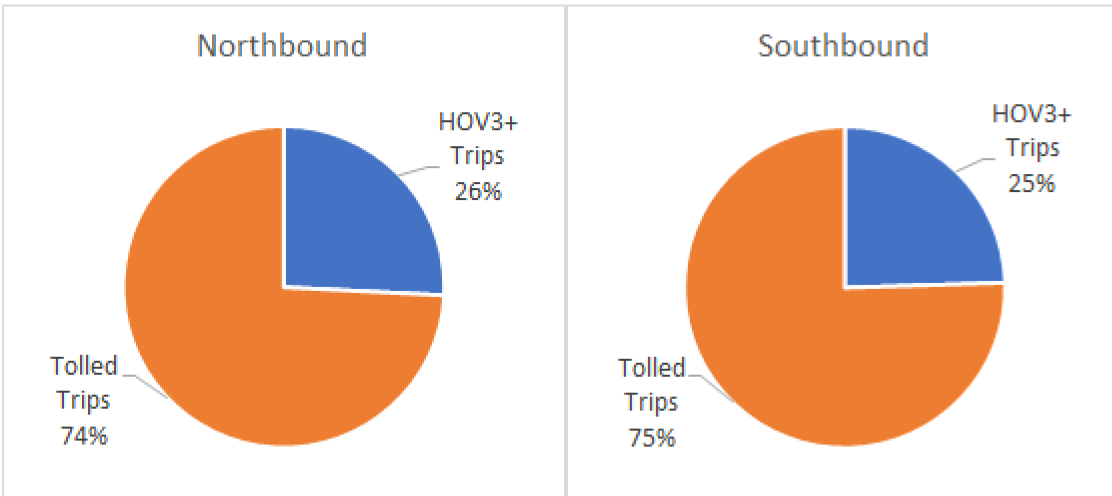
Table 8. Southbound ETL volume by entry and exit points from transaction data

					Double ETL					
	From \ To	SB02	SB03 (SR527)	SB04 (SR522)	SB05	SB06 (NE128th)	SB08 (NE85th)	SB09	SB10 (NE8th)	SB11 (NE8th)
Single ETL	SB01 (I-5)	218	93	50	425	512	644	49	968	346
	SB02		14	8	27	17	27	6	36	9
	SB03 (SR527)			16	129	116	271	18	403	124
Double ETL	SB04 (SR522)				242	117	835	56	1333	511
	SB05					31	230	17	309	114
	SB07 (Rose Hill)						376	21	589	306
	SB08 (NE85th)							40	564	137
	SB09								319	40

The percentage of 3+ HOV and tolled trips on the ETLs during the peak period is presented in Figure 12. In each direction, about one quarter of the trips are 3+ HOV and the rest are tolled. These numbers are for peak period and they shows how the ETLs carry more traffic when the corridor congestion level is high.

About 11 percent of the tolled trips travel from the beginning to the end of the corridor – that is, from Bellevue to I-5 or the opposite direction.

Figure 12. ETL trips breakdown in the peak period, from transaction data



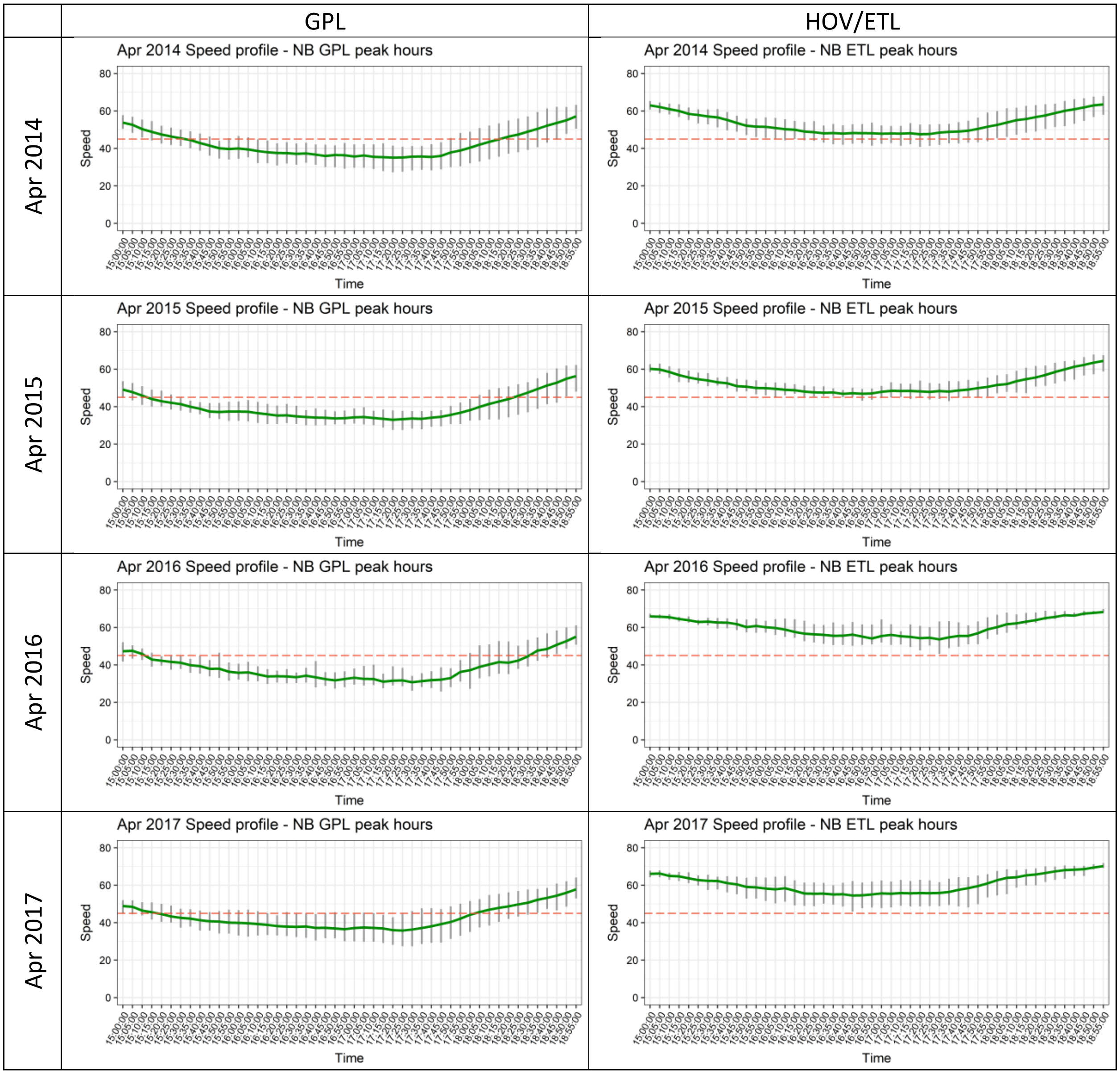
4.3 Speed Analysis

Speed analysis by loop detector data: Loop detectors collect lane-by-lane speeds every 0.5 miles along the corridor. Speed profiles with respect to time are created for both lane types and both directions and for the 42-month duration of study. For illustration, data for the month of April in the four consecutive years are presented in Figures 13 and 14. The green line shows the average speed and the vertical bars show the range between the 10th percentile and the 90th percentile speeds. The red line shows the 45 mph threshold.

The following observations can be made from analysis of northbound speed profiles in Figure 13, although conclusions would require a more comprehensive investigation of the results, including the consideration of volume growth in the corridor:

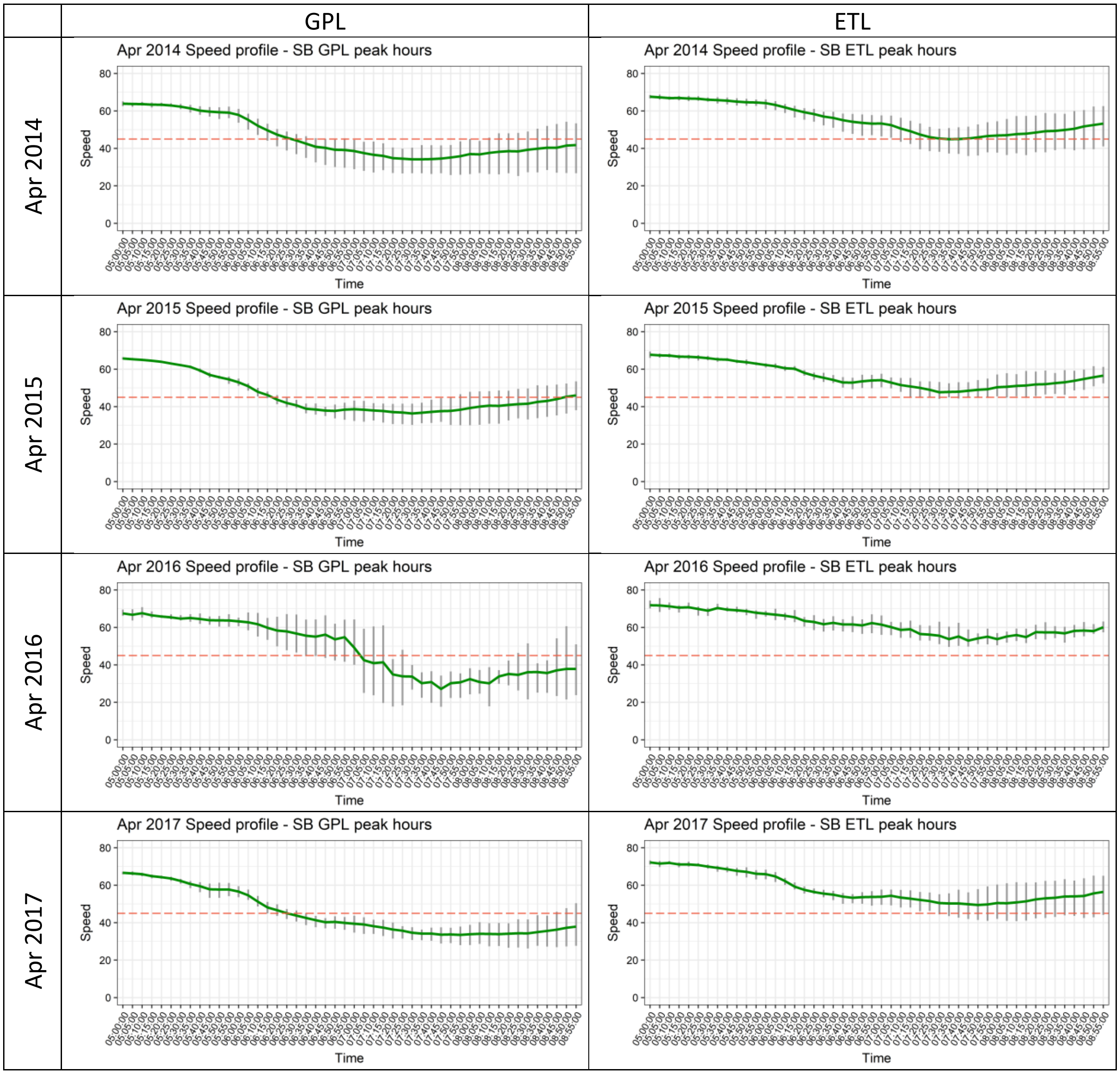
- The HOV lane speed was close to the 45 mph in 2014 and 2015 and improved in 2016 and 2017, which is likely due to the opening of the ETLs;
- The GPL speed was below 45 mph and gradually decreased from 2014 to 2016 and increased in 2017, likely due to the shoulder lane opening; and

Figure 13. Speed profiles in the northbound ETLs and GPLs in the peak period for the month of April 2014-2017



In the southbound direction (Figure 14), GPL speed was below 45 mph for a period of time within peak period in April 2014 to 2017. The graphs do not show noticeable change in average speed from 2014-2017. However, high speed variations (low reliability) is observed in April 2016 and low speed variations (high reliability) is observed in April 2017. In general, and most noticeably in 2016, the observed speed drop is in the later hours of the peak period (5AM-9AM) and extends beyond it. This suggests a need to revisit the peak period definition, albeit with proper studies and consideration of travelers’ behavior. As was the case with the northbound HOV, southbound HOV speed was close to 45 mph in 2014 and 2015 and improved after the ETL opening. The southbound speed improvement became smaller by volume growth through 2017.

Figure 14. Speed profiles in the southbound ETL and GPL in the peak period for the month of April 2014-2017



While the graphs in Figures 13 and 14 show the average vehicle speeds in the entire corridor for April of each year, and although they look above 45 mph, some locations have average speeds below 45 mph. This fact is carefully taken into account when calculating the percentages in Figures 15 and 16 – which show the percentage of time in the peak period where ETL speed is above 45 mph. For example, if one out of 10 detectors showed speed below 45mph on eight out of 20 days, the percentage would be calculated as 1 - 1x8/(10x20) = 0.96 or 96 percent.

The graphs indicate that, in general, the percentage is below the 90 percent threshold. However, the percentage was noticeably lower before the opening of the ETLs and improved after that. In some months after opening of the ETLs, the 90 percent threshold was achieved, but over time the percentage has declined gradually; that can be attributed to the volume growth in the corridor as explained in Section 4.2

(more than 11 percent overall VMT growth after opening of ETL) as well as other factors not considered in this study. On average, the ETL speed is above 45 mph 85 percent of the time in the northbound lanes, and 82 percent in the southbound lanes from September 2015 to June 2017. In the last six months of the study period, the percentages are 85 percent in the northbound and 78 percent in the southbound.

Before the ETLs opened, from January 2014 to August 2015 the HOV lane was above 45 mph during the peak period 69 percent of the time in the northbound direction and 67 percent of the time in the southbound direction.

Figure 15 . Percent time in peak period with northbound ETL speed above 45 mph

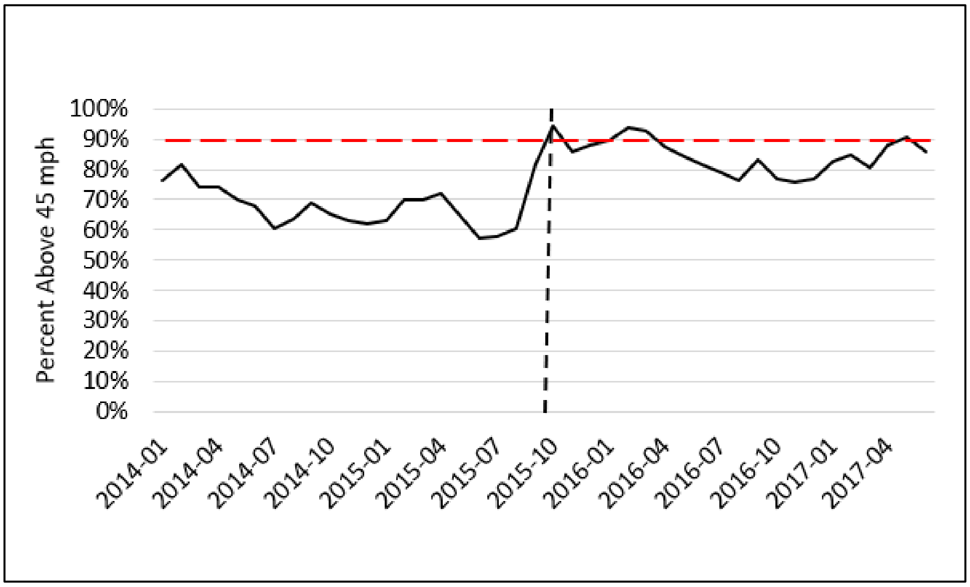
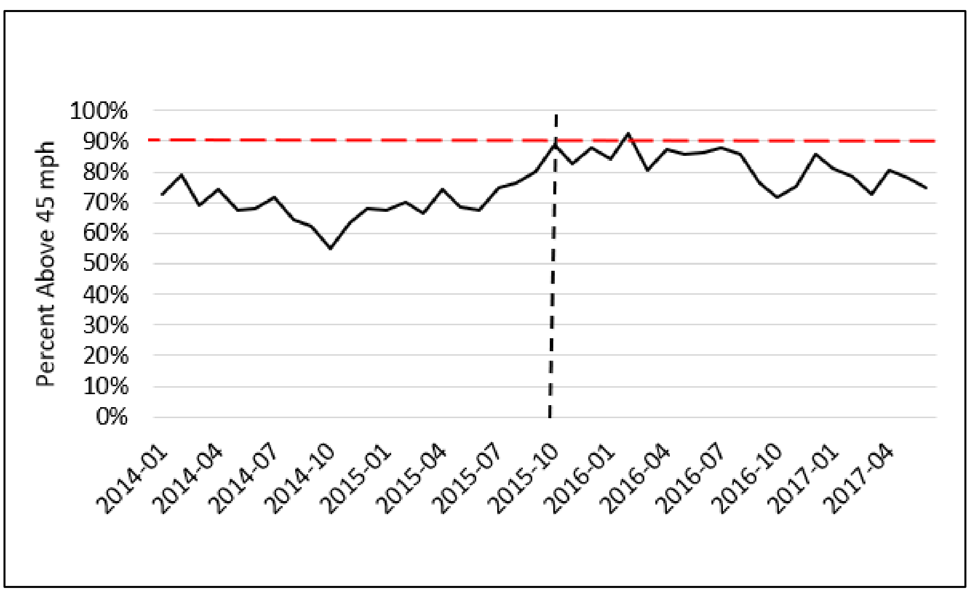


Figure 16. Percent time in peak period with southbound ETL speed above 45 mph

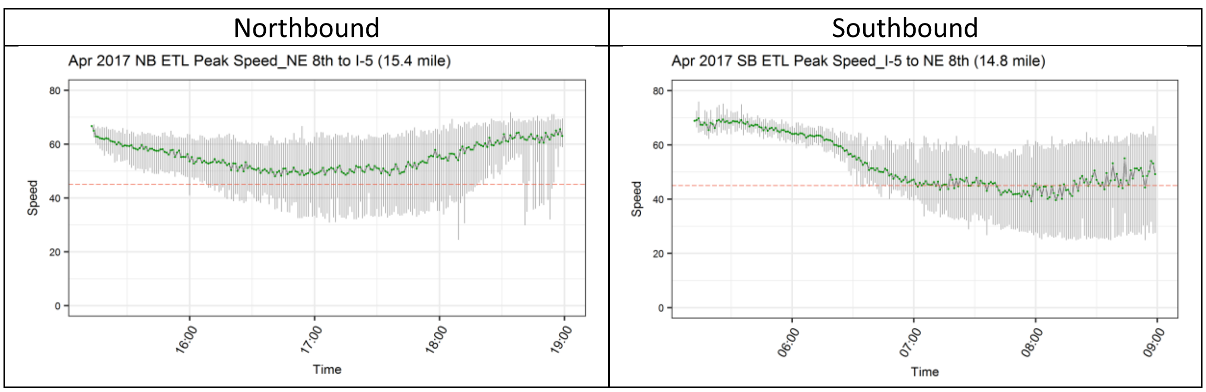


Speed analysis by transaction data: Speeds are also calculated for the ETL traffic using ETL transaction data (as explained in the methodology) and are used for validating the speeds obtained from detector data. In this case, speeds are calculated for the ETL trips for every month from January 2016 to June 2017. Comparison of average speeds from transaction data and from detector data confirms that the measures calculated from detector data are reliable and the conclusions are robust. In other words, this comparison adds another level of confidence to detector data as a reliable data source.

Figure 17 shows a minute-by-minute speed profile in the peak period for the sample month of April 2017. The green lines display average speed and the vertical bars show the range between the 10th percentile and the 90th percentile speed. Speed profiles in Figure 17 indicate that:

- In both directions, speed drops below 45mph in the peak period;
- In the northbound direction, while the average speed (the green line) is above 45mph, since speed varies among vehicles, some users experience a speed below 45mph; and
- In the southbound direction, the low speed is observed almost one hour later than the start of the defined peak period. Indeed, while the defined peak period is from 5AM to 9AM, speed starts to decline noticeably after 6AM and doesn't recover by 9AM.

Figure 17. Peak speed profiles in the ETL for April 2017



4.4 Tolling Analysis

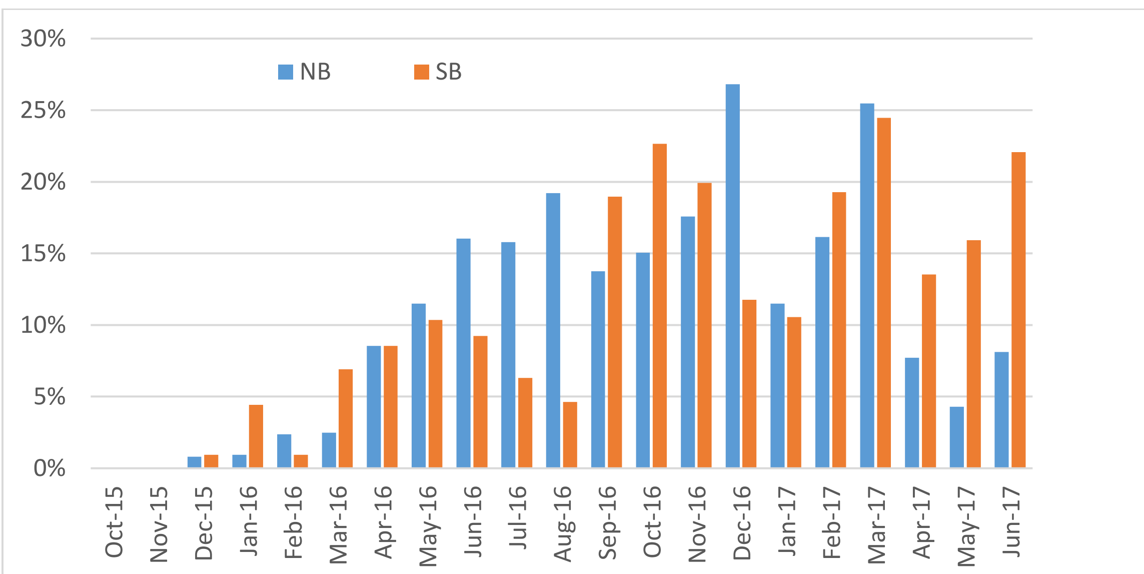
To shed light on how the tolling algorithm works on the ETL facility, data from ETL transactions and applied toll rates were analyzed. Figure 18 shows the percentage of time the toll has reached the maximum value of $10.

- The $10 maximum toll rate was reached during 15 percent of the peak period during the last six months of the study time (January – June, 2017); and
- The percentage is higher in the southbound direction than in the northbound direction.

This is a high percentage of time to hit the maximum toll rate, which could indicate that the demand for the ETLs exceeds expectations, and the algorithm must frequently adjust the price to the maximum to avoid congestion on the ETLs.

Potential reasons for this could be either *high demand and high willingness to pay on the part of ETL users* and/or *an insufficient pricing algorithm* that fails to keep up with increasing traffic volumes during the peak period, reaches the $10 maximum toll rate too frequently, and thus contributes to "breakdown" in the ETL facility.

Figure 18. Percent time the maximum toll is reached in the peak period



In Figure 19 the average paid toll in April 2017 is shown as a sample. Each square represents the toll at an entrance plaza in five-minute time intervals. Deep red squares represent higher tolls and green squares represent lower tolls. Highest toll rates (darker red squares) are observed at the NB07 plaza, which is located at SR 522; however, traffic in the segment downstream of SR522 primarily comes from other locations ranging from NE 8th Street and NE 128th Street, which are located upstream from SR522. This could suggest that the tolling algorithm does not control the traffic proactively on time at upstream entrance points, like NE 8th Street or NE 128th Street, and has to do it at downstream points, like SR522, when traffic is already close to capacity.

Figure 19. Northbound peak period average toll paid in April 2017

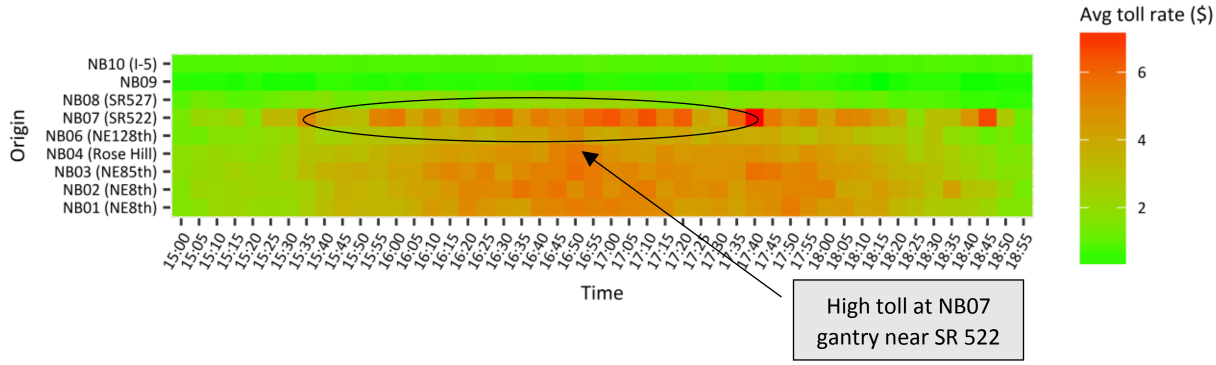


Figure 20. Northbound peak period average toll difference in April 2017

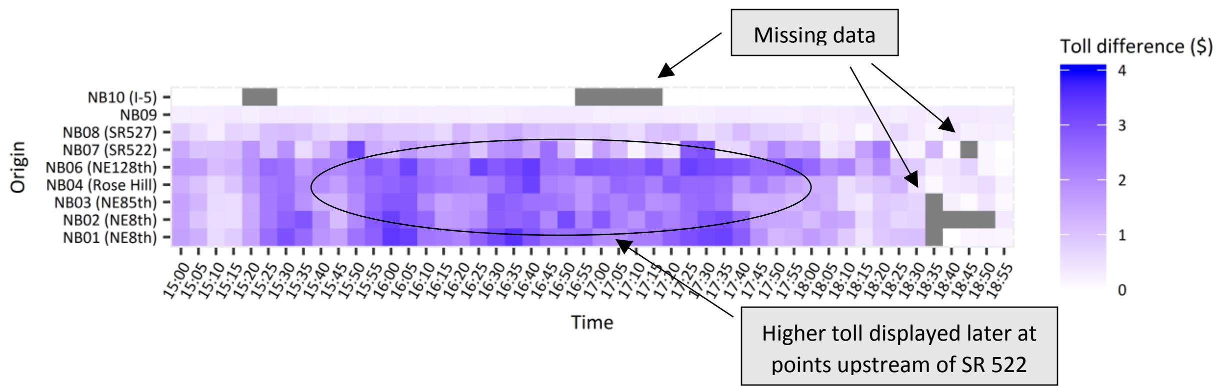


Figure 20 shows the difference between the toll that users paid and the toll that was displayed at their starting points when they arrived at the ending point. Darker cells represent a larger difference between the paid toll and the displayed toll at trips' end time. High toll differences represent that users' contribution in congestion is greater than what they pay. This suggests that the tolling algorithm should be more responsive and raise the price faster or more consistently with traffic increases on the ETLs. In other words, higher values in the graph represent the delay in toll rate setting to control the performance of the ETLs. In particular, entrance points ranging from NE 8th Street to NE 128th Street show darker squares indicating that they contribute in downstream congestion but pay less. Simply put, vehicles are locked in at a low price at an upstream point and may not be charged according to their impact on the downstream congestion. This contributes to facility breakdown – failure to maintain 45 mph speed at least 90 percent of the time.

As shown in Figure 20, toll differences are as high as $4, which is an indicator for imperfect dynamic toll setting algorithm. This suggests a focused study might be needed on the pricing algorithm, which could lead to improvements in corridor performance.

5. DISCUSSION

This section provides a brief discussion on the data analysis in reference to the following items:

- Minimum speed on the ETLs
- GPL speed changes
- Other performance criteria

Even though the ETL facility is not meeting the 45 mph speed requirement, it is serving far more vehicles than the HOV lane served – 59.2 percent more vehicle-miles in the northbound direction and 94.5 percent more vehicle-miles in the southbound direction (See Tables 4 and 5) – and is performing in a predictable way. By increasing traffic volume in the ETL facility without significantly reducing speeds along the GPLs, the corridor is experiencing increased vehicle throughput: 9.1 percent in the northbound direction and 19.0 percent the southbound direction, for overall increased vehicle throughput of nearly 14.1 percent.

Regarding the 90 percent threshold to maintain the ETL speed above 45 mph, the study team has observed that this criterion has not been satisfied in several months. The southbound corridor has a higher frequency of failing the minimum speed. Aside from overarching factors such as population growth, land use changes around the corridor, and economic growth, two potential factors could be considered for this phenomenon.

First, evaluating speed by itself is not sufficient, as traffic is a complex phenomenon and factors such as density and volume play roles. The volume observation analysis indicates there has been a significant vehicle-mile increase of more than 14 percent after opening the ETLs, bringing more vehicles to the corridor. This new volume could be associated with new population, new trips being made in the region, induced demand, existing trips diverted to the I-405 corridor upon ETL opening, or existing trips using longer segments of the corridor. In any case, this new volume can have noticeable impact on corridor performance.

Volumes on the corridor are up 14% since its opening, impacting corridor performance.

Second, our observation of the toll rates leads us to conclude that the way toll rates change in response to traffic congestion may not be optimal. A dynamic pricing algorithm such as that designed for this corridor should reduce the number of vehicles entering the ETLs before they break down. However, it seems that the I-405 algorithm either does not respond fast enough or locks in a toll rate for vehicles for too long a segment of the corridor. For example, a vehicle entering at the beginning of the corridor may pay a low toll because at that time there is no congestion in the corridor, but by the time it reaches a downstream segment 10 to 15 miles away, congestion may be built up, while the vehicle still pays the same low toll. An improvement would be to apply variable toll charges to smaller segments of the facility; this would allow the algorithm to take more information into account, and set toll rates that are more responsive to congestion before it actually happens.

The algorithm controlling toll rates in the I-405 ETLs allows too many vehicles into the ETLs when congestion is building, and that leads to breakdown of the facility. At peak times, it sets toll rates too low to optimally manage the facility.

Regarding the speed changes in the corridor, the most important factor is the corresponding volume increase in the corridor. Analyses show that in most cases, after opening the ETLs, speed on the GPLs slightly increased. However, because of the volume increase over time, the GPL speeds did not change substantially. In the northbound direction, opening of the shoulder lane showed improvements in GPL speed in recent months of the analysis.

Finally, the study of the corridor as a closed system using available data provides some insights into the facility performance, but the underlying factors go beyond the corridor and to the broader region. Indeed, by changing transportation facilities, users change their travel habits accordingly to achieve the best available outcome from their travel. The changes could be in their departure time, mode of transportation, or route/path.

For a better understanding of how a transportation facility performs and why, a more comprehensive regional study could provide greater insight into various factors influencing traffic conditions along the I-405 corridor in general and within the ETL facility in particular.

6. RECOMMENDATIONS

In addition to providing independent and objective analysis of traffic data and I-405 corridor performance, we were asked to provide recommendations – both short-term and long-term – for improving the ETL facility in particular and I-405 corridor generally.

Study of traffic data and research about other ETLs around the world has revealed a number of opportunities for improving the I-405 ETL facility and corridor performance. We are confident the following recommendations are both actionable and have a high likelihood of addressing challenges identified in our data analysis. However, additional study described in the corresponding section of this report would offer important detail and insight informing recommendation implementation.

Top Tier Short-Term Recommendations

The following recommendations could be implemented in the relative short term and offer the greatest promise for addressing current congestion and improving corridor performance:

1) Improve ETL speed though a more responsive dynamic toll algorithm

Our analysis reveals that the tolling algorithm is not optimally responsive. More specifically, the toll rate is too low as traffic volume builds in the ETL. In fact, the difference between the toll rate actually paid and the toll rate displayed at a trip's conclusion can be as high as $4. That is, a motorist might enter the ETL and lock in a toll rate that does not reflect the actual traffic volume building during their respective trip along the ETL corridor. Particularly during peak travel times, the toll algorithm and pricing is not adequately controlling input traffic along the ETL, which in turn can result in unmanageable ETL congestion and breakdown – and thus unacceptably low average ETL vehicle speeds.

This is a short-term recommendation. It could be implemented without new infrastructure investment. However, it may require additional study focused on the specifics of how WSDOT would make its toll algorithm more responsive to volume changes.

- Impact achievable in short term
- Additional study recommended
- $ (relatively low cost compared with other recommendations)

2) Improve ETL speed through segmented corridor tolling

WSDOT currently allows motorists to "lock in" one corridor-long toll rate upon entering the facility. This is a business rule which WSDOT enacted for simplicity and ease-of-use for motorists. However, locking in one corridor-long toll rate also has significant traffic management disadvantages. Traffic conditions and volumes can change considerably along the 17-mile tolled corridor – especially during peak periods. Applying tolls on a segment-by-segment basis, with segment-specific toll rates that are more reflective of real-time traffic conditions and volumes, will improve speeds in the ETLs and corridor performance overall.

Under this approach, an electronic dynamic pricing sign would advise motorists entering the facility of segment-specific toll rates. The toll rates for each segment would be updated every few minutes based upon the volume in each segment. Segment pricing is used in many U.S. cities, and there are many different approaches for structuring and communicating segment prices.

This recommendation also could be implemented in the short term. Although it would involve certain infrastructure enhancements, such as additional dynamic pricing signs and access points through striping, these changes would be comparable to other facility adjustments that have been made in the past. However, this change in WSDOT's business rule would require clear communication with motorists who currently expect to lock in a corridor-long toll rate.

- Impact achievable in short term
- Additional study recommended
- $$ (relatively moderate cost compared with other recommendations)

Second Tier Short-Term Recommendations

The following recommendations also could be implemented in the relative short term, and we believe they would complement those recommendations above to help address current congestion and improve corridor performance:

3) Move toward an "open access" ETL facility to smooth lane transfer

The ETL facility currently is striped to limit entrance from and exit to the GPLs. Controlling the flow of traffic between lanes has advantages, especially in situations where prevailing lane speed can contrast considerably.

However, in some cases, limiting the number of entrance and exit points can concentrate lane transfer and actually impede traffic flow and reduce speed overall. Therefore, we believe that implementing an open access strategy <u>on some parts of the ETL facility</u> could improve traffic flow and throughput. Any changes in access policy should be in concert with the corridor segment toll structure described above.

Although this recommendation can be considered short-term in nature, further study of how best to apply an open access approach may reveal corridor segments where restricted ETL access remains beneficial.

- Impact achievable in short term
- Additional study recommended
- $$ (relatively moderate cost compared with other recommendations)

4) Increase maximum toll rate to reduce ETL breakdown

Analysis reveals that the maximum toll rate was applied on average 15 percent of the time in either direction during the daily peak hours of the last six months of the study period. The maximum toll rate set in administrative rule is $10.

This is an indication of ETL breakdown. For dynamically-priced toll facilities such as the I-405 ETLs, the goal is to reach the maximum toll rate only rarely. Reaching the maximum toll rate is problematic from a traffic management standpoint, because once the maximum is reached the lane volume can no longer be managed through pricing to ensure ETL speed. This phenomenon is known as a facility breakdown. During breakdown, the travel time reliability benefits of the ETL facility are lost altogether while the resulting congestion can seriously disrupt travel for extended periods.

Although this recommendation could be implemented in the short term, it should be considered complementary to the recommendations described above. We believe that the combination of a more responsive dynamic toll algorithm and application of toll rates by segment should significantly reduce congestion in the ETL, and thus reduce the frequency the $10 maximum toll rate is charged. However, to ensure ETL speed and facility performance during the most adverse traffic conditions, an increased maximum toll rate is recommended – required, even – to produce full benefits from recommendations described above.

- Impact achievable in short term
- Additional study recommended
- $ (relatively low cost compared with other recommendations)

5) Adjust AM peak period times to increase ETL speed

Extending the AM peak period for an additional hour in order to remove 2+ HOVs during this time would improve ETL performance by reducing the frequency and/or intensity of ETL breakdown.

The AM peak period is currently defined as 5AM to 9AM, Monday through Friday. However, analysis reveals that traffic volumes along the corridor are consistent with peak period condition between 9AM and 10AM – and significantly greater between 9AM and 10AM than between 5AM and 6AM. Although ETL toll rates apply to motorists in these lanes throughout each weekday, 2+ HOV motorists are allowed into the ETL facility without paying a toll during non-peak hours. As such, the current AM peak period hours restrict free use of the ETL facility for 2+ HOV motorists at a time when the facility could support them (5-6AM), and they permit 2+ HOV motorists to use the facility for free at a time when the facility is congested, and therefore doesn't have the capacity to support them (9-10AM).

We have two alternative recommendations to address this:

a) As a recommendation that could be implemented in the short-term, expanding the AM peak period to 5AM – 10AM would provide ETL congestion relief.
b) As an alternative, adjusting the AM peak period from 5AM – 9AM to 6AM – 10AM would produce ETL congestion relief during the latter portion of the AM commute; however, shifting the peak period rather than expanding it could invite more motorists into the ETL lane as volumes begin to mount and contribute to unintended congestion early in the AM peak period.

Either approach would help alleviate AM peak period congestion in the ETL.

- Impact achievable in short term
- Additional study recommended
- $ (relatively low cost compared with other recommendations)

Long-term Recommendations

The following recommendations would require a longer period of time to implement, but nonetheless offer promise for addressing congestion and improving corridor performance:

6) Extend second full ETL in each direction to improve ETL speed

In high-growth and geographically confined traffic corridors such as the I-405 corridor, congestion pricing approaches such as the ETL facility offer the dual promise of predictable ETL drive time and increased throughput, as compared to GPL-only facilities. This is the case with the I-405 corridor. Based upon how similar facilities have performed around the country, we are confident that extending two full ETLs from 160 Street NE in Woodinville to I-5 in Lynnwood would remove current ETL bottleneck conditions and improve the flow of traffic along the ETL facility – likely producing improved ETL speeds and overall corridor traffic throughput.

This recommendation would require more time to implement than the others described above. Optimal design of the additional ETLs would require in-depth traffic modeling and scenario analysis, and construction would take additional time. Nonetheless, researchers are confident that congestion pricing has and will continue to improve traffic performance along and the I-405 corridor.

- Impact achievable in long term
- Additional study recommended
- $$$ (relatively high cost compared with other recommendations)

7) Add Capacity to Ensure Lane Continuity and Ease Bottlenecks

Bottlenecks occur in areas where traffic volumes converge – be it through lane loss, on-ramps, etc. The I-405 corridor includes a number of bottlenecks in both the GPLs and ETLs, and it may be beneficial to add lane capacity in areas with bottlenecks to improve corridor continuity. We recommend studying this issue to better inform a final decision on the question.

This is a long-term recommendation, because it would require time to study where and how GPLs should be expanded, and additional time to construct GPL expansions.

- Impact achievable in long term
- Additional study recommended
- $$$ (relatively high cost compared with other recommendations)

8) Increase transit options to improve throughput and speed

Growth in VMT along the I-405 corridor is well outpacing statewide and national averages. Therefore, regardless of the ETL changes we describe in this section, the corridor will continue to experience significant pressure from recent and projected population and motorist growth. Over time, the short-term benefits of added lane capacity will be reduced by growth in VMT. As a result, maintaining and improving long-term corridor performance requires a balanced approach of roadway infrastructure improvements and transit options. Research conducted by others has found that well-designed transit options can help move more people through a corridor in fewer vehicles. In this way, transit can help improve corridor throughput efficiency in both the ETLs and the GPLs.

Over the long term, implementation of I-405 master plan transit improvements will reduce congestion and increase passenger throughput in the high-growth corridor. These improvements include new transit centers and park and ride spaces, a bus rapid transit (BRT) system, vanpools, direct access ramps for transit and carpools, and an overall increase in transit service.

- Impact achievable in long term
- Additional study recommended
- $$ (relatively moderate cost compared with other recommendations)

As time passes and conditions change, even the most sophisticated ETL facilities require regular adjustments. This is particularly true of those operating in traffic corridors like the I-405 corridor that serve rapidly growing regions. Therefore, these recommendations should be considered part of the natural evolution of the corridor, not criticisms of work that has been done in the past. We are confident that implementation of these recommendations will improve I-405 ETL performance and significantly increase throughput and efficiency along the corridor.

7. RECOMMENDED FUTURE STUDY

This study focused on analyzing the corridor data to answer whether the ETL facility is meeting the performance requirements. Although evidence is introduced on potential reasons for ETL performance, more in-depth studies are recommended to investigate the factors contributing in facility performance. Moreover, the recommendations in this report are provided based on the past data. For evaluating the effectiveness of the recommendations and for optimizing the ETL facility, future studies are strongly recommended.

In the recommended studies, two important factors must be considered; first, the broader geographical region that generates travel demand for the I-405 corridor; and, second, travelers' behavior pertinent to origin-destinations, route choice, value of time, etc. The following additional study should be considered:

i. Analyze ETL customer demand patterns to identify points of entry to I-405 (entrance ramps) and trip lengths. Analyze the availability of alternative path for each origin-destination trip and propose an alternative pricing algorithm with prices varying by entrance ramp location.
ii. Conduct field tests of different price ranges and price change increments to determine Value of Time (VOT) and price elasticities. Field tests would inform adjustments to the ETL price schedule.
iii. Develop a traffic simulation model to experiment with different pricing algorithms and to optimize pricing algorithm parameters.
iv. Model the customer base size for the ETL at the level of census blocks and use this information to inform and calibrate the pricing strategy.

8. CONCLUSION

The I-405 ETL facility is meeting the statutory performance measure related to financial sustainability, but not the performance measure related to average ETL speeds. This is due in part to overall traffic volume growth and a toll rate algorithm and pricing not adequately responsive to rapidly-increasing traffic volume during peak periods. Our findings suggest that a number of adjustments could be made that should lead to both of the primary statutory performance measures being met.

Even though the ETL facility is not meeting the 45 mph speed requirement, its lanes are serving more vehicles than did the HOV lane. As a result, overall corridor throughput has increased significantly. Also, average ETL speeds and travel times have improved significantly following ETL facility opening, and average GPL speeds and travel times have not changed significantly.

As time passes and conditions change, even the most sophisticated ETL facilities require regular adjustments. This is particularly true of those operating in traffic corridors like the I-405 corridor that serve rapidly growing regions. Therefore, these recommendations should be considered part of the natural evolution of the corridor, not criticisms of work that has been done in the past. We are confident that implementation of these recommendations will improve I-405 ETL performance and significantly increase throughput and efficiency along the corridor.