GEORGIA DOT RESEARCH PROJECT 07-13

FINAL REPORT

EVALUATION OF THE EFFECTIVENESS OF CONVERGING CHEVRON PAVEMENT MARKINGS

OFFICE OF MATERIALS AND RESEARCH

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Converging chevron pavement markings have recently seen rising interest in the United States as a means to reduce speeds at high-speed locations in a desire to improve safety performance. This report presents an investigation into the effectiveness of chevron markings in reducing vehicle speeds on two-lane freeway-to-freeway directional ramps in Atlanta, Georgia. The evaluation is based on a statistical comparison at pre-selected sites of speeds before and after the installation of the chevron markings. The analysis focuses on the impact of converging chevrons over the range of speed percentiles and on the mean speed.
The analysis indicates that the chevrons had a minimal impact on vehicle speeds, with drivers adjusting back to their previous speeds as they acclimate to the treatment. The effect of the chevrons' treatments on speed tended to be most pronounced immediately after the chevron implementation. However, by the ninth month after implementation the magnitude of the effect dropped to under 1 to 2 mph for the mean speed and most vehicle speed percentiles. While this result does not necessarily imply that the chevron treatment is not a meaningful safety treatment, any safety benefits are not likely to result from a general decrease in speeds.</td></tr>
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Evaluation of the Effectiveness of Converging Chevron Pavement Markings

FINAL REPORT
OCTOBER 2010

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Executive Summary

This report presents an investigation into the effectiveness of chevron markings in reducing vehicle speeds on two-lane freeway-to-freeway directional ramps in a desire to improve safety performance. The evaluation is based on a statistical comparison of speeds before and after the installation of the chevron markings at pre-selected sites in the Atlanta, GA area. The analysis focuses on the impact of converging chevrons over the range of speed percentiles and on the mean speed through the use of diverse sampling and control ramps.

Study Sites
The evaluation of the effectiveness of converging chevron pavement markings has been performed at two interchange locations in Atlanta, Georgia: Interstate 75/85 interchange and Interstate 75/285 interchange. For each site two ramps were selected - a treatment ramp, i.e. the ramp containing the chevron installation, and a control ramp, i.e. a ramp with no treatment applied, to monitor potential underlying changes in traffic operations at the interchange. Data collection stations are placed immediately upstream and downstream of the chevron marking location.

Data Description
Streaming Per-Vehicle Record (PVR) data and binned vehicle speed data was recorded in the field and periodically downloaded for analysis. The PVR record data for each vehicle contained parameters including time stamp, lane number, vehicle class, vehicle speed, vehicle length, time headway, and distance between axles. The data were collected between March 2008 and February 2009. This study compared speed distributions during six time periods including:

- Before the treatment (5 weeks of measurements)
- One week after the treatment (1 week)
- One month after the treatment (1 week)
- Three months after the treatment (2 weeks)
- Six months after the treatment (1 week)
- Nine months after the treatment (1 week)

Findings
Analysis of the speed data indicates that the presence of the chevrons had only a modest impact on overall vehicle speeds. The observed changes in the speed distributions are reasonably consistent between the test sites thus increasing confidence in the findings. The effect of the treatments was most pronounced immediately following implementation, with the impact waning over the duration of the study. By the ninth month the magnitude of the impact was less than 2 mph over most of the vehicle speed percentiles.

To account for sampling differences and potential distributional difference between the data collected over the different time periods, a "Monte Carlo" random sampling strategy of lead vehicles was adopted for the analysis. The results of this analysis showed an average speed reduction upon entering the controlling ramp geometry on the order of 0.5 to 2.0 mph by the ninth month after treatment, with much of this effect

related to increased speeds on the control ramp. In addition, it is noted that there was minimal effect on the speed variance of vehicles entering the controlling ramp geometry. When considering the potential for speed reductions between the detectors it would appear the chevrons had little to no impact, with the control ramps experiencing similar trends as the treatment ramps. Taken together this would imply the mean effect of the chevrons is limited to a 0.5 mph to 2.0 mph reduction in mean speed as the vehicles enter the controlling ramp geometry.

Thus, it was found that the impact of the chevron treatment on speed tends to be minimal, with drivers adjusting back to their previous speeds as they acclimate to the treatment. However, this does not necessarily indicate that the chevrons are not a meaningful safety treatment but rather that any safety benefits are likely not due to a general decrease in speeds. For example, it is possible that the chevron treatment may help alert an inattentive driver thus reducing the likelihood of an accident occurrence without having a significant impact on the overall population. Additionally, an incident analysis for the subject ramps showed that a significant subset of the crashes occurred under wet or snowy conditions and it is possible that the chevrons function differently under these adverse conditions. Data collection constraints precluded examination of this possibility. Prior to any final judgment on the effectiveness of the chevron treatment on safety it is recommended that a direct accident study (as opposed to utilizing a surrogate such as speed) be conducted after sufficient accident data has been gathered. It is also noted that the minimal speed reduction is based on two two-lane freeway ramp sites in one geographic area and additional research is needed.

TABLE OF CONTENTS

Executive Summary ... iii
CHAPTER 1. INTRODUCTION ... 1
CHAPTER 2. LITERATURE REVIEW ... 2
Introduction ... 2
Previous Studies ... 2
Speed as Surrogate Safety Measure ... 3
CHAPTER 3. EXPERIMENTAL DESIGN ... 4
Study Sites ... 4
Data Collection Equipment ... 9
Data Descriptions ... 9
Binned Data ... 9
PVR Data ... 10
Data Quality Analysis ... 10
Binned vs. PVR – Traffic Volume ... 11
CHAPTER 4. DATA ANALYSIS ... 16
Speed Cumulative Distribution Functions ... 16
Speed Density Function ... 19
Analysis of Speed Difference ... 20
Lead Vehicle Analysis ... 22
Monte Carlo Analysis ... 23
CHAPTER 5. CRASH DATA ANALYSIS ... 28
Site A: Test Ramp (from I-75S to I-85N) ... 29
Site A: Control Ramp (from I-85S to I-75N) ... 30
Site B: Test Ramp (from I-285E to I-75N) ... 31
Site B: Control Ramp (from I-75S to I-285W) ... 31
CHAPTER 6. SUMMARY OF FINDINGS ... 32
REFERENCES ... 34

APPENDIX A. Bin Sizes for Binned Data
APPENDIX B. Confidence Intervals of Speed Differences of Leading Vehicles
APPENDIX C. Time Series Data Plots for Speeds at Each Station
APPENDIX D. CDF Plots for Sites (All Vehicles) for Different Periods
APPENDIX E. PDF Plots for Sites (All Vehicles) for Different Periods
APPENDIX F. Difference of CDF Plots for Sites (All Vehicles) for Different Periods
APPENDIX G. CDF Plots for Sites (Lead Vehicle) for Different Periods
APPENDIX H. PDF Plots for Sites (Lead Vehicle) for Different Periods
APPENDIX I. Difference of CDF Plots for Sites (Lead Vehicle) for Different Periods
APPENDIX J. PDF Plots for Sites (Lead Vehicle) for Monte Carlo Simulations
APPENDIX K. CDF Plots for Sites (Lead Vehicle) for Monte Carlo Simulations
APPENDIX L. Difference of CDF Plots for Sites (Lead Vehicle) for Monte Carlo Simulations

LIST OF FIGURES

Figure 1: Study Sites 4
Figure 2: Site A Data Collection Stations with Travel Directions for the Treatment Ramp (Yellow Line) and the Control Ramp (Red Line) 6
Figure 3: Site A Treatment Ramp Lane Configuration 7
Figure 4: Site B Data Collection Stations with Travel Directions for the Treatment Ramp (Yellow Line) and the Control Ramp (Red Line) 8
Figure 5: Site B Treatment Ramp Lane Configuration 9
Figure 6: Five-Minute Sample Interval of Traffic Counts from Binned (Black) and PVR (Red) Data 11
Figure 7: Cumulative Difference between Binned and PVR Counts vs. Time of Day 12
Figure 8: Overlapped Time Series plots with PVR Data at Detector 011 Lane 1 15
Figure 9: PVR data CDF Plot, Lane 1 of Detector Site 012 17
Figure 10: Binned Data CDF Plot, Lane 1 of Detector Site 012 18
Figure 11: PVR Data CDF plot, Lane 1 of Detector Site 022 19
Figure 12: PVR Data PDF plot, Lane 1 of Detector Site 012 20
Figure 13: PVR Data Percentile Speed Difference for All Vehicles, Lane 1 of Site 012 Lane 1 21
Figure 14: PVR Data Percentile Speed Difference for All Vehicles, Lane 1 of Site 022 22
Figure 15: Spread between CDF plots with PVR Data at Detector Site 012 Lane 1 for Leading Vehicles 23
Figure 16: Ramp Section Diagram (Source: Jack Carver, Office of Traffic Safety and Design, GDOT) 29

LIST OF TABLES

Table 1: Data Collection Station Descriptions... 9
Table 2: Data Collection Periods 13
Table 3: Monte Carlo Results 25
Table 4: Crash Data Attributes and Description 28
Table 5: Crashes by Type of Collision at the Ramp Section from I-75S to I-85N........... 30
Table 6: Crashes by Type of Collision at the Ramp Section from I-85S to I-75N........... 30
Table 7: Crashes by Type of Collision at the Ramp Section from I-285E to I-75N......... 31
Table 8: Crashes by Type of Collision at the Ramp Section from I-75S to I-285W........ 31

CHAPTER 1. INTRODUCTION

Speed is a prime factor in highway safety. In 2002, there were 42,815 traffic fatalities in the United States (1,523 in Georgia) of which 13,713 (313 in Georgia) were speeding-related, accounting for 32% (20% in Georgia) of the total fatalities. Of the total number of speeding-related fatalities in the U.S. in 2002, 7,039 (51%) occurred on roads with posted speed limits above 55 mph [1].

Measures for discouraging speeding, especially at high-speed locations, are of major interest to the traffic engineering community. First proposed nearly a decade ago in Japan, converging chevron pavement markings (abbreviated as "chevron markings" hereafter) have recently seen rising interest in the United States. The first documented U.S. test of chevron markings was undertaken in Milwaukee County, Wisconsin in 1999. This experiment concluded that "Converging chevron pavement markings appear to reduce speeds but more research is needed.[2]"

The purpose of this study is to evaluate the effectiveness of chevron markings in reducing vehicle speeds on freeway ramps in a desire to improve safety performance. This study investigates the effectiveness of chevron markings at high-speed locations, in particular two-lane freeway-to-freeway directional ramps. The evaluation is based on a statistical comparison of speeds before and after the installation of the chevron markings at two pre-selected sites. The analysis focuses on the impact of converging chevrons on the mean speed and over the range of speed percentiles. Ramp crash history is also considered. To investigate whether the speed reduction, if any, may be attributed to the installation of the chevron markings, factors such as the traffic conditions, weather, time of day, day of week, road conditions, driver population, traffic pattern, and the like, are taken into consideration through the use of diverse sampling and control ramps.

This study provides specific insights in the applicability and suitability of chevron markings in high speed-speed, controlled access locations in urban Georgia area. In addition, this evaluation study may be considered part of the systematic nationwide effort to provide additional and complementary assessments of the effectiveness of chevron markings in reducing speeds. Though proposed nearly a decade ago, utilizing chevron markings for speed control is still a relatively new concept in the United States. Prior to large-scale implementation, systematic studies on the effectiveness of the chevron markings, such as this study, must be undertaken at test locations. This study helps move forward the state-of-the-practice by contributing to the evaluation of the effectiveness of chevron markings, and testing their effectiveness in reducing the speed of Georgia traffic.

CHAPTER 2. LITERATURE REVIEW

INTRODUCTION

Pavement markings are used as a means to guide or inform the road user of the existence of a potentially hazardous location and of local and federal regulations [3]. The advantage of the pavement markings over other traffic control devices (e.g., signs and traffic signals) is that pavement markings allow motorists to focus on the roadway while the information is being communicated. The MUTCD[4] lists the four basic types of pavement markings:

- Longitudinal lines – e.g., centerlines, edge lines, and lane lines;
- Transverse lines – e.g., stop line, yield line, and crosswalk markings;
- Arrows, words, and symbol markings; and,
- Special markings – e.g., raised pavement markers, TWLTL markings, etc.

The two most common types of pavement markings used to influence a driver's speed choice are longitudinal and transverse markings [5]. Several studies indicate reduced speeds given narrower lane widths [6-11]. Longitudinal markings are one mean utilized to reduce lane widths. A more commonly utilized speed reduction countermeasure is transverse pavement markings. Transverse pavement markings are generally installed in advance of horizontal curve sections, intersection approaches, work zones, and freeway off ramps to warn road users of the potentially hazardous location [3, 12]. Transverse lines typically consist of a bar or chevron pattern across the travel lane. Short bars placed only on the edge of the travel lane are called peripheral transverse lines [13, 14]. In many applications the spacing between transverse lines decreases as the driver approaches the potentially hazardous location. If a driver continues at a constant speed the decreasing spacing creates a perception of acceleration, hopefully encouraging the driver to reduce their speed [3].

PREVIOUS STUDIES

Several studies in the past have evaluated the effectiveness of the pavement markings as a speed reduction counter measure.

The first converging chevron pavement markings in the U.S. were installed in 2003 at an exit ramp located in Milwaukee, Wisconsin. A study was conducted by Drakopoulos and Vergou [2] to evaluate the chevron treatment impact on speed and safety. Speed data was collected (5 min bin data) before and 18 months after the chevron pavement marking installation. The results showed that speeds were significantly reduced during all weekday and weekend hours. The mean and the 85th percentile speed reductions were 15 and 17 mph at the downstream detector of the chevron treatment. Crash data for the test ramp and a comparison ramp were also presented in the report. It was shown that the number of crashes decreased at both ramps. However, the authors stated that the crash data was available only for a short time frame and that a statistical crash analysis could not be conducted.

A later study in Kentucky [3] was conducted to evaluate the effectiveness of several treatments (i.e., warning sign, post delineators, transverse lines, flashers) in reducing speeds. Three rural sites were included in this study. The speed measurement data revealed mixed results. One site indicated no significant speed reduction but considerable speed variance reduction for most treatments, including the transverse markings. The other two sites showed significant speed reductions under all treatments tested. For all three sites, the speeds over the 85^{th} percentile speed are more significantly affected by the treatments than lower speed values. Furthermore, the authors suggested that the use of transverse markings through the curve, as opposed to stopping at the point of curvature, as a more effective treatment application.

A comprehensive study by Katz [14] evaluated the effectiveness of peripheral transverse lines on speed reduction. Included in the study were a freeway exit ramp and two rural arterials, with each of the three sites in a different state. The results of this study also showed a mixed effect for the peripheral transverse line treatment. The freeway exit ramp at the New York site showed the most significant speed reduction at approximately four mph in mean speed and five mph in the 85^{th} percentile speed. The rural arterials in Mississippi and Texas were only slightly impacted by the treatment. The author suggested that several factors influenced the magnitude of the treatment effect including driver familiarity with the road, degree of curvature, and visibility of the pavement markings.

SPEED AS SURROGATE SAFETY MEASURE

It is well know that as speed at impact decreases the severity of a collision decreases. The purpose of a pavement markings treatment is to warn road users of a potentially hazardous location and encourage the user to reduce their speeds. This reduction in speeds at hazardous locations is expected to improve road safety [15-17]. Thus, the magnitude of speed reduction is often used as a surrogate safety measure to estimate the effectiveness of pavement marking treatments. Another measure also often used as a safety surrogate measure is speed variance. Several studies indicate that high speed variance is associated with high crash risk [18-22].

In summary, three forms of speed-related measures are used to evaluate the effectiveness of transverse pavement markings treatment [16]:

- Reduction of mean speed,
- Reduction of operating speed or the 85^{th} percentile speed, and
- Reduction of speed variance.

CHAPTER 3. EXPERIMENTAL DESIGN

STUDY SITES

The evaluation of the effectiveness of converging chevron pavement markings has been performed at two interchange locations:

- Site A: Interstate 75/85 interchange (North Atlanta)
- Site B: Interstate 75/285 interchange (North-West Atlanta)

The study sites are shown in Figure 1. These sites were selected by the Georgia Department of Transportation in consultation with the research team. The driving factor influencing the selection of these ramps was the desire to test the chevron treatment at freeway-to-freeway ramp locations where the ramp geometry requires a significant decrease in vehicle speeds. As seen in the background discussion, the desired direct impact of the chevron implementation is a reduction of vehicle speeds prior to the controlling ramp geometry, potentially resulting in an improved safety performance of the ramps.

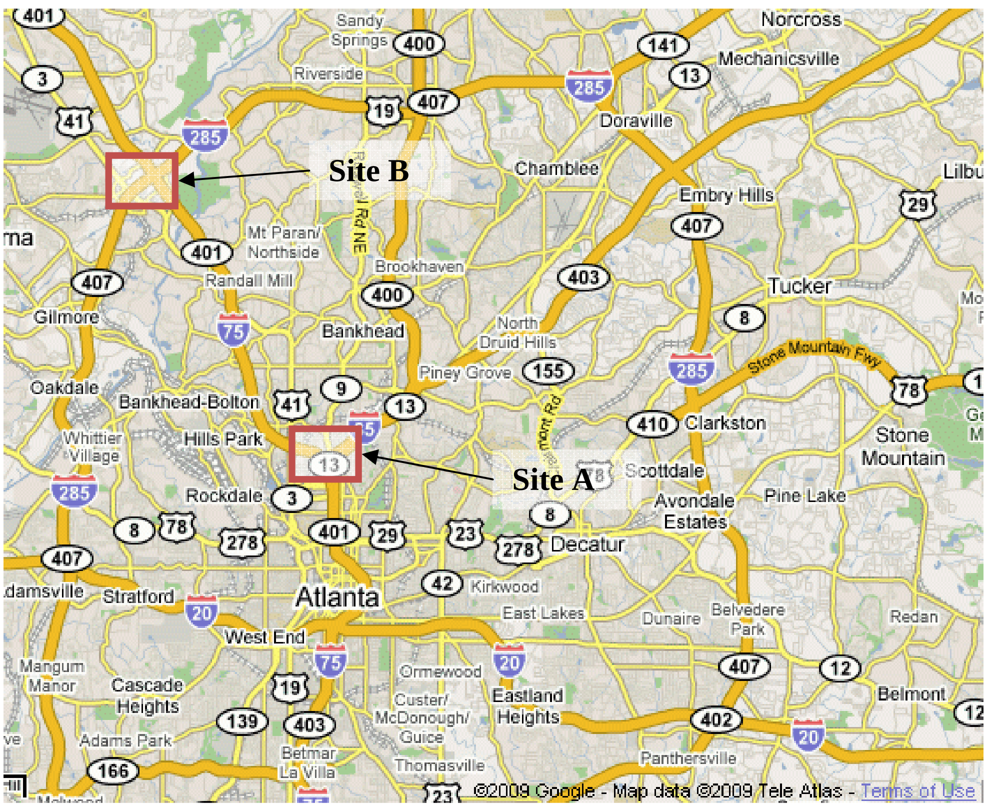

Figure 1: Study Sites

To monitor potential underlying changes in traffic operations at the interchange, two ramps were selected at each site: a treatment ramp (i.e., the ramp on which the chevron treatment would be installed) and a control ramp (i.e., a ramp with no treatment applied).

At Site A, the treatment ramp is the interchange ramp from I-75 Southbound to I-85 Northbound. The ramp serves approximately 18,000 weekday vehicles per day per lane (vpdpl) and 14,000 weekend vpdpl. There are approximately two percent heavy vehicles. Shown in Figure 2 are the data collection stations installed at this interchange. Data collection stations are placed immediately upstream (S011) and downstream (S012) of the chevron markings. The distance between the two stations is approximately ¼ mile. The average speeds at the upstream and downstream stations before the chevron markings installation are 51 mph and 31 mph, respectively. A third station, S013, collects main line traffic data upstream of the chevron installation. Also seen in Figure 2 are the Site A control ramp data collection stations, S031 and S032. These collect the traffic data for the control ramp from I-85 Southbound to I-75 Northbound. These data collection stations where chosen to encompass the likely location of a chevron installation had this been a treatment ramp. In Figure 2 the yellow dashed line represents the direction of travel of the treatment ramp and the red dashed line represents the direction of travel of the control ramp. The lane configuration of the treatment ramp of Site A is shown in Figure 3. Table 1 provides a summary of the data collection stations.

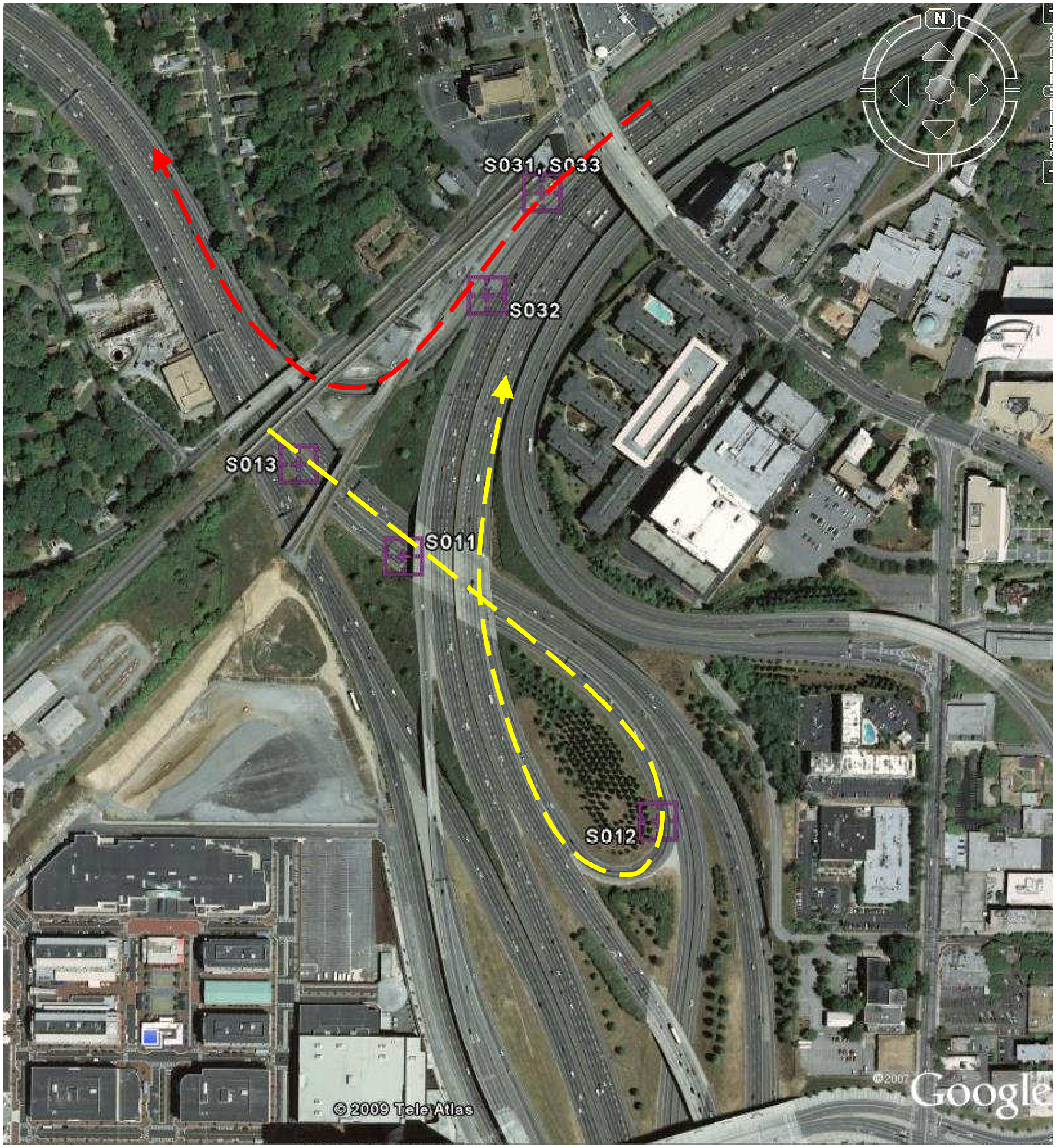

Figure 2: Site A Data Collection Stations with Travel Direction for the Treatment Ramp (Yellow Line) and the Control Ramp (Red Line)

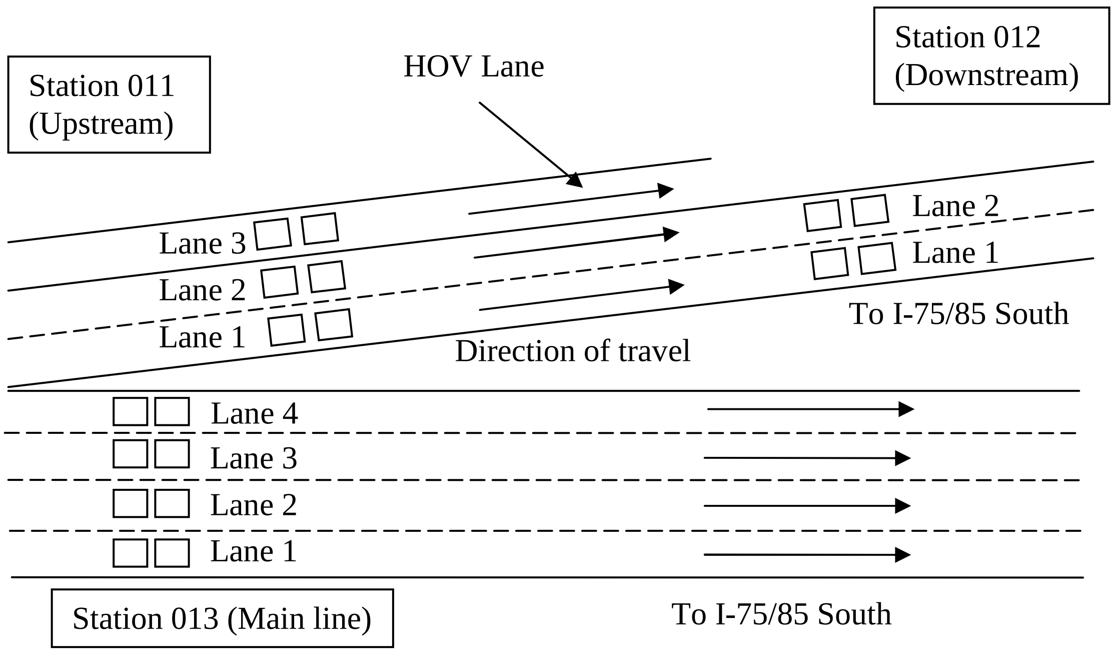

Figure 3: Site A Treatment Ramp Lane Configuration

At Site B, the interchange ramp from I-285 Eastbound to I-75 Northbound was selected as the treatment ramp and the interchange ramp from I-75 Southbound to I-285 Westbound serves as the control ramp. The treatment ramp serves approximately 18,600 weekday vpdpl and 16,700 weekend vpdpl, with six percent truck traffic. The treatment ramp is composed of two data collection stations. Station S021 is located upstream of the chevron markings location and the station S022 is located immediately downstream of the markings location. The distance between the two stations is approximately ¼ mile. The average speeds at the upstream and downstream stations before the chevron markings installation are 60 and 45 mph, respectively. The treatment ramp lane configuration is shown in Figure 5. Data collection equipment was placed at the upstream (S041) and downstream (S042) stations of the Site B control ramp. As with Site A, the control ramp data collection points were selected to be representative of the chevron markings location had this been a treatment ramp. The locations of data collection stations at Site B are depicted in Figure 4. Similar to Site A, the yellow dashed line represents the direction of travel of the treatment ramp and the red dashed line represents the direction of travel of the control ramp.

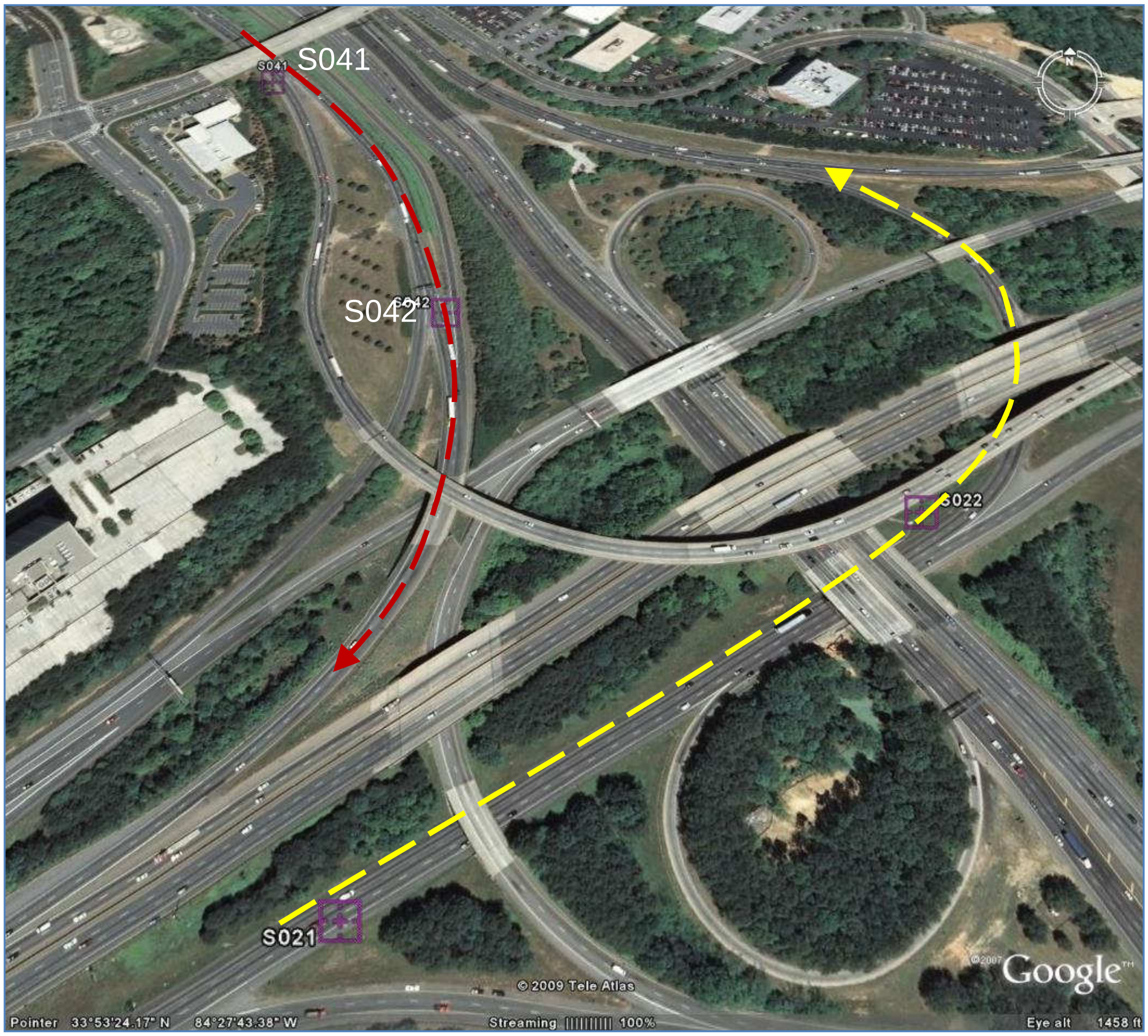

Figure 4: Site B Data Collection Stations with Travel Direction for the Treatment Ramp (Yellow Line) and the Control Ramp (Red Line)

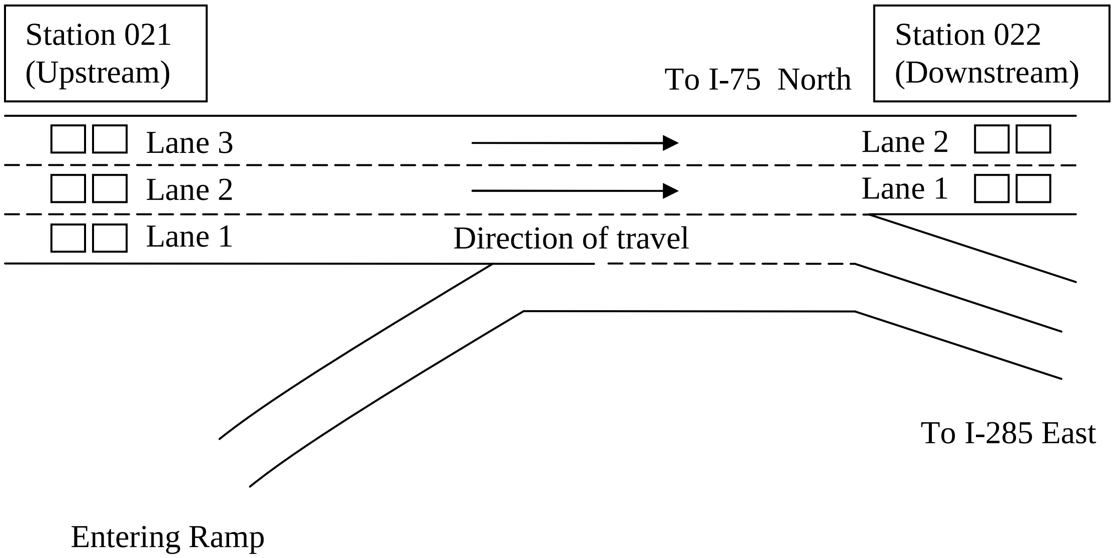

Figure 5: Site B Treatment Ramp Lane Configuration

Table 1: Data Collection Station Descriptions

Site	Interchange Location	Test Ramp			Control Ramp		
		Upstream	Downstream	Mainline	Upstream	Downstream	Mainline
A	I-75/85	S011	S012	S013	S031	S032	S033
B	I-75/285	S021	S022	-	S041	S042	-

DATA COLLECTION EQUIPMENT

Each detection station consists of a dual loop with a piezoelectric detection device between the two inductance loops. The piezoelectric device is intended to allow for an accurate measurement of the distance between axles and increase the accuracy of the classification of the vehicles.

DATA DESCRIPTIONS

Binned Data

The equipment used for data collection natively supported the collection of binned data, that is, providing counts of the number of vehicles within certain user selectable speed ranges (e.g., 0 mph to 5 mph, 6 mph to 10 mph, 10 mph to 15 mph and so on) for a given time interval (e.g., 5 minutes). The maximum number of speed bins allowed by the data collection equipment was 20. For this study variable bin sizes were adopted in order to focus the smallest granularity (smallest bins) in the zone of interest (anticipated impact).

A sample interval of five minutes was selected to aggregate speed and traffic volume data. The bins limits used are provided in Appendix A. The binned data was downloaded remotely from the data collection devices daily through the use of a cellular modem.

PVR Data

In addition to binned data, Per-Vehicle Record (PVR) data was also recorded. The equipment did not natively support the recording of PVR data. However, since the equipment supported the streaming of PVR data, external data recorders were utilized to collect the PVR data. Given equipment and communication limitations, PVR data was not able to be downloaded remotely from the sites. Thus, the data on the external drives was downloaded during periodic site visits over the study period.

The PVR record data for each vehicle contained values corresponding to the following variables:

- Time stamp (to the nearest second),
- Lane number,
- Vehicle class,
- Vehicle speed (to the nearest tenth of a mile),
- Vehicle length,
- Time headway (between front bumpers of consecutive vehicles), and
- Distance between axles.

DATA QUALITY ANALYSIS

As part of the equipment installation, the speed detections were calibrated by the equipment vendor. Speeds were also spot checked by the research team using a laser gun. Based on the vendor calibrations and checked vehicle speeds, the equipment generally provided a high level of accuracy. However, it is noted that occasionally speeds were recorded by the detection device significantly different from that observed. This typically was a result of a vehicle changing lanes while crossing the detector pairs. It is also noted that speed calibration was conducted while the traffic was moving at typical (uncongested) speeds. Detectors were not calibrated for congested scenarios and become potentially less accurate as speeds drop below 10 mph. Finally, once the initial data collection was completed, the devices were not re-calibrated during the study period. As the critical measure was the relative change in speeds, not the absolute speed measure, it was determined to leave the detector settings once the project was under way.

Binned and PVR traffic count data were compared to determine the consistency between these methods. The binned and PVR data collected on April 27, 2008, from 00:00:00 to 23:59:59 of the station S021 (the upstream station of Site B) were selected for this analysis.

Binned vs. PVR – Traffic Volume

During the 24-hour period, the total traffic volume recorded using the binned data was 31,226 vehicles while the total PVR traffic volume recorded was 30,457 vehicles. Thus, the binned method counted 769 more vehicles, approximately 2.5 percent, than the PVR method. For a more detailed comparison of the PVR data to the binned data, the PVR traffic volume of lane numbers 2 and 3 were aggregated into 5 minutes bins over the 24-hour period. Figure 6 illustrates the 5-minute traffic counts of binned (black solid line) and PVR (red dashed line) data. As seen, the two methods generally record similar traffic volumes.

The difference between the 5 minutes PVR counts and binned volume data was calculated and the cumulative difference plotted against time of day, as shown in Figure 7. It is seen that the binned and PVR counts are rather consistent from midnight to noon. However, the PVR undercounted the traffic volume in the afternoon and evening, e.g., the count difference between 15:00 and 20:00 is approximately 70 percent of the total difference. The larger difference in the afternoon is likely due to higher traffic volume at this particular location, exceeding the capabilities of the data collection equipment to stream and record the PVR data. This hypothesis is supported by field observations, where it was noted that under high demand conditions the ability of the detection device to stream PVR data could be compromised, resulting in some missed vehicles.

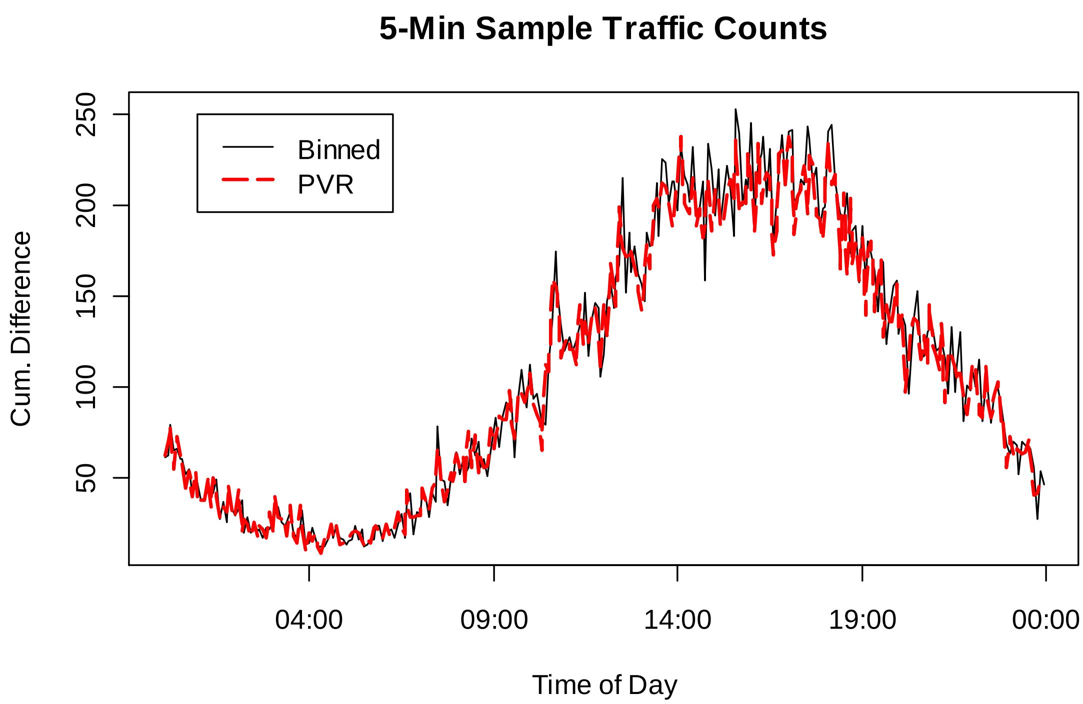

Figure 6: Five-Minute Sample Interval of Traffic Counts from Binned (Black) and PVR (Red) Data

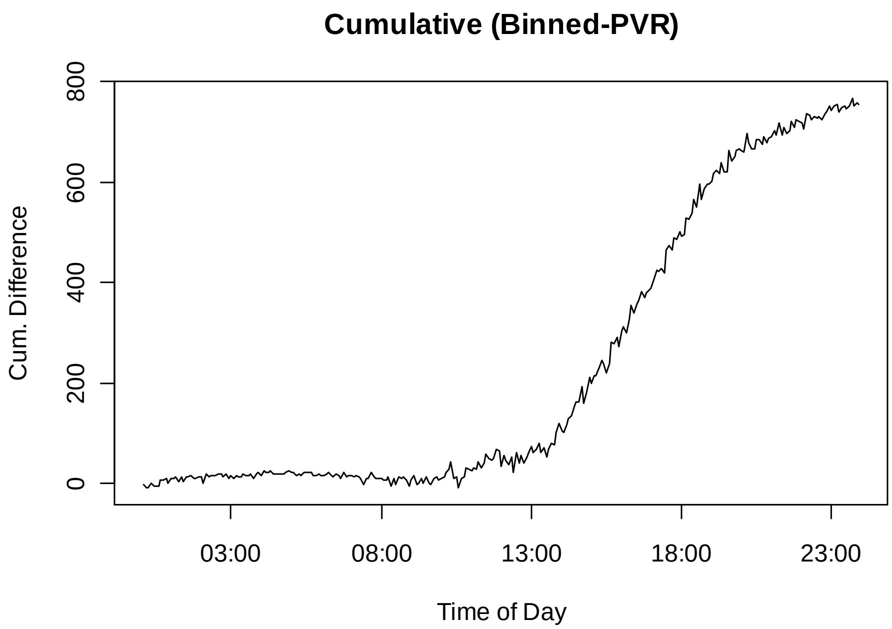

Figure 7: Cumulative Difference between Binned and PVR Counts vs. Time of Day

Both methods appeared to offer similar overall counts and both appear equally suitable for data analysis. However, PVR data does offer the advantage of allowing for post-processing of individual vehicle data, providing a higher granularity in the data analysis.

Finally, it is also noted that while equipment was in the field throughout the study period, the data collection is not continuous. Inherent instability in the data collection equipment did result in random periodic outages spread among the data collection sites, requiring both remote and in-field equipment resets. Data would not be recorded between the equipment outage and the equipment reset. This problem was found to particularly impact the PVR data, where intermittent data outages (on the order of an hour to a few days) are witnessed, often resulting in higher binned data counts than PVR data. Fewer PVR data points are also typically available on a daily basis as the PVR data recording was interrupted daily during the period the binned data was downloaded. However, even with these instabilities, significant and sufficient quantities of data were collected to allow for a detailed analysis of the chevron effects. It is also noted that in a few instances smaller binned data sizes are seen, usually indicating loss of binned data primarily due to equipment failure. The dates for which data is compared for analysis in Chapter 4 are listed in Table 2.

Table 2: Data Collection Periods

Before		After 1 Week		After 6 months	
Date	**Number of Datapoints**	**Date**	**Number of Datapoints**	**Date**	**Number of Datapoints**
Wednesday, March 05, 2008	283180	Tuesday, April 15, 2008	571257	Sunday, October 05, 2008	336732
Thursday, March 06, 2008	395762	Wednesday, April 16, 2008	596086	Monday, October 06, 2008	451190
Friday, March 07, 2008	326374	Thursday, April 17, 2008	623674	Tuesday, October 07, 2008	491612
Saturday, March 08, 2008	191602	Friday, April 18, 2008	643340	Wednesday, October 08, 2008	426438
Sunday, March 09, 2008	173028	Saturday, April 19, 2008	562284	Thursday, October 09, 2008	462959
Monday, March 10, 2008	249178	Sunday, April 20, 2008	484244	Friday, October 10, 2008	415615
Tuesday, March 11, 2008	303016	Monday, April 21, 2008	578364	Saturday, October 11, 2008	332461
Wednesday, March 12, 2008	419045	Tuesday, April 22, 2008	577808	Thursday, October 23, 2008	729184
Thursday, March 13, 2008	468666	**After 1 Month**		Friday, October 24, 2008	794618
Friday, March 14, 2008	461956	**Date**	**Number of Datapoints**	Saturday, October 25, 2008	739004
Saturday, March 15, 2008	353201	Sunday, May 11, 2008	434145	Sunday, October 26, 2008	724742
Sunday, March 16, 2008	309782	Monday, May 12, 2008	568240	Monday, October 27, 2008	872460
Monday, March 17, 2008	402558	Tuesday, May 13, 2008	586120	Tuesday, October 28, 2008	1048488
Tuesday, March 18, 2008	440494	Wednesday, May 14, 2008	536190	Wednesday, October 29, 2008	1043042
Wednesday, March 19, 2008	409918	Thursday, May 15, 2008	526469	**After 9 Months**	
Thursday, March 20, 2008	325422	Friday, May 16, 2008	545127	**Date**	**Number of Datapoints**
Friday, March 21, 2008	259015	Saturday, May 17, 2008	459156	Saturday, January 31, 2009	453449
Saturday, March 22, 2008	222477	**After 3 months**		Sunday, February 01, 2009	408671
Sunday, March 23, 2008	225177	**Date**	**Number of Datapoints**	Monday, February 02, 2009	510259
Monday, March 24, 2008	282247	Wednesday, July 09, 2008	591348	Tuesday, February 03, 2009	524227
Tuesday, March 25, 2008	342043	Thursday, July 10, 2008	548960	Wednesday, February 04, 2009	525331
Wednesday, March 26, 2008	453546	Friday, July 11, 2008	580931	Thursday, February 05, 2009	540291
Thursday, March 27, 2008	519751	Saturday, July 12, 2008	544835	Friday, February 06, 2009	522603
Friday, March 28, 2008	522648	Sunday, July 13, 2008	429413		
Saturday, March 29, 2008	473260	Monday, July 14, 2008	561207		
Sunday, March 30, 2008	434430	Tuesday, July 15, 2008	569518		
Monday, March 31, 2008	531907				
Tuesday, April 01, 2008	549078				
Wednesday, April 02, 2008	463415				
Thursday, April 03, 2008	349529				
Friday, April 04, 2008	432163				
Saturday, April 05, 2008	403907				
Sunday, April 06, 2008	376822				
Monday, April 07, 2008	526925				
Tuesday, April 08, 2008	525509				
Wednesday, April 09, 2008	530385				
Thursday, April 10, 2008	526402				

The quantitative data analysis in the preceding discussion provided a check for inconsistencies in the reporting methods of the data collection instruments. To check for any anomalies in the PVR data, a final visual confirmation was deemed necessary. It was not possible to conduct this detailed level visual confirmation on the binned data as individual vehicle speeds are not available, with potential anomalies essentially lost in the aggregation.

Error! Reference source not found. Figure 8 is a plot of the individual PVR speeds versus the time of day (labeled as seconds from midnight), irrespective of the date, for detector 011. The plots for the other detectors may be found in Appendix C. Data from the different periods were superimposed to study the possible presence of any outlying data clusters. In the legend, the “n” indicates the number of points corresponding to each period plotted in the graph. No outstanding shift was observed at any detector location. Some periods of congestion are seen, for example in the before data between approximately 55,000 and 60,000 seconds some flow breakdown is observed. It is also noted for all time periods (i.e., before, 1 week after, 1 month after, etc.) that a few very high speeds, ranging from 70 mph to over 100 mph, were noted. Given the geometry of ramps, it is probable that these are erroneous data points, likely the results of vehicles changing lanes while crossing a detection zone, closely spaced vehicles, or some other detection error. As direct observation of the vehicles in question is not possible, it may not be confirmed with certainty if these are erroneous speeds, thus these data points have not been removed from the data set. Only those speeds in excess of 100 mph are not considered in the analysis as these values fall well outside any reasonable range. It is also noted that there was a period (spanning several days) when the detectors at Site A were constantly generating suspiciously high speeds. The data for this period was eliminated entirely.

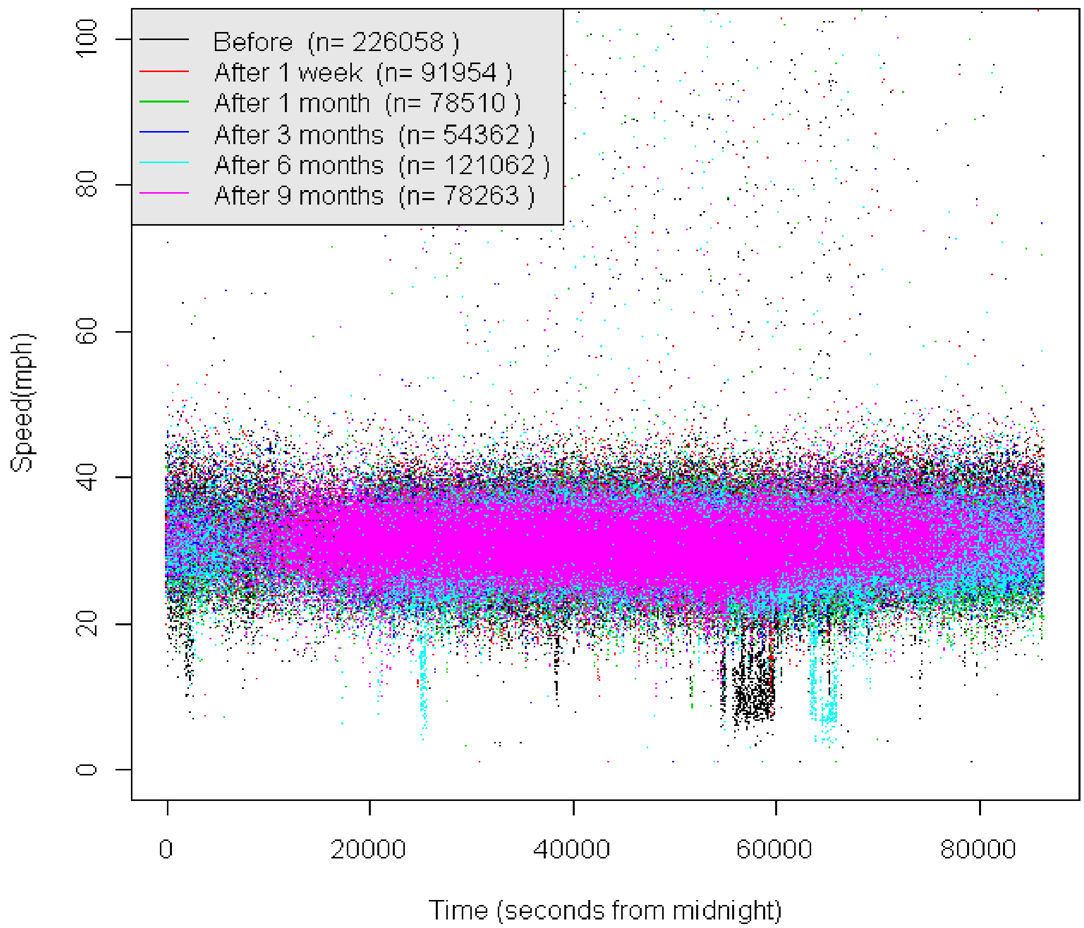

Figure 8: Overlapped Time Series plots with PVR Data at Detector 011 Lane 1

In the next chapter, the findings from a detailed analysis of the PVR and binned data are reported.

CHAPTER 4. DATA ANALYSIS

The initial analysis considers the downstream detectors at each treatment ramp, that is, Site A - detector site 021, and Site B - detector site 022. These detector locations should reflect any change in vehicle speeds entering the controlling ramp geometry resulting from the chevron treatments. As discussed in Chapter 3, for each of these detector locations, speed distributions for each data collection time period were recorded during the data collection process. These data will now be examined in terms of both direct and cumulative speed distributions and how these distributions change across time periods. A leading vehicle (i.e., free flow) analysis and Monte Carlo based analysis incorporating the upstream detectors and control ramps are also conducted.

SPEED CUMULATIVE DISTRIBUTION FUNCTIONS

For each data collection time period, Figure 9 illustrates the Cumulative Distribution Function (CDF) of the PVR speed data for lane one of detection site 021. The CDF plot for lane one of this site using binned speed data is shown in Figure 10 (refer to Appendix A for bin sizes). Figure 11 provides the CDF plots for lane one data collection detector site 022. In all of these figures, the "n" in the legend represents the number of data points available.

While some shifts in the plot shapes are apparent in the binned data (Figure 10), the low-resolution of the data makes interpretation difficult. The range of speeds covered (i.e., 0 to 70+ mph) and the 20-bin limitation result in bin sizes of 2 to 3 mph at the highest resolution. Thus, any data collection time period speed differences less than 2 to 3 mph are difficult to distinguish. This limitation affects most of the binned detector data across the treatment and control sites. The potential effect of the chevrons, which may be smaller than this bin size, is therefore difficult to determine using the binned data.

Since the PVR data are available at a higher resolution, the remaining analysis focuses on these data. The speed distribution shifts for detector site 021 can be seen clearly in the PVR data (Figure 9). There is shifting of ramp speeds to lower (slower) levels at one, three, six and nine months after treatment, with the largest change observed after one month. By the nine month data collection period, the largest observed shift at any percentile is on the order of 0.5 to 1 mph. Data from detector site 022, illustrated in Figure 11, shows the same general trend with slower speeds observed immediately after the chevron treatment installation and speeds generally returning to the pre-treatment levels by the nine month period. The only significant differences in the nine month data at this detector site are seen in the lower percentiles, where fewer low speed vehicles are observed in the before treatment data. Similar results were seen in the lane two data for detector site locations 011 and 022 (see appendix D). Only lane two of detector site 022 demonstrated any consistent speed reduction at the nine month period, generally on the order of 1 to 2 mph.

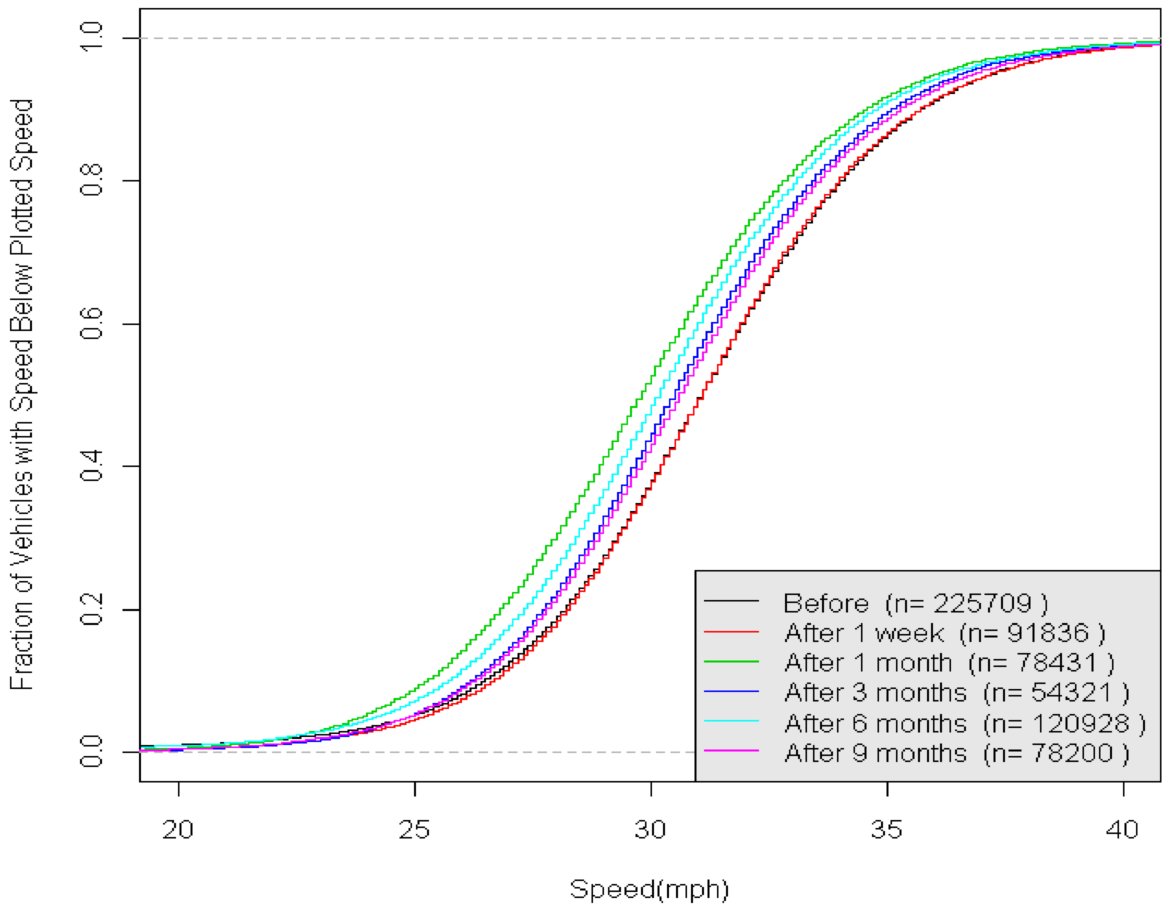

Figure 9: PVR data CDF Plot, Lane 1 of Detector Site 012

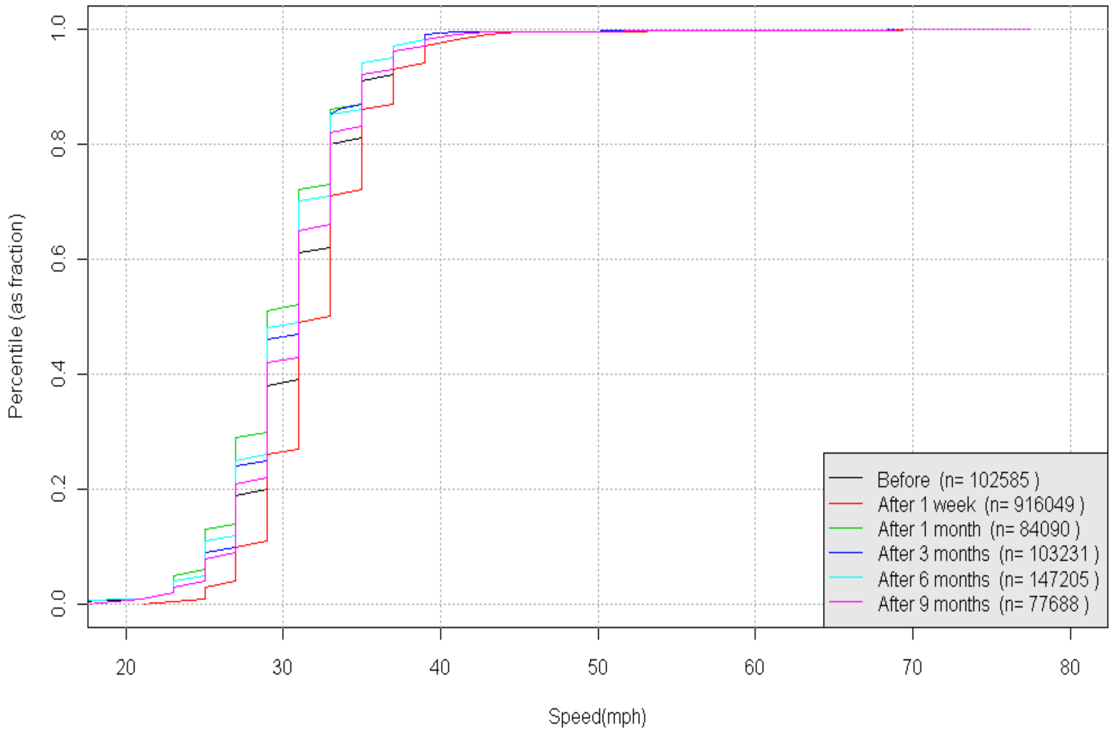

Figure 10: Binned Data CDF Plot, Lane 1 of Detector Site 012

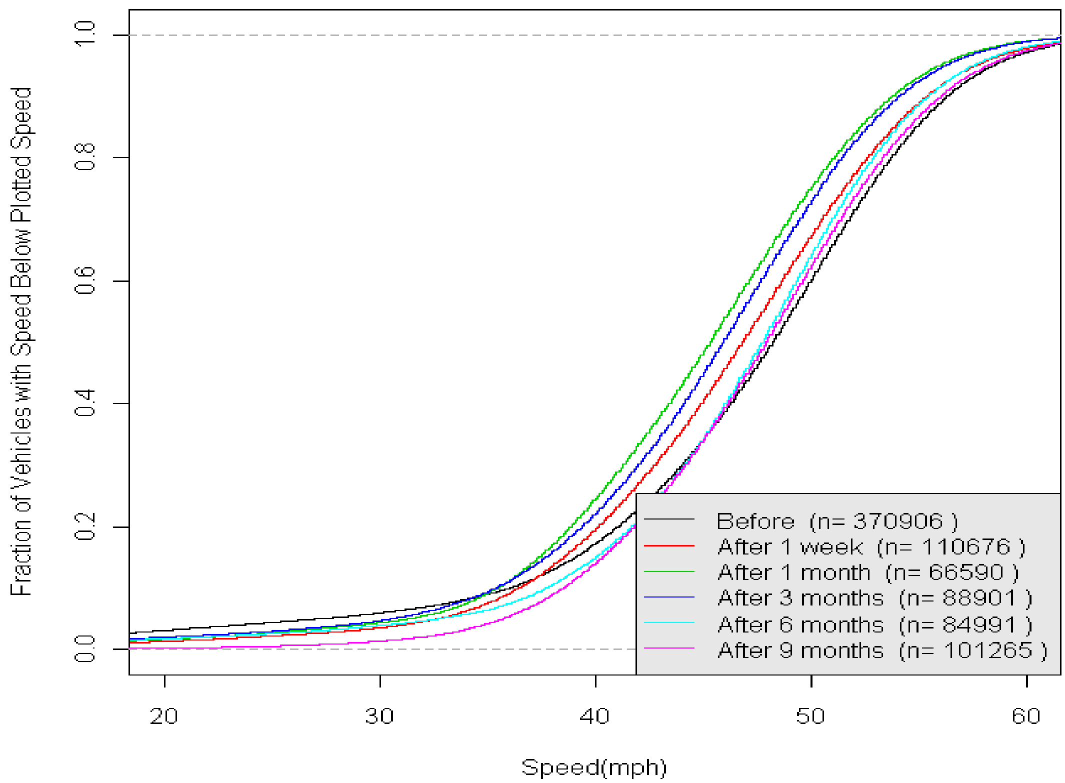

Figure 11: PVR Data CDF plot, Lane 1 of Detector Site 022

SPEED DENSITY FUNCTION

Figure 12 is a plot of the speed density function (equivalent to a probability density function (PDF)) of the Lane 1 PVR data at detector site 012. The shifting of the distributions that were observed in the CDF plots can also be seen in the PDF plot. In this figure it is also seen that the form of the speed distributions is generally constant between time periods. Only the 1 month data seems to show some skewing of the distribution to lower speeds, with the remaining distributions demonstrating little change in the speed variability. As with the CDF plots (see Appendix E) similar results are seen across all lanes of detector sites 011 and 022. Again, only slight changes in the distributional form are seen by the nine month period, indicating minimal lasting impact of the chevron treatment on the speed variability.

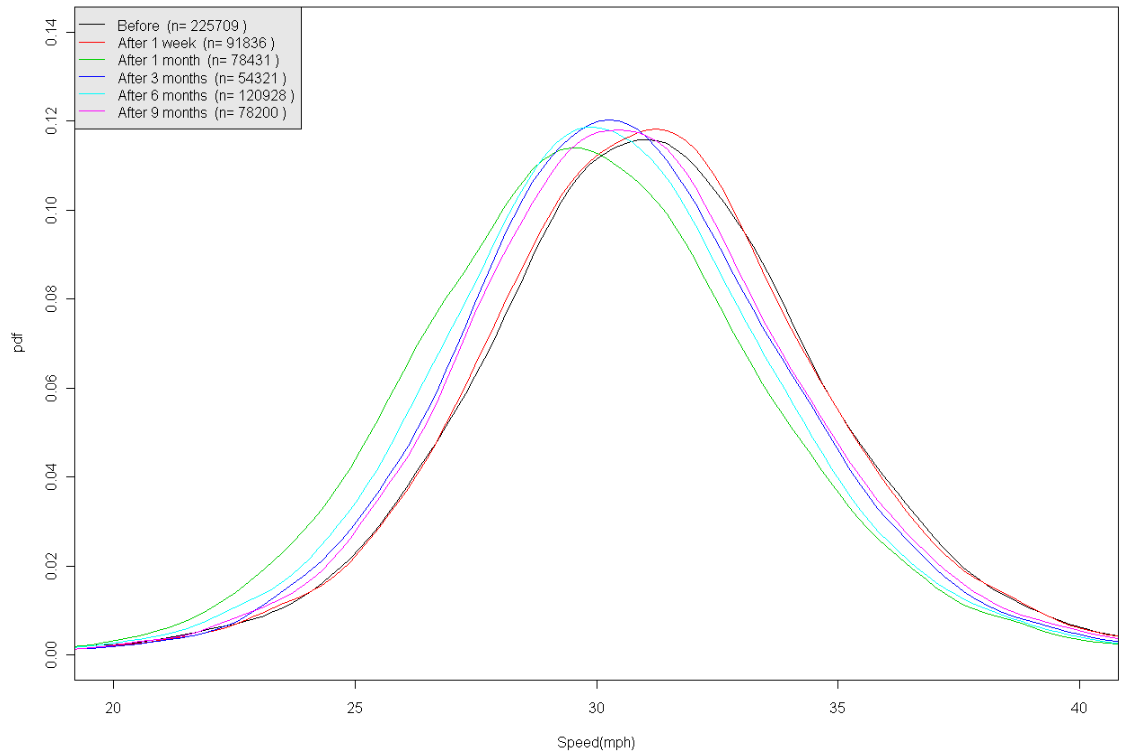

Figure 12: PVR Data PDF plot, Lane 1 of Detector Site 012

ANALYSIS OF SPEED DIFFERENCE

To further illustrate the differences in the speed distributions before and after treatment, the speed at each percentile of each distribution is compared to the pre-treatment value. Figure 13 illustrates the speed differences for lane one of detector site 012 and Figure 14 shows the results for lane one of detector site 022. In these plots a negative value indicates a speed reduction from the before to after treatment time periods, a positive value indicates a speed increase. For example, in Figure 13, at the 40th percentile (i.e., 0.4) the speed difference between the before treatment data and the one month data is approximately negative 1.5 mph, reducing to approximately negative 0.5 mph by the nine month period. This indicates a speed reduction one month after the treatment of 1.5 mph, lessening to 0.5 mph by nine months after treatment installation. This result is in agreement with earlier observations based on the CDF plot. Further, it is seen in Figure 13 that speed reductions occur over broad percentile range. From approximately the 5th to past the 99th percentile, the 9 month period speed reductions are consistently on the order of 0.5 mph. While there are some clear shifts in the before versus nine months after speed data, the size of the deviations appears to be very small over most of the distributional range. Figure 14 illustrates the same effects for detector site 022, i.e., relatively minimal impacts by the nine month period over the range of observed speeds with the lower percentiles speeds seen to increase by the nine month period. As seen in Appendix F, the finding for the lane two speeds on the detector site 012 and 022 are similar.

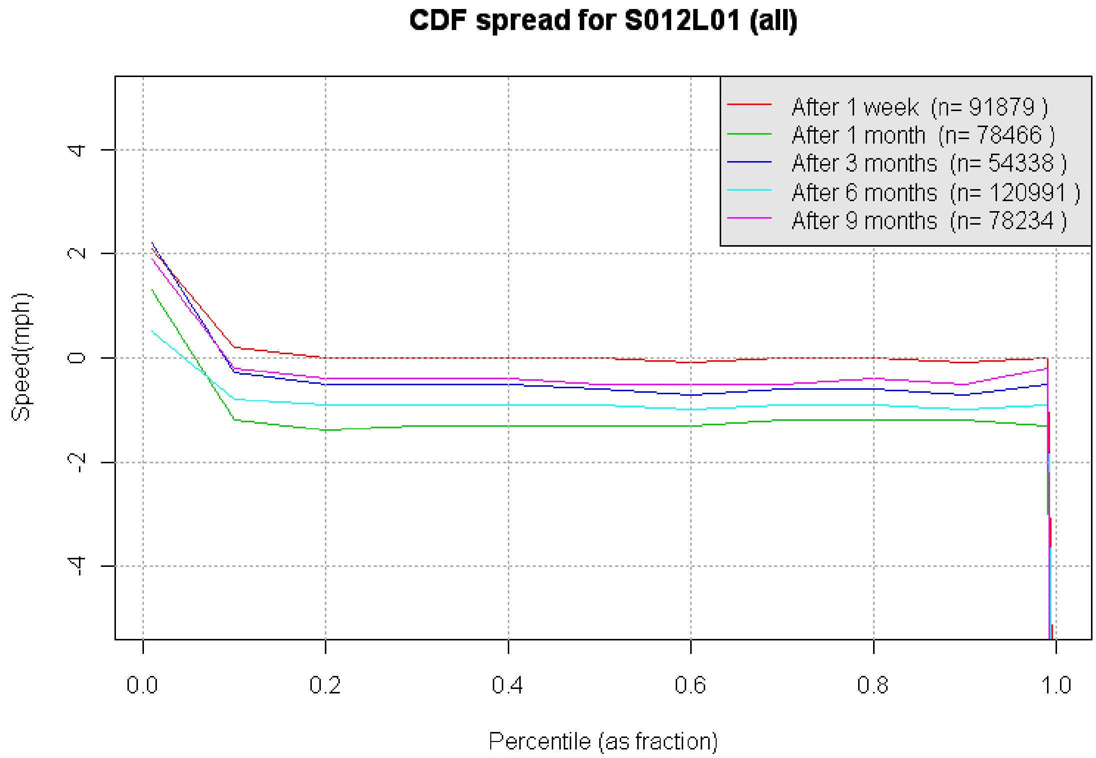

Figure 13: PVR Data Percentile Speed Difference for All Vehicles, Lane 1 of Site 012 Lane 1

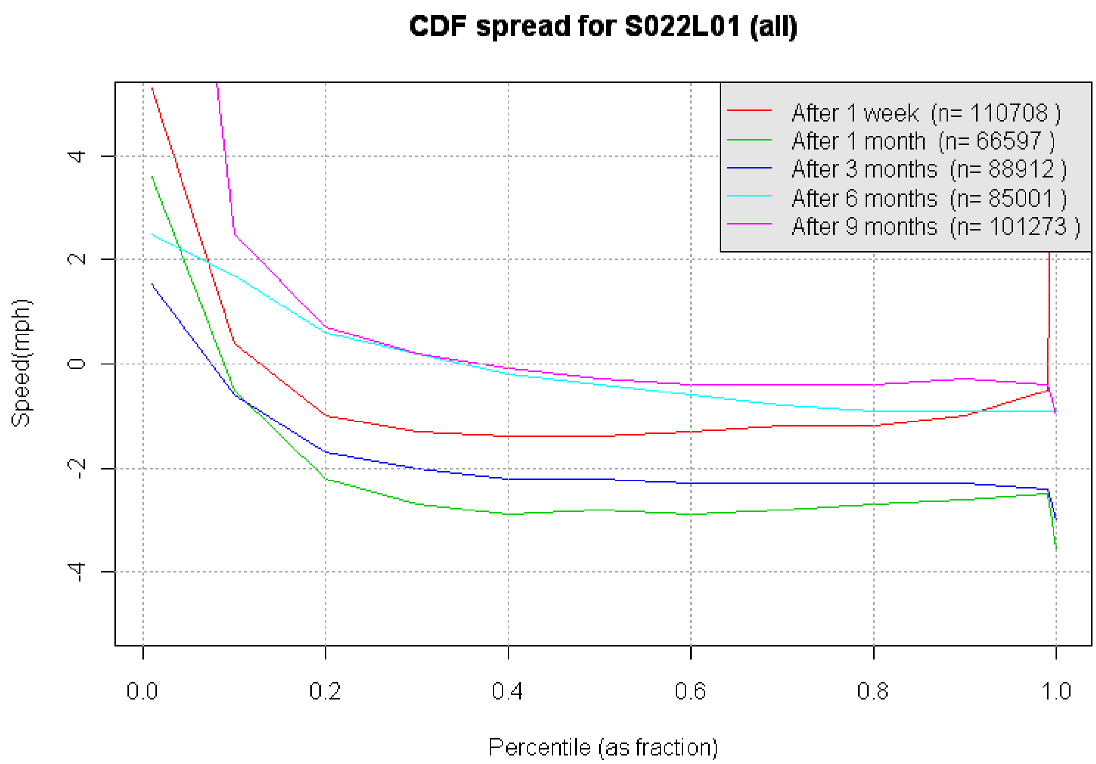

Figure 14: PVR Data Percentile Speed Difference for All Vehicles, Lane 1 of Site 022

LEAD VEHICLE ANALYSIS

As stated earlier, an expected effect of the chevron treatment is a reduction in driver speeds. However, if a vehicle is closely following another vehicle, as is typical in congested conditions, it is not known if the subject vehicle speed selection is due to roadway conditions (e.g., ramp geometry, chevrons, signage, etc.) or car-following behavior. Thus far, the analysis for each time period has utilized all available data for each time period. However, it is not known if similar percentages of vehicles experienced congested and uncongested traffic conditions across time periods. Differences in congestion levels could potentially result in an underlying bias due to differing percentages of forced flow behavior. To investigate this concern the vehicle data is separated into leading and following vehicles. Any vehicle with headway of 5 seconds or more is considered a leading vehicle for this analysis. The general assumption is that a leading vehicle, or platoon leader, is free to travel at its desired speed. Thus, lead vehicles should more clearly indicate any effect of the chevron treatment. The CDF speed differences for the leading vehicles are plotted in Figure 15 for lane one of detector site 012. While the sample size (n) is nearly half that of the all vehicle data, the magnitude and direction percentile speed differences for the leading vehicles are similar to that observed for all vehicles (Figure 13). That is, the lead vehicle analysis results in nearly the same speed distribution, and speed difference, as the all vehicle analysis. This same result is also seen in the lead vehicle analysis results for the lane 2 of detector site 012 and all lanes of detector site 022 (figures found in Appendices G, H and I).

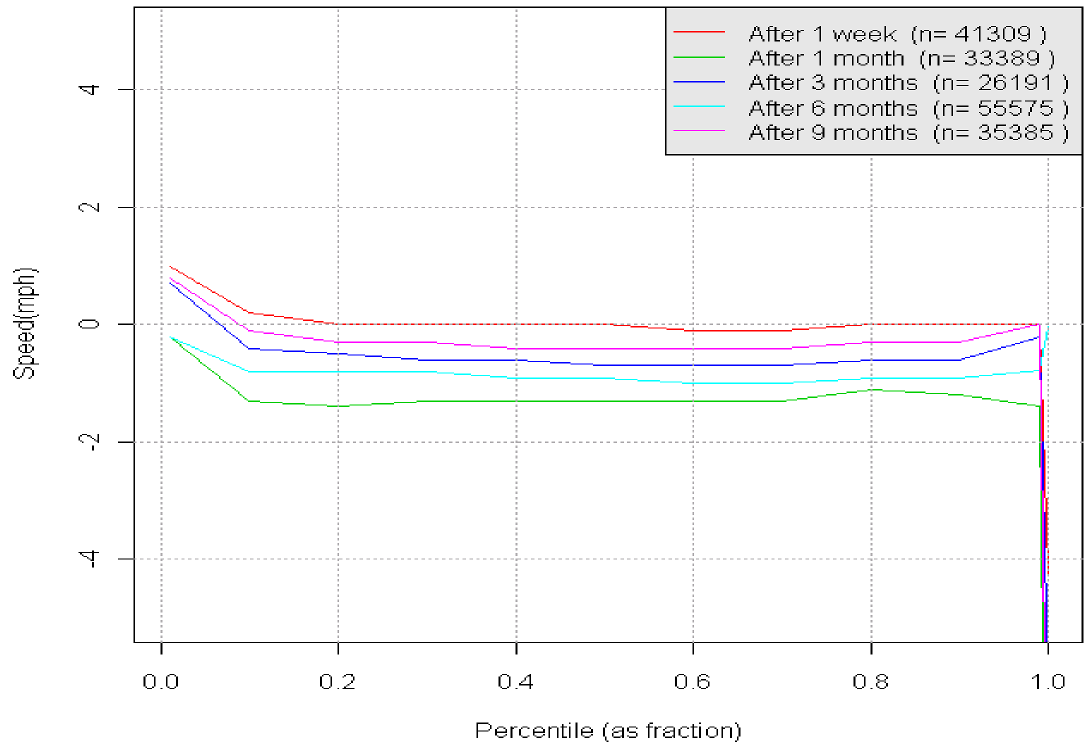

Figure 15: Spread between CDF plots with PVR Data at Detector Site 012 Lane 1 for Leading Vehicles

MONTE CARLO ANALYSIS

Monte Carlo analysis utilizes random sampling to readily allow for an unbiased statistical evaluation of the mean difference between data sets with different population parameters. For example, in the first Monte Carlo analysis of this effort, a vehicle speed is randomly selected from the before data and vehicle speed is randomly selected from the after data, for a detector location. This creates a before-after speed data pair. The difference between the individual speeds of this data pair represents a single sample of the before-after speed difference. By drawing multiple samples, the average of these differences is an unbiased estimate of the mean speed difference between the time periods. Since only the mean differences between the populations (i.e., the before and after data sets) is being considered, it is not required that the before-after speed data pair be for the same vehicle.

In this effort several different Monte Carlo based analyzes were performed:

1) Estimate of the difference in the mean speed at the downstream treatment detector locations across the before and after time periods.
2) Estimate of the difference in the change in speed between the upstream and downstream treatment detectors across the before and after periods.
3) Estimate of the difference in the mean speed at downstream control detector locations across the before and after time periods.
4) Estimate of the difference in the change in speed between the upstream and downstream control ramp detectors across the before and after periods.

The first analysis is undertaken for the downstream treatment detectors, specifically detector sites 012 (Site A) and 022 (Site B). This analysis allows for a more formal estimate of the mean speed difference observed on the chevron treatment ramps as the vehicles enter the controlling ramp geometry than that found in the earlier discussion. The second analysis seeks to determine if there is a difference in the speed reduction through the chevron treatment area across the before and after time periods. This analysis explores the possibility that a background trend in increasing, or decreasing, traffic speeds has masked the treatment effect. For example, earlier discussion implied minimal impact on speed at the downstream detectors by the ninth month. It is possible that over this time period background speeds had increased. Thus, the mean speed entering the chevron treatment zone would be higher. If the vehicle speeds exiting the treatment zone remained unchanged than the speed reduction through the zone would have increased between the before and after time periods. By considering only the downstream detectors this potential treatment impact could be overlooked.

The third and fourth Monte Carlo analyzes are similar to the first and second, except that they are conducted on the control ramp data. The control ramp findings may then be compared to the treatment ramp findings to determine if the measured effects ,or lack of, are a result of the chevron treatment or a background traffic trend. For example, the earlier analysis found minimal impact on the speed as vehicles entered the treatment ramp controlling geometry. However, if the control ramps show an increase in speed on their downstream detectors, indicating a background increasing speed trend, then a speed reduction may be attributed to the chevron treatment equal to the increase in speed on the control ramp that was not witnessed on the treatment ramp.

Error! Reference source not found. summarizes the results for the before treatment versus ninth month comparisons on Site A (I-75/I-85 Interchange) and Site B (I-285/I-75 Interchange). For brevity, this discussion focuses on the nine month data. The full Monte Carlo analyzes across all time periods are presented in Appendix B. The plots of the data used in the Monte Carlo analysis are available in Appendices J, K, and L. For each analysis, three iterations of the Monte Carlo analyzes were performed. Each analysis iteration drew a sample of 2000 data points (with replacement) from a population of roughly 100,000 vehicles in each period. Each vehicle speed was chosen randomly from each period's dataset. Averages are computed across the three iterations using a pooled estimate. Only lead vehicle speeds are utilized for the Monte Carlo analysis.

Table 3: Monte Carlo Results

Speed Measurement	Ramp Type	Detector	Before Treatment (95% CI) (mph)	Nine Months After Treatment (95% CI) (mph)	Mean Diff Ninth Month - Before (95% CI) (mph)	Mean Diff Significant at 95% level
Downstream Detector Mean	Site A Treatment	S012 Left Lane	31.74 (31.55,31.92)	31.55 (31.34,31.75)	-0.19 (-0.47, 0.09)	No
		S012 Right Lane	32.42 (32.25,32.60)	32.13 (31.97,32.29)	-0.29 (-0.53, -0.06)	Yes
	Site A Control	S032 Left Lane	40.37 (40.13,40.61)	40.55 (40.31,40.78)	0.18 (-0.15, 0.51)	Yes
Reduction Between Detectors	Site A Treatment	S011 to S012 Left Lane	-20.28 (-20.63, -19.92)	-21.91 (-22.28, -21.55)	-1.64 (-2.15,-1.13)	Yes
		S011 to S012 Right Lane	-21.06 (-21.43, -20.70)	-22.31 (-22.65, -21.97)	-1.24 (-1.74,-0.74)	Yes
	Site A Control	S033 to S032 Left Lane	-16.99 (-17.55, -16.44)	-17.16 (-17.75, -16.56)	-1.05 (-1.79,-0.32)	Yes
Downstream Detector Mean	Site B Treatment	S022 Left Lane	48.03 (47.65,48.41)	48.47 (48.16,48.78)	0.44 (-0.05,0.93)	No
		S022 Right Lane	48.16 (47.76,48.57)	47.68 (47.37,47.99)	-0.48 (-0.99,0.03)	No
	Site B Control	S042 Left Lane	51.54 (51.20,51.88)	52.39 (52.08,52.71)	0.85 (0.39,1.32)	Yes
		S042 Right Lane	52.59 (52.22,52.97)	54.07, (53.76,54.39)	1.48 (0.99,1.96)	Yes
Reduction Between Detectors	Site B Treatment	S021 to S022 Left Lane	-12.32 (-12.90,-11.75)	-13.63 (-14.09,-13.16)	-1.30 (-2.04,-0.56)	Yes
		S021 to S022 Right Lane	-11.61 (-12.23,-10.99)	-14.16 (-14.63,-13.70)	-2.55 (-3.32,-1.77)	Yes
	Site B Control	S041 to S042 Left Lane	-0.22 (-0.72,0.28)	-3.22 (-3.66,-2.78)	-3.00 (-3.67,-2.33)	Yes
		S041 to S042 Right Lane	-0.68 (-1.21,-0.15)	-3.04 (-3.52,-2.56)	-2.36 (-3.08,-1.64)	Yes

Estimate of the difference in mean speed at the downstream treatment detector locations across the before and after time periods.

The first result discussed from the Monte Carlo analysis is the speed on the treatment ramps as the vehicles cross the downstream detectors, entering the controlling ramp geometry. The earlier analysis suggested that the chevrons have a minimal impact on speeds in this location. The Monte Carlo analysis furthers this assessment, with the mean measured speed differences at Site B of 0.44 mph (an increase in the nine month speed) on the leftmost lane and -0.48 (a decrease in after speed) on the rightmost lane. Site A experienced similar results with mean speed decreases of -0.19 and -0.29 on the leftmost and rightmost lanes, respectively. Of the Site A and B results, only the -0.29 was found to be statistically significant.

Site B control ramps do exhibit some increase in the speed of vehicles entering the controlling ramp geometry, with increases of .85 mph and 1.48 mph on the leftmost and rightmost lanes, respectively. Both of these differences were found to be statistically significant. Assuming similar behavior may have been observed on the treatment ramp this would indicate a potential 0.5 mph to 2 mph speed reduction due to the chevrons, figured by subtracting the measured control ramp effect from the measured treatment ramp effect. The Site A control ramp exhibited a statistically significant 0.18 mph change in speed. Combined with the observed treatment ramp results, the overall impact of the chevrons remains under 0.5 mph.

Estimate of the difference in the change in speed between the upstream and downstream treatment detectors across the before and after.

In estimating the difference in the change in speed between the upstream and downstream detectors, the speed difference between these locations is determined for each time period and, then the difference in the speed reductions between analysis periods is determined. For the Site B treatment ramp increases from the before to ninth month after in speed-reduction-between-detectors of 1.30 and 2.55 are seen for the leftmost lane and rightmost lanes respectively. That is, in the ninth month period drivers reduce their speeds by approximately 1.30 mph more in after period than in the before period, in the leftmost lane, and similarly 2.55 mph in the rightmost lanes. In the Monte Carlo estimate of speeds entering the controlling ramp geometry on the treatment ramps, little effect was seen between the before and ninth month data, thus, most of the observed increase in speed-reduction-between-detectors is due to higher chevron zone entering speeds in the after period. Similar speed reductions are seen on the Site A ramps, at 1.64 mph and 1.24 mph on the leftmost and rightmost ramps respectively.

In the final Monte Carlo analysis the speed reduction between the detectors was observed for the control ramps. In a review of **Error! Reference source not found.**, it is seen that similar reductions are seen as on the treatment ramps, with the Site B reductions even slightly higher than that on the treatments. Given the control ramps also experience an increase in speed reduction between detectors, the effect on the treatment ramp cannot be associated with the treatment itself but instead is likely due to changes in background conditions.

Monte Carlo Summary

When analyzing the speed entering the controlling ramp geometry, it is seen that the speed reduction is on the order of 0.5 to 2 mph, with much of this effect related to an observed increased speed on the control ramp. This finding corresponds well to the earlier CDF and PDF analysis. When considering the potential for speed reductions between the detectors, it would appear the chevrons had little to no impact, with the control ramps experiencing similar trends as the treatment ramps. Taken together this would imply the mean effect of the chevrons is limited to 0.5mph to 2 mph reduction in speed as the vehicles enter the controlling ramp geometry.

CHAPTER 5: CRASH DATA ANALYSIS

This section analyzes the crash characteristics at the four study freeway ramps. Since the crash data for the extended period after the pavement markings implementation are not available at the time of this report, only the "before" crash characteristics have been examined. A before-and-after study should be conducted once the "after" data are available. This future study will allow for a direct determination of the effect of chevron pavement markings on the total number of crashes as well as the crash type distribution (i.e., rear end, run-off-the-road, and sideswipe).

Crash data at the study segments from 2002 to 2006 were obtained from the Office of Traffic Safety and Design, Georgia Department of Transportation (GDOT). Each record of crash data contains several attributes as shown in Table 4.

Table 4: Crash Data Attributes and Description

Attribute	Description
Accident No	Accident ID
Date	Accident Date
Time	Accident Time
County	County Name
Route Type	Route Type, e.g., State Route, County Road, Collector-Distributor, etc.
Route	Route ID
Milelog	Milelog of the Route
Intersecting Rt Type	Intersecting Route Type
Intersecting Rt	Intersecting Route ID
Ramp Section	Ramp Section, e.g., 0, 1, 2, and 3
Injuries	Number of Injuries
Fatalities	Number of Fatalities
Collision	Manner of Collision, e.g., Rear End,
Location of Impact	Location of Impact, e.g., On Roadway, On Shoulder, Off Roadway, etc.
Harmful Event	First Harmful Event, e.g., Motor Vehicle in Motion, Guardrail, Median Barrier, etc.
Light	Light Condition, e.g., Daylight, Dark-lighted, Dark-Not Lighted, etc.
Surface	Road Surface Condition, e.g., Dry, Wet, Snowy, etc.
DirVeh1	Direction of Travel of Vehicle 1
DirVeh2	Direction of Travel of Vehicle 2
MnvrVeh1	Maneuver of Vehicle 1
MnvrVeh2	Maneuver of Vehicle 2

It is noted that some crash records contain inconsistent attribute values and require interpretation. For example, the type of collision listed (e.g., angle, head-on, and opposite direction sideswipe) may be unlikely given the listed vehicle orientations. When this occurs the type of collision is reassigned to a more likely type.

Note that the attribute “Ramp Section” indicates crash locations on a ramp section. The value “0” indicates the crash is located on the mainline before or after the ramp. The value “1” indicates the crash is located at the intersection between the mainline and the ramp section. The value “2” indicates the crash is located on the ramp section. The value “3” indicates the crash is located at the intersection between the ramp and another facility. Figure 16 illustrates the ramp section and its corresponding identifiers.

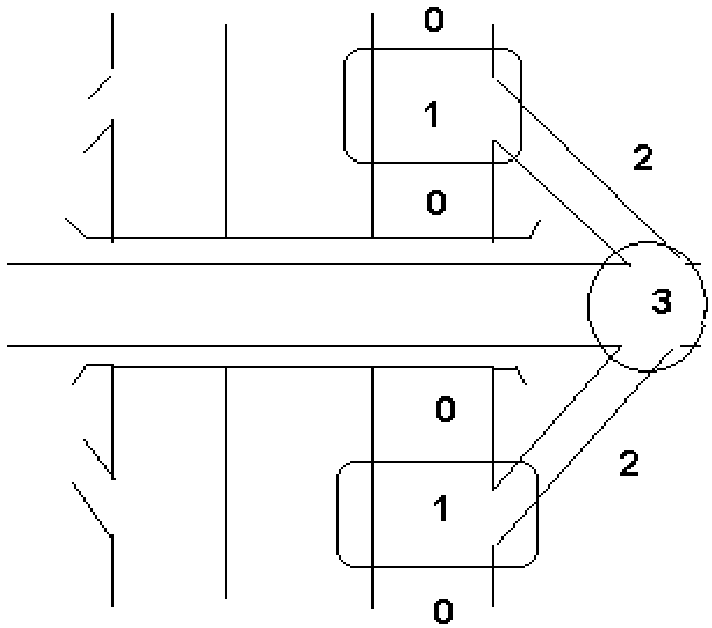

Figure 16: Ramp Section Diagram (Source: Jack Carver, Office of Traffic Safety and Design, GDOT)

The crash data characteristics of the four locations for the “before” period are described as follows:

Site A: Test Ramp (from I-75S to I-85N)

Table 5 shows the distribution of crashes by type of collision at the test ramp of Site A, i.e., the section from I-75S to I-85N. There were a total of 369 crashes during the five year period at the test ramp. Of those 369 crashes, 105 resulted in injury and one resulted in a fatality. Forty-nine percent of crashes occurred during wet or snowy road surface conditions. Forty-four percent of crashes occurred during a non-daylight condition (i.e., dark, dawn, and dusk).

The ramp is divided into three sections defined in the GDOT’s crash database – Section 1 being the most upstream and Section 3 being the most downstream of this ramp. It is seen that Section 1 is dominated by rear end collisions, followed by sideswipe and single vehicle collisions. Section 2 is dominated by single vehicle collisions, followed by sideswipe and rear end collisions. Section 3 is dominated by sideswipe collision, followed by single vehicle and rear end collisions.

Table 5: Crashes by Type of Collision at the Ramp Section from I-75S to I-85N

Ramp Section	Not A Collision With A Motor Vehicle	Rear End	Sideswipe	Total Crashes
1	25%	40%	35%	160
2	47%	14%	39%	152
3	25%	32%	44%	57
Grand Total	34%	28%	38%	369

Note that 48 records were identified as angle crashes, a highly unlikely occurrence on a freeway ramp. These angle crashes were therefore recoded as same direction sideswipe crashes in the above analysis. Furthermore, one record was identified as opposite direction sideswipe. However, this maneuver is also not possible on a freeway ramp. Based on the traveling direction and maneuver type of the involved vehicles, this record was recoded as same direction sideswipe. Lastly, four records were identified as head-on crashes and recoded as same direction sideswipe. However, it is noted that in the final analysis, each of individual accident reports should be obtained and the recoding verified (to the best extent possible) using the actual officer comments and descriptions.

Site A: Control Ramp (from I-85S to I-75N)

Table 6 shows the crash type distribution of the control ramp at Site A. The control ramp has a slightly higher number of crashes than the test ramp(i.e., 373 crashes during the five year period). Of the 373 crashes, 100 resulted in injury and none resulted in a fatality. Sixty-one percent of crashes occurred during wet or snowy road surface conditions. Thirty-seven percent of crashes occurred during a non-daylight condition.

Similar to the test ramp, Sections 1 and 2 are dominated by rear end and single vehicle collisions, respectively. More than half of the crashes on Section 3 of the control ramp are rear end collisions.

Table 6: Crashes by Type of Collision at the Ramp Section from I-85S to I-75N

Ramp Section	Not A Collision With A Motor Vehicle	Rear End	Sideswipe	Total Crashes
1	35%	49%	15%	79
2	66%	20%	14%	138
3	19%	59%	22%	156
Grand Total	40%	42%	18%	373

Note that 20 angle crashes and four head-on crashes at this location were recoded as same direction sideswipe.

Site B: Test Ramp (from I-285E to I-75N)

The test ramp at Site B has 39 crashes during the five year period. Of 39 crashes, eight resulted in injury and none in fatalities. Sixty-two percent of crashes occurred during wet road surface conditions. Thirty-six percent of crashes occurred during a non-daylight condition (i.e., dark, dawn, and dusk).

Table 7 depicts the crash type distribution at this location. Sections 1 and 2 are dominated by single vehicle collisions. Section 3 has only one crash during the selected period and the crash is of the rear end type.

Table 7: Crashes by Type of Collision at the Ramp Section from I-285E to I-75N

Ramp Section	Not A Collision With A Motor Vehicle	Rear End	Sideswipe	Total Crashes
1	63%	25%	13%	8
2	43%	23%	33%	30
3	0%	100%	0%	1
Grand Total	46%	26%	28%	39

Note that one angle crash at this location is recoded as same direction sideswipe.

Site B: Control Ramp (from I-75S to I-285W)

The control ramp at Site B has 50 crashes during the five year period. Of the 50 crashes, six resulted in injury and no fatalities were reported. Fifty-two percent of crashes occurred during wet or snowy road surface conditions. Forty-four percent of crashes occurred during a non-daylight condition (i.e., dark, dawn, and dusk).

Table 8 depicts the crash type distribution at this location. Sections 1 and 3 are dominated by rear end and sideswipe crashes. Section 2 is dominated by single vehicle collision.

Table 8: Crashes by Type of Collision at the Ramp Section from I-75S to I-285W

Ramp Section	Not A Collision With A Motor Vehicle	Rear End	Sideswipe	Total Crashes
1	18%	41%	41%	22
2	52%	29%	19%	21
3	14%	43%	43%	7
Grand Total	32%	36%	32%	50

Note that three angle crashes, two head-on crashes, and one opposite direction crashes at this location are recoded as same direction sideswipe.

CHAPTER 6. SUMMARY OF FINDINGS

The speed data analysis indicates that the chevrons had only limited impact on vehicle speeds. The effect of the chevron treatment on speed was most pronounced immediately after the chevron implementation, with the impact waning by the ninth month, with the magnitude of the impact under 1 to 2 mph over most of the vehicle speed percentiles. The observed changes in the speed distributions are reasonably consistent between the test sites.

The binned data was limited to a maximum of 20 bins; and therefore, limited the minimum bin size permissible while allowing for coverage of the full speed range experienced at these sites. Given the limitation in bin sizes, the binned data granularity was insufficient to measure the impact if the chevron markings treatment. While the PVR data experienced higher rates of data loss than the binned data, sufficient PVR data was obtained to measure the potential impacts.

To account for sampling differences and potential distributional difference between the data collected over the different time periods, a Monte Carlo random sampling strategy of lead vehicles was adopted for analysis of the speed differences. When analyzing the speed entering the controlling ramp geometry, it is seen that the average speed reduction is on the order of 0.5 to 2 mph, with much of this effect related to increased speeds on the control ramp. In addition, it is noted that there is only a minimal effect on the speed variance of vehicles entering the controlling ramp geometry. These finding correspond well to CDF and PDF analysis discussed earlier. When considering the potential for speed reductions between the detectors it would appear the chevrons had little or no impact, with the control ramps experiencing similar trends as the treatment ramps. Taken together this would imply the mean effect of the chevrons is limited to a 0.5 mph to 2 mph reduction in mean speed as the vehicles enter the controlling ramp geometry.

The crash analysis determined the crash characteristics of each location before the pavement markings treatment is implemented. The “before” data included a five year period (2002-2005) of crash data provided by GDOT. The analysis showed that the first and last sections of the ramp are dominated by either rear end or sideswipe, while the middle section of the ramp is dominated by the single vehicle crash type. When the “after” crash data are available for the study locations, it is important to determine the impact of the markings treatment on the total number of crashes, as well as the changes in crash type distribution.

In summary, the impact of the chevron treatment on speed tends to be minimal, with drivers adjusting back to their previous speeds as they acclimate to the treatment. However, this does not necessarily imply that the chevron treatment is not a meaningful safety treatment; it only implies that any safety benefit is likely not the result of a general decrease in speeds. It is possible that, given the rare nature of accidents (rare in the statistical sense), the chevron treatment may help alert some of the small set of drivers likely to be in an accident, potentially raising the awareness of the inattentive driver, reducing the likelihood of an accident occurrence. Additionally, it is noted in the incident analysis that a significant subset of the crashes occurred under wet or snowy conditions. Given the data collection constraints, it was not possible to guarantee before and after data during wet conditions. However, it is possible that the effect of the chevrons could be different during wet conditions. Prior to any final judgment on the effectiveness of the chevron treatment on safety, it is recommend that a direct accident study (as opposed to utilizing a surrogate such as speed) be conducted after two to three years of accident data may be gathered.

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