Reliability and Duration of Congestion metrics are measured for the first time in 2016 further utilizing the benefits of commercial speed data

7 | Big Data Performance Metrics

Recently, new data technologies and performance measurement approaches have been radically transforming congestion monitoring practices nationwide. These technologies and approaches revolve around the emerging fields of Big Data and Analytics. These analytical techniques improve the monitoring program by providing more data for a lower cost and widening the scope of congestion analysis.

Using the commercial speed data from INRIX, big data performance metrics of reliability and duration of congestion are computed (for informational purposes) for the first time in the 2016 LOS Monitoring Report. Data for these additional performance metrics was used from all Tuesdays, Wednesdays and Thursdays in the defined monitoring period. In this report, the reliability and duration of congestion performance measures are analyzed for the Alameda County freeway network.

7.1 | Reliability

The reliability metric considers the travel time variability. For a user, this is important to determine how much time to allow for a trip to arrive on time with a degree of certainty. Unreliable travel times can be caused by normal fluctuations in demand, inclement weather, incidents, work zones and special events.[15] These influencing factors can cause significance variation in the travel times.

The calculation of reliability for the current project includes the following assumptions:

- The monitoring periods for this reliability analysis were 7:00 a.m. to 9:00 a.m. for the morning peak period and 4:00 p.m. to 6:00 p.m. for the afternoon peak period.
- Reliability metrics were calculated based on INRIX measurements of average speed of all vehicles from each minute within the monitoring period. This differs from a traditional reliability calculation which is calculated for each individual vehicle.

7.1.1 | The Reliability Concept

A reliability analysis is typically depicted using a probability distribution function. For example, if a driver takes the same trip for 34 days, the graphic shows the travel time results for each of those 34 surveys (see Figure 7-1). Insights may be obtained by reviewing the:

- High point on the graph which aligns with the most commonly experienced travel times;

[15] SHRP2 LO8: Proposed Chapters for Incorporating Travel Time Reliability into the Highway Capacity Manual. Transportation Research Board of the National Academies, Washington D.C. 2013.

- Leftmost and rightmost parts of the distribution which align with the minimum and maximum experienced travel times; and
- The range of travel times or the difference between the maximum and minimum occurring travel times.

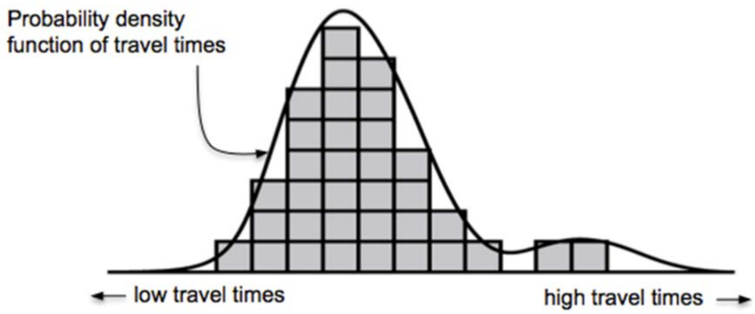

Figure 7-1: Example Probability Distribution Function

In order to compare the reliability across various travel time distributions, the following performance measures are defined.[16]

Planning Time: In planning a trip, how much time should one allow for a trip to ensure 95% on-time arrival. It is equivalent to the 95th percentile of travel times experienced (i.e. if the same trip was taken 100 times, the 95th percentile would be equal to the travel time of the 95th longest trip).

$$Planning\ Time = 95th\ Percentile\ Travel\ Time$$

Planning Time Index (PTI): To allow for comparison across different routes and different trip lengths, the planning time index is a ratio of the 95th percentile travel time to the free flow travel time. If a trip takes 20 minutes in light conditions (i.e. free flow) and a planning time of 30 minutes will ensure 95% on-time arrival, then the planning time index is 1.5. A free flow of 65 mph was assumed as is common practice in reliability analysis. [17]

$$Planning\ Time\ Index = \frac{95th\ Percentile\ Travel\ Time}{Free\ Flow\ Travel\ Time}$$

Buffer Time/Index: The buffer index (BTI) represents the extra buffer or cushion that one allows in addition to the average travel time to account for any delay. For example, if a trip in the morning peak normally takes 25 minutes (i.e. mean travel time), and 30 minutes will ensure a 95% chance

[16] Travel Time Reliability: Making it there on time, All the time. Federal Highway Administration. 2005. http://ops.fhwa.dot.gov/publications/tt_reliability/TTR_Report.htm
[17] Technical Memorandum: Analysis Procedures and Mobility Performance Measures – 100 Most Congested Texas Road Sections. Texas A&M Transportation Institute. 2014.

of on-time arrival, then the buffer time is 5 minutes and the buffer index is 0.2. A larger buffer index indicates a wider range of travel times and represents less reliable travel.

$$Buffer\ Time = 95th\ Percentile\ Travel\ Time - Mean\ Travel\ Time$$

$$Buffer\ Index = \frac{95th\ Percentile\ Travel\ Time - Mean\ Travel\ Time}{Mean\ Travel\ Time}$$

Figure 7-2 shows an example probability distribution and labels the reliability metrics.

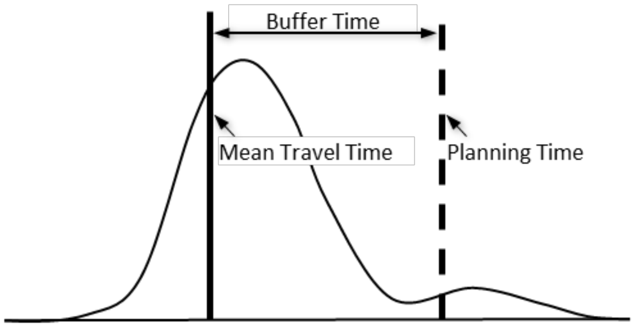

Figure 7-2: Example Probability Distribution Function with Reliability Metrics

7.1.2 | Reliability Case Study for I-880 Corridor

Since reliability is calculated for the first time in this monitoring cycle, the reliability concept is expanded in a case study on the I-880. This section reviews the probability distribution functions on the I-880, then shows the reliability metrics for this road and finally provides discussion about the reliability in the northbound and southbound directions in both the morning and afternoon peak periods.

The probability distribution function on the full length of I-880 in Alameda County is presented in Figure 7-3. It shows the distribution of morning and afternoon peak period travel times for the northbound and southbound directions separately. Note that the graphs in this chapter and the Appendix show two colored distributions, pink and green, for the morning and afternoon peak periods, respectively, while the darker shades of both colors represent regions occupied by both peak period distributions.

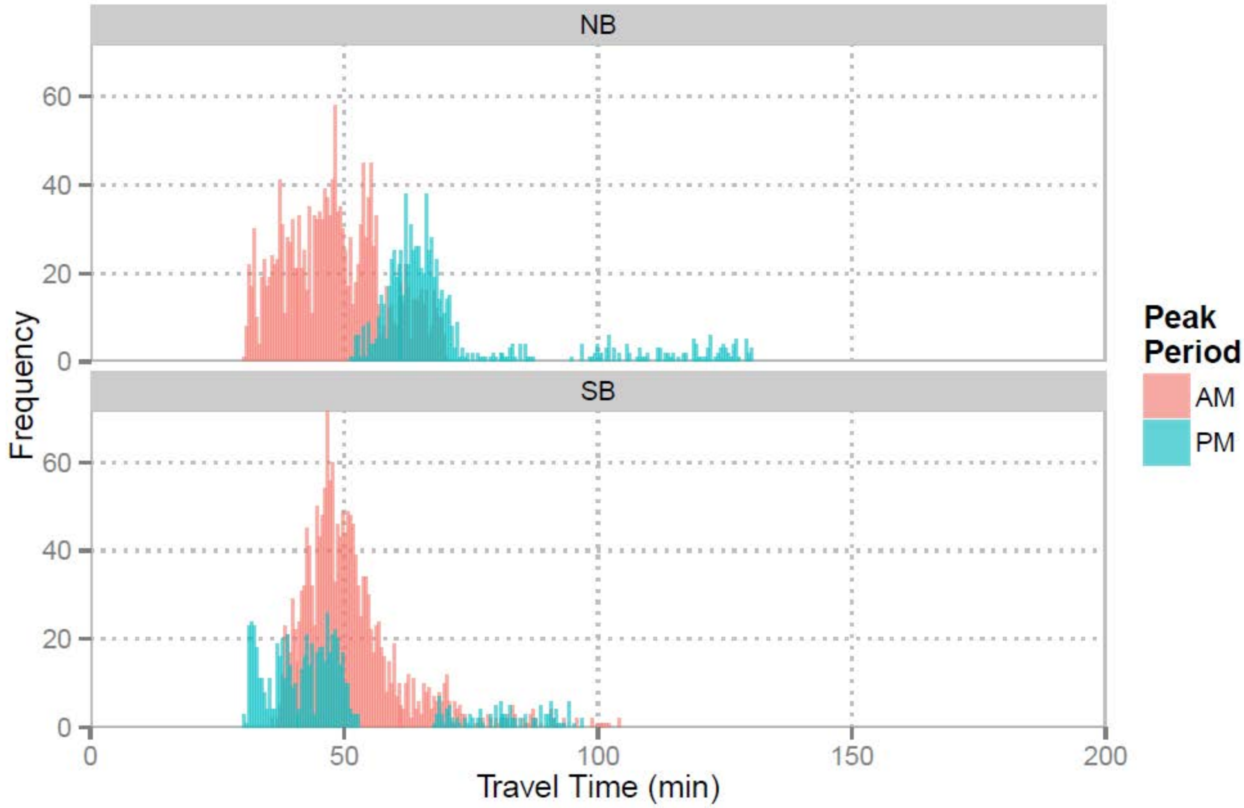

Figure 7-3: Distribution of Travel Times along I-880 in Alameda County (2016)

In the northbound direction, which has a total length of 35.4 miles, the lower limits for travel time for the morning and afternoon periods were approximately 30 minutes (71 mph) and 51 minutes (42 mph) respectively. The morning travel time distribution had a median of 48 minutes (44 mph) and a maximum of 70 minutes (30 mph). The afternoon travel time distribution had a median of 65 minutes (33 mph) and a maximum of 130 minutes (16 mph). Overall, in the morning, the northbound direction experiences moderate congestion with a small amount of free flow traffic. The afternoon period has heavier congestion with a wider range of travel times.

In the southbound direction, which has a total length of 35.2 miles, the lower limits for travel time for the morning and afternoon periods were approximately 36 minutes (59 mph) and 30 minutes (70 mph) respectively. The morning peak travel time distribution has a median of 49 minutes (43 mph) and a maximum of 104 minutes (20 mph). The afternoon travel time distribution has a median of 44 minutes (48 mph) and a maximum of 94 minutes (23 mph). Overall, the southbound direction experiences heavier congestion in the morning period and a mixture of moderate congestion and free flow in the afternoon period. Both directions have a wide range of travel times. The higher frequency of longer travel time for southbound morning trips and northbound afternoon trips correspond to the commuter traffic flows to and from the employment centers in the South Bay and southern Peninsula which are reached by I-880.

Figure 7-4 then adds the reliability measures to previous figure. For the northbound direction, the morning peak period has a lower mean travel time and shorter buffer time (meaning better travel time reliability), compared to the afternoon peak. For the southbound direction, the mean morning and afternoon peak mean travel times are similar, but the afternoon has a much longer buffer time (meaning poorer travel time reliability).

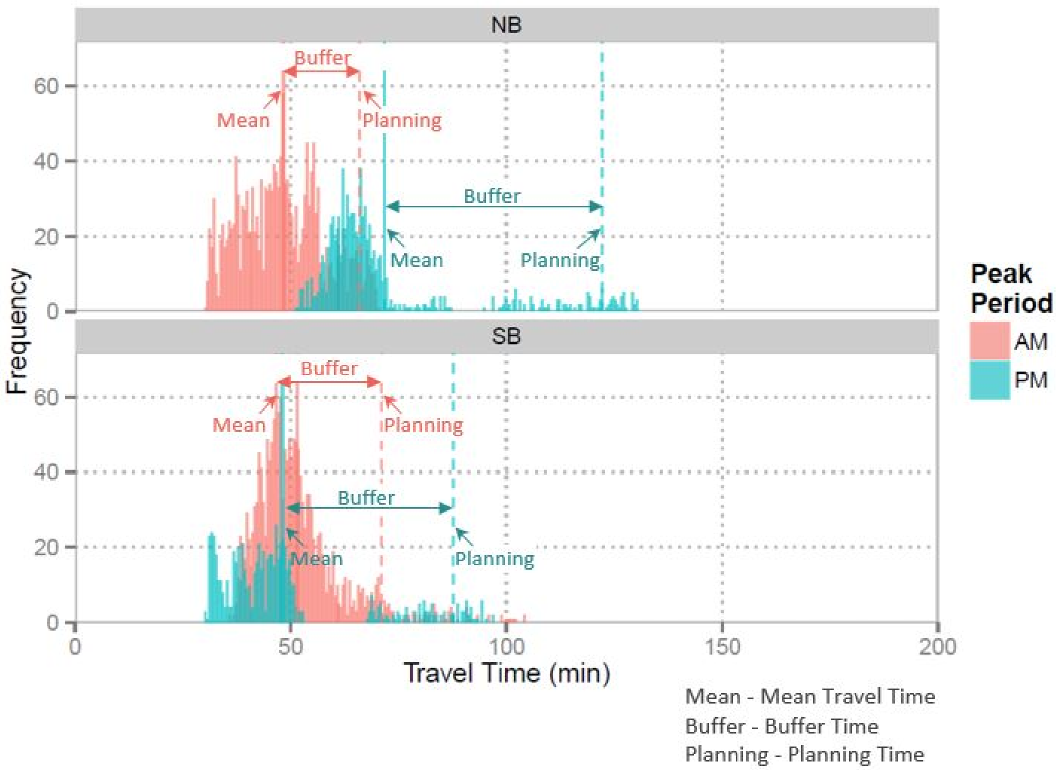

Figure 7-4: Travel Time Distributions on I-880 with Reliability Measures (2016)

A summary of all these values is presented in Table 7-1. The table shows that southbound I-880 in the afternoon peak period is the least reliable (BTI = 0.8). A value of 0.8 indicates that drivers would need to allow nearly the same amount of travel time beyond the mean travel time to ensure 95% on-time arrival. It also shows that morning peak period travel, in both directions, is generally more reliable with the lowest BTI value of 0.4.

Table 7-1: Summary Reliability Statistics for I-880 (2016)

Dir	Length (mi)	Peak	Free Flow Travel Time (mins)	Mean Travel Time (mins)	95th Percentile / Planning Time (mins)	Buffer Time (mins)	PTI	BTI
NB	35.4	AM	32.7	48.3	65.9	17.5	2.0	0.4
		PM	32.7	71.8	122.1	50.3	3.7	0.7
SB	35.2	AM	32.5	51.5	71.0	19.4	2.2	0.4
		PM	32.5	48.1	87.7	39.6	2.7	0.8

7.1.3 | Results

The results for the reliability measures were computed individually for smaller freeway segments across the entire CMP freeway network. The study team determined the limits of these smaller freeway segments by combining one or more CMP segments between major freeway system interchanges or county borders. Considering the I-880 case study further to illustrate this concept, there were three Reliability Segments: between I-80 and State Route 92, between State Route 92 and State Route 84 / Decoto Road, and between State Route 84 / Decoto Road and the Santa Clara County Line. The reason for using these longer segments to analyze reliability is to provide more useful results to freeway managers and agencies, by better reflecting the typical traveler experience of the combined effects of the smaller segments on the travel corridor. If CMP segments were used, then the analysis would be focused toward the location of individual bottlenecks, rather than travel on a length of corridor. The commercial speed data was aggregated for both peak periods during the monitoring period to compute travel time distributions on these individual Reliability Segments.

The segments and their reliability results for the complete CMP freeway network are presented in Appendix H, along with tables, graphs and maps for the following:

- Travel time and reliability for each individual Reliability Segment.
- Travel time distributions for each Reliability Segment.
- Morning and afternoon period maps showing the reliability for each Reliability Segment

Additional findings can also be seen on the reliability distributions. Continuing the case study on I-880, the southern segment of I-880 (between the Santa Clara County Line and State Route 84 / Decoto Road, Reliability Segments N23 and N28) exhibits poor reliability and longer travel times to and away from the South Bay employment centers during the commute direction peak period. The middle segment (between State Route 84 / Decoto Road and State Route 92, Reliability Segments N24 and N27) shows similar but relatively less pronounced

commuter peaking. The northern segment (between State Route 92 and I-80, Reliability Segments N25 and N26) has no peaking, with poor reliability and long travel times in both directions in both the morning and afternoon peak periods. It is likely that the northern section is serving a combination of commute trips to and from San Francisco, Peninsula, as well as South Bay employment centers.

Now reviewing other parts of the freeway network, the reliability results can be compared to the LOS monitoring results to yield interesting observations. In general, the reliability is worse on segments that also experience a lot of congestion. For example, one of least reliable segments is on the I-80 westbound between the Contra Costa County Line and the Bay Bridge Toll Plaza in the afternoon peak period. Much of this segment is LOS F at this time. However, this relationship is not universal. For example, in the afternoon peak period, State Route 24 showed LOS F in the eastbound direction and LOS A in the westbound direction. However, the reliability in both directions was approximately equal. For the eastbound direction, there is poor reliability that results from the presence of congestion. However, the westbound could possibly warrant more investigation to determine the source of the poor reliability. They may include occasional queuing back from the MacArthur Maze which is already known to have heavier congestion. Alternatively, it could be caused by regular incidents either on this segment or around the MacArthur Maze, or a greater variation by the day of week.

There are also examples of roadways that experience congestion, yet are more reliable. Consider State Route 92 in the afternoon peak period. The westbound direction experiences LOS E conditions, quite reliably. One can travel at the free flow speed in just over 10 minutes; however on average during the peak it takes approximately 19.5 minutes. The 95th percentile travel time is nearly 24 minutes. So despite the longer travel time on average in the peak (i.e. nearly double the free flow travel time), the buffer time is just over four minutes. In other words, the variation between the average and 95th percentile travel times is smaller and therefore, this road can be viewed as *reliably slower*. This may be perceived by drivers as more desirably than unreliably slower, since they can more accurately predict their travel time.

Since this analysis was conducted for the first time in 2016, these results can be used as a baseline in future monitoring studies. In 2018, comparisons of reliability between cycles will be possible.

7.1.4 | **Most/Least Reliable Segments**

This section highlights the most reliable and least reliable freeway segments in Alameda County using the Buffer Index (BTI) as the primary metric (See Table 7-2 and Table 7-3). The most reliable segments tend to be those which are less congested, but as discussed in the previous section, this is not always true as a severely congested segment may also be reliable if it is consistently congested. Reliability can be improved through improvements other than reducing traffic demand, such as:

- Operational improvements: adaptive ramp metering, dynamic pricing, adjustments to freeway service patrols, variable speed limits and lane control systems; and
- Geometric improvements: Accessible shoulders, emergency crossovers, improvements to detour routes, and vehicle turnouts.

Table 7-2: Most Reliable Freeway Segments (2016)

Reliability Segment ID	Peak Period	Description	Length (mi)	PTI	BTI
N20	PM	I-680 - SB from Contra Costa County Line to I-580	1.9	1.0	0.1
N16	AM	I-580 - WB from I-80 to Contra Costa County Line	0.9	1.1	0.1
N12	AM	I-580 - EB from SR 13 to I-238	7.9	1.0	0.1
N23	AM	I-880 - NB from Santa Clara County Line to SR 84 / Decoto Rd.	10.1	1.1	0.1
N17	AM	I-680 - NB from Santa Clara County Line to SR 238 (Mission Blvd.)	6.3	1.1	0.1
N21	PM	I-680 - SB from I-580 to SR 238 (Mission Blvd.)	13.1	1.1	0.1
N19	PM	I-680 - NB from I-580 to Contra Costa County Line	1.9	1.1	0.1
N11	AM	I-580 - EB from I-80 to SR 13	7.5	1.1	0.1
N30	AM	I-980 - EB from I-880 to I-580	2.4	1.1	0.1
N12	PM	I-580 - EB from SR 13 to I-238	7.9	1.2	0.1

Table 7-3: Least Reliable Freeway Segments (2016)

Reliability Segment ID	Peak Period	Description	Length (mi)	PTI	BTI
N15	PM	I-580 - EB from Contra Costa County Line to I-80	0.7	3.0	1.2
N3	PM	I-80 - WB from Contra Costa County Line to Toll Plaza	6.0	4.6	1.1
N19	AM	I-680 - NB from I-580 to Contra Costa County Line	1.9	3.2	0.9
N4	PM	I-80 - WB from Toll Plaza to SF County Line	5.3	4.3	0.8
N6	AM	I-238 - WB from I-580 to I-880	2.5	5.5	0.8
N5	AM	I-238 - EB from I-880 to I-580	2.6	2.5	0.8
N31	AM	SR 13 - NB from I-580 to SR 24	5.8	3.3	0.8
N30	PM	I-980 - EB from I-880 to I-580	2.4	2.7	0.8
N7	PM	I-580 - EB from I-238 to I-680	10.4	2.9	0.7
N13	AM	I-580 - WB from I-238 to SR 13	7.9	3.3	0.7

7.2 | Duration of Congestion

The duration of congestion commonly increases when roadways become more congested resulting in peak spreading and nullifying the old concept of the "rush hour." There is an upper limit to capacity of a roadway and as the demand increases beyond this, the peak period must extend in duration in order to serve the demand.

The duration of congestion is a performance measure that adds another dimension to assessing congestion levels. For example, two separate freeways could experience similar magnitudes of congestion during the peak period, however, one of the freeways could be congested for four hours and the other for just one hour. So while the LOS could be similar at the peak, travelers can more easily shift their commute time to avoid congestion on the second freeway. In such cases, the second freeway may be perceived as overall less congested during a specific time period.

The duration of congestion was calculated as the average length of time per day in which speeds fell below 30 mph between the hours of 4 a.m. and 10 p.m. For example, if the speed falls below 30 mph for 60 minutes on Day 1 and 50 minutes on Day 2, then the average duration of congestion is 55 minutes. The 30 mph threshold for this analysis is equivalent to the threshold for LOS F conditions on freeways based on the 1985 HCM shown in Table 2-3. This analysis is conducted for each freeway CMP segment. The benefits of this analysis are as follows:

- While a traditional LOS analysis would have just shown LOS F, this analysis differentiates this segment from others at LOS F by showing how long it is congested. Thus it is conceivable to conclude that a segment that experiences LOS F for one hour is better than another segment that experiences LOS F for four hours.
- The time value is also tangible and understandable to constituents and the public, whereas total vehicle-hours of delay (i.e. values in the thousands) is often difficult to perceive.

Table 7-4 shows the Top 10 longest congested CMP segments and their corresponding LOS in both the morning and afternoon peak periods (from Chapter 3 |). Many of these segments were on I-80 westbound in Emeryville and Berkeley, with one having congestion lasting 442 minutes (i.e. over 7 hours per day). Four of these segments experienced significant congestion (i.e. LOS F) across both peak periods. A further four segments experienced LOS F in one peak period and then LOS D or E conditions in the other peak. Two of the Top 10 segments experienced LOS F in one peak period and then uncongested conditions in the other peak period indicating that there is a long period of congestion in the afternoon peak. One such segment was on the I-680 northbound from Vargas Road to Andrade Road with 270 minutes (i.e. 4.5 hours) of congestion daily most likely attributed to commuters returning from Silicon Valley. This is an example of the congestion spreading beyond the two hour peak period window allocated for monitoring the LOS in Chapter 3 |, and where the duration of congestion performance measure can more completely describe the roadway performance experienced by commuters. A complete listing of the duration of congestion for all freeway segments is provided in Appendix H.

Table 7-4: Top 10 Segments Impacted by Congestion for the Longest Duration per Day (2016)

Rank	CMP	Description	Length (mi)	Duration of Congestion (Avg. mins per day) [1]	LOS AM / LOS PM
1	F11	I-80 - WB from Ashby Ave. to Powell St.	0.7	442	(F30) / (F20)
2	F10	I-80 - WB from University Ave. to Ashby Ave.	1.3	394	(F30) / (F20)
3	F9	I-80 - WB from Jct I-580 to University Ave.	1.5	310	(F20) / E
4	F14	I-80 - WB from Toll Plaza to SF County	2.0	291	(F30) / E
5	F56	I-580 - WB from SR 24 On-ramp to I-80/580 Split	1.2	289	(F30) / (F30)
6	F13	I-80 - WB from I-580 Split to Toll Plaza	1.3	286	(F10) / E
7	F12	I-80 - WB from Powell to I-80/I-580 (Split)	0.5	276	(F30) / (F30)
8	F64	I-680 - NB from Vargas Rd. to Andrade Rd.	2.2	270	A / (F20)
9	F61	I-680 - NB from Durham Rd. to Washington Blvd.	1.3	262	A / (F10)
10	F91	I-880 - NB from Alvarado-Niles to Tennyson Rd.	2.6	253	D / (F20)

1. Includes times between 4:00 a.m. and 10 p.m. covering both the morning and afternoon peak periods.