TRC1202

Evaluation of New Technology for Traffic Monitoring

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Final Report

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EVALUATION OF NEW TECHNOLOGY FOR TRAFFIC MONITORING

ADAS Version 1 and 2 Data Collection Report

By

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ABSTRACT

According to the National Highway Transportation Safety Administration (NHTSA), 29,757 fatal crashes occurred along U.S. highways in 2011. With an estimated 38%, the most contributing factor of related crashes occurred due to excessive speeding for current conditions or disregarding posted speeds. Therefore, an economical noninvasive system to forewarn drivers of traffic congestion and potentially hazardous conditions could be an essential tool in reducing highway accidents and saving lives.

VisuaLogistic Technologies Inc. developed an innovative product, the Automated Detection and Alert System, to address these problems and more. This report introduces this new product, describes the product's evaluation methodology and results, and provides a recommendation.

INTRODUCTION

State and local transportation agencies often deploy technology solutions commonly referred to as Intelligent Transportation Systems (ITS). ITS is applied technology intended to provide innovative and advanced services involving various modes of transportation and traffic management. ITS provide drivers decision-making tools to formulate safer and better alternatives along the U.S. Interstate and Highway systems. The capability of various ITS technology integrates live-data from numerous sources, which can be communicated through vehicle navigation, traffic signalization systems and variable message boards. Information Analysis incorporates monitoring equipment such as Closed Caption TV (CCTV) with speed cameras and automatic plate recognition applications. In addition, Siemens Drive Technology and Cisco Systems Connected Transportation showcase abilities to improve safety, enhance passenger experience, encompass complex modeling, and comparison through historical data.

Although ITS may refer to all modes of transport, EU Directive 2010/40/EU defines ITS as systems in which information and communication technologies are applied in the field of road transport, including infrastructure, vehicles and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport [1]. Specifically, various wireless communications and technologies have become one of the latest trends proposed for ITS. Radio modem communications is a modern way to establish short and long range communications within ITS through licensed frequencies either in UHF or VHF band.

TRC 1202 focused on field implementation and development of a noninvasive ITS, the Automated Detection and Alert System (ADAS) by VisuaLogistic Technologies Incorporated (VLT), to detect traffic congestion and other environmental conditions such as approaching vehicles, inclement weather, and highway hazards to forewarn drivers of such hazards while gathering valuable data for various purposes.

The Arkansas Highway and Transportation Department's research section of the product evaluation committee purchased 12 nodes to test on a three mile interstate section to evaluate durability, functionality, and data collection. The safety or light feature of the product will be evaluated at another time. This report provides a recommendation for AHTD's product evaluation committee and describes the product, testing methodology, results, and VLT's future work, which includes updates on ADAS's specifications and features.

Chapter 1: ADAS Version 1

DEVICE INFORMATION

OVERVIEW

The Automated Detection and Alert System (ADAS), senses hazardous road conditions such as stopped traffic, slowed traffic, pulled over or upcoming emergency vehicles, and icing conditions, and visually forewarns drivers in advance of the hazard. ADAS utilizes electronic nodes placed alongside a highway, with sensors to detect traffic congestion and other hazardous conditions, a multi-colored LED to visually notify drivers of a detected hazardous condition, and a wireless transceiver to wirelessly communicate the hazardous condition to neighboring nodes in order to notify drivers well in advance of the hazard, as depicted in Figure 1. A detected hazardous condition can also be transmitted through the existing cellular network to enable remote traffic flow monitoring and notification of detected hazardous conditions, in order to support a real-time traveler information system. VLT recommends node spacing of 1/8 to ¼ of a mile to enhance driver exposure and to provide a robust wireless communication network in various conditions, but can be extended to 1 mile or greater based upon line of site from one node to the next, geographic and man-made obstacles, or through the use of repeater nodes. Drivers can expect to see this forewarning in the form of a small, mounted box placed at sub-mile intervals that will deliver a high-powered, color-coded light depending on the specific hazard.

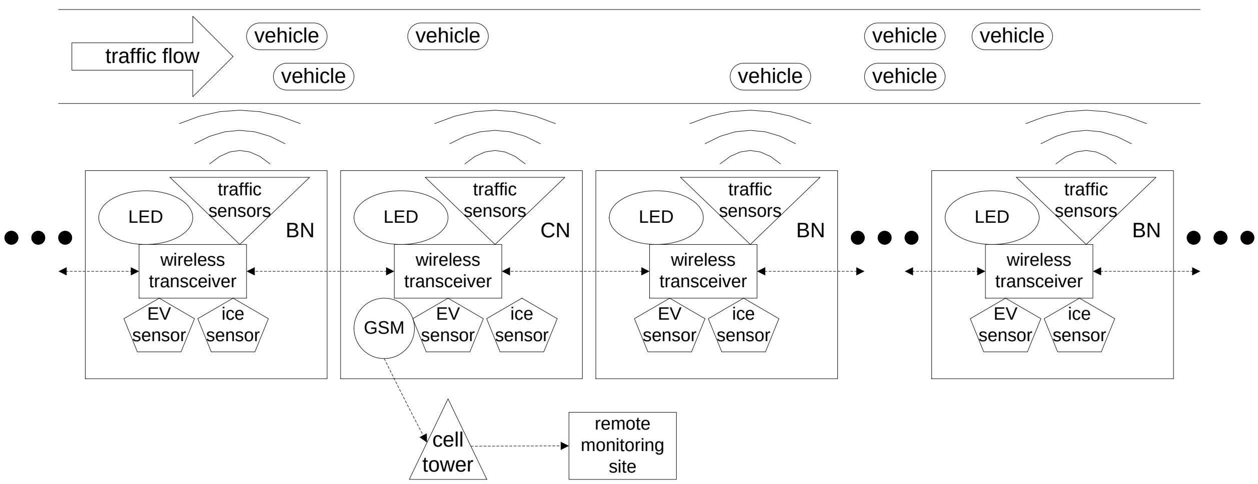

Figure 1: ADAS Overview

DATA COLLECTION

OVERVIEW

Each ADAS sensor node constantly monitors the nearby road, aggregates and averages the information every 60 seconds, and then sends the information from the sensor node to the central data hub and finally to VLT's server. The server's database saves the node identification number, date/time stamp, average speed, moving speed, temperature, and six condition flags (normal, caution, hazard, construction zone, icing and emergency) for each node per central data hub transmission. A zero was placed in each field if a sensor node did not send information to the central data hub. Therefore, the normal, caution, and hazard flags' status are checked during data processing to determine if transmission occurred.

SPEED CALCULATIONS

Two methods were used to sample the traffic radar data. The first was a moving average filter, and the second was a moving average filter which ignores any zero speed measurements from the radar [2]. The moving average filter is produced by keeping some finite number of speed data points, $\{x_1, x_2, \ldots, x_N\}$, measured from the radar. N is the number of data points. This set of data may be referred to as a window. As a new speed data point is measured, it replaces the oldest data point in the list of overall points. Thus, the total number of data points in the filter remains constant. This action may be referred to as the window sliding forward in time. Fig. 2 shows an example data set where two cars have recently passed by the radar unit during some 60 second time span or window. Fig. 3 shows a spatial representation of what occurred to produce the data shown in Fig. 2.

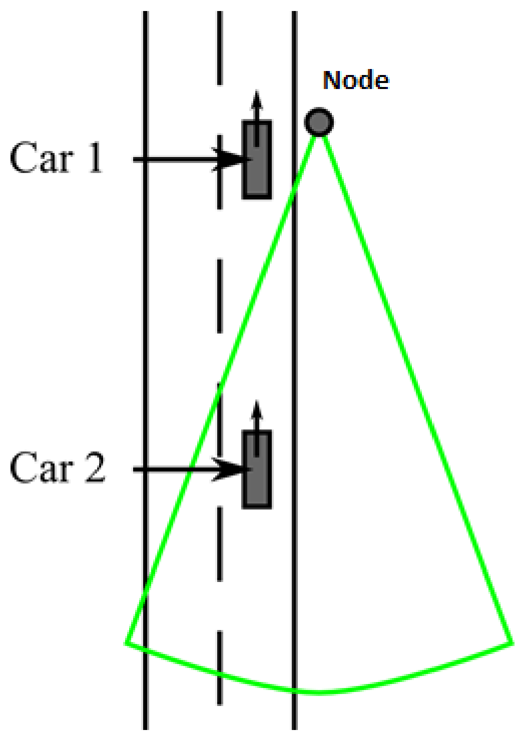

Figure 2: Node data collection

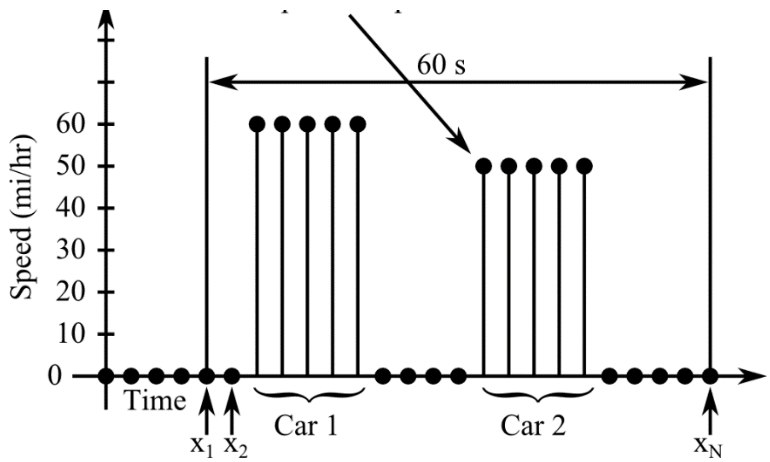

Figure 3: Speed data collection example

The first method which takes the average of all of these stored data points, even zero entries, is named Average Speed. The Average Speed is the conventional output of a moving average filter, namely the average or mean of all data points in the window. The equation to produce Average Speed S_{avg} is as follows:

$$S_{avg} = \frac{1}{N}\sum_{i=1}^{N} x_i. \tag{1}$$

The second method or Moving Speed is similar to the first, but ignores any zero radar speed measurements. In Fig. 2, there are multiple data points which have zero value in the spaces between where Car 1 and Car 2 passed within the range of the radar system. If an average value for the speed of moving vehicles is desired, these zeroes need to be removed because they do not truly represent vehicles travelling at zero speed on the road. These zeroes only represent the absence of moving vehicles on the road. Moving Speed S_m is calculated by the following formula:

$$S_m = \frac{1}{M}\sum_{i=1}^{N} x_i. \tag{2}$$

The only difference is the dividing factor M which represents the total number of non-zero points in the radar data. The same summation is used from the previous formula because the zeroes do not affect the summation.

Traffic density may be estimated by using the ratio of the Average Speed and Moving Speed. For example, if a continuous line of vehicles is passing the radar without any breaks in traffic, no zero entries for the radar will be recorded. The Average Speed and Moving Speed measures will be equivalent in this case yielding a ratio of 1.0. If only a single car passes in a minute interval, only a small subset of the data in the window will contain data points greater than zero. Thus, Average Speed will be low and Moving Speed high yielding a low number for the ratio. If no vehicles are detected and both Average Speed and

Moving Speed are effectively zero, a default value of zero is applied to the ratio. The term Traffic Density Indicator is used on the Sensor Status page on visualogistics.net to represent this ratio.

$$Tden = \frac{S_{avg}}{S_m} \tag{3}$$

TEMPERATURE CALCULATION

Icing conditions are probable if moisture is present on the road surface and if temperature is below 0°C [3]. ADAS measures temperature by using a linear temperature sensor that outputs 10mV/°K and is recorded in degree Celsius.

CONDITIONS

ADAS produces six conditions (normal, caution, hazard, icing, emergency, and construction zone). The first five are set by using algorithms on collected data, while the last one is set manually. Normal, caution, and hazard uses a combination of speed and proximity to determine the condition. The icing flag means that icing conditions could occur; this is set if the temperature is less than 4°C. The emergency flag is set when an emergency clicker is activated in proximity of the sensor node or central data hub. The number of nodes that the clicker affects is configurable based upon distance from the clicker and location. The last flag, the construction zone flag, is the only manual flag. This flag may be set on each node to show that the sensor node or central data hub is in a construction zone.

EVALUATION METHODOLOGY

LOCATION

It was very important to select the right location for this product evaluation to ensure all Federal Highway Administration (FHWA) rules and standards were followed. This required a location with installed guardrails (since the equipment had not been crashed tested for clear zones) located on the outside lane, to accommodate the design of the node.

The initial location was a section on Interstate 40 Eastbound in District 8 near Russellville, Arkansas. This was the location of 5 nodes (1 central data hub and 4 sensor nodes) starting in January 2014. These nodes were spaced between the planned location of node 0, the central data hub, and node 1, which spanned roughly 152 meters. Nodes 0 through 3 were placed on one side of a bridge spaced evenly along a 91 meter span with node 4 on the other side of the bridge 61 meters from node 3. Node 4's spacing was found to be too far and was unable to communicate with the rest of the network.

In March 2014, the evaluation was moved further Eastbound to allow for the installation of additional hardware, as seen in Figure 4 with spacing defined in Table 1. This figure has the central data hub's location indicated in red, sensor nodes' locations in green, and repeater nodes' locations in yellow. Orange indicates sensor nodes with repeater hardware.

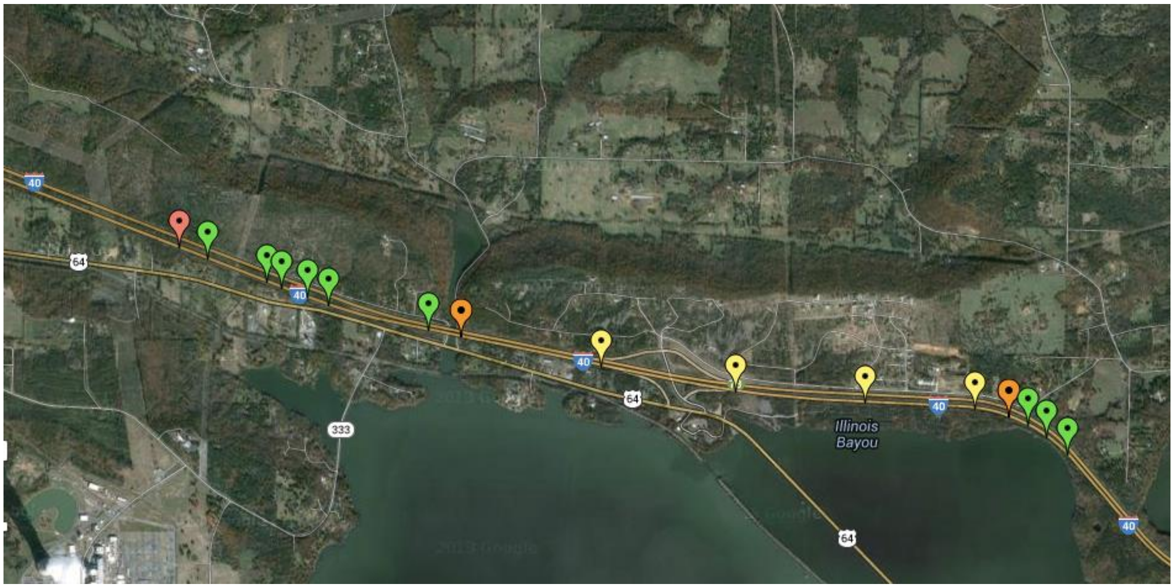

Figure 4: Final Evaluation Location

This was the final location of all 12 nodes until the beginning of May 2014. At the end of this time period, in June, the construction company controlling that section of the interstate removed nodes 6 and 7, which took offline nodes 6 through 11.

Table 1: Final Location Node Spacing

Node	Distance From Previous (Miles)
0 (Central data hub)	Starting Point
1	0.14
2	0.22
3	0.09
4	0.09
5	0.11
6	0.38
7 with Repeater	0.13
Repeater	0.58
Repeater	0.53
Repeater	0.58
Repeater	0.37
8	0.49
9	0.07
10	0.07
11	0.07
Total Distance	**3.92**

IMPLEMENTATION

ORIGINAL LOCATION

On January 28, 2014, VLT started the installation of all 12 nodes in the original location. Only 5 nodes were installed at this time due to communication issues not prevalent during VLT's local testing. The remaining 7 nodes were taken to VLT headquarters in Fayetteville, Arkansas to troubleshoot the communication issue. These 5 nodes sent data to the VLT server 8% to 21% of the time depending on the node, until the central data hub went down at the beginning of February due to a hardware connection failure, which required nodes 0 and 1 to be taken to Fayetteville for repairs on February 9th. This low data transmission rate was due to the identified communication issue between nodes and intermittent cellular service connection failures similar to a dropped call. **This communication down time is different from node down time.** Communication down time reflects data points where no data was collected on the server due to communication issues between nodes or to the server. Node down time is the actually time a node is physically not installed or collecting data due to power or hardware failure. 60,444 unique data points (5,037 data points per node) were collected during this time period (January 28 – February 9, 2014) of around 12 days. Table 2 shows the communication connection down time statistics during this time period.

Table 2: Communication Connection Down Time Statistics January 28 – February 9, 2014

Units		Days	%	Min	Min	Min	Days
Node	**# of**	**Total Time**	**% Down**	**Median Time**	**Mode Time**	**Min. Time**	**Max. Time**
0	8	8	71%	99	34	34	5
1	3	11	92%	132	125	125	11
2	5	9	75%	35	34	34	9
3	5	9	75%	35	34	34	9
4	6	12	100%	2	2	2	11
Total	27						
Average	5	10	1	61	46	46	9

On February 13, nodes 0 and 1 were reinstalled. At this point, nodes 0 through 3 began transmitting data back to the server with node 4 communicating intermittently due to the same spacing issue. This proved durability since the nodes left on the interstate continued to stay on during snow, ice, rain and up to 30° Celsius temperature fluctuations. The nodes continued intermittent communication with the server 50% to 85% of the time depending upon node and produced 431,448 unique data points (35,954 per node) for around 29 days (February 13 – March 14, 2014). This "up" communication time would have been greater, but the telecommunication company providing the cellular service did not renew as scheduled. This caused VLT to switch cellular service to a U.S based mainstream telecommunication provider to prevent this problem in the future. Table 3 shows the communication connection down time statistics during this time period. The durability was once again tested due to ADAS staying on during heavy rain, snow, very strong winds, and greater than 50° Celsius temperature fluctuations.

Table 3: Communication Connection Down Time Statistics February 13 – March 14, 2014

Units		Days	%	Min	Min	Min	Days
Node	**# of**	**Total Time**	**% Down**	**Median Time**	**Mode Time**	**Min. Time**	**Max. Time**
0	33	5	15%	35	35	3	4
1	62	8	28%	13	2	2	4
2	52	14	47%	11	2	2	9
3	60	15	50%	7	2	2	5
4	68	29	98%	2	2	2	13
Total	275						
Average	55	14	0	14	9	2	7

FINAL LOCATION

A solution to the communication issue was found in February, while AHTD looked for a new location to deploy all 12 nodes. On March 15, 2014, VLT moved and upgraded nodes 0 through 4 with the new hardware and software solution and installed the prior updated nodes 5 through 9.

Another software update was required 7 days later due to a few nodes being configured for a separate network. The software update, hardware connection issues on the central data hub, and nodes 6 through 11 still being spaced too far apart, produced a data connection rate ranging from 0% to 59% depending on node. 224,736 data points (18,728 per node) were produced in a 22 day time period (March 15 – April 5, 2014) with the communication connection down time statistics shown in Table 4.

Table 4: Communication Connection Down Time Statistics March 15 – April 5, 2014

Units		Days	%	Min	Min	Min	Days
Node	**# of**	**Total Time**	**% Down**	**Median Time**	**Mode Time**	**Min. Time**	**Max. Time**
0	22	9	41%	36	35	3	3
1	45	14	64%	6	2	2	4
2	55	14	64%	8	2	2	4
3	67	14	64%	4	2	2	5
4	62	14	64%	8	3	2	4
5	61	14	65%	8	2	2	4
6	4	22	98%	5626	3	3	14
7	3	22	99%	9	3	3	22
8	1	22	100%	31679	31679	31679	22
9	1	22	100%	31679	31679	31679	22
Total	321						
Average	32	17	1	6906	6341	6338	10

On April 6, 2014, the hardware connection issue was corrected and a trial repeater was installed on node 7. This repeater enabled nodes 0 through 7 to send data consistently. The success was seen in an

84% to 87% data connection rate for nodes 0 through 7. Nodes 8 and 9 were still spaced too far, causing their data connection rate to continue to be 0%. 89,592 unique data points (7,466 per node) were collected during the 6 day repeater evaluation (April 6 – 11, 2014) with all communication connection down time statistics shown in Table 5.

The repeater's success motivated AHTD to purchase multiple repeaters to ensure connection at extended ranges since node 8 was placed 2.55 miles from node 7, which is outside VLT's recommended spacing. These repeaters were installed at the same time as nodes 10 and 11. All of the nodes immediately started sending data to the server once the repeaters were installed. This once again proved that nodes 8 and 9 were still powered on and working even when they were not able to send information through the network. Nodes 0 through 7 had a data connection rate of around 94%, while nodes 8's through 11's data connection rate was 0% to 12%. Table 6 shows the communication connection down time statistics for this 10 day evaluation (April 12 -21, 2014) on 162,444 unique data points (13,537 per node)

Table 5: Communication Connection Down Time Statistics April 6 - 11, 2014

Units		Days	%	Min	Min	Min	Days
Node	**# of**	**Total Time**	**% Down**	**Median Time**	**Mode Time**	**Min. Time**	**Max. Time**
0	5	1	13%	35	3	3	1
1	5	1	14%	35	3	3	1
2	7	1	13%	11	2	2	1
3	21	1	16%	3	2	2	1
4	6	1	13%	29	3	3	1
5	5	1	13%	35	3	3	1
6	22	1	15%	5	2	2	1
7	27	1	15%	3	2	2	1
8	1	6	100%	8639	8639	8639	6
9	1	6	100%	8639	8639	8639	6
Total	100						
Average	10	2	0	1743	1730	1730	2

Table 6: Communication Connection Down Time Statistics April 12 - 21, 2014

Units		Days	%	Min	Min	Min	Days
Node	**# of**	**Total Time**	**% Down**	**Median Time**	**Mode Time**	**Min. Time**	**Max. Time**
0	8	1	6%	56	2	2	0
1	8	1	6%	56	2	2	0
2	9	1	6%	36	2	2	0
3	102	1	7%	2	2	2	0
4	9	1	6%	45	2	2	0
5	7	1	6%	76	2	2	0
6	8	1	6%	56	2	2	0
7	8	1	6%	56	2	2	0
8	15	10	100%	2	2	2	8
9	141	9	91%	2	2	2	8
10	206	9	88%	2	2	2	7
11	61	9	95%	2	2	2	8
Total	582						
Average	49	4	0	33	2	2	3

VLT found node 8's data connection issue to be caused by geographical obstacles. Repeater 4 was moved after a land survey. The intermittent communication of nodes 9 through 11 proved that the mesh network worked properly and can communicate even when another node is not communicating. This also showed that the nodes can be placed further than the recommended distance. 149,100 unique data points (12,425 per node) were collected over 9 days (April 22 -30, 2014) with all statistical data listed in Table 7.

Table 7: Communication Connection Down Time Statistics April 22 - 30, 2014

Units		Days	%	Min	Min	Min	Days
Node	**# of**	**Total Time**	**% Down**	**Median Time**	**Mode Time**	**Min. Time**	**Max. Time**
0	13	0	3%	35	2	2	0
1	13	0	3%	35	2	2	0
2	15	0	3%	35	2	2	0
3	41	2	27%	3	2	2	2
4	20	0	5%	35	2	2	0
5	13	0	3%	35	2	2	0
6	17	0	5%	35	2	2	0
7	14	0	3%	35	2	2	0
8	219	8	87%	2	2	2	4
9	461	5	50%	2	2	2	2
10	345	4	46%	2	2	2	2
11	133	8	88%	2	2	2	4
Total	1304						
Average	109	2	0	21	2	2	1

All nodes continued to communicate until the data plan auto renewed a day late. During this time, the construction company needed to remove nodes 6 and 7, which prevented data communication from nodes 6 through 11. Nodes 0 through 5 were left for continued evaluation, which ended on June 3, 2014. This time period of 33 days (May 1 – June 3, 2014) produced 496,716 unique data points (41,393 per node) with data connection statistics listed in Table 8.

Table 8: Communication Connection Down Time Statistics May 1 – June 3, 2014

Units		Days	%	Min	Min	Min	Days
Node	**# of**	**Total Time**	**% Down**	**Median Time**	**Mode Time**	**Min. Time**	**Max. Time**
0	43	5	14%	35	35	2	3
1	43	5	14%	35	35	2	3
2	67	5	14%	34	2	2	3
3	234	17	49%	3	2	2	7
4	56	5	14%	35	35	1	3
5	44	5	14%	35	35	1	3
Total	487						
Average	81	7	0	29	24	2	4

DATA ANALYTICS

VLT used the collected data to analyze connection down time (as described in the previous section), vehicle speed, and temperature. VLT collected 1,614,480 unique data points (134,540 per node) over 126 days.

SPEED

The Data Collection section of this document describes the formulas used to calculate the average speed, moving speed, and a traffic density indicator. The output data from each node was averaged over 15 minute intervals for each day of the week. This average was then graphed versus the 15 minute time interval for each day of the week while using a different color to indicate a different day. No lines between points indicate no data was collected for that time period. This is plausible since some nodes were down longer than others, such as nodes 8 through 11. The data results from the evaluation are described below.

AVERAGE SPEED

The average speed is the mean of all data points in the corresponding time window. The curvature for each node is similar, as shown in Figure 5, which graphs the average speed by day for node 0.

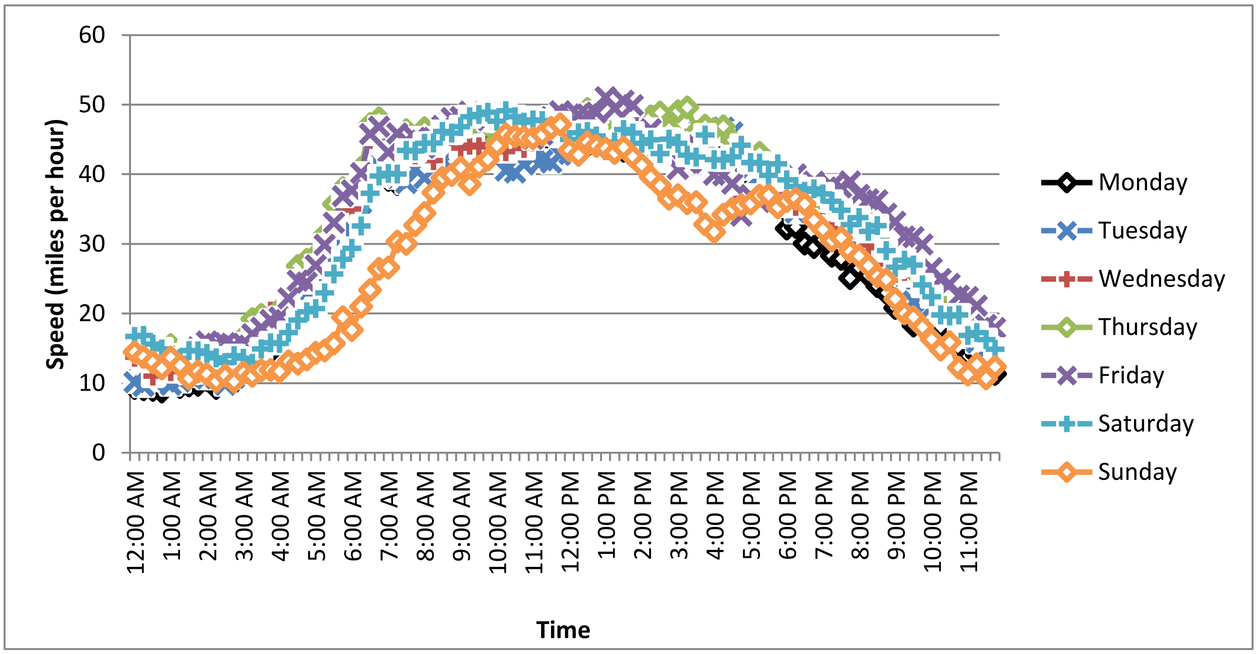

Figure 5: Node 0 Average Speed by Day

The average speed for each graph varies by node for each day. Traffic appears to slow down after the first node, when entering the construction zone. It speeds up slightly around node 6 and slows down once again around node 7 at the slight curve in the road. The series of average speed graphs, as shown in Figure 5 for node 0 and Appendix A for nodes 1-11, demonstrate that traffic does slowdown in the construction zone.

Traffic has a lower average speed in the morning. The average speed increases as the day progresses because more drivers are on the highway, and then decreases at night as drivers arrive home or at their final destination.

MOVING SPEED
Moving speed is calculated by taking the mean speed of a time window without accounting for the zero speeds since they do not represent traffic moving at zero miles per hour but the absence of traffic. This provides an insight into the highway's instantaneous speeds.

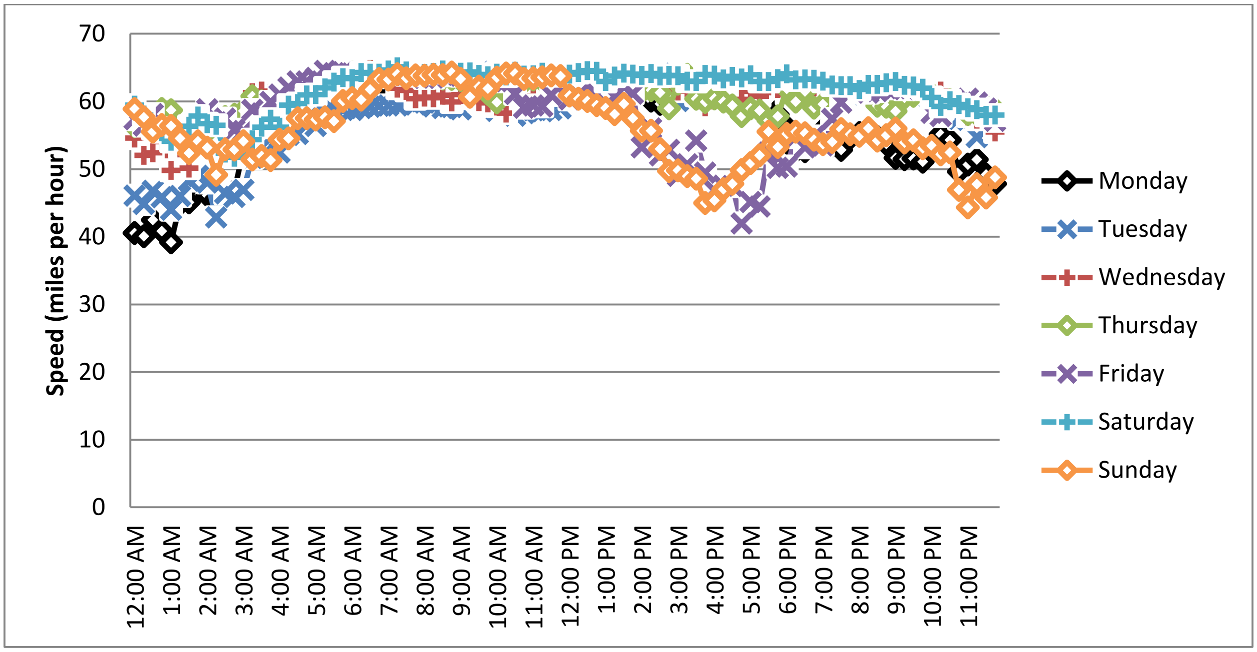

Figure 6: Node 0 Average Moving Speed by Day

The average moving speed graphs, as illustrated above in Figure 6 for node 0 and in Appendix B for all other nodes, show that drivers typically drove between 55 and 65 miles per hour in the evaluation area, which had a posted speed limit of 60 miles per hour.

An interesting pattern is that drivers typically drove slower before 5am and after 8pm with some variation. They also drove faster at the beginning of the construction zone with speeds at or above 60 miles per hour. Traffic then slowed down as the construction zone continued and where the road curved or lanes switched due to construction. This is seen at nodes 8 through 11.

TRAFFIC DENSITY INDICATOR
The last speed analytic is a ratio of the average speed and average moving speed. This calculation provides an insight into the traffic density at each node location. A ratio of 1 indicates that the average speed, the calculation with zeroes, is close to the average moving speed without zeroes, showing that more drivers are on the road. Node 0's traffic density indicator is shown in Figure 7. Remember this is an average over 15 minute intervals for the entire evaluation period. Real time data showed times when this ratio was close to 1, which is expected in construction zones during accidents or rush hour. This can be seen better on graphs with fewer data points, such as for nodes 8 through 11.

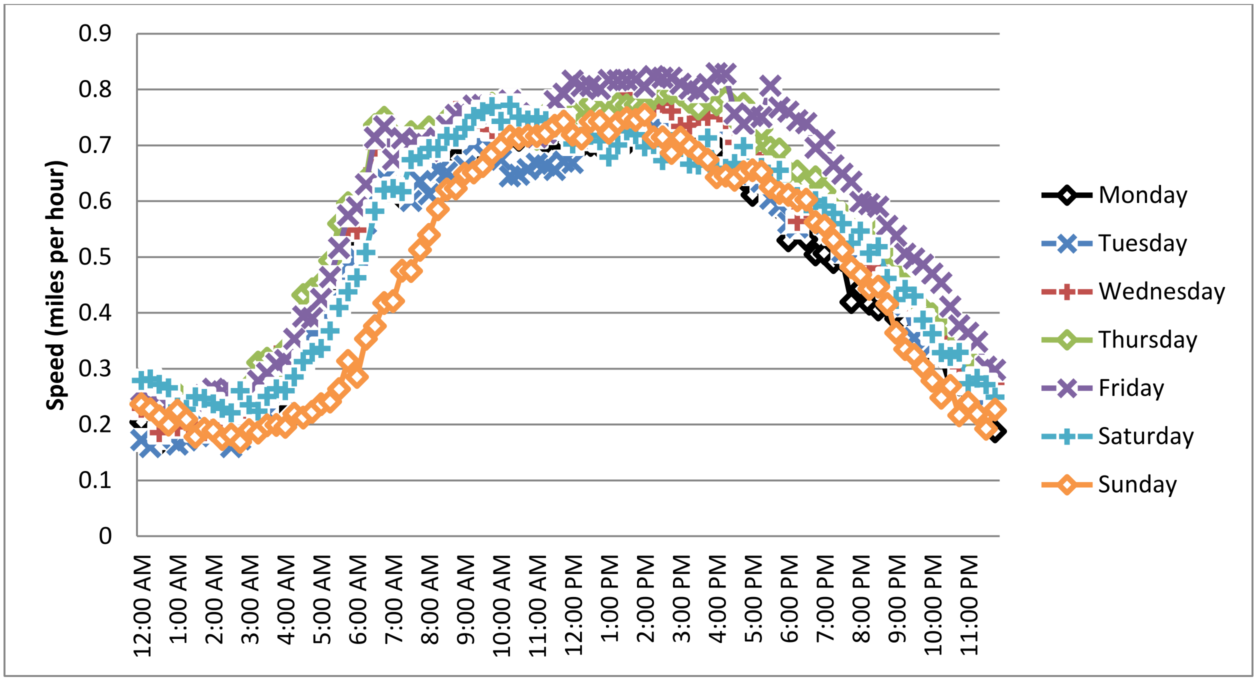

Figure 7: Node 0 Traffic Density Indicator

The curvatures for these graphs are similar to each other and the average speed graphs' curvature. Traffic is more dense between 7am and 7pm. The rest of the traffic density indicator graphs are provided in Appendix C.

TEMPERATURE

Temperature in degrees Celsius was collected at each node and averaged each 60 second time period when sent to VLT's server. This information was then averaged for each evaluation day for each node. All data points were removed from the day averages when the node's data connection was inactive. This data was statistically compared to average day temperatures from weather.com using a two-sample t-test for unequal variances. The statistical test results for nodes 0 through 5 are listed in Table 9, with the rest of the nodes' data in Table 10.

Node 0's test provides the most accurate comparison since it collected the most 60 second average data points. The mean temperature for node 0 (M=19.05, N= 108) was significantly greater than the temperatures from weather.com (M=13.54, N= 109) using the two-sample t-test for unequal variances, $t(108) = 4.96$, $p <= 0.0000017$. Nodes 1, 2, 4, 5, 6, 7, 8, 9, and 10 produced similar results, where the mean temperatures were significantly different. The desired results were for the temperatures to not be significantly different.

The temperature inconsistency was found to be caused by the location of the temperature sensor. The sun would heat up the ADAS enclosure causing the temperature sensor to provide a slightly higher reading.

Table 9: Node 0 – 5 Temperature Statistical Testing Results

	Weather.com	node 0	node 1	node 2	node 3	node 4	node 5
Mean	13.54	19.05	17.33	17.10	14.54	18.33	17.46
Variance	33.40	100.06	67.02	95.43	89.38	51.65	43.94
Observations	109.00	108.00	97.00	92.00	84.00	78.00	71.00
Hypothesized Mean Difference		0.00	0.00	0.00	0.00	0.00	0.00
df		171.00	170.00	142.00	129.00	143.00	135.00
t Stat		4.96	3.79	3.07	0.85	4.87	4.08
P(T<=t) one-tail		8.53E-07	1.03E-04	1.29E-03	1.99E-01	1.47E-06	3.85E-05
t Critical one-tail		1.65	1.65	1.66	1.66	1.66	1.66
P(T<=t) two-tail		1.71E-06	2.06E-04	2.58E-03	3.97E-01	2.93E-06	7.69E-05
t Critical two-tail		1.97	1.97	1.98	1.98	1.98	1.98
Reject null		Yes	Yes	Yes	No	Yes	Yes

Table 10: Node 6 – 11 Temperature Statistical Testing Results

	Weather.com	node 6	node 7	node 8	node 9	node 10	node 11
Mean	13.54	17.11	16.85	19.75	19.25	17.92	17.00
Variance	33.40	24.25	25.28	88.79	12.93	14.58	39.20
Observations	109.00	28.00	27.00	8.00	12.00	13.00	6.00
Hypothesized Mean Difference		0.00	0.00	0.00	0.00	0.00	0.00
df		48.00	45.00	7.00	18.00	19.00	5.00
t Stat		3.29	2.97	1.84	4.85	3.67	1.32
P(T<=t) one-tail		9.32E-04	2.38E-03	5.43E-02	6.40E-05	8.19E-04	1.22E-01
t Critical one-tail		1.68	1.68	1.89	1.73	1.73	2.02
P(T<=t) two-tail		1.86E-03	4.77E-03	1.09E-01	1.28E-04	1.64E-03	2.43E-01
t Critical two-tail		2.01	2.01	2.36	2.10	2.09	2.57
Reject null		Yes	Yes	No	Yes	Yes	No

CONDITIONS

The six conditions produced by ADAS version 1 are normal, caution, hazard, icing, emergency, and construction zone flags. The normal, caution, and hazard conditions were watched on VLT's live website throughout the test by AHTD, but are not part of this evaluation. These conditions, with the emergency and construction conditions, will be assessed during the upcoming light/safety evaluation

The icing condition was accessed during this evaluation. The algorithm was validated by comparing the temperature to 4 degrees Celsius, while looking at the icing flag for each valid data point. The condition is correct if the data point's temperature is less than 4 degrees Celsius and the icing flag is equal to 1 or if the temperature is equal to or greater than 4 degrees Celsius with the icing flag equal to 0. A false positive error was defined as detecting an effect that is not present. This was produced if the icing flag was equal to 1, while the corresponding data point's temperature was equal to or greater than 4 degrees Celsius. A false negative error was defined as failing to detect an effect that is actually present. This was produced if the icing flag was equal to 0 even though the temperature was less than 4 degrees Celsius. Table 11 shows the results, in percentages, for each node comparing the temperature produced for a valid data point and the icing flag. Nodes 1 – 11 produced a very low error rate (0% to 2%), while node 0 had a high error rate of 58%. This high rate was due to a software issue found on the central data hub (node 0) after the completion of the evaluation. The sensor nodes were not affected since they are updated differently than the central data hub.

Table 11: Icing Condition Flag and Temperature Comparison for each Node

Node	0	1	2	3	4	5	6	7	8	9	10	11
Correct	42%	98%	98%	98%	99%	99%	99%	99%	100%	100%	100%	100%
False Positive	58%	2%	2%	2%	1%	1%	1%	1%	0%	0%	0%	0%
False Negative	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

CONCLUSION

The Arkansas Highway and Transportation Department's evaluation of VisuaLogistic Technologies Inc.'s Automated Detection and Alert System (ADAS) produced successful results that proved durability, functionality, and data collection. ADAS senses hazardous road conditions such as stopped traffic, slowed traffic, pulled over or upcoming emergency vehicles, and icing conditions, and visually forewarns drivers in advance of the hazard. It was evaluated by spacing 12 nodes over a total of 3.92 miles. It recorded and analyzed average speed, moving speed, speed ratio, and temperature data. This report describes ADAS, its evaluation methodology and results, and ADAS's future specifications and features. The safety or light feature of the product will be evaluated in a subsequent test.

This evaluation collected 1,614,480 unique data points (134,540 per node) over 126 days. The conclusions drawn during this time period are summarized below:

- Remained on during heavy rain, snow, very strong winds, and greater than 50° temperature fluctuations
- Average speed and VLT's traffic density indicator produced similar graph curvatures
- Traffic slows down when entering the construction zone and where the road curved or lanes switched due to construction
- Traffic has a lower average speed in the morning, increases as the day progresses, and then decreases at night
- Drivers typically drove between 55 and 65 miles per hour in the evaluation area, where the posted speed limit is 60 miles per hour
- Drivers typically drove slower before 5am and after 8pm with some variation
- Traffic is denser between 7am and 7pm.

- Most nodes produced significantly higher mean temperatures compared to weather.com average data due to sensor location
- Icing flag was 98% to 100% correct for nodes 1 – 11 but produced a false positive error 58% of evaluation period for node 0 due to a software issue.

RECOMMENDATION

The purpose for this research was to evaluate an ITS system that provides the ability to collect and disseminate traffic, weather, and hazardous conditions through the cellular network to a remote monitoring site. Results from field data were formulated through specific methodology, using algorithms to calculate and indicate traffic volume, density, and speed, as well as current ambient air temperatures for the test site. Data was visible to the Arkansas Highway and Transportation Department via the company's web site, offering current condition and information every 60 seconds.

It is recommended that VLT includes personnel with transportation engineering knowledge. During initial testing, it was detected that certain guiding principles were not employed as they pertained to transportation engineering. Explanations were required as to how transportation engineers calculate, density, volume, speed and other highway metrics is different from other engineering disciplines. The initial viewable information was considered an indicator since the raw data was not calculated using algorithms/formulas and guidelines according to the Highway Capacity Manual (HCM) or the Traffic Monitoring guide.

Another issue is the ADAS equipment needs to be crash-tested through a certified independent laboratory specializing in this type of testing. In its current state, all nodes were required to be installed behind a guardrail or barrier wall.

The last recommendation is to improve the solar panel mounting brackets. The "L" bracket's steel was too thin and the tack welds were too sparse for the total load of a solar panel. At least two "L" Bracket mounts have broken or bent: one during installation and another during tear down. Deflection and failure could be a problem over time for these mounts. A simple calculation for the dead load of the solar panel would help determine a more durable "L" Bracket.

Overall, the initial testing was successful in demonstrating the ability to gather traffic data and disseminating information. VLT's data results were compared to IDriveArkansas' website, which showed consistency of traffic volume. It also proved durable through periods of inclement weather occurrences. With the success of the initial testing, AHTD has purchased an upgrade to VLT's Version 2 equipment for further evaluation.

FUTURE WORK

After completion of the AHTD evaluation, VisuaLogistic Technologies Inc. started the development of ADAS version 2 using AHTD feedback. ADAS version 2 will include:

- 25+ user updateable fields per central data hub including remote construction zone identification
- Remote node battery monitoring
- Web-based node management system
- Custom printed circuit board design to reduce hardware connection failures
- Use of parallel data paths to increase node performance

- Migration to 900 MHz band to improve wireless communication
- Flexible network infrastructure that allows integration of additional ITS products
- Additional sensors added to weather node to improve accuracy
- Separation of weather node from central data hub and sensor nodes to add flexibility of sensor placement
- Addition of car counting stored in 5 mph speed bins
- Development of custom larger light node for modularity and indication
- Central data hub redesigned to be located off of highway for increased network protection
- Improved solar mounts to increase reliability and strength
- Improved ease of installation through custom mounting hardware and integration of easy disconnect connectors
- Addition of GPS to emergency clickers for improved reliability and information
- Improved notification and communication algorithms

Chapter 2: ADAS Version 2

DEVICE INFORMATION

VERSION DIFFERENCES

Version 2 maintained the functionality of version 1, described in the Chapter 1 Device Information Overview section above, and was enhanced based upon the recommendations from AHTD.

An emphasis on manufacturability and robustness was placed on the hardware redesign. The central data hub was modified to accommodate off-road placement for increased protection from traffic hazards and improved reliability of the mesh network. Custom circuit boards were designed for the sensor nodes to allow advanced processing, high-volume manufacturing capabilities, expandability for future upgrades, and reliability from previously-used assembly methods. The custom light previously integrated into the sensor node was implemented in a separate enclosure and increased to a 6” x 6” square viewing window. Instead of a single high-power LED, 36 multi-color LEDs were implemented with powerful driver circuitry to allow acceptable visual indication during high-intensity sunlight. The solar enclosure mounts were reinforced to prevent both sagging of the L-bracket and breaking of the manufacturer’s welds for the metal pole support. Additionally, custom mounting hardware was designed out of durable metal to allow for fast installation utilizing bayonet connectors for cable connections.

The software was redesigned to accommodate a web-based management system. This system allows for user-updatable fields within the sensor nodes to allow for remote reconfiguration, tuning settings depending on node location, and reduce maintenance costs if any updates or changes are necessary. Additionally, car-counting was implemented with 5 MPH speed bins along with battery monitoring information so that the current charge state of the battery may be checked remotely and issues related to low battery strength are indicated. The notification and communication algorithms were improved to allow for a more reliable mesh network with reduced overhead.

Due to the numerous network communication issues encountered within the first version, the network infrastructure was drastically altered to allow for improved performance and reliability. Instead of using a 2.4 GHz band, 900 MHz transceivers were implemented in each of the nodes to increase the range of the system while allowing a reduction in environmental effects. The strength was also increased by including the transmitter hardware directly onto the antenna, greatly improving transmission efficiency. With this range increase, the mesh network was capable of additional parallel paths back to the central data hub, which reduced the necessary number of hops that information packets must encounter. The infrastructure was designed to allow for simple integration of additional ITS products in the future.

EVALUATION METHODOLOGY

LOCATION

AHTD and VLT selected the same testing location as ADAS version 1 for consistency and since version 2 was required to be installed behind guardrails, as seen in Figure 8. The central data hub was placed out of the clear zone 1.53 miles from the I-40 eastbound entrance ramp, Exit 74. There is a notable spacing increase between nodes 2 and 3 (0.24 miles) and nodes 6 and 7 (0.41 miles).

Figure 8: ADAS Version 2 Location

IMPLEMENTATION

In March, 2015, VLT installed 8 sensor nodes and 1 central data hub. AHTD pre-installed twelve foot standard breakaway U channel poles, which simplified installation. The entire installation took less than 3 hours. These 8 nodes sent data to the VLT server 64% to 98% of the time depending on the node, as described in Table 12.

Table 12: Version 2 Server Connection Statistics

Packet Errors			Connection Loss						
Units					Days	Min	Min	Min	Days
Node	**# of**	**%**	**# of**	**%**	**Total**	**Min**	**Median**	**Mode**	**Max**
0	1516	7	9	5	4	11	11	11	2
1	1676	8	11	5	4	8	11	11	2
2	1305	8	6	22	18	11	38	11	16
3	935	7	49	36	30	10	76	11	3
4	1635	8	11	5	4	9	11	11	2
5	1798	8	9	2	2	8	11	8	2
6	1424	7	12	2	2	9	11	11	2
7	1485	7	11	2	2	8	11	11	2

All of the sensor nodes started with an insufficient charge remaining in their batteries since there was a delay between the delivery of the nodes and field testing. The central data hub was left disconnected from power prior to delivery since it was much simpler to open and was reconnected to power during the installation by simply plugging in a DC power jack. However, all of the sensor nodes automatically powered on and connected to the network once adequate charge was accumulated by the solar panels. There was some difference between the power-on times of individual nodes due to differing states of charge upon installation and charging amounts during sunlight, but no issues arose from this.

Node 2 appeared to be malfunctioning after powering on with sporadic and invalid data transmissions. Upon inspection, one of the bayonet connecters was not properly inserted into the sensor node. When properly inserted, the node began functioning normally, and the system appeared to be fully operational.

As the testing progressed, an issue began to arise for node 3 where it would not fully charge and would lose power in the early evening. This was due to overshadowing foliage growth in the spring but was necessary due to placement limitations requiring guardrails or a large offset from the highway. This node had the highest percent connection loss to the server, 36%, arising from these non-ideal lighting conditions. Although this sensor node would lose power daily, all other nodes remained connected and transmitting data due to the increased range of the network communications with a server connection loss range of 2% to 5%. This server connection loss is due to lack of sun or, more typically, cellular service issues. The cellular service issues are mitigated as much as possible using an algorithm to automatically reset the central data hub when appropriate to regain connection. This low connection loss time proves that all communication problems with version 1 were corrected by version 2. It also proves that range will not be an issue. Nodes 5 through 7 were the first to gain power and to connect to the central data hub.

DATA ANALYTICS

During version 2 research, AHTD placed a pneumatic car counting tube near Node 0 for comparison from April 20 to April 22, 2015. VLT found that Node 0 produced non-statistically different data for the lane closest to Node 0 but statistically significantly different data for the outside lane and the total of the two lanes, as seen in Table 13.

Table 13: Node 0 and Pneumatic Tube Counter Comparison

	N0	L1	L2	Tube Total
Mean	307.7183	272.14	236.12	508.26
Variance	32213.86	25173.22	28107.82	74111.34
Observations	71	50	50	50
Pooled Variance		29314.78	30523.14	49465.76
Hypothesized Mean Difference		0	0	0
df		119	119	119
t Stat		-1.12555	-2.21978	4.883979
P(T<=t) one-tail		0.131311	0.014164	1.64E-06
t Critical one-tail		1.657759	1.657759	1.657759
P(T<=t) two-tail		0.262622	0.028329	3.27E-06
t Critical two-tail		1.9801	1.9801	1.9801

This is interesting since there are several previous research projects that prove the radar utilized by ADAS produces more accurate data [4]. This inconsistency could be caused by improper calibration or installation of the pneumatic tubes. Research also states that the pneumatic tubes over and under count [5]. This was observed when comparing the 5 MPH speed bins of Node 0 to the tubes (9 bins statistically different and 6 not), seen in Table 14.

Table 14: Speed Bin Comparison

Speed Bin	P-value
20	2.027779
25	0.454859
30	0.372362
35	0.983011
40	-0.5814
45	-1.11226
50	-2.03288
55	-6.62796
60	-4.8017
65	0.05338
70	3.124034
75	5.461428
80	7.974581
85	8.855465
>85	8.543263

The data cannot be verified since a camera was not used for comparison. It should be noted that ADAS had a 0% server connection loss, seen in Table 15, during the comparison period for all nodes.

Table 15: ADAS Connection Statics for Testing Period

Node	# of	% Disconnected	Total Time	# Packet Errors	% Errors
0	0	0	0	60	6
1	0	0	0	85	8
2	0	0	0	58	5
3	0	0	0	55	5
4	0	0	0	73	7
5	0	0	0	81	8
6	0	0	0	76	7
7	0	0	0	73	7

A two sample T-test was used to compare the consistency of all nodes, as shown in Table 16, to ensure that all of the nodes collected similar data.

Table 16: ADAS Car Count Comparison to Node 0

	N0	N1	N2	N3	N4	N5	N6	N7
Mean	307.7	334.3	344.9	312.4	324.8	363.2	268.9	305.9
Variance	32213.9	38997.6	38870.6	30850.9	37102.6	47213.1	24790.4	33901.4
Observations		71	71	71	71	71	71	71
Pooled Variance		35605.7	35542.2	31532.4	34658.3	39713.5	28502.1	33057.6
Hypothesized Mean Difference		0	0	0	0	0	0	0
df		140	140	140	140	140	140	140
t Stat		0.84	1.18	0.16	0.55	1.66	-1.37	-0.06
P(T<=t) one-tail		0.20	0.12	0.44	0.29	0.05	0.09	0.48
t Critical one-tail		1.66	1.66	1.66	1.66	1.66	1.66	1.66
P(T<=t) two-tail		0.40	0.24	0.88	0.59	0.1	0.17	0.95
t Critical two-tail		1.98	1.98	1.98	1.98	1.98	1.98	1.98

BATTERY LEVEL

A new feature added to version 2 was the ability to remotely monitor the battery levels of each node. AHTD can monitor this information, live, through the online portal. These values can be analyzed individually or via a graph. Figure 9 demonstrates this feature by showing the battery levels for each node over the pneumatic tube comparison testing period. This clearly demonstrates when a node has charging issues such as Node 3 due to foliage.

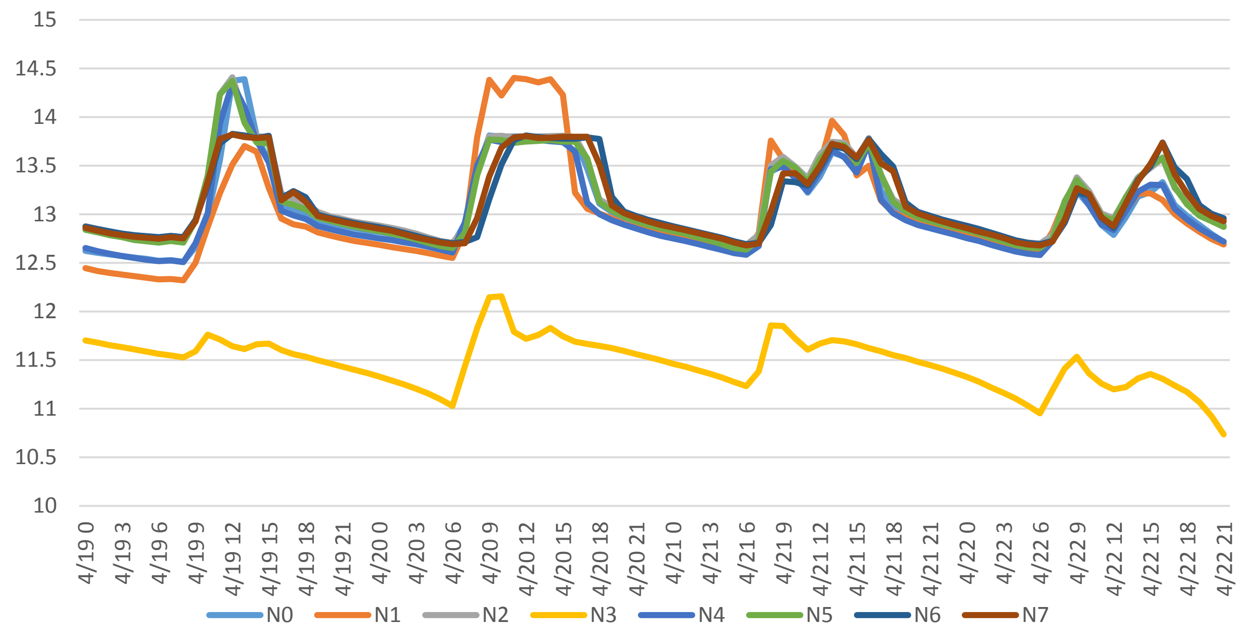

Figure 9: Node Battery Levels

RECOMMENDATION

The purpose of this research was to evaluate an ITS system that provided the ability to collect and disseminate traffic, weather, and hazardous condition data through the cellular network to a remote monitoring site. Data was visible to the Arkansas Highway and Transportation Department via the company's web site, offering current condition information in real time**.**

Based on the results observed from field testing, ADAS has exhibited enhanced robustness in terms of physical reliability, wireless communication and range, and data collection. The mesh network allowed for improved communication.

Since differences were observed between the data provided by a tube counter and the traffic data collected by ADAS, it is recommended that additional field testing be performed to compare the performance of the sensor nodes with several sources for extended periods of time, preferably including a source, such as a camera system, that allows for human verification for small sets of data.

Another issue is that the ADAS equipment needs to be crash-tested through a certified independent laboratory specializing in this type of testing. In its current state, all nodes are required to be installed behind a guardrail or barrier wall.

Like other innovative projects involving lights [6] [7] [8], it is imperative to turn on the light to determine the light's effect on traffic. This was the original idea for the system, which was not tested during this evaluation. A careful human factors study should be completed. This will help prove or disprove the safety nature of this type of device.

Overall, the initial testing was successful in demonstrating the ability to gather traffic data and disseminating information. It also proved durable through periods of inclement weather.

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[1] European Parliament, "Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport," *Official Journal of the European Union Legislation,* vol. 53, no. 207, pp. 1-13, 01 January 2010.

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[4] M. Marti, R. Kuehl and S. Petersen, "Traffic Data Collection Improvements," Minnesota Department of Transportation, St. Paul, 2014.

[5] P. McGowens and M. Sanderson, "Accuracy of Pneumatic Road Tube Counters," in *2011 Western District Annual Meeting*, Anchorage, 2011.

[6] J. Hayden, D. Garlarus, P. N. Ward and D. Z. Ye, "Final Report for the Western Transportation Institute's augmented Speed Enforcement Project," California Department of Transportation, Sacramento, 2013.

[7] J. Hourdos, "Portable, Non-Intrusive Advance Warning Devices for Work Zones with or without Flag Operators," Minnesota Department of Transportation, St. Paul, 2012.

[8] D. Y. Zhang, H. Suarez and S. Perea, "Next Generation Smart Barrel System For Workzone Safety Enhancement," Oklahoma Department of Transportation, Oklahoma City, 2012.

APPENDIX

A: V1 AVERAGE SPEED GRAPHS

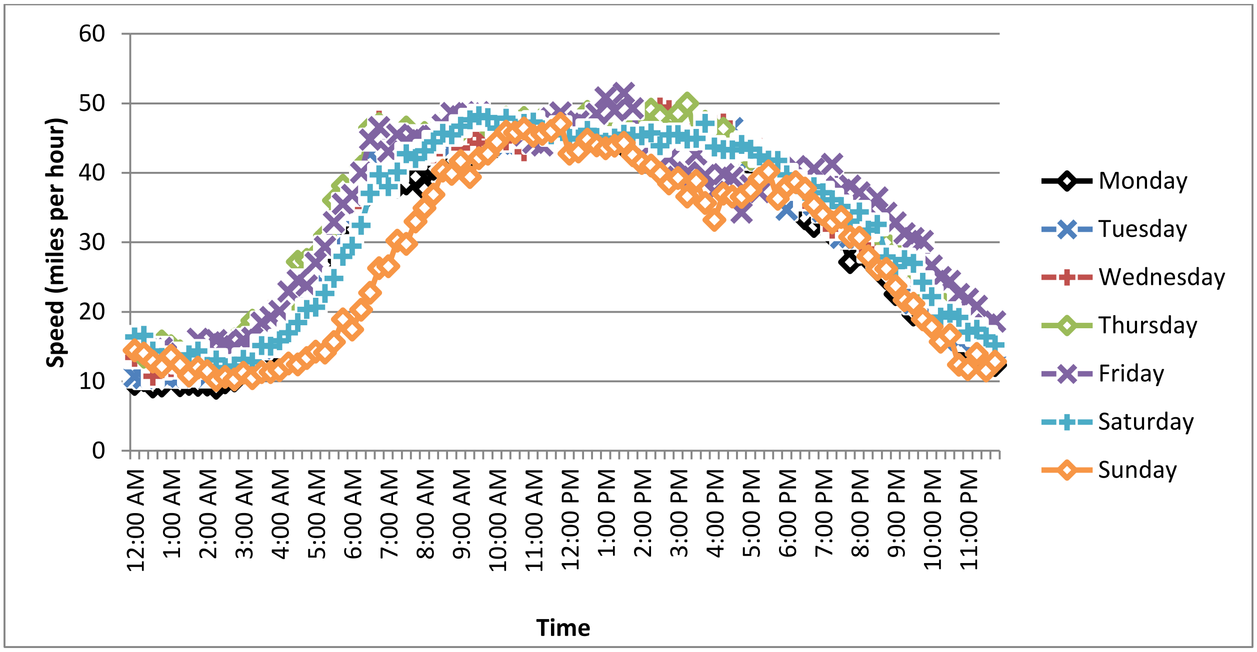

Figure A.1: Node 1 Average Speed by Day

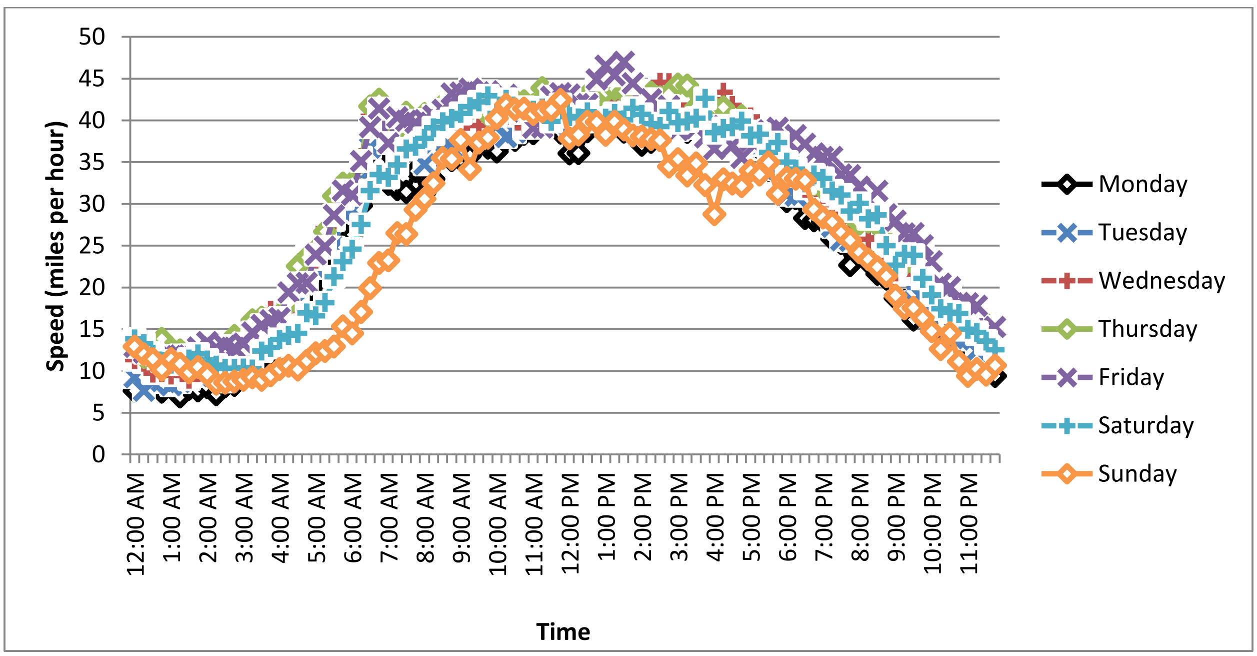

Figure A.2: Node 2 Average Speed by Day

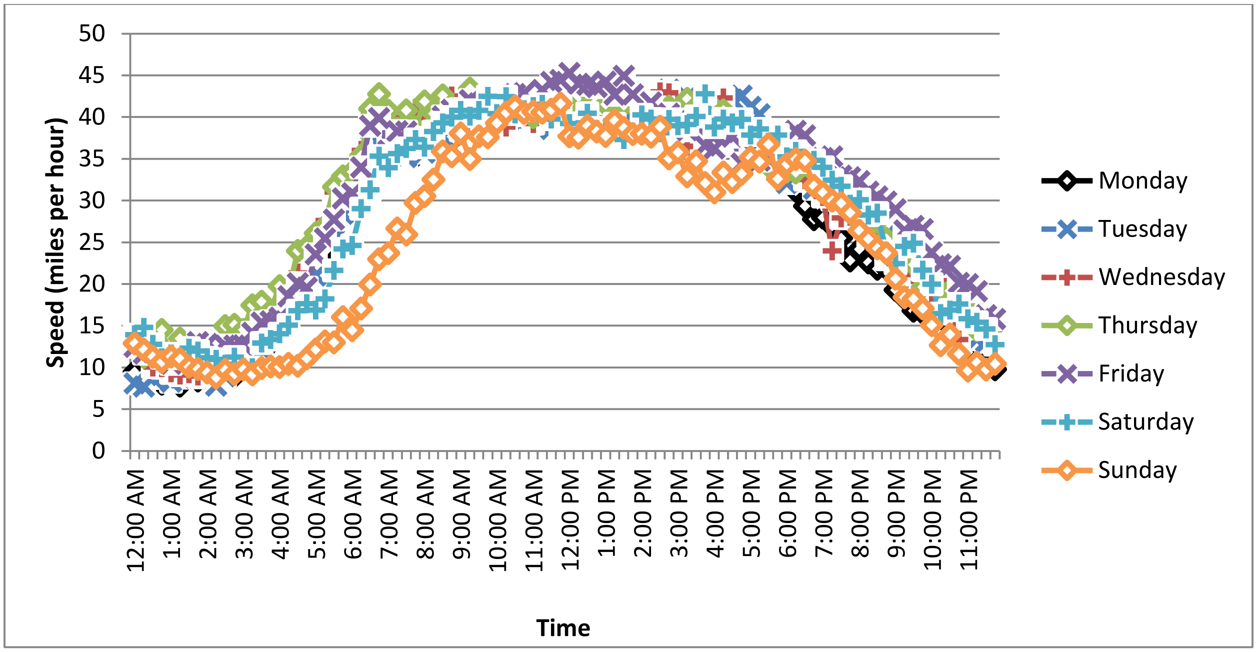

Figure A.3: Node 3 Average Speed by Day

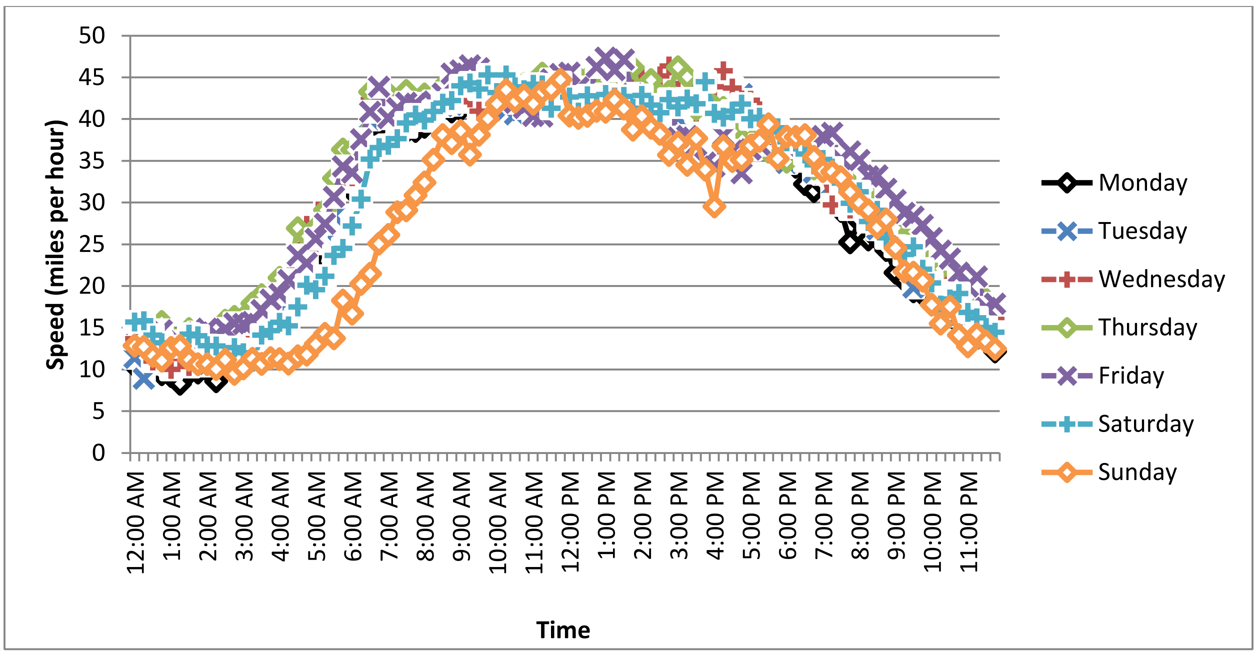

Figure A.4: Node 4 Average Speed by Day

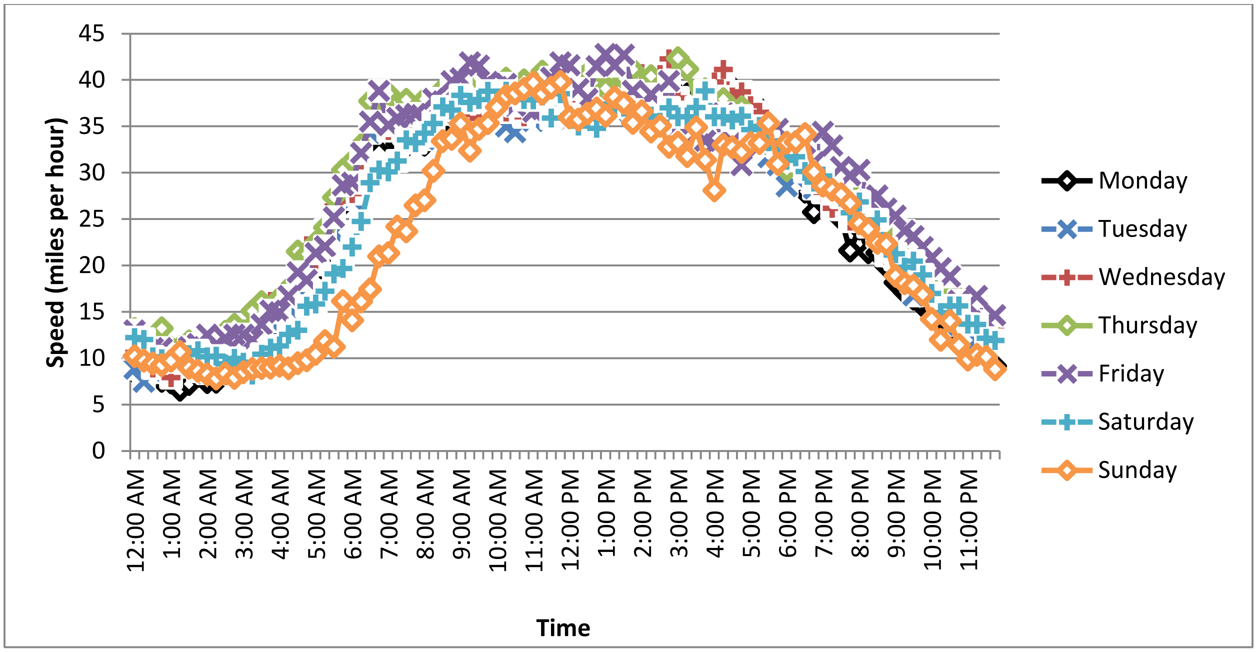

Figure A.5: Node 5 Average Speed by Day

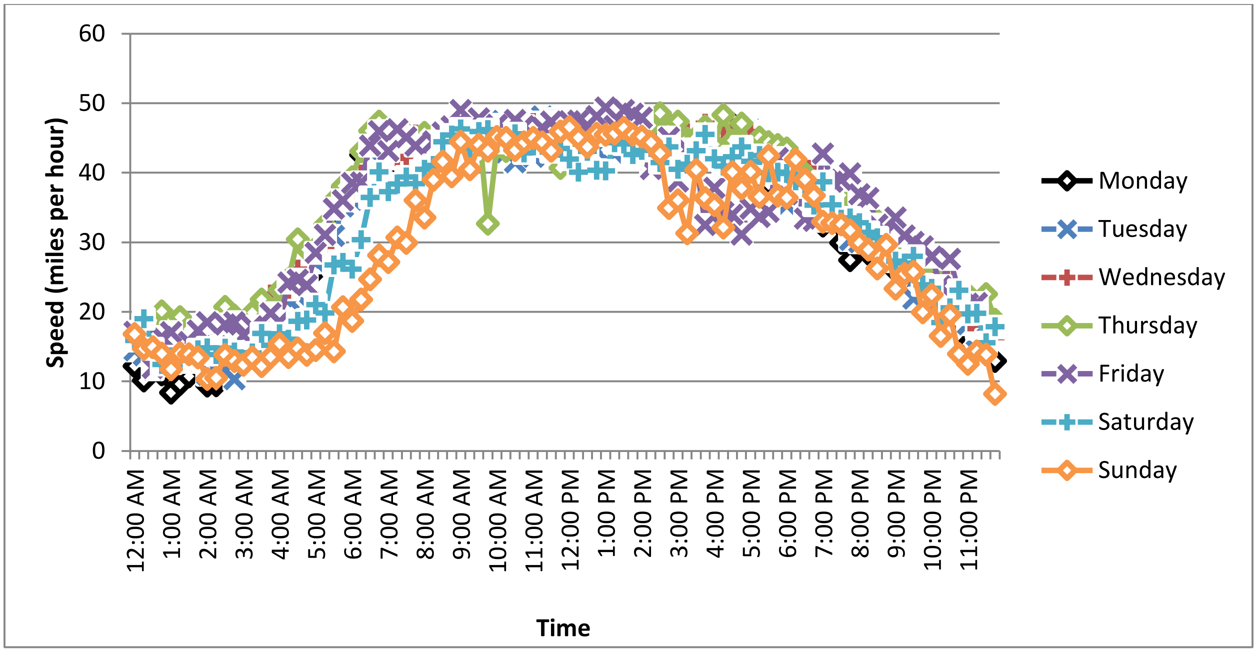

Figure A.6: Node 6 Average Speed by Day

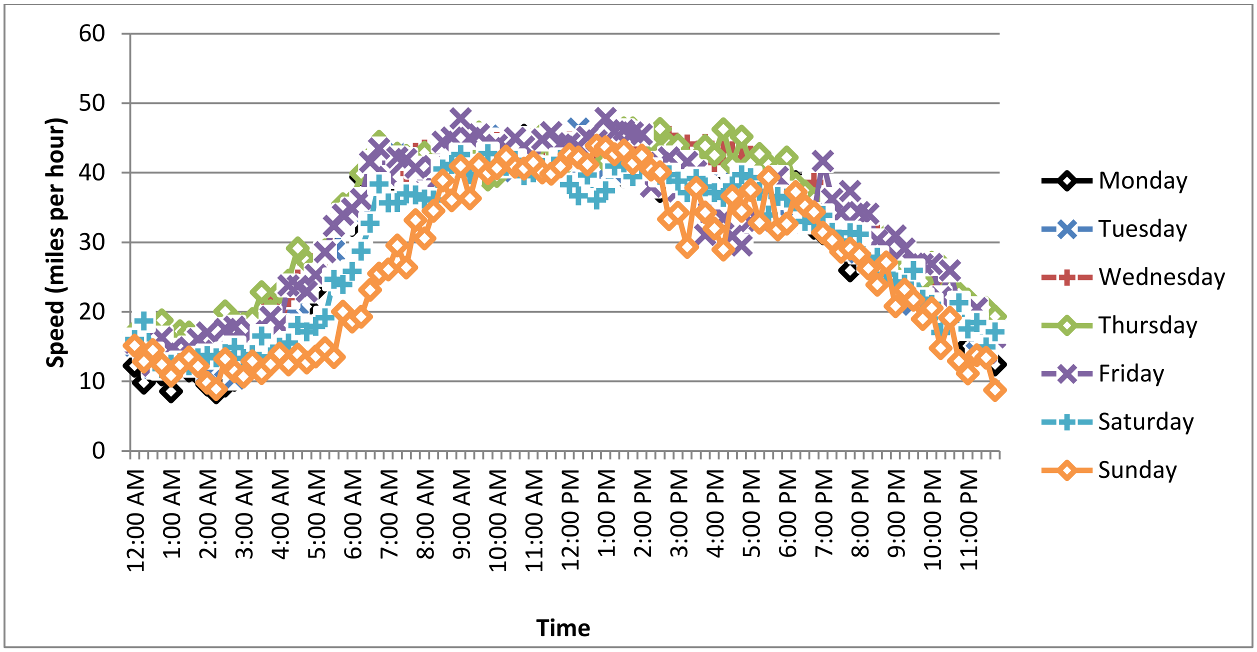

Figure A.7: Node 7 Average Speed by Day

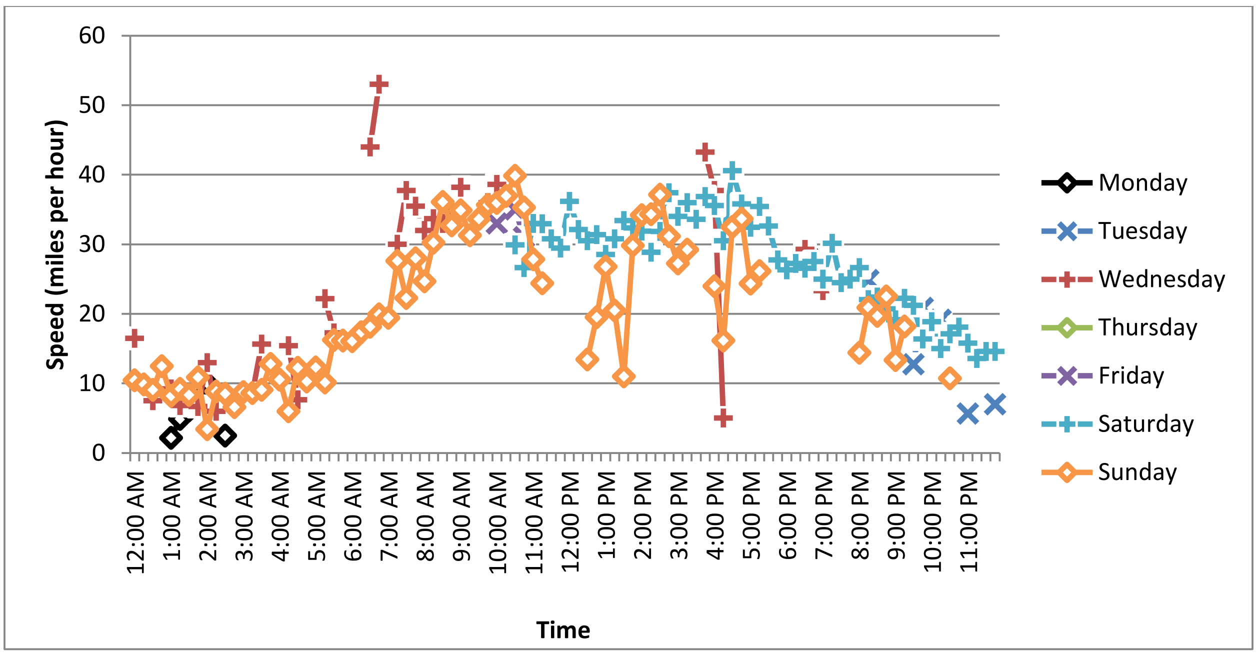

Figure A.8: Node 8 Average Speed by Day

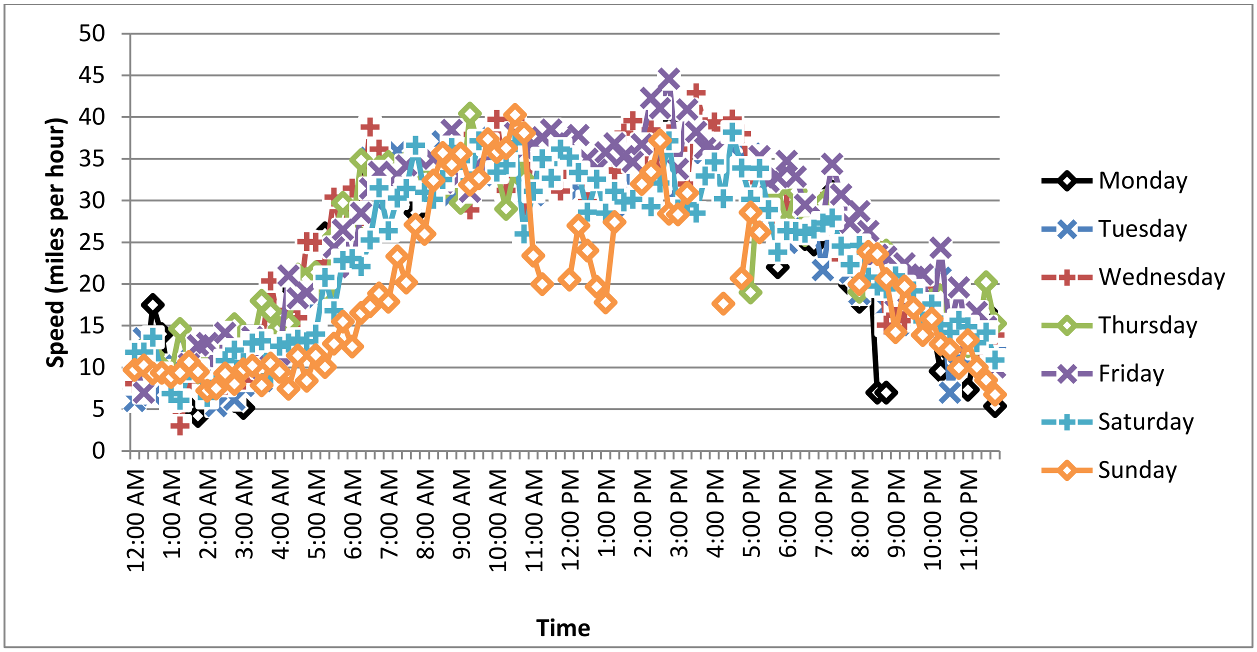

Figure A.9: Node 9 Average Speed by Day

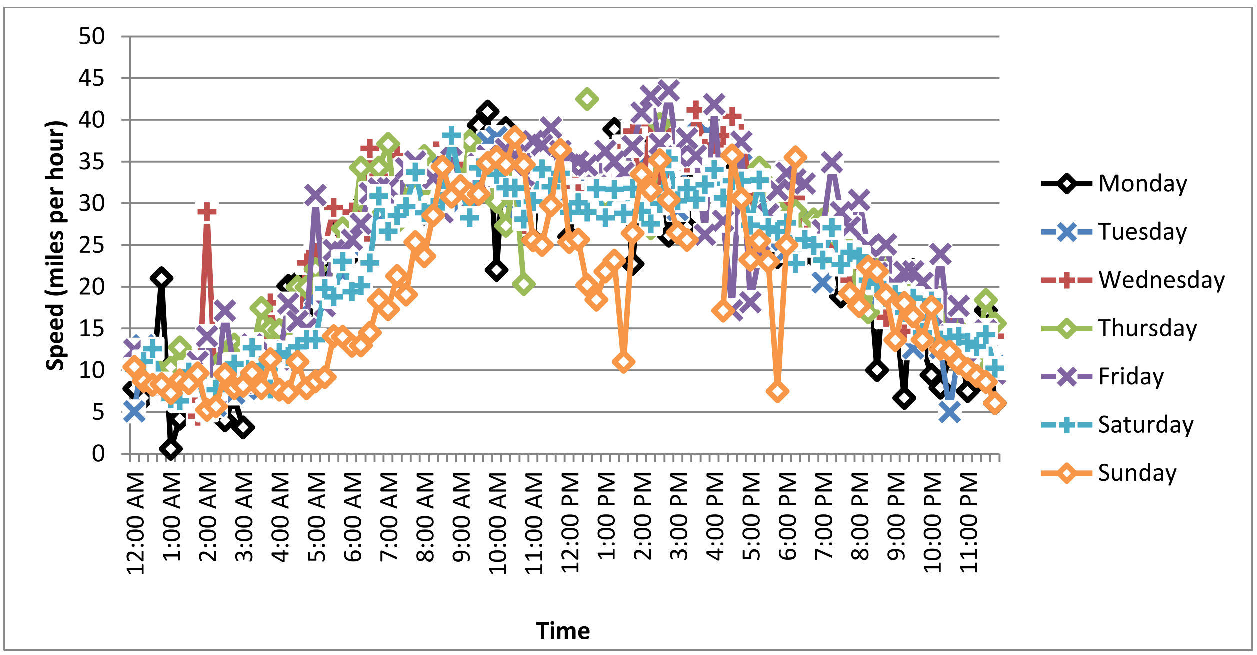

Figure A.10: Node 10 Average Speed by Day

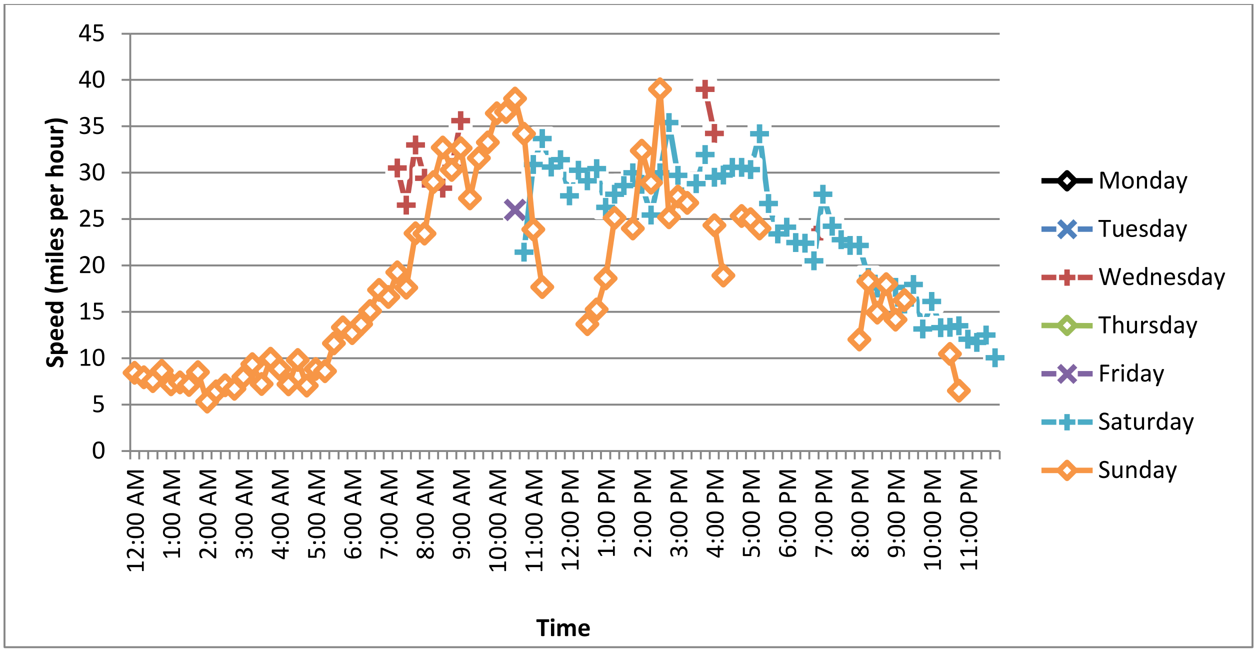

Figure A.11: Node 11 Average Speed by Day

B: V2 MOVING SPEED GRAPHS

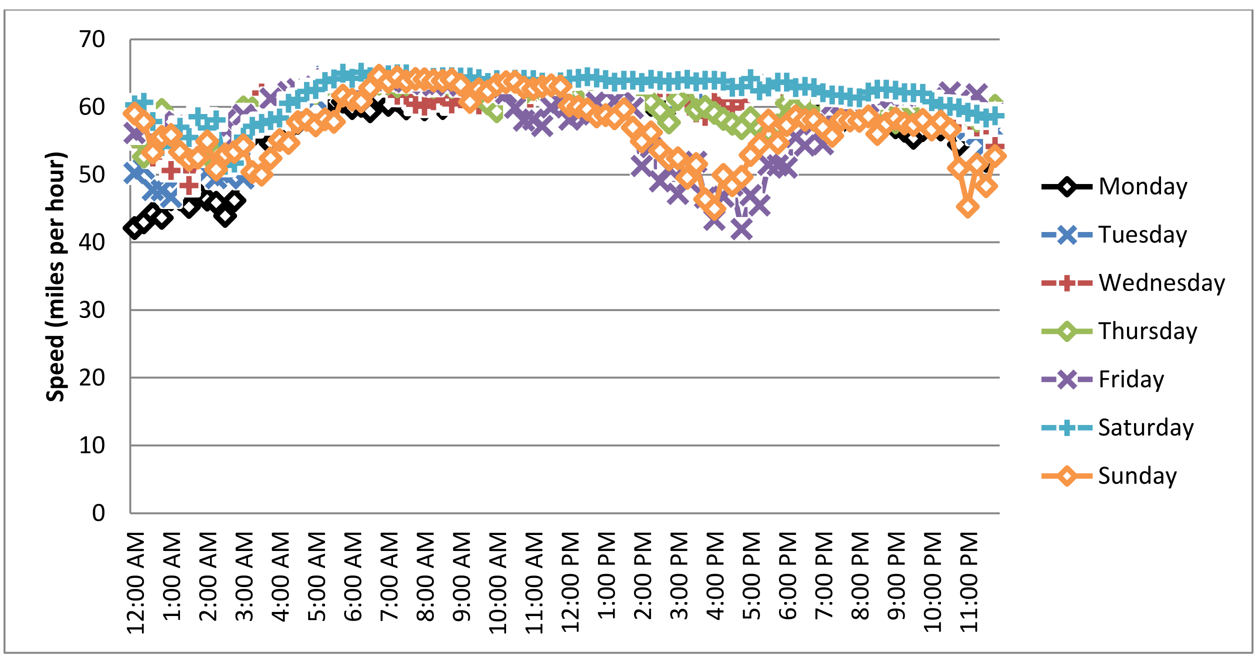

Figure B.1: Node 1 Average Moving Speed by Day

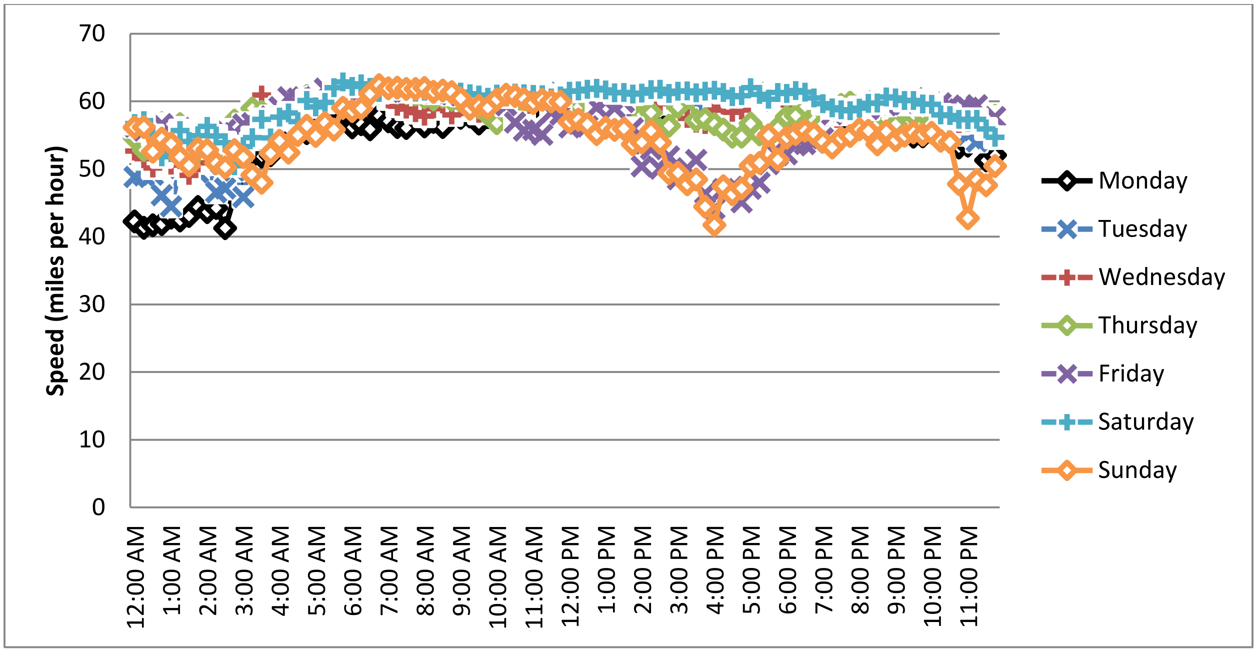

Figure B.2: Node 2 Average Moving Speed by Day

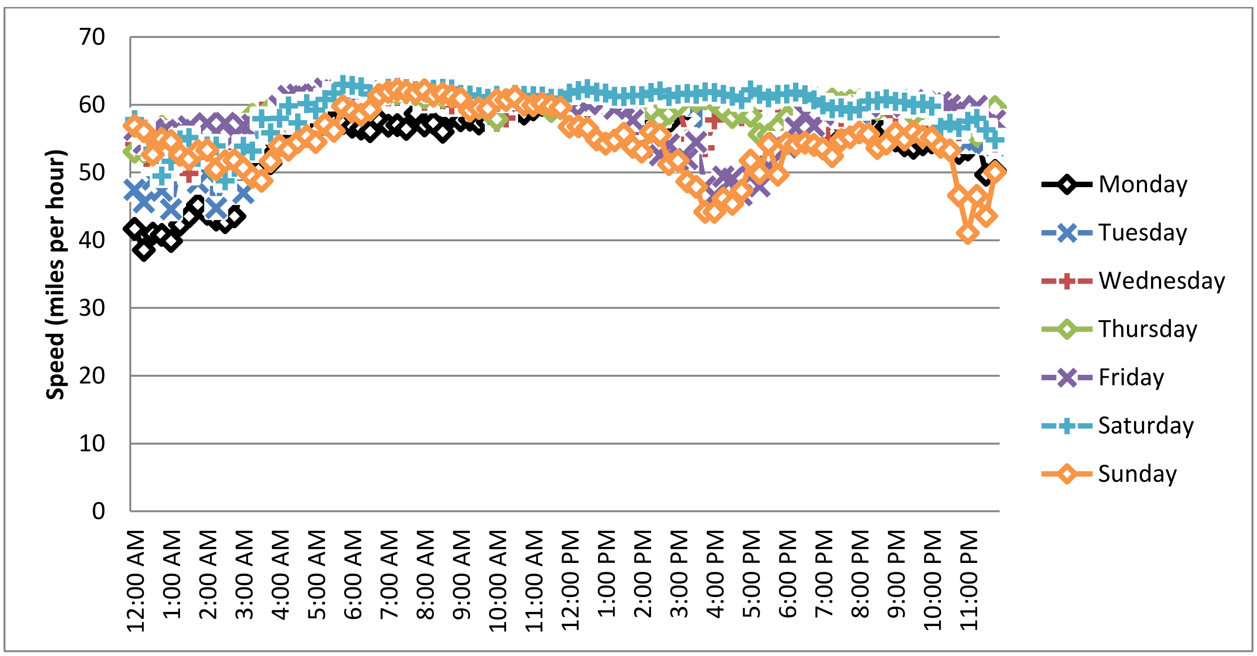

Figure B.3: Node 3 Average Moving Speed by Day

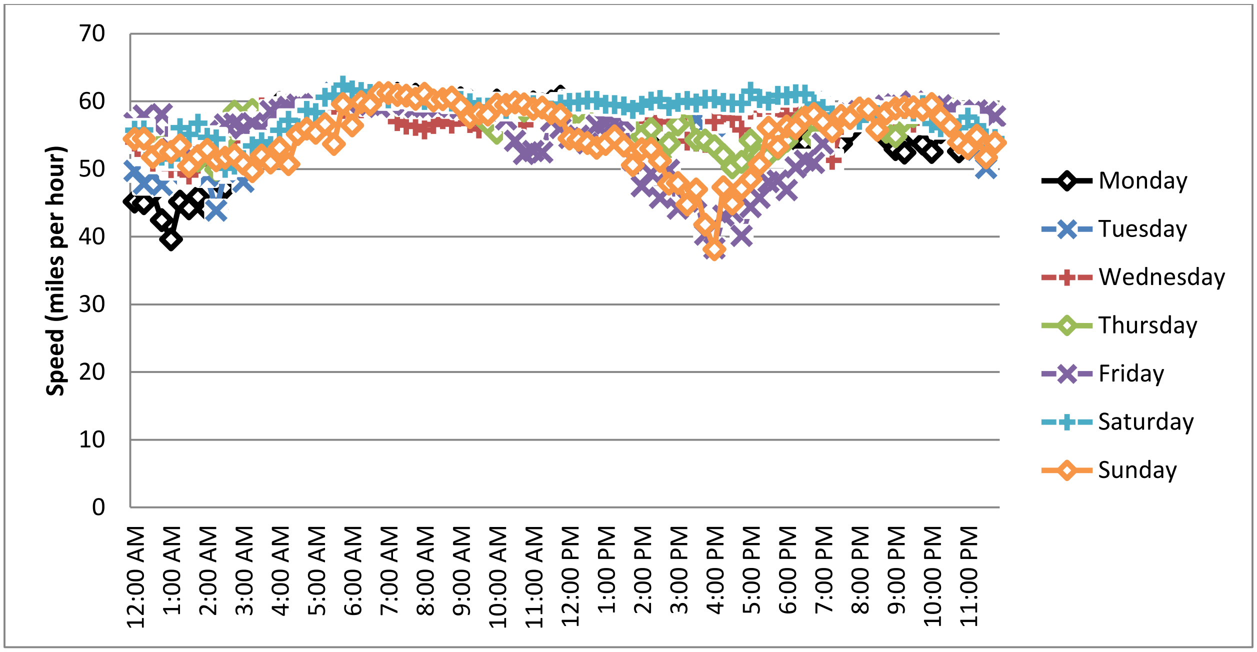

Figure B.4: Node 4 Average Moving Speed by Day

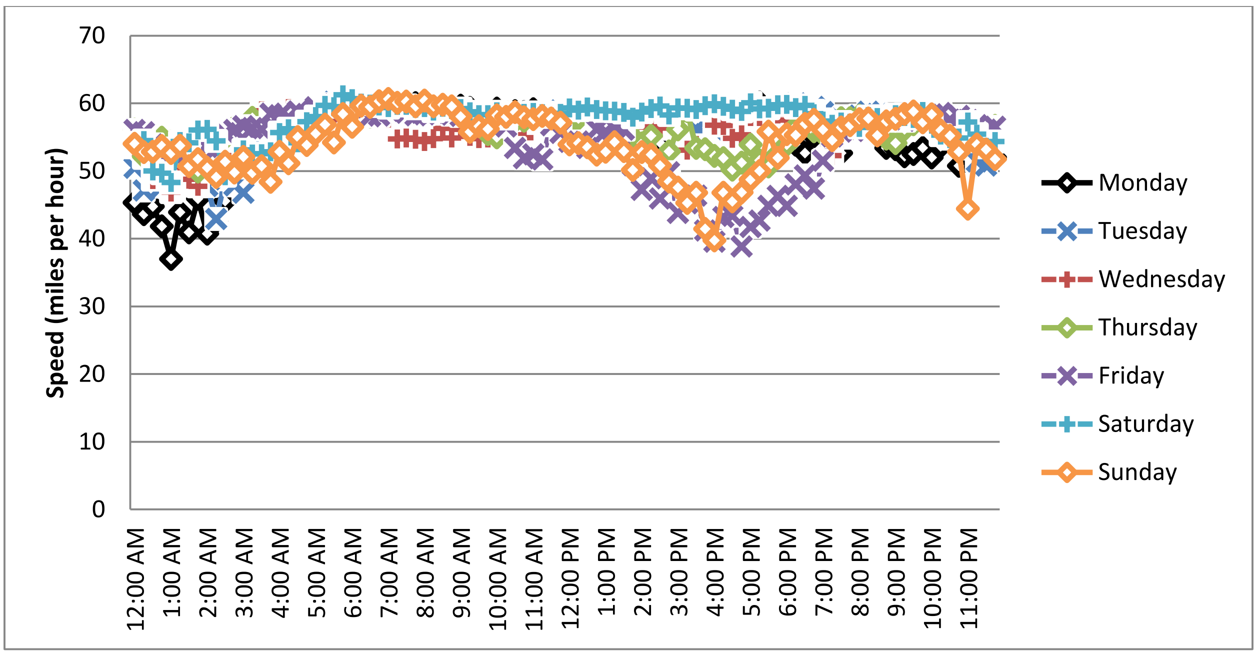

Figure B.5: Node 5 Average Moving Speed by Day

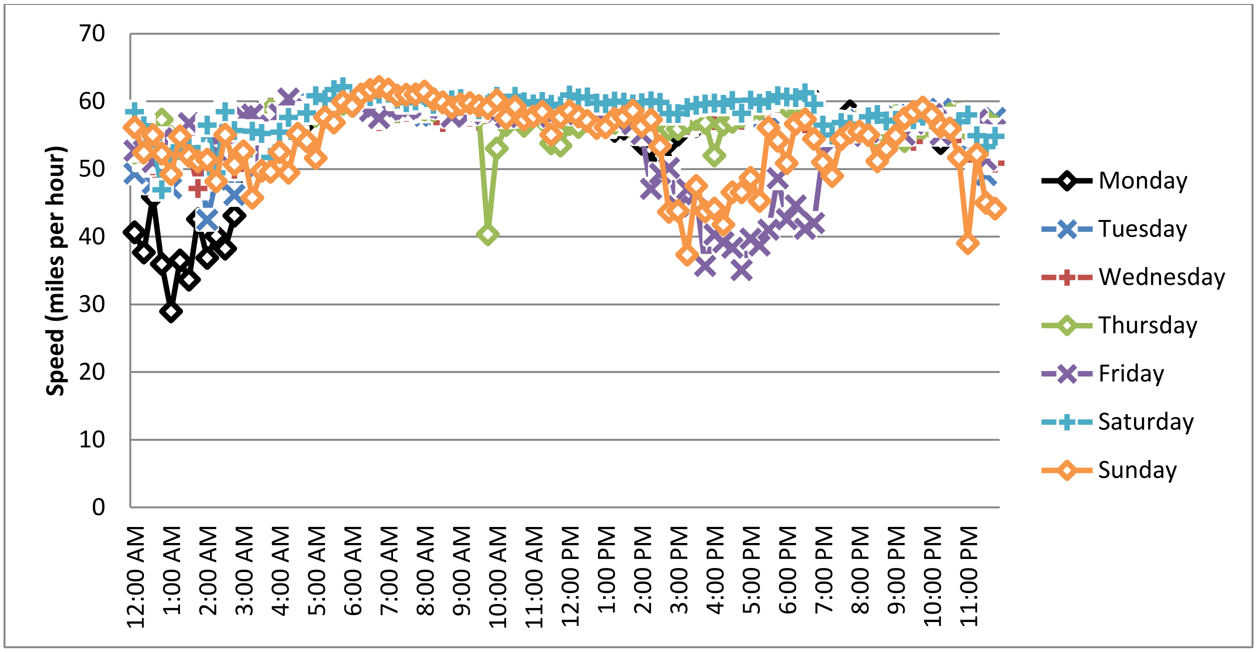

Figure B.6: Node 6 Average Moving Speed by Day

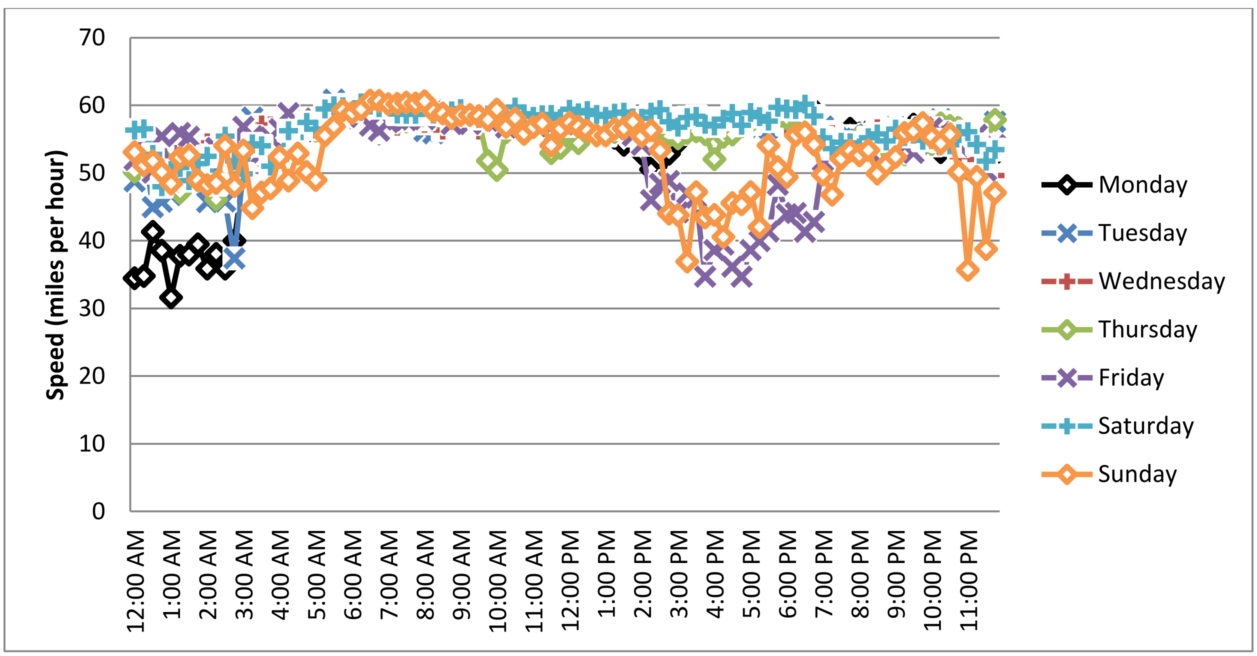

Figure B.7: Node 7 Average Moving Speed by Day

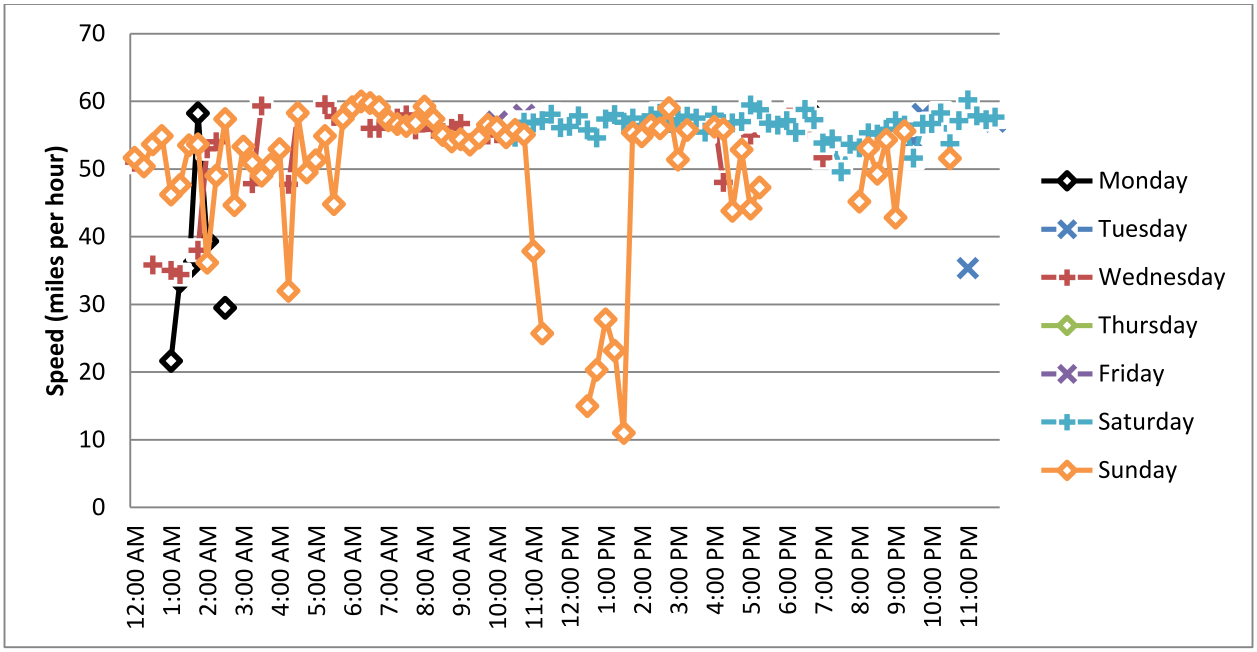

Figure B.8: Node 8 Average Moving Speed by Day

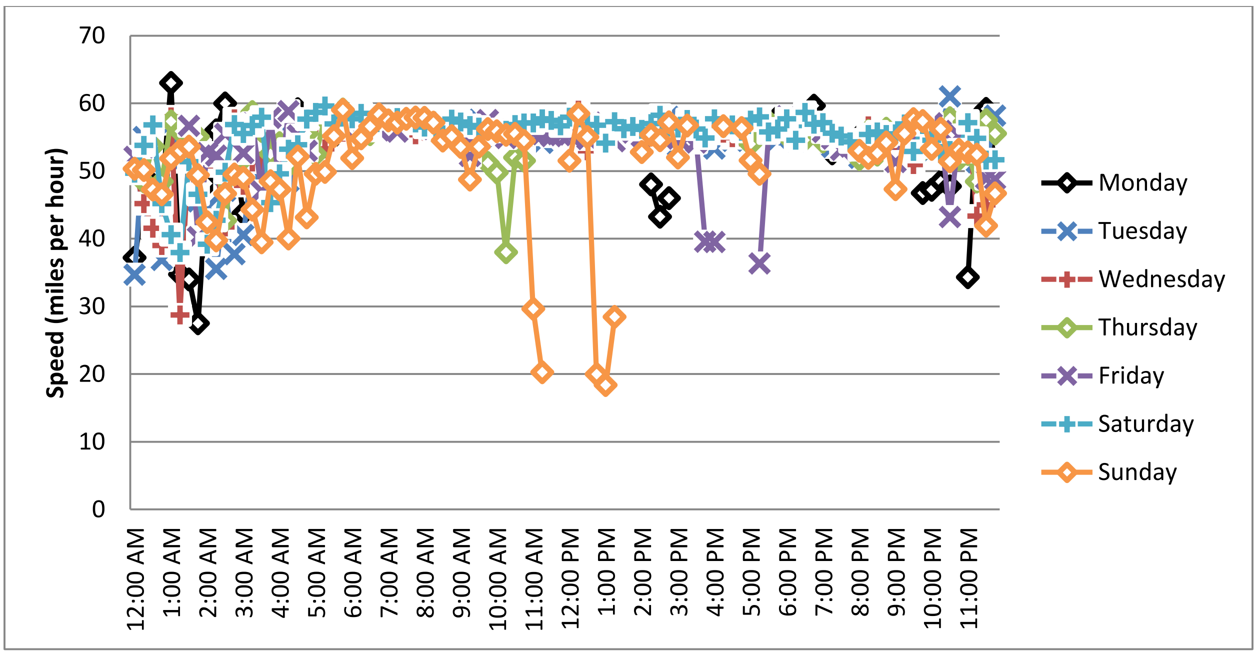

Figure B.9: Node 9 Average Moving Speed by Day

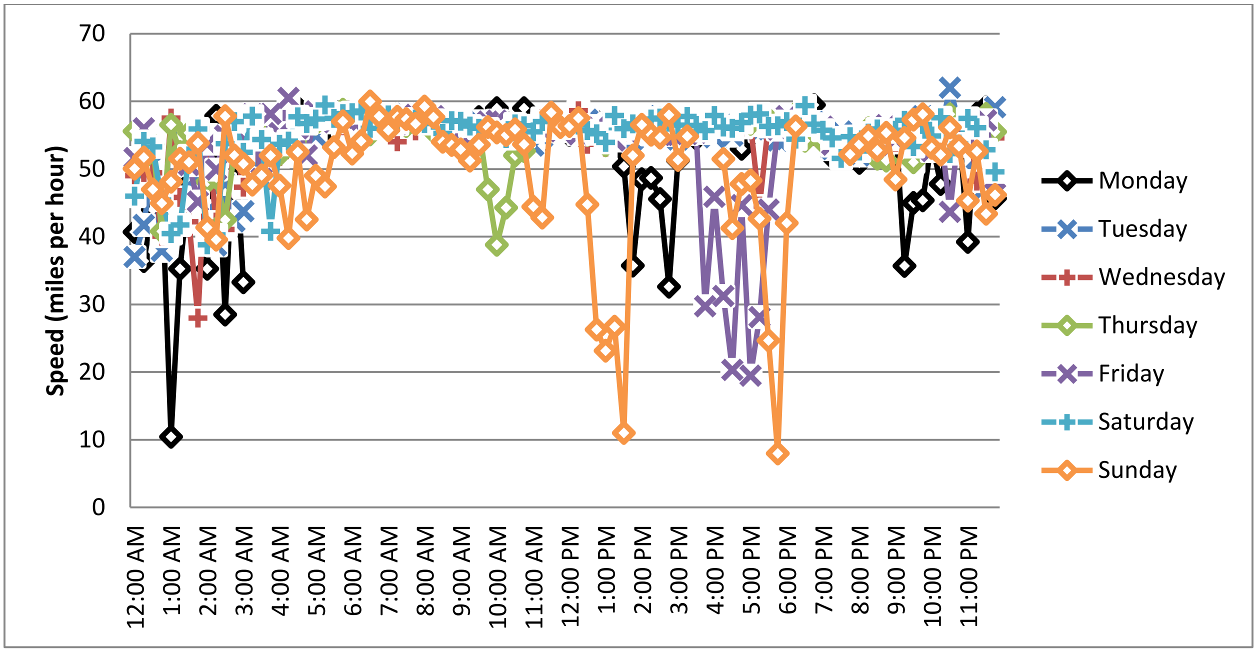

Figure B.10: Node 10 Average Moving Speed by Day

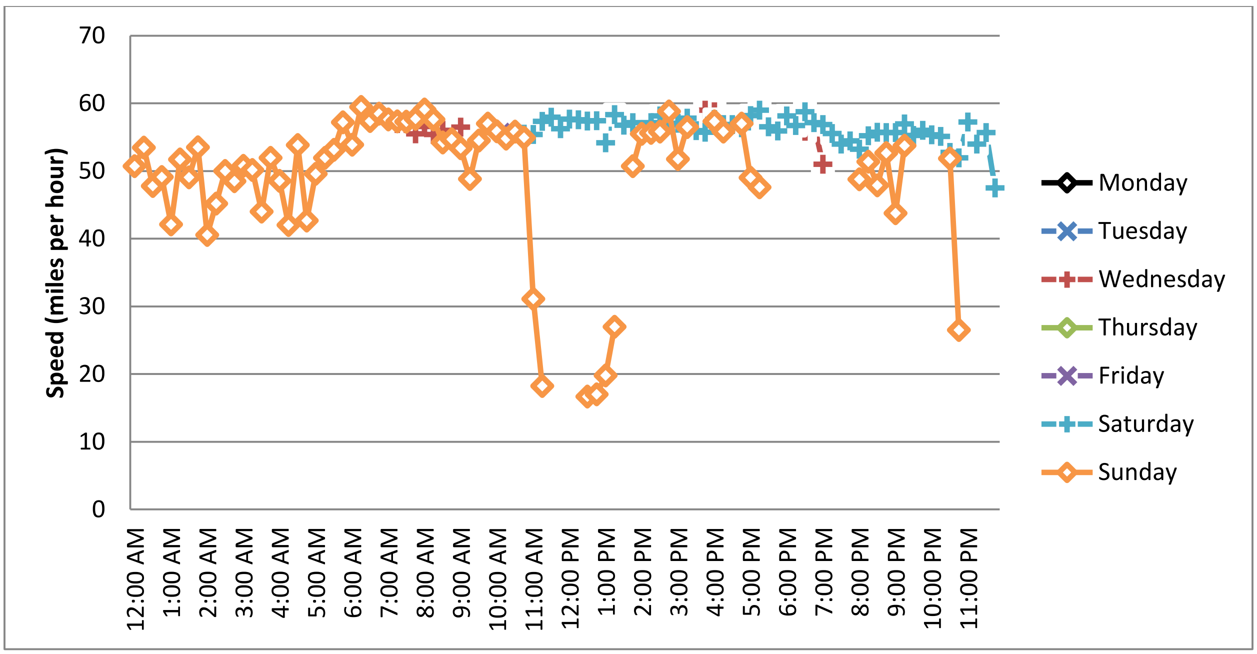

Figure B.11: Node 11 Average Moving Speed by Day

C: V3 TRAFFIC DENSITY INDICATOR SPEED GRAPHS

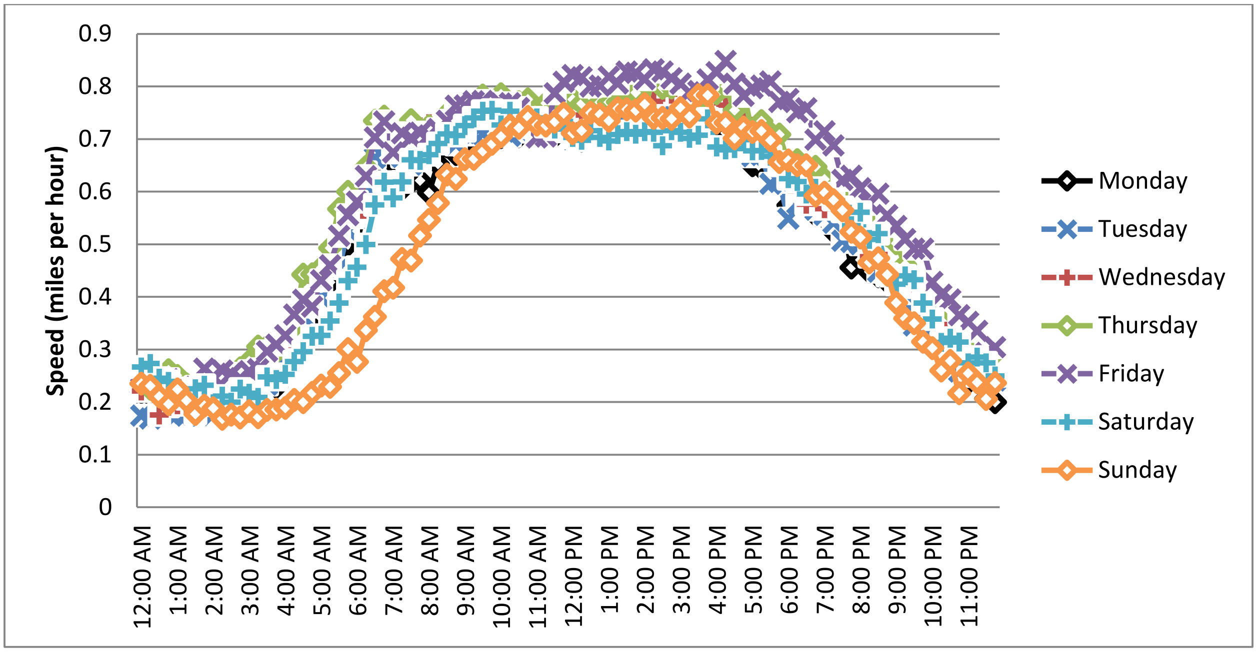

Figure C.1: Node 1 Average Speed Ratio by Day

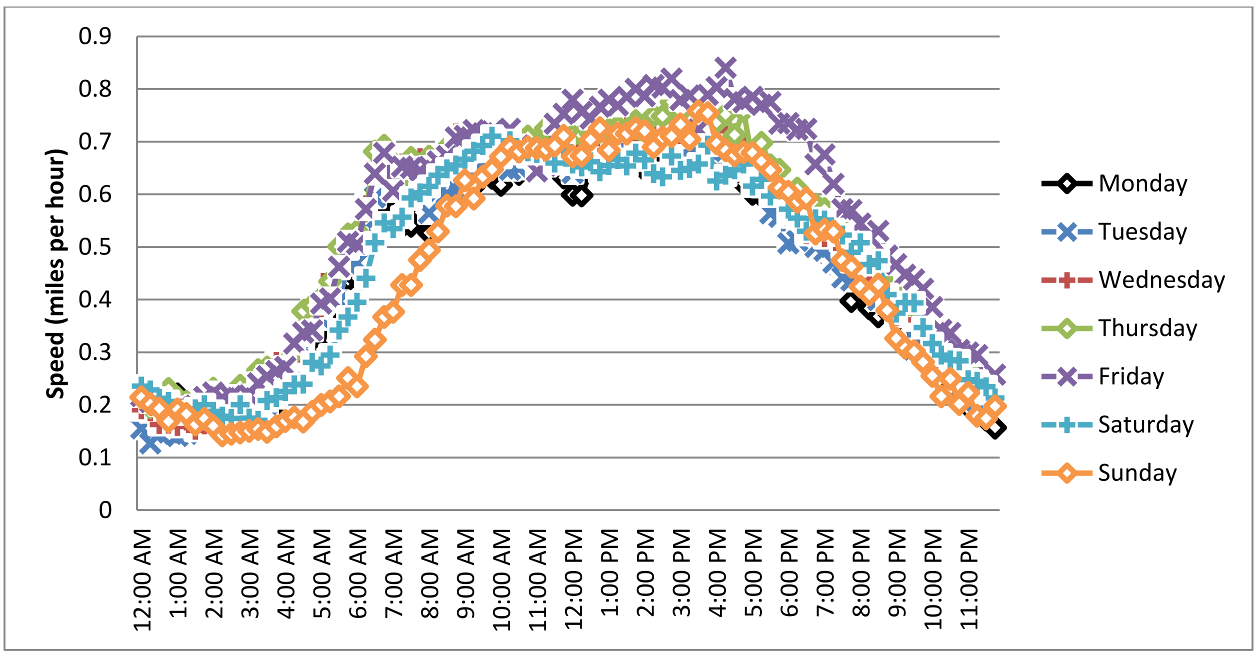

Figure C.2: Node 2 Average Speed Ratio by Day

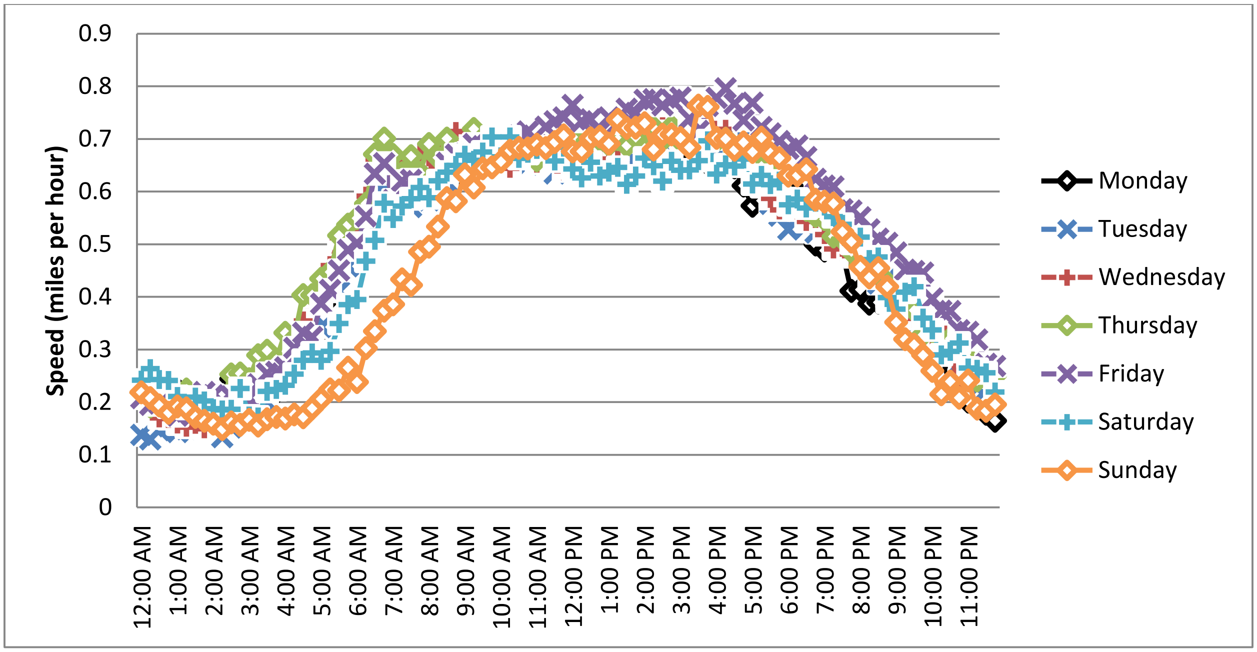

Figure C.3: Node 3 Average Speed Ratio by Day

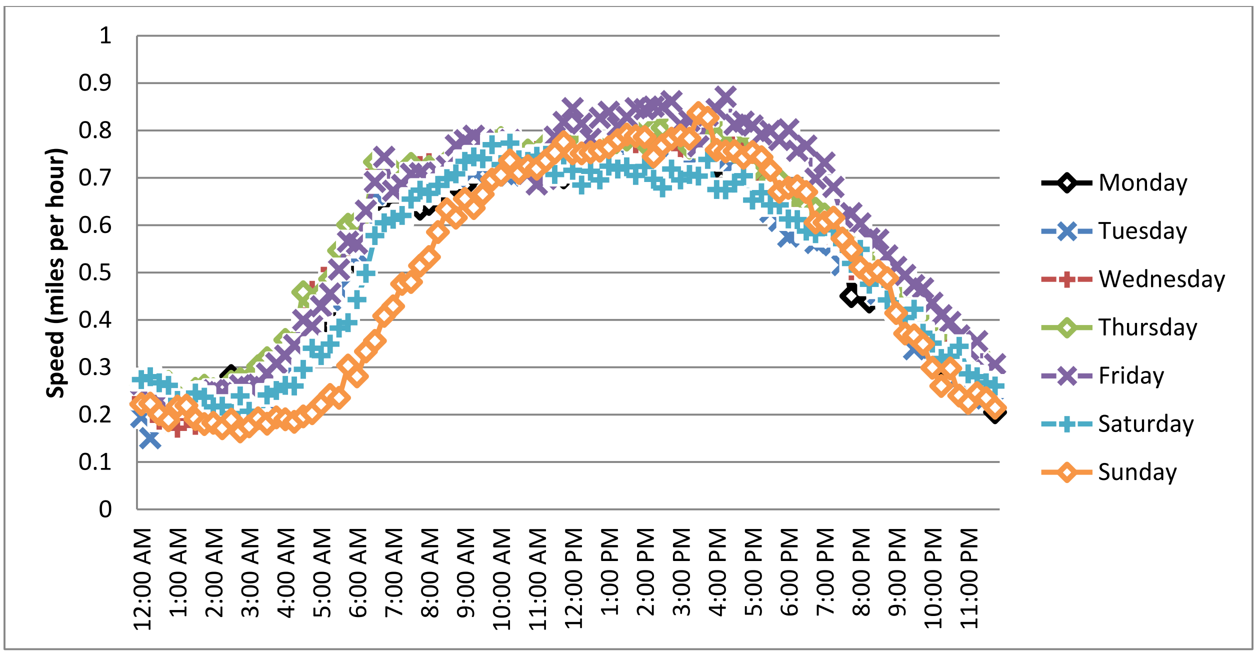

Figure C.4: Node 4 Average Speed Ratio by Day

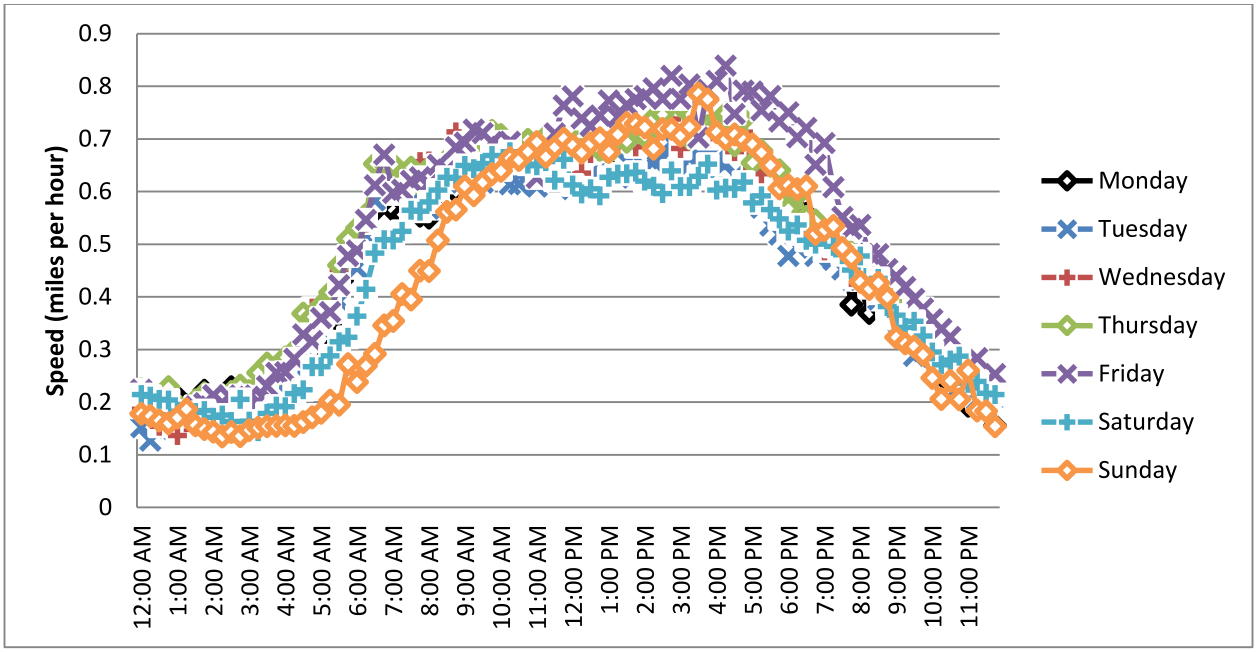

Figure C.5: Node 5 Average Speed Ratio by Day

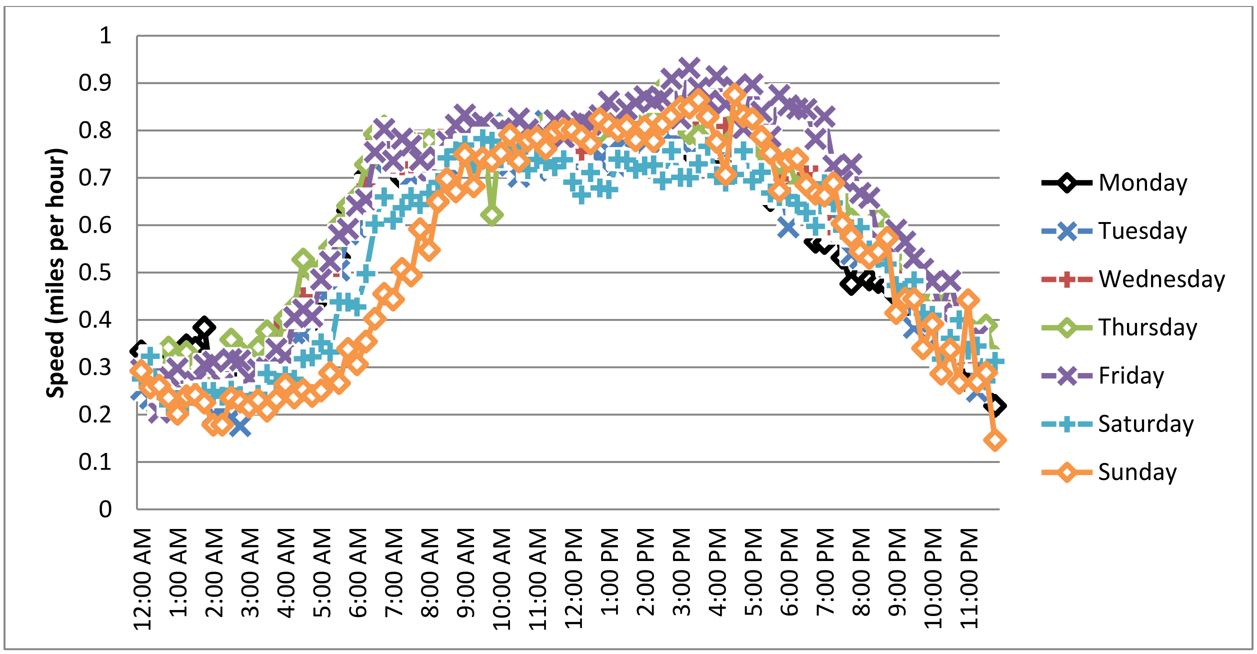

Figure C.6: Node 6 Average Speed Ratio by Day

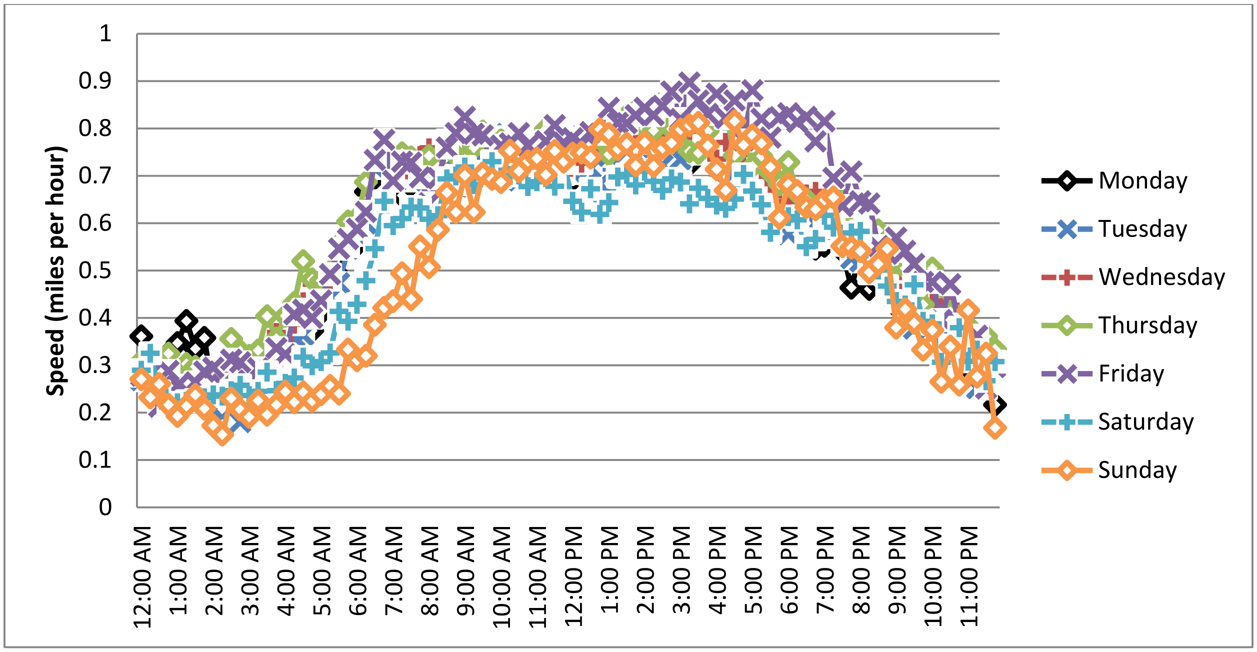

Figure C.7: Node 7 Average Speed Ratio by Day

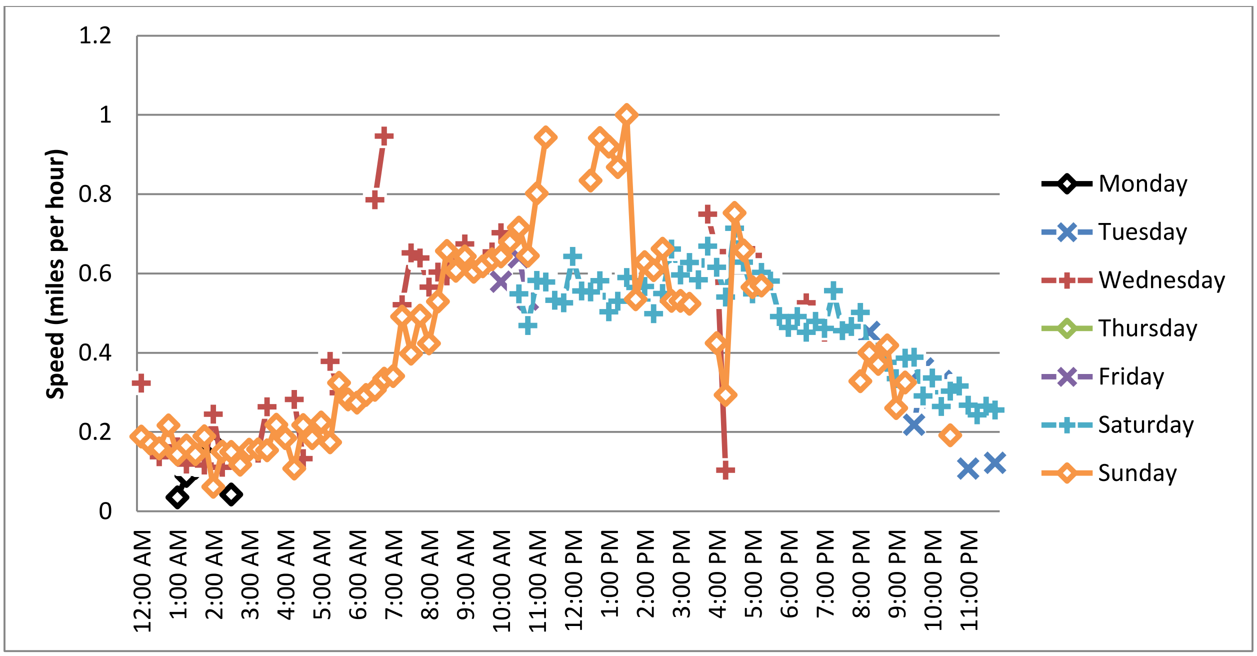

Figure C.8: Node 8 Average Speed Ratio by Day

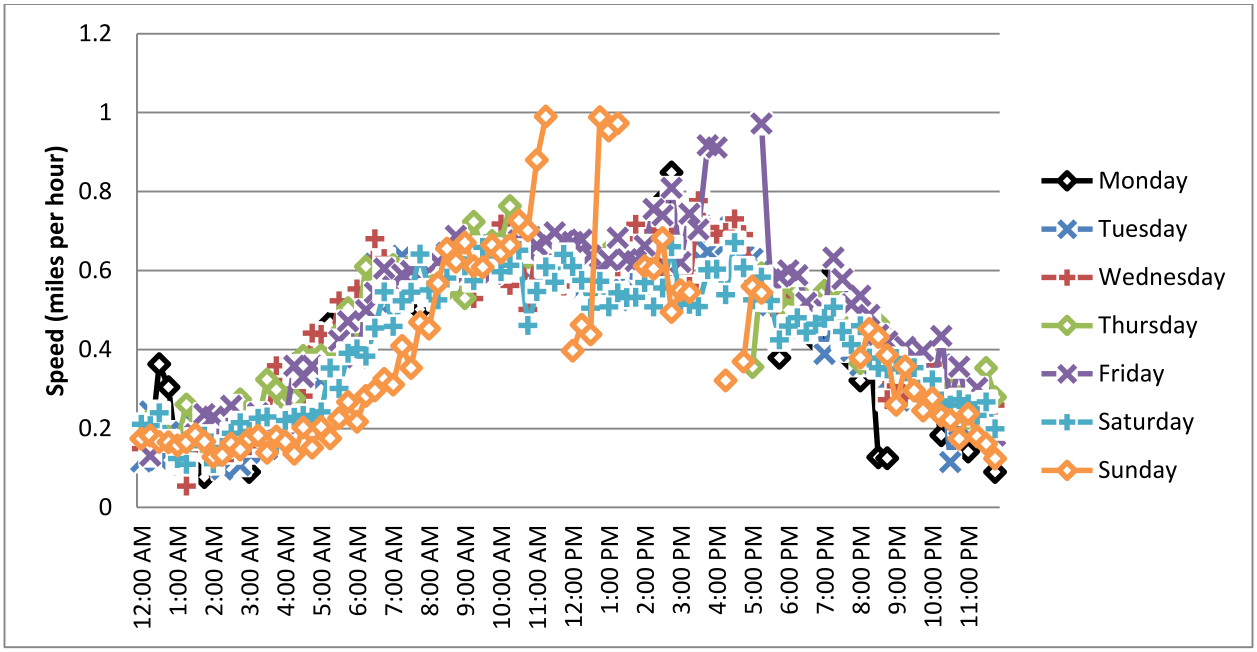

Figure C.9: Node 9 Average Speed Ratio by Day

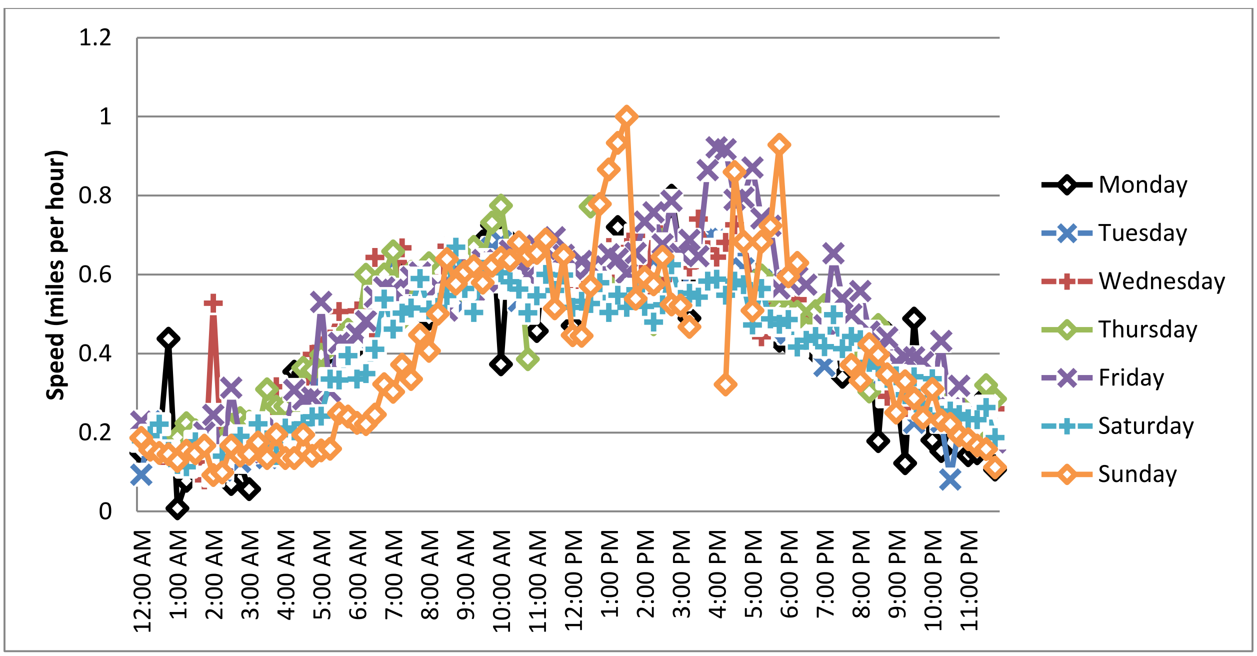

Figure C.10: Node 10 Average Speed Ratio by Day

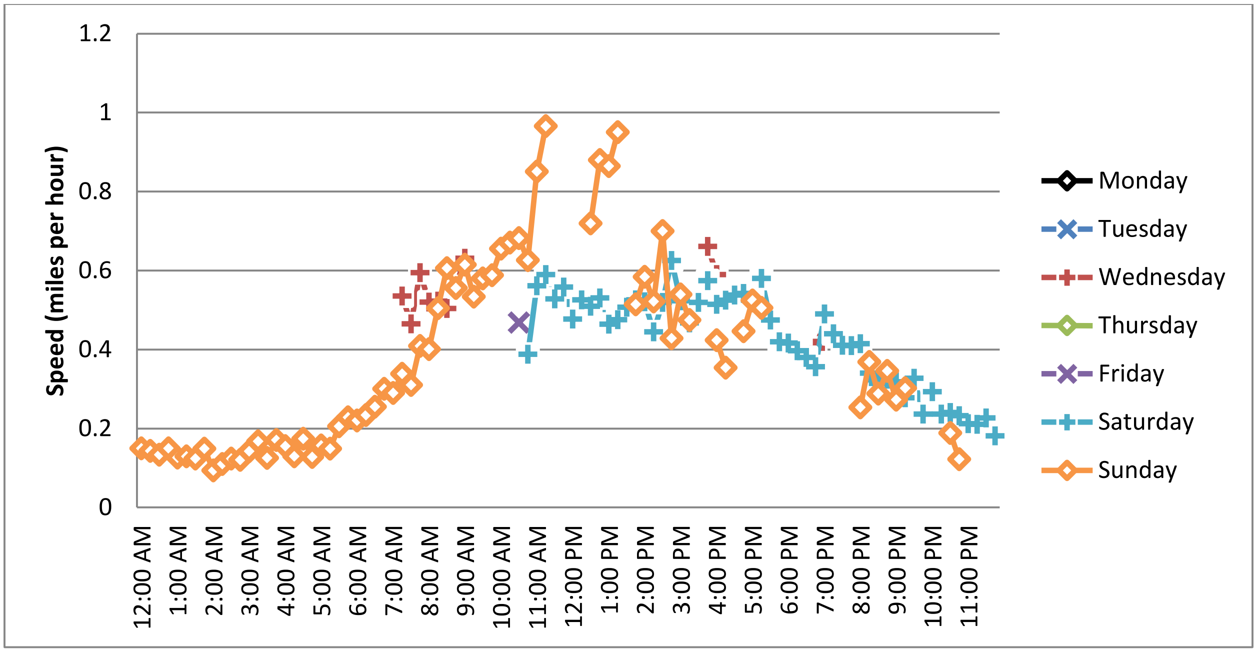

Figure C.11: Node 11 Average Speed Ratio by Day