Project Title: Using Truck GPS Data for Freight Performance Analysis in the Twin Cities Metro Area
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Task Due: 9/30/2013

TASK #4: PROCESS AND ANALYZE AVAILABLE ATR, WIM AND LOOP DETECTOR DATA

Introduction

The research team obtained traffic data from Automatic Traffic Recorder (ATR), Weigh-In-Motion (WIM) sensors, and loop detectors at selected locations from MnDOT. These data were processed, analyzed and compared with performance measures derived from raw truck GPS data in this task. The purpose of this task is to examine and validate the processed truck GPS data with WIM, ATR, and loop detector data. Data of heavy commercial vehicles (class 9 and higher) from ATR and WIM stations were compared with truck GPS data. Loop detector data from detectors nearby ATR and WIM were compared with all traffic data from WIM and ATR systems because the loop detector data does not contain any vehicle classification information.

Summary of Automatic Traffic Recorder (ATR) Data

A list of automatic traffic recorder (ATR) stations on key freight corridors in the Twin Cities metro area were identified for data analysis and comparison (See Table 1). The ATR units collect binned vehicle counts by hour, class, and speed instead of speed and classification of each vehicle.

Table 1 List of ATR Stations

ATR_ID	Route Name	Milepost	True Mile	Direction	Route ID	Segment ID	Direction Sign
188	US 52	061+00.860	62.245	N	29	19	1
191	I-35	137+00.500	137.519	N	33 (34)	88 (90)	1
200	I-94	182+00.200	183.084	N	24	77	1
335	I-35W	033+00.752	33.787	N	34	74	1
341	I-694	053+00.290	53.237	N	4	18	-1
351	US 12	142+00.839	142.285	E	9	15	-1
352	US 10	218+00.450	220.364	E	31	55	-1
353	US 169	096+00.670	96.198	N	37	49	1
365	MN 65	016+00.720	18.577	N	26	31	1
381	US 212	133+00.500	133.195	E	14	7	1
382	US 52	111+00.966	112.328	N	29	67	1
388	US 8	002+00.330	2.282	N	25	3	1
400	CSAH 92	010+00.330	10.33	N	9	15	1
422	CSAH 14	010+00.100	10.1	E	1	8	1

ATR Volume Processing and Analysis

ATR volume data in 2012 by vehicle classification were obtained from MnDOT. Aggregated volume for vehicle class 9 and higher were grouped by hour to compute hourly truck volume percentage. Hourly volume variation of trucks at ATR station #188 on US52 near Rochester, MN is displayed in Figure 1 along with the volume percentage computed from truck GPS data. The difference of the two curves indicated that probe trucks have a slightly higher representation in the AM peak hours (5-10AM) than the general hourly volume distribution from ATR. Additional volume comparisons for the other ATR stations are listed in Appendix A. The hourly truck

volume correlation between GPS and ATR data was computed and listed in Table 2 for all the ATR stations in TCMA. The hourly volume percentages from GPS and ATR data are highly correlated except at ATR station #341 and #365. ATR #341 is located on I-694 in northbound in Oakdale, MN. There was construction on I-694 in 2012. The discrepancy of hourly volume distribution was probably caused by the roadway construction last year. ATR station #365 is located on state highway 65 in Ham Lake, MN. As illustrated in Figure 1, the truck GPS data has a higher volume distribution in the AM peak hours while the ATR data has a higher volume distribution in the PM peak hours.

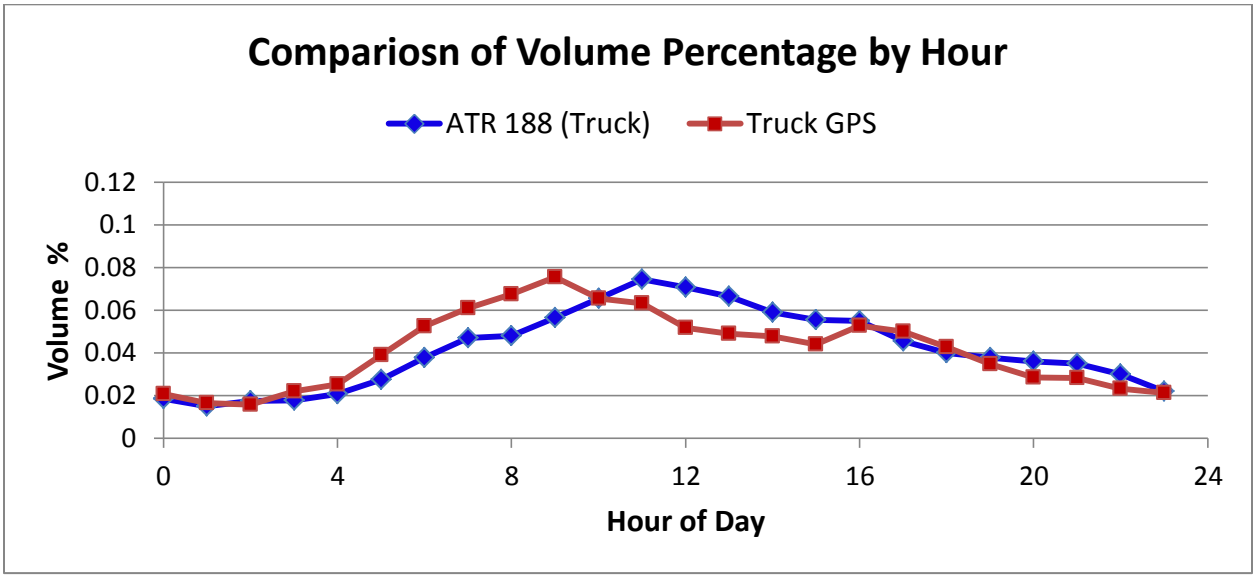

Figure 1 Comparison of Truck Volume Percentage by Hour (ATR Station #188)

Table 2 Hourly Truck Volume Correlation between GPS and ATR data

ATR Data		Truck GPS Data			Correlation Coefficient
ID	HCAADT	Route ID	Segment ID	Count	
188	2600	29	19	43199	**0.83**
191	2150	33	88	11961	**0.94**
200	7900	24	77	129595	**0.87**
335	3450	34	74	19741	**0.93**
341	5100	4	18	70873	**0.61**
351	1600	9	15	4107	**0.93**
352	1600	31	55	11686	**0.86**
353	1750	37	49	26821	**0.96**
365	1700	26	31	4933	**0.51**
381	1350	14	7	22530	**0.99**
382	2700	29	67	42469	**0.97**
388	830	25	3	2576	**0.84**
400	1600	9	15	2841	**0.81**
422	NA	1	8	433	**0.96**

ATR Speed Estimation and Analysis

Vehicle counts in 13 or 20 ATR speed bins were collected hourly at each station. A sample of ATR vehicle count data by 13 speed bin is listed in Table 3. The ATR hourly speed can be estimated using equation (1) assuming normal speed distribution. The hourly comparisons of vehicle speed for both the truck GPS and the ATR station 191 data are plotted in Figure 2. The computed ATR speed includes speeds from all vehicles is slightly higher than the truck GPS speed. The average standard deviation of speed from ATR191 is about 9.5 MPH and the average standard deviation of the truck GPS speed is about 4.6 MPH. Additional speed comparisons for the other ATR stations are displayed in Appendix B.

$$Speed_j = \frac{\sum v_i \times n_i}{\sum n_i} \qquad \text{Eq. (1)}$$

Where,

$Speed_j$ is the hourly average speed in hour j,

v_i is the speed of bin i, and

n_i is the vehicle counts in speed bin i.

Table 3 List of Sample ATR Data in Speed Bins

Date	Hour	40 MPH	45 MPH	50 MPH	55 MPH	60 MPH	65 MPH	70 MPH	75 MPH	80 MPH	85 MPH	100 MPH	110 MPH	>110 MPH
1/1/2012	05:00	3	3	1	12	12	34	38	41	22	10	1	0	0
1/1/2012	06:00	16	1	3	10	18	49	54	43	23	7	1	0	0
1/1/2012	07:00	0	0	1	7	17	48	71	107	58	18	4	0	0
1/1/2012	08:00	0	0	0	1	10	32	91	196	157	44	12	1	0
1/1/2012	09:00	0	0	0	2	12	33	129	313	321	110	29	1	0
1/1/2012	10:00	0	0	0	0	14	38	176	486	570	183	43	1	0
1/1/2012	11:00	1	0	0	0	10	33	252	613	801	263	44	1	0
1/1/2012	12:00	3	0	1	0	4	50	247	735	947	315	62	0	0

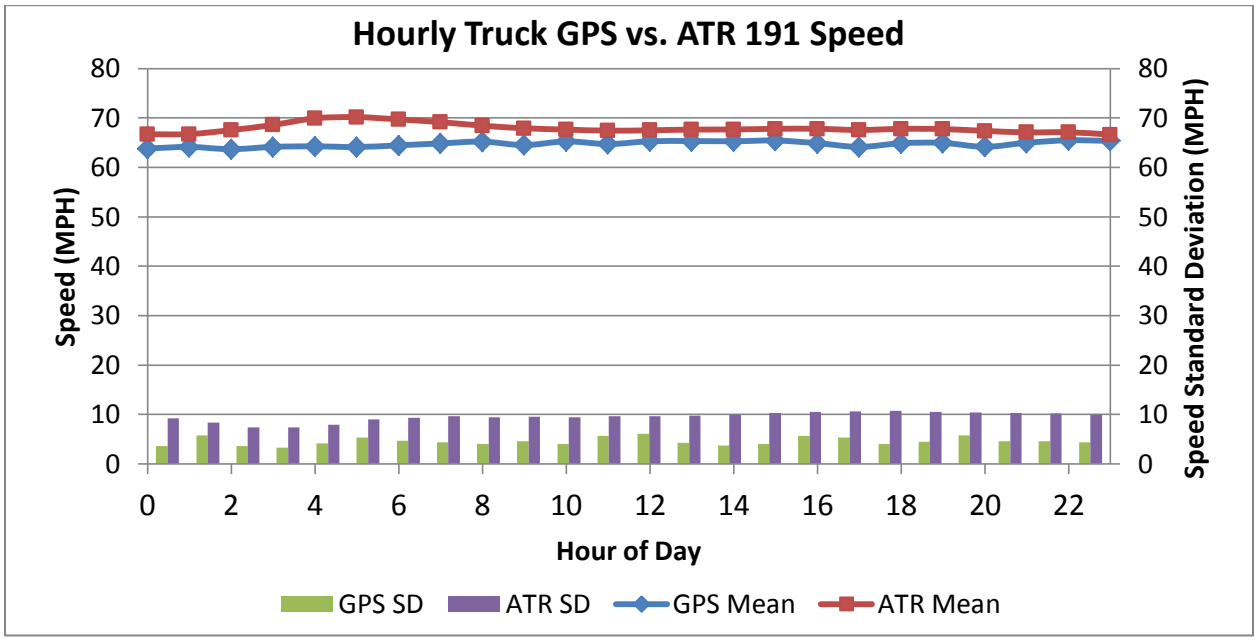

Figure 2 Weekday Hourly Truck GPS vs. ATR 191 Speed Comparisons

Summary of WIM Data

Data from four weight-in-motion (WIM) stations, as shown in Table 4, in TCMA were analyzed for speed and volume comparisons. The WIM data source, containing all volume, speed and classification information, presents an ideal benchmark source for truck GPS data validation

Table 4 List of WIM Stations in TCMA

WIM ID	36	37	40	42
Route Name	MN 36	I-94	US 52	US 61
County Name	Washington	Wright	Dakota	Washington
City Name	Lake Elmo	Otsego	West St Paul	Cottage Grove
Direction	EB	WB	NB	SB
Mile Post	15	200	127	119
WIM Location Description	.7 mi W of CSAH17 Lake Elmo Ave N) in Lake Elmo	1.2 mi NW of CSAH19 (La Beaux Ave) in Otsego	0.5 mi N of CSAH14 in West St. Paul	0.4 mi S of TH95 (Manning Ave S), S of Cottage Grove
WIM Type	VOLUME/SPEED/CLASS/WEIGHT			
Route ID	5	24	29	27
Roadway Segment ID	15	59	81	16
Linear Ref Direction	1	1	1	-1
2011 HCAADT	1100	6900	4400	1750

WIM Data Processing and Analysis

Vehicle data from the four WIM stations in 2012 were obtained from MnDOT. The WIM data were processed and grouped by hour of day. Figure 3 illustrates the hourly comparison of truck GPS speed with the speed from passenger vehicles and heavy commercial vehicles collected by WIM #37 in 2012. Average speed of passenger vehicles is about 70 MPH at this roadway segment. The average truck speeds measured from WIM and probe vehicles are about 65 and 63 MPH, respectively. The average standard deviation of speed measured from WIM for both passenger and trucks are pretty close (6.1 and 5.6 MPH, respectively) while the average standard deviation of truck GPS speed is about 7.6 MPH, slightly higher than the WIM speed.

Hourly volume percentage is selected to verify the truck volume variations in a weekday. Figure 4 illustrates the volume variations from truck GPS and WIM37 data. The truck GPS spot volume percentage uses only the vehicle counts from spot speed data excluding the derived space mean speed data points. The hourly volume variation of truck GPS data follows closely to the curve from WIM37 station as shown in Figure 4. Additional speed and volume comparisons between the truck GPS and the WIM data are displayed in Appendix C.

The hourly truck volume correlation between GPS and WIM data was computed and listed in Table 5 for all the WIM stations in TCMA. The hourly volume percentages from GPS and WIM data are highly correlated (0.84 or higher).

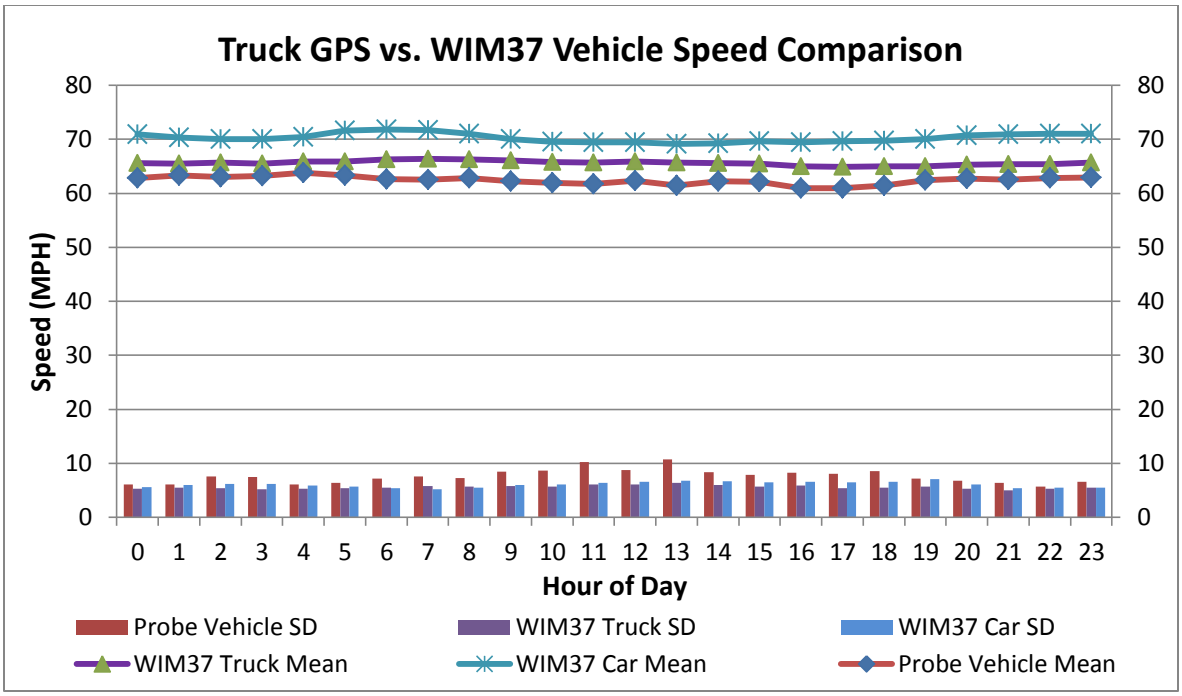

Figure 3 Truck GPS Speed vs. WIM Speed by Hour at WIM#37

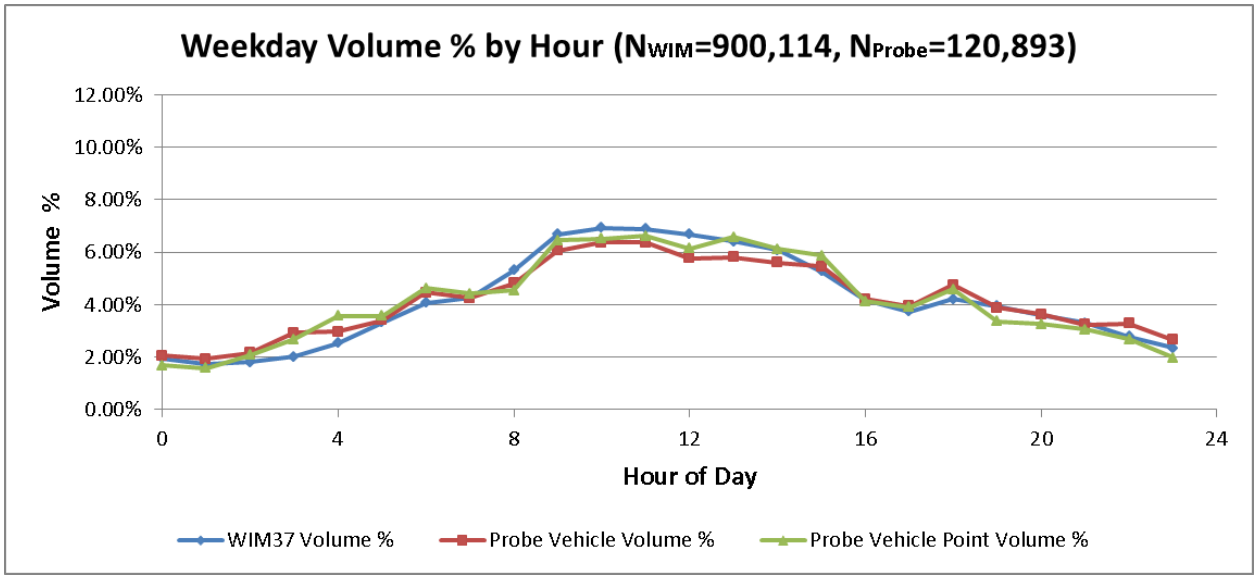

Figure 4 Truck GPS vs. WIM Volume % by Hour at WIM#37

Table 5 Hourly Volume Correlation of Truck GPS vs. WIM Data

WIM Data		Truck GPS Data			Correlation Coefficient
ID	HCAADT	Route ID	Segment ID	Count	
36	1100	5	15	2,023	**0.84**
37	6900	24	59	120,839	**0.98**
40	4400	29	81	13,386	**0.96**
41	1750	27	16	3,764	**0.86**

Summary of Loop Detector Data

A list of loop detectors, as displayed in Table 6, nearby the WIM and ATR stations in the Twin Cities metro area were identified for data analysis. Loop detector data were processed and grouped by hour of day for comparisons with WIM and ATR data.

Table 6 List of Loop Detectors nearby WIM and ATR Stations

Detector Station	Detector ID	Direction	Lane #	Nearby WIM/ATR Station
1222	6314	WB	1	WIM 37
1222	6315	WB	2	WIM 37
1171	5634	NB	1	WIM 40
1171	5635	NB	2	WIM 40
1172	5638	NB	1	WIM 40
1172	5639	NB	2	WIM 40
1232	7219	WB	1	ATR 200
1232	7220	WB	2	ATR 200
1555	6451	NB	1	ATR 335
1555	6452	NB	2	ATR 335
1418	6244	NB	1	ATR 341
1418	6245	NB	2	ATR 341

Loop Detector Data Processing and Analysis

Vehicle data in 2012 from the identified loop detectors were obtained from MnDOT. A sample of processed loop detector data is listed in Table 7.

Table 7 Sample Loop Detector Data

year	month	day	time	station	L_v	volume	occupancy	speed
2012	1	26	1921	S1171	32.5	10	9.222222	80.0931
2012	1	26	1922	S1171	32.5	4	4.8333335	61.12853
2012	1	26	1923	S1171	32.5	6	5	88.63636
2012	1	26	1924	S1171	32.5	4	3.2777777	90.13868
2012	1	26	1925	S1171	32.5	6	4.888889	90.65083
2012	1	26	1926	S1171	32.5	7	5.888889	87.80017

Raw loop detector data from MnDOT contains volume and occupancy information in 30 seconds aggregation. The following equation was used to compute the speed of traffic flow.

$$Speed\ (MPH) = \frac{Volume\ \times\ L_v}{Occupancy\ \times \frac{30}{100}} \times \frac{3600\ sec\ in\ an\ hour}{5280\ ft\ in\ a\ mile}$$

Eq. (2)

Where,

Volume is the number of vehicle counts in 30 seconds,

$\boldsymbol{L_v}$ is the effective vehicle length in feet, and

Occupancy is the percentage of time a detector is occupied by vehicles in 30 seconds.

As shown in equation (2), the accuracy of speed calculation from a loop detector depends on the effective vehicle length. The effective vehicle length needs to be calibrated frequently by the traffic engineer due to the dynamic mixture of vehicle classes. The speed of longer vehicles (for example, semi-trucks) is usually underestimated. On the other hand, the speed of a shorter vehicle (for example, motorcycles or compact cars) is usually overestimated.

Figure 5 displays the hourly speed average from loop detector station 1222 nearby WIM station 37 on I-94 in WB direction. Detector d6314 is located in lane 1 (outer or right lane) and detector d6315 is located in lane 2 (inner or left lane). The average speed difference confirms that the speed in the right lane (blue line with circle marker) is about 15 MPH lower than the average speed in the left lane (red line with diamond marker). This is probably caused by more trucks traveling in the right lane and the loop detector tends to underestimate the speed of trucks.

In addition to the speed difference, the pattern of hourly average speed variation looks abnormal. The lowest average speed occurs at 4AM. And higher traffic speed occurs in PM peak and around 9PM. This is a different pattern from our expectation that the AM and PM peak periods usually have lower average traveling speed than mid-day and mid-night off-peak periods. This speed pattern was further verified with processed data from MnDOT online tool using the "Data Plot application" as shown in Appendix D.1.

The average traffic speed derived from loop detector is less reliable because it heavily relies on the estimated effective vehicle length, traffic volume, and mixture of trucks and cars. Loop detector speed data will not be compared with the WIM speed due to the unreliable nature of the loop data.

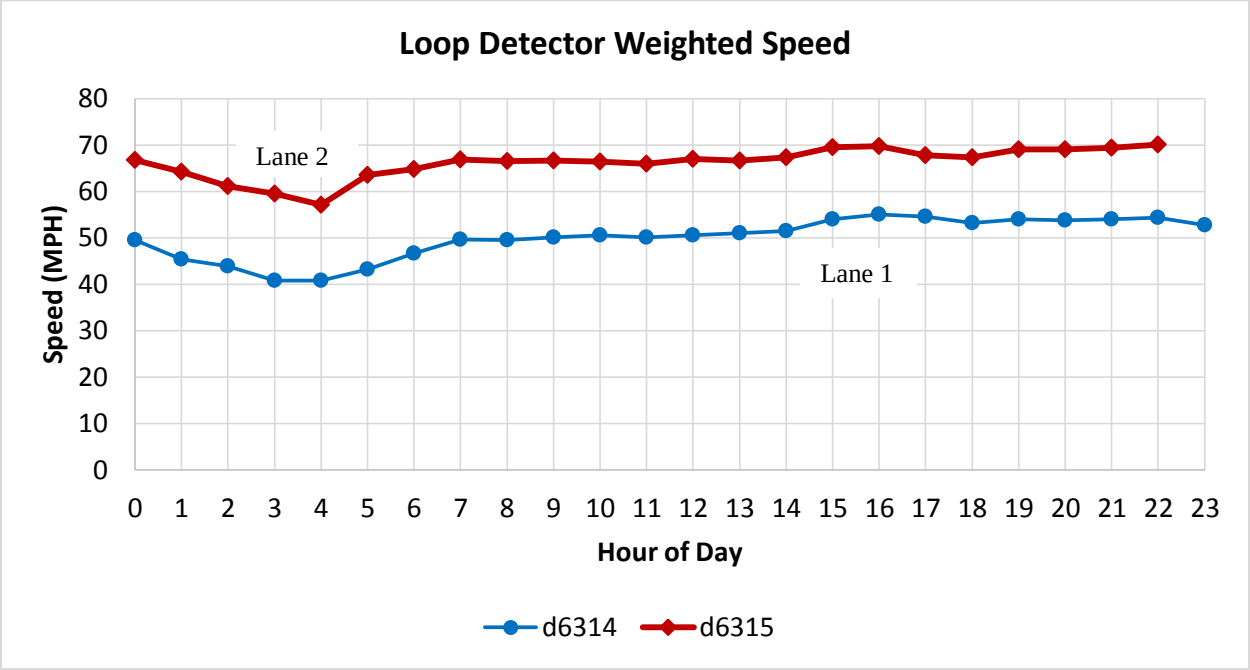

Figure 6 Hourly Speed Variations by Lane at Loop Detector Station #1222

The hourly volume percentages for both detectors at station #1222 were plotted in Figure 6. Lane 2 (left lane, in red color) has relatively higher volume percentage than the volume percentage in lane 1(right lane, blue color) during the day (10AM to 6PM). More vehicles travel in the right lane after 7PM and before 9AM as Figure 6

illustrated. The hourly volume percentage of loop detector station 1222 (both lanes combined) is compared with the volume percentage from the nearby WIM station 37. As displayed in Figure 7, the volume distribution from the loop detector in the mid-day period (9AM to 2 PM) is higher than the distribution from the WIM data. The volume distribution from the WIM data in the AM and PM peak is slightly higher than the distribution from the loop detector data as illustrated in Figure 8. Additional plots of loop detectors compared with data from WIM40 are displayed in Appendix D.2. More plots of loop detector data compared with ATR data (station 200, 335 & 341) are displayed in Appendix D.3 & D.4.

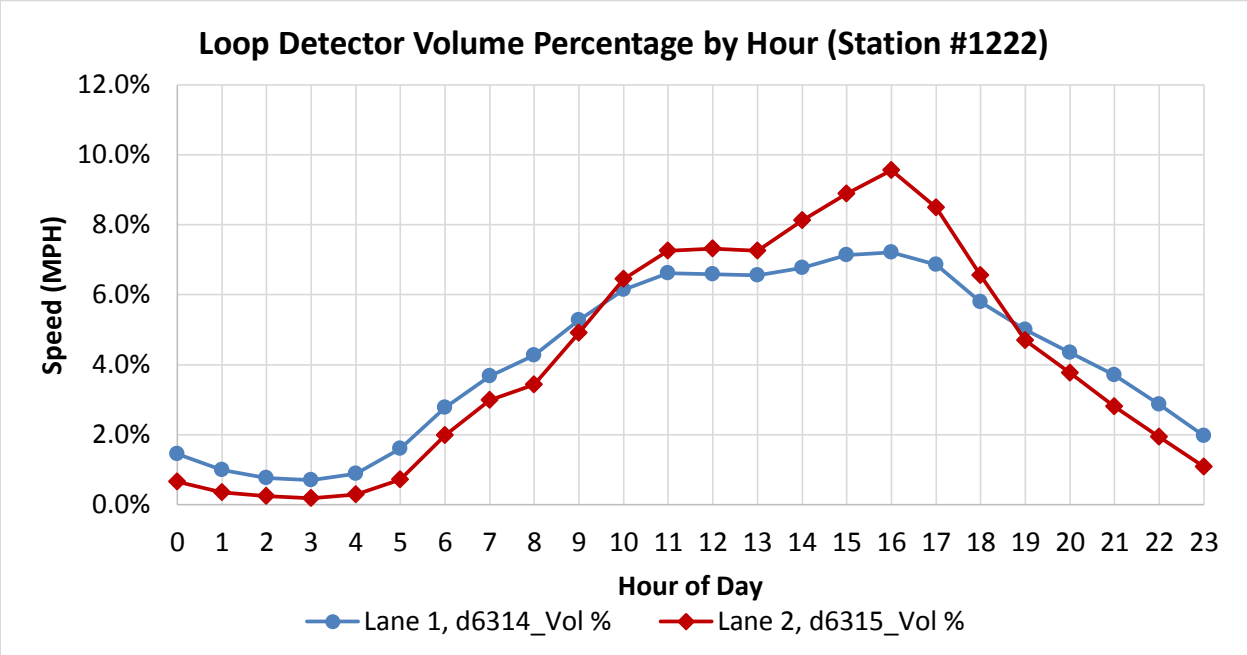

Figure 7 Hourly Volume Percentages by Lane at Loop Detector Station #1222

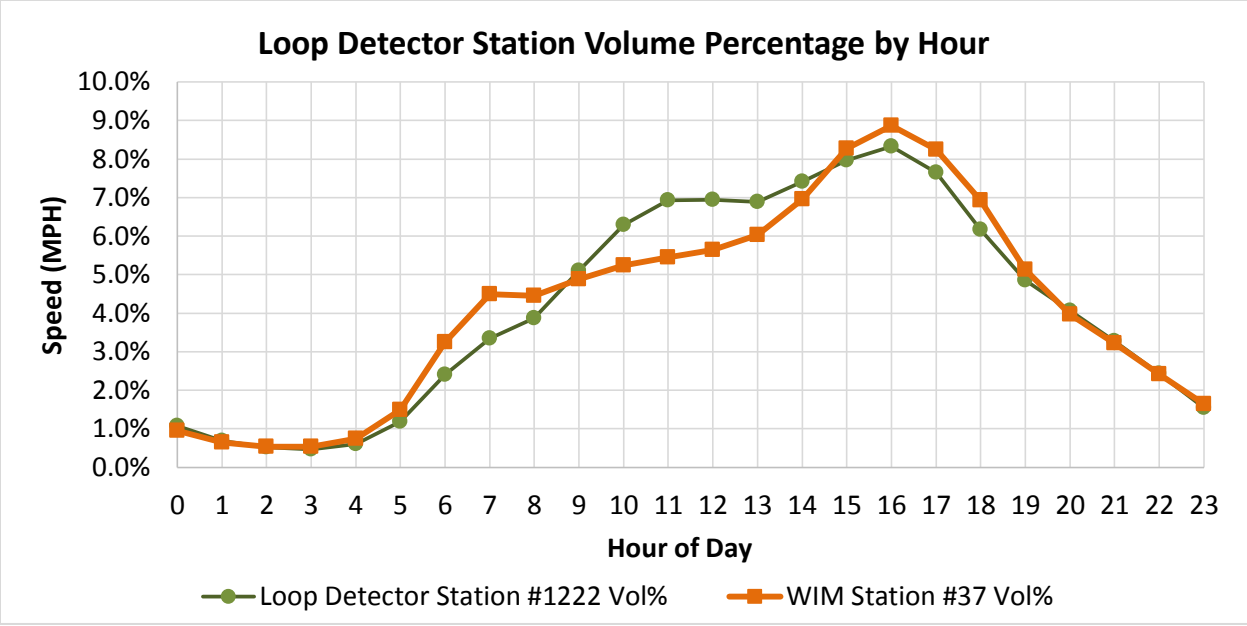

Figure 8 Hourly Volume Percentage Comparisons (Loop Detector Station 1222 vs. WIM 37)

Summary
Data from loop detectors, Automatic Traffic Recorder (ATR) stations, and Weigh-In-Motion (WIM) sensors in 2012 were obtained from MnDOT. The data were processed, analyzed and compared with speed and volume data processed from truck GPS data. The purpose is to validate the results from processed truck GPS data with WIM, ATR, and loop detector data. A comparison of different traffic data sources is listed in Table 8.

The loop detector does not provide vehicle classification information and vehicle speed derived from occupancy data relies heavily on calibrated vehicle length by location and time of day. Many ATR devices can collect vehicle volume, speed, and classification data. However, many of them were designed to collect counts in a pre-configured speed or vehicle class bins and thus make it difficult to compare with truck GPS data. The WIM data source, containing all volume, speed and classification information, presents an ideal benchmark source for truck GPS data validation. However, most of the WIM stations were instrumented in rural area for vehicle weight monitoring and pavement maintenance.

Table 8 Comparison of Different Traffic Data Sources

Data Source	Vehicle Class	Volume	Speed or Travel Time
Truck GPS	9 and higher	Sample	Yes
Loop Detector	No	Yes	Calc. from occupancy
ATR	Yes	Yes	Yes
WIM	Yes	Yes	Yes

Appendix A: ATR Truck Volume Comparison by Hour

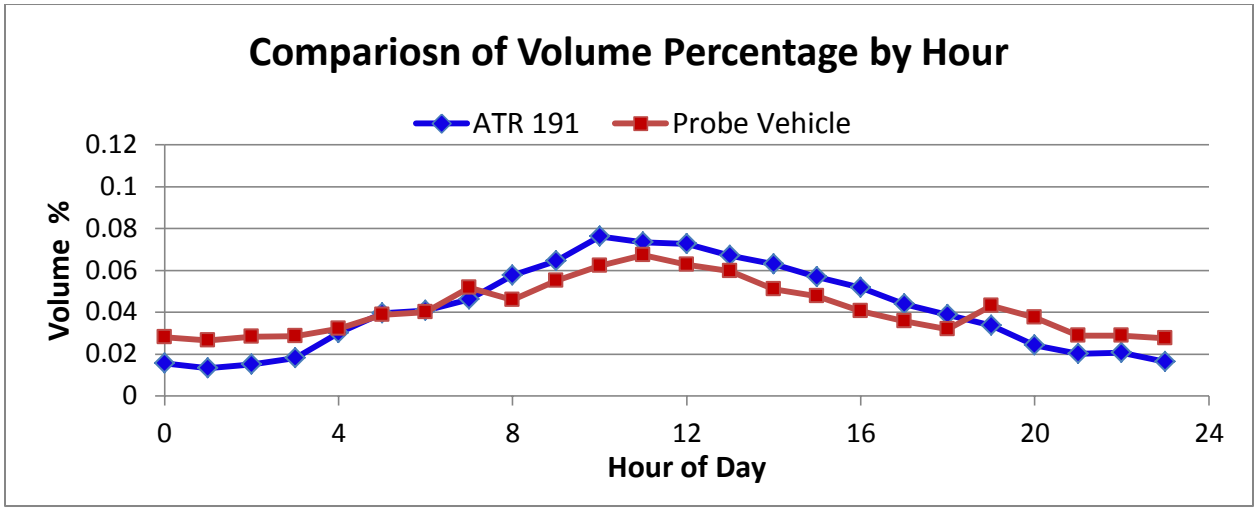

Table A.1 Comparison of Truck Volume Percentage by Hour (ATR Station #191)

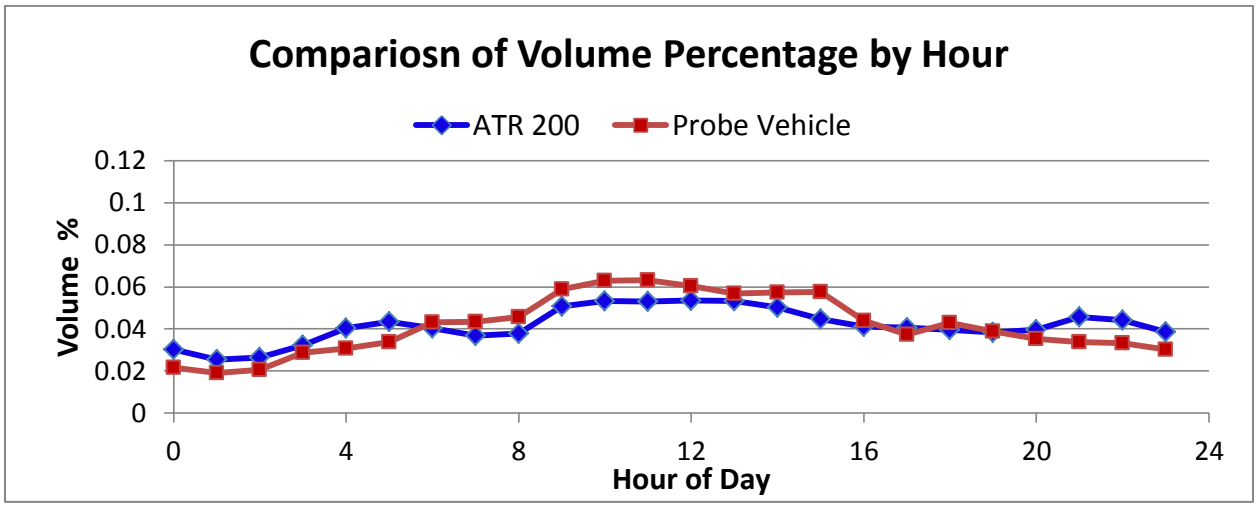

Table A.2 Comparison of Truck Volume Percentage by Hour (ATR Station #200)

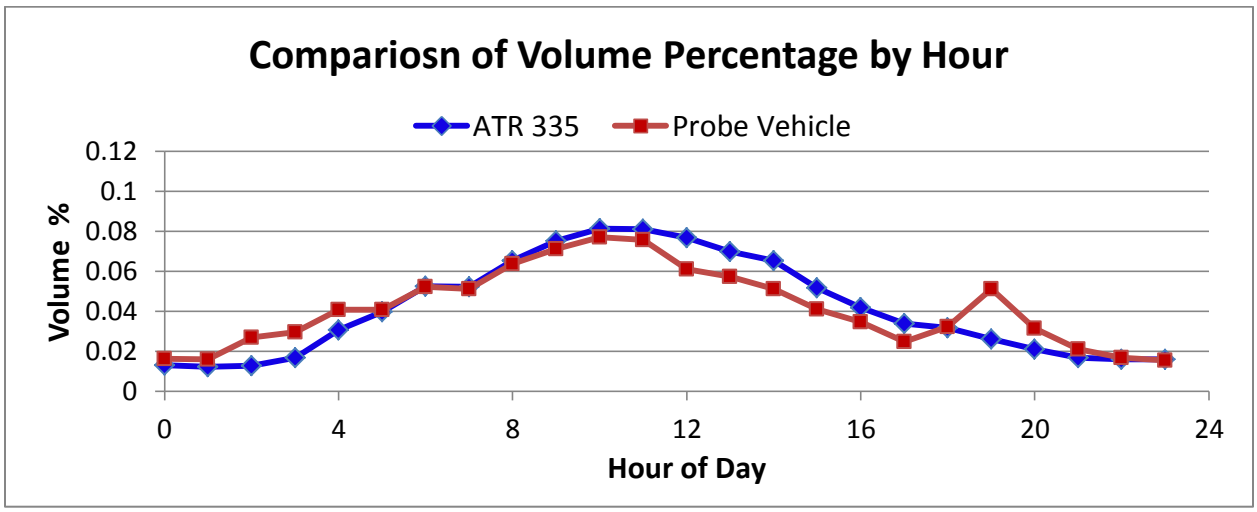

Table A.3 Comparison of Truck Volume Percentage by Hour (ATR Station #335)

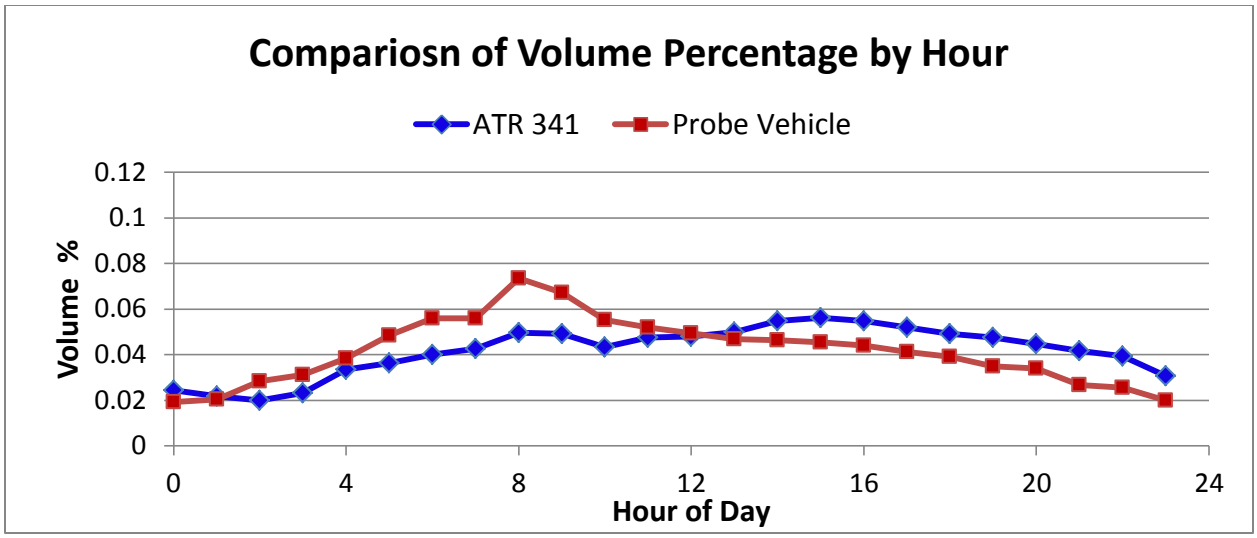

Table A.4 Comparison of Truck Volume Percentage by Hour (ATR Station #341)

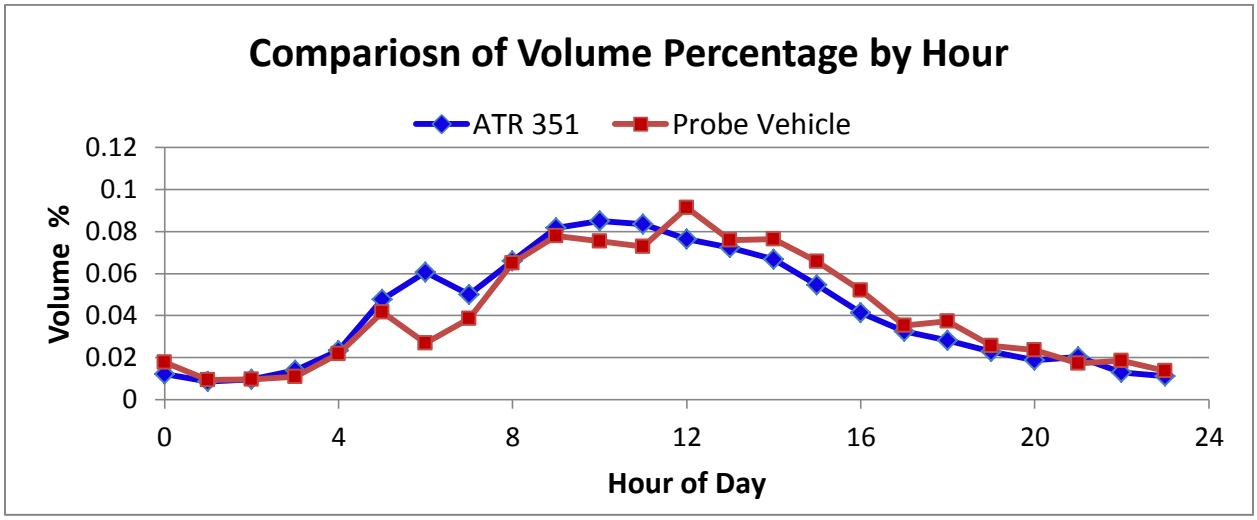

Table A.5 Comparison of Truck Volume Percentage by Hour (ATR Station #351)

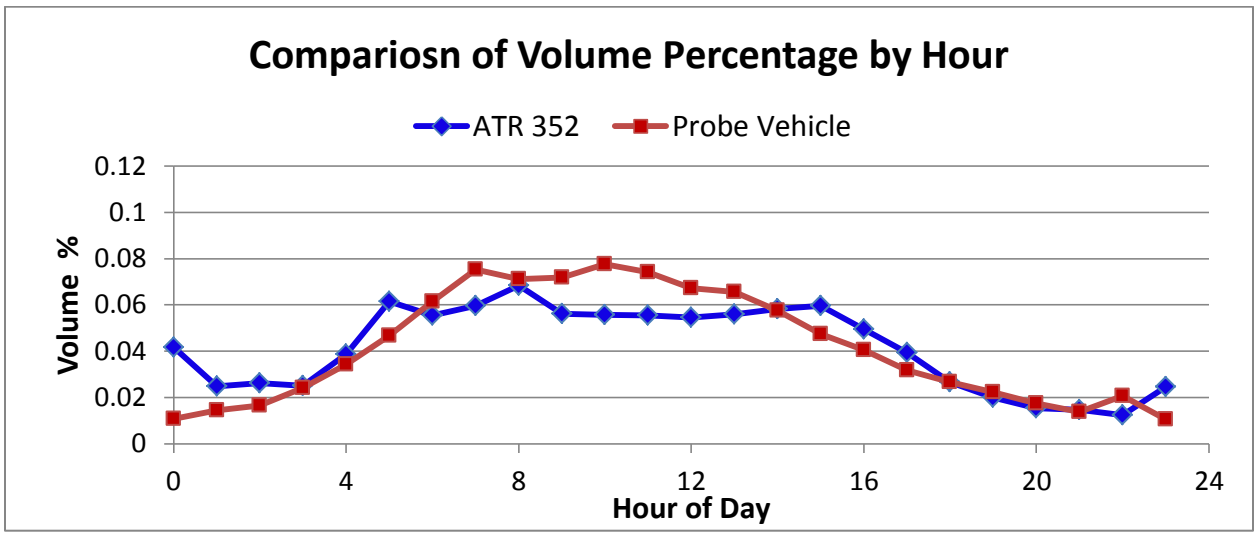

Table A.6 Comparison of Truck Volume Percentage by Hour (ATR Station #352)

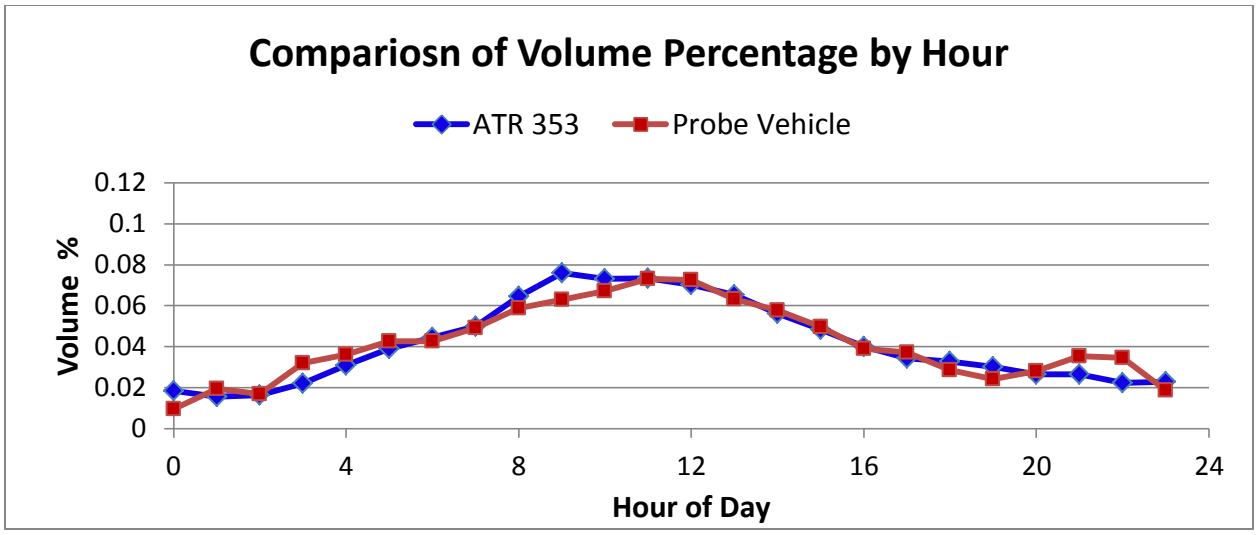

Table A.7 Comparison of Truck Volume Percentage by Hour (ATR Station #353)

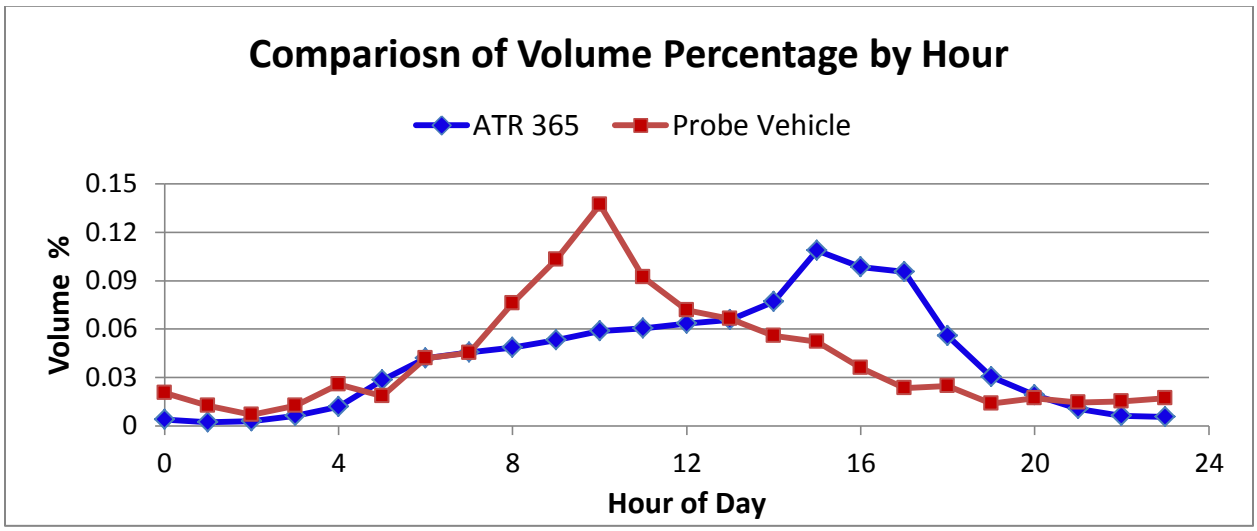

Table A.8 Comparison of Truck Volume Percentage by Hour (ATR Station #365)

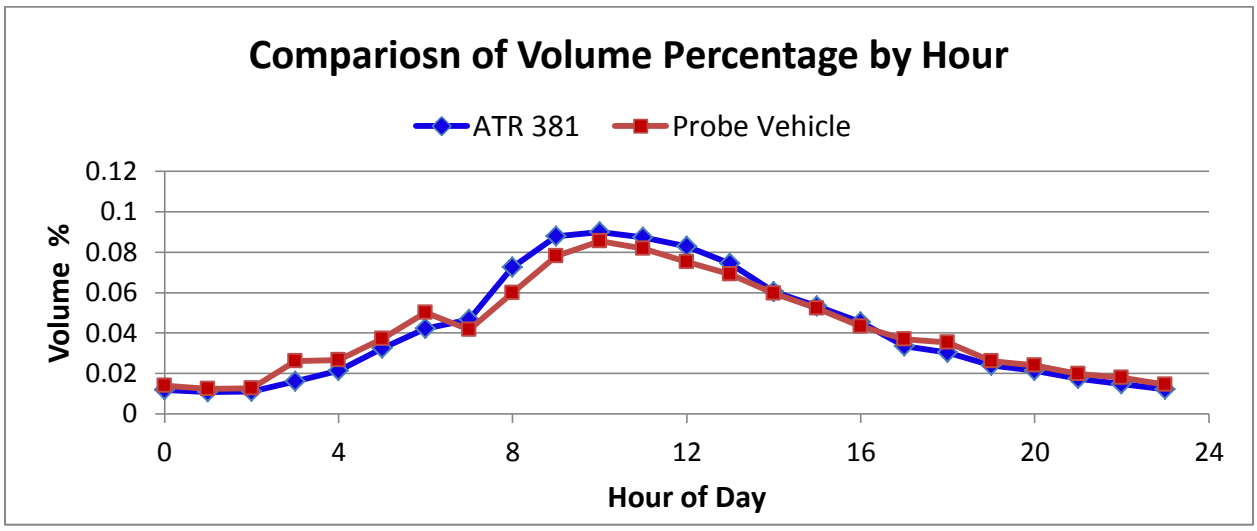

Table A.9 Comparison of Truck Volume Percentage by Hour (ATR Station #381)

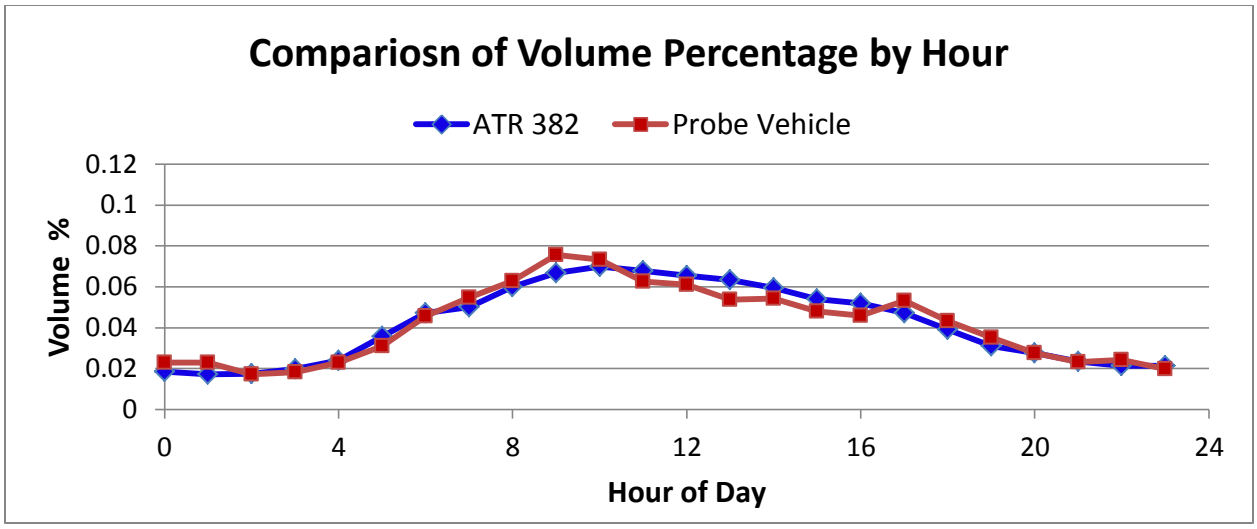

Table A.10 Comparison of Truck Volume Percentage by Hour (ATR Station #382)

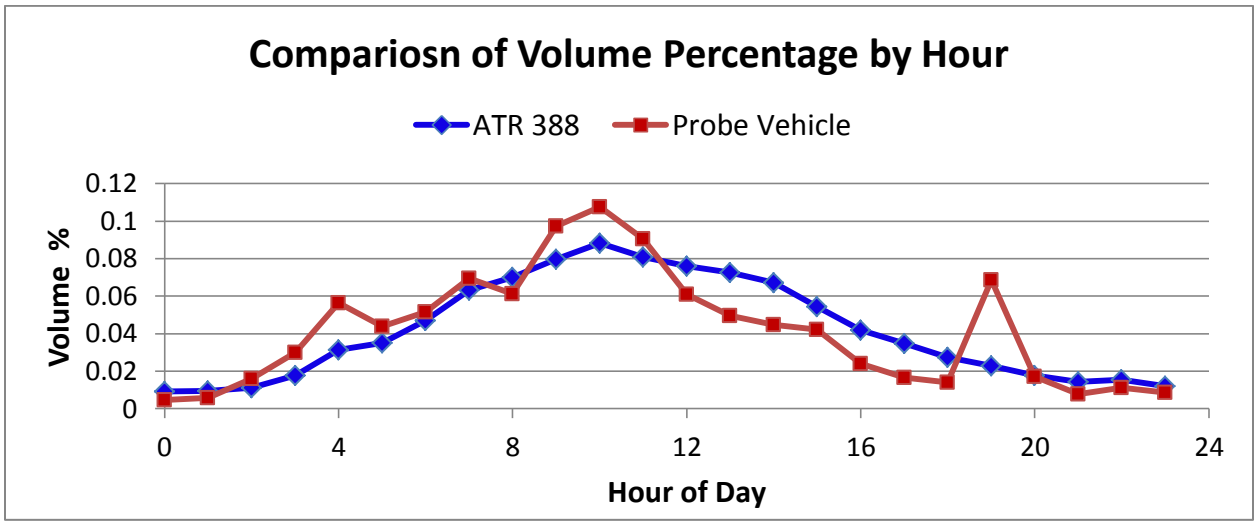

Table A.11 Comparison of Truck Volume Percentage by Hour (ATR Station #388)

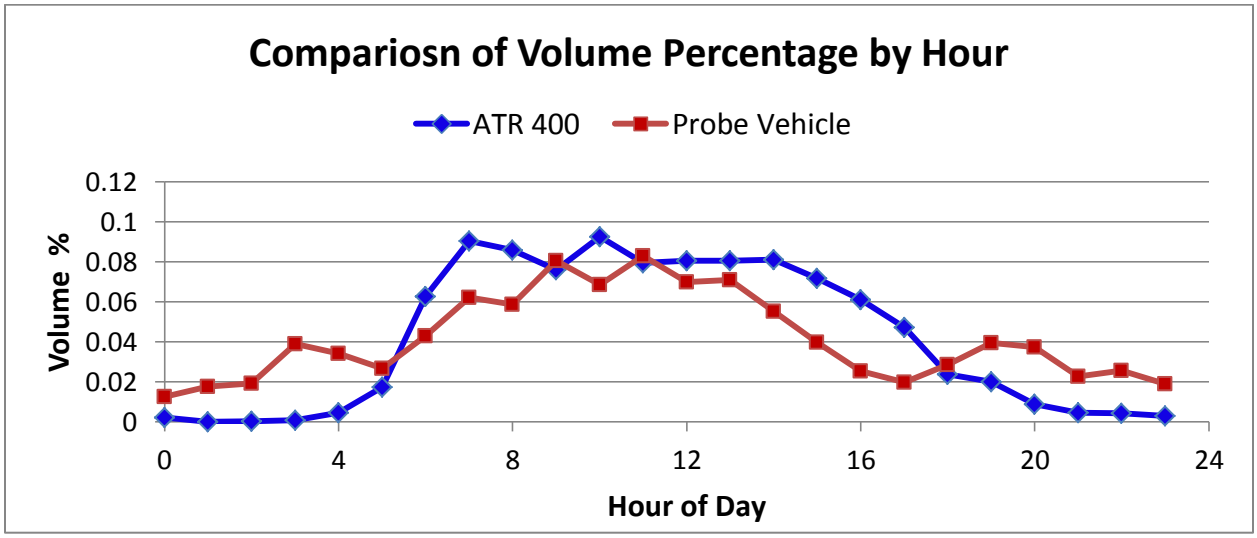

Table A.12 Comparison of Truck Volume Percentage by Hour (ATR Station #400)

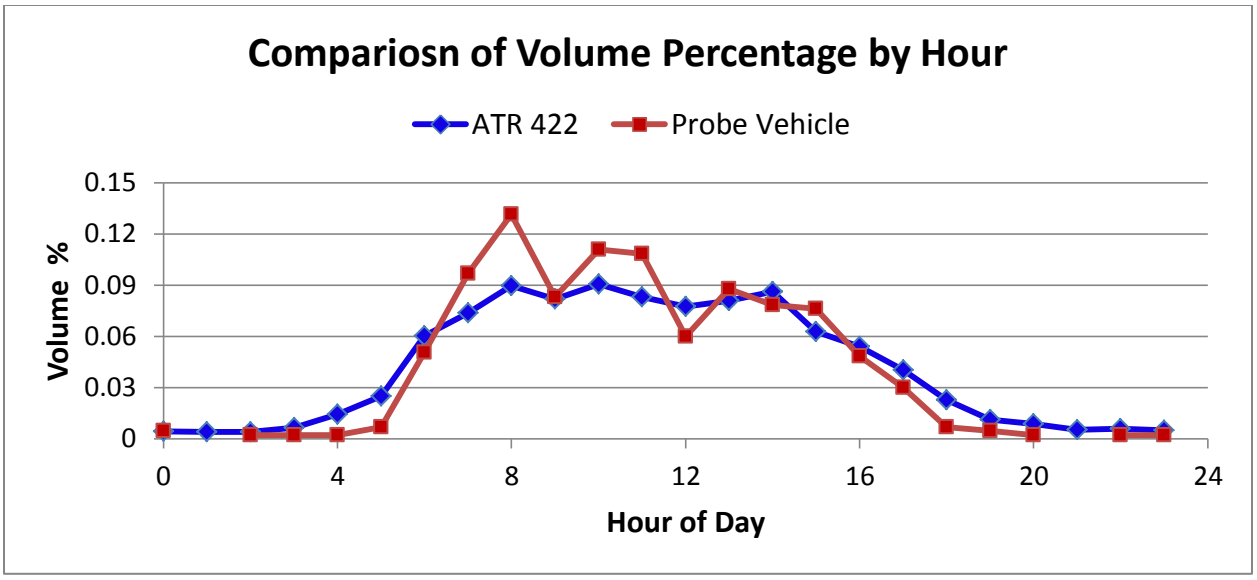

Table A.13 Comparison of Truck Volume Percentage by Hour (ATR Station #422)

Appendix B: ATR Speed Comparison by Hour

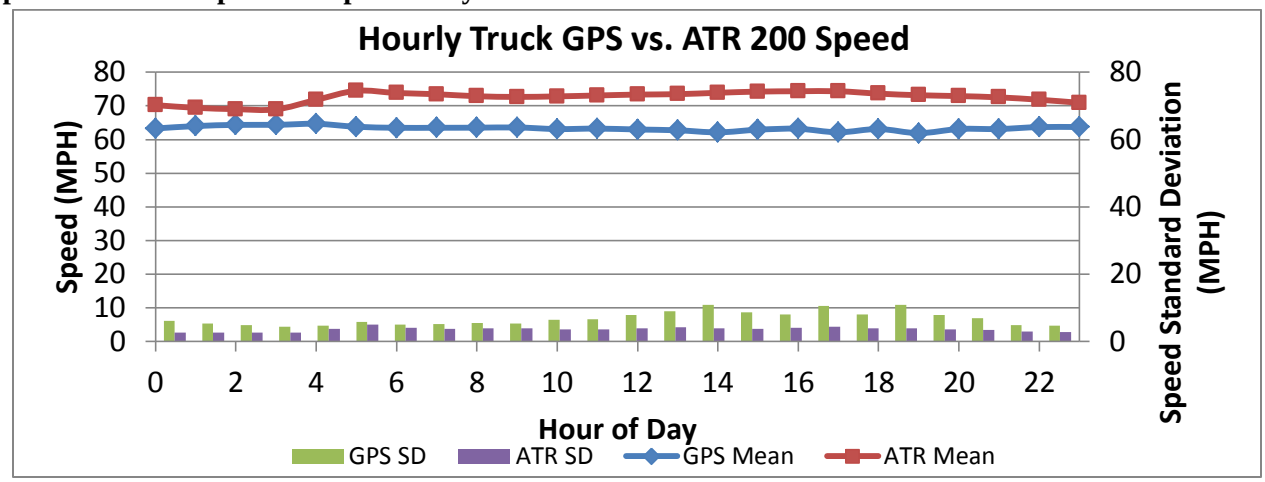

Figure B.1 Weekday Hourly Truck GPS vs. ATR 200 Speed Comparisons

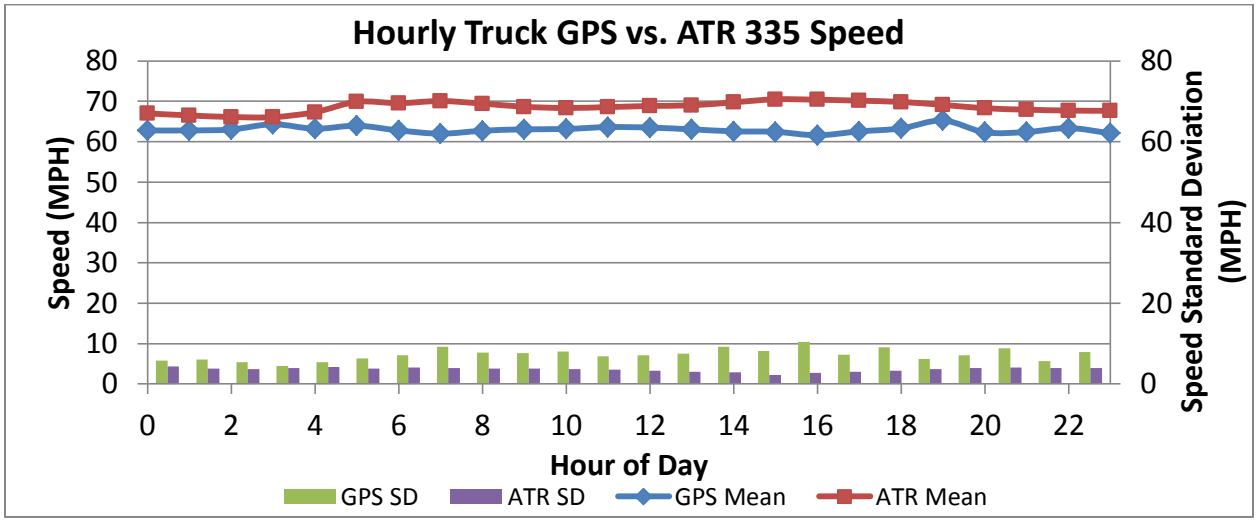

Figure B.2 Weekday Hourly Truck GPS vs. ATR 335 Speed Comparisons

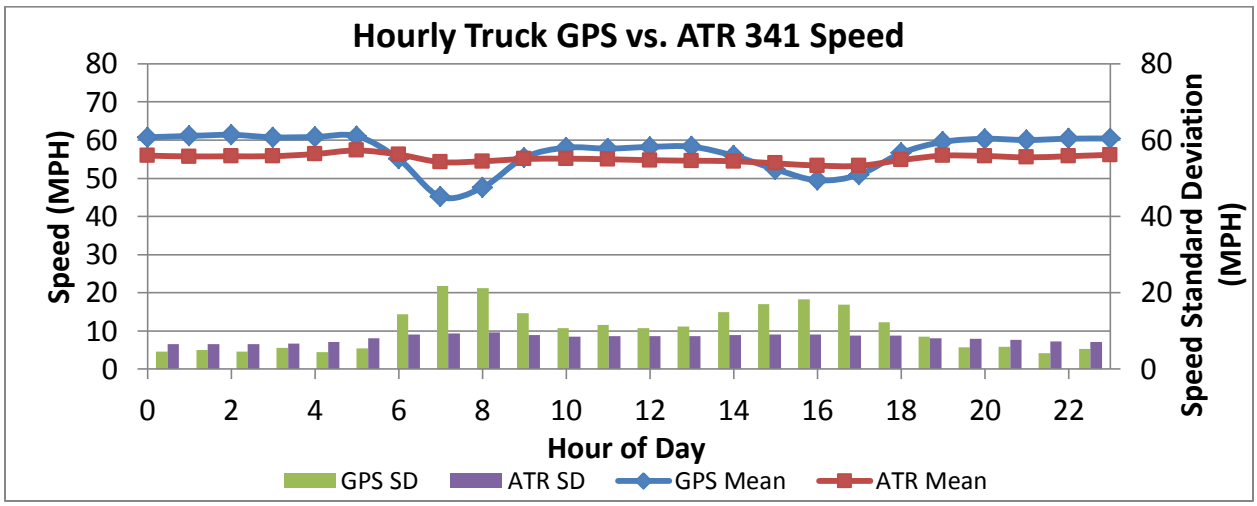

Figure B.3 Weekday Hourly Truck GPS vs. ATR 341 Speed Comparisons

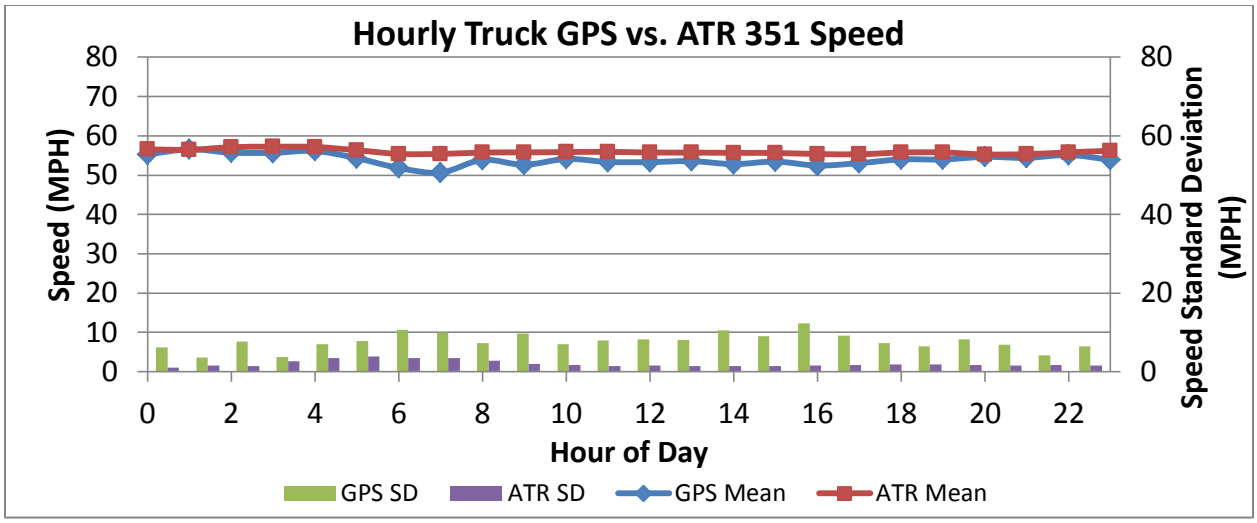

Figure B.4 Weekday Hourly Truck GPS vs. ATR 351 Speed Comparisons

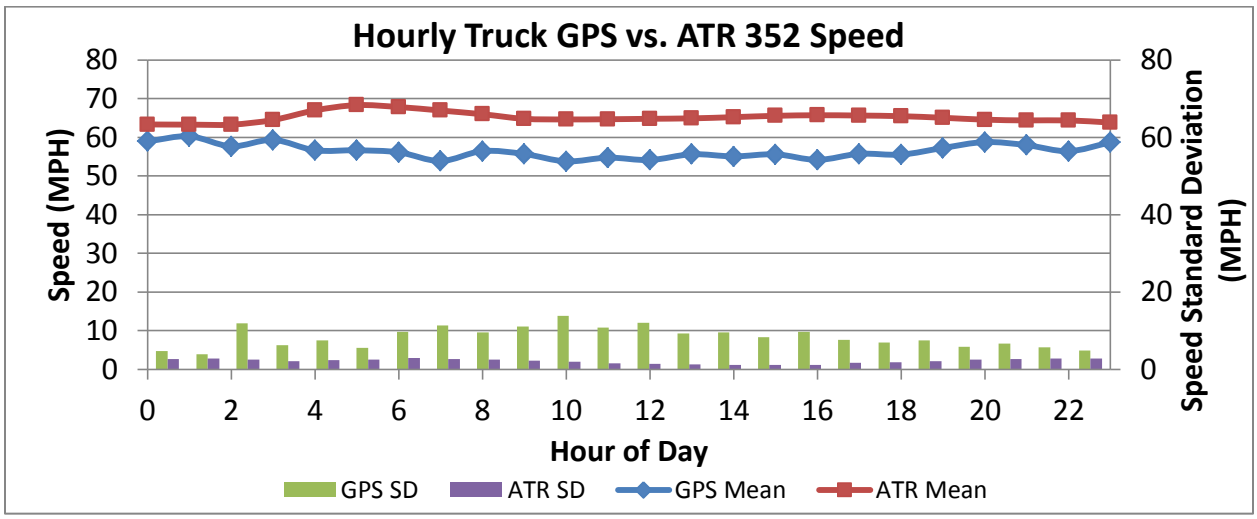

Figure B.5 Weekday Hourly Truck GPS vs. ATR 352 Speed Comparisons

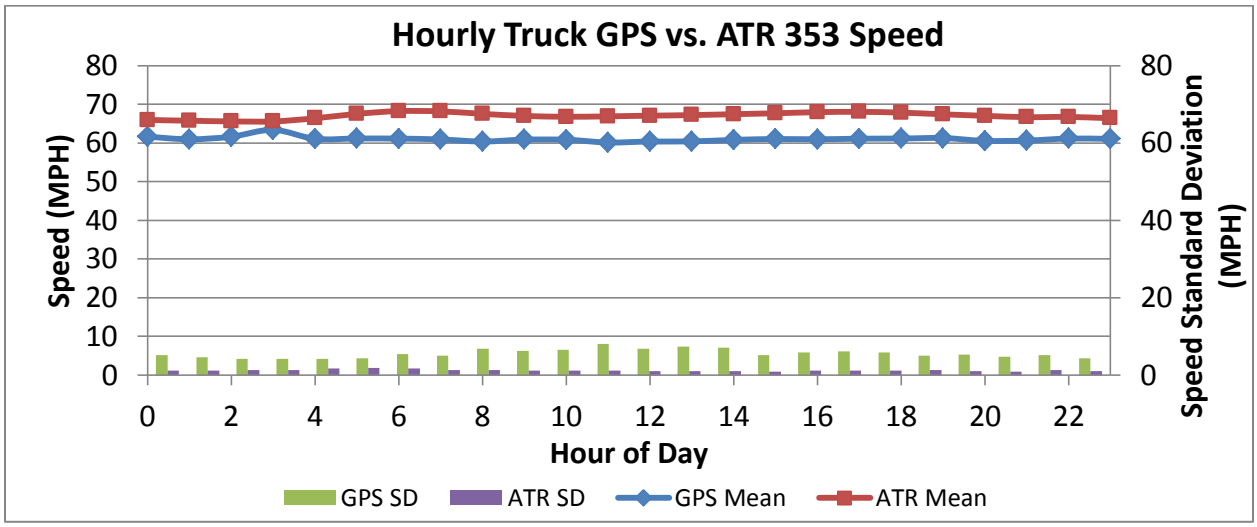

Figure B.6 Weekday Hourly Truck GPS vs. ATR 353 Speed Comparisons

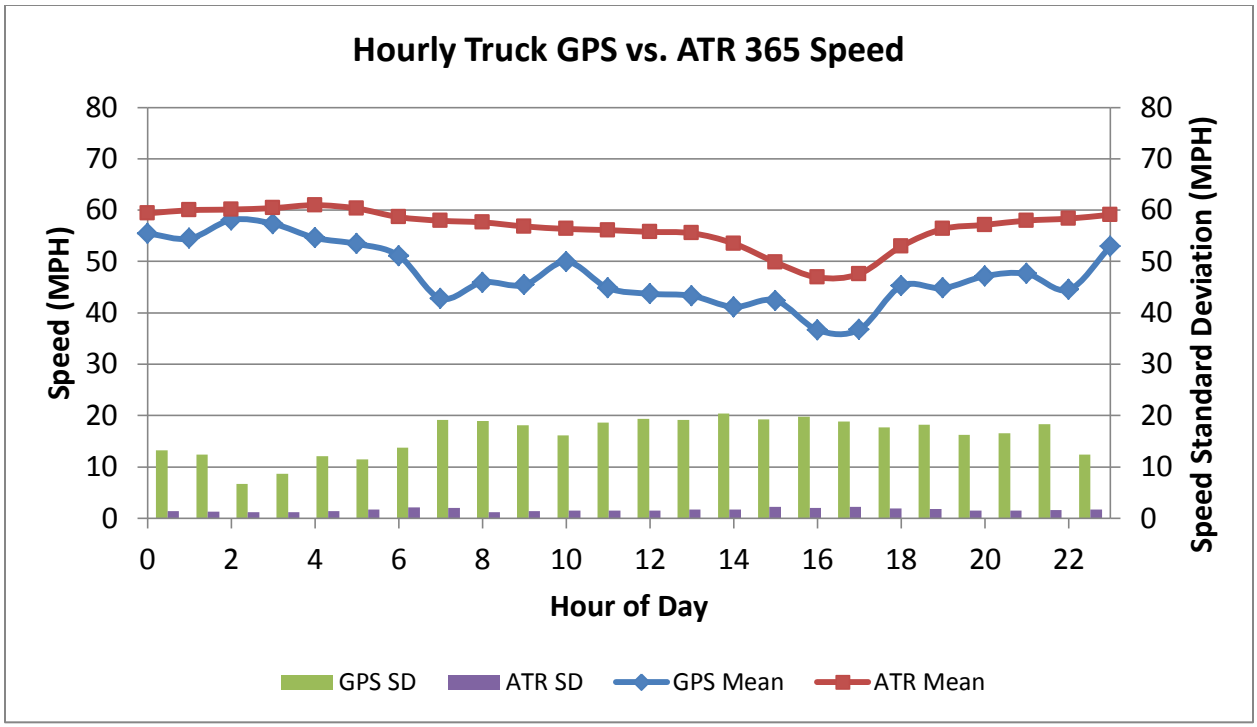

Figure B.7 Weekday Hourly Truck GPS vs. ATR 365 Speed Comparisons

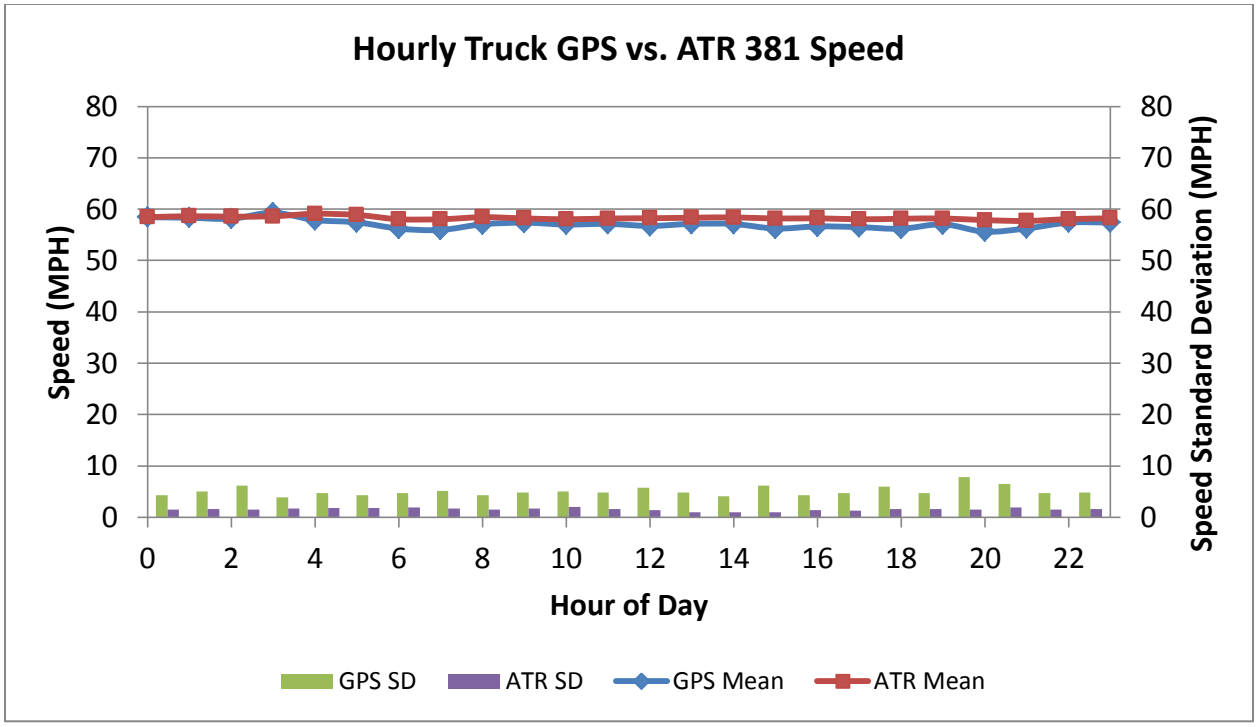

Figure B.8 Weekday Hourly Truck GPS vs. ATR 381 Speed Comparisons

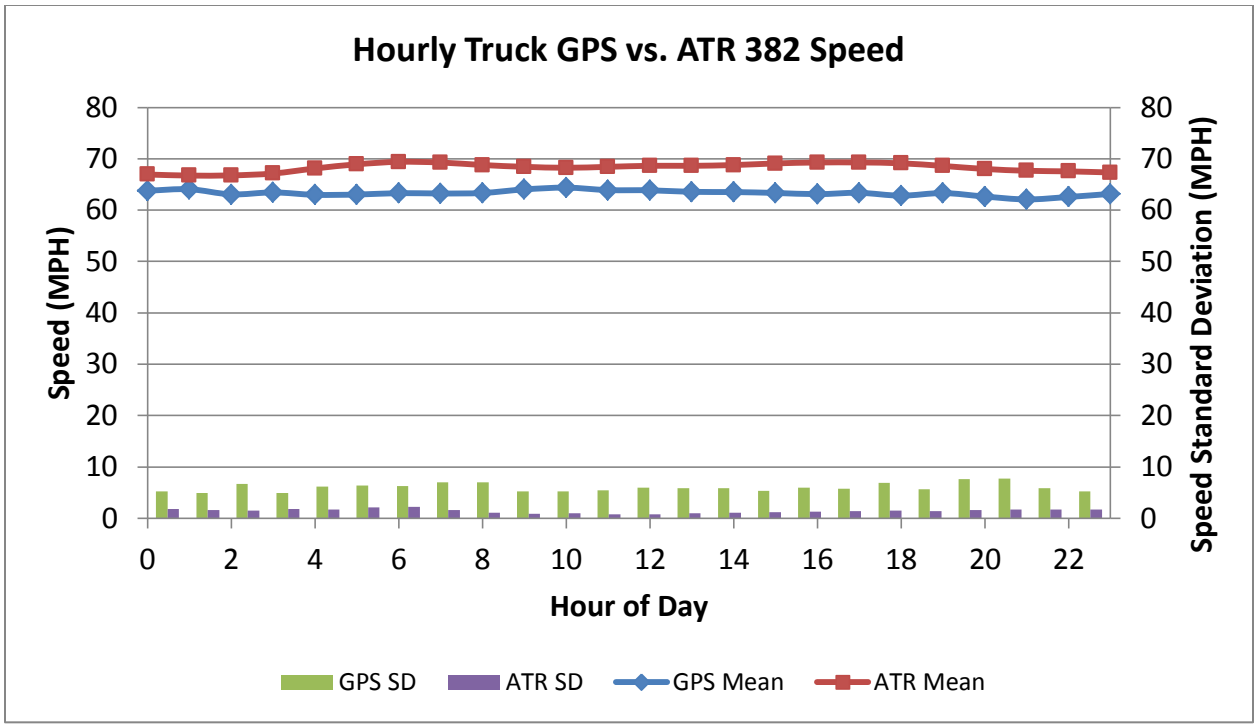

Figure B.9 Weekday Hourly Truck GPS vs. ATR 382 Speed Comparisons

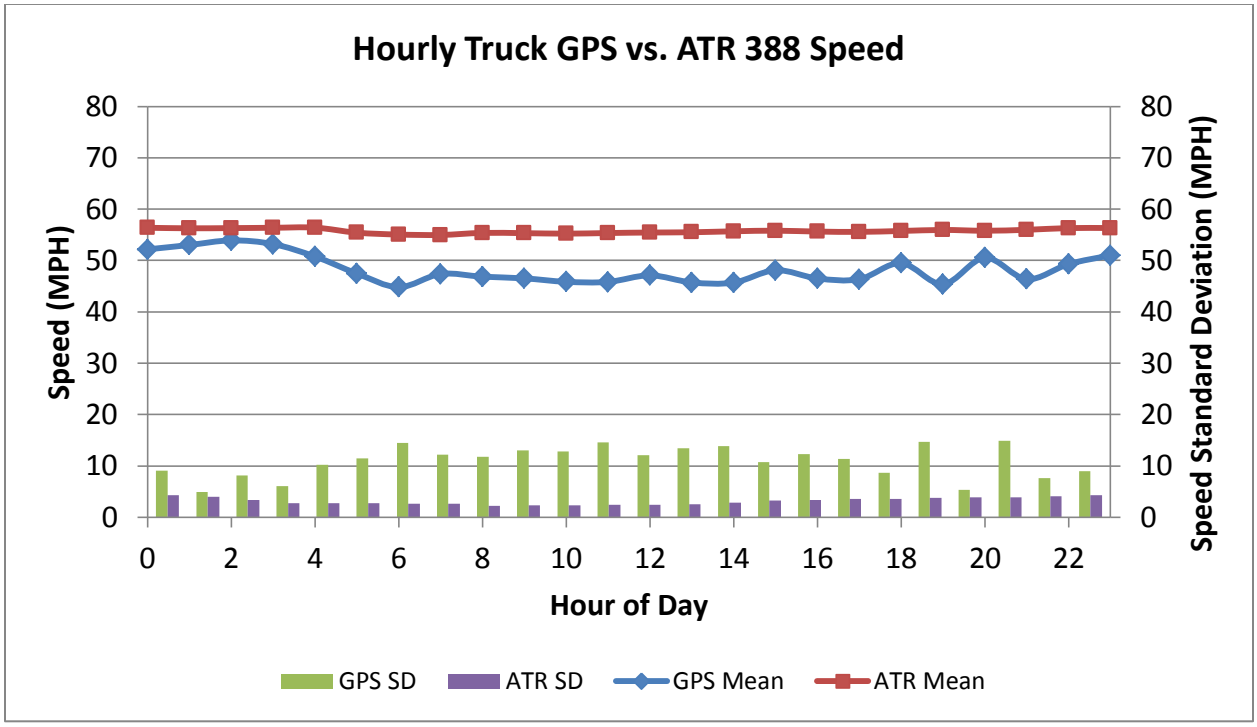

Figure B.10 Weekday Hourly Truck GPS vs. ATR 388 Speed Comparisons

Appendix C Comparison of WIM and Truck GPS Data

C.1 Speed Comparison

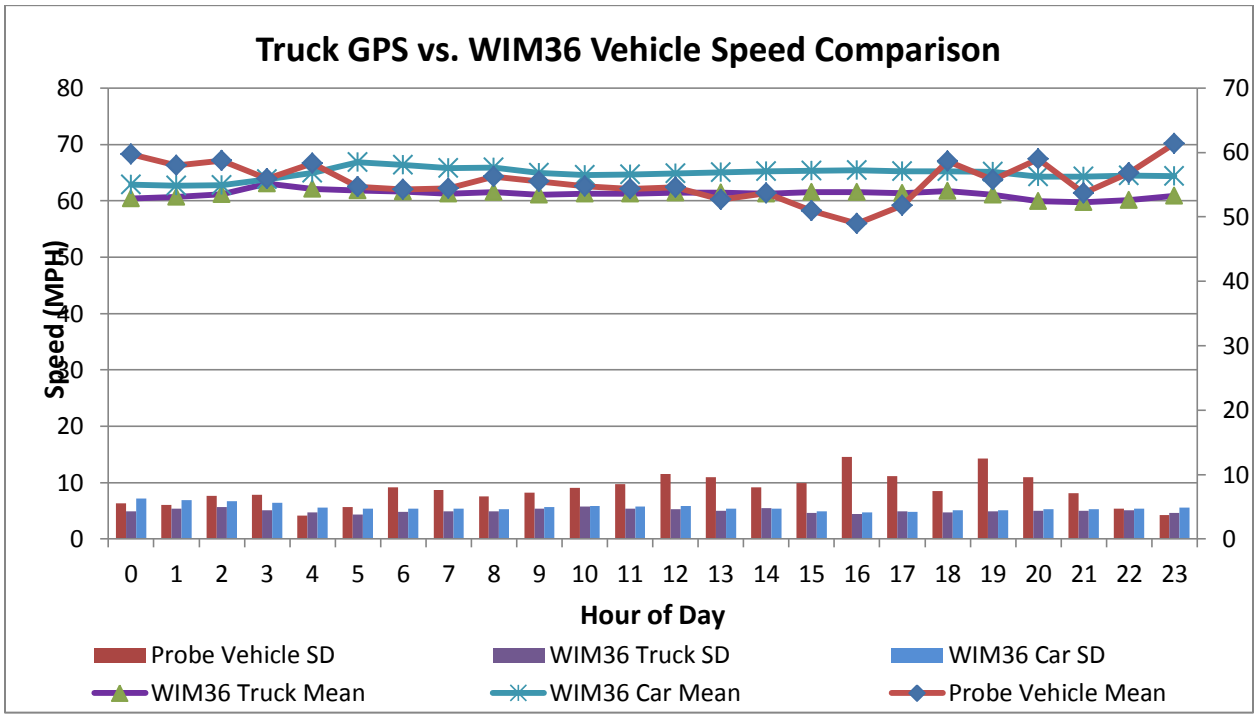

Figure C.1 Truck GPS Speed vs. WIM Speed by Hour at WIM#36

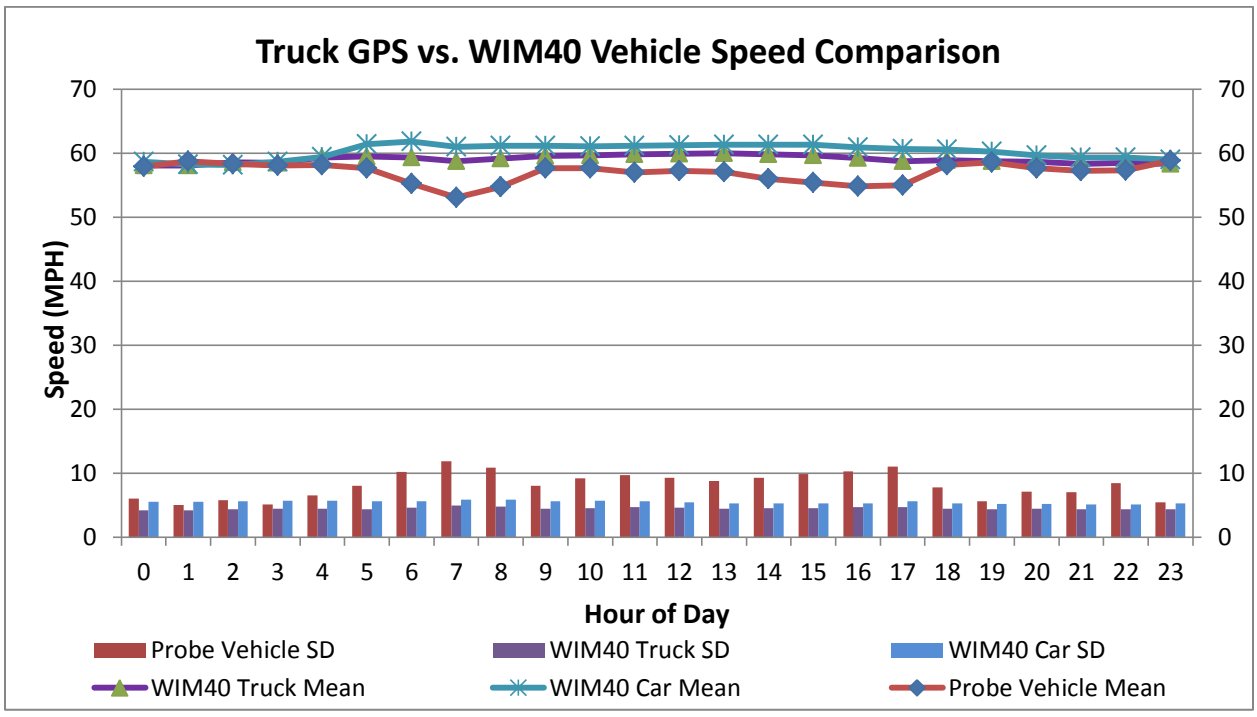

Figure C.2 Truck GPS Speed vs. WIM Speed by Hour at WIM#40

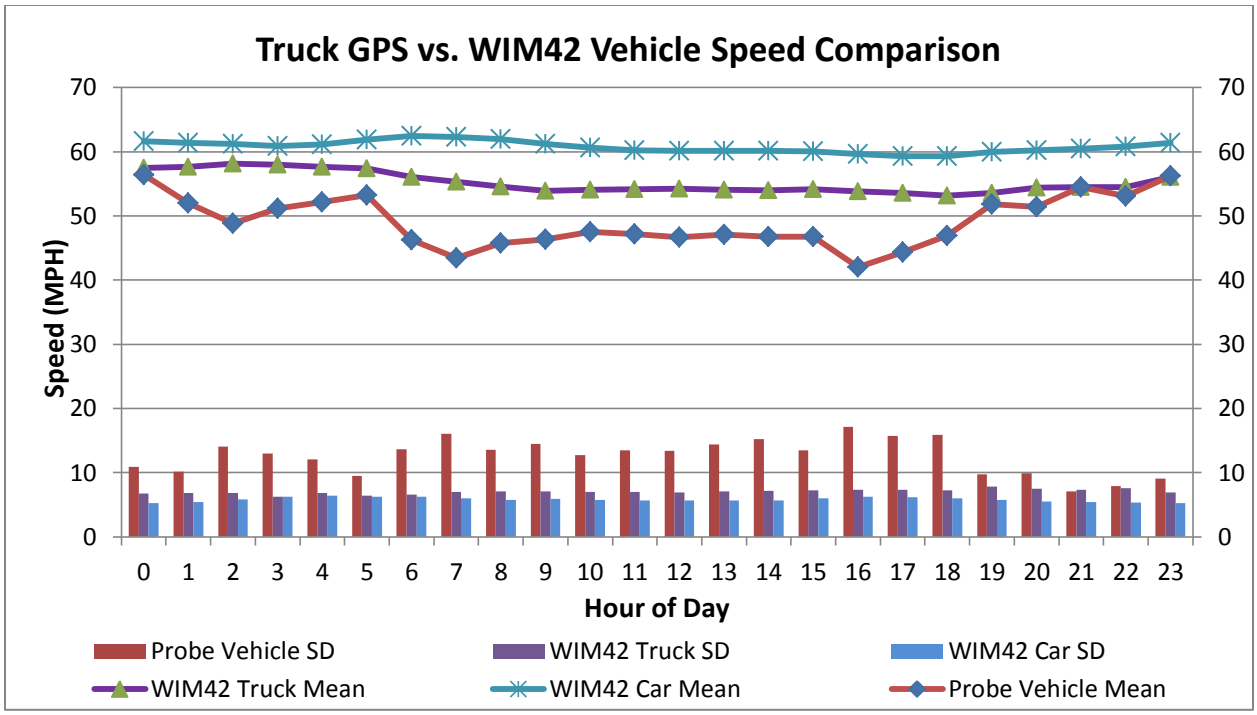

Figure C.3 Truck GPS Speed vs. WIM Speed by Hour at WIM#42

C.2 Volume Comparison

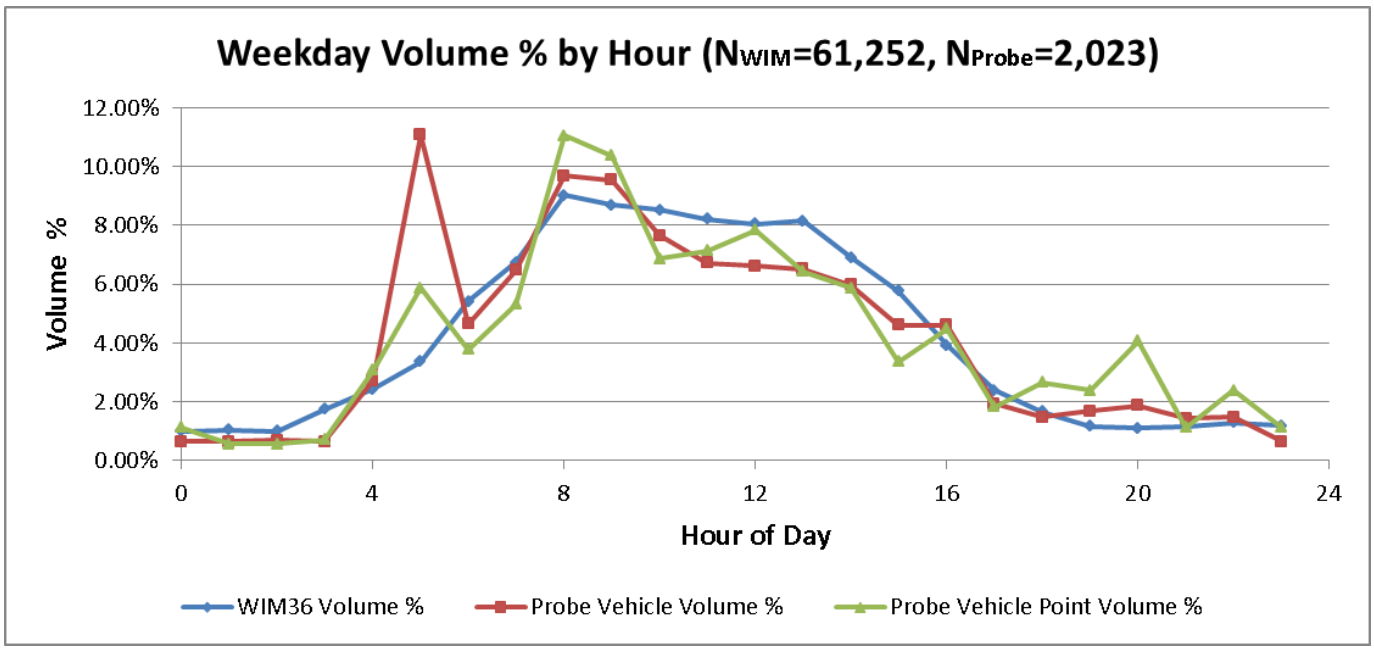

Figure C.4 Truck GPS vs. WIM Volume % by Hour at WIM#36

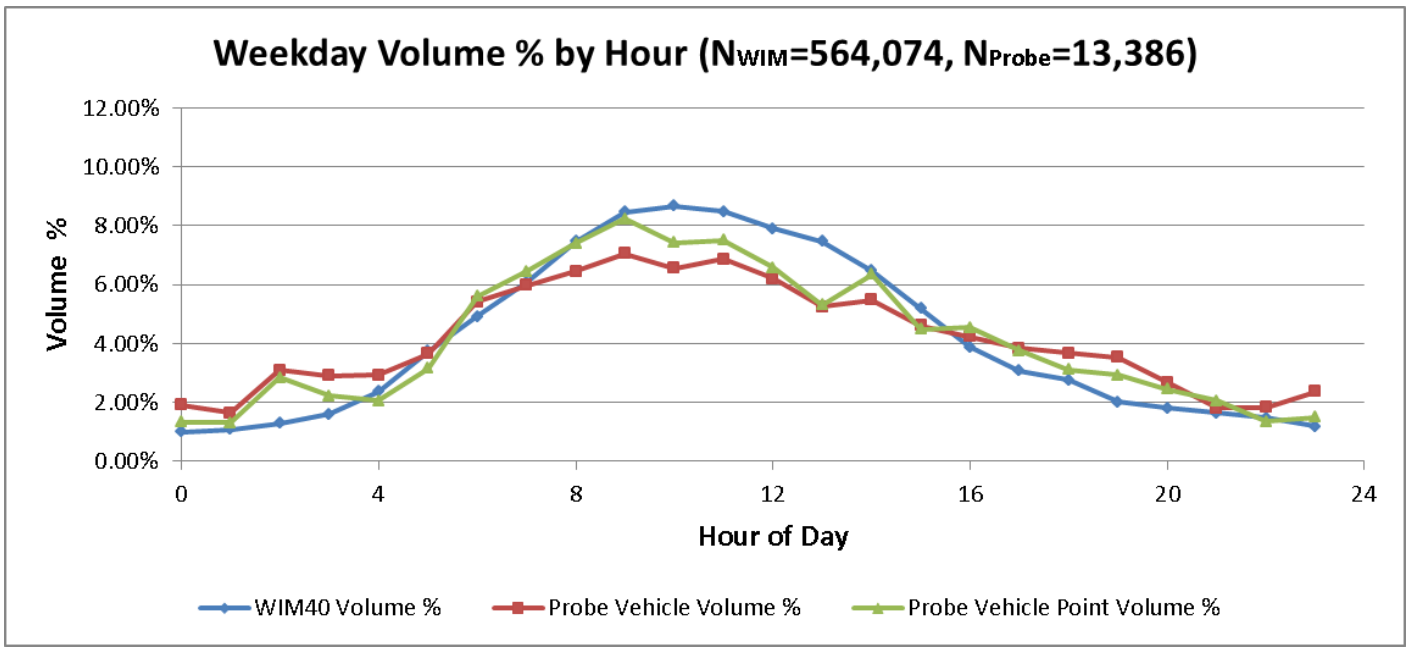

Figure C.5 Truck GPS vs. WIM Volume % by Hour at WIM#40

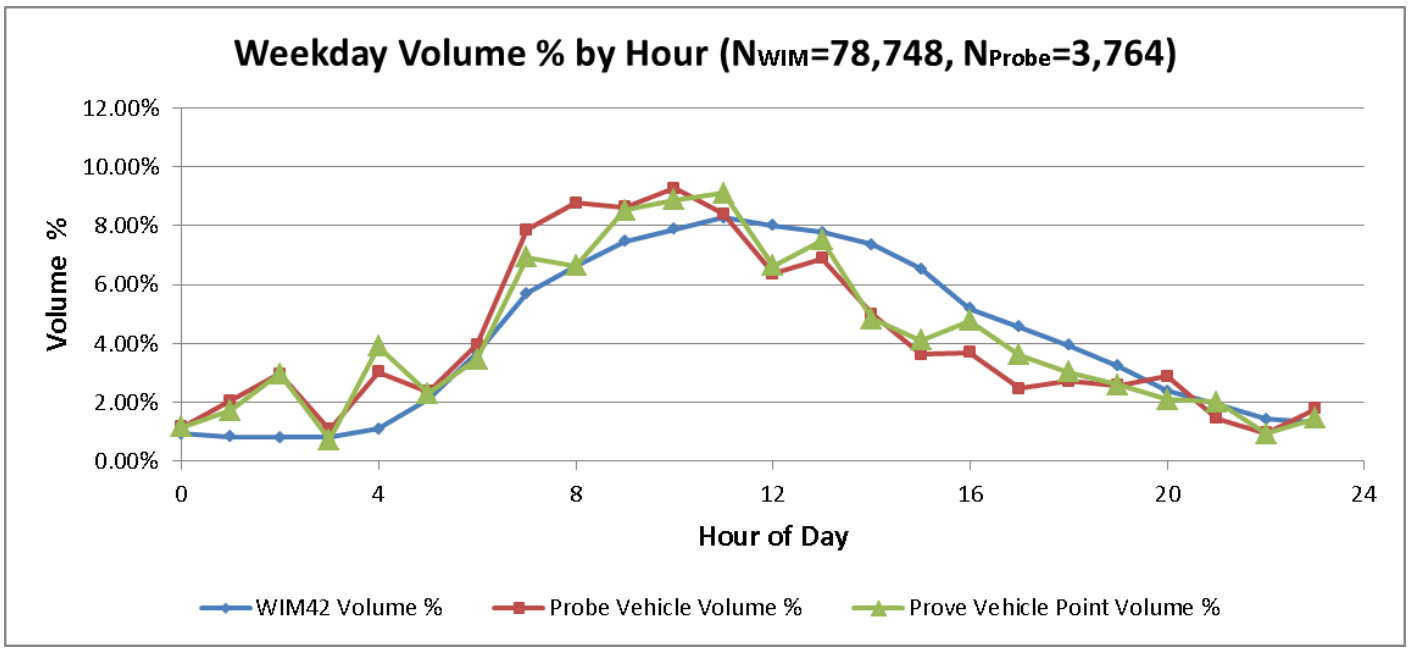

Figure C.6 Truck GPS vs. WIM Volume % by Hour at WIM#42

Appendix D Comparison of Loop Detector Data

D.1 MnDOT Data Plot Application

MnDOT data plot applet is available online (http://data.dot.state.mn.us/datatools/dataplot.html). Individual loop detector volume and speed can be queried and visualized (Figure D.1).

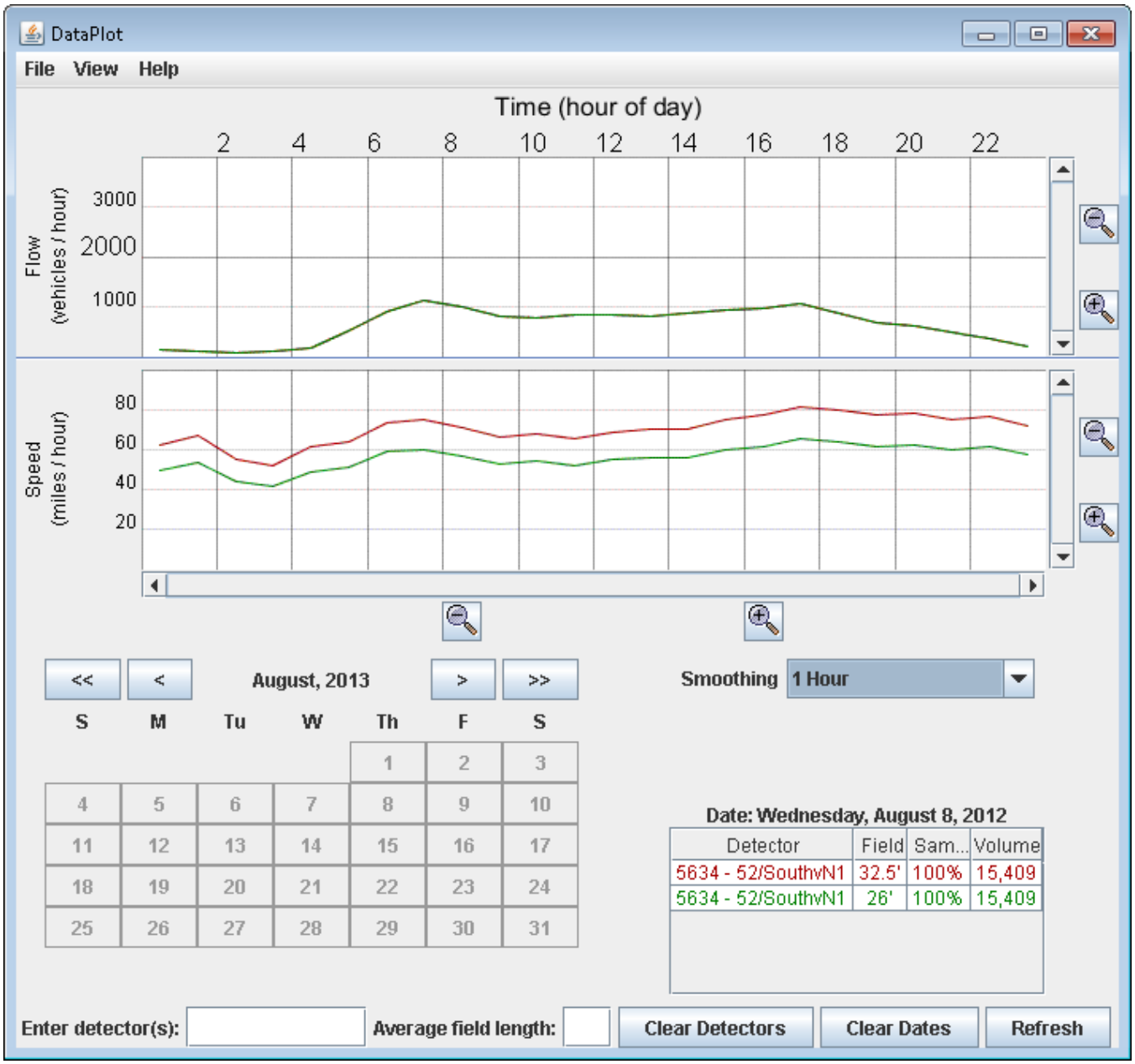

Figure D.1 Snapshot of MnDOT Data Plot Application

D.2 Loop Detector Volume Comparison with WIM Data

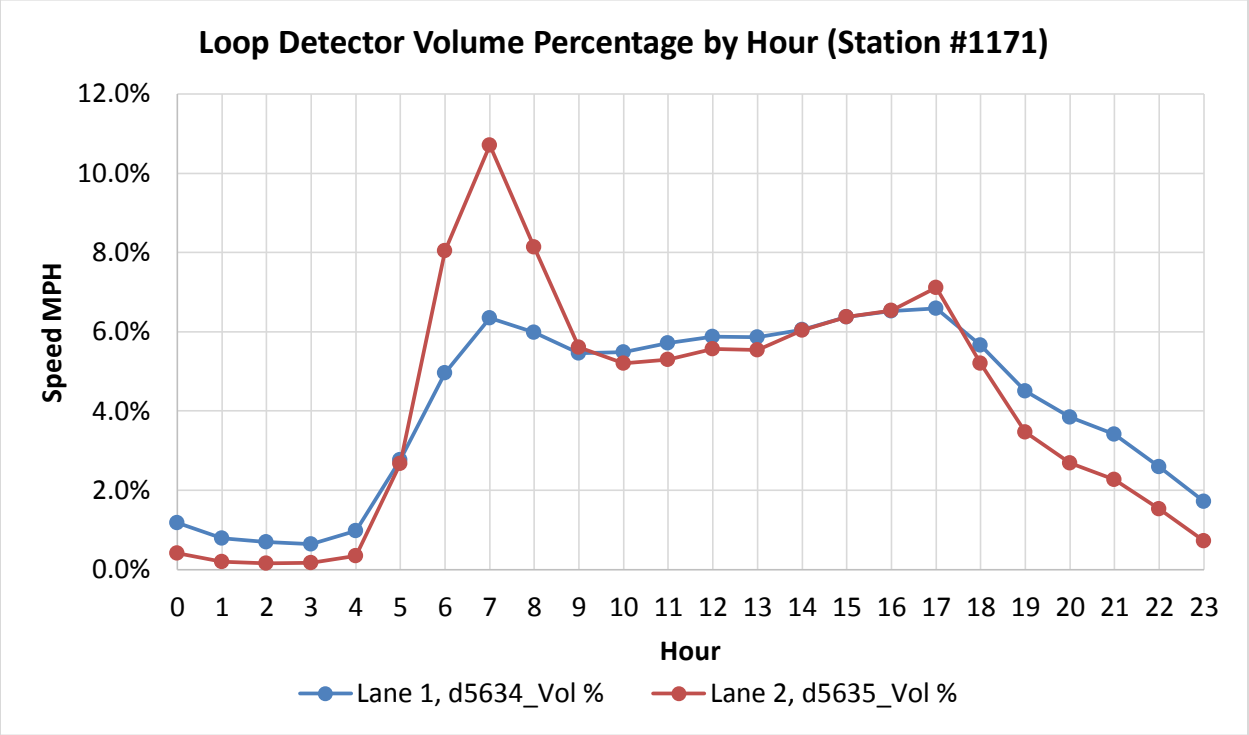

Figure D.2 Hourly Volume Percentages by Lane at Loop Detector Station #1171

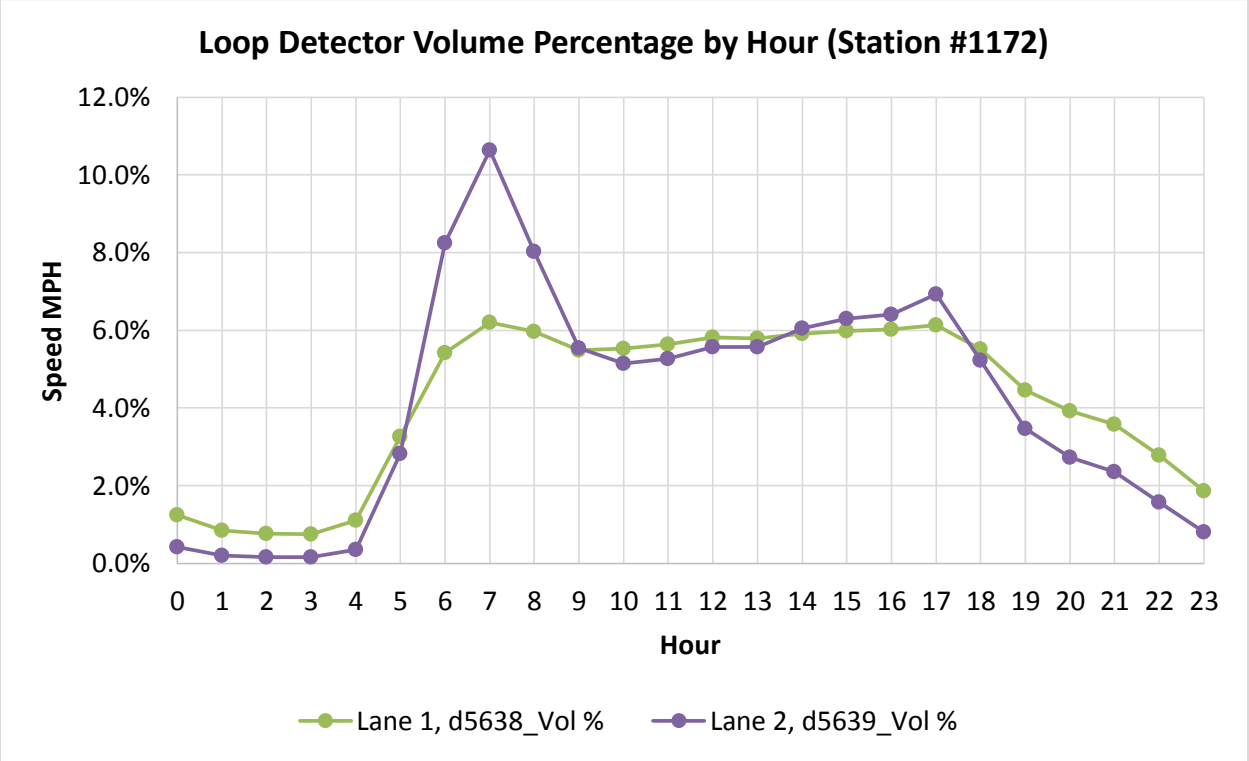

Figure D.3 Hourly Volume Percentages by Lane at Loop Detector Station #1172

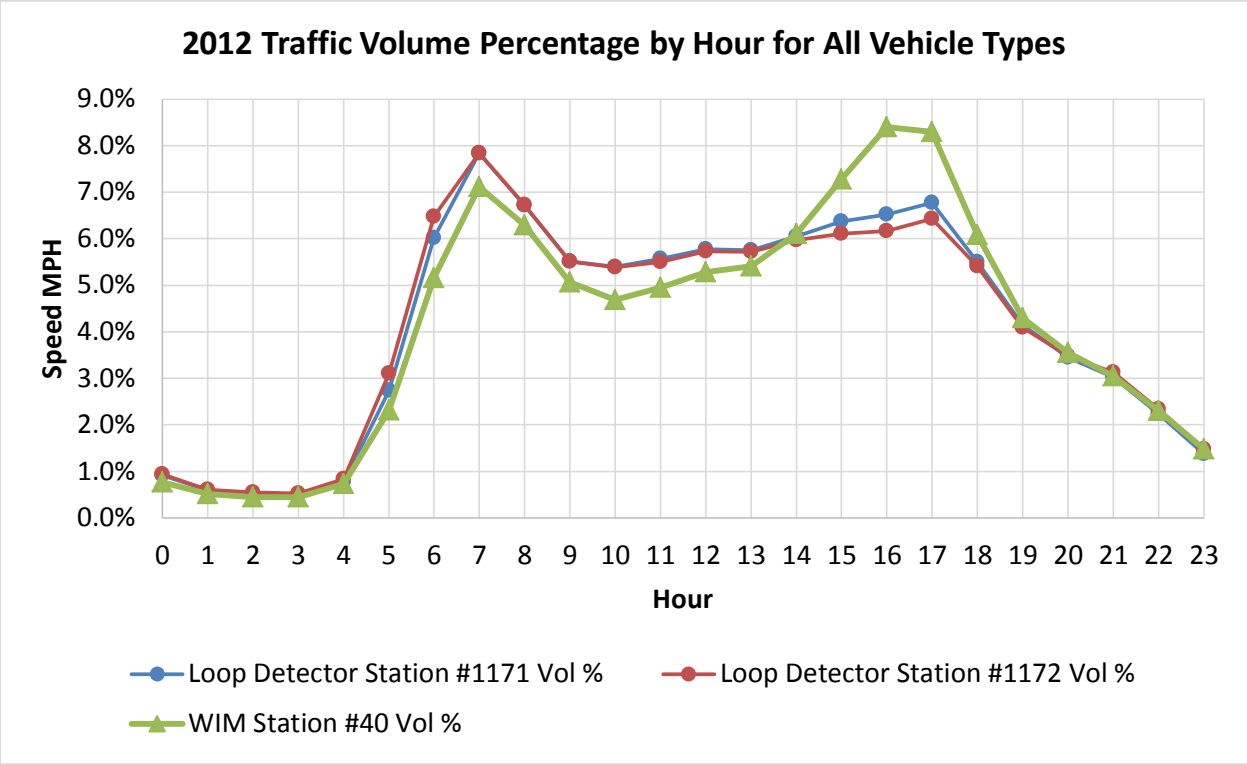

Figure D.4 Hourly Volume Percentage Comparisons (Loop Detector Station 1171 & 1172 vs. WIM 40)

D.3 Loop Detector Volume Comparison with ATR Data

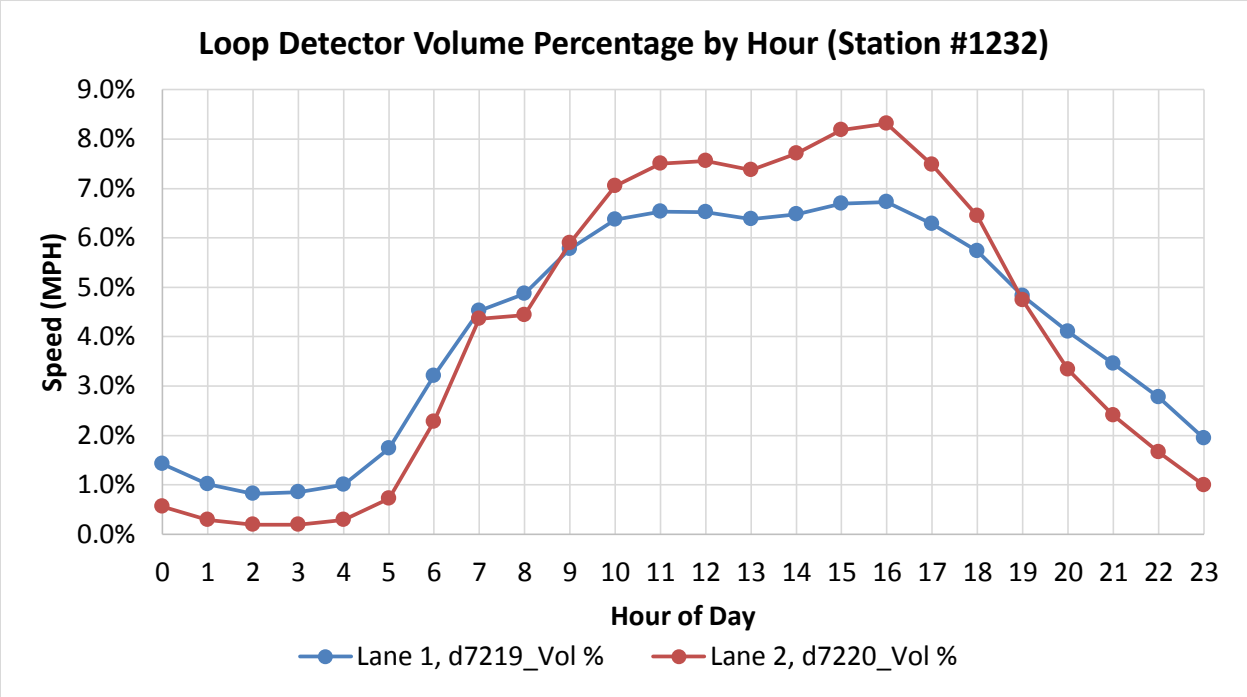

Figure D.5 Hourly Volume Percentages by Lane at Loop Detector Station #1232

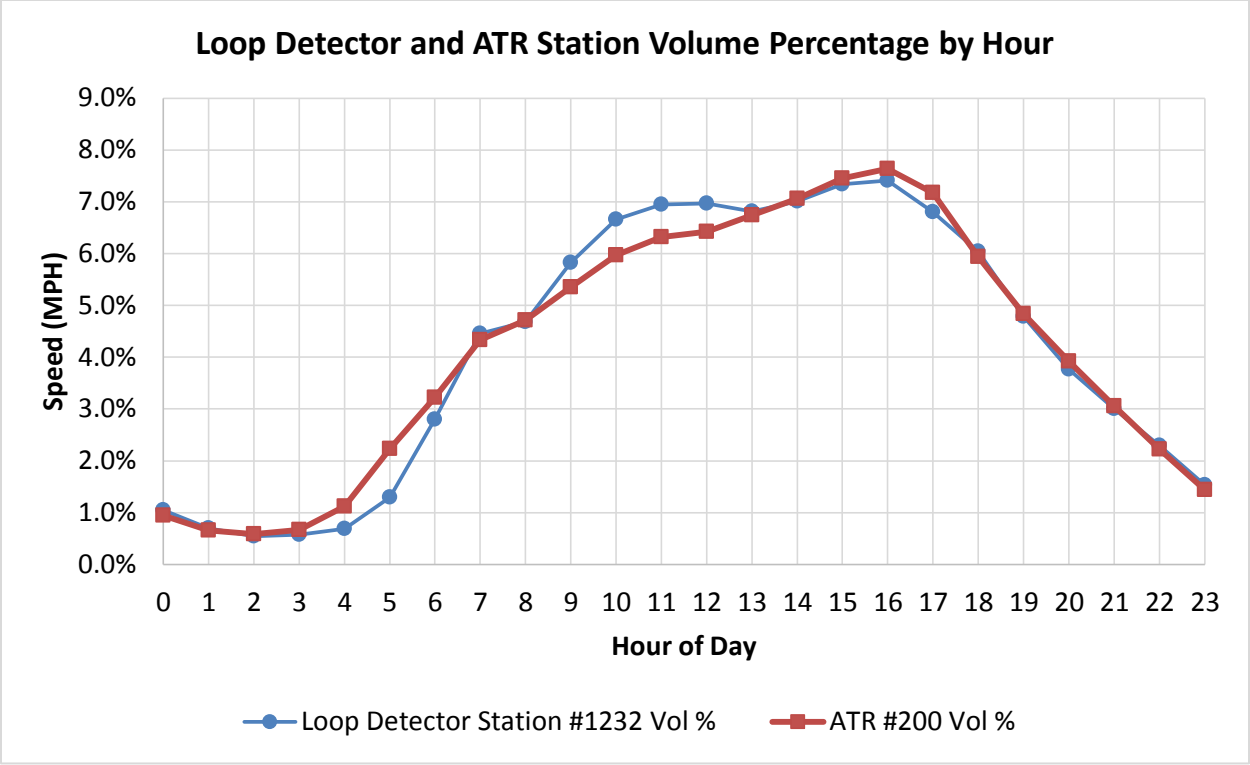

Figure D.6 Hourly Volume Percentage Comparisons (Loop Detector Station 1232 vs. ATR200)

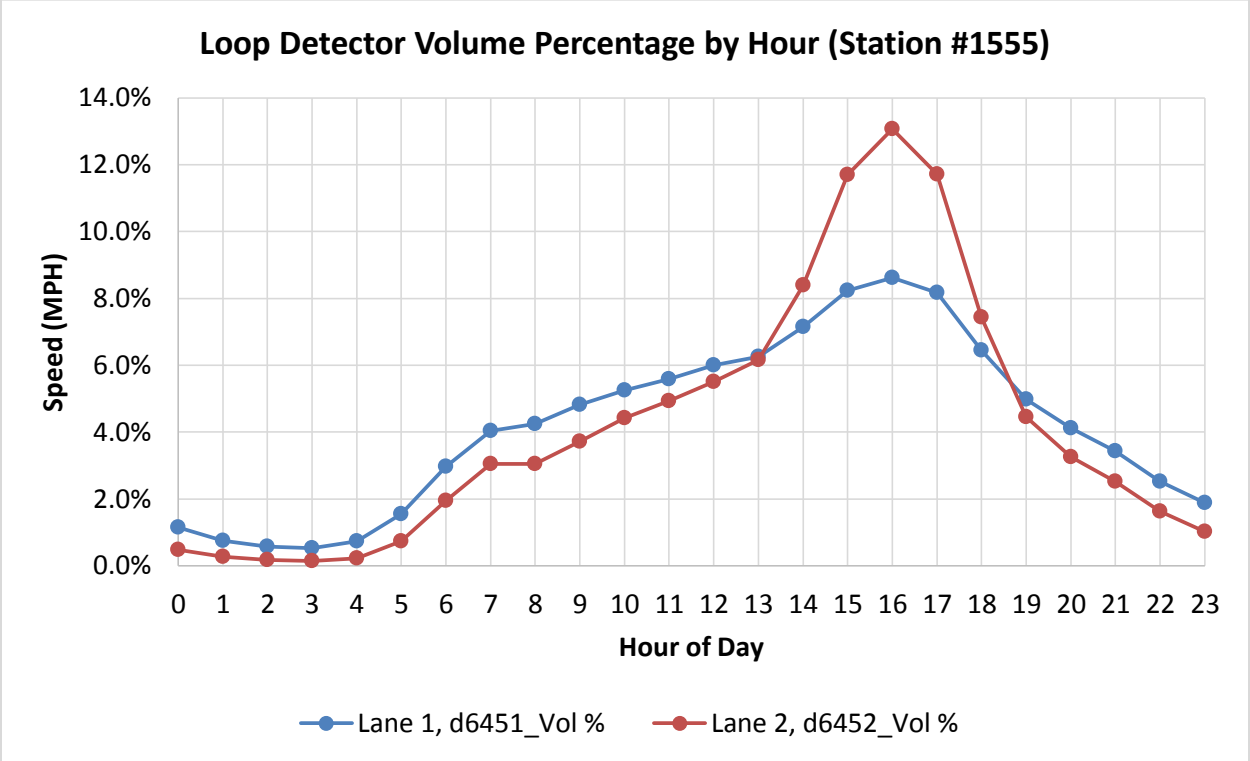

Figure D.7 Hourly Volume Percentages by Lane at Loop Detector Station #1555

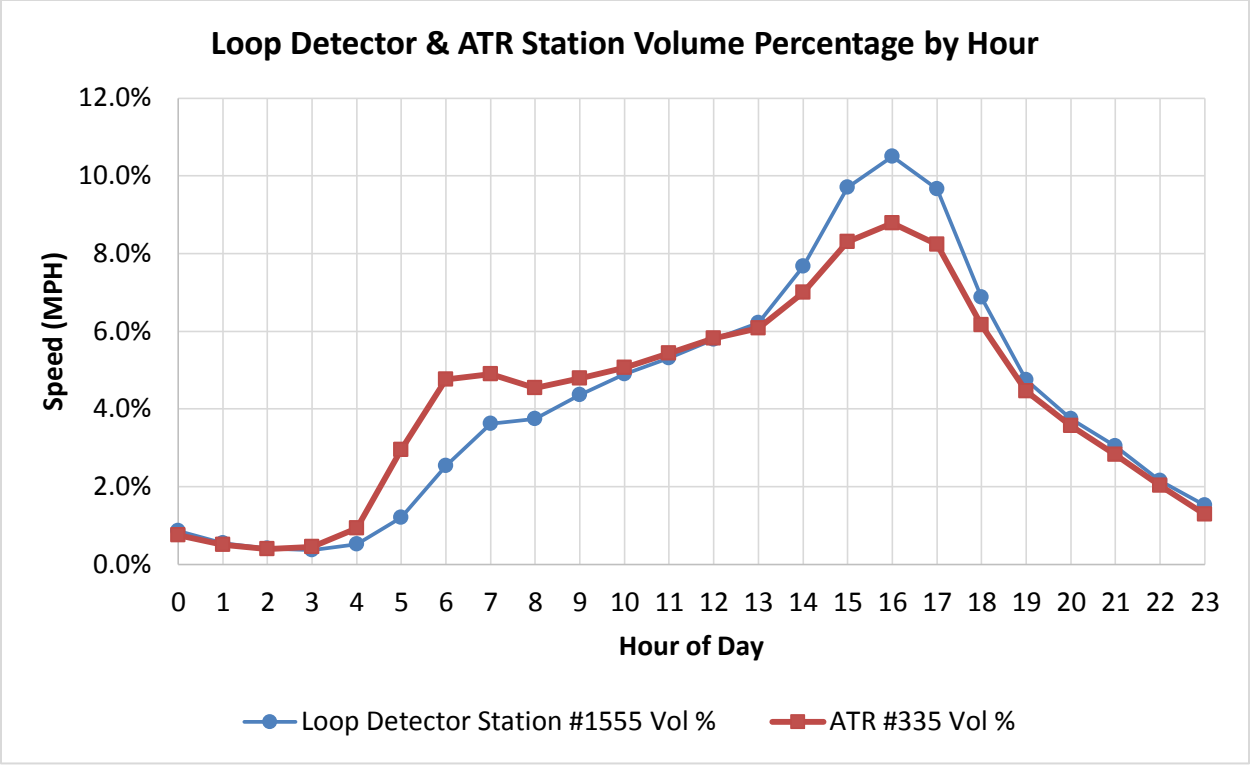

Figure D.8 Hourly Volume Percentage Comparisons (Loop Detector Station 1555 vs. ATR335)

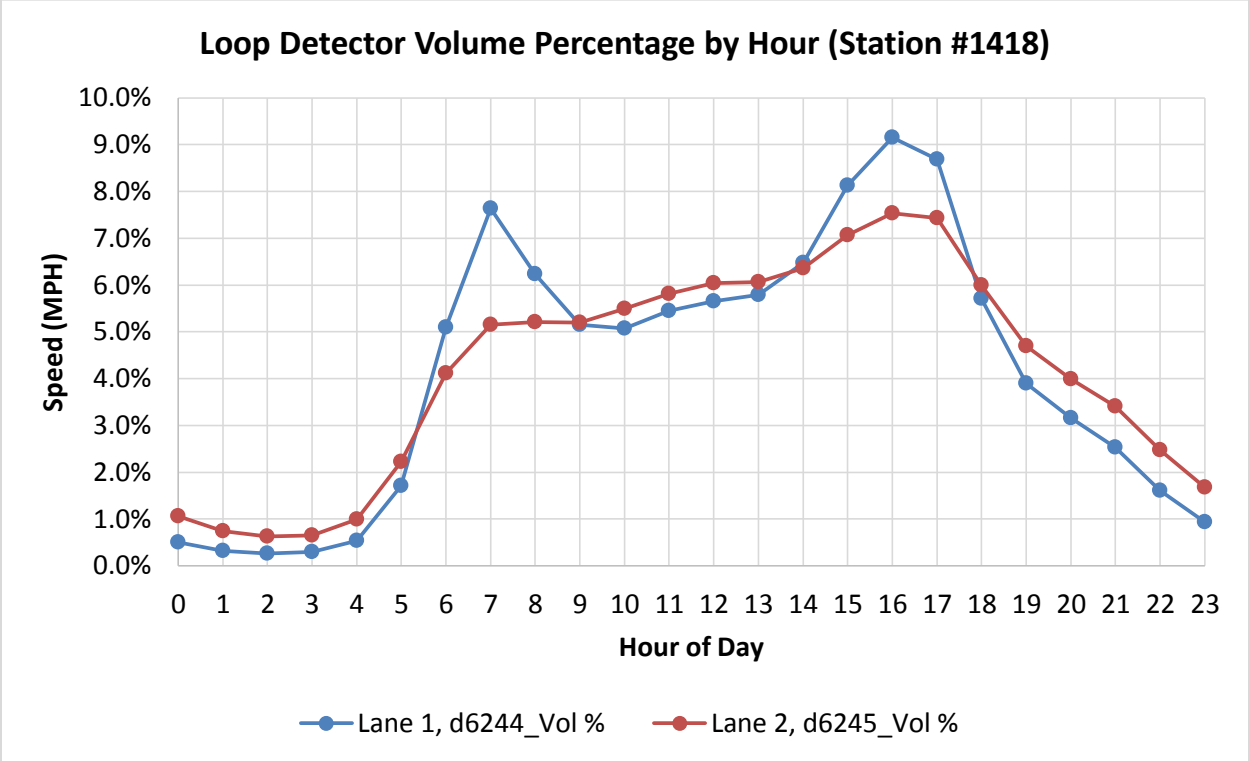

Figure D.9 Hourly Volume Percentages by Lane at Loop Detector Station #1418

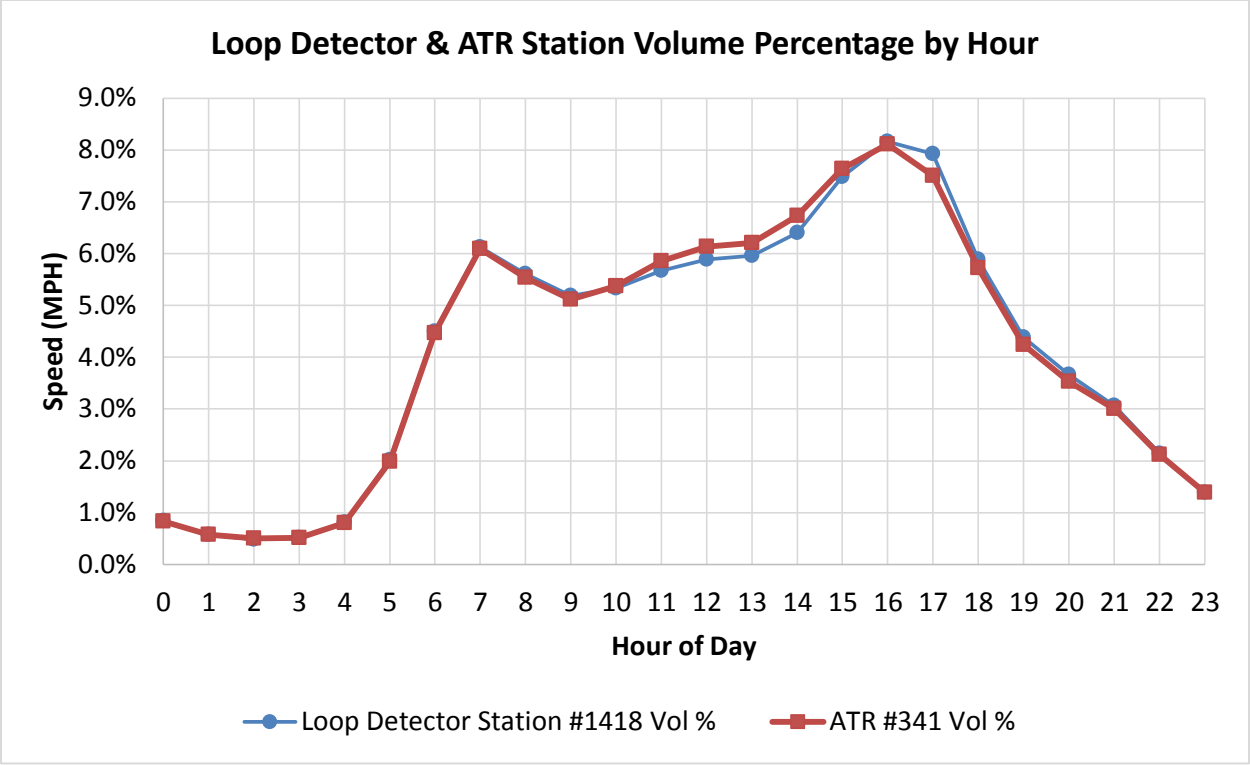

Figure D.10 Hourly Volume Percentage Comparisons (Loop Detector Station 1418 vs. ATR341)

D.4 Loop Detector Volume Comparison with ATR Data

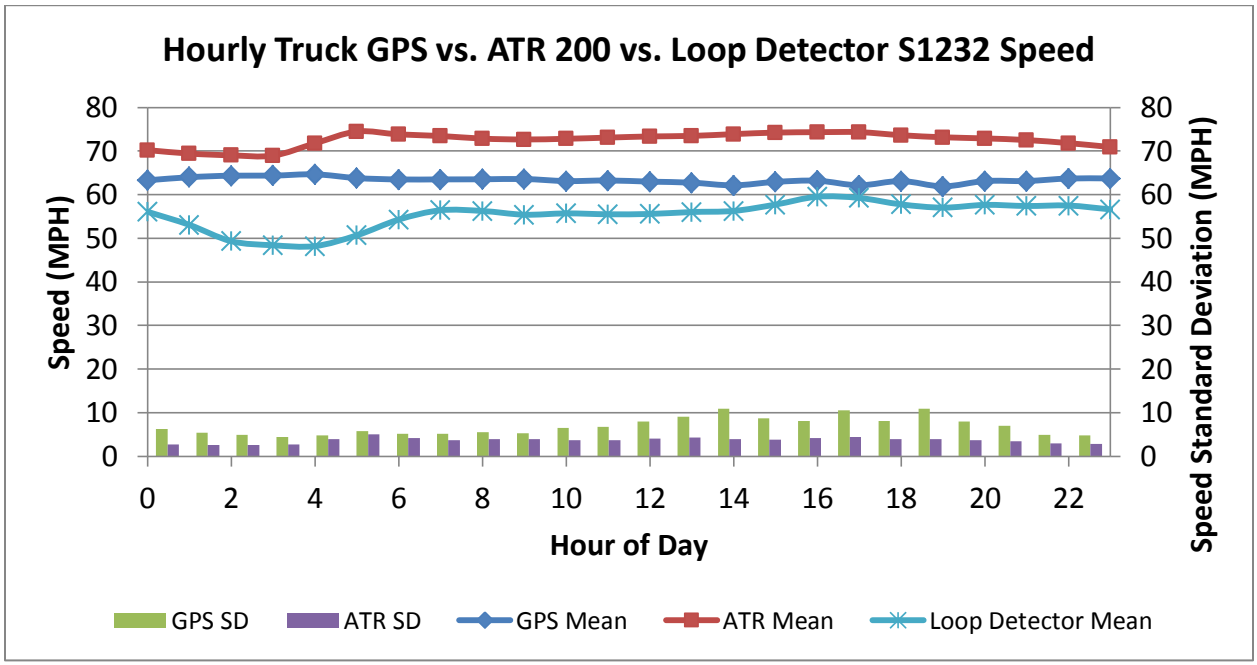

Figure D.11 Hourly Speed Comparisons (Loop Detector Station 1232 vs. ATR200)

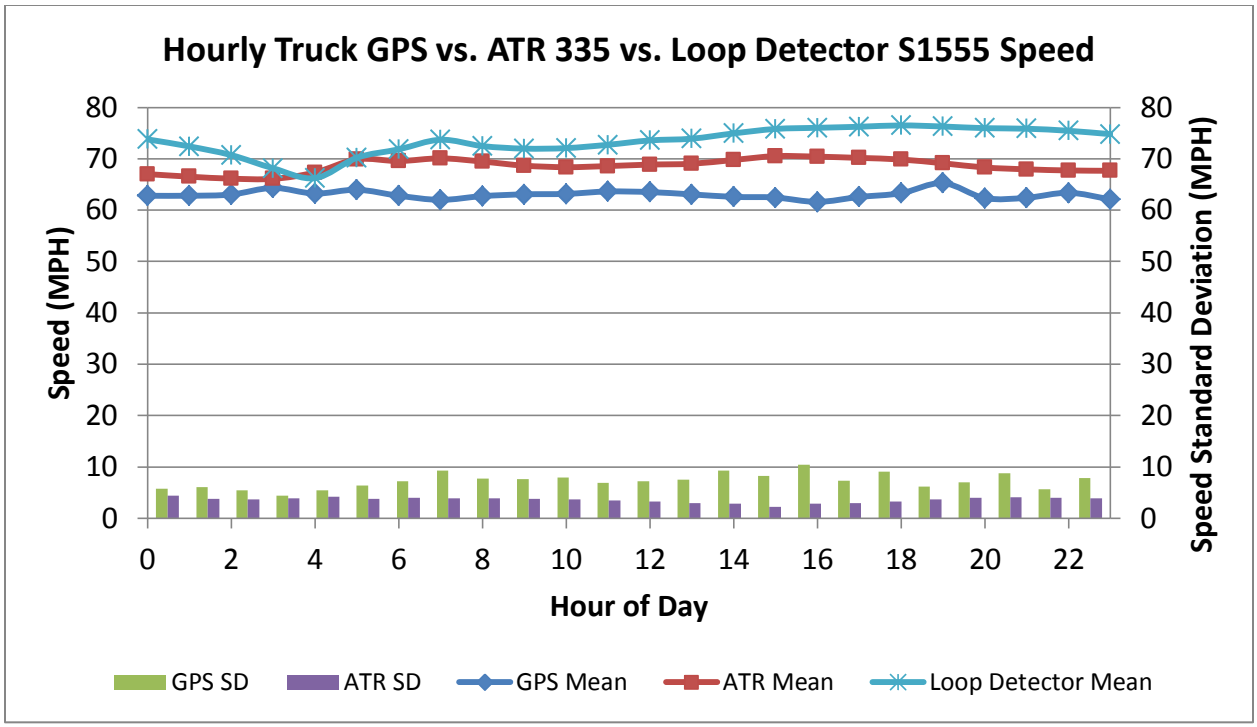

Figure D.12 Hourly Speed Comparisons (Loop Detector Station 1555 vs. ATR335)

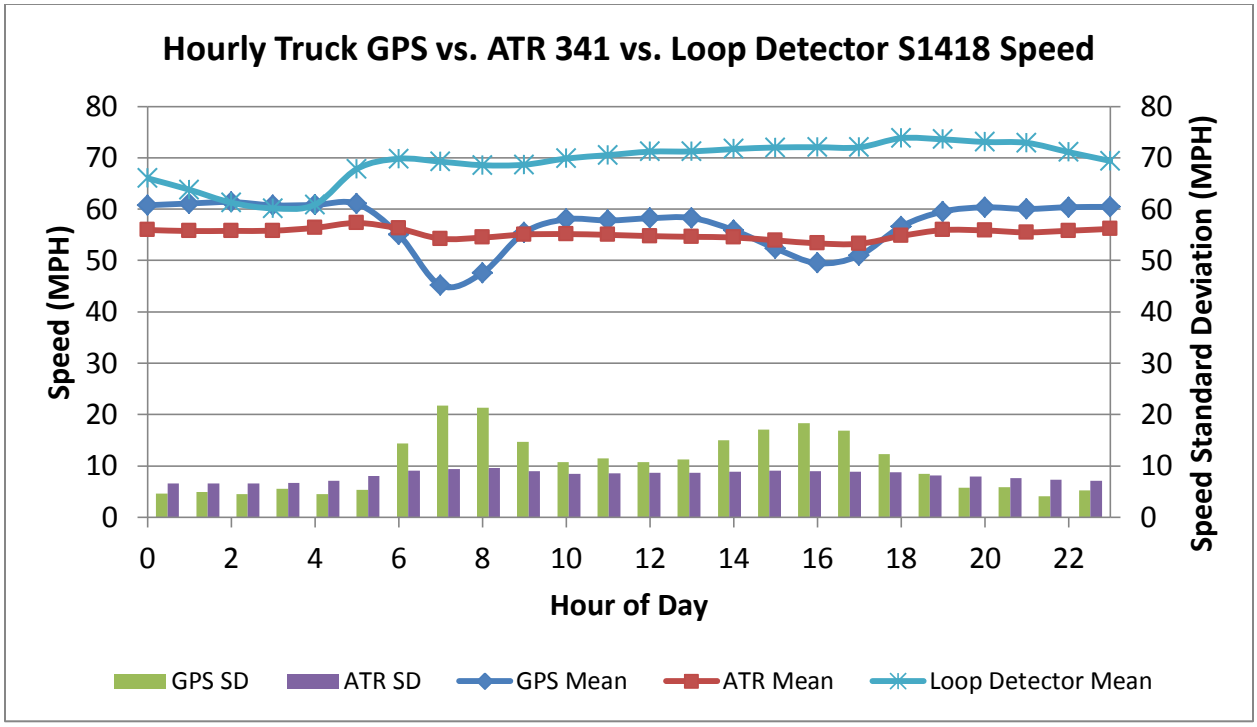

Figure D.13 Hourly Speed Comparisons (Loop Detector Station 1418 vs. ATR341)