DRAFT

CDM Smith

Memorandum

To: *Terri Slack, Carley Francis*

From: *Ron Davis, Tim Boesch*

Date: *April 5, 2013*

Subject: *Columbia River Crossing Commercial Vehicle Through Trip Origin-Destination Survey Results*

Summary

In order to further refine the Columbia River Crossing tolling model being developed by CDM Smith, a commercial vehicle through trip origin-destination survey was conducted. "Through trips" in context of this study refer to vehicle trips that have both their origin and destination outside of the greater Portland/Vancouver study area. A through trip estimate for commercial vehicles is especially important due to the relatively high number of commercial vehicles currently traveling on the I-5 Bridge, the fact that commercial vehicles tend to make longer trips than passenger cars on average, and the anticipated commercial vehicle toll rates for the new bridge.

To address this data need, a license plate based O-D matching survey was conducted in November 2012 over several days. The basic survey technique involved video collection of commercial vehicle license plates at four survey stations:

- I-5 south of the I-5/I-205 split in Oregon
- I-205 crossing the Columbia River
- I-5 crossing the Columbia River
- I-5 north of the I-5/I-205 split in Washington

To limit expense, only northbound commercial vehicle traffic was surveyed. Due to lighting and weather conditions, infrared video technology was used and data was collected over several days to achieve 24 hours of good quality data. License plates were read from the video and recorded in a data set which included time, location, and class of commercial vehicle by size. Then, license plates were matched between each of the survey stations to ascertain through movements. Results were thoroughly reviewed for inherent errors and adjustments made to account for uncertainties in plate matching.

The results of the commercial origin-destination through survey are shown in Table S-1 and Figure S-1.

Table S-1: Weekday Daily Commercial Vehicle Through Trips

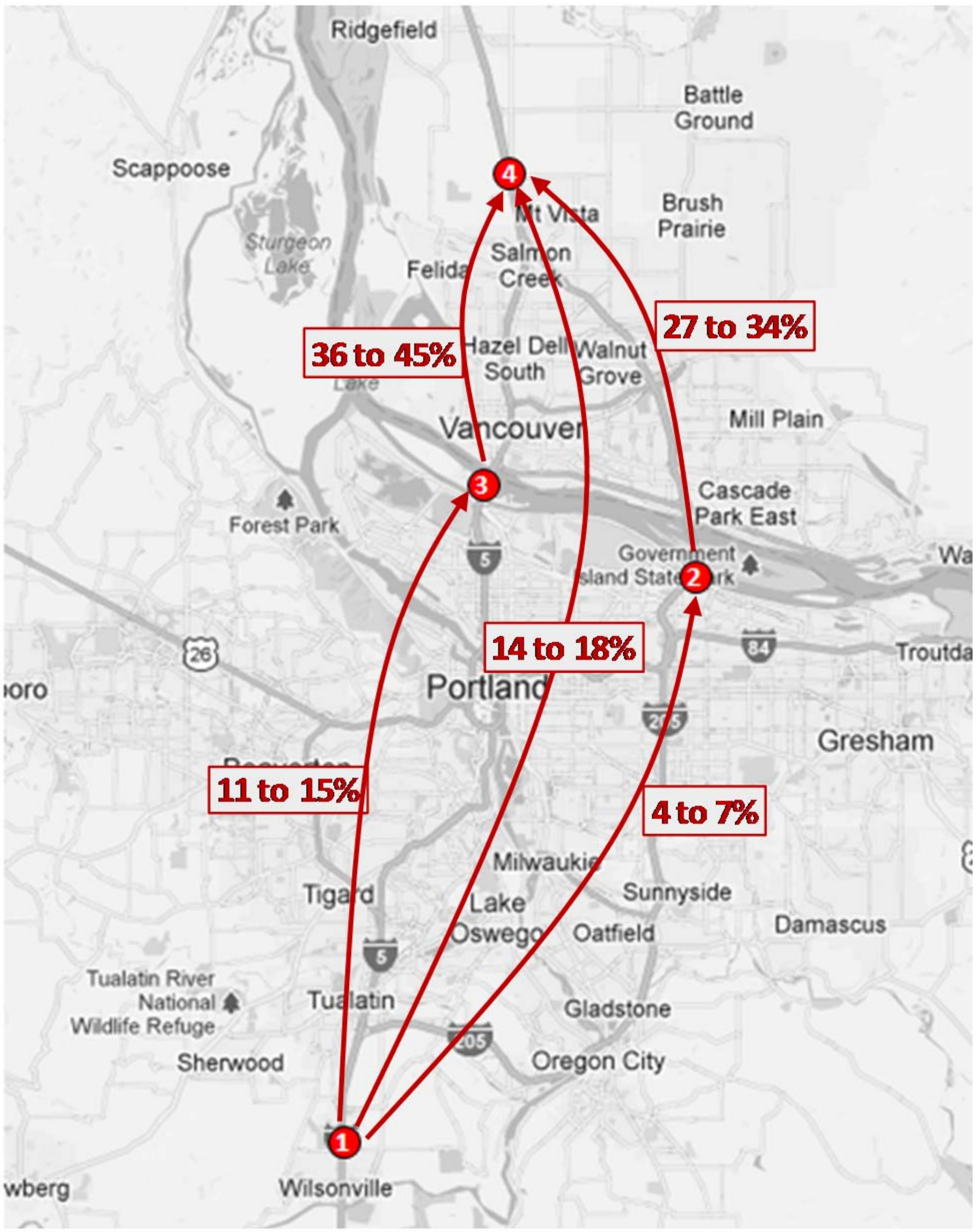
Start Location	End Location	Lower Match Volume	Lower Match % of Start	Upper Match Volume	Upper Match % of Start
I-5 South of I-205 Split in Oregon	I-205 Columbia River Bridge	254	4%	442	7%
	I-5 Columbia River Bridge	722	11%	1,016	15%
	I-5 North of I-205 Split in Washington	945	14%	1,207	18%
I-205 Columbia River Bridge	I-5 North of I-205 Split in Washington	856	27%	1,105	34%
I-5 Columbia River Bridge	I-5 North of I-205 Split in Washington	1,863	36%	2,326	45%

Source data was collected by National Data & Surveying Services (NDS) in November, 2012.
A matching algorithm was run by NDS and additional adjustments were applied by CDM Smith.

The results can be broken down as follows:

- Of the truck trips heading northbound on I-5 in Oregon at Point 1 in Figure S-1:
  - 14% to 18% cross one of the two bridges and continues north on I-5 past point 4 where I-205 and I-5 merge in Washington – The "through" trips
  - 4% to 7% cross the I-205 bridge
  - 11% to 15% cross the I-5 bridge
  - Approximately 1% to 4% cross the Columbia River but do not continue north on I-5 past the I-205 and I-5 merge in Washington
  - The remaining 78% to 85% does not cross the Columbia River on either I-5 or I-205
- Of the truck trips heading northbound on I-5 at the Columbia River, approximately 36% to 45% continue north on I-5 past the I-5 / I-205 merge
- Of the truck trips heading northbound on I-205 at the Columbia River, approximately 27% to 34% continue north on I-5 past the I-5 / I-205 merge
- After combining truck trips crossing both bridges northbound and accounting for volume differentials, 32% to 41% of the trucks continue north on I-5 past the I-5 / I-205 merge

Figure S-1: Weekday Daily Commercial Vehicle Through Trips



Introduction

An online Origin-Destination (O-D) survey has been conducted as part of the Columbia River Crossing (CRC) Traffic and Revenue (T&R) Analysis by CDM Smith. The survey is being used to obtain actual data on trip movements across the I-5 Bridge needed for development of the study toll model. From past experience with other O-D surveys it is expected that "through trips" (also known as external-external trips in modeling) will not be well represented in this online O-D survey. In the context of this study, "through trips" refer to vehicle trips that have both their origin and destination outside of the greater Portland/Vancouver study area. CDM Smith was not able to locate any existing data sources that address the need for through trip data.

An estimate of through trips will be important to the overall T&R study in assessing the time and cost tradeoffs between the I-5 Bridge and I-205 Bridge for long distance travel. A through trip estimate for commercial vehicles is especially important. This is due to the relatively high number of commercial vehicles currently traveling on the I-5 Bridge, the fact that commercial vehicles tend to make longer trips than passenger cars on average (and therefore tend to make more through trips), and the anticipated relatively high commercial vehicle toll rates for the new bridge resulting in a greater share of commercial vehicle revenue than transactions.

To augment the results of the online O-D survey, a separate commercial vehicle through trip O-D survey was therefore conducted by National Data & Surveying Services (NDS) as a sub-consultant to CDM Smith at a cost of $62,000. To conduct the survey commercial vehicle license plates were recorded by video at several critical locations in the greater Portland/Vancouver study area. The plate numbers were then manually reviewed and matched between the different locations. This memo presents the methodology and documents the results of this survey.

Survey Methodology

Vehicles Surveyed

Only commercial vehicles were analyzed in this survey. Commercial vehicles considered for this study are those in FHWA Classes 4 to 13. Note passenger cars and other two-axle, four-tire single unit vehicles pulling recreational or light trailers (for example a van pulling a pop up camper) are included in FHWA Classes 2 and 3 and were thus not considered in this study. Classes 4 to 13 are described below:

- Class 4 (Buses): Any vehicle manufactured as a bus with at least two axles and six tires that is used to carry passengers.
- Class 5 (Two-axle, six-tire, single unit trucks): Includes camping and recreational vehicles in addition to normal single framed trucks with two axles and dual rear wheels. Note that truck tractor units traveling without a trailer are considered to be single unit trucks.
- Class 6 (Three-axle, single unit trucks): Includes camping and recreational vehicles in addition to normal single framed trucks with at least three axles. Note that truck tractor units traveling without a trailer are considered to be single unit trucks.
- Class 7 (Four or more axle single unit trucks): Same as Class 6 except with four or more axles.
- Class 8 (Four or less axle single trailer trucks): All vehicles with four or less axles consisting of two units, one of which is a tractor or straight truck power unit.
- Class 9 (Five-axle single trailer trucks): Same as Class 8 except with five axles.
- Class 10 (Six or more axle single trailer trucks): Same as Class 8 except with six or more axles.
- Class 11 (Five or less axle multi-trailer trucks): All vehicles with five or less axles consisting of three or more units, one of which is a straight truck power unit.
- Class 12 (Six-axle multi-trailer trucks): Same as Class 11 except with six axles.
- Class 13 (Seven or more axle multi-trailer trucks): Same as Class 11 except with seven or more axles.

The FHWA classes described above were combined into three groups for the matching process: Class 4, Classes 5 to 7, and Classes 8 to 13.

Survey Time Period

The survey was conducted in November, 2012. A weekday, 24 hour time period survey was preferred to allow easy comparison with the travel demand model. However, there were challenges with conducting a 24 hour survey in late 2012 due to fewer daylight hours and rainy conditions. For example, sunrise on Friday November 30, 2012 was at 7:29am and sunset was at 4:29pm. Rain reduces the number of successful license plate reads as rainfall and water spray from the roadway obstructs clear vision of the license plates. Dense, dark cloud cover during rainy conditions can compound this issue. Consequently, NDS was scheduled for video collection for a full week, from Monday, November 26th to Friday, November 30th, to ensure adequate collection with the weather uncertainty. The video collection occurred from Monday morning through Tuesday mid-afternoon (11/26/12 to 11/27/12) and from Wednesday evening through Thursday morning (11/28/12 to 11/29/12). The highest quality video available from each time of day was then processed by NDS to make a full weekday, 24 hour set of results. In choosing time periods to report, time overlaps were included to allow for travel time between locations.

Camera Technology and License Plate Reads

Waterproof, infrared camera technology was used by NDS for the survey. The waterproof feature of the camera collection equipment allowed the survey to continue successfully in light or intermittent rain conditions. However, still degraded the success of plate reads to an unusable level at times. Infrared camera technology allowed overnight matching results to be produced by NDS.

Commercial vehicle plates tend to be more difficult to read than passenger cars. Commercial vehicle plates are generally dirtier which can prevent the plate number from being read. Additionally, commercial vehicles sometimes have multiple plates or plates in abnormal locations which can cause confusion in data processing and missed reads in data collection. However, focusing the survey solely on commercial vehicles helped to improve read rates as camera equipment need only capture commercial vehicles. NDS was careful to account for partial license plate reads in the matching process which increased the number of successful reads.

Survey Locations

Four locations were selected to capture the long distance commercial vehicle trips through the Portland-Vancouver region and whether they take the I-5 Bridge or the I-205 Bridge over the Columbia River. The four locations are shown in **Figure 1**. The survey was conducted only in the northbound direction due to the high survey cost. The northbound direction was selected to capture the high northbound congestion during the PM peak.

Figure 1: Survey Locations (Northbound Only)

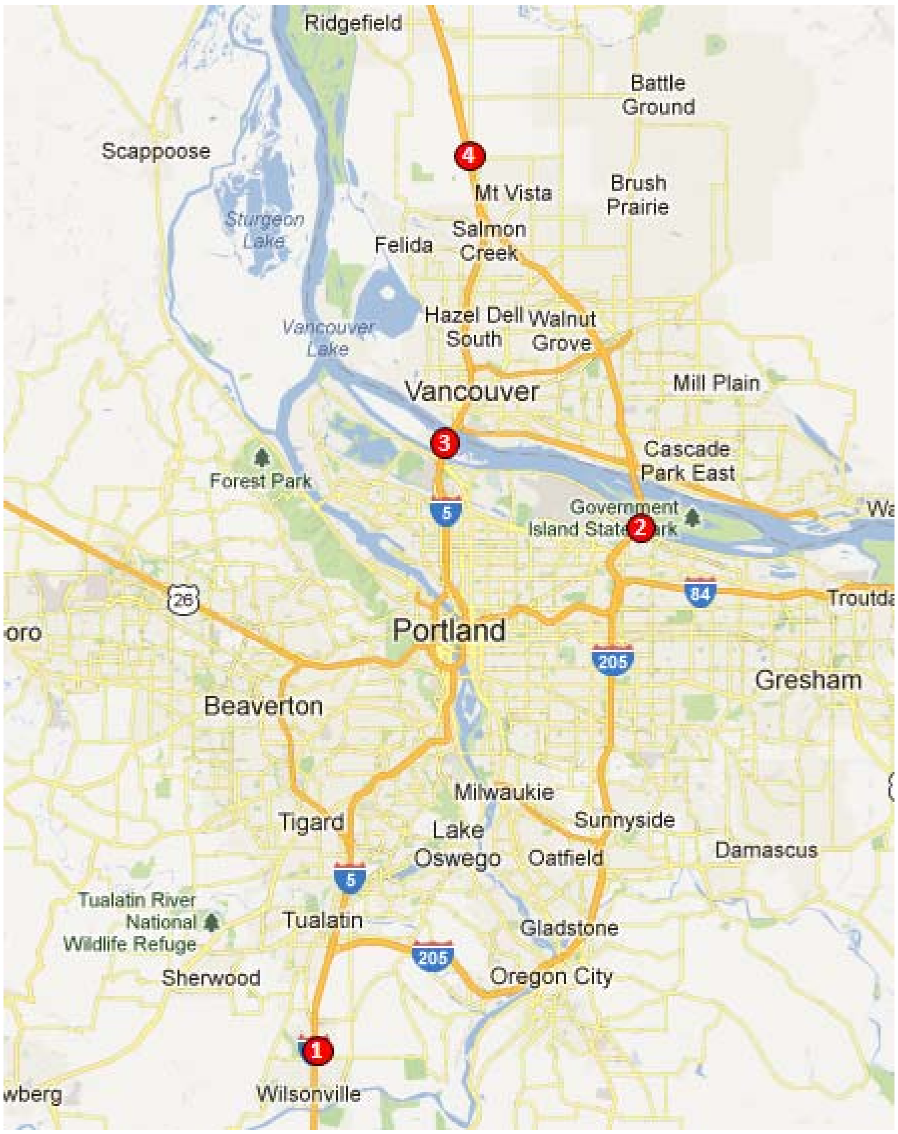


Figure 2 and **Table 1** show the detailed views and Latitude-Longitude coordinates of the video cameras used for the survey. The locations were selected to maximize safety, provide good access, and to limit the number of lanes needed to record. Locations 1, 2, and 4 each had guardrail or a jersey barrier between the camera and the traffic stream. The cameras were mounted on tripods and an operator was on site at all times. The operator periodically adjusted camera settings and made sure the cameras were operating correctly. Only the two right mainline lanes were captured at each location. The leftmost "fast lane" was not captured because laws in both Washington and Oregon limit its use by commercial vehicles and almost all commercial vehicles were observed to obey these laws. This approach helped keep costs reasonable.

Figure 2: Survey Camera Locations

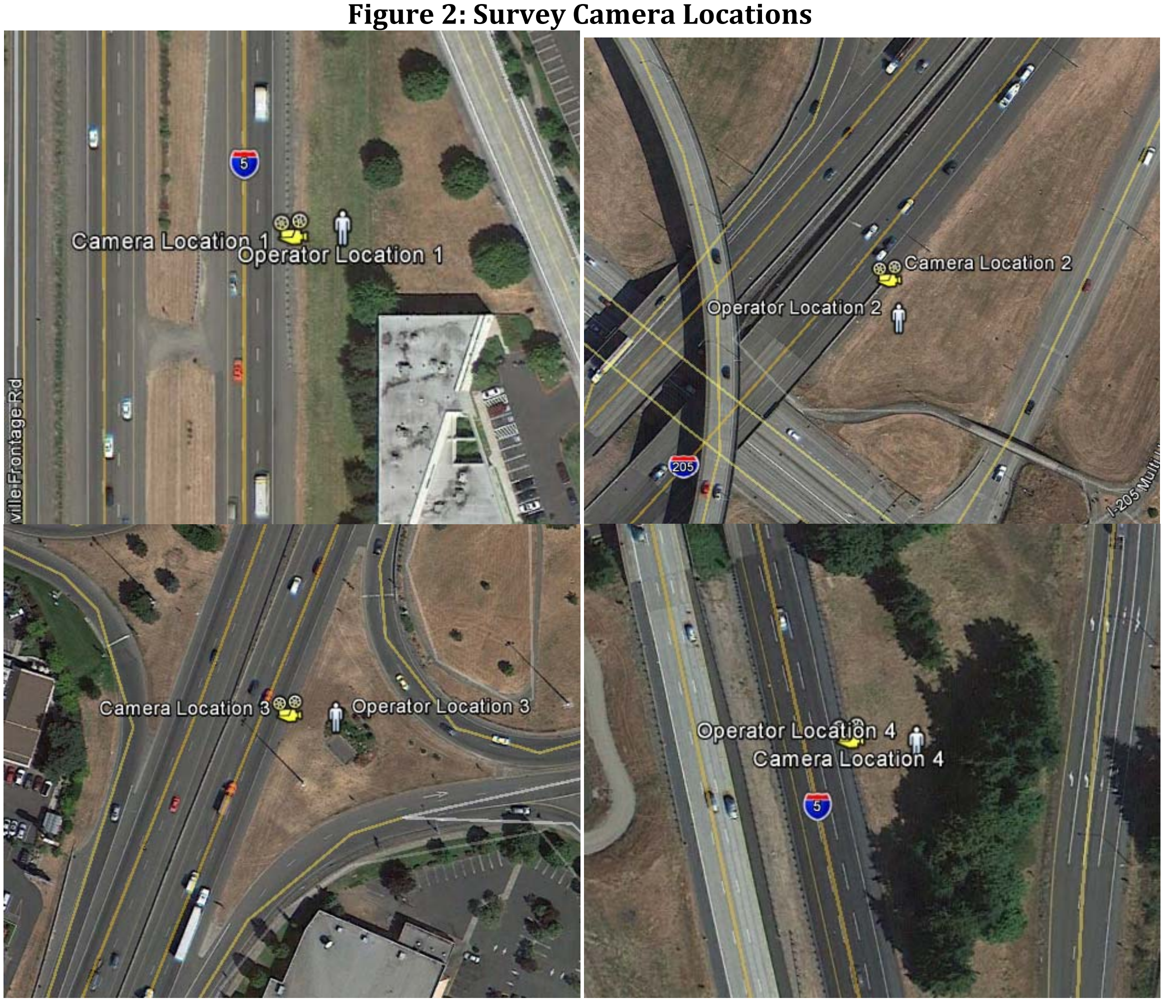


Table 1: Camera Location Coordinates

Location	Latitude	Longitude
1	45°19'21.14"N	122°46'8.24"W
2	45°34'16.61"N	122°32'55.99"W
3	45°36'40.03"N	122°40'44.66"W
4	45°45'0.38"N	122°39'44.13"W

License Plate Matching Methodology

Manual observation of the video was used to identify the commercial vehicle license plate numbers. Plates with all digits not visible were coded as "NV" in the results and vehicles with no plates were coded as "NP" in the results. The symbol "#" was used in the manual observation to account for plates where a portion of the digits were readable. For example, a seven digit plate where only the last three numbers "232" were readable would be indicated as "####232".

NDS then applied an algorithm to match plates between the different locations for each of the three commercial vehicle groups specified (FHWA Class 4, Classes 5 to 7, and Classes 8 to 13) . The algorithm accounted for possible misread digits as well as partial plate reads with at least three digits. Plates where only one or two digits were readable, such as "#A#####" or "####98#", were not included in the matching process. For each location pair the algorithm grouped the results into a matrix of five minute bins based on start times from the first location and five minute travel time bins to the second location. For example, a commercial vehicle passing by Location 1 at 8:06am and Location 2 at 8:37am would be binned into starting time "8:05" and travel time "0:30" (8:35am minus 8:05am equals 30 minutes) for matrix pair 1 to 2. A travel time cutoff of two hours was used by NDS between all location pairs. It was understood that CDM Smith would determine reasonable maximum travel times between locations. **Table 2** shows an example of the raw matching results for FHWA Classes 8 to 13 from Location 3 to Location 4. For example, five vehicles in these classes were observed to depart from Location 3 between 8:00:00 and 8:04:59am and arrive at Location 4 around ten minutes later.

Table 2: Example Matching Results for FHWA Classes 8 to 13 from Location 3 to Location 4

Start Time	Travel Time (min)					
	0:00	0:05	0:10	0:15	0:20	…
…						
8:00			5			
8:05			3			
8:10				2		
8:15			1			
8:20			2	1		
8:25			3			
8:30			3			
8:35						
8:40			3	1		
8:45			5	1		
8:50			4			
8:55			2	1		
…						

The full results of the matching process, a summary of the total commercial vehicle traffic by location, as well as a database of all the license plates by location and commercial vehicle class was delivered by NDS to CDM Smith on January 7, 2013. CDM Smith reviewed the data with NDS and made adjustments to account for unread and partially read plates. These adjustments result in a range of through trips which account for uncertainties in the matching algorithm. These adjustments are documented in **Appendix 1**.

Results

Table 3 presents the weekday daily results of matching between locations. For example, of the 6,722 commercial vehicles observed passing Location 1, it is estimated that between 722 and 1,016 (11 to 15 percent of the total) also pass Location 3. The results by time of day are presented in **Table 4** and by vehicle classification in **Table 5**.

A number of observations can be made, including:

- **Table 4** shows that the number of through trips is significantly lower from Location 1 to Location 3 during the 3:00pm to 6:00pm time period (PM peak period) compared to the rest of the day. It is likely that commercial vehicles avoid traveling this segment of northbound I-5 during the PM peak period due to heavy congestion.

- In **Table** 4, the highest match rates occur during the 6:00pm to 6:00am time period for all location pairs except from 1 to 2. It appears that overnight commercial vehicle trips are generally more likely to be through trips than trips made during other time periods.
- **Table 5** shows that larger commercial vehicles (FHWA Classes 8-13) were observed to have a higher rate of through trips compared to smaller commercial vehicles (FHWA Class 4 and Classes 5-7).

Table 3: Weekday Daily Results

Start Location	Daily Start Volume	End Location	Lower Match Volume	Lower Match % of Start	Upper Match Volume	Upper Match % of Start
I-5/I-205 South	6,722	I-205 Columbia River Bridge	254	4%	442	7%
I-5/I-205 South	6,722	I-5 Columbia River Bridge	722	11%	1,016	15%
I-5/I-205 South	6,722	I-5/I-205 North	945	14%	1,207	18%
I-205 Columbia River Bridge	3,210	I-5/I-205 North	856	27%	1,105	34%
I-5 Columbia River Bridge	5,177	I-5/I-205 North	1,863	36%	2,326	45%
I-5/I-205 North	5,840	-				

Source data was collected by National Data & Surveying Services (NDS) in November, 2012.
A matching algorithm was run by NDS and additional adjustments were applied by CDM Smith.
Locations are shown in **Figure 1** and **Figure 2.**

Table 4: Weekday Time of Day Results

Start Location	Daily Start Volume	End Location	Lower Match Volume	Lower Match % of Start	Upper Match Volume	Upper Match % of Start
6am to 9am						
1	992	2	25	3%	69	7%
1	992	3	61	6%	136	14%
1	992	4	79	8%	138	14%
2	522	4	136	26%	209	40%
3	857	4	291	34%	452	53%
9am to 3pm						
1	2,898	2	131	5%	214	7%
1	2,898	3	217	7%	285	10%
1	2,898	4	217	7%	255	9%
2	1,438	4	326	23%	399	28%
3	2,022	4	488	24%	567	28%
3pm to 6pm						
1	882	2	18	2%	39	4%
1	882	3	2	0%	42	5%
1	882	4	37	4%	67	8%
2	531	4	79	15%	108	20%
3	667	4	155	23%	207	31%
6pm to 6am						
1	1,950	2	80	4%	120	6%
1	1,950	3	442	23%	553	28%
1	1,950	4	612	31%	747	38%
2	719	4	315	44%	389	54%
3	1,631	4	929	57%	1,100	67%

Source data was collected by National Data & Surveying Services (NDS) in November, 2012.
A matching algorithm was run by NDS and additional adjustments were applied by CDM Smith.
Locations are shown in **Figure 1** and **Figure 2.**

Table 5: Weekday Class Results

Start Location	Daily Start Volume	End Location	Lower Match Volume	Lower Match % of Start	Upper Match Volume	Upper Match % of Start
FHWA Class 4						
1	66	2	6	9%	7	11%
1	66	3	4	6%	11	17%
1	66	4	7	11%	9	14%
2	99	4	2	2%	5	5%
3	172	4	13	8%	26	15%
FHWA Classes 5-7						
1	1,507	2	47	3%	80	5%
1	1,507	3	106	7%	213	14%
1	1,507	4	121	8%	170	11%
2	884	4	131	15%	184	21%
3	1,230	4	226	18%	341	28%
FHWA Classes 8-13						
1	5,149	2	201	4%	355	7%
1	5,149	3	612	12%	792	15%
1	5,149	4	817	16%	1,028	20%
2	2,227	4	723	32%	916	41%
3	3,775	4	1,624	43%	1,959	52%

Source data was collected by National Data & Surveying Services (NDS) in November, 2012.
A matching algorithm was run by NDS and additional adjustments were applied by CDM Smith.
Locations are shown in **Figure 1** and **Figure 2.**

Appendix 1

Commercial Vehicle License Plate Matching Adjustments

In the data collected, there were many plates which could not be read at all or only partially read. This resulted in adjustments to the raw matching results to account for unknown plates, "false positive" matches, unreasonable trip times, and "false negative" matches as described below. Adjustments were applied at a disaggregate level (by time period, travel time, and commercial vehicle class) for each location pair. It was decided to present the matching results as a range to account for uncertainty in some of the adjustments. The adjustments applied to estimate the lower range and upper range are shown in **Table A1**. All adjustments are discussed in detail below.

Table A1: Adjustments Applied to Estimate Lower Range and Upper Range

Adjustment	Lower Range	Upper Range
Unknown Plates	X	X
"False Positive" Matches	X	X
Unreasonable Trip Times	X	
"False Negative" Matches		X

Unknown Plate Adjustment

Table A2 summarizes the adjustments made to account for unknown plates in the analysis. This adjustment was made to factor the plate reads up to the daily observed commercial vehicle volume. It therefore does not change the match rate but rather the absolute number of matches. The number of plates read for the matching algorithm at each location (plates with at least three digits visible) and the daily total commercial vehicle volume observed at each location are both listed. A total read rate of 73 percent was obtained in the survey. The "Daily Total to Daily Read" column is a summary of the total daily volume to read ratio used to factor up the matching results for the beginning location of each location pair.

Table A2: Summary of Unknown Plate Adjustment Factors

Location	Daily Total Volume	Successful Daily Reads	Read Rate	Daily Total to Daily Reads
1	6,700	4,800	72%	1.39
2	3,200	2,100	65%	1.53
3	5,200	3,700	72%	1.39
4	5,800	4,600	78%	1.28
Total	20,900	15,200	73%	1.37

"False Positive" Match Adjustment

"False positive" matches are a negative consequence of accounting for unknown plate digits and misread plate digits in the algorithm. For example, if the plate "YAR####" was observed at location 1 and "YARC727" was observed at Location 2 there is a risk of a false positive match as the numbers may not actually be the same. False positive matches were quantified in the matching process by evaluating unreasonably fast travel times between matched pairs. These results from unreasonably fast travel times were then applied to all travel times. **Table A3** summarizes this process. For example, a minimum reasonable travel time of 18 minutes was calculated from Location 1 to Location 2. Assume there were 13 trips in the daily matching matrix travel time bins 0:00, 0:05, and 0:10 in the results for this location pair. Then 13 trips divided by 3 bins, or 4.3 trips per five minute period would be subtracted from the results for all time periods and rounded to the nearest integer to account for false positive matches.

Table A3: False Positive Match Adjustment Summary

From	To	Minimum Dist (mi)[1]	Minimum Travel Time (min)[2]	Unreasonable Travel Time Bins
1	2	25	18	0:00, 0:05, 0:10
1	3	23	16	0:00, 0:05, 0:10
1	4	33	23	0:00, 0:05, 0:10, 0:15
2	4	14	10	0:00, 0:05
3	4	10	7	0:00

[1]From Googlemaps.com assuming highway travel

[2]Assumes travel speed of 85 miles per hour

Unreasonable Trip Time Adjustment

Some vehicles may exit the highway for a period of time and then return to the highway to continue their trip later, resulting in unreasonably long trip times. However, even after the "false positive" adjustment was applied there appeared to be too many longer travel times between certain locations. For this reason a trip time adjustment was applied by assuming a maximum reasonable travel time for direct travel between locations. All trips with travel times greater than the maximum reasonable travel time were removed. This adjustment was applied in addition to the unknown plate and "false positive" adjustments and provided the lower bound of the matching range. **Table A4** lists the maximum reasonable direct travel times assumed for each location pair for this adjustment.

Table A4: Maximum Reasonable Direct Travel Times for Location Pairs

Location From	Location To	Maximum Distance (mi)[1]	Maximum Travel Time (min)[2]	Unreasonable Travel Time Bins
1	2	27	41	0:45 - 2:00
1	3	23	34	0:40 - 2:00
1	4	39	59	1:05 - 2:00
2	4	18	27	0:35 - 2:00
3	4	10	15	0:20 - 2:00

[1]From Googlemaps.com, assumes longest reasonable highway travel route

[2]Assumes travel speed of 85 miles per hour

"False Negative" Match Adjustment

Three types of "false negative" matches occur when a vehicle travels between two locations: (1) the license plate is not readable at either location, (2) the license plate is readable only at the first location, or (3) the license plate is readable only at the second location. The first and third cases are accounted for in the unreadable plate adjustment shown previously in **Table A2**. The second case would not be and would incorrectly lower the match rate from Location 1 to Location 2. One simple approach to account for this case of false negative matches would be to proportionally increase the match rate based on the number of plates not read at the second location. For example, assume the match rate from 1 to 2 was 10 percent and Location 2 had a read rate of 60 percent. This approach would increase the match rate to 100 percent divided by 60 percent times 10 percent, or about 17 percent. However, this simple approach would not account for the fact that if a commercial vehicle plate was not visible at one location, it would have a much higher probability of also not being visible at other locations. This simple adjustment approach would overstate the matches. Therefore, an assumption was made that 50 percent of the unread plates in the study would not be able to be read at any location (due to dirt covering the plate, missing plate, etc.). This was thought to be a reasonable assumption (and perhaps could have been higher) given the understood challenges of capturing commercial vehicle license plates. If this assumption was applied to the example of the simple approach described above, the resulting adjusted match rate would be 80 percent divided by 60 percent times 10 percent, or about 13 percent. This adjustment was applied on top of the unknown plate and "false positive" adjustments and the results provided the upper bound of the matching range.