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EVALUATION OF DATA FROM TEST APPLICATION OF OPTICAL SPEED BARS TO HIGHWAY WORK ZONES

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16 Abstract

The proximity of traffic and workers in highway work zones demand that safety be a high priority. The issue of traffic speeds in highway work zones has long been an issue receiving much attention. Over the past three decades, many different measures have been developed to address the issue of speed in work zones. One that has garnered interest recently in the United States is the use of optical speed bars, transverse bars set out at gradually decreasing spacing in order to provide drivers with a heightened perception of speed. Studies have shown this technique to be effective at roundabout approaches and freeway exit ramps.

This report discusses a test application of optical speed bars to a highway work zone. Accommodations had to be made for the unique characteristics of highway work zones. Simulations were developed to aid in visualizing the effects of various design parameters. The tested pattern comprised three components, a leading pattern of uniformly spaced bars, a primary pattern of bars with graduated spacings, and a work zone pattern consisting of intermittent groups of six uniformly spaced bars with large gaps between groups.

The pattern was found cause reductions in mean and 85th percentile speeds, as well as in standard deviations. Changes in speeds were small, and resulted from both warning effects and perceptual effects. The warning effects persisted downstream of the pattern while the perceptual effects did not, as drivers increased their speed once out of the area with graduating spacings. Reductions in speed variations also persisted downstream of the pattern. The work zone pattern did not appear to have any effect on speeds or speed variations.

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Final Report

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A Report on Research Sponsored By

THE KANSAS DEPARTMENT OF TRANSPORTATION
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UNIVERSITY OF KANSAS
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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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ABSTRACT

Evaluation Of Data From Test Application Of Optical Speed Bars To Highway Work Zones

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The proximity of traffic and workers in highway work zones demand that safety be a high priority. The issue of traffic speeds in highway work zones has long been an issue receiving much attention. Over the past three decades, many different measures have been developed to address the issue of speed in work zones. One that has garnered interest recently in the U.S. is the use of optical speed bars, transverse bars set out at gradually decreasing spacings in order to provide drivers with a heightened perception of speed. Studies have shown this technique to be effective at roundabout approaches and freeway exit ramps.

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ACKNOWLEDGEMENTS

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Thanks to Tom Mulinazzi, Associate Dean of the University of Kansas School of Engineering, and Sabrina Kao, Graduate Research Assistant, who both participated in portions of this research.

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The author especially appreciates the efforts of Alan Spicer, Bill Hughes, and the KDOT TFO Unit for their assistance in planning, installing, and maintaining the data collection; Jason Meyers for his work downloading data from the counters; the rest of the advisory panel for their valuable input; and Matt Volz, ITS Coordinator and KDOT project monitor, for his tireless cooperation and persistence, without which this evaluation would never have come about.

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CHAPTER 1: INTRODUCTION

In highway work zones, it is often necessary for workers to operate in close proximity to moving traffic. Motorists, on the other hand, often become accustomed to traveling at highway speeds and do not adequately reduce their speed in work zones. Consequently, safety is a priority in highway work zones. The occurrence and severity of accidents is related to both vehicle speed and speed variation.

Traffic calming techniques have been used effectively in residential areas to induce slower operating speeds. However, these techniques involve significant geometric alterations to the roadway which themselves present the greater hazard when applied to segments where highway speeds are prevalent.

Over the past 30 years, a number of innovative pavement marking techniques have been used to induce lower speeds on curves, approaches to roundabouts and other high accident locations. Some of these techniques have become common in England and Australia, and Japan has used similar innovative techniques to reduce crashes on several bridges.

One of these innovative techniques is the application of *optical speed bars*, transverse stripes spaced at gradually decreasing distances, presumably to affect the driver's perception of speed, resulting in a speed reduction. Several applications of this innovative traffic control device have resulted in significant reductions in both speed and speed variation. When this device is applied to highway work zones, however, some significant differences must be considered. In previous applications, drivers were expected to be travelling at highway speeds as they entered the pattern, come to a stop or a near stop at the end of the pattern, then return to highway speeds once they were through the intersection. In contrast, speed reductions in highway work zones are intended to be comparatively small, and the reduced speed must often be maintained for long distances. This paper examines some of the adaptations that may improve the effectiveness of this device when applied to highway work zones. A design methodology is described and a pattern design is developed. Finally, a test project conducted by the Kansas Department of Transportation and evaluated by The University of Kansas is discussed, in which the effectiveness of optical speed bars at reducing speeds and speed variations in highway work zones is examined.

1.1 Crash Statistics

According to the National Center for Statistics & Analysis, the economic cost alone of motor vehicle crashes in 1994 was more than $150.5 billion. (NCSA, 1996a) Similar costs in 1995 resulted from 41,798 motor vehicle related fatalities, 3,386,000 injuries and 4,409,000 crashes that involved only property damage. These numbers represent an increase in fatalities of 2.7%. On average, 115 fatalities occurred each day during 1995. Motor vehicle crashes have been cited as the leading cause of death for every age from 5 to 32 years old and the leading cause of injury for all age groups. (Advocates for Highway and Auto Safety, 1995)

1.2 Role of Speed in Crashes

In 1995, speeding was a contributing factor in 31% of all fatal crashes. (National Center for Statistics & Analysis, 1996) Above 80 kph (50 mph), for every additional 16 kph (10 mph) the chances that a crash will result in a fatality or serious injury are doubled. (National Highway Traffic Safety Administration, 1996) A vehicle traveling 16 kph (10 mph) above or below the average speed is nearly six times as likely to be involved in a crash.

There is a natural tendency for drivers to underestimate speed. (Godley et al, 1996, based on Triggs, 1986). High speeds tend to be underestimated to a greater extent than do lower speeds. (Leiser, Stern & Meyer, 1991) The tendency is exacerbated on major roads, such as divided and multi-lane roads. (Fildes et al, 1987) Furthermore, the effect of speed adaptation causes the driver to underestimate speed even more than usual after driving at a high speed for a prolonged time. (Denton, 1976) Speed adaptation may exacerbate the safety issues associated with highway work zones, where drivers are in an environment in which they do not expect to have to slow down.

In addition to mean speeds, the variance of speeds is a contributing factor to work zone crashes. A study of accident records in Kentucky found that for work zones, rear end or same-direction sideswipe accidents accounted for three times the percentage of the total as compared with statewide percentages. (Pigman and Agent, 1990) A study of 177 sites during construction and during the same time period the year prior to construction supported the importance of speed variation in highway work zones. (Hall and Lorenz, 1989) The percentage of all collisions corresponding to rear end collisions increased from 9.4 percent prior to construction to 13.8 percent during construction.

1.3 Conventional Countermeasures

Historically, the most common techniques for reducing traffic speeds in highway work zones have been reducing the posted speed limit, posting flaggers at each end of the work zone, and actively enforcing work zone speed limits with on site law enforcement. These techniques have met with various degrees of success at slowing traffic, depending on the characteristics of the work zone and the manner in which these techniques are applied. For example, it is commonly accepted that reducing the posted speed limit alone is ineffectual at changing driver behavior, whereas reduced speed limits used in conjunction with active law enforcement have been observed to be effective at reducing speeds.

Other techniques that have been used to improve safety in highway work zones by reducing traffic speeds include changeable message signs (CMS), radar drones, lane width reduction, and rumble strips. A comprehensive review of these devices and their relative effectiveness can be found in the KDOT report entitled, *A Comprehensive Literature Review of Perceptual Countermeasures to Speeding.* (Meyer, 2000)

1.4 Perceptual Countermeasures

Perceptual countermeasures include techniques intended to alter or enhance the driver's perception of speed. There are three general categories of techniques that have been tested, all consisting of pavement markings applied in an innovative pattern or style. The three categories are virtual lane width reduction, optical speed bars, and radius enhancements. Each of these techniques will be discussed briefly in the following sections. A more exhaustive review of these devices and their relative effectiveness can be found in the KDOT report entitled, *A Comprehensive Literature Review of Perceptual Countermeasures to Speeding.* (Meyer, 2000)

1.4.1 Virtual Lane Width Reduction

Lorscheider and Dixon cite usable lane and shoulder width as one of the "most profound variable[s] affecting the speed in a work zone," along with the type of work activity being performed and the size and quantity of the equipment. (Lorscheider and Dixon, 1996)

A Virginia study evaluated the effect on vehicle speeds and lateral placement of 8-inch edge lines relative to 4-inch edge lines. (Cottrell, 1985) Data was collected at 12 locations on sections of two-lane rural highways totaling 89 km (55.2 miles). Based on the policies of the Virginia Department of Motor Vehicles, a placement that centers the vehicle within the lane was considered optimal placement. Vehicle deviations from the optimal placement were measured at all 12 locations. The results indicated that the 8-inch wide edge lines produced improvements in lateral placement that were statistically significant.

Encroachments on the opposing lane (i.e., instances when vehicles crossed the centerline) were also compared. The actual dimension measured was the distance of each vehicle's outer tire from the edge line. Thus, an average vehicle width had to be assumed to determine whether encroachment occurred. Based on data from Consumer Reports, 1.83 m (72 inches) was used for passenger cars. Based on AASHTO design vehicle dimensions, a width of 2.4 m (96 inches) was used for trucks. The results showed a significant reduction in encroachments for trucks at night when 8-inch edge lines were present. Other encroachment categories showed no significant difference. The author later noted that, while there was some statistically significant difference in the mean lateral placement, the difference had no relevant practical implications. (Cottrell, 1986)

An urban study examined the effects of reducing the width of urban freeway lanes from 3.66 m (12 ft) to 3.35 m (11 ft). (DeLuca, 1985) Vehicle speeds were not considered directly, but rather traffic volumes and capacities, and accident rates for rear-end crashes, sideswipes, and roadway median accidents. Before and after data was collected and analyzed for sections of I-95 in Miami Florida, where a 0.91 m (3 ft) shoulder provided no refuge area for vehicles disabled on the 8- to 10-lane cross-section. This combination was beginning to create a rear-end collision problem. In efforts to alleviate the problem, the shoulder was widened to 2.13 m (7 ft) by reducing the lane widths by 0.3 m (1 ft) each. Data was also collected for two control sections so that any changes in accident rates could be analyzed to determine if they were a result of a regional phenomenon, as opposed to the lane width reduction.

The study found no significant capacity reduction due to the reduced lane widths. However, it is possible that the additional lateral clearance counterbalanced the effects of the narrower lanes. After the reduction, rear-end crashes declined while sideswipes increased. The author stated, "It is very probable that other factors not reviewed in this work play a far more important role in the operation of freeway facilities than does the difference between 11 and 12 ft [3.35 and 3.66 m] lanes..."

A study of 11 residential segments was conducted in which double edge lines were applied to effectively reduce each lane from 3.6 m (11 ft) to 2.7 m (9 ft). (Lum, 1984) Raised pavement markers were also added on the centerline and/or between the edge lines at some locations. With mean speeds ranging from 42 kph (26 mph) to 56 kph (35 mph), no effect was observed on either the mean speeds or the speed distributions of drivers on the segments studied.

Proving ground tests were conducted to compare the use of striping for reducing effective lane width to the use of cones or barrels, with respect to speed reduction, speed variance, and overall hazard. (Richards et al, 1985b) The study concluded that the effective lane width reduction using striping was ineffective. The markings were not visible from an adequate distance and they did not create a feeling of confinement. For truly narrow lanes, it is adjacent traffic that causes the feeling of confinement for the driver.

In contrast, another study described the use of effective lane width reduction as an effective technique for reducing speeds in work zones, though speed variance and erratic maneuvers increase. (Richards and Dudek, 1986) While striping is mentioned as one device for implementing effective lane width reduction, only cones were evaluated in this study. Consequently, these findings may not necessarily be applicable.

1.4.2 Optical Speed Bars

Optical speed bars are a technique for reducing speeds and speed variation. The technique has been used in several countries, most notably Great Britain, where the technique has become a typical device used at approaches to roundabouts. Other applications have been almost exclusively situations where traffic traveling at highway speeds is required to slow to a stop or near stop, such as on a freeway exit ramp ending at a stop sign or traffic signal. Results have been somewhat mixed, though most studies show the technique has significant merit.

1.4.2.1 Transverse Bar

In May of 1982, the Traffic Operations Division and the Calgary Police Traffic Analysis Unit, both of the City of Calgary, Alberta, Canada, conducted a test of optical speed bars. (Leibel and Bowron, 1984) In the experiment, transverse bars were applied to an exit ramp of a major freeway with the intent of reducing accidents at the ramp terminus. The application is shown in Figure 1. The lines extended from edge line to edge line, as can be seen in Figure 1. The markings occupied 404 m (1325 ft) of the 900 m (2952 ft) ramp. The spacing between the lines was graduated from 7.7 m (25 ft) to 2.75 m (9 ft). Each individual line was 0.6 m (2 ft) wide and 3.5 to 4 m (11.5 to 13 ft) long. The initial cost of installation was $1,512, and the cost of repainting the lines was $600.

The installation site was observed for a total of 39 days, 19 days prior to the installation and 20 days after the installation. Speeds were recorded at a point 150 m (492 ft) from the traffic signals located at the end of the ramp. The average speed decreased from 63.5 kph (39.5 mph) before the installation to 61.4 kph (38.1 mph) afterwards. As well, the percentage of vehicles exceeding 80 kph (50 mph) decreased from 5.45% to 4.05%. A total of 106,444 vehicles were recorded.

Figure 1. Transverse bar pattern tested in Calgary, Alberta. (Source: Robert Dewar)

In October 1983, another ramp at the same interchange was painted with the same pattern of transverse lines. While the available data is inconclusive, there is some suggestion that the markings may contribute to a decrease in the crash severity.

Jarvis reported several interesting findings from his work with transverse bar patterns. (Jarvis, 1989) Bars placed further from the intersection have a greater effect on speed. However, the reductions in speed seem to occur because the bars act as a large, visual warning to the driver to reduce speed and use caution, as opposed to the expected mechanism of adjusted speed perception. Since the pattern is a visual warning rather than a perceptual device, there is no need for sophisticated bar spacings. His recommended configuration consists of 30 bars, at consistent 7.5 m (25 ft) spacings, beginning 185 m (607 ft) from the intersection and extending to 402.5 m (1320 ft) from the intersection. Such a configuration "would appear to have a reasonable chance of maximizing the effect of such devices." A later report on the same study noted that the effects of the markings on accident rates could not be determined without a much longer term of study. (Jarvis and Jordan, 1990)

In a test comparing the effects of a transverse bar pattern with the effects of a similar pattern of rumble strips, the two devices were installed on opposite approaches to a rural intersection. (Zaidel et al, 1984) The tested configuration consisted of 38 stripes, the first at 269 m (882 ft) from the intersection, and the last at 17.4 m (57 ft) from the intersection. The stripes were spaced such that a vehicle approaching the treated area at 80 kph (50 mph) and decelerating at a constant rate of 0.9 m/sec^2 (3.0 ft/sec^2) would cross 2 stripes per second. All stripes were 60 cm (2 ft) wide, and were installed across the full width of the two-lane road except where the lanes were separated by a traffic island. Special advance warning signs were added to the normal sequence of signs on each approach. Speeds were measured at 8 points.

The painted stripes produced a 3 kph (2 mph) reduction in average speed. The deceleration pattern did not change significantly. Before and after average speeds and 85th percentile speeds at each measuring point are plotted in Figure 2 and Figure 3, respectively. The application of the stripes gave a slight increase in compliance rate. Prior to the application, 79% stopped, 11% made a rolling stop, and 10% did not stop. With the stripes in place, 85% stopped, 7% rolled through, and 8% did not stop. When the stripes were evaluated again after one year, no significant changes were observed.

Agent (1980) studied an implementation of a transverse pavement marking pattern on a rural two-lane highway in Meade County, Kentucky. A particular section, (average daily traffic, ADT, = 4890) was observed to be particularly hazardous due to a curve at one end of the section. In the six years prior to the project, 48 accidents occurred in this curve, 46 of them involved eastbound vehicles (the approach to receive the pavement marking treatment). Speed was mentioned as a contributing circumstance in 36 of the accident reports.

Reflective tape was used to create the stripes. The details of the striping pattern were based on an assumed speed at the beginning of the pattern of 25 m/s (55 mph), a desired speed at the beginning of the curve (also the end of the pattern) of 16m/s (35 mph), and a stripe interval of two stripes per second. The final configuration consisted of 30 stripes with an installed pattern length of 247 m (810 ft), ending at the beginning of the curve. The stripe spacings gradually decreased from 12 m (40 ft) to 4.6 m (15 ft) at the curve. The widths of the stripes were decreased, as well, to a minimum of 0.6 m (2 ft). The source did not specify the initial stripe width.

In the year following the installation, three accidents occurred which involved eastbound vehicles. Of the three, two involved an intoxicated driver, and in the third, the driver fell asleep. Speeding was cited as a contributing circumstance in one of the accident reports.

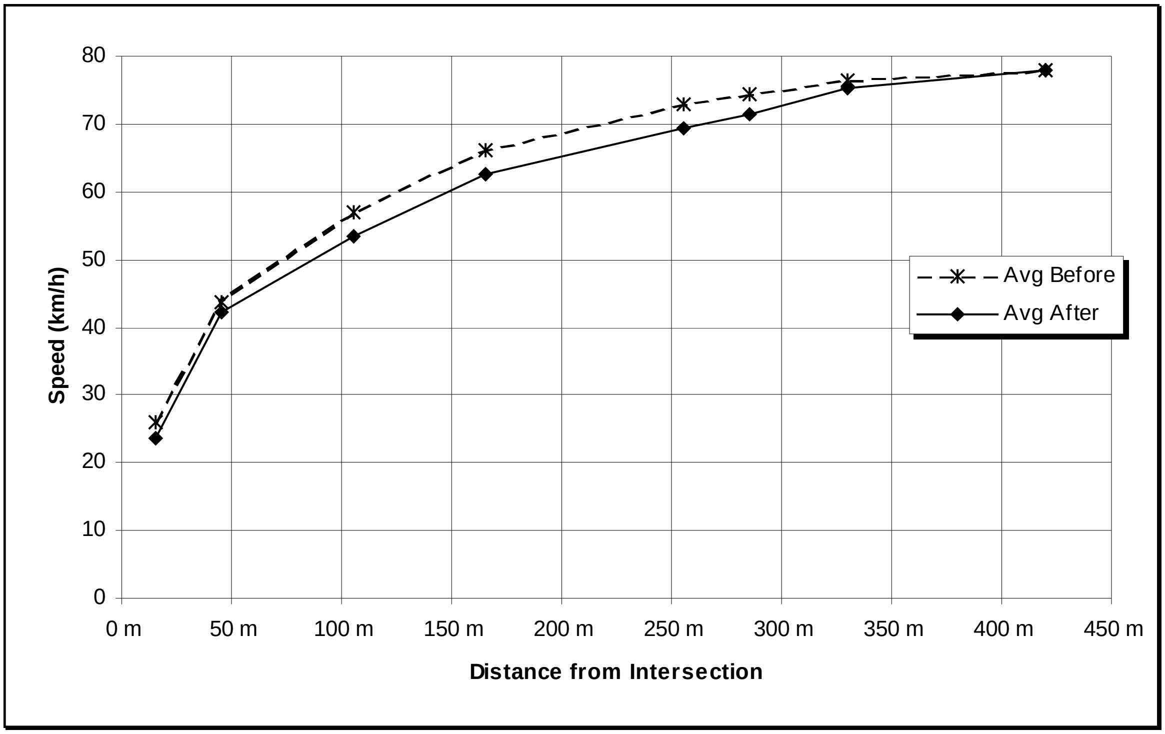


Figure 2. Average speeds at all 8 measuring points before and after painted stripe application.

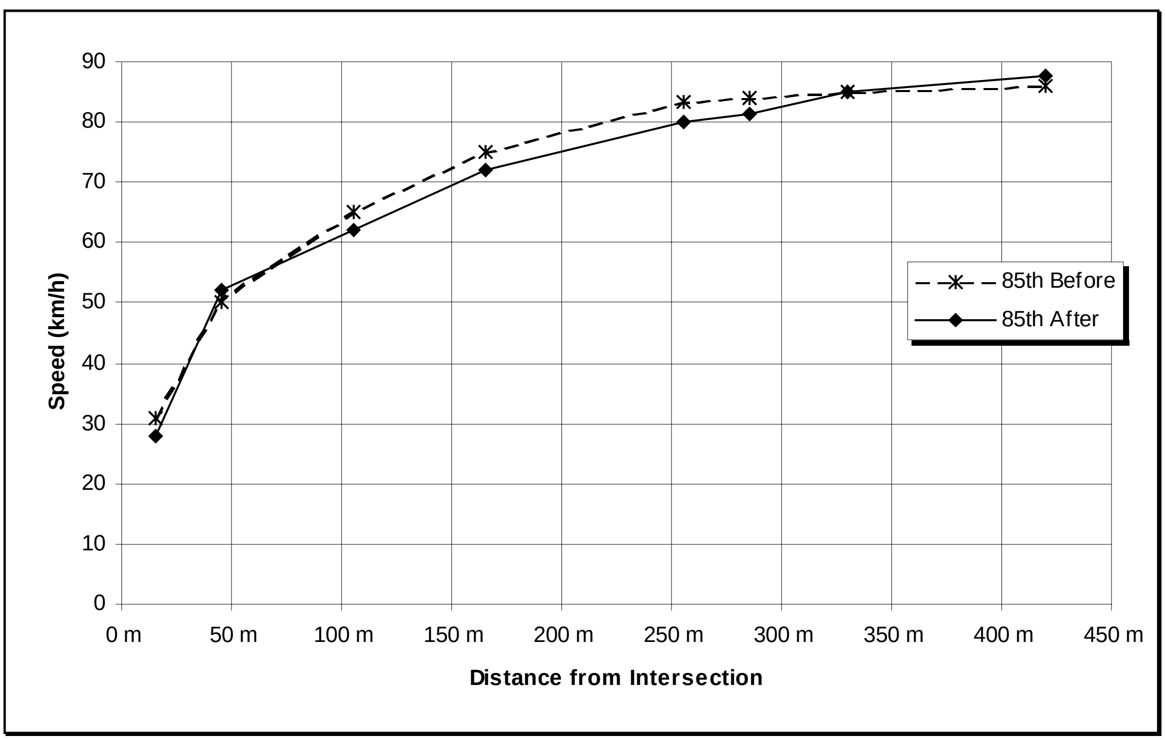


Figure 3. 85th percentile speeds at all 8 measuring points before and after painted stripe application.

Speed data was collected before the application of the stripes, one week after the installation, and six months after the installation. Speeds were measured at both the beginning and the end of the markings. Speed reductions are plotted in Figure 4. Prior to the installation, the average nighttime speed reduction was 1.1 m/s (2.4 mph). A week after the installation, the average nighttime speed reduction increased to 4.2 m/s (9.3 mph), decreasing over the subsequent six months to 3.0 m/s (6.8 mph). During the daytime, the average speed reduction before the installation was 3.8 m/s (8.5 mph). This number increased to 6.8 m/s (15.3 mph) over the first week after the installation, and decreased slightly to 5.5 m/s (12.3 mph) over the next six months. All reductions were statistically significant at the 0.005 level.

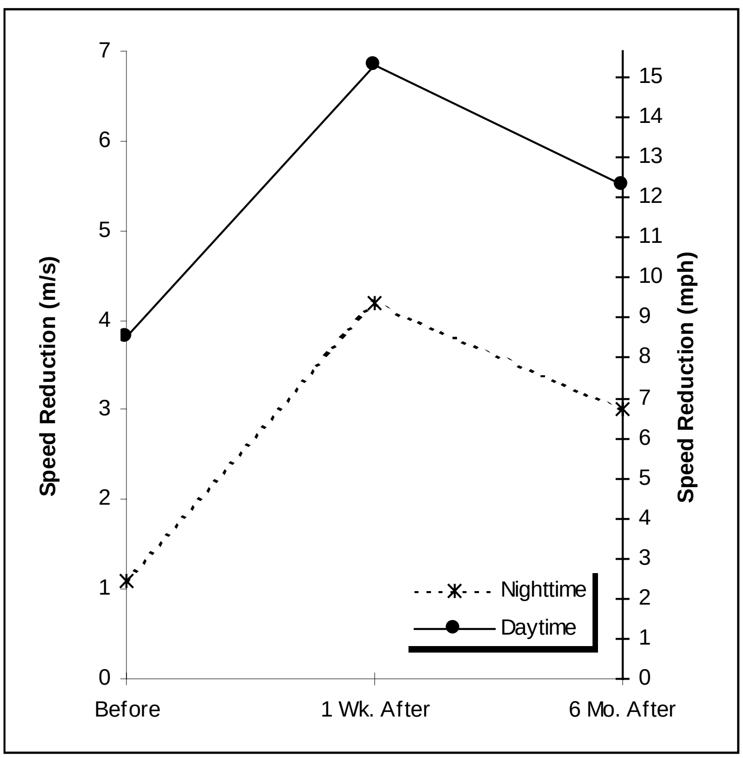


Figure 4. Average speed reductions.

Using then current monetary figures, an estimated benefit/cost ratio was calculated as 45.9, based solely on savings from a reduction in accidents. In conclusion, Agent states,

> *Results showed that transverse stripes on pavement can effectively reduce speed. At the single site investigated, the obedience of drivers to this type of hazard warning was more effective than to signing alone. At the very least, transverse striping alerts drivers to the upcoming hazard more effectively than signing does. Further use of this traffic-control method may be warranted at locations at which excessive speeds have contributed to accidents. Consideration should be given to increasing the warning distance in future installations. A distance of about 365 m (1200 ft) may be desirable.*

Denton (1973) studied a transverse bar pattern applied to an approach to the Newbridge Roundabout in the county of Midlothian, Scotland. The pattern, detailed by Denton (1971) for the Road Research Laboratory, consisted of 0.6 m (2 ft) wide yellow stripes that stretched from edge line to edge line on the approach side of the divided roadway. In all, 90 stripes were applied, with spacings decreasing exponentially from 6 m (20 ft) to a minimum of 3 m (10 ft). Denton's pattern design was later adopted as a *Departmental Standard TD 6/79* by the Department of Transport. The standard is reproduced in APPENDIX A.

As can be seen from Table 1 and Table 2 (plotted in Figure 5 and Figure 6, respectively), the pattern had a significant effect on both mean and 85th percentile speeds. Figure 7, Figure 8, and Figure 9 show comparisons of the speed distributions before and after the installation for each time period observed. Each of these plots shows a marked reduction in speed variation after the pattern installation. Additionally, there were 14 accidents during the 12 months prior to the installation, and only 2 during the 16 months following the installation. While the time frame is still too short for findings from the accident data to be conclusive, these intermediate results are very promising.

Table 1. Mean speeds before and after with percent reduction.

	7-9 AM	2-4 PM	6-8 PM	MEAN
Before	59.1 (36.7)	57.8 (35.9)	54.9 (34.1)	57.0 (35.4)
After	42.2 (26.2)	45.2 (28.1)	44.7 (27.8)	44.1 (27.4)
% reduction	28.6%	21.7%	18.5%	22.6%

*Speeds are in both SI and English units: kph (mph)

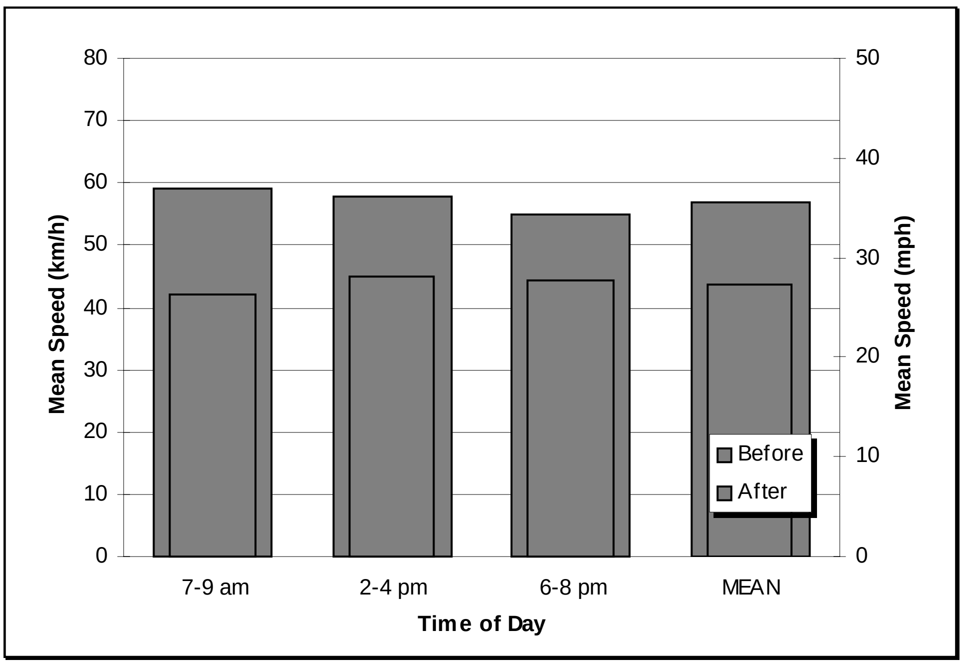


Figure 5. Mean speeds before and after.

Table 2. 85th percentile speeds before and after with percent reduction.

	7-9 AM		2-4 PM		6-8 PM		MEAN	
Before	77.4	(48.1)	75.9	(47.2)	72.4	(45.0)	75.1	(46.7)
After	50.8	(31.6)	54.1	(33.6)	53.7	(33.4)	52.8	(32.8)
% reduction	34.3%		28.8%		25.8%		29.8%	

*Speeds are in both SI and English units: kph (mph)

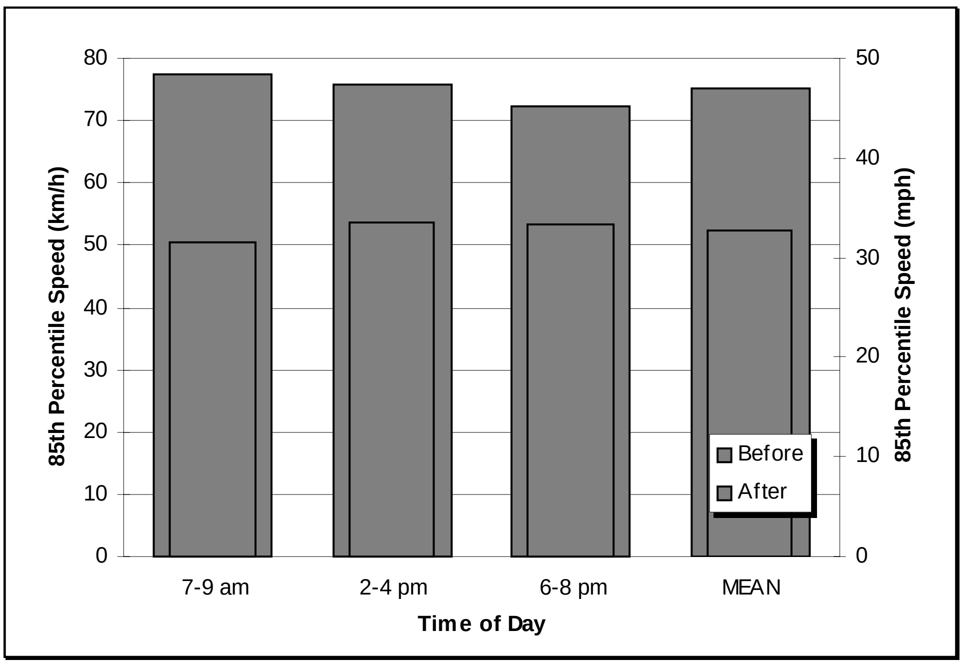


Figure 6. 85th percentile speeds before and after.

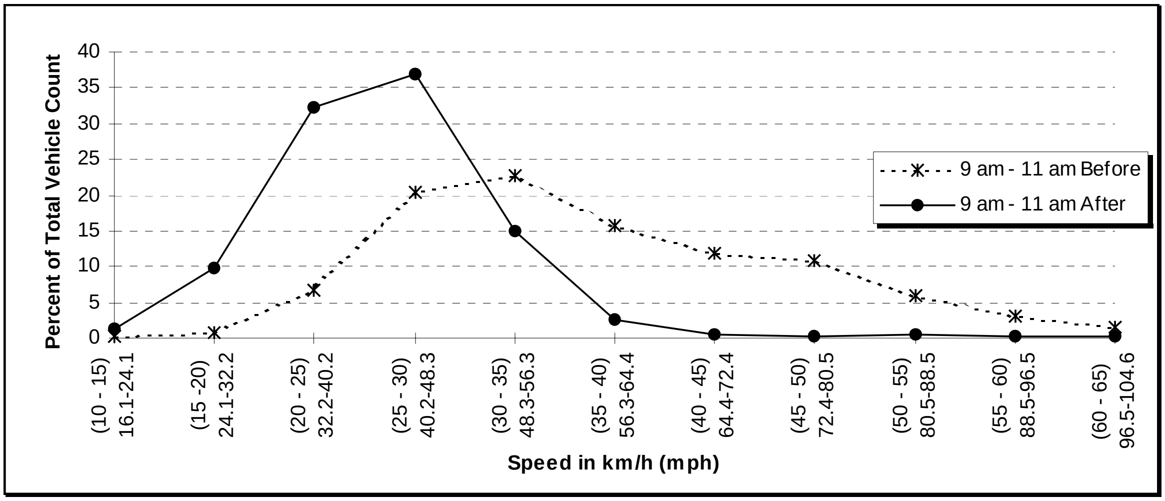


Figure 7. Before and after speed distribution for 9 AM to 11 AM.

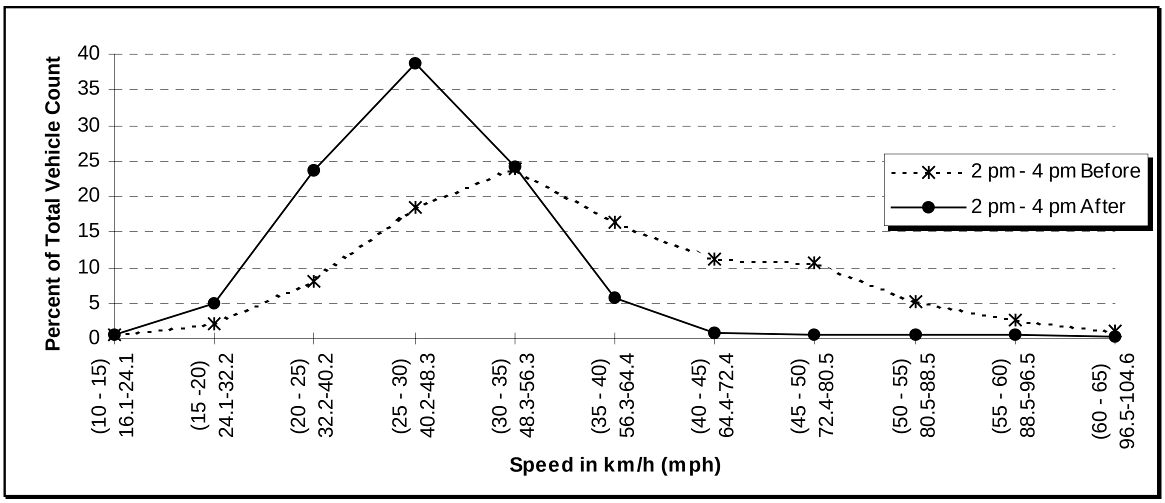


Figure 8. Before and after speed distribution for 2 PM to 4 PM.

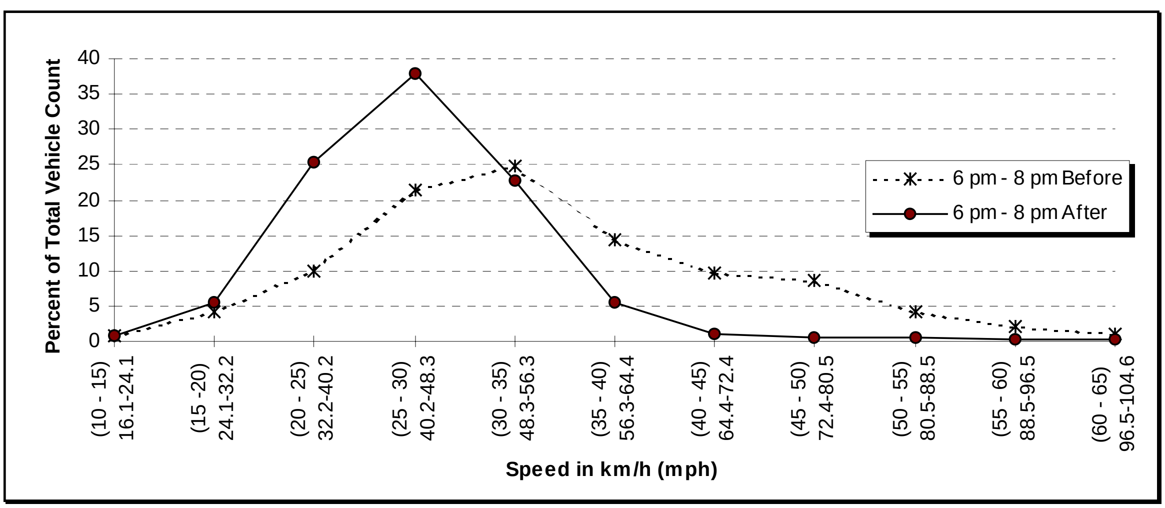


Figure 9. Before and after speed distribution for 6 PM to 8 PM.

In proving ground tests, Richards et al (1985b) compared the effect on speed and speed variance of transverse stripes to that of rumble strips and that of effective lane width reduction. The rumble strips were tested in three different configurations: individual rumble strips, clusters of strips with equal spacings, and clusters of strips with unequal spacings. Effective lane width reduction was studied in three tests, one using each of painted stripes (edge lines), cones, and barrels. The three configurations of transverse stripes tested are shown in Figure 10. Each of the configurations consisted of 15 stripes. The spacings of the stripes varied as shown in Table 3. Richards found that, compared to rumble strips and effective lane width reduction, transverse striping resulted in relatively low speed variations, with standard deviations ranging from 7.10 to 9.69 kph (4.41 to 6.02 mph). The comparisons are plotted in Figure 11 and Figure 12 for comparison. Other values are shown in Table 4. In the preference surveys performed afterward on the test subjects, 88% of the subjects thought the shoulder only treatment produced the least speed reduction of the three patterns. 65% thought the herringbone pattern produced the greatest speed reduction, and 35% thought the full width pattern produced the greatest speed reduction.

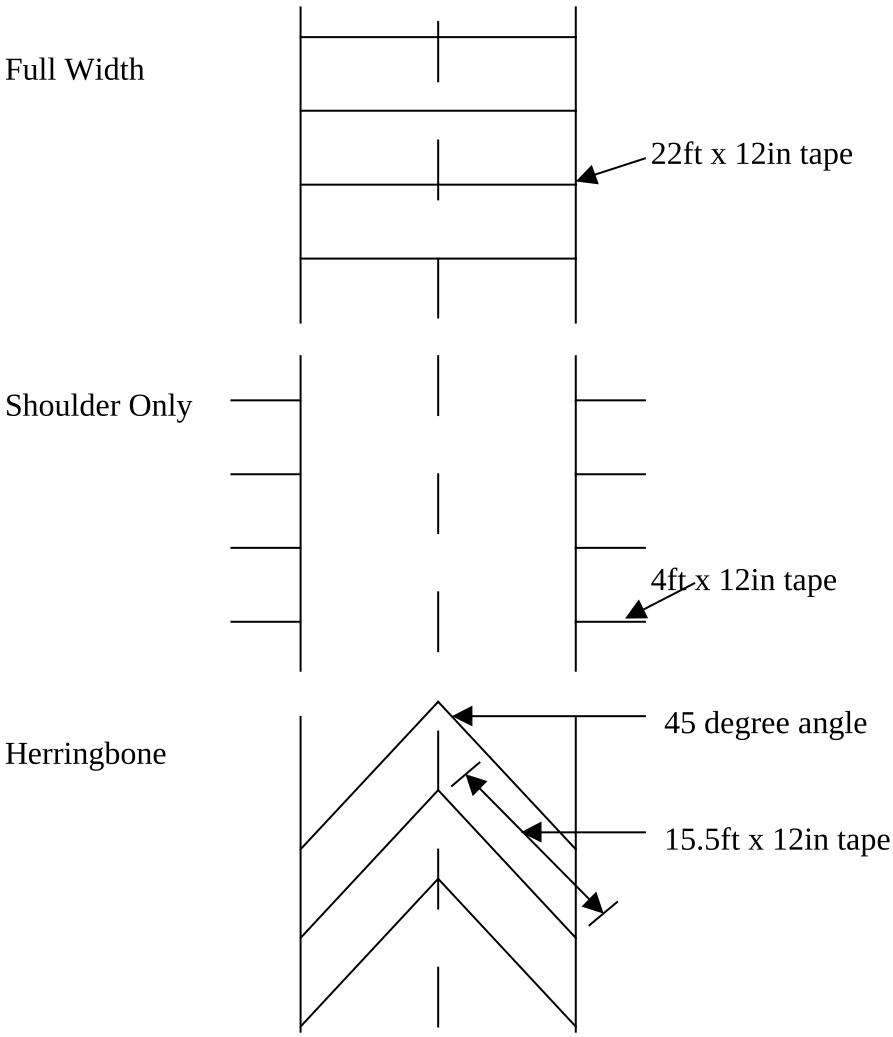


Figure 10. Tested configurations of transverse stripes.

Table 3. Stripe spacings for proving ground tests.

Stripes	Spacing
1 - 5	20.1 m (66 ft)
6 - 10	17.7 m (58 ft)
11 - 15	15.9 m (52 ft)

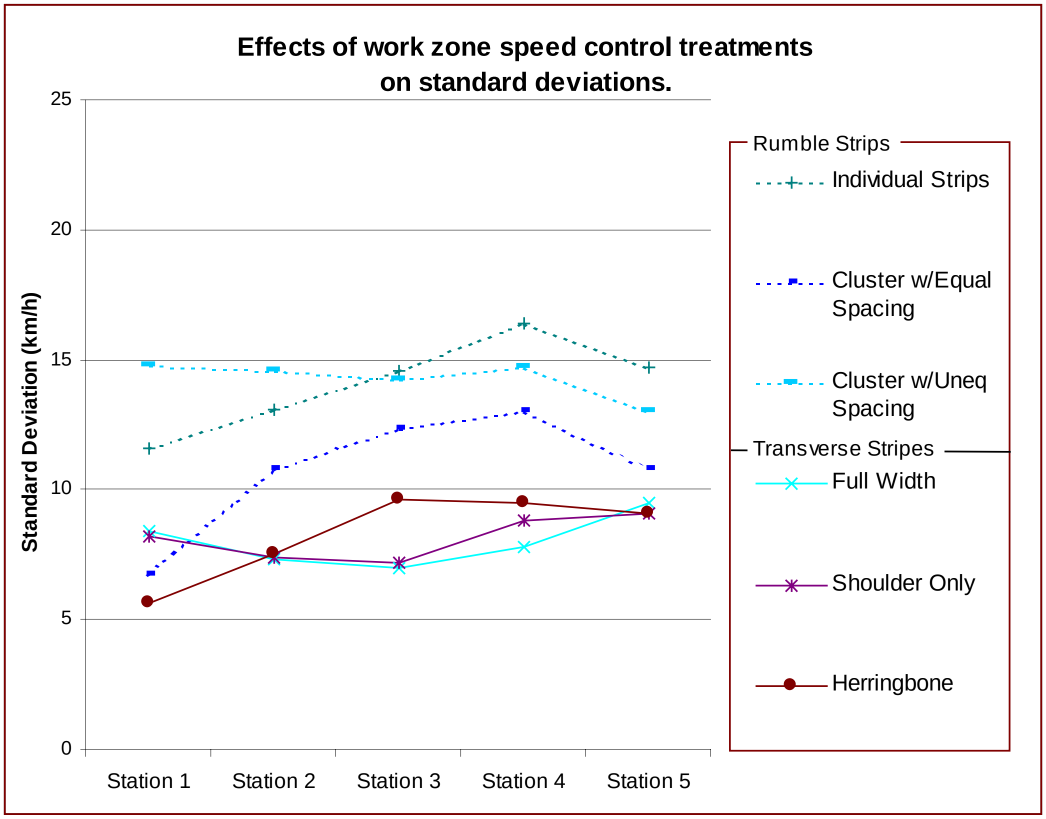


Figure 11. Effects of rumble strips and transverse stripes.

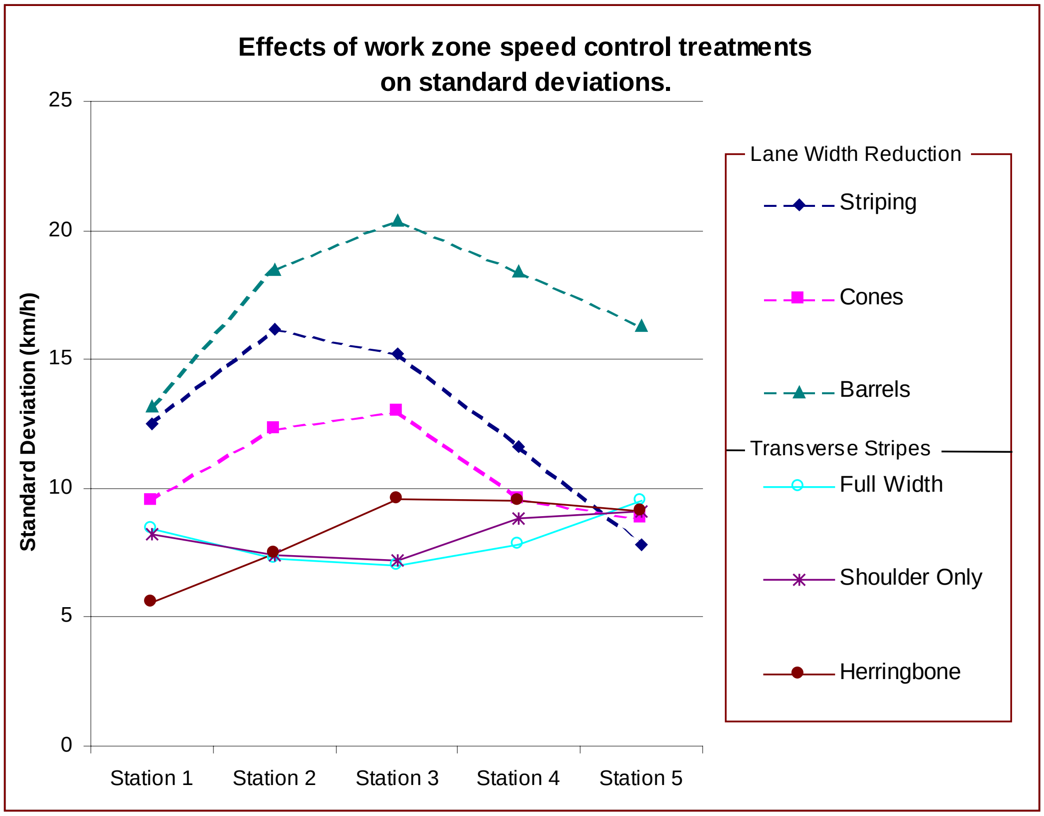


Figure 12. Effects of lane width reduction and transverse stripes.

Table 4. Effects of work zone speed control treatments on standard deviations.

	Standard Deviation, kph (mph)				
Treatment	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**
Effective Lane Width Reduction (N=18)					
Striping	12.5 (7.7)	16.2 (10.0)	15.2 (9.5)	11.6 (7.2)	7.8 (4.8)
Cones	9.5 (5.9)	12.3 (7.6)	13.0 (8.0)	9.6 (6.0)	8.8 (5.4)
Barrels	13.2 (8.2)	18.5 (11.5)	20.4 (12.7)	18.4 (11.4)	16.3 (10.2)
Transverse Striping (N=17)					
Full Width	8.4 (5.2)	7.3 (4.5)	7.0 (4.4)	7.8 (4.8)	9.5 (5.9)
Shoulder Only	8.2 (5.1)	7.4 (4.6)	7.2 (4.4)	7.7 (4.8)	9.1 (5.6)
Herringbone	5.6 (3.4)	7.5 (4.7)	9.6 (6.0)	9.5 (5.9)	9.1 (5.6)
Rumble Strips (N=18)					
Individual Strips	11.6 (7.2)	13.1 (8.1)	14.6 (9.0)	16.4 (10.2)	14.7 (9.1)
Cluster w/Equal Spacing	6.7 (4.1)	10.8 (6.7)	12.3 (7.6)	13.0 (8.1)	10.8 (6.7)
Cluster w/Unequal Spacing	14.8 (9.2)	14.6 (9.0)	14.2 (8.8)	14.7 (9.1)	13.0 (8.1)

1.4.2.2 Transverse Chevron

In Japan, several bridges that have historically high accident rates were identified as candidates for optical speed bars. The patterns, detailed by Ito (1995), used chevrons (as shown in Figure 13) rather than straight bars, but the concept was the same. The gradually increasing frequency of the chevrons is intended to increase the driver's perception of speed. Griffin et al (1996) points out that while no speed data is available for these sights, and the time frame is still too short to draw any definitive conclusions, the application of the patterns seems to be having a marked effect on accidents. The general dimensions of the chevrons are shown in Figure 14. The spacings between chevrons are shown in Figure 15.

Figure 13. Converging chevron pattern on the Yodogawa River bridge (Japan).

Another application of chevron markings was evaluated at two sites in England. Unlike the Japanese application, these chevron markings were evenly spaced at 40-meter

(131 ft) intervals. Signs were posted advising drivers to “Keep Apart, 2 Chevrons”. Vehicle headways and speeds were used as measures of effectiveness.

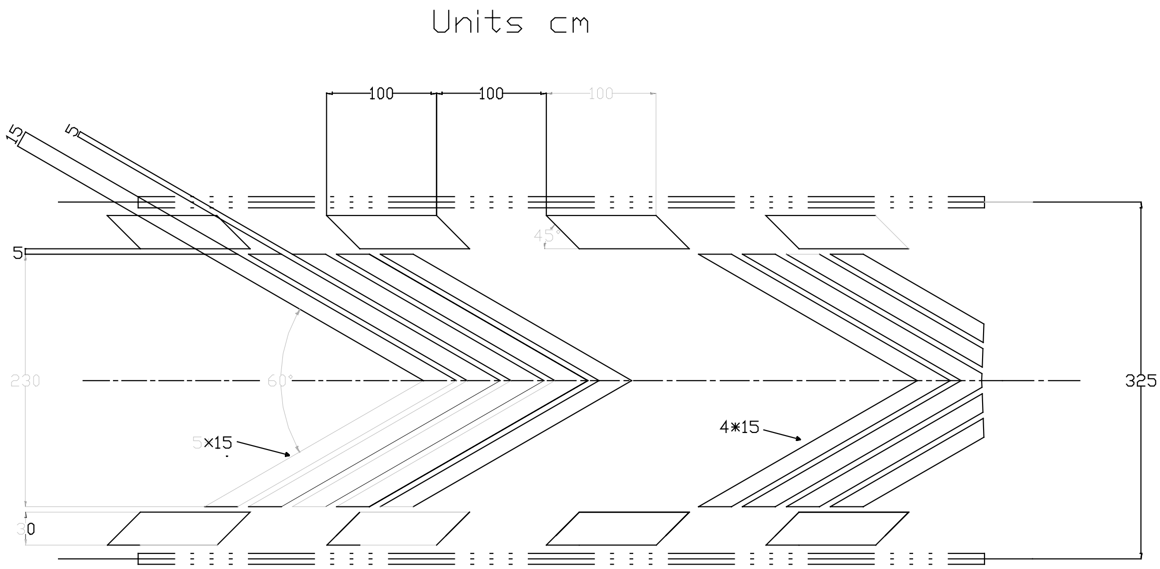


Figure 14. Converging chevron pattern dimensions.

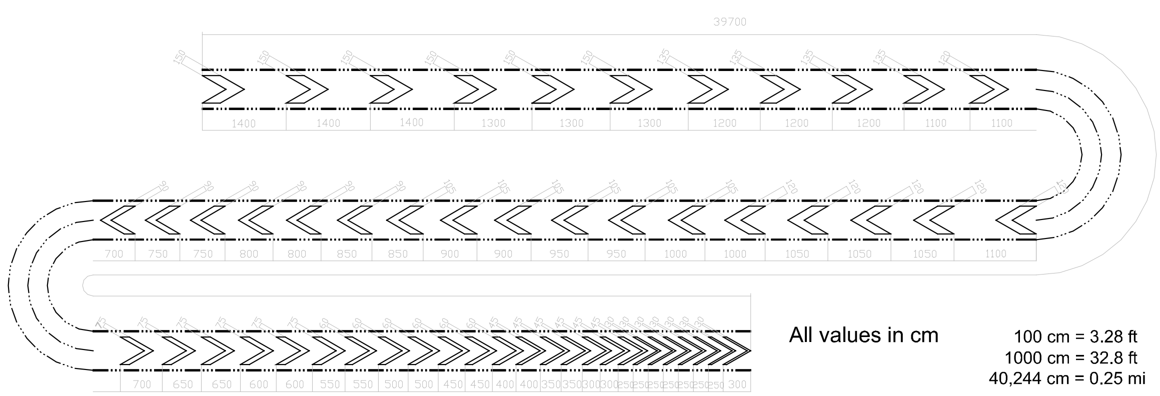


Figure 15. Spacings for converging chevron pattern.

1.4.2.3 Radius Enhancements

Radius enhancements refer to the use of pavement markings to reduce the apparent radius of a curve without altering the actual pavement width. Because this device is not applicable to the context being considered in this study, it will not be discussed here. More information can be found in the KDOT report entitled, *A Comprehensive Literature Review of Perceptual Countermeasures to Speeding.* (Meyer, 2000)

CHAPTER 2: PROJECT DESCRIPTION

In 1996, the Kansas Department of Transportation (KDOT) applied for funds from the Federal Highway Administration's Priority Technologies Program to evaluate the use of optical speed bars as a means to slow traffic entering highway work zones. In 1997, following funding approval, KDOT contracted with The University of Kansas to perform a literature review and develop recommendations for evaluating the device. Preliminary investigation revealed that the complexities of using optical speed bars in the context of a highway work zone were greater than anticipated. In addition, the data collection was extremely problematic.

The University of Kansas developed a methodology for generating the spacing pattern for the bars, and a series of drive-through simulations were developed to evaluate various combinations of pattern parameters related to the spacing of the bars and the rate of change in the spacings throughout the pattern.

In 1998, a pattern design was selected, and included in a set of design plans. A second contract with The University of Kansas was executed to perform the evaluation of the data collected from the site. On Wednesday, June 26, 1999, the section that included the device was opened to traffic. The remainder of this report discusses the design of the pattern, the implementation of the evaluation, and the results of four weeks of data collection.

2.1 Objective

While the available evaluations of optical speed bars demonstrate their effectiveness at reducing speeds, the contexts in which the evaluations were conducted were all associated with large desired speed reductions (i.e., from highway speeds to a stop or near stop). The primary objective of the evaluation discussed in this report was to evaluate the effectiveness of optical speed bars at reducing speeds and speed variations in highway work zones, wherein *small* reductions in speed are desired, typically only 8-16 kph (5-10 mph). Two other objectives were formative in the development of the project. The first of these two objectives was to determine the extent to which any speed reduction that might be observed could be attributed to a change in driver perception of speed, as opposed to simply a warning effect, a result of the bars focusing driver attention on the driving task. The second of these two objectives was to determine if bars could be used over a distance of several kilometers to maintain any reduction in speed that might occur in the initial pattern.

2.2 Site Selection

A study site was chosen on I-70, approximately 44 km west of Topeka, near Paxico, in Wabaunsee County. The study site is shown in Figure 16. Average annual daily traffic (AADT) for this segment is 18,000 vpd, 20.5% of which are heavy vehicles. The segment is a rural four-lane divided highway, carrying relatively little commuter traffic. The work zone was approximately 8 km (5 mi) in length, about 2.2 km (1.4 mi) of which was monitored for traffic characteristics during the evaluation.

The construction project was a two-phase reconstruction project. During Phase I, the westbound lanes were reconstructed while both directions of traffic were carried on the eastbound lanes, separated by vertical tube delimiters and reflective bricks. During Phase II, traffic was carried in the newly constructed westbound lanes while the eastbound lanes were being reconstructed. The project was required to be completed during 1999, although the contractor was free to schedule elements of the project as desired.

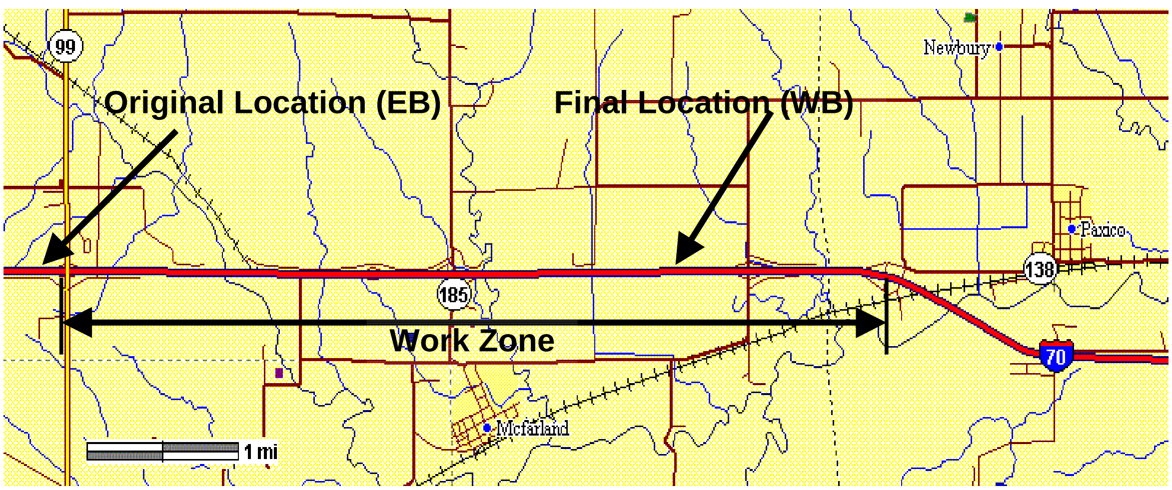


Figure 16. Location of the original and final study locations.

The intent of the evaluation was to isolate the effects of the optical speed bars from other aspects of the environment that could potentially affect speeds, either masking or falsely enhancing the effectiveness of bars. Toward that end, the evaluation was initially sited at the western end of the work zone, where the alignment was straight and the surrounding terrain simple. The speed bars were to be installed prior to Phase I in the eastbound lanes, between the lane drop and the westernmost crossover.

In early 1999, it was learned that the contractor had decided to begin work in early March, much earlier in the year than had been anticipated. Traffic control considerations mandated that the installation of the optical speed bars occur prior to the beginning of construction, requiring the speed bars and data collection equipment be set up in the last week of February. Pavement temperatures in late February are frequently below freezing. The risk of the low pavement temperatures preventing proper adhesion of either the pavement markings or the data collection apparatus to the pavement was high enough that the evaluation was moved to Phase II of the construction project, scheduled to begin in mid-July.

Using the eastbound lanes for the evaluation would have necessitated that traffic be stopped while the pavement markings were applied. Because this would have resulted in unacceptable delays, the evaluation was changed to the westbound lanes. The westbound approach to the work zone was not suitable for the evaluation. The effects of two interchanges and two opposing curves on traffic characteristics would obscure the effects of the optical speed bars.

In order to eliminate entering and exiting vehicles within the test segment and to minimize the impact of installation on traffic, the optical speed bars were installed just west of the Spring Creek Road exit ramps, and east of the K-185 junction. The volumes associated with these interchanges are shown in Figure 17 and Figure 18. Entering and exiting volumes are small enough that they can be safely ignored in the data analysis.

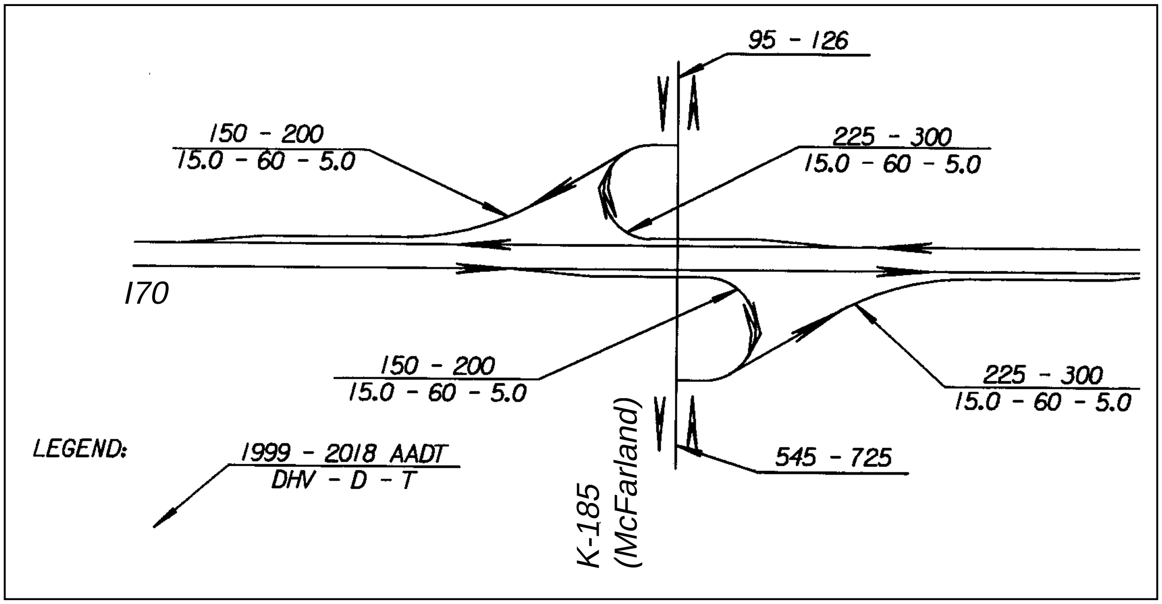


Figure 17. I70-K185 interchange volumes. (Source: KDOT Project Plan Sheets)

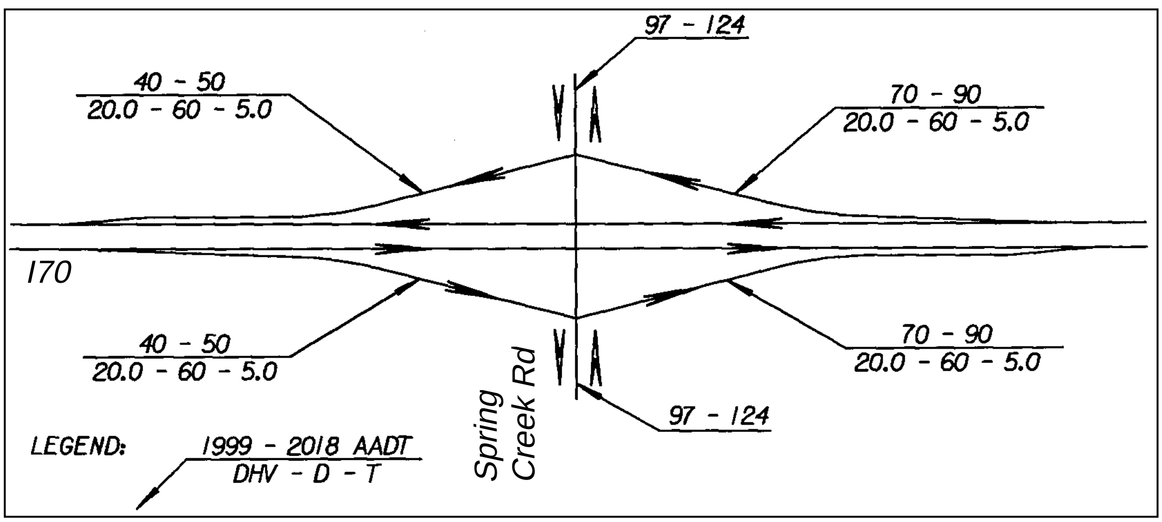


Figure 18. I70-Spring Creek Rd interchange volumes. (Source: KDOT Project Plan Sheets)

The final study site is straight and has a gradient of less than 1%, excepting the last 122 m (400 ft). Figure 19 shows the vertical profile of the test section. The section contains no interchanges or horizontal curves. The regulatory speed limit is 113 kph (70 mph) during normal operation, and 97 kph (60mph) during construction. The reconstructed section (in both directions) has a lane width of 3.7 m (12 ft), an inside shoulder width of 1.8 m (6 ft), and an outside shoulder width of 3.0 m (10 ft).

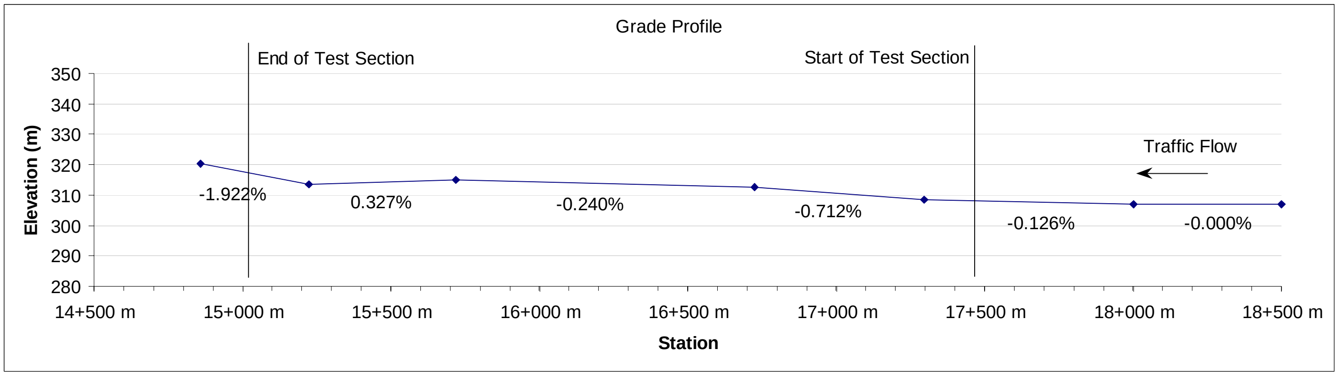


Figure 19. Vertical profile of test section.

CHAPTER 3: PATTERN DESIGN

Few of the previous applications of optical speed bars discussed in the literature detail the parameters used in designing the pattern of bar spacings. Based on the similarities between the patterns, the design principles used in most of the recorded studies were similar to those used by Agent (1980) for a pattern applied to an approach to a sharp curve on a rural two-lane highway in Meade County, Kentucky. In his design methodology, an initial speed and a desired ending speed are assumed. Based on these speeds, the bars are spaced such that a driver decelerating at a constant rate from the initial speed to the ending speed crosses 2 bars per second.

Agent's design principles served as the basis for the initial pattern design for this study. Differences between the context of a highway work zone and the contexts of previous applications require that Agent's methodology be modified. The initial speed is similar, but the ending speed is only 8-16 kph (5-10 mph) less than the initial speed. In previous applications, vehicles were coming to a stop or near stop. Essentially, the intended perceptual effect had to be exaggerated relative to Agent's design in order for the effect to be noticeable in simulations.

Additionally, in the case of a highway work zone, it is desirable that the reduced speed be maintained throughout the work zone, often for several kilometers. If optical speed bars are successful at changing driver perception of speed, it is reasonable to expect drivers to return to previous speeds after leaving the speed bar pattern.

Potentially, a recurring pattern throughout the work zone could serve to reinforce the altered perception of speed.

3.1 Pattern Elements

In order to meet the objectives of the test, a design consisting of three separate patterns was developed. The optical speed bars comprise the pattern designated the *primary pattern*. Some studies have suggested that the effect of the bars is due to their acting as a warning sign that cannot be ignored, rather than having any perceptual effect. To facilitate the separation of warning effects and perceptual effects, a pattern element was added upstream of the primary pattern. This element is called the *leading pattern*. Based on the suspicion that drivers will resume their previous speeds after leaving the primary pattern, a third pattern element was added downstream of the primary pattern. This element is called the *work zone pattern*. A sketch of all three pattern elements is shown in Figure 20.

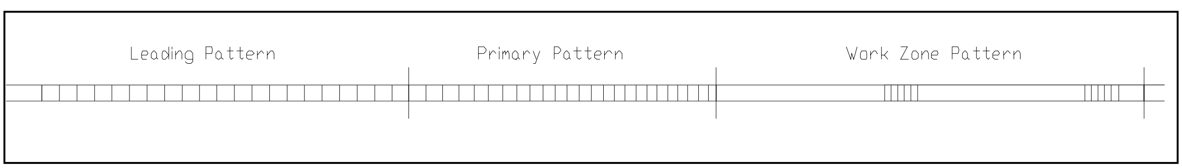


Figure 20. Sketch of experimental pattern elements.

3.1.1 Primary Pattern

The primary pattern is where perceptual effects are intended to occur. The spacing between the bars decreases with a downstream progression. In similar fashion, the longitudinal width of the bars decreases in the downstream direction. Presumably, the appropriate deceleration rate is lower in the work zone context than in other contexts where the desired change in speed is larger. A conservative deceleration rate of 1.6 kph (1 mph) per second was chosen, requiring 10 seconds for the desired speed change, given that the rate of deceleration is constant. At 2 bars/second, the resulting pattern requires 20 bars spread over approximately 291 m (956 ft). When it was recognized that this design model did not produce a noticeable effect (i.e., the change in spacing was almost imperceptible), an approximate pattern length of 305 m (1000 ft) was selected, based on the length of the pattern just described. Further discussion of the design of the primary pattern is given in Section 3.2.

3.1.2 Leading Pattern

The leading pattern, comprised of evenly spaced bars placed immediately upstream of the primary pattern, is intended to serve a dual function. The first function is that the evenly spaced bars form a clear reference against which drivers observe the primary pattern. The second function relates to the design of the experiment itself.

Previous studies have suggested that the effect of optical speed bars is due to their warning effect, rather than an alteration of driver perception. If true, a shorter, uniformly spaced pattern of stripes would be just as effective as a more sophisticated design, and much less expensive to install and remove. Thus, one of the objectives of this evaluation was to discern the role played by perception in any speed reductions realized.

To separate warning effects from perceptual effects, the leading pattern was incorporated. The spacing of the bars in the leading pattern was equal to the largest spacing occurring in the primary pattern. The length of the primary pattern was also selected as the approximate length of the leading pattern. This length of 305 m (1000 ft) requires approximate 10 seconds to traverse at 113 kph (70 mph). Any speed reductions resulting from a warning effect would likely occur within the first 10 seconds after entering the pattern (much of it could occur *prior* to entering the pattern). Any further speed reduction observed in the primary pattern is likely due to a perceptual effect.

3.1.3 Work Zone Pattern

In addition to requiring only a small decrease in speed, the application of optical speed bars to work zones differs from previous applications in that speed reductions need to be maintained for an extended distance. An intermittent work zone pattern was installed immediately downstream of the primary pattern in order to evaluate its effectiveness at maintaining speed reductions occurring in the leading and primary patterns.

Based on the visibility and duration of the patterns as viewed in simulations of the patterns from the driver's perspective, each intermittent pattern was set to be approximately 30 m (100 ft) long, with approximately 150 m (500 ft) between them. Specific dimensions are given in Section 3.4.

3.2 Design Parameters

Based on the design principle used by Agent (1980), a pattern was designed and a computer simulation of the pattern from the driver's perspective was generated. Upon viewing the simulation, it was evident that the change in the bar spacings from the beginning of the pattern to the end was insufficient. Because the desired change in speed was only 16 kph (10 mph), the change in the spacings was very slight. So slight, in fact, that it was very difficult to discern any difference at all. The intended effect of these patterns is perceptual, and not subliminal. Thus, Agent's design methodology needed to be altered somewhat. Starting with Agent's general methodology, several parameters were developed to allow aspects of the design to be methodically changed and compared. The following sections discuss the nature of the parameters developed. The specific values used in the final design are discussed in Section 3.4.

3.2.1 Multiplier, *M*

To compensate for the small speed reduction desired in work zones, the perceptual effect of the pattern needed to be exaggerated by decreasing the spacings between bars more rapidly. There was a concern among the project advisory panel that if the effect were too exaggerated, some drivers might become alarmed and exhibit erratic driving behavior, i.e., brake suddenly causing rear end collisions. A parameter was introduced to facilitate the exaggeration of the perceptual effect in the design process.

A multiplier, *M*, was applied to the *desired* speed reduction, and Agent's design process was followed using the *exaggerated* speed reduction. When the bar spacings are plotted against the distance upstream of the pattern's end, an approximately linear function results, as shown in Figure 21. (The function is actually linear with travel time, rather than distance.) The application of a multiplier greater than 1 effectively increases the slope by lowering the terminal spacing (i.e., the spacing at the end of the pattern).

Because the spacings between bars actually have a linear relationship with travel time, the graph of the relationship between bar spacing and distance is bowed slightly upward.

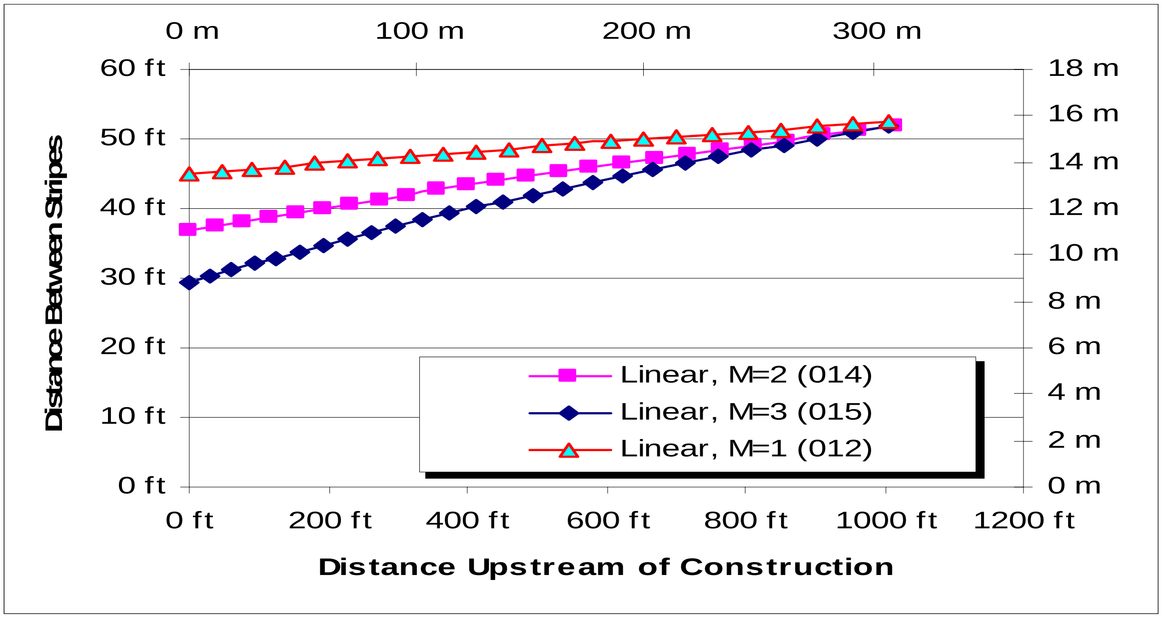


Figure 21. Effect of Multiplier (*M*) on Spacing Patterns.

Simulations were developed using different values for *M*. The use of an exaggerated speed reduction (i.e., $M > 1$) resulted in simulations that showed an obvious improvement in perceptual effects. At values of *M* greater than 3, however, an unexpected characteristic became apparent. Human cognition of frequency is based on a logarithmic scale. In a linear model, bar spacings vary at a constant rate. Consequently, if the change in spacings is expressed as a percentage of the distance between bars, the value will be smallest at the beginning of the pattern and largest at the end of the pattern. This characteristic resulted in a perceptual effect that seemed to occur suddenly around the middle of the pattern. The potential for such an impact to cause alarm among drivers was identified as an important consideration in pattern design. Such alarm could cause erratic maneuvers such as sudden braking, potentially leading to rear end crashes.

3.2.2 Exponent, *E*

An examination of a plot of the bar spacings used in the pattern applied to roundabout approaches in the United Kingdom reveals three interesting characteristics. As can be seen in Figure 22, the function is linear with distance, rather than time, as indicated by the absence of the slight upward bow. Also, the pattern begins with five evenly spaced bars, analogous to a leading pattern. Finally, the rate of change in bar spacings is significantly higher at the beginning of the pattern following the leading section. The documents in which this pattern is described (see APPENDIX A) do not discuss the motivation behind these design characteristics. It is reasonable to suppose that the evenly spaced bars are intended to serve as a reference for driver perception, and the abrupt change in spacing is intended to compensate for the logarithmic aspect of human frequency perception.

A mathematical approach was taken to provide a similar compensation in the pattern developed for final evaluation under this project. The spacing of the bars is calculated using Equation 3-1.

$$S = \frac{v}{f} \tag{3-1}$$

where

- S is the spacing (leading edge to leading edge),
- v is the velocity at the leading bar, and
- f is the frequency of bars (e.g., 2 bars/sec).

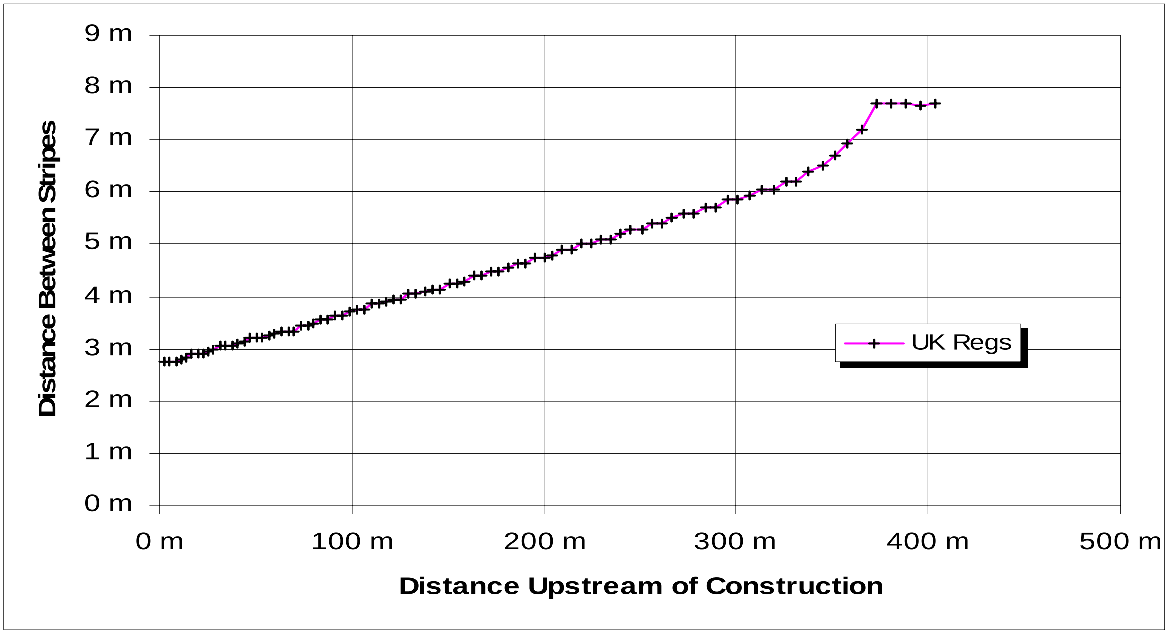


Figure 22. Spacing pattern from the United Kingdom traffic regulations.

The velocity v depends on the deceleration rate or the deceleration function. It is important to note that the objective here is not to model driver behavior, but to establish a parameter for pattern design. With that in mind, a deceleration function can be assumed such that the velocity at any point in the pattern is calculated by Equation 3-2.

$$v = v_f + (v_o - v_f)\left(\frac{1-d}{D}\right)^E \qquad \textbf{3-2}$$

where

- v is the instantaneous velocity, which varies from v_o to v_f,
- v_f is the exaggerated final velocity,
- v_o is the initial velocity,
- d is the distance traveled from the first bar in the (primary) pattern,
- D is the length of the (primary) pattern, and

- E is the exponential design parameter.

Because the purpose is to calculate the spacings between bars, there is no need to define the deceleration function explicitly. Using Equation 3-2 to calculate the spacings, the net change in spacings is identical to a linear spacing model, and values of E greater than 1 will result in spacings changing at a greater rate at the beginning of the pattern than at the end of the pattern. Figure 23 shows the effect of various values of E on the relationship between bar spacing and location within the pattern. A linear pattern (by time) corresponds to $E=1$. Higher values of E cause the rate of change in bar spacing to increase at the start of the pattern and decrease at the end of the pattern. At $E=3$, the changes in bar spacing in the last third of the pattern are practically imperceptible. The numbers in parentheses in the graph's legend refer to simulation IDs in the list given in APPENDIX E. Simulations will be discussed in Section 3.3.

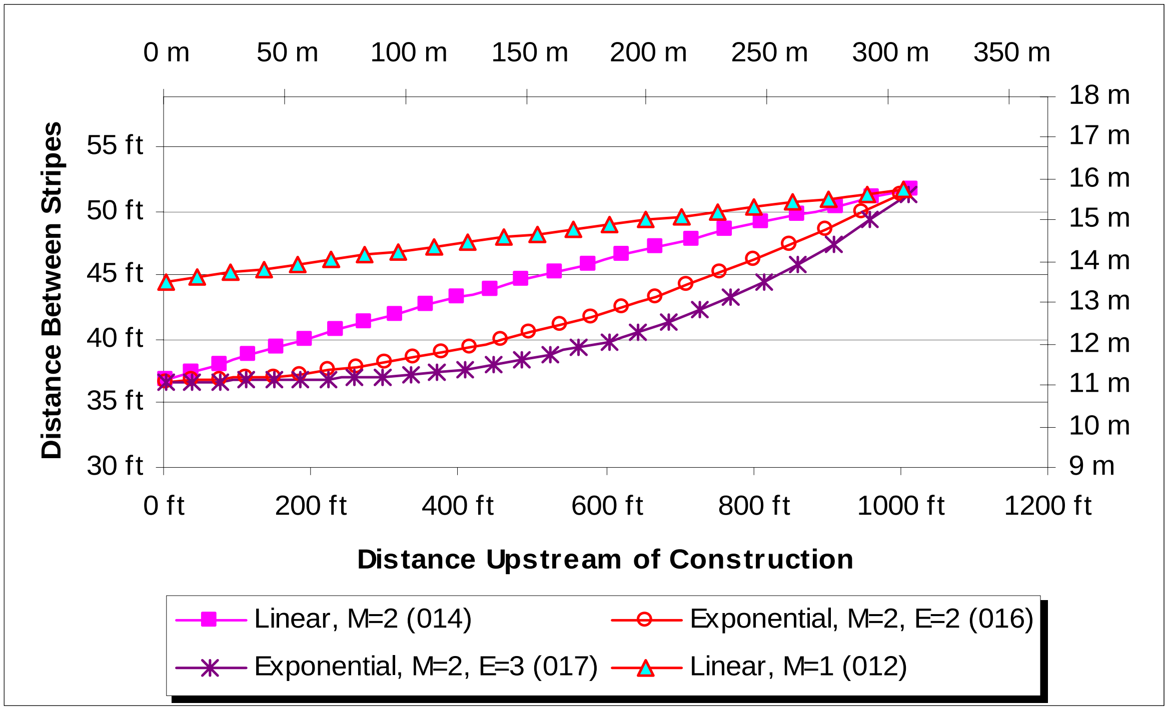


Figure 23. Effect of Exponent (E) on Spacing Patterns.

3.2.3 Mode

Another parameter developed to assist in designing the pattern pertains to the manner in which the spacings calculated using Equations 3-1 and 3-2 are implemented. Two implementation modes were considered: continuous and stepped. When a continuous mode is used, the spacings are calculated for each individual bar. This is the mode represented in the plots in Figure 21 and Figure 23. When a stepped mode is used, a smaller number of spacings are calculated, and multiple bars are set at the same spacing. The change in spacings over the entire pattern is calculated as with the continuous mode. In this study, the total change was divided into three equal portions, and the locations within the pattern where the continuous spacing values equal the division values were identified. All bars in each of the three portions of the pattern were given the spacing of the last bar in that portion. The resulting patterns are illustrated with their continuous mode counterparts in Figure 24. Again, the numbers in parentheses in the legend of the graph are simulation IDs.

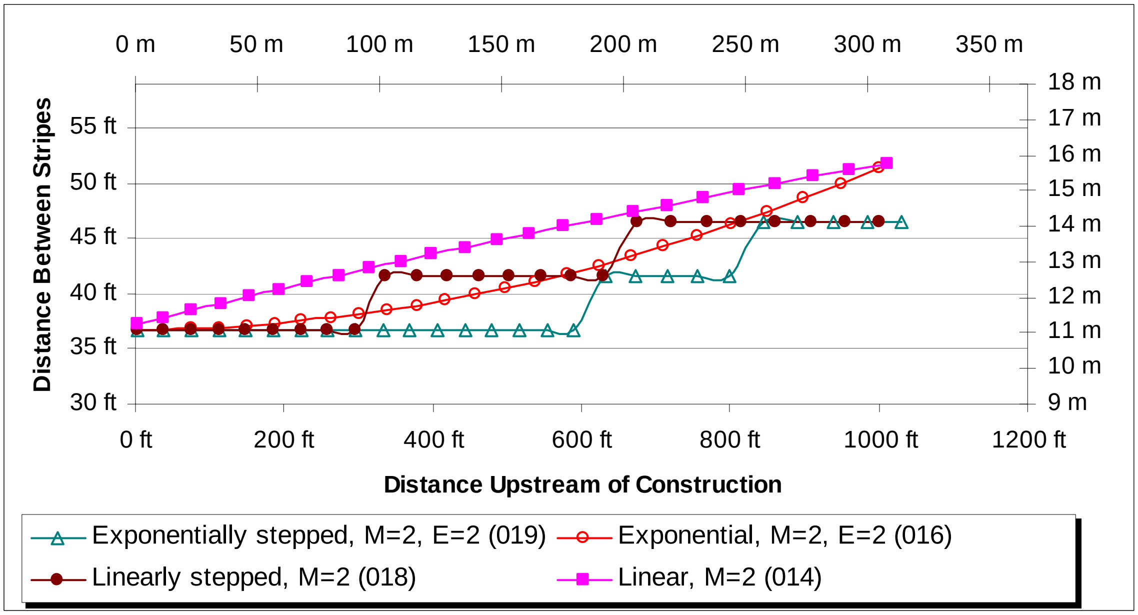


Figure 24. Effect on patterns of using stepped mode versus continuous mode.

The leading pattern is spaced at the value corresponding to the continuous mode spacing at the beginning of the pattern, thus forming the top step, which is not shown in Figure 24.

3.2.4 Frequency

Frequency refers to the number of bars per second that would be encountered by a vehicle decelerating at the design rate. Agent (1980) commented that initially a frequency of 1 bar/sec was considered, but was decided to be too low to provide the driver with adequate stimulus to achieve any change in perception. His final design used a frequency of 2 bars/sec. If an entry speed of 113 kph (70 mph) is assumed, the UK pattern would have a frequency of 4.1 bars/sec. In this evaluation, frequency values of 1, 2, and 3 were considered.

3.2.5 Pattern Length

Initially, a constant deceleration rate of 0.6 m/s^2 (2 ft/s^2) was assumed based on Agent (1980), resulting in a pattern length of approximately 213 m (700 ft). When the multiplier *M* was introduced to the design process, continuing to use the deceleration rate of 0.6 m/s^2 (2 ft/s^2) resulted in infeasibly long pattern lengths. Using a constant rate of 1.8 m/s^2 (6 ft/s^2) essentially cancelled out the use of the multiplier. A constant pattern length of approximately 305 m (1000 ft) was selected based on an actual deceleration of 1.6 kph per second (1 mph per second). While perhaps a little slower than the average driver might select, this value would help to ensure that all of the deceleration that occurs does so within the pattern, rather than after the vehicle leaves the pattern. This would ensure that all of the effects of the pattern are properly captured by the data collection equipment. A consistent length is also helpful in comparing the values of other design parameters.

3.2.6 Work Zone Pattern Type

The work zone pattern is a facet of this project that is entirely unprecedented. Because the contexts of previous applications of optical speed bars have not required that the speed reductions be maintained over an extended distance, there has been no previous consideration of effective techniques. Consequently, the design of the work zone pattern had to be based on simulations, common sense, and intuition.

The length of the intermittent patterns that comprise the work zone pattern was determined by trial and error using subjective evaluations of simulations. The spacing was set so as to allow the next intermittent pattern to become visible as a vehicle leaves the preceding intermittent pattern. The parameter that required the most careful consideration was the *type* of pattern to be used for the intermittent pattern. Three pattern types were evaluated using simulations.

1. A graduated pattern similar to that used in the primary pattern.
2. A uniform pattern (i.e., pattern of uniform spacings) with spacings equal to the minimum spacing in the primary pattern.
3. A uniform pattern with spacings significantly less than the minimum spacing in the primary pattern.

3.2.7 Leading Pattern

Simulations were also used to assess the utility of the leading pattern. The leading pattern, when used in simulations, was always a uniform pattern with spacings equal to the maximum spacings in the primary pattern, so as to achieve a frequency of 2 bars/sec at the design speed. The overall pattern was considered with and without the presence of a leading pattern.

3.2.8 Pylon Spacings and Color

Pylon delineators are commonly spaced 30 m (100 ft) apart. Simulations were generated to assess the effectiveness of using pylons instead of and in addition to the bars in the primary pattern, graduating the pylon spacings as given by Equations 3-1 and 3-2. Also considered was the use of alternating orange and yellow pylons.

3.2.9 Bar Type

Three different bar types were considered.

1. Full bar, 2.75 m (9 ft) wide.
2. Split bar, two segments, each 1 m (3.5 ft) wide, with a gap in between of 0.6 m (2 ft).
3. Chevron, using lead angles of 30 and 45 degrees.

3.2.10 Pavement Coverage

Because pavement markings have a lower coefficient of friction than pristine pavement, there was some concern that the amount of markings necessary to facilitate the overall pattern would significantly decrease safety by increasing the necessary stopping distance. To assess the merit of this concern, the percent of pavement (longitudinally) covered by pavement markings in each pattern design was considered, although this parameter was not used in the design of the patterns.

While the pavement coverage was as high as 10.3% among pattern designs considered, most of the designs covered less than 7%. For comparison, the design detailed by Ito (1995) covers 11.3% of the pavement, and the UK design covers 13.4%. The pavement coverage of the final design, 6.9%, was deemed acceptable by the project advisory panel.

3.3 Simulation Development

Because optical speed bar design parameters used in previous studies have been largely arbitrary, computer simulations were developed by The University of Kansas to aid in assessing the relative merit of various designs. Both daytime and nighttime conditions were reviewed. Figure 25 shows a frame from a simulation using chevrons. Figure 26 and Figure 27 are frames from simulations using bars during daylight and nighttime, respectively.

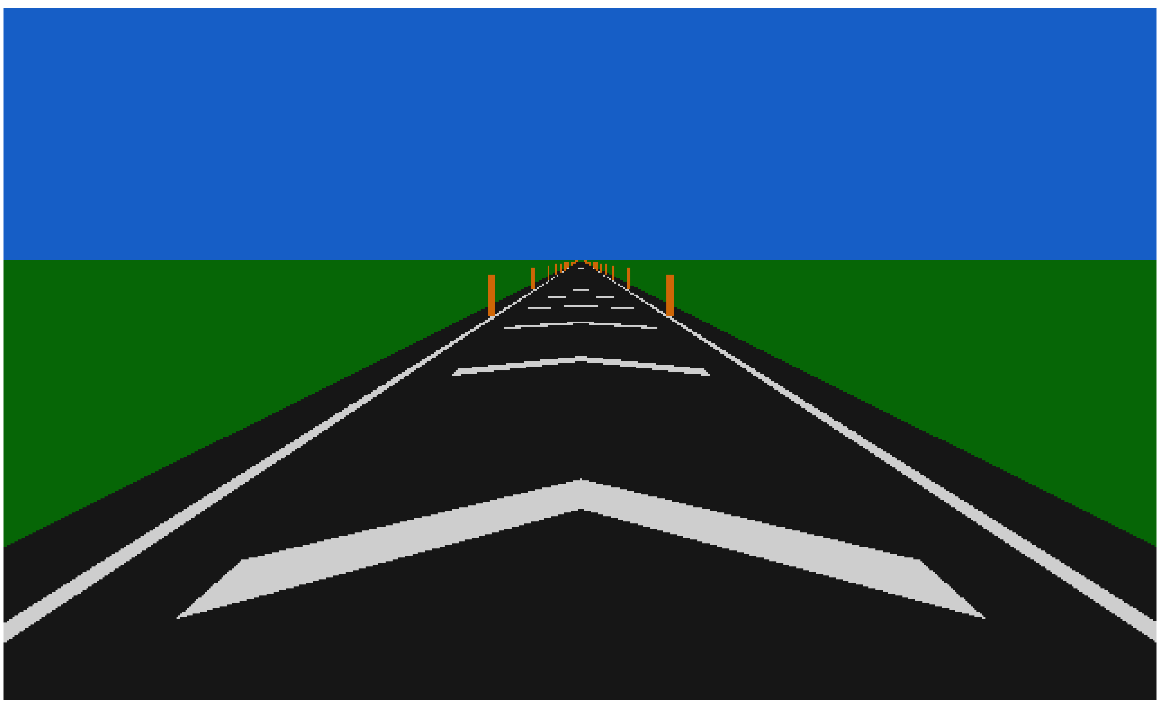


Figure 25. Simulation of a chevron pattern.

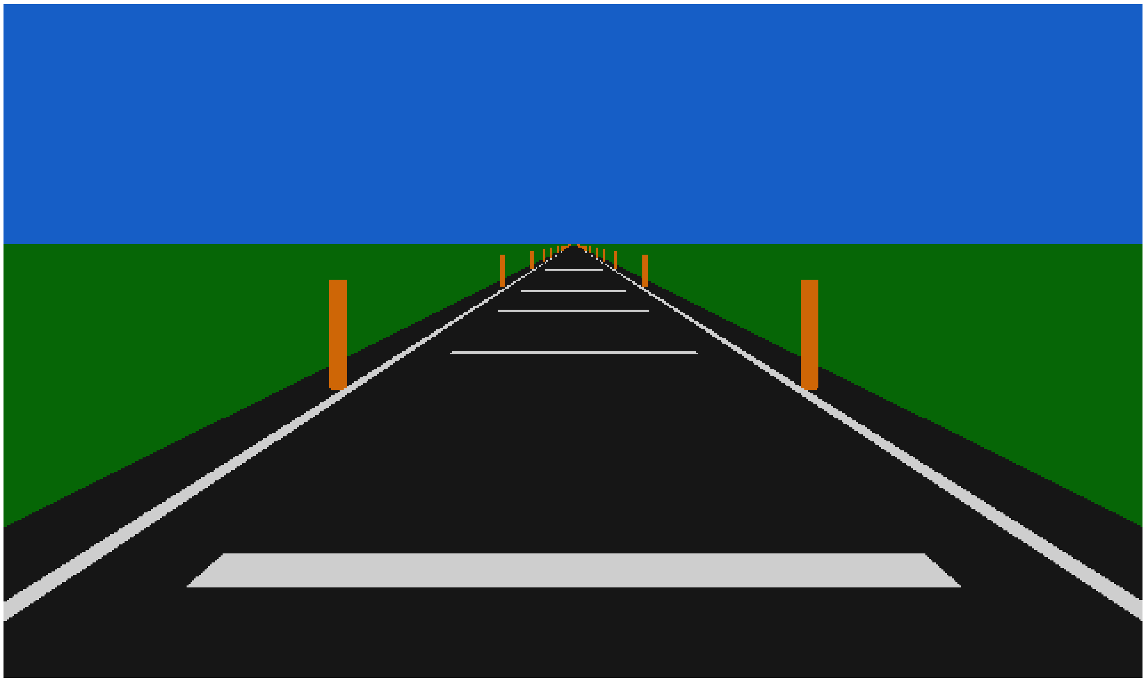


Figure 26. Simulation of optical speed bars in daylight.

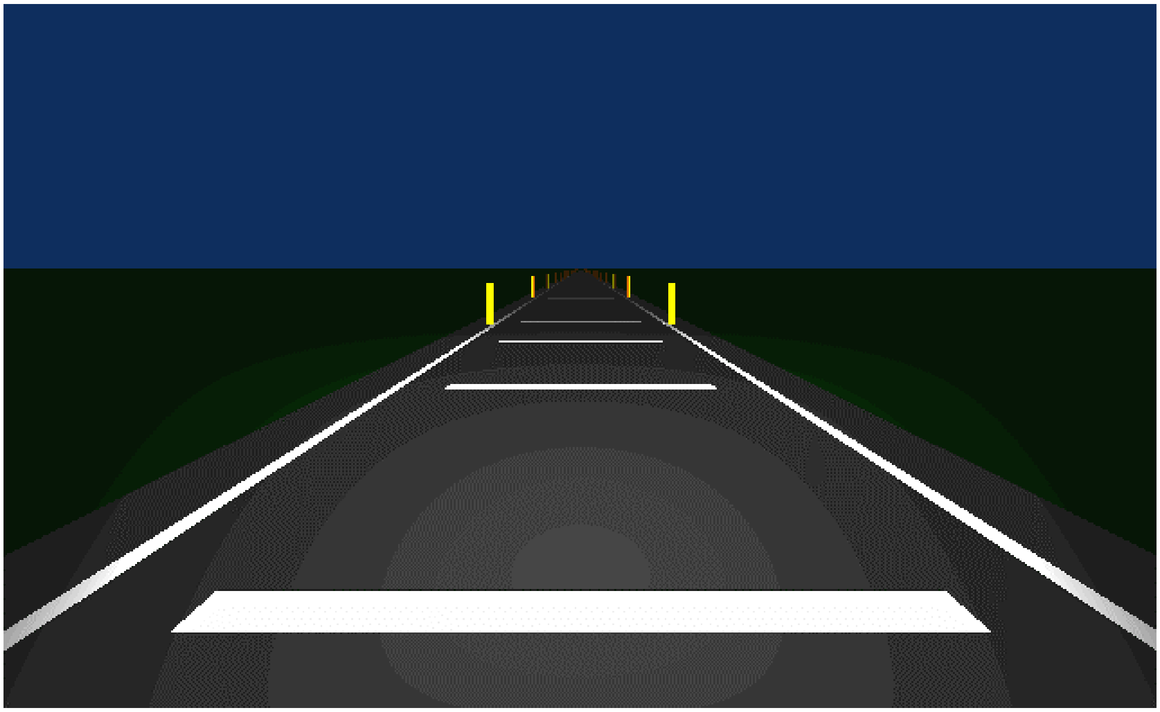


Figure 27. Simulation of optical speed bars at night.

The simulations developed to assist in pattern selection were passive simulations, as opposed to interactive simulations. In other words, the simulations presented a drivers-eye view without requiring any response from the observer such as steering or braking.

3.3.1 Process and Software

The purpose in developing simulations of various patterned designs was to increase the chance of selecting the design most likely to perform effectively. Because the scope of the project precluded any formal evaluation using simulations and test subjects, passive simulations, or animations, were used.

The first step in generating a simulation is to describe the elements that are to be simulated. For example, in simulating a highway, objects described may include the roadway itself with centerline and edge line markings, if any; roadside features such as signs, drums, or trees; or intersecting roads. Once the objects are described, the individual frames of the simulation are created. And, finally, the frames are compiled into an animation that simulates the driver's view as the road is traveled.

The following sections provide more detail regarding the necessary software and the steps involved in creating a drive-through simulation.

3.3.1.1 Hardware Configuration

With regard to computer hardware, the minimal configuration would depend on the type of simulation to be created. In this paper, all processing times refer to a 90 MHz Pentium computer with 32 MB of RAM. The simulations mentioned in this paper (unless otherwise noted) are standard VGA resolution (640 pixels X 480 pixels), 256 colors, and around 720 frames. At 15 frames per second, the lowest rate at which motion still appears relatively smooth, such a simulation would run for 48 seconds and take up 1 to 7 MB of hard disk space (more space is needed for the intermediate steps in generating the simulation). A slower computer could be used, but, of course, the images will take longer to render.

3.3.1.2 Spreadsheet (e.g., Microsoft Excel)

There are three software programs needed for generating a simulation. First, a spreadsheet (e.g., Microsoft Excel) may be helpful in generating descriptions of objects that occur repeatedly in the environment to be animated. For example, a broken centerline can be easily created within a spreadsheet. Each segment is a separate object, but the color characteristics and dimensions will all be identical. Only the location, and perhaps the orientation, of the segments will change. Because the changes in location are predictable and quite regular, a spreadsheet is the perfect tool to generate the text necessary to formally describe the broken line. Once the text is generated, it can be copied and pasted into the software, which then generates the images of the individual frames. In the work described in this paper, Microsoft Excel was used to help generate the scene descriptions.

3.3.1.3 Rendering Package (e.g., POV-Ray for Windows)

To generate the images that make up the simulation, ray-tracing software was used for several reasons. Ray tracing software that can be obtained at no cost can produce extremely high quality images. These software packages require that scenes are described in a text file, rather than in an interactive graphical environment, but this method can actually be more efficient when mathematical formulae can be used to generate objects. For the simulations discussed in this report, a textual description of a series of pavement markings is generated very quickly using a spreadsheet. If a graphical description were used, the same spreadsheet would have been employed to determine the location of each component, and then each component would have to be placed individually. Furthermore, many ray-tracing packages can import design files in popular CAD formats, such as DXF. In other cases, low- or no-cost utilities are available for converting between formats.

Several ray-tracing packages are available at little or no cost. Many have comparable features and would be suitable for creating the images for a simulation. The package used in the work discussed in this paper was POV-Ray for Windows (POV stands for Persistence Of Vision). POV-Ray was chosen for this work based on the author's previous experience with the package. POV-Ray is capable of producing photo-realistic images, is relatively efficient and well documented, provides important features specific to generating animation sequences such as a simulation, and may be downloaded from the Internet.

It should be noted that the generation of these files might take a significant amount of time. There are a number of variables that can affect the time required, but several hours may be needed to generate all the frames for a single simulation. Additionally, these images can occupy a large amount of space on the computer's hard disk, perhaps several hundred megabytes. The images that make up a simulation typical of those discussed in this report take approximately 8 hours to generate, and occupy about 10 MB of disk space. Other simulations were generated using simple shading and low-level anti-aliasing (anti-aliasing is a technique for improving image quality by shooting additional rays at strategic areas of the scene). The same number of frames took about 3 times as long to generate, and occupied a total of over 400 MB of hard disk space. Fortunately, the software can run unattended, allowing large projects such as this to be run during off-hours over the course of several days. Additionally, the simulation can be created in pieces and the pieces joined together. That way all 400 MB of images do not have to be present on the hard disk simultaneously.

3.3.1.4 Bitmap Animator (e.g., Dave's Targa Animator)

Once the individual frame images have been created, they must be combined into an animated sequence to form the simulation. Again, there are a number of options. The software used in this work is Dave's Targa Animator, or DTA (Targa is the format of the images created by POV-Ray), a shareware software package. This software is actually a DOS program, which must be run from a DOS prompt. However, it is simple to use and runs efficiently, creating an animation from several hundred images in a matter of minutes. The examples discussed in this paper required approximately 10 minutes to generate.

3.3.1.5 Animation Viewer (e.g., Autodesk Animation Player for Windows)

DTA generates animations in the Autodesk Animator animation format. The files have an extension of ".FLI" or ".FLC" and are called *flics* or *flic files*. DTA has a companion software that can be used to view the files, called Dave's Flic Viewer, or DFV. DFV is freeware. However, Autodesk has now made available via the Internet the Autodesk Animation Player for Windows, or AAWIN, also free of charge. This program can be called from popular presentation software (e.g., Microsoft PowerPoint), enabling flics to be integrated with nearly any presentation.

3.3.2 Application to Design Selection

As discussed in a previous section, the purpose of the simulations was to facilitate consensus among the members of the advisory panel with respect to various design parameters. The number of parameters and possible values precluded direct comparison of every combination using simulations. As many decisions as possible were made prior to the consensus exercise. The number of direct comparisons used totaled 15. Table 5 shows the descriptions of the simulations used in the comparisons. A description of all simulations generated is given in APPENDIX E.

These simulations were viewed by two groups of people. One group consisted of KDOT personnel and the other consisted of graduate students from The University of Kansas. The KDOT group, comprised primarily of members of the project advisory panel, was given the task of eliminating designs that were unacceptable for any reason. The two primary criteria that seemed to govern comments were the effectiveness of the pattern at enhancing the perception of speed, and the potential for the pattern to change driver perception suddenly, alarming the driver. These two parameters were incorporated into the consensus exercise involving the graduate students by requesting participants to rate each pair of patterns relative to one another. A tool was developed to facilitate the exercise. Shown in Figure 28, the response sheet includes responses for 15 comparisons (comparison numbers are at the left of the sheet). For each comparison, participants were asked to rate option B relative to option A with respect to the perception effect and the potential for alarming the driver. A second sheet (identical to the first) was used for comparisons 13-15. A summary of the responses is provided in Table 6.

Table 5. Simulation comparisons used in consensus exercise.

Comparison	ID	Multiplier	Bars/s	Distance	time	Leading	Work Zone Pattern Type	Exponent	Deceleration (Stripe Spacing) Model	Pylon Spacings	% of Pavement Covered	Description
1	20	2	2	1000 ft	9.7 s	Y	Graduated	2	Exponential	Uniform	5.5%	Graduated work zone pattern
	22	2	2	1000 ft	9.7 s	Y	Graduated	2	Exponential	Uniform	5.5%	Split Stripes
2	16	2	2	1000 ft	9.7 s	Y	Uniform	2	Exponential	Uniform	5.5%	Exponential deceleration
	32	3	2	1011 ft	9.9 s	Y	Uniform	2	Exponential	Uniform	6.9%	
3	32	3	2	1011 ft	9.9 s	Y	Uniform	2	Exponential	Uniform	6.9%	
	33	4	2	1000 ft	9.7 s	Y	Uniform	2	Exponential	Uniform	9.2%	
4	38	3	2	1011 ft	9.7 s	Y	Uniform	3	Exponential	Uniform	6.9%	
	32	3	2	1011 ft	9.9 s	Y	Uniform	2	Exponential	Uniform	6.9%	Exaggerated deceleration
5	15	3	2	1006 ft	9.8 s	Y	Uniform	1	Linear	Uniform	7.1%	Exaggerated deceleration
	32	3	2	1011 ft	9.9 s	Y	Uniform	2	Exponential	Uniform	6.9%	
6	20	2	2	1000 ft	9.7 s	Y	Graduated	2	Exponential	Uniform	5.5%	Graduated work zone pattern
	26	2	2	1000 ft	9.7 s	N	Graduated	2	Exponential	Uniform	5.5%	No Leading Pattern
7	20	2	2	1000 ft	9.7 s	Y	Graduated	2	Exponential	Uniform	5.5%	Graduated work zone pattern
	27	2	2	1010 ft	9.8 s	Y	Graduated	2	Exponential	Uniform	5.5%	Chevron, 30
8	32	3	2	1011 ft	9.9 s	Y	Uniform	2	Exponential	Uniform	6.9%	Exaggerated deceleration
	38	3	2	1011 ft	9.7 s	Y	Uniform	3	Exponential	Uniform	6.9%	
9	32	3	2	1011 ft	9.9 s	Y	Uniform	2	Exponential	Uniform	6.9%	
	30	6	4.1	1325 ft	12.7 s	N	n/a	1	Linear	Uniform	13.4%	British bar
10	32	3	2	1011 ft	9.9 s	Y	Uniform	2	Exponential	Uniform	6.9%	
	31	8	2.25	1302 ft	12.7 s	N	n/a	0.5	Inverse Exp	n/a	11.3%	Ito, original
11	16	2	2	1000 ft	9.7 s	Y	Uniform	2	Exponential	Uniform	5.5%	Exponential deceleration
	39	2	2	1000 ft	9.7 s	Y	Uniform	2	Exponential	Uniform	5.5%	Tighter Work Zone Pattern
12	17	2	2	1011 ft	9.7 s	Y	Uniform	3	Exponential	Uniform	6.9%	Exponential deceleration
	19	2	2	1031 ft	10.0 s	Y	Uniform	2	Exponentially Stepped	Uniform	5.7%	Exponentially stepped deceleration
13	39	2	2	1000 ft	9.7 s	Y	Uniform	2	Exponential	Uniform	5.5%	Tighter Work Zone Pattern
	16	2	2	1000 ft	9.7 s	Y	Uniform	2	Exponential	Uniform	5.5%	Exponential deceleration
14	33	4	2	1000 ft	9.7 s	Y	Uniform	2	Exponential	Uniform	9.2%	
	32	3	2	1011 ft	9.9 s	Y	Uniform	2	Exponential	Uniform	6.9%	
15	19	2	2	1031 ft	10.0 s	Y	Uniform	2	Exponentially Stepped	Uniform	5.7%	Exponentially stepped deceleration
	17	2	2	1011 ft	9.7 s	Y	Uniform	3	Exponential	Uniform	6.9%	Exponential deceleration

Perceptual Countermeasures to Speeding

Name

Design Evaluation Form June 15, 1998

Compared to B, Option A is…

	(Speed)	(Alarm)	
	Much Slower / Slightly Slower / About the same / Slightly Faster / Much Faster	Much Less / Slightly Less / About the same / Slightly More / Much More	
1	- +	- +	Comments
2	- +	- +	Comments
3	- +	- +	Comments
4	- +	- +	Comments
5	- +	- +	Comments
6	- +	- +	Comments
7	- +	- +	Comments
8	- +	- +	Comments
9	- +	- +	Comments
10	- +	- +	Comments
11	- +	- +	Comments
12	- +	- +	Comments

Figure 28. Consensus exercise response sheet.

Table 6. Consensus exercise response summary.

Comparison No.	1		2		3	
Option A (ID, Desc)	20	Full stripes	16	M=2	32	M=3
Option B (ID, Desc)	22	Split stripes	32	M=3	33	M=4
	Speed	Alarm	Speed	Alarm	Speed	Alarm
Favoring opt A	2/8	3/8	1/8	2/8	2/8	3/8
Favoring opt B	6/8	3/8	4/8	1/8	5/8	1/8

Comparison No.	4		5		6	
Option A (ID, Desc)	38	E=3	15	E=1	20	With Leading
Option B (ID, Desc)	32	E=2	32	E=2	26	W/o Leading
	Speed	Alarm	Speed	Alarm	Speed	Alarm
Favoring opt A	1/8	0/8	2/8	3/8	0/8	2/8
Favoring opt B	0/8	2/8	6/8	0/8	7/8	1/8

Comparison No.	7		8		9	
Option A (ID, Desc)	20	Stripes	32	E=2	32	E=2
Option B (ID, Desc)	27	Chevron	38	E=3	30	UK Pattern
	Speed	Alarm	Speed	Alarm	Speed	Alarm
Favoring opt A	1/8	3/8	2/8	0/8	2/8	6/8
Favoring opt B	7/8	2/8	4/8	1/8	6/8	1/8

Comparison No.	10		11		12	
Option A (ID, Desc)	32	E=2	16	Basic WZ	17	Exponential
Option B (ID, Desc)	31	Ito, original	39	Tighter WZ	19	Stepped
	Speed	Alarm	Speed	Alarm	Speed	Alarm
Favoring opt A	2/8	6/8	1/8	6/8	1/8	1/8
Favoring opt B	6/8	1/8	6/8	1/8	3/8	1/8

Comparison No.	13		14		15	
Option A (ID, Desc)	39	Tighter WZ	33	M=4	19	Stepped
Option B (ID, Desc)	16	Basic WZ	32	M=3	17	Exponential
	Speed	Alarm	Speed	Alarm	Speed	Alarm
Favoring opt A	6/8	1/8	1/8	0/8	2/8	0/8
Favoring opt B	1/8	2/8	2/8	3/8	3/8	2/8

3.3.3 Interpreting Results

The results shown in Table 6 summarize the responses of eight participants. Under each comparison, the rows labeled "Favoring opt A" and "Favoring opt B" indicate the number of participants who chose one of the two leftmost or two rightmost categories and either question on the response sheet. For the *Speed* category, the responses tallied are those that indicated option B was “much slower” or “much faster” relative to option A. For the *Alarm* category, the responses tallied are those that indicated option B was “much less” or “much more” alarming than option A. For some comparisons, one option is highlighted to indicate a highly favored option.

3.3.3.1 Comparison 1: Full Stripes Versus Split Stripes

Six of the eight participants indicated that split stripes were more effective than full stripes. However, the remaining two participants indicated that full Stripes were the more effective as of the two. The purpose of split stripes—to provide a path for motorcyclists—was explained to the participants prior to the exercise. Responses may have reflected participants favor for the purpose of the split stripes, and not necessarily the effectiveness of the split stripes at producing a perceptual effect. It was decided that full stripes should be used in the actual application because of the ease of installation.

3.3.3.2 Comparisons 2, 3, and 14: M Values

Comparison 2 shows a slight group preference for an *M* value of 3 over a value of 2. While comparison three shows a slight preference for an *M* value of 4 based on *Speed*, an *M* value of 3 is preferred based on the *Alarm* category. Meanwhile, comparison 14, in which the order of comparison was reversed, shows no clear preference toward either value of *M* based on the *Speed* category, and the preference for a value of 3 recurs, based on the *Alarm* category.

3.3.3.3 Comparisons 4, 5, and 8: E Values

In comparison 5, an *E* value of 2 was preferred based on the *Speed* category, while a value of 1 was preferred based on the *Alarm* category. In comparing *E* values of 2 and 3, comparisons 4 and 8 show contradicting preferences based on both the *Alarm* category and the *Speed* category.

3.3.3.4 Comparison 6: Leading Pattern

While the consensus of the participants favored the pattern without the leading pattern, the presence of the leading pattern is necessary for separating the warning effects from the perceptual effects. Consequently, the leading pattern must be included in the installation.

3.3.3.5 Comparison 7: Chevron Versus Stripes

The group consensus favored the pattern comprised of chevrons over the pattern comprised of stripes. Because of the lack of data in the literature related to the use of chevrons and the greater effort required for installation, bars were used for the installation, even though the consensus exercise favored the use of chevrons.

3.3.3.6 Comparisons 9 and 10: UK Pattern and Ito's Design

Based on the feedback of the project advisory panel prior to the consensus exercise, the combination of an *M* value of 3 and an *E* value of 2 was expected to be the most effective pattern design. In comparisons 9 and 10, the expected design was compared with two designs taken from the literature. In both cases, the expected design was not favored based on the *Speed* category and was favored based on the *Alarm* category. This result could be expected, because both the UK pattern and the pattern developed by Ito were designed for contexts in which traffic was transitioning from highway speeds to a near stop. Even with the exaggeration of the speed reduction facilitated by the use of an *M* value of 3, the speed reduction used in the design was only about half that applicable for the other two designs.

3.3.3.7 Comparisons 11 and 13: Work Zone Pattern Spacing

The patterns described as "Basic WZ" use uniformly spaced bars for the work zone pattern with a spacing equal to the minimum spacing in the primary pattern, in this case equal to 11.2 m (37 ft) (corresponding to a *M* value of 2 and an *E* value of 2). The patterns described as "Tighter WZ" use uniformly spaced work zone patterns with a spacing of 7.6 m (25 ft) between the bars in the intermittent patterns. In both comparisons, the smaller spacing was favored based on the *Speed* category. In comparison 11, the larger spacing was favored based on the *Alarm* category, while neither was favored in comparison 13.

3.3.3.8 Comparisons 12 and 15: Stepped Versus Continuous Pattern

In both comparisons, no clear preference was evident for either option based on either category.

3.4 Final Design

The final design selected used a leading pattern, a primary pattern with the characteristics shown in Table 7, and a uniformly spaced work zone pattern with spacings of 6 m (20 ft). A continuous mode pattern was chosen using full bars. As shown in Figure 29, the length of the bars (i.e., the transverse dimension) is a constant 2.75 m (9 ft). The width of the bars (i.e., in the direction of vehicle travel) varies across the pattern sections. The leading pattern spans 332.2 m (1090 ft) and consists of 20 bars, each with constant width of 1050 mm (42 in) and being 15.849 m (52 ft) apart. Figure 30 shows a plan view of the pattern (longitudinal dimension only). Table 8 shows stations of the bars in the leading pattern.

Table 7. Final Pattern Design Parameters.

ID	Multiplier	Exponent	Bars/s	Distance	Leading	Work Zone Pattern Type	Deceleration (Stripe Spacing) Model	Pylon Spacings	% of Pavement Covered	Description
41	3	2	2	1011 ft	Y	Uniform	Exponential	Uniform	6.9%	Work Zone spacing of 20 ft

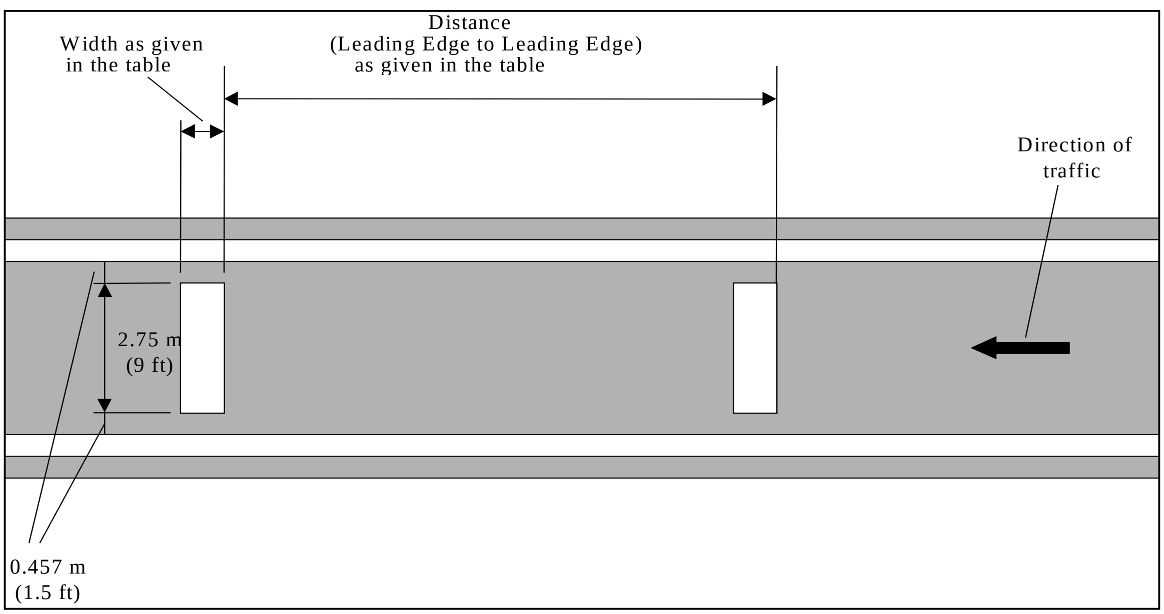


Figure 29. Optical speed bars dimensions.

The primary pattern is 278.9 m (915 ft) long and consists of 29 bars. The widths of the bars vary from 1050 mm (42 in) to 600 mm (24 in). The bar spacings vary from 15.7 m (51.4 ft) to 9.0 m (29.4 ft). Stations and spacings of the primary pattern are listed in Table 9.

The work zone pattern spans 746.8 m (2450 ft) and consists of four sets of six bars, with 152 m (500 ft) between sets. Each bar is 600 mm (24 in) wide with a spacing of 6 m (20 ft). Details of the work zone pattern are listed in Table 10.

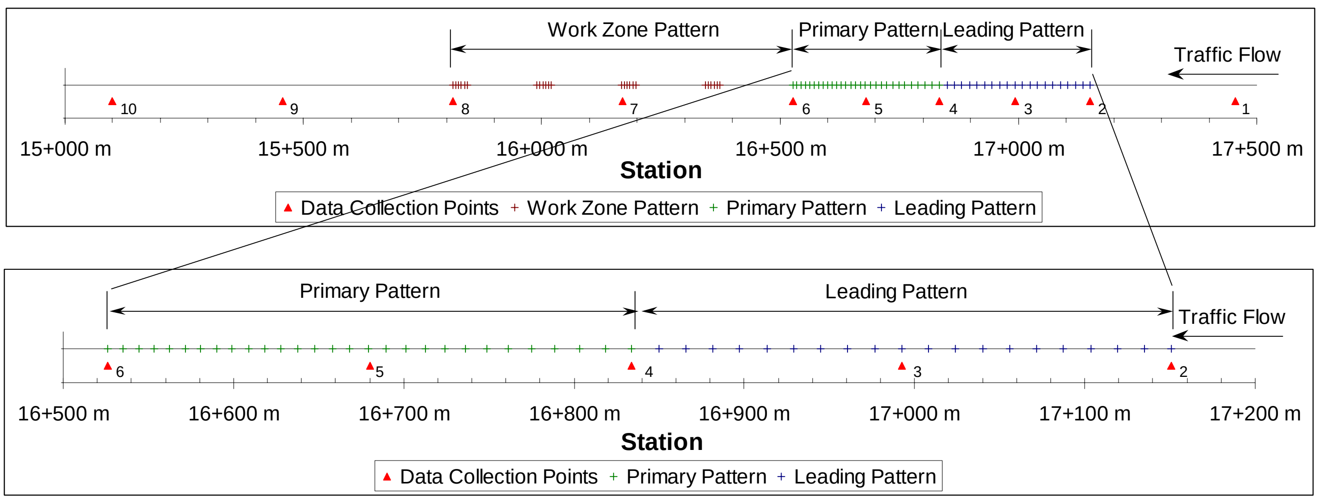


Figure 30. Diagram of bar locations and data collection points.

Table 8. Leading pattern stations (as designed).

Bar No.	Station* of Leading Edge	Width of Bar	Distance From Leading Edge to Leading Edge of Next Stripe
1	17+150.972	1050 mm	15.849 m
2	17+135.123	1050 mm	15.849 m
3	17+119.275	1050 mm	15.849 m
4	17+103.426	1050 mm	15.849 m
5	17+087.577	1050 mm	15.849 m
6	17+071.728	1050 mm	15.849 m
7	17+055.879	1050 mm	15.849 m
8	17+040.030	1050 mm	15.849 m
9	17+024.182	1050 mm	15.849 m
10	17+008.333	1050 mm	15.849 m
11	16+992.484	1050 mm	15.849 m
12	16+976.635	1050 mm	15.849 m
13	16+960.786	1050 mm	15.849 m
14	16+944.938	1050 mm	15.849 m
15	16+929.089	1050 mm	15.849 m
16	16+913.240	1050 mm	15.849 m
17	16+897.391	1050 mm	15.849 m
18	16+881.542	1050 mm	15.849 m

*All stations are in meters.

Table 9. Primary pattern stations (as designed).

Bar No.	Station* of Leading Edge	Width of Bar	Distance From Leading Edge to Leading Edge of Next Stripe
21	16+833.995	1050 mm	15.681 m
22	16+818.314	1050 mm	15.014 m
23	16+803.299	900 mm	14.408 m
24	16+788.891	900 mm	13.857 m
25	16+775.035	900 mm	13.354 m
26	16+761.681	900 mm	12.895 m
27	16+748.786	900 mm	12.476 m
28	16+736.310	750 mm	12.093 m
29	16+724.216	750 mm	11.743 m
30	16+712.473	750 mm	11.423 m
31	16+701.050	750 mm	11.131 m
32	16+689.919	750 mm	10.863 m
33	16+679.056	750 mm	10.619 m
34	16+688.436	750 mm	10.397 m
35	16+658.039	750 mm	10.195 m
36	16+647.844	600 mm	10.012 m
37	16+637.833	600 mm	9.846 m
38	16+627.987	600 mm	9.697 m
39	16+618.290	600 mm	9.563 m
40	16+608.727	600 mm	9.445 m
41	16+599.282	600 mm	9.340 m
42	16+589.942	600 mm	9.250 m
43	16+580.692	600 mm	9.172 m
44	16+571.520	600 mm	9.107 m
45	16+562.413	600 mm	9.054 m
46	16+553.359	600 mm	9.013 m
47	16+544.345	600 mm	8.984 m
48	16+535.361	600 mm	8.967 m
49	16+526.394	600 mm	152.393 m

*All stations are in meters.

Table 10. Work zone pattern stations (as designed).

Bar No.	Station* of Leading Edge	Width of Bar	Distance From Leading Edge to Leading Edge of Next Stripe
50	16+374.002	600 mm	6.096 m
51	16+367.906	600 mm	6.096 m
52	16+361.810	600 mm	6.096 m
53	16+355.715	600 mm	6.096 m
54	16+349.619	600 mm	6.096 m
55	16+343.523	600 mm	152.393 m
56	16+191.131	600 mm	6.096 m
57	16+185.035	600 mm	6.096 m
58	16+178.939	600 mm	6.096 m
59	16+172.844	600 mm	6.096 m
60	16+166.748	600 mm	6.096 m
61	16+160.652	600 mm	152.393 m
62	16+008.260	600 mm	6.096 m
63	16+002.164	600 mm	6.096 m
64	15+996.068	600 mm	6.096 m
65	15+989.973	600 mm	6.096 m
66	15+983.877	600 mm	6.096 m
67	15+977.781	600 mm	152.393 m
68	15+825.389	600 mm	6.096 m
69	15+819.293	600 mm	6.096 m
70	15+813.197	600 mm	6.096 m
71	15+807.101	600 mm	6.096 m
72	15+801.006	600 mm	6.096 m
73	15+794.910	600 mm	

*All stations are in meters.

CHAPTER 4: IMPLEMENTATION

4.1 Data Collection

The primary measures of effectiveness for the evaluation were reduction in mean and 85th percentile speed, and reduction in speed variation as indicated by changes in standard deviation, speed distribution, and Pearson's correlation coefficient. While KDOT routinely collects speed data, their typical needs and the needs dictated by a research context are quite different. The means of data collection for the evaluation was constrained by the following requirements.

1. The data must include the vehicle classification.
2. Vehicle speeds must be collected with a precision of ±0.8 kph (±0.5 mph) or less.
3. Individual vehicle data must be available for analysis.
4. Data must be collected at 10 locations simultaneously (in each direction).
5. Traffic cannot be stopped for the removal or maintenance of data collection equipment (installation could be performed before the lanes are opened to traffic).
6. Equipment must not reduce driver safety in any way (e.g., no equipment cabinets in the clear zone).

An additional consideration was that the project had no funds budgeted for equipment. Developing a data collection plan to meet these requirements was quite challenging.

4.1.1 Technology

Significant investigation was conducted on available data collection technologies. Many of the most commonly used technologies for collecting traffic data had to be removed from consideration because they were incapable of reporting speeds on a per vehicle basis. Other technologies, such as video and microwave detection, require mounting hardware. In the absence of an overpass or light standards, poles would have to be erected at the roadside for mounting the equipment. Consequently these technologies were not viable alternatives.

Early in the project, the Microloop sensor, manufactured by 3M, seemed very appealing because it could provide the needed data while not requiring roadside appurtenances nor the interruption of traffic during installation. While 3M was willing to contribute some hardware to the project, the number of data collection points and the cost of device installation made this technology infeasible.

The Traffic and Field Operations unit of KDOT's Bureau of Transportation Planning had need of several new automatic traffic recorders (ATRs). They agreed to not only allow the use of the equipment they intended to purchase, but they also performed the installation and maintenance during the project.

Timemark ATR units were initially selected to be used in conjunction with temporary inductive loops. Difficulties with the operation of the software and demonstration units led to the decision to use Jamar ATRs. Because the selected counters do not have the ability to classify vehicles when collecting data with inductive loops, it was decided to use pneumatic hoses with the Jamar units.

4.1.2 Setup

The primary objective in developing the data collection plan was to locate the data collection points so that the effects of the three pattern elements could be separated from one another during the data analysis. Data collection would occur at the same station for both directions of traffic using a separate counter for each traffic stream. This allows for the identification of environmental factors other than the optical speed bars by comparing traffic characteristics between the eastbound lane and the westbound lane. For example, a reduction in speed caused by construction activity near a data collection point would appear at that location in both directions of traffic. Reductions due to the perceptual effect of the bars, however, will only occur in the westbound traffic stream.

The first data point in the westbound stream is Point 1. Point 1 serves as baseline for the other data points in the westbound stream. Points 2, 4, and 6 occur at the beginning and end of the leading pattern and primary pattern, as shown in Figure 30. Point 8 occurs at the end of the work zone pattern, and Point 10 occurs at the end of the work zone pattern control section. Points 3, 5, 7, and 9 are intermediate points intended to provide more detailed information about drivers' acceleration and deceleration patterns. For example, Point 5 help provide an estimate of the length of the primary pattern that would provide the desired perceptual effect, and yet minimize installation effort. The stations of the data points are given in Table 11. While some of the discrepancies between planned stations and actual stations are substantial, none are likely to significantly impact the effectiveness of the evaluation.

Table 11. Planned and actual stations of data collection points.

Data Point	Actual Stations	Plan Stations	Difference	Reason for difference
1	17+467.759 m	17+455.757 m	12.002 m	East bound exit of spring creek Rd. was too close
2	17+159.024 m	17+150.972 m	8.052 m	Both tubes were placed before first painted bar
3	16+992.043 m	16+992.483 m	0.440 m	
4	16+832.866 m	16+833.995 m	1.129 m	
5	16+680.015 m	16+680.195 m	0.180 m	
6	16+536.560 m	16+526.394 m	10.166 m	Ending bar was not in correct location
7	16+095.020 m	16+160.652 m	65.632 m	Tube placed between center of work zone pattern, work zone pattern not in correct location
8	15+793.877 m	15+794.910 m	1.033 m	
9	15+542.302 m	15+429.168 m	113.134 m	Tube placed between the center of data point 8 and 10
10	15+281.936 m	15+063.426 m	218.510 m	East bound exit ramp to K-185 was too close

4.2 Installation

Optical speed bars were painted on June 17, 1999, and the highway was opened to traffic on Wednesday, June 26, 1999. The implementation of the study was accomplished as follows: Optical speed bars and detection equipment were installed while westbound lanes were still closed for reconstruction. Contractors painted white bars on the outside westbound lane, the lane that would carry the westbound traffic during Phase II of the construction project. Glass beads were added to the paint to improve the reflectivity of the bars. Detection equipment was installed by KDOT personnel at designated locations following the installation of the optical speed bars. Following the completion of detection installation, centerline delineation devices were installed and westbound I-70 was opened, carrying both directions of traffic in adjacent lanes while the eastbound lanes were being reconstructed. A more complete project chronology is provided in APPENDIX C.

Figure 31. Paint denoting the location of a speed bar.

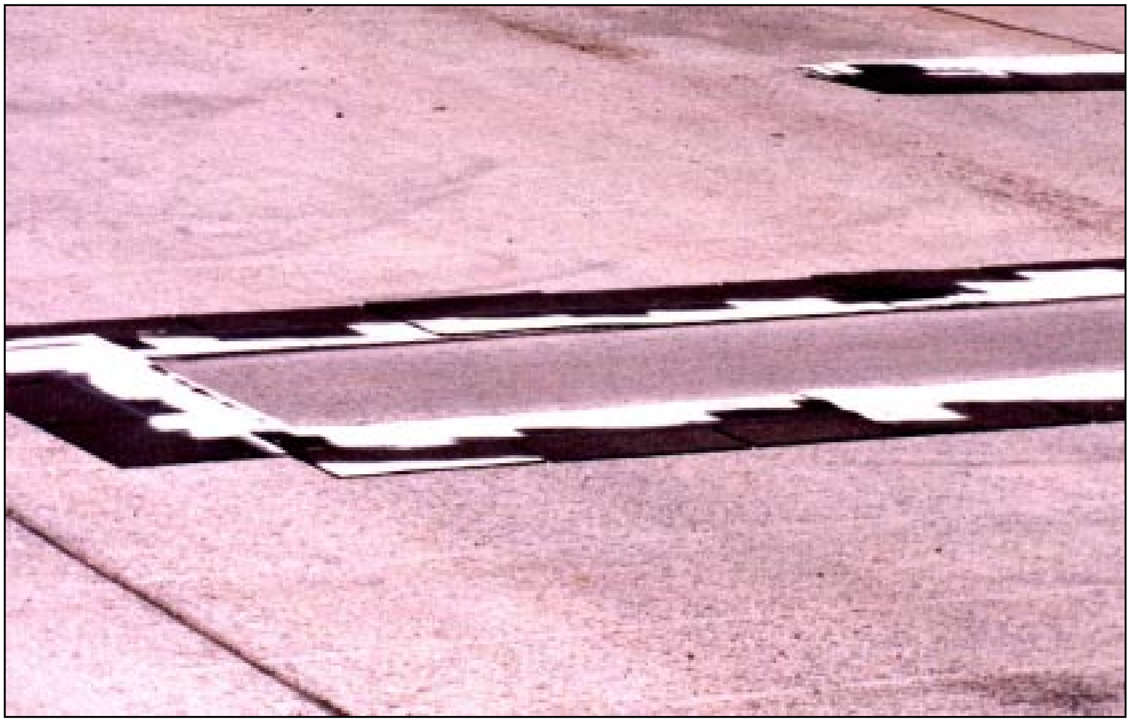


Figure 32. Shingles used to edge the bars.

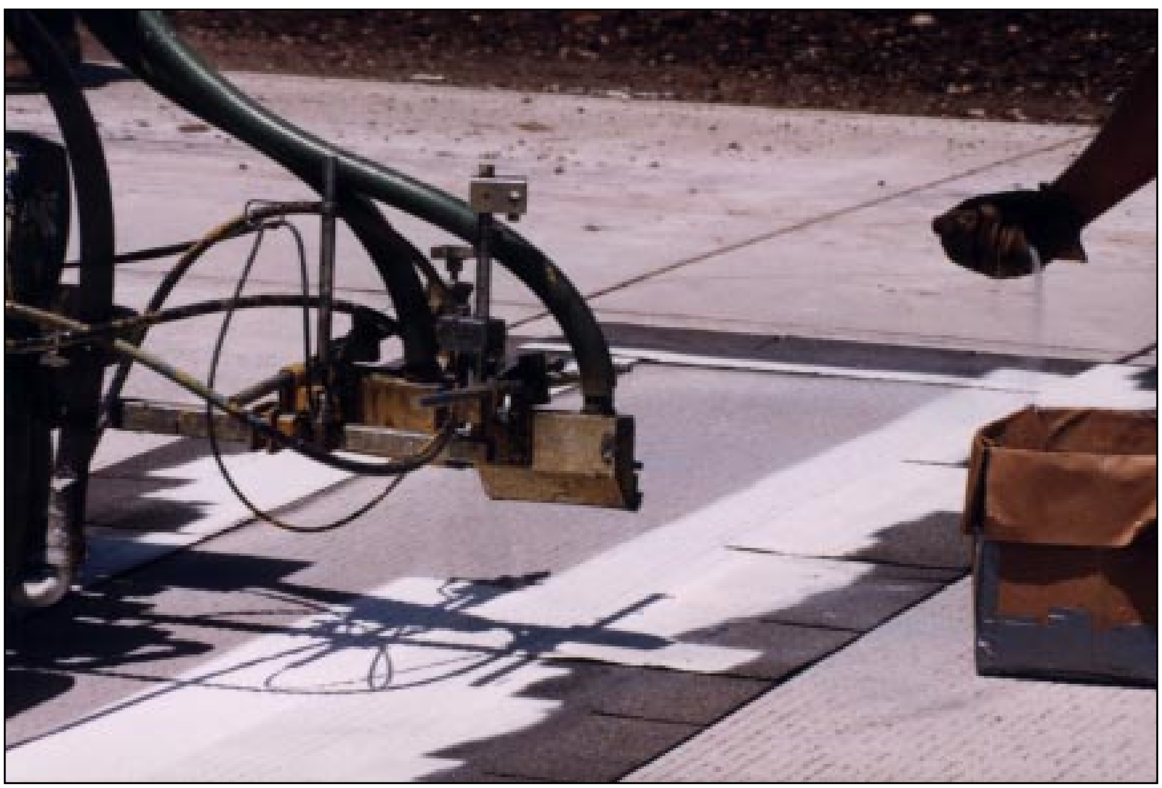


Figure 33. Glass beads were thrown onto the wet paint.

Figure 34. Paint crew installing the bars.

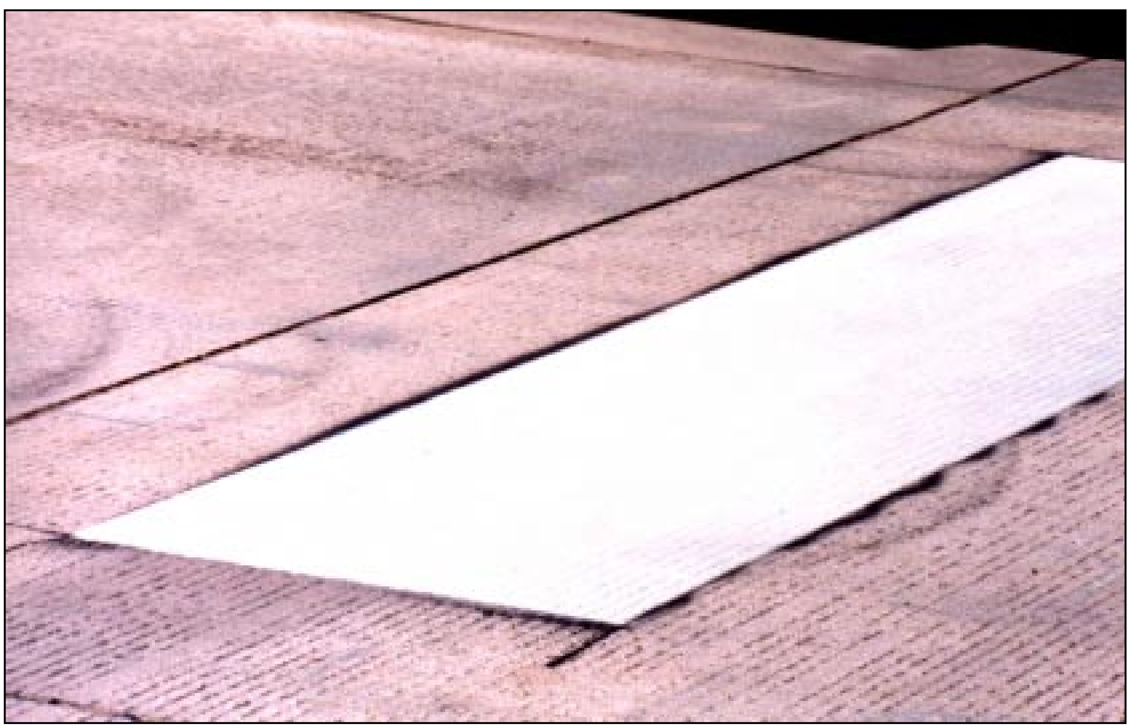


Figure 35. A finished speed bar.

The bars were laid out on June 16, requiring a 2-man crew approximately 6 hours. The bars were painted on the following day, taking a 6-man crew approximately 6 hours to complete the 73 stripes. The total labor required for the installation was 48 man-hours, averaging approximately 40 minutes per worker per bar.

Table 12. Modification of optical speed bars pattern location.

Patterns	Actual stations*	Planned stations*	Difference	Reason for difference
Leading pattern	17+151.753	17+150.972	0.781 m	Leading pattern is longer than it should be
	to	to		
	16+819.481	16+849.845	30.364 m	
Primary pattern	16+803.62	16+833.995	30.375 m	Hard to find beginning of primary pattern, primary pattern is short
	to	to		
	16+540.655	16+526.394	14.261 m	
Work zone pattern				
Set 1	16+388.140	16+374.002	1.138 m	
Set 2	16+204.954	16+191.131	13.823 m	
Set 3	16+020.838	16+008.260	12.578 m	
Set 4	15+839.101	15+825.389	13.712 m	

*All stations are in meters.

4.3 Difficulties

The installation of the bars was performed by the contractor, and proceeded smoothly. As detailed in the chronology of the project in APPENDIX C, the installation and maintenance of the data collection equipment proved to be more difficult. The first problem was that the construction vehicles damaged the data collection equipment on two occasions prior to the opening of the roadway. The second problem is alluded to in the chronology, but not explicitly identified. Several of the counters filled with water. In one case, the counter was located in a ditch that filled with water, submerging the counter. In the other cases, the hoses wore through, and the water entered the counters through the hoses.

4.3.1 Failure of Data Collection Equipment

The durability of the hoses was a concern throughout the planning of the evaluation. Based on the traffic volumes expected and the duration of the study, the manufacturer's published expected service life for the hoses suggested that they should have no problem lasting throughout the study. A second concern pertaining to the hoses was the durability of the installation. Hoses are typically fastened to concrete pavement with nails at the centerline and edge line, and at least one strip of mastic tape in the center of the lane. KDOT set out several sets of hoses on I70 east of the construction site, using various experimental configurations. Shown in Figure 38 are three experimental installations tested by the KDOT Traffic and Field Operations unit. Not shown is a fully taped configuration, similar to the installation at the extreme right of Figure 38, except using only one thickness of mastic tape.

Figure 38. Experimental hose installations.

All of the experimental hose installations were found to perform acceptably. Wear occurred on the mastic tape, but no significantly detrimental wear occurred to the hoses. Figure 38 shows the hoses approximately two weeks after their installation. When inspected after three weeks, the mastic tape had incurred additional wear, but the hoses appeared to be intact.

During the actual evaluation, however, neither the installation of the hoses nor the hoses themselves performed as well as in the experimental installations. Hoses were initially pulled up by construction equipment prior to the opening of the roadway. After the roadway was opened, several hoses detached from the pavement, and many hoses wore through on the bottom, preventing the impulse from vehicle tires from triggering the traffic counter. A picture of a section of one of the failed hoses is shown in Figure 39.

Figure 39. Failed pneumatic hose.

In retrospect, the cause of the hose failure is clear. In order to improve safety by increasing vehicle traction, the surface of concrete pavement is given a rough texture. For the soft rubber hoses, held in place by mastic tape and rocked back and forth by passing vehicles, the surface was abrasive. In some cases, hoses failed in less than a week. Re-examination of Figure 38 reveals that the test hoses were installed atop an asphaltic overlay that had significant wear, a surface much smoother than that of pristine Portland cement concrete. When using pneumatic hoses on a concrete surface, it is recommended that a layer of mastic tape be used between the hoses and the pavement, at least in the wheel path, if not the entire lane.

Some of the failed hoses were replaced by the KDOT Traffic and Field Operations unit, but the work had to be done under traffic (i.e., without stopping traffic). Consequently, only a small number of the hoses could be replaced. Data from the first week of the installation was used to determine the hour of the workweek with the lowest volume in order to maximize the safety of the work crew during hose replacement.

4.3.2 Deviations from Prescribed Bar Pattern Layout

As detailed in Table 12, discrepancies existed between the planned stations for the bar pattern and the actual stations as installed. The magnitude of the discrepancies ranged from 1 to 30 m (3 to 100 ft)—a relatively small distance compared to the length of the patterns. It is highly unlikely that the discrepancies had any significant impact on the performance of the optical speed bars.

4.3.3 Contractors Log Unavailable

A request was made to the contractor to obtain a copy of the log of events during the time of the evaluation. The log would allow some anomalies in the traffic data to be associated with weather events or construction activities. At the time of the writing of this report, the contractor had not responded.

4.4 Performance

While the maintenance of the data collection equipment was quite problematic, the pavement markings performed surprisingly well. The color contrast between the white paint and the concrete was not as high as would be the case with asphalt, but the bars were nonetheless visible, and the visibility did not dissipate from wear to the extent anticipated. Figure 40 and Figure 41 show the bars just prior to the opening of the roadway to traffic.

Figure 40. Optical speed bars during daytime.

Figure 41. Optical speed bars during nighttime.

The image in Figure 42 is a portion of a frame taken from a video, shot a week following the opening of the section to traffic. The poor image quality is due to the limitations of the video camera used (an 8mm Sony HandyCam). For comparison, the images in Figure 40 and Figure 41 were scanned photographs taken with a 35mm still camera. In spite of the image quality, the bars are easily visible.

Figure 42. Work zone pattern on July 2—one week after installation.

Figure 43 depicts the driver's view of part of the work zone pattern on September 25, 1999, three months after its installation. The 250,000 to 300,000 vehicles that traversed the segment during the three month period did cause some noticeable wear of the paint, but the visibility of the bars was still very good relative to the one week old bars shown in Figure 42. It should be noted that the degree of camera zoom was greater in Figure 43. This factor, as well as the lighting conditions at the time of taping, post-processing of the images, and the method of viewing (i.e., monitor or printer characteristics) can distort the relative brightness and contrast of the images. The author's observation of the bars at the time of taping suggested that the visibility of the stripes had decreased due to wear, but perhaps slightly less than it appears in these images.

Some of the advisory panel had supposed that wear would quickly deteriorate any effectiveness the patterns might have, based on experience with other transverse pavement markings, most notably crosswalks and stop lines. Apparently, the wear that occurs on crosswalks and stop lines is largely due to the frictional forces generated between the tires and the pavement during acceleration, deceleration, and turning movements. The paint used in this evaluation wore very well—much better than was expected based on experience with pavement markings at intersections.

Figure 43. Work zone pattern on September 25—three months after installation.

CHAPTER 5: DATA ANALYSIS

Data was collected over a time period of 30 days, from June 25, 1999, to July 25, 1999. Because the interest of this evaluation was the effect of the bar patterns on drivers speed choices, only vehicles with headways of 5 seconds or more were considered in any of the analyses. Thus, the lead vehicle in a platoon of vehicles would be included, the remaining vehicles in the platoon—whose speeds are dictated by the lead vehicle rather than the drivers perception—were excluded from the analyses. Daytime and nighttime were always analyzed separately. Vehicles were separated by classification (i.e., passenger cars and heavy vehicles) in some analyses and aggregated in others. As shown in Figure 44, grades on the test section are all less than 1%—except for the last 122 m (400 ft) of the work zone pattern control section—and, consequently, are ignored in the data analyses.

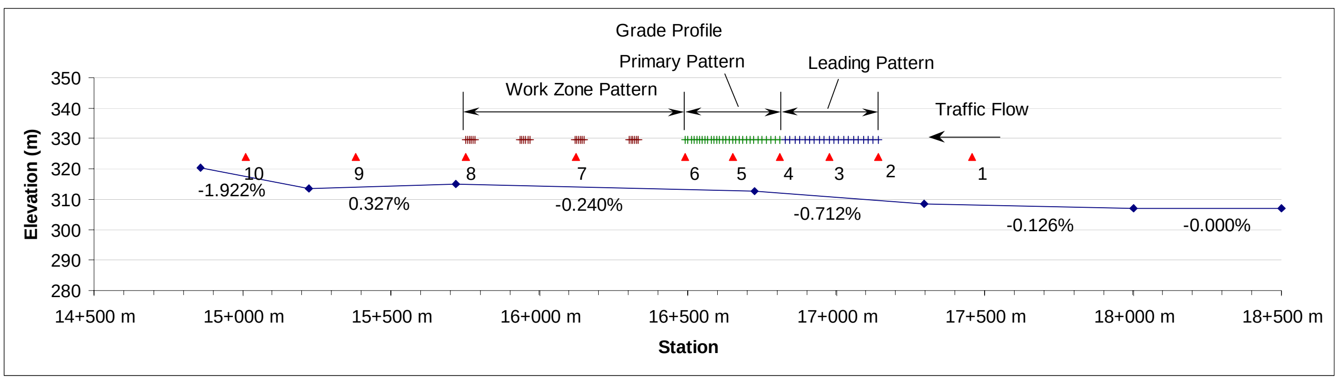


Figure 44. Grades relative to data points and pattern components.

5.1 Methodology

The first analysis used *TAS Plus*, and comprised comparisons of mean speeds and 85th percentile speeds between data points, time periods, and directions of travel. In this analysis, all vehicle classifications were aggregated. All data collected during a time period in which at least four data collection points were operational were considered. Applicable dates are shown in Figure 45. Data from June 29 was not included in some portions of the analysis because no data was available for westbound traffic.

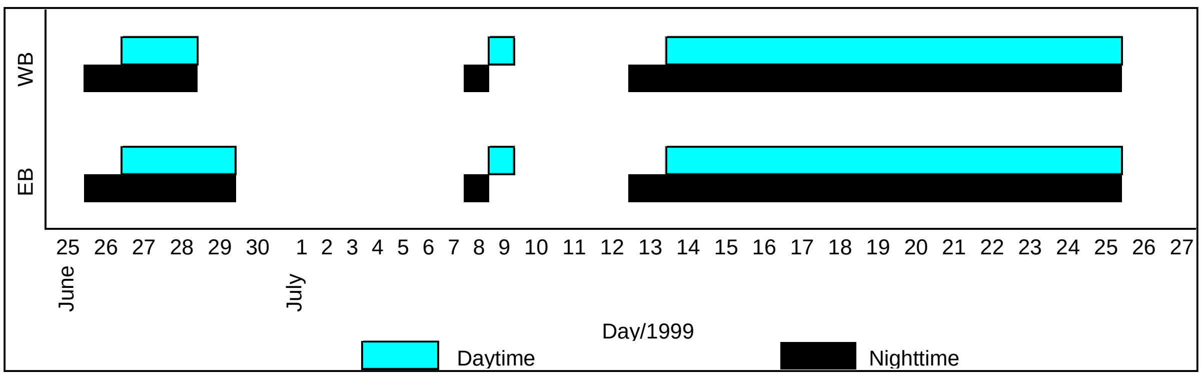


Figure 45. Dates used in data analysis.

The second analysis used the same data as the first, comparing the data over time to analyze temporal changes. Again, all classifications were aggregated. Both directions of traffic were examined.

The third analysis used data processed by the *Velocity* software package, developed at The University of Kansas. In this analysis, only the data from the time period of 5:30 PM, June 25, to 1:00 PM, June 28, was used. This is the only time period during which the ATR at data point 1 (WB) and the ATR at either data point 9 or 10 (WB) were operational. The purpose of this analysis was to consider passenger cars and heavy vehicles separately and to examine the effects of the work zone pattern. To filter out data from times during which glare from the sun can be a particularly significant factor, only data collected between 10:00 AM and 6:00 PM was considered for the daylight analyses. Nighttime analyses included data collected between 10:00 PM and 5:00 AM.

The *Velocity* software was also used for the fourth analysis. Data from the first 6 data points were integrated using a technique called *vehicle tracing*. *Vehicle tracing* is a process in which individual vehicles are identified at each data point so that actual speed changes can be examined on a per vehicle basis. Daytime and nighttime were considered separately in this analysis, as were passenger cars and heavy vehicles. Only the first 24 hours of westbound data were considered in this analysis due to the computation limitations imposed by *Velocity*'s *vehicle tracing* module.

5.1.1 Data Processing Software

The traffic counters were operated in a raw data mode in which each axle detected was recorded with a precise time stamp. Using this mode, the data could be used for multiple analyses. Two software packages were used for post-processing the data, *TAS Plus*, sold by Jamar for use with their counters, and *Velocity*, a custom software package developed by The University of Kansas.

5.1.1.1 TAS Plus

The software initially shipped by Jamar was *TAS Plus for Windows*, a port of their DOS software to the Windows operating system. This package was quite buggy, including not only an unexplained data loss problem described below, but other bugs as well, such as ignoring user-entered file paths and overwriting existing data files without notice. These bugs were reported to Jamar, who openly acknowledged that there were problems with the software, and promptly sent the DOS version to replace it.

The DOS version, *TAS Plus*, was used for some preliminary analysis and for downloading data from the counters. *TAS Plus* is capable of a wide variety of analyses, including the processing of raw data to obtain per vehicle speed and classification data. Two shortcomings in the software, however, eventually limited its use to data downloads.

First, the software could not facilitate the integration of data from multiple counters in a process called *vehicle tracing*, which is explained in the following section. Second, certain operations within the software would result in unexplained data loss. While the magnitude of the loss was on the order of only a few records, an error of no practical significance for transportation planning purposes, for research purposes the data loss was deemed unacceptable.

This problem was also reported to Jamar, who did not respond, neither acknowledging the problem nor offering a solution.

5.1.1.2 Velocity

Velocity is a multi-purpose traffic data analysis package developed at The University of Kansas for use in Transportation Research. One of the unique features of *Velocity* that led to its use in this project is its capability to perform *vehicle tracing*, the integrating of data from multiple traffic recorders in a traffic stream by matching vehicles based on classification and speed data. With the use of vehicle tracing, speed reductions of individual vehicles can be examined, as opposed to simply comparing mean speeds and 85th percentiles.

Velocity is also capable of reading data that has been downloaded from Jamar traffic counters using *TAS Plus*, and performing vehicle identification and classification of the downloaded data.

5.1.2 Data Characteristics

As discussed previously, the maintenance of the data collection equipment was very problematic. As a result of equipment failure, primarily the pristine pavement wearing through the hoses, the data collected was incomplete, and in some cases the collected data was unusable due to the failure of one hose connected to a traffic recorder. For the comparison of statistics between data points, the only data considered was data collected during periods in which at least four of the 10 westbound data points were operational.

5.2 Data Point Comparisons

Before examining the data itself, several characteristics of the test site should be noted. During Phase II of the reconstruction project, two-way traffic was carried on the westbound lanes. While the oncoming traffic is a distraction, potentially reducing the effectiveness of the patterns, it also serves as a measure of environmental effects. For example, if construction activities draw the attention of drivers, slowing the pace of traffic, the change would occur to both directions of flow. An effect of the bar patterns would only appear in the westbound flow.

The section used in the evaluation was straight and nearly level, as can be seen in Figure 46, which is a driver's view of the test section from data point 1. The surrounding terrain is flat and featureless, used primarily for agriculture. Data point 1 occurs at the end of the westbound acceleration ramp from the Spring Creek Rd. interchange. It is 309 m (1013 ft) upstream from data point 2 and the first bar in the leading pattern. The bars cannot be seen from data point 1, allowing it to serve as an appropriate baseline measurement. (The light strip immediately in front of the vehicle is not a painted bar, but likely the location of one of the hoses at data point 1, which had been damaged and subsequently removed. The mastic tape that held down the hose protected the pavement underneath from becoming discolored from the tires of passing traffic.) Figure 46 was taken from a video shot at approximately 4:30 PM, Friday, July 2, 1999, one week after the roadway was opened.

Figure 46. Driver's view from data point 1.

The vehicle from which the video was shot was a 1992 Honda Accord. The camera was set on a tripod approximately at the driver's eye height over the center of the vehicle. The camera was a Sony HandyCam with SteadiShot image stabilization.

Figure 47, also taken shot on July 2, shows the driver's view of the first bars of the primary pattern at data point 2. It should be noted that the limitations of video imaging make the visibility of the bars appear to be somewhat inferior to what was actually observed.

Figure 47. Driver's view from data point 2.

Both mean and 85th percentile speeds generally decreased between data point 1 and data point 5, as shown in the daytime data for June 27, shown in Figure 48, and in the nighttime data for June 26, shown in Figure 49. The decreases did not occur on all days, however. The data from other dates considered in the analysis is given in APPENDIX F and APPENDIX G. The reductions were modest in nearly all cases. The 85th percentile speeds generally decreased more than the mean speeds at data points 2 through 5, compared with data point 1.

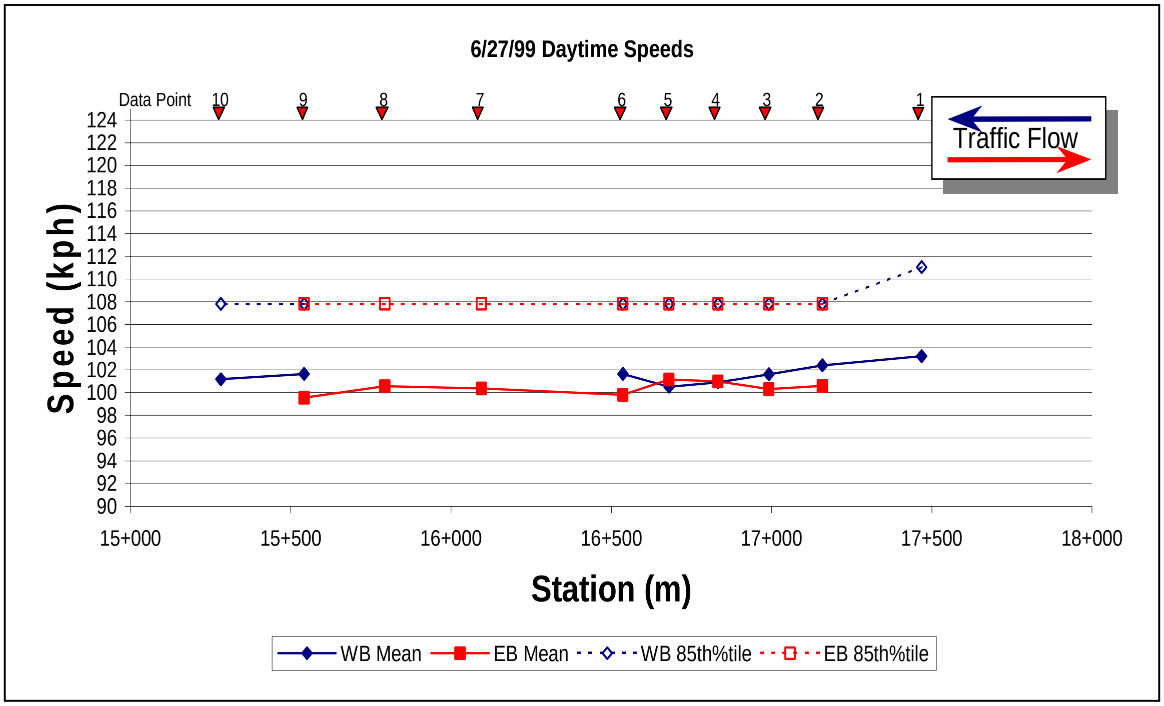


Figure 48. Daytime speeds for June 27, 1999.

The reduction in speeds at data point 5 compared to data point 1 was not observed on all days. The eastbound traffic does not follow the same trend, suggesting that the speed reductions may be attributable to the optical speed bars. However, the fact that the trend does not occur consistently for all days makes the assertion suspect, at best.

Mean speeds decreased to data point 5, and then mean speeds increased between data point 5 and data point 6 (the second half of the primary pattern), in both the daytime and the nighttime data. This could be an indication that there was a perceptual effect on driver speeds in the first half of the primary pattern, where the changes in spacing are the most dramatic. Then, in the last third of the pattern, where the bar spacings are nearly uniform, drivers made a speed correction. The small magnitude of the changes, combined with only partial corroboration with data collected on other days, make it difficult to pinpoint the cause of the changes from this data alone.

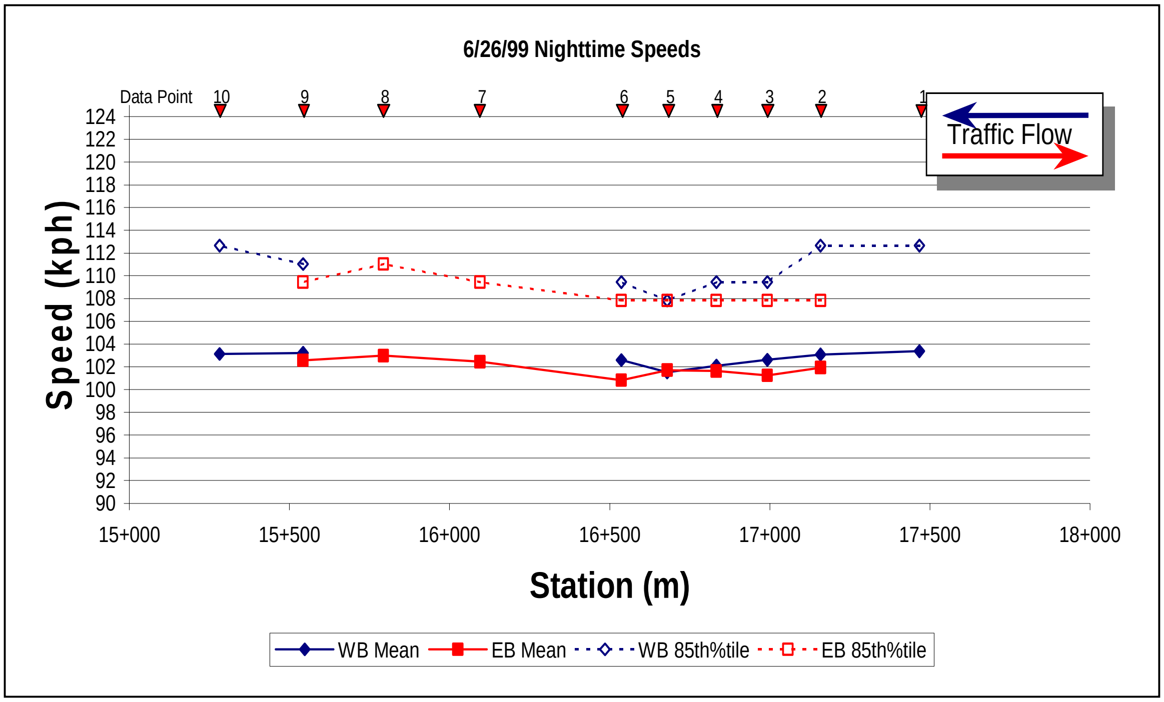


Figure 49. Nighttime speeds for June 26, 1999.

5.3 Temporal Changes in Speed

Many devices that have been intended to reduce speeds have proven to have short-lived effects. Radar activated speed displays, for instance, are effective at reducing speeds for a short period of time, but the common experience has been that their effectiveness diminishes as drivers become accustomed to their presence. This effect is sometimes called a *novelty effect*, a change in behavior caused by an unexpected (i.e., novel) change in the environment. After passing a speed display for several days in a row, it is no longer unexpected. It loses its novelty. It is important to understand how quickly and to what degree a novelty effect decreases the benefits of a device.

With respect to optical speed bars, other experiences have found their effects to decrease over time, but not dissipate entirely, perhaps because the perceptual element of the speed reduction effects persists, though the warning effect may disappear with driver familiarity.

Figure 50 and Figure 51 show the temporal variations in mean and 85th percentile speeds, respectively. While the differences between data points are small, the speeds at data point 1 are consistently the highest and the speeds at data point 5 are consistently the lowest. If the difference is attributable to the optical speed bars, then their effect does not seem to diminish significantly over time. In both figures, data collected July 19 at data point 2 is suspect, based on the fact that equipment failures severely limited the amount of data available and may have distorted the data collected during that time period.

The nighttime data (provided in APPENDIX J) shows a very similar phenomenon to the daytime data. Data point 1 is the highest for both mean speed and 85th percentile speed, and data point 5 is the lowest.

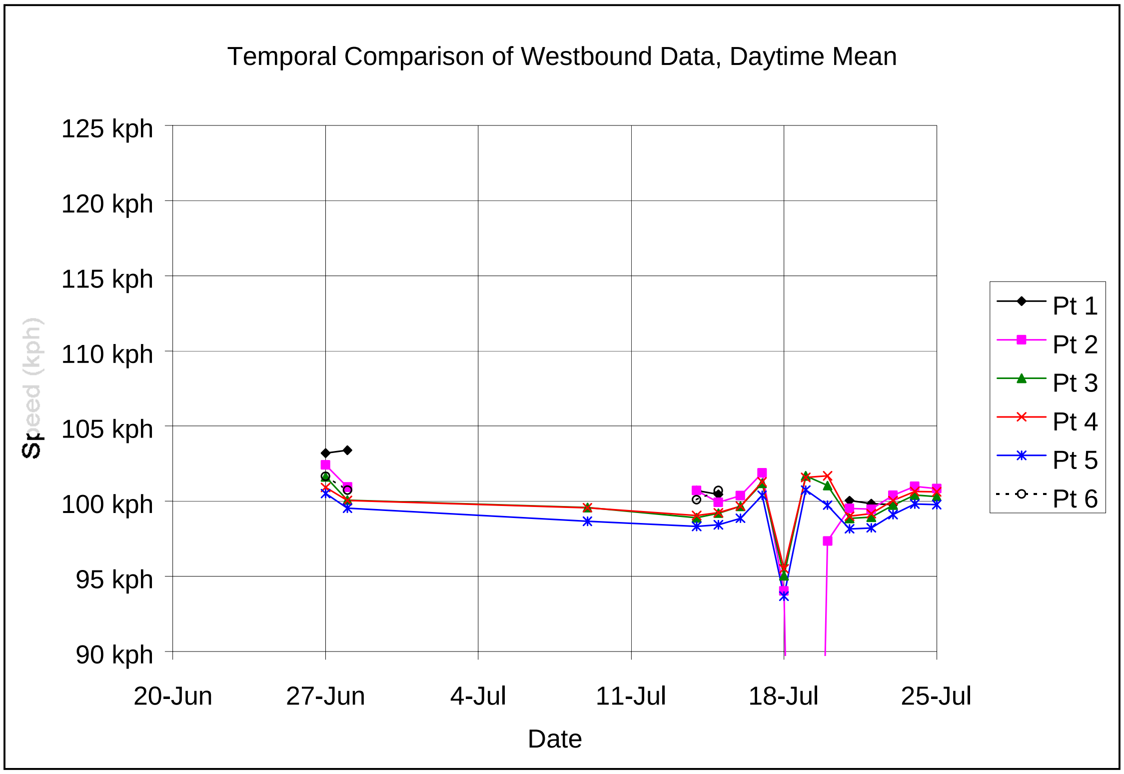


Figure 50. Temporal comparison of westbound data, daytime mean speeds.

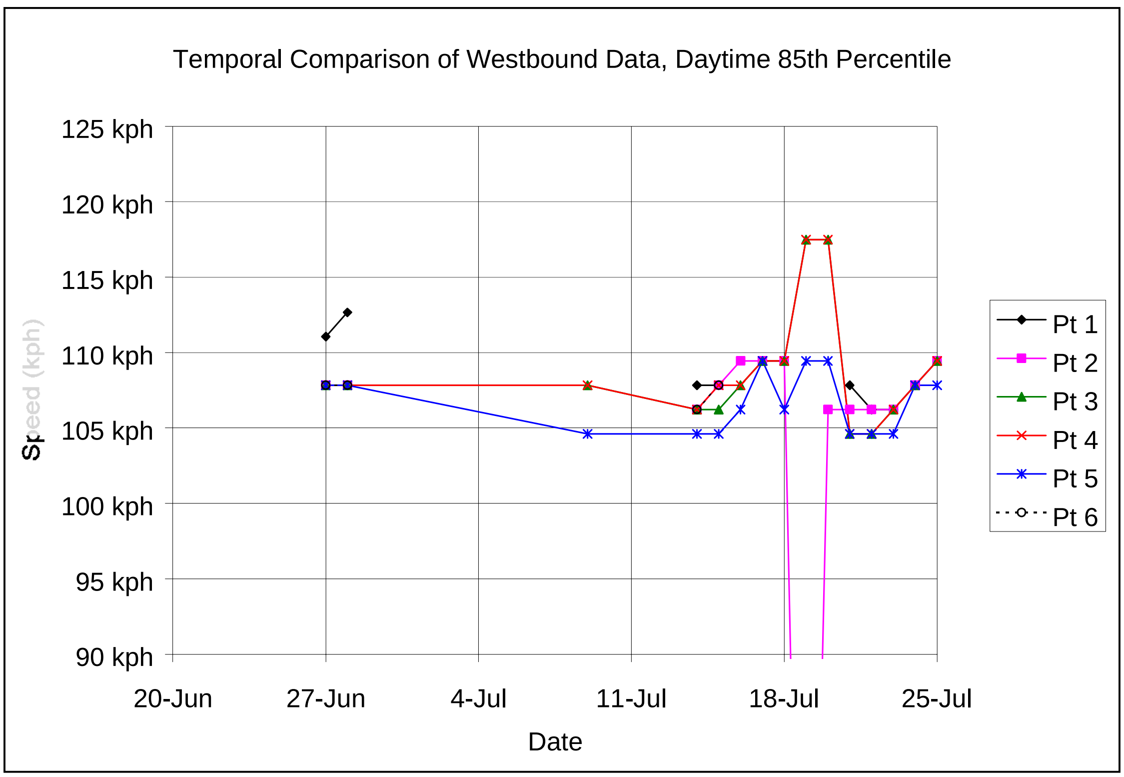


Figure 51. Temporal comparison of westbound data, daytime 85th percentile speeds.

As shown in Figure 52, the westbound speeds are consistently higher than the eastbound speeds, but they rise and fall in concert. Most, though not all, of the data points show a similar phenomenon during both daytime and nighttime. There is a very slight grade on the section. However, the grade slopes downward in the eastbound direction, and so is not a potential explanation for higher speeds in the westbound direction.

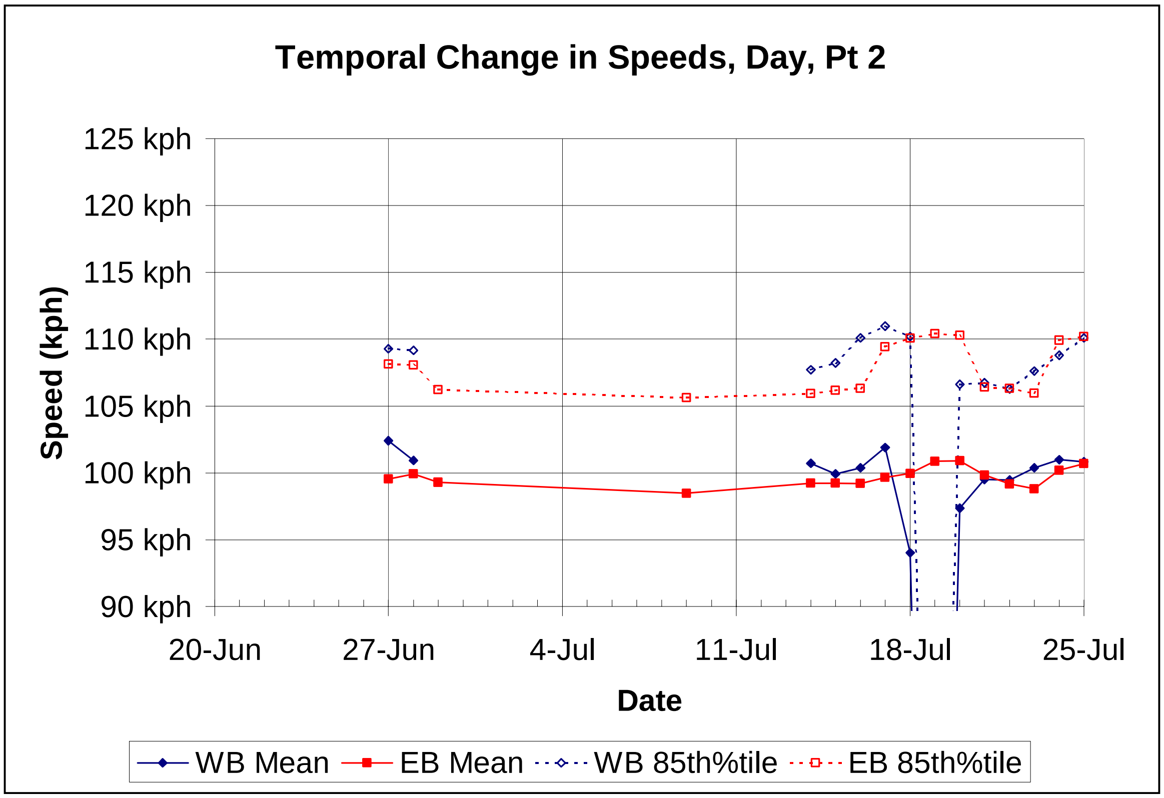


Figure 52. Temporal changes in mean and 85th percentile speeds at data point 2.

There are two potential explanations for the slower speeds in the eastbound lanes, one of which is the proximity to the construction activity being conducted on the eastbound lanes. This explanation is unlikely. The distance across the median is considerably larger than the distance between the two traffic streams. Consequently, both are likely to be affected equally by any distractions involving the construction. Additionally, the phenomenon exists for the entire month. There was no construction activity near this section for at least part of this time period. Specifically, Figure 46 and Figure 47 clearly show that on July 2, when the video footage from which these pictures were taken was shot, there were no signs of the reconstruction activity on this section.

While it cannot be verified from the data collected, the second possibility seems to be much more likely. The test section is closer to the eastern end of the work zone. Consequently, the eastbound traffic has traveled a greater distance through the work zone, all of which was two-lane, two-way traffic. The head-to-head traffic may serve as a calming device. Even if this is only true for a portion of the drivers, the longer distance without passing opportunities would result in a larger proportion of the faster drivers being forced to slow down as they approach a slower vehicle from the rear. When this occurs, the headway becomes less than 5 seconds and the vehicle would be excluded from the analysis.

However, under this assumption, it would be expected that speeds would be highest at data points 9 and 10 for eastbound traffic, and that speeds would decrease as the stream moves downstream, resulting in the lowest speeds at data point 1. However, what is observed Figure 54 and Figure 55 is that speeds increase from data point 10 to data point 5, then decrease to data point 1.

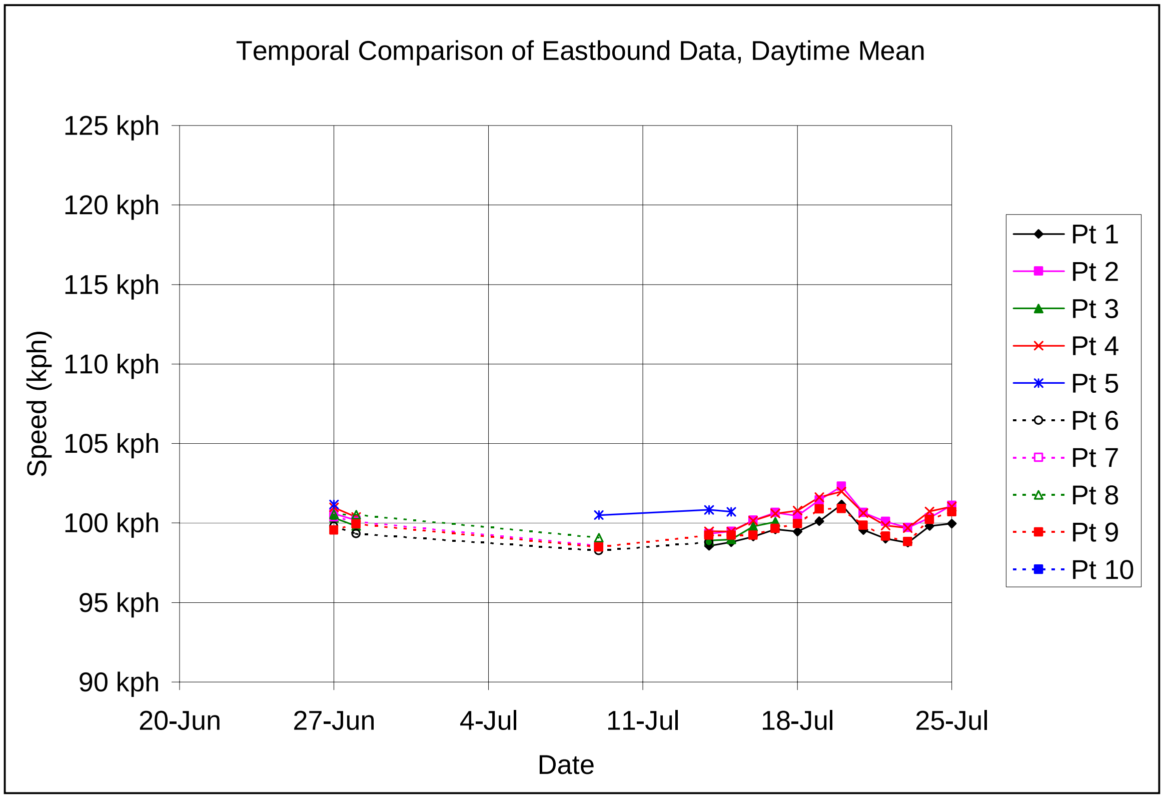


Figure 54. Temporal comparison of eastbound data, daytime mean speeds.

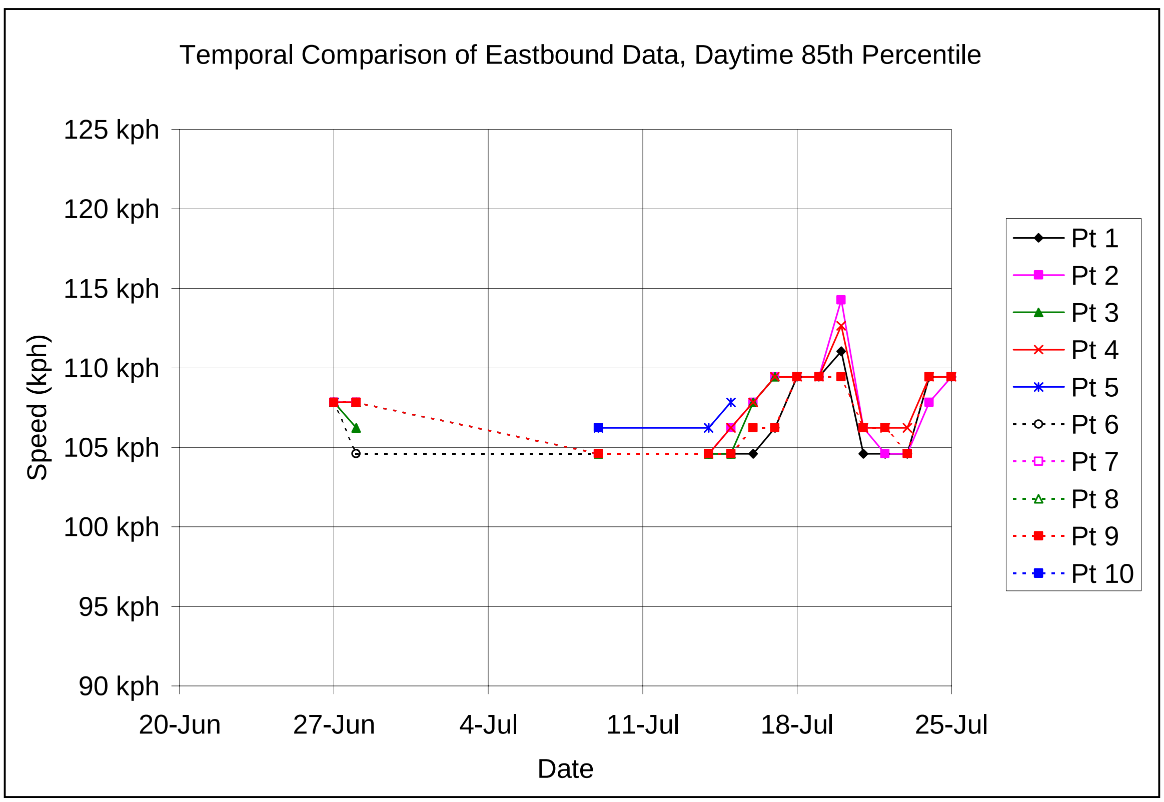


Figure 55. Temporal comparison of eastbound data, daytime 85th percentile speeds.

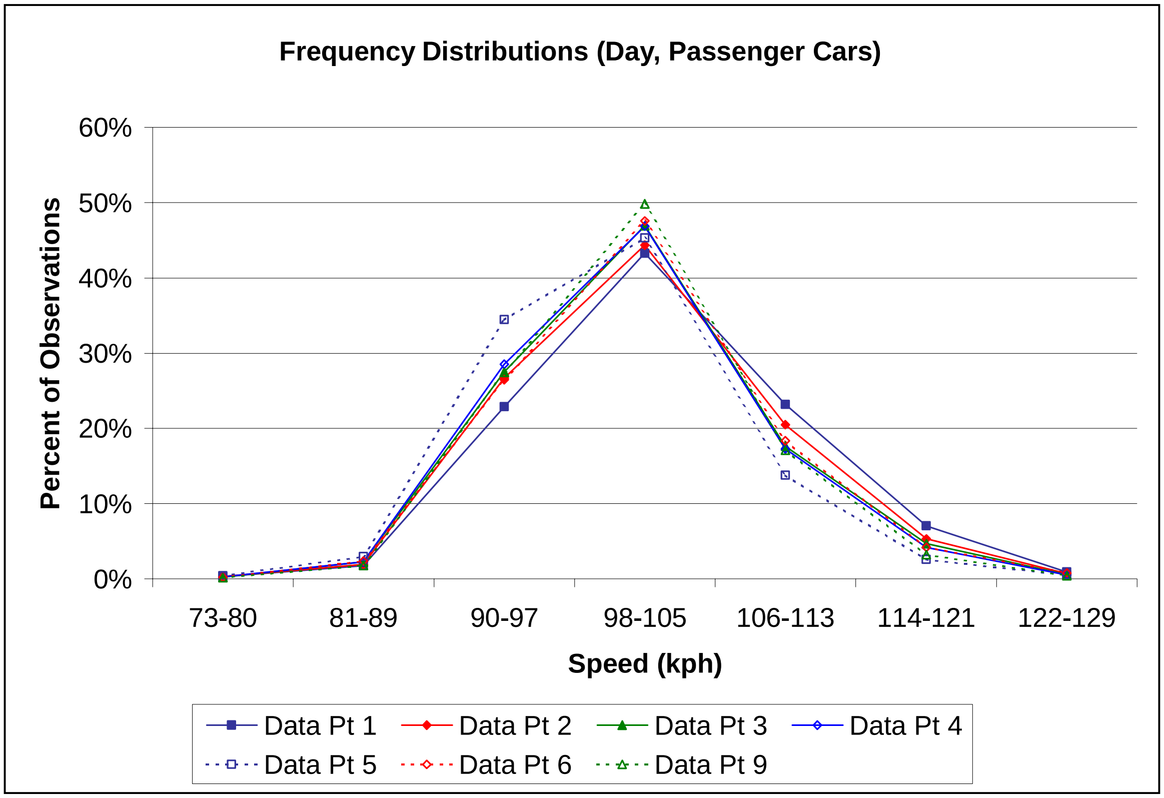
5.4 Speeds by Vehicle Classification

Velocity was used to process the raw data and export speed distributions, mean speeds, 85^{th} percentile speeds, standard deviations, and other statistical parameters necessary to perform an analysis of variance (ANOVA).

5.4.1 Speed Distributions

Speed distributions for data points 1 through 6 and data point 9 are shown in Figure 56 and Figure 57. Daytime distributions for both passenger cars and heavy vehicles are shown in Figure 56, while nighttime distributions are given in Figure 57.

None of the distributions changed dramatically from one data point to another, but one very interesting characteristic can be observed, nonetheless. In each of graphs, the distribution at data point 5 is shifted to the left of the other distributions, suggesting a reduction in speed that is born out the mean and 85^{th} percentile speeds (see section 5.4.2). This is true for both daytime and nighttime data, and for both passenger cars and heavy vehicles. For passenger cars during daylight, the distribution at data point 9 shifted back toward the baseline (i.e., data point 1), but remained to the left of it. For all other categories, the distribution at data point 9 was nearly identical to that of data point 1.



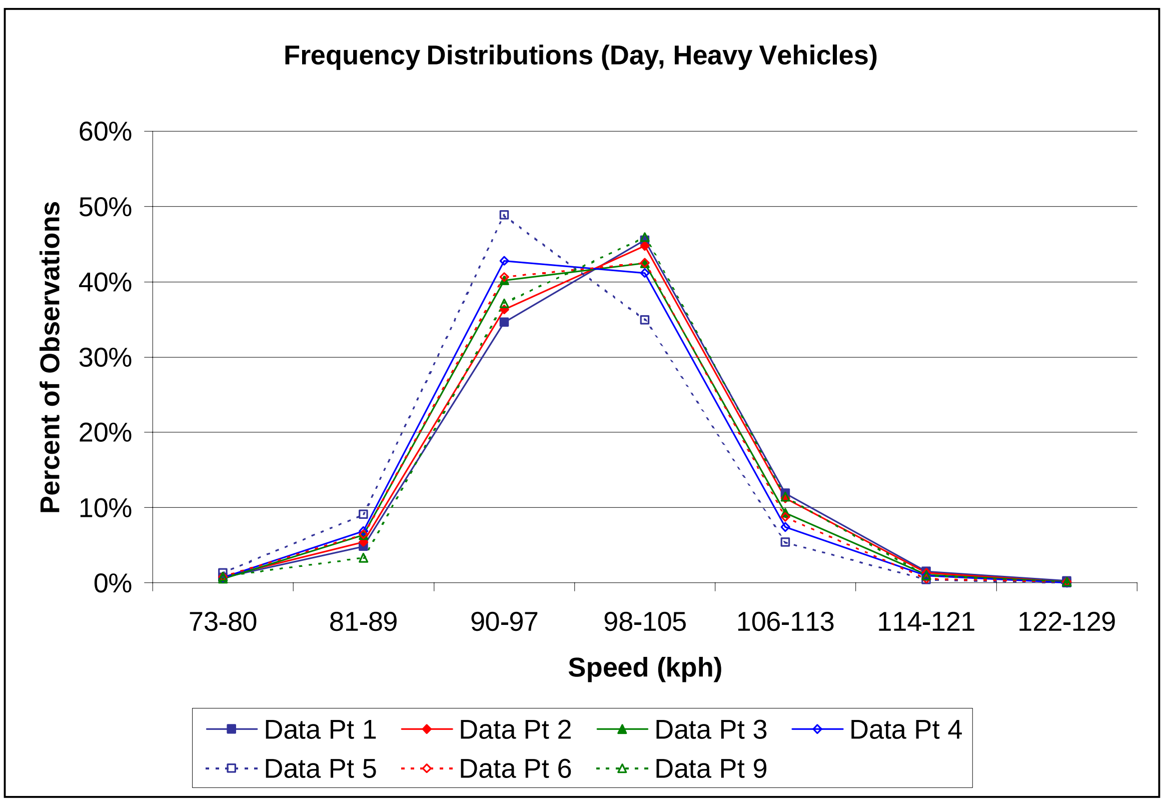
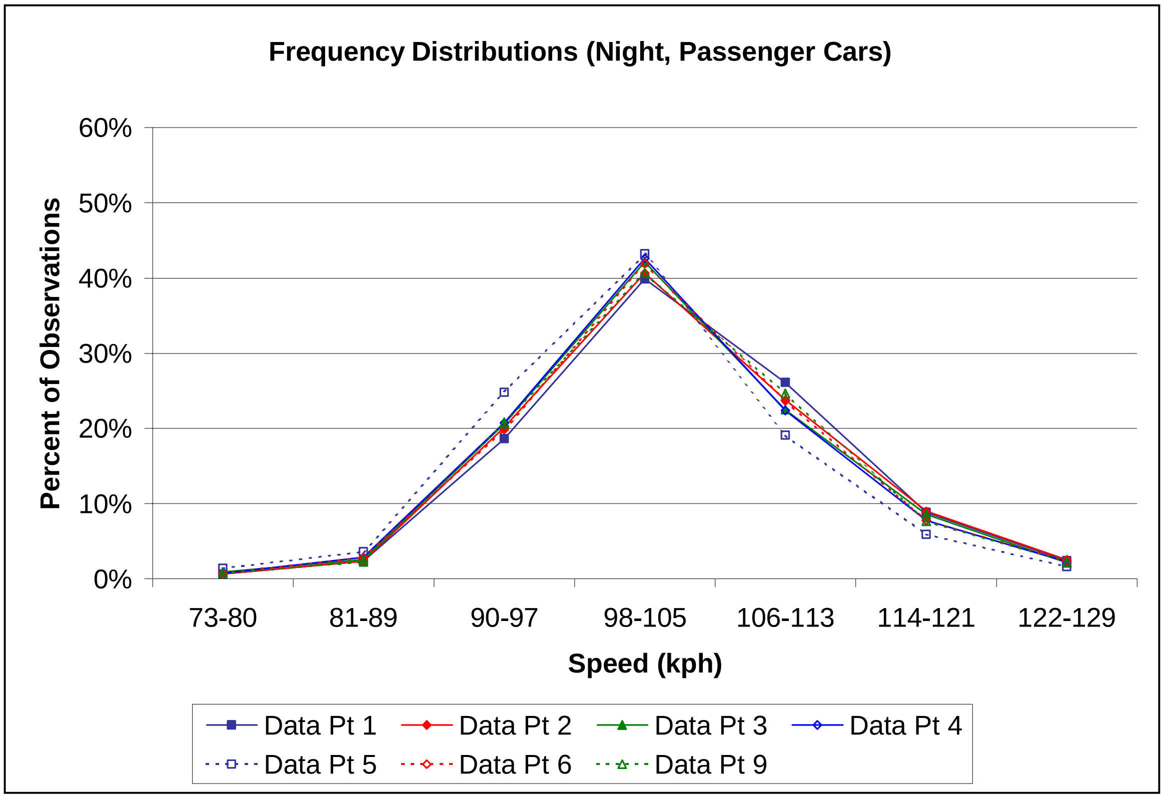


Figure 56. Speed distributions, Daylight.



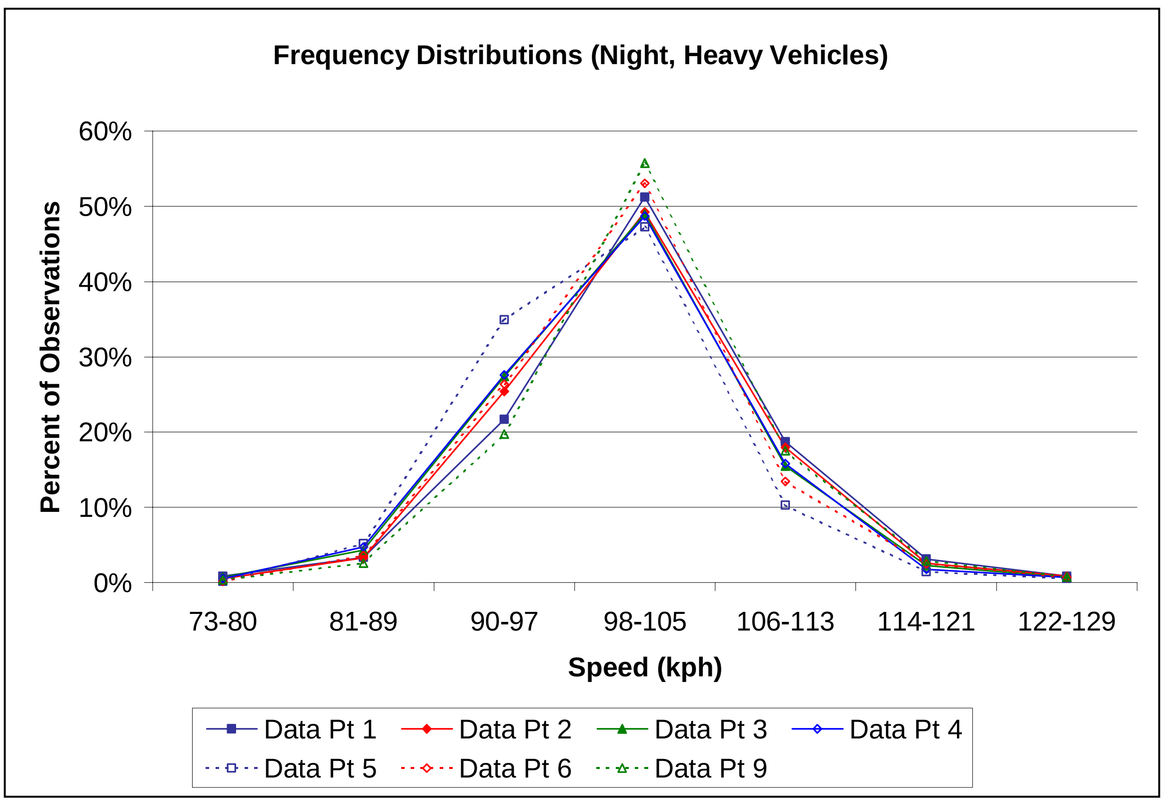


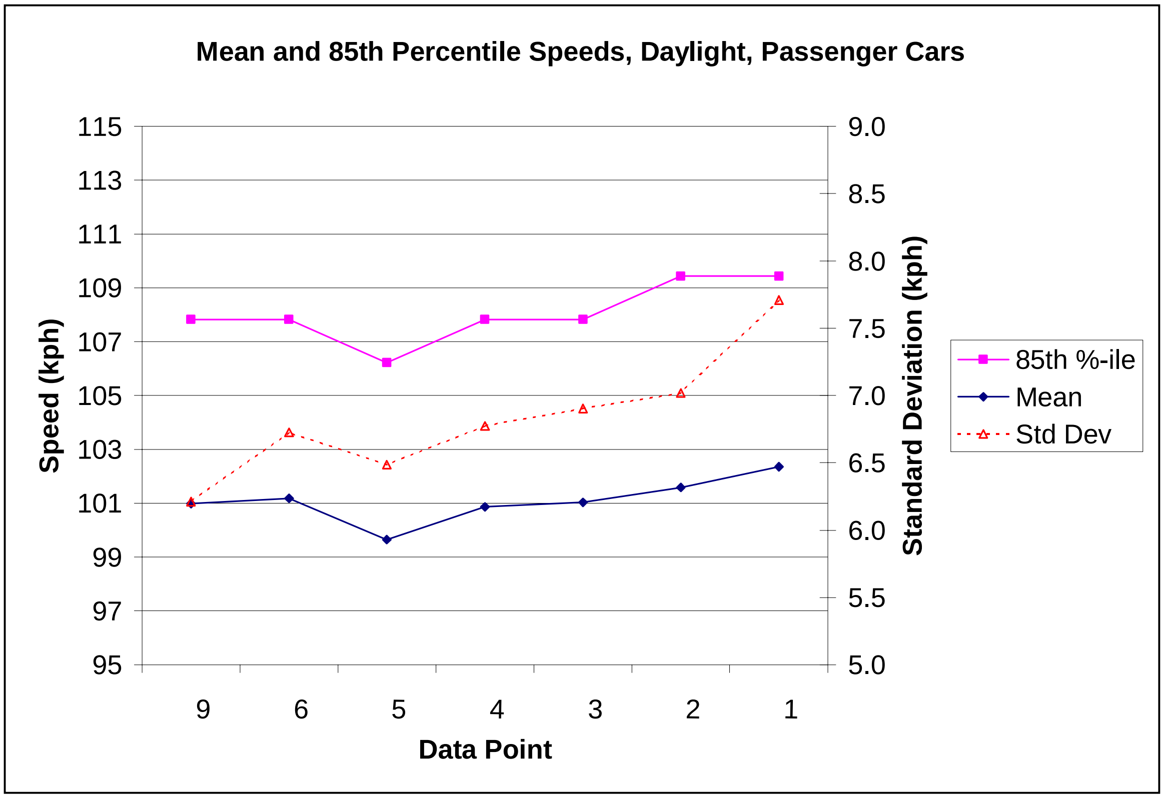
Figure 57. Speed distributions, Nighttime.

5.4.2 Mean Speeds, 85th Percentile Speeds, and Standard Deviations

When the same data shown in the speed distributions in Section 5.4.1 is examined with respect to mean speeds, 85th percentile speeds, and standard deviations, the effects of the optical speed bars can be seen more clearly. Figure 58 contains graphs of speeds and standard deviations for both passenger cars and heavy vehicles during daylight. Figure 59 contains the analogous plots for nightime hours. The supporting data for daylight observations is given in Table 13 and Table 14. Other data is provided in APPENDIX H.

In all categories, the highest values for mean speed, 85th percentile speed, and standard deviation occur at data point 1, with the exception of the mean speed for heavy vehicles at night, which was higher at data point 9 by 0.2 kph (0.1 mph), a difference that is not statistically significant (95% confidence level). All three parameters were lowest for all categories at data point 5. It is noteworthy that the 85th percentile speeds for heavy vehicles during the day (except at data point 5) were all 104.6 kph (65 mph). Most likely this is due to a large proportion of heavy vehicles having their speeds limited by governors set at that speed.

The 85th percentile lines show a clear pattern in which speeds decrease between data points 2 and 3 (the first half of the leading pattern), decrease again between data points 4 and 5 (the first half of the primary pattern), then increase between data points 5 and 6. For passenger cars, 85th percentile speeds remain below the baseline between data point 6 and data point 9.



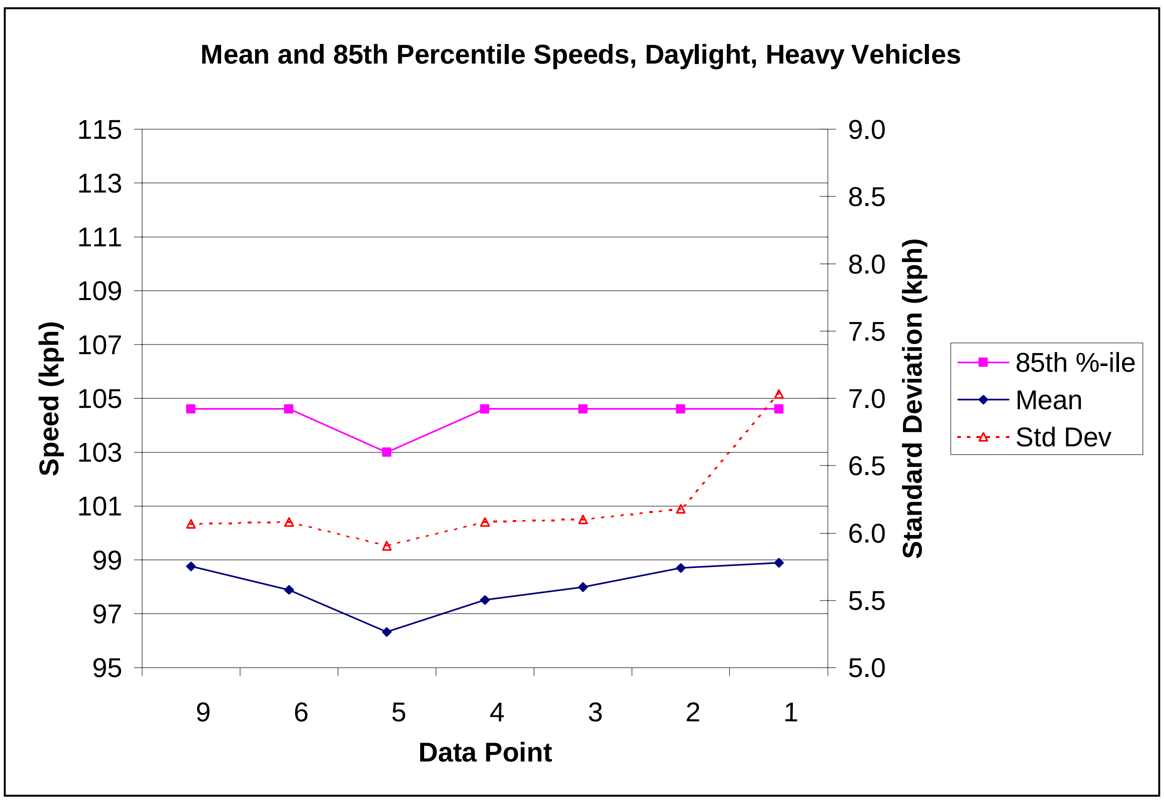
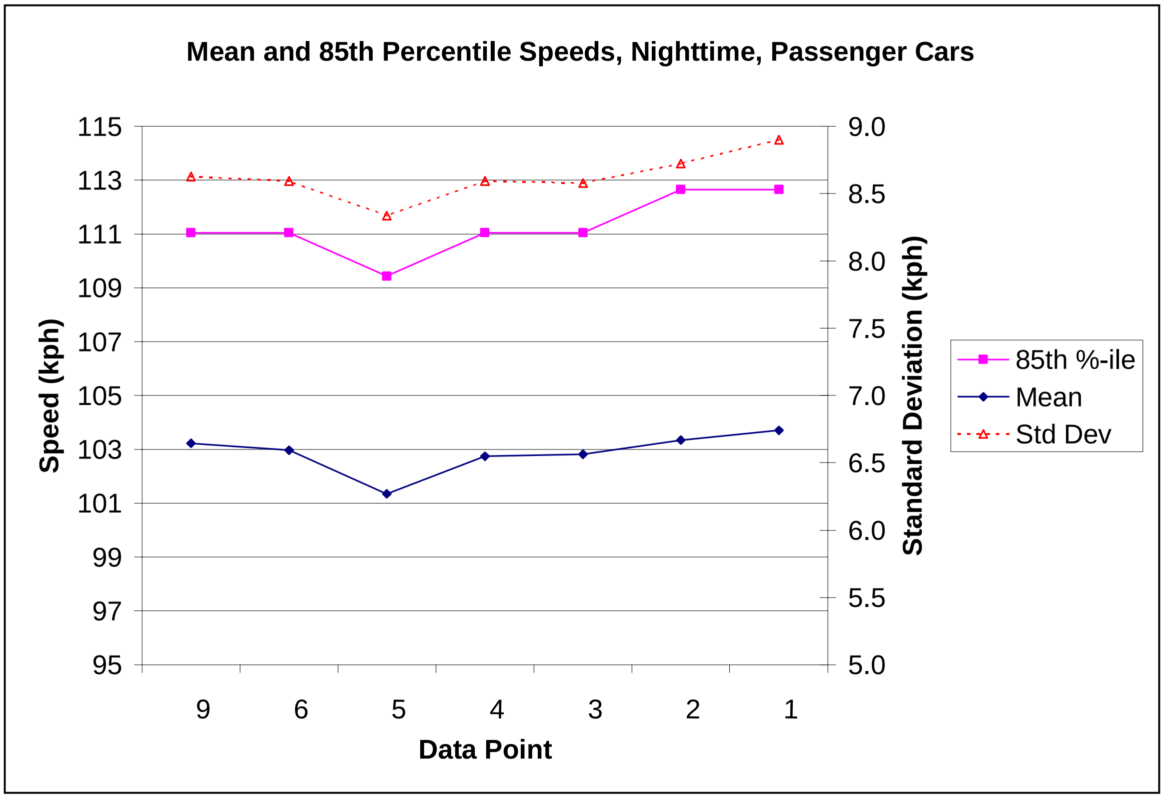


Figure 58. Mean speeds, 85th percentile speeds, and standard deviations, daylight.



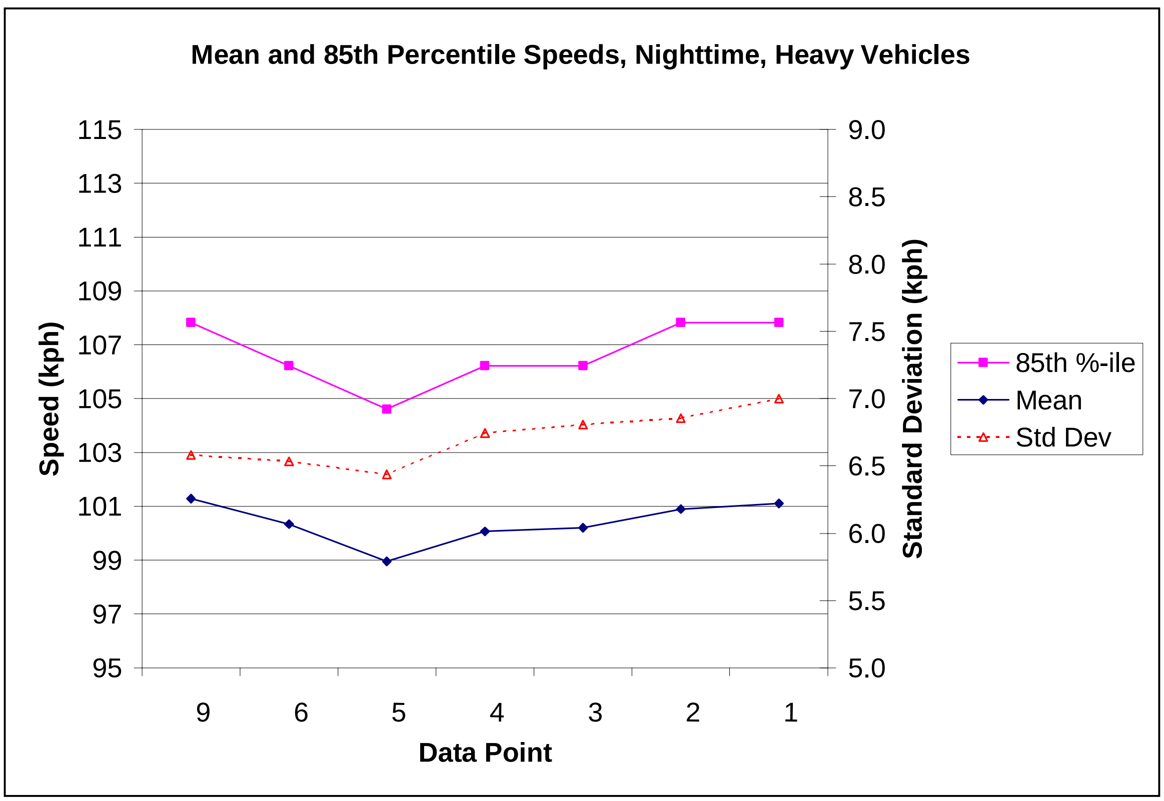


Figure 59. Mean speeds, 85th percentile speeds, and standard deviations, nighttime.

Table 13. ANOVA comparisons, daylight, passenger cars.

Comparisons With Previous Data Point, Daylight, Passenger Cars								
			Total			Before	After	Total
Description	P	F	Count	Sum	SumSq	SS	SS	SS
Data Pt 2	0.000	13.78	5169	527091	54037234.8	160854	127374	288996
Data Pt 3	0.007	7.40	5015	508062	51720407.6	127374	121709	249451
Data Pt 4	0.367	0.81	4951	499790	50689752.9	121709	115597	237345
Data Pt 5	0.000	39.67	4933	494556	49806038.6	115597	107082	224471
Data Pt 6	0.000	62.96	4898	491790	49601494.3	107082	112820	222731
Data Pt 9	0.356	0.85	4636	468643	47574038.6	112820	87180	200037
			(vehicles)	(kph)				

Table 14. ANOVA comparisons, daylight, heavy vehicles.

Comparisons With Previous Data Point, Daylight, Heavy Vehicles								
			Total			Before	After	Total
Description	P	F	Count	Sum	SumSq	SS	SS	SS
Data Pt 2	0.578	0.31	1497	147905	14680311.6	37429	29687	67129
Data Pt 3	0.025	5.03	1511	148602	14673357.5	29687	28946	58828
Data Pt 4	0.142	2.16	1497	146336	14362217	28946	28421	57450
Data Pt 5	0.000	13.82	1447	140266	13651016.7	28421	25373	54308
Data Pt 6	0.000	23.78	1447	140541	13704683.8	25373	28313	54570
Data Pt 9	0.007	7.38	1457	143248	14139413.3	28313	27149	55744
			(vehicles)	(kph)				

Mean speeds show a similar pattern, though somewhat less pronounced. Based on the ANOVA results shown in APPENDIX H and a confidence level of 95% (P-Values are reproduced, for the reader's convenience, in Table 15), the changes in mean speed from data point 4 to data point 5 and that from data point 5 to data point 6 are statistically significant for all categories, and the changes from data point 2 to data point 3 are statistically significant during daylight hours. Nighttime P-values are only slightly below the 95% confidence level.

This pattern is evidence that indeed there are both warning effects and perceptual effects associated with optical speed bars. The fact that no significant changes occurred between data points 3 and 4 indicates that the warning effect occurred during the first half of the leading pattern. That speeds increased from data point 5 to data point 6 indicates that the perceptual effect occurred in the first half of the primary pattern. The design of the primary pattern resulted in very little change in spacings between bars in the second half of the pattern, so it is possible that a different design could increase the magnitude of the perceptual effect.

Table 15. P-Values from ANOVA.

P-Values for Adjacent Data Points				
	Daylight		Nighttime	
Data Points	PC	HV	PC	HV
from 1 to 2	0.000	0.578	0.265	0.625
from 2 to 3	0.007	0.025	0.072	0.088
from 3 to 4	0.367	0.142	0.786	0.742
from 4 to 5	0.000	0.000	0.000	0.006
from 5 to 6	0.000	0.000	0.000	0.000
from 6 to 9	0.356	0.007	0.407	0.019

85th percentile speeds for passenger cars were maintained below baseline levels between data point 6 and data point 9. This suggests that the speed reductions realized in the leading and primary patterns do not dissipate entirely once drivers leave the patterns. The work zone pattern extends from data point 6 to data point 8. Data points 9 and 10 are control points for the effects of the work zone pattern. The distance from data point 8 to data point 9 is 251.6 m (825 ft). In the case where no speed change occurred between data point 6 and data point 9, the work zone pattern either had no effect, or its effect was reversed in the control section between data points 8 and 9. It is most reasonable to conclude that the work zone pattern had no effect.

Standard deviations follow a similar pattern to mean and 85th percentile speeds, with two notable exceptions. First, in each category, standard deviations decrease between data point 1 and data point 2. Second, they do not increase after data point 6, even with heavy vehicles. So, while some of the speed reduction occurring in the leading and primary patterns is reversed after data point 6, improvements in the uniformity of the traffic stream are maintained. While it is difficult to quantify the relationship between uniformity and safety, the existence of such a relationship is widely accepted.

5.5 Speed Reductions by Vehicle Tracing

Using the vehicle tracing capability of the *Velocity* software, an analysis of speed reductions was conducted. A small subset of the available data was used for the analysis, as shown in Table 16. For this analysis, passenger cars and heavy vehicles were analyzed separately. Only vehicles that could be identified at each of the first six westbound data points (1-6) were included. The records were also filtered to remove any vehicles with headways of 5 seconds or less at any of the six data points. Only a small amount of data was used due to software limitations.

There are two primary reasons that vehicles fail to be identified at all data points. One is that an axle was not recorded by the ATR for some reason. The other is that when a vehicle tailgates the vehicle in front of it, the axle spacings sometimes appear to indicate a single vehicle with four axles, rather than two vehicles with two axles each, for example. In either case, the number of axles does not match and all records involved are excluded.

Table 16. Records used for speed reduction analysis.

Daytime (6/26/99, 12:00pm to 6/26/99, 2:00pm)			
Total records	1656		
Full records	1490	90%	Pct matched at all 6 data points
Full FF records	331	22%	Pct of full recs with >=5 sec headway
Cars	252		
Trucks	79	24%	Pct trucks (FF only)
Nighttime (6/25/99, 10:00pm to 6/26/99, 5:00am)			
Total records	1520		
Full records	1241	82%	Pct matched at all 6 data points
Full FF records	703	57%	Pct of full recs with >=5 sec headway
Cars	536		
Trucks	167	24%	Pct trucks (FF only)

Table 17 shows a statistical summary of the speed changes for passenger cars during daylight. Both the mean and 85th percentile speeds decrease from data point 1 to data point 5, then increase slightly at data point 6 (compared to 5). Note also that the standard deviation follows the same pattern, suggesting less disparity in speeds.

The bottom portion of the table shows the cumulative changes in speed at each data point, relative to data point 1. At data point 5, where the largest change is observed, the cumulative speed change is -1.7 kph ± 0.6 kph (1.0 mph ± 0.4 mph) at a 95% confidence level.

The bottom row of Table 17, labeled *Correlation (r)*, contains the Pearson correlation coefficient (an indicator of the degree to which two variable are linearly related) for vehicle speed at data point 1 and the vehicle's change in speed between data point 1 and data point 6. The values range from -1.0 to +1.0. A value of 1.0 indicates a perfectly linear relationship, with the relationship having a positive slope (i.e., as one variable increase, the opposing variable also increases). A value of -1.0 also indicates that the two variables have a perfectly linear relationship, but with a negative slope (i.e., as one variable increases, the opposing variable decreases). A value of zero indicates that the two parameters are not correlated at all.

Table 17. Speed reduction statistics for passenger cars during daylight.

	Speed (kph)					
Data Point	**1**	**2**	**3**	**4**	**5**	**6**
Count	252	252	252	252	252	252
Min	49.8	85.4	85.0	85.4	84.3	85.6
Max	121.4	122.1	121.1	120.2	120.2	122.1
Median	100.2	100.1	99.3	99.9	98.7	99.8
Average	100.9	100.7	100.3	100.2	99.2	100.6
Conf Int (95%)	0.9	0.8	0.8	0.8	0.8	0.8
StdDev	7.3	6.3	6.2	6.1	6.1	6.4
85th %ile	108.2	107.7	106.6	106.5	105.2	106.6

	Cumulative Speed Change (kph)				
Data Point	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**
Min	-15.5	-17.3	-13.3	-14.8	-18.6
Max	38.9	40.3	43.6	44.4	46.7
Median	-0.2	-0.4	-0.5	-1.4	0.0
Average	-0.2	-0.6	-0.7	-1.7	-0.3
Conf Int (95%)	0.4	0.5	0.5	0.6	0.6
StdDev	3.6	4.3	4.4	4.6	5.1
Correlation (r)	-0.49	-0.52	-0.55	-0.55	-0.50

The data from data point 6 is shown in Figure 60. Scatter plots, plots of cumulative speed reductions, and supporting data for both daytime and nighttime, and both passenger cars and heavy vehicles are provided in APPENDIX K.

The negative value of *r* indicates that the vehicles with the higher speeds at data point 1 tend to be the vehicles that reduce their speed the most. That is a very desirable characteristic. However, the correlation is not exceptionally strong (i.e., the value is not particularly close to –1.0), and the speed changes are small. Statistics for nighttime and for heavy vehicles show weaker correlations, but all correlations are negative.

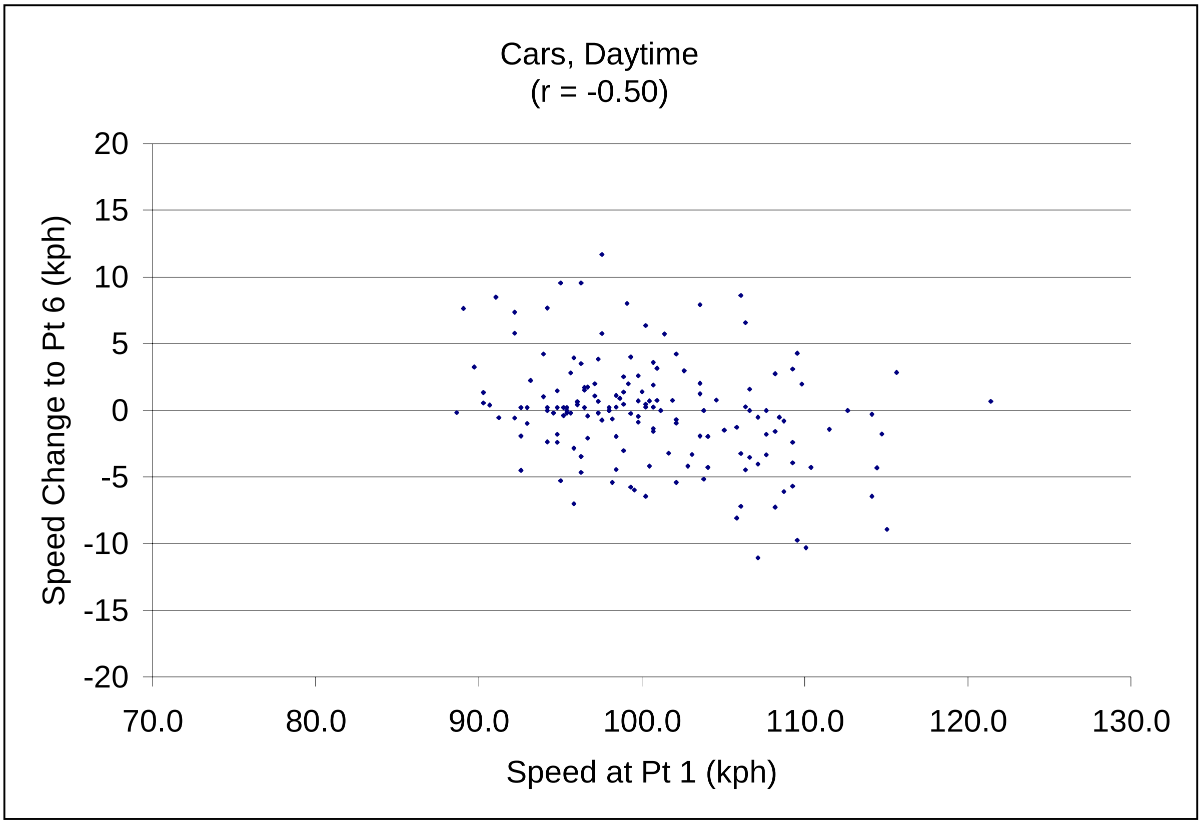


Figure 60. Scatter plot of speed changes at data point 6 relative to data point 1 versus speed at data point 1 (r = -0.50).

Figure 61 shows a plot of the mean speed change for three groups of vehicles: (1) all vehicles, (2) those vehicles at data point 1 with speeds above the 85th percentile speed, and (3) those vehicles with speeds above the 95th percentile speed. This graph supports the suggestion that the largest reductions in speed are occurring among those vehicles traveling the fastest.

Similar graphs for nighttime and heavy vehicles are provided in APPENDIX K. It should be noted that for combinations other than passenger cars during daylight the populations are small, especially when examining the upper 15% and upper 5%. The statistical data for passenger cars during daylight is given in Table 18 and Table 19 for the upper 15% and the upper 5%, respectively.

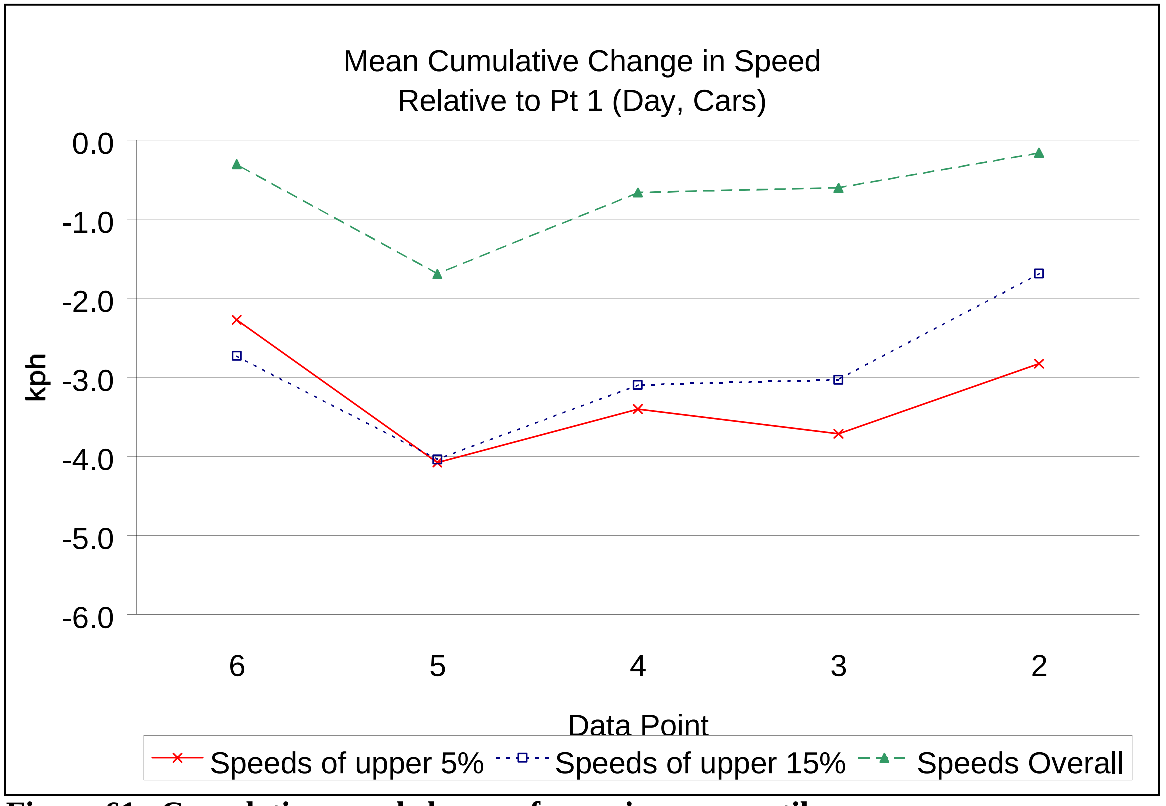


Figure 61. Cumulative speed changes for various percentiles.

Table 18. Speed change statistics for the upper 5% of passenger cars, daytime.

	Cumulative Speed Change of upper 15% (kph)				
Data Point	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**
Responses	36	36	36	36	36
Min	-15.5	-17.3	-13.3	-14.8	-18.6
Max	5.8	5.2	5.4	3.8	5.7
Median	-0.7	-2.2	-2.1	-4.0	-1.9
Average	-1.7	-3.0	-3.1	-4.0	-2.7
Conf Int (95%)	3.9	4.7	4.3	4.1	4.9
StdDev	1.3	1.6	1.5	1.4	1.7

Table 19. Speed change statistics for the upper 5% of passenger cars, daytime.

	Cumulative Speed Change of Upper 5% (kph)				
Data Point	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**
Responses	13	13	13	13	13
Min	-15.5	-17.3	-13.3	-9.6	-8.9
Max	2.5	1.8	2.3	2.6	5.7
Median	-1.9	-3.2	-4.1	-4.5	-2.0
Average	-2.8	-3.7	-3.4	-4.1	-2.3
Conf Int (95%)	2.9	3.2	2.6	2.1	2.5
StdDev	4.9	5.3	4.4	3.5	4.2

If the number of vehicles observed to reduce speed is considered, rather than the magnitude of those reductions, the effects of the primary pattern can be clearly seen. As shown in Figure 62 (with supporting data in Table 20), the percent of vehicles slowing between data point 1 and data point 4 does not vary by much. The percent of vehicles slowing between data point 4 and data point 5, on the other hand, is notably higher—greater than 80% for passenger cars, approximately 20% to 30% higher than previous data points. Very few drivers reduced their speeds between data points 5 and 6—less than 10%.

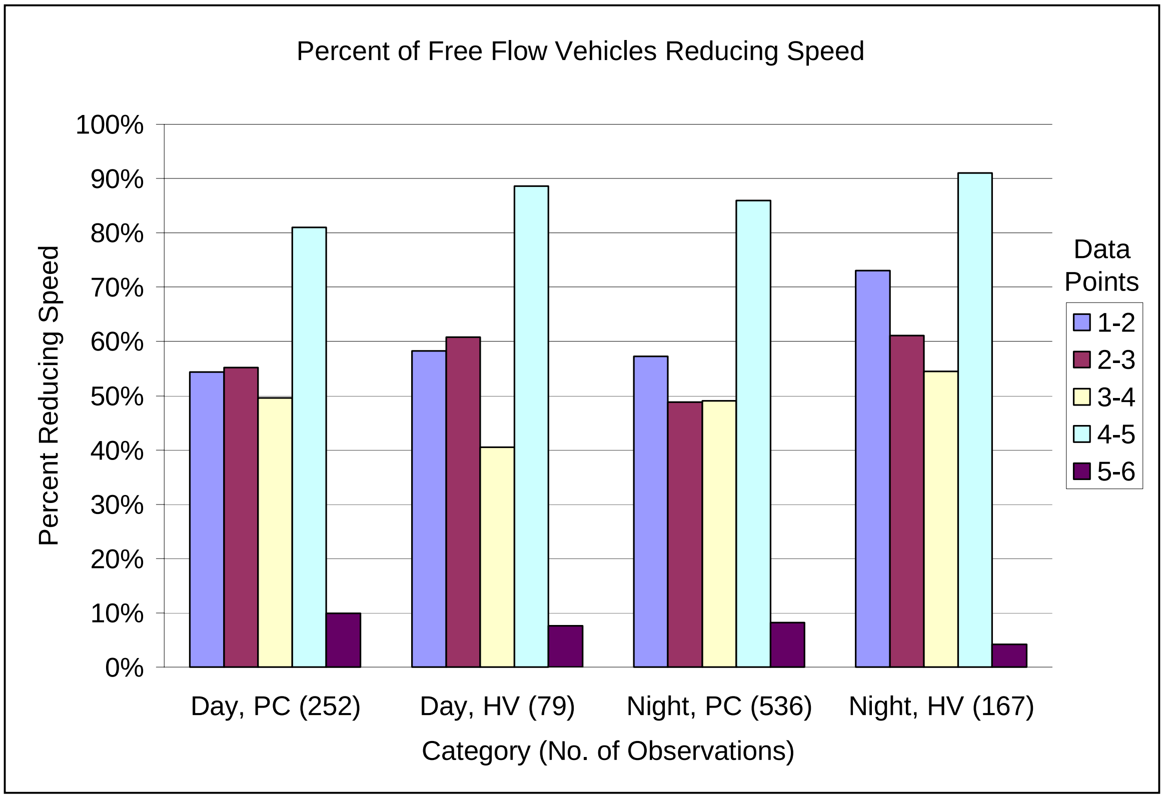


Figure 62. Percent of Vehicles Reducing Speed by Data Point.

Table 20. Percent of Vehicles Reducing Speed by Data Point.

	1-2	2-3	3-4	4-5	5-6	Total Vehicles
Day, PC	137 (54%)	139 (55%)	125 (50%)	204 (81%)	25 (10%)	252
Day, HV	46 (58%)	48 (61%)	32 (41%)	70 (89%)	6 (8%)	79
Night, PC	307 (57%)	262 (49%)	263 (49%)	461 (86%)	44 (8%)	536
Night, HV	122 (73%)	102 (61%)	91 (54%)	152 (91%)	7 (4%)	167

It is possible that a large portion of those slowing between data points 4 and 5 are simply continuing a speed change begun earlier. Figure 63 shows slowing vehicles between data points 4 and 5 as a percentage of drivers who either maintained or increased their speed between data points 3 and 4. That is, Figure 63 shows the percent of drivers who *initiated* a slowing maneuver between data points 4 and 5. The percentages are approximately equal to the percentages overall. This is additional evidence that the optical speed bars were responsible for the slowing that occurred between data points 4 and 5, and not the continuance of a previously initiated speed change. There was no change in the roadway other than the bar spacings, no construction work was occurring in that area of the work zone during the time this data was collected, and any congestion-caused speed changes were filtered out by the requisite 5-second headway.

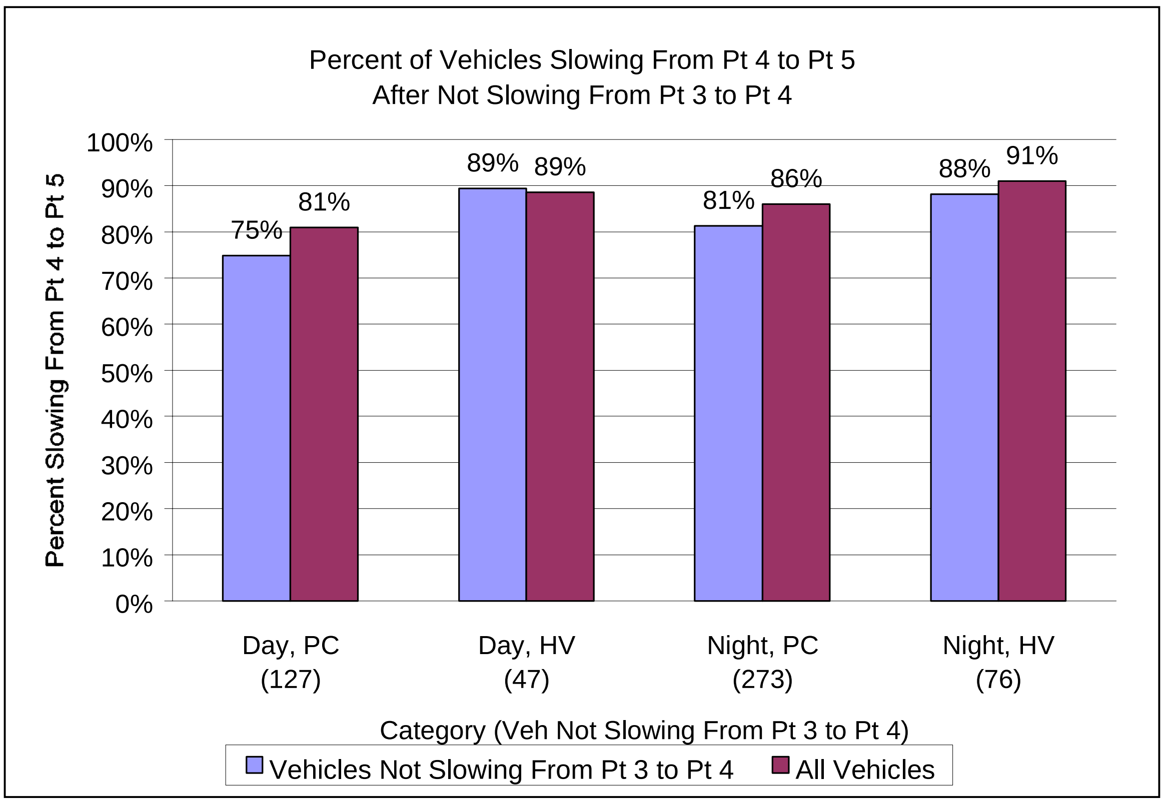


Figure 63. Percent Vehicles Not Slowing Between Pts 3 and 4, Then Slowing Between Pts 4 and 5.

Figure 64 shows the percent of vehicles slowing between data points 2 and 3 (the first half of the leading pattern) that also slowed between data points 4 and 5 (the first half of the primary pattern). The percentage of observations that show a reduction in speed both between data point 2 and data point 3, and between data point 4 and data point 5 is very close to the overall percentage of vehicles showing a reduction in speed between data points 4 and 5. This reinforces the existence of both a warning effect and perceptual effect.

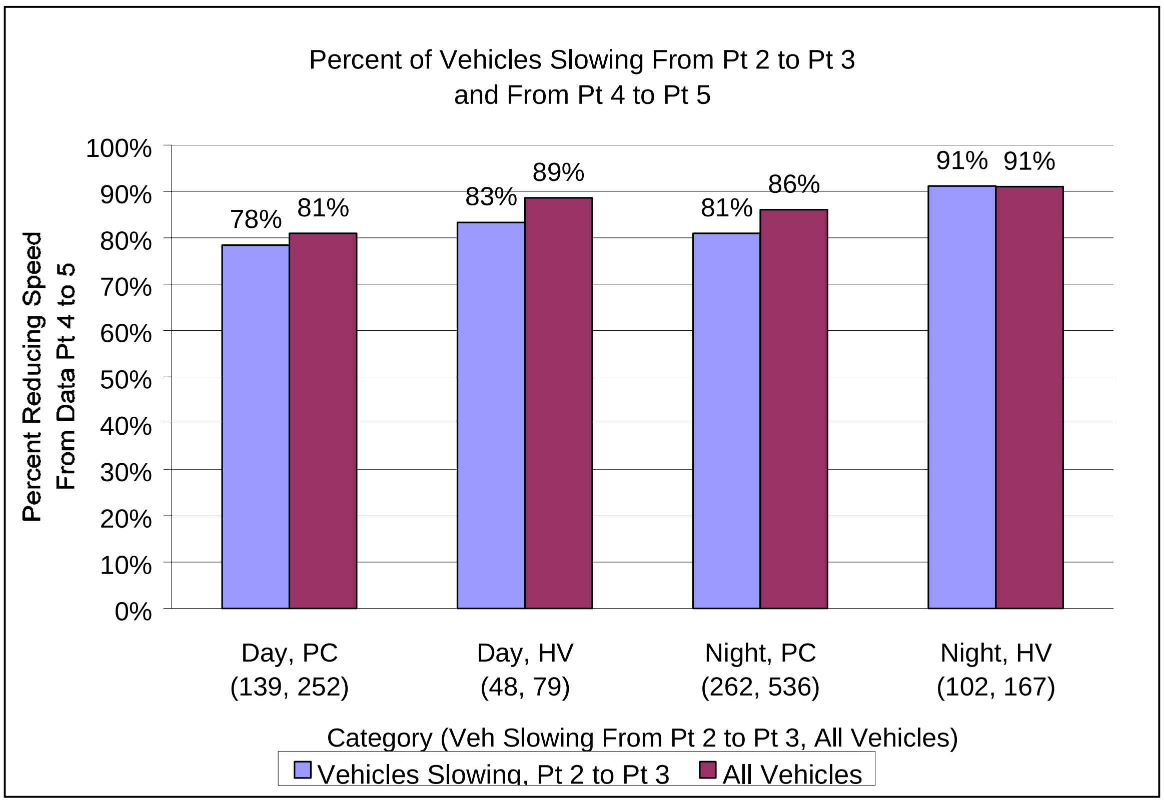


Figure 64. Percent of Vehicles Slowing Between Pts 2 and 3 and Between 4 and 5.

CHAPTER 6: SUMMARY AND CONCLUSIONS

The decision on the part of the contractor to accelerate the construction schedule of Phase I necessitated moving the evaluation Phase II, and subsequently moving the test site to a location other than that originally planned. The final site selected for the implementation of the striping patterns had both assets and drawbacks. The segment was straight and nearly level with no entering or exiting traffic, allowing the effects of the speed bars to be isolated. However, because of the change from Phase I to Phase II, the implementation could not be done on the approach to the work zone, but had to occur within the work zone, where both directions of traffic were being carried in the westbound lanes.

Difficulties associated with the site change probably reduced the effects of the bar pattern, meaning the effects of the pattern in other implementations could be expected to be greater than what was observed in this study. Three of the likely impacts are particularly noteworthy. (1) The presence of the oncoming traffic in the adjacent lane undoubtedly detracted from the effectiveness of the speed bars, placing a greater demand on the driver and reducing the percentage of driver input coming from the pavement markings. The original site was on the approach to the work zone, before the first crossover. (2) The surface of the original site was an asphaltic overlay. The final implementation occurred on new Portland cement concrete. The color difference between the two resulted in a decrease in contrast between the pavement and the speed bars. Because human perception is relative, and the magnitude of response is proportional to the relative magnitude of the stimulus, the reduction in contrast between the bars and the pavement most likely reduced the effectiveness of the bars. (3) The data collection was hindered greatly by the failure of the pneumatic hoses. The hoses failed because of the abrasive surface of pristine concrete. Had the original site been used, a much more complete data set could have been collected, thus enhancing the data analysis.

In spite of the difficulties of the site selection and data collection, the evaluation went smoothly and yielded valuable information about the use of optical speed bars in highway work zones. The installation of the bars required approximately 48 man-hours of labor. The paint wore well, and was still in acceptable condition three months after its installation, having endured the passing of 250,000 to 300,000 vehicles. The data supports the following conclusions.

6.1 Optical Speed Bars Are Effective At Reducing Speed

Reductions in mean and 85th percentile speeds were observed. The magnitudes of the reductions were small but statistically significant (95% confidence level). While the reductions in mean speeds observed during this evaluation were probably too small to be of practical significance, they would have been larger had the original site been used.

6.2 Optical Speed Bars Are Effective for As Long As Three Months in a Rural Context.

No noticeable decay in the effects of the bars was observable in the data. This result was expected. The rural context of the site almost certainly gives a very low percentage of repeat traffic (though this aspect of the traffic characteristics was not measured in this study). At the same time, the lack of temporal decay underscores the fact that the little wear than did occur on the bars was not substantial enough to reduce their effectiveness.

6.3 Both a Warning Effect and a Perceptual Effect Exist

The characteristics of the speed changes at different locations within the test site indicated that there was both a warning effect of the bars and a perceptual effect of the bars. Because the changes were very small, it was difficult to compare the relative magnitudes of these two effects. However, the data did show that they can be additive, substantiating the effectiveness of using a leading pattern of uniformly spaced bars preceding the primary pattern.

6.4 Speed Reductions Dissipate Downstream of the Pattern

Speed reductions that occurred in the first half of the primary pattern were generally lost in the second half of the primary pattern, where the spacing of the bars is nearly uniform (i.e., little perceptual change exists). For passenger cars, a small portion of the speed reduction realized in the leading pattern persisted at data point 9. For heavy vehicles, little or none of the speed reduction persisted at data point 9.

6.5 Intermittent Work Zone Pattern is Ineffective at Maintaining Speed Reductions

The intermittent work zone pattern did not seem to be effective at maintaining speed reductions. While a small portion of the speed reduction that occurred in the leading pattern persisted downstream of the primary pattern, it persisted at data points 9 and 10 at similar levels to data points 7 and 8. Thus, it can be concluded that the work zone pattern did not contribute to the persistence of the speed reductions.

6.6 Optical Speed Bars are Effective at Reducing Speed Variation

In addition to reducing speeds, the optical speed bars were effective at reducing the variation in speeds. This was evidenced in several ways. First, standard deviations declined through the test segment, particularly in the first half of the primary pattern and the first half of the secondary pattern. Second, the speed reductions observed at data point 5 in the vehicles among the fastest 5% and 15% of vehicles at data point 1 were substantially larger than the overall reductions observed at the same location.

6.7 Reductions in Speed Variation Persist Downstream

The reductions in standard deviations, and the comparison of the fastest 5% and 15% with the overall population reveal that the reductions in speed variation persist well downstream of the optical speed bars. While it is difficult to quantify the safety effects of reducing speed variation, the existence of a positive correlation between reductions in speed variation and reductions in crashes is widely accepted.

6.8 Effectiveness is Greatest for Passenger Cars During Daylight Hours

The reductions in speeds and speed variations were slightly larger among passenger cars than for trucks. Among passenger cars, reductions were larger during the daytime than at night. Among heavy vehicles, the opposite was true—reductions in both speeds and speed variations were larger at night.

CHAPTER 7: RECOMMENDATIONS

The intent of this study was to examine the potential effectiveness of optical speed bars at slowing traffic in highway work zones. The test was designed to answer four primary questions.

1. Do optical speed bars help to reduce speeds and/or speed variation?
2. Are the reductions caused by a warning effect, a perceptual effect, or both?
3. Are the reductions persistent downstream of the pattern?
4. Does an intermittent work zone pattern enhance the persistence of the reductions?

In brief, the answers to these questions are that the speed bars help to reduce both speeds and speed variations. The reductions were caused by both a warning effect and a perceptual effect. The warning effect appears to be persistent downstream of the pattern, while the perceptual effect does not. The intermittent work zone pattern was not effective at enhancing the persistence of the effects of the speed bars.

The following sections outline the recommendations resulting from this study.

7.1 Leading Pattern

The reductions in mean and 85th percentile speeds within and prior to the leading pattern were not of practical significance. However, the decrease in the standard deviations could be of practical significance. Especially during the day for both passenger cars and heavy vehicles, a pronounced decrease in standard deviation occurred between data points 1 and 2. Attributing this decrease to a warning effect, **it is recommended that the use of transverse pavement markings used on the approach to work zones be considered for adoption as a standard practice.** The number and spacing of the markings is not likely to be of much consequence, so long as they are amply visible. The dimensions used for the intermittent work zone pattern are recommended. **Before the practice is adopted, it is recommended that a test installation of this type should be evaluated and compared with an appropriate control site to better quantify the benefits that can be expected.**

7.2 Primary Pattern

While the data indicated that the primary pattern did yield a reduction in speed due to a change in driver speed perception, the reductions were small and were lost once drivers left the area where the perceptual effect existed. Reductions in standard deviations were also small, and were also lost downstream of the pattern. Consequently, **the use of a primary pattern is not recommended for highway work zones. It is recommended that the primary pattern be considered for other applications where speed reductions do not need to be maintained, such as at rural intersections or work zones established solely for bridge maintenance.**

7.3 Intermittent Work Zone Pattern

The persistence of the effects of the leading and primary pattern did not appear to be affected by the presence of the intermittent work zone pattern. Therefore, **it is recommended that an intermittent work zone pattern not be used.**

7.4 Alternate Applications

Another application of optical speed bars that has been suggested is their use at rural intersections where drivers are not required to stop, or where stop signs are in place but stop sign violations have been identified as a high priority safety issue. It has been hoped that this study would provide some indication of whether or not the application of optical speed bars to the approaches at such intersections would be an effective countermeasure to unsafe driving practices.

As has already been established, this study showed that optical speed bars do reduce speeds and speed variations, but the magnitudes of the speed reductions in this study were too small to recommend the use of optical speed bars on this basis alone. However, several factors unique to this application served to dampen the effects of the bars. Additionally, while the perceptual effects were not persistent downstream of the primary pattern, an application of speed bars to a rural intersection would not need for the speed reductions to be maintained for any significant distance.

An important question in considering a permanent application, such as a rural intersection, is whether the effects of the patterns would dissipate over time. Although this study does not bear it out because of the (likely) small percentage of repeat traffic, it is reasonable to expect that the effects of the patterns would lessen somewhat over time, particularly the warning effects. The perceptual effects, on the other hand, would not be expected to decrease with driver familiarity.

With these issues in mind, **it is recommended that a study be conducted to examine the effectiveness of applying optical speed bars to rural intersections.** The specific characteristics of the pattern would depend on the characteristics of the application, but several recommendations related to pattern design can be drawn from the results of this study.

1. **A leading pattern should be included. While the warning effect may dissipate over time, the leading pattern may serve as a frame of reference, enhancing the perceptual effect of the primary pattern.**
2. **The primary pattern should be altered from that used in this study to extend the perceptual effects for the entire length of the pattern. This could be accomplished using the design methodology described in section 3.2 by increasing the value of the multiplier, *M*, and decreasing the value of the exponent, *E*.**
3. **The intermittent work zone pattern is not applicable and should be omitted.**

In order to develop the best possible understanding of the effectiveness and appropriate use of the speed bars in the context of a rural intersection, the following elements of the experimental design are recommended.

1. **The opposing approach should be used as an experimental control.**
2. **The primary pattern should be applied initially without a leading pattern. After a month, apply a leading pattern upstream of the primary pattern with a length of approximately 100 m (328 ft). After another month, extend the leading pattern by an additional 100 m (328 ft). By this process, the length of the leading pattern that maximizes the effectiveness of the device can be approximately identified.**
3. **48 hrs of baseline data should be collected on the test approach (and control approach) before installation of the primary pattern.**
4. **48 hrs of data should be collected the first week and the fourth week after the installation of the primary pattern, and the first and fourth week following each of the leading pattern installations.**

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APPENDIX A: UK PATTERN SPECIFICATIONS

ROAD TRAFFIC REGULATION ACT 1984-SECTION(S) 64 AND 65

AUTHORISATION OF TRAFFIC SIGNS

The Secretary of State for Transport, in exercise of his powers under Section(s) 64 and 65 of the Road Traffic Regulation Act 1984, and of all other enabling powers, hereby:

1. authorises the placing in the vicinity of the site outlined in [colour] on the attached plan marked with Department of Transport number ……………. of a traffic sign consisting of markings on the carriageway (hereinafter referred to as "the authorised markings") which shall conform as to size, colour and character with the markings specified in Annex A and Annex B attached [attach either Annexes A1 and A2 or Annexes B1 and B2 as appropriate]; and

2. • directs, without prejudice to any statutory provision to the like effect, that it is a condition of this authorisation that the placing of the authorised markings in the vicinity of the said sites shall continue to have effect only until such day as may be appointed by one month's notice given by the Secretary of State in writing to the traffic authority for the removal or alteration of the authorised markings and on that day the said authorisation shall, without prejudice to the giving of any further authorisation or direction, cease to have effect.

The provisions of regulations 11, 12, 28 and 29 of the Traffic Signs Regulations and General Directions 1994 (SI 1994/1519) shall apply to the authorised markings in the same manner as they apply to the marking shown in diagram 1017 in Schedule 6 to those Regulations.

Dated …………………………...199
Signed by authority of the Secretary of State

…………………..
A Grade 7 Official in the [Highways Agency of the] Department of Transport

• omit this paragraph for markings on trunk roads

INTERNAL ADVICE NOTE 1/80

TRANSVERSE YELLOW BAR MARKINGS

Issued by RSTL March 1980
Amended version issued by DITM August 1996

1. These markings have been shown to have a significant effect in reducing accidents associated with speed. Their purpose, correction of unconscious speed adaptation, is wholly different from that of any other traffic sign, and prolific use of them would (particularly if it led to their automatic association with roundabout approaches) seriously diminish their value as an indication of something out of the ordinary, not to be found or expected at all roundabouts. Furthermore, they are not effective at reducing speeds in other situations.

2. Responsibility for authorising transverse yellow bar markings was delegated to Regional Offices in 1980, but only in respect of sites which meet all the following criteria:

i. the carriageway on which the bar markings are to be laid is a one-way approach to a roundabout;

ii. there is at least 3km of dual carriageway with no major intersections or bends with a horizontal radius of curvature less than the desirable minimum shown in Table 3 of TD9/93 for 120 kph design speed, prior to the roundabout;

iii. the road is subject to the national speed limit restriction of 70 mph; and

iv. the accident history for the roundabout shall record 3 accidents during the preceding 3 years in which speed or speed misjudgement on the approach road was a principal contributory factor. (Where all the other criteria are met but there is not yet 3 years of accident data the report should be referred to DITM for authorisation).

In addition, it should be noted that:

i. each approach to a given roundabout shall be treated as a separate site and the use of the markings on each approach shall be justified independently;

ii. the markings are not intended for use at bends; and

ii. the markings are intended to be used in addition to conventional signing arrangements.

3. Where motorway slip roads are being considered as potential sites for these markings, it should be borne in mind that:

i. sites with a protected left filter lane to the roundabout, those with offset roundabouts, and those with permanent traffic signals should not be considered for yellow bar marking installation; and

iii. it is recommended that only sites with a severe accident history should be considered for this measure. The most likely type of accident to be influenced by the markings are single-vehicle and over-run accidents.

4. The pattern of markings specified in Annexes B1 and B2 should be used on motorway exit slip roads. The pattern of markings specified in Annexes A1 and A2 should be used on other approaches to roundabouts.

5. To assist surface water drainage each transverse line should be terminated so as to leave a gap of about 150mm between it and the edges of the carriageway on either side. Where edge of carriageway markings are laid the 150mm gap shall be left between the transverse bars and the edge of carriageway markings.

6. The model authorisation is attached, together with copies of the annexes mentioned in paragraph 4 above.

7. Any proposals to install these markings at sites where the criteria are not met, but where nevertheless installation seems desirable, should be referred to DITM.

YELLOW BAR MARKINGS

12.42 Yellow bar markings are used in certain conditions on high speed approaches to roundabouts, either on the main carriageway or on a motorway slip road. Details of the pattern of markings are given in tables 12.4 for main carriageways and 12.5 for slip roads. Research has shown that they can make a useful contribution to road safety at sites where there is history of speed related accidents. The markings are not prescribed in the Traffic Signs Regulations and General Directions 1994. Prior authorisation will need to be obtained from the Department for each site where it is proposed to use them (see para 2.1).

12.43 Authorisation will be given only where the following criteria are met:

(i) the carriageway on which they are to be laid is a one-way approach to a roundabout (i.e. a dual carriageway or a one-way slip road);

(ii) there is at least 3km of dual carriageway with no major intersections or severe bends in advance of the site;

(iii) the road is not subject to any speed restriction other than the national limit of 70mph; and

(iv) the accident record for the roundabout includes at least three accidents involving personal injury during the preceding three years, in which speed or speed misjudgement on the relevant approach was a contributory factor.

12.44 Each approach to a given roundabout shall be treated as a separate site and the use of the markings on each approach shall be justified independently. The application on the criteria in 12.43 will ensure that the markings are used only at sites where they are likely to make a positive contribution to road safety; overuse will undermine their effectiveness. They should not be used on sharp bends, and are intended to be used in addition to, not in substitution for the conventional signing arrangements.

12.45 The installation of yellow bar markings is not normally appropriate on motorway slip roads where there is a protected left filter lane to the roundabout, or an offset roundabout, permanent traffic signals or cattle grids.

12.46 The marking for use on main carriageways consists of 90 yellow transverse lines, 600mm wide, laid at right angles to the centre line of the carriageway (see figure 12-6). The first bar is laid at a distance of 50m measured along the centre line of the carriageway in advance of the Give Way line at the roundabout. Successive lines shall then be spaced in accordance with the running measurements given in table 12.4.

12.47 The marking for use on motorway slip roads consists of 45 yellow transverse lines, 600mm wide, laid at right angles to the centre line of the carriageway. The first bar should be laid at a distance of 50m measured along the centre line of the carriageway in advance of the Give Way line at the roundabout. Successive lines shall then be spaced in accordance with the running measurements given in table 12.5.

12.48 Only sites with a severe accident history should be considered for the installation of yellow bar markings. The types of accidents most likely to be influenced by the markings are single vehicle and over-run accidents.

12.49 To assist surface water drainage, each transverse line should be terminated about 150mm from the edge of the carriageway on either side. Where edge of carriageway markings are laid, the 150mm gap should be left between the transverse bars and the edge of the carriageway marking.

12.50 Yellow transverse bar markings should be laid in hot screed applied thermoplastic material complying with the requirements of BS 3262 or an equivalent European standard, except as varied in table 12.6.

ANNEX A1

SETTING OUT & LAYING FOR DUAL CARRIAGEWAY ROUNDABOUTS

1. The pattern of the transverse yellow bar markings for use on the approaches to roundabouts is illustrated in Annex A2.

2. It comprises 90 yellow transverse lines (referred to as bars) 0.60 metres wide, laid at right angles to the centre line of the carriageway and spaced in accordance with the table below.

3. The first bar shall be laid at a distance of 50 metres measured back along the centre line of the carriageway from the "GIVE WAY" line at the roundabout. Successive line shall then be spaced in accordance with the running measurements given in the table below.

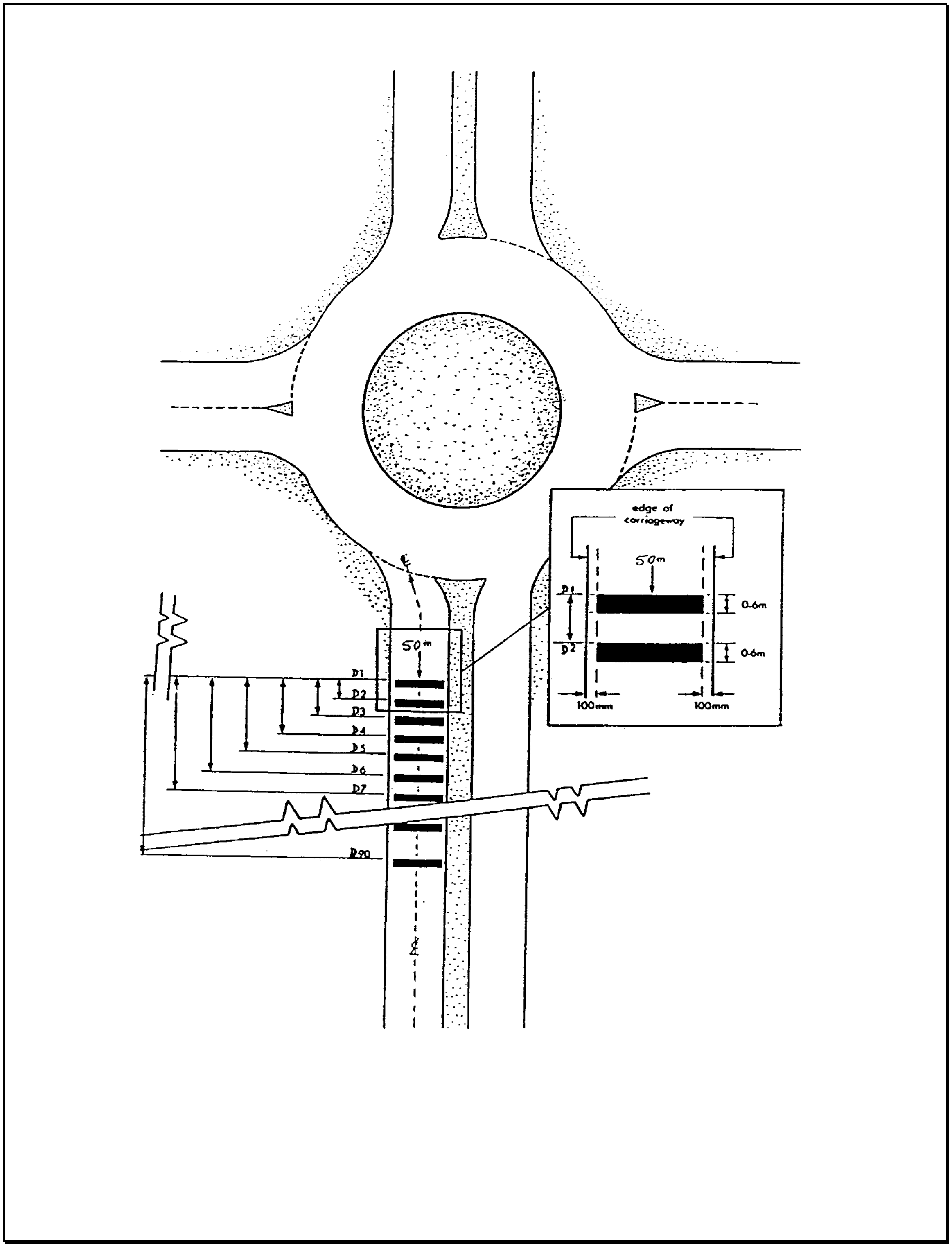
Bar No.	Distance from D1 (m)	Bar No.	Distance from D1 (m)	Bar No.	Distance from D1 (m)
D1	0.00	D31	94.95	D61	224.70
D2	2.75	D32	98.65	D62	229.80
D3	5.50	D33	102.40	D63	234.90
D4	8.25	D34	106.15	D64	240.10
D5	11.05	D35	110.00	D65	245.40
D6	13.90	D36	113.85	D66	250.70
D7	16.80	D37	117.75	D67	256.10
D8	19.70	D38	121.70	D68	261.50
D9	22.60	D39	125.65	D69	267.00
D10	25.55	D40	129.70	D70	272.60
D11	28.55	D41	133.75	D71	278.20
D12	31.60	D42	137.85	D72	283.90
D13	34.65	D43	142.00	D73	289.60
D14	37.70	D44	146.15	D74	295.45
D15	40.80	D45	150.40	D75	301.30
D16	43.95	D46	154.65	D76	307.25
D17	47.15	D47	158.95	D77	313.30
D18	50.35	D48	163.35	D78	319.35
D19	53.55	D49	167.75	D79	325.55
D20	56.80	D50	172.25	D80	331.75
D21	60.10	D51	176.75	D81	338.15
D22	63.45	D52	181.30	D82	344.65
D23	66.80	D53	185.95	D83	351.35
D24	70.15	D54	190.60	D84	358.30
D25	73.60	D55	195.35	D85	365.50
D26	77.05	D56	200.10	D86	370.20
D27	80.55	D57	204.90	D87	380.90
D28	84.10	D58	209.80	D88	388.60
D29	87.65	D59	214.70	D89	395.25
D30	91.30	D60	219.70	D90	403.95

Notes:

a. Where practical installation procedures make it desirable, all distances can be measured from the "GIVE WAY" line rather than the edge of the first bar (D1). With this method, 50 must be added to all the distances listed above.

b. For indication of points of measurement see Annex A2.

ANNEX A2


edge of
carriageway
50m
D1
D2
0.6m
0.6m
100mm
100mm
50m
D1
D2
D3
D4
D5
D6
D7
D90

ANNEX B1

SETTING OUT & LAYING FOR MOTORWAY SLIP-ROADS

1. The pattern of the transverse yellow bar markings for use on the approaches to roundabouts is illustrated in Annex B2.

2. It comprises 45 yellow transverse lines (referred to as bars) 0.60 metres wide, laid at right angles to the centre line of the carriageway and spaced in accordance with the table below.

3. The first bar shall be laid at a distance of 50 metres measured back along the centre line of the carriageway from the "GIVE WAY" line at the roundabout. Successive line shall then be spaced in accordance with the running measurements given in the table below.

Bar No.	Distance from D1 (m)	Bar No.	Distance from D1 (m)	Bar No.	Distance from D1 (m)
D1	0.00	D16	47.70	D31	112.90
D2	2.75	D17	51.45	D32	118.00
D3	5.55	D18	55.30	D33	123.30
D4	8.45	D19	59.20	D34	128.20
D5	11.35	D20	63.15	D35	134.20
D6	14.35	D21	67.20	D36	139.80
D7	17.40	D22	71.35	D37	145.50
D8	20.50	D23	75.60	D38	151.35
D9	23.70	D24	79.90	D39	157.40
D10	25.90	D25	84.30	D40	163.60
D11	30.20	D26	88.30	D41	170.00
D12	33.55	D27	93.45	D42	176.70
D13	37.00	D28	98.20	D43	183.90
D14	40.50	D29	103.00	D44	191.60
D15	44.05	D30	107.90	D45	199.30

Notes:

a. Where practical installation procedures make it desirable, all distances can be measured from the "GIVE WAY" line rather than the edge of the first bar (D1). With this method, 50 must be added to all the distances listed about.
b. For indication of points of measurement see Annex B2.

APPENDIX B: MUTCD EXCEPTION REQUEST

August 7, 1998

David R. Geiger
Federal Highway Administration
3300 South Topeka Blvd., Suite 1
Topeka, KS 66611-2237

Attn: Robert Alva, Safety and Traffic Engineer

Dear Mr. Geiger:

This letter is a *request for permission to experiment* as is codified in section 1A-6 of the 1988 Manual on Uniform Traffic Control Devices. This request is being made in reference to KDOT project No. 70-99 K-5628-01, I-70 in Wabaunsee County, which is scheduled for letting in September of 1998.

The Problem:

In highway work zones, it is often necessary for workers to operate in close proximity to moving traffic. Motorists, on the other hand, often become accustomed to traveling at highway speeds and do not adequately reduce their speed in work zones. Consequently, safety is a priority in highway work zones. The occurrence and severity of accidents is related to vehicle speed and speed variation. We propose to incur greater speed zone compliance through the use of innovative pavement markings. This proposal is being made in conjunction with the FHWA PTP funded project, "*A Comprehensive Literature Review of Perceptual Counter Measures to Speeding*", being performed by Dr. Eric Meyer of The University of Kansas.

The Proposed Change:

One strategy that has been used to reduce speeds on intersection approaches is the application of optical speed bars; transverse stripes spaced at gradually decreasing distances. The premise is that such a pattern will give the driver an increased perception of speed and a corresponding inclination to slow down.

While the mechanism through which optical speed bars influence speed is uncertain, the effect is significant. Several variations of optical speed bars have been investigated over the past 30 years. The two general categories that have shown the most promise are patterns of straight bars and patterns of chevrons. We propose to apply patterns of straight bars through a work zone in order to test their effect on vehicle speeds.

These bars shall be in addition to the regularly prescribed pavement markings through a work zone. The experimental pavement markings shall not cover or compromise the form of the regularly prescribed pavement markings. In a 3.66m (12ft.) driving lane, the bars shall be 2.75m (9ft.) long, perpendicular to the traveled way, and centered in the lane. Figure 1 shows the general concept of the bar application. Each bar shall be a single piece of white Type 1 temporary striping. According to the pattern specified by the researcher, the bars will be 600mm, 750mm, 900mm, or 1050mm wide.

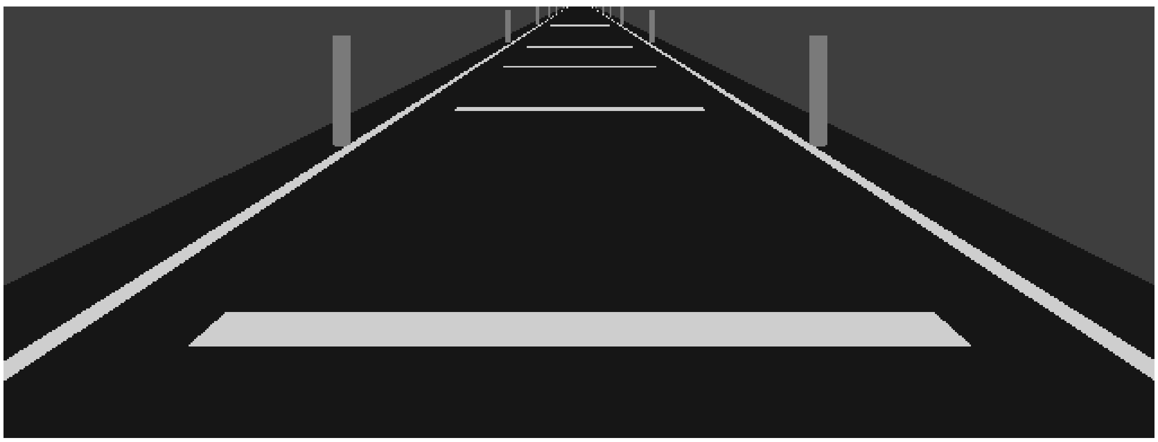


Figure 1. Example of Transverse Bar Application

Supporting Data:

Leibel et al (1984) report on an experiment conducted in May 1982, by The Traffic Operations Division and the Calgary Police, Traffic Analysis Unit, both of the City of Calgary, Alberta, Canada. In the experiment, optical speed bars were applied to an exit ramp of a major freeway with the intent of reducing accidents at the ramp terminus.

The installation site was observed for a total of 39 days, 19 days prior to the installation and 20 days after the installation. Speeds recorded at a point 150 m (492 ft) from the traffic signals located at the end of the ramp showed a small decrease in average speed from 63.5 km/h (39.5 mph) before the installation to 61.4 km/h (38.1 mph) afterwards. As well, the percentage of vehicles exceeding 80 km/h (50 mph) decreased from 5.45% to 4.05%.

In October 1983, another ramp at the same interchange was painted with the same pattern of transverse bars. While the available data is inconclusive, there is some suggestion that the markings may contribute to a decrease the crash severity.

Agent (1980) studied a domestic implementation of a transverse pavement-marking pattern on a rural two-lane highway in Meade County, Kentucky. One section, (average daily traffic, ADT, = 4890) was observed to be particularly hazardous due to a curve at one end of the section. In the six years prior to the project, 48 accidents occurred in the curve, 46 of them involving eastbound vehicles. Speed was mentioned as a contributing circumstance in 36 of the accident reports. Because of the high percentage of accidents involving eastbound vehicles, the eastbound approach was selected as a test location for a transverse-striping pattern.

Reflective tape was used to create the stripes. The details of the striping pattern were based on an assumed speed of 25 m/s (55 mph) at the beginning of the pattern and a desired speed of 16m/s (35 mph) at the beginning of the curve (also the end of the pattern). Stripes were spaced such that a vehicle decelerating at a constant rate of 0.75 m/s^2 (1.67 mph/s) would cross two stripes per second. The final configuration consisted of 30 stripes with an installed pattern length of 247 m (810 ft), ending at the beginning of the curve. The stripe spacing gradually decreased from 12 m (40 ft) to 4.6 m (15 ft) at the curve. The widths of the stripes were decreased, as well, from a maximum width of approximately 0.9 m (36 in) to a minimum of 0.6 m (24 in). The maximum width was not explicitly given in the source, but can easily be calculated from other information given, assuming widths were rounded to the nearest 100 mm (4 in).

In the year following the installation, three accidents occurred which involved eastbound vehicles. Of the three, two involved an intoxicated driver, and in the third, the driver had fallen asleep. Speeding was cited as a contributing circumstance in one of the accident reports.

Speed data was collected before the application of the stripes, one week after the installation and six months after the installation. Speeds were measured at both the beginning and the end of the markings. Speed reductions are plotted in Figure 2. Prior to the installation, the average nighttime speed reduction was 1.1 m/s (2.4 mph). A week after the installation, the average nighttime speed reduction increased to 4.2 m/s (9.3 mph), decreasing over the subsequent six months to 3.0 m/s (6.8 mph). During the daytime, the average speed reduction before the installation was 3.8 m/s (8.5 mph). This number increased to 6.8 m/s (15.3 mph) over the first week after the installation, and decreased slightly to 5.5 m/s (12.3 mph) over the next six months. All reductions were statistically significant at the 0.005 level.

Using then current monetary figures, an estimated benefit/cost ratio was calculated as 45.9, based solely on savings from a reduction in accidents. In conclusion, Agent states,

> *Results showed that transverse stripes on pavement could effectively reduce speed. At the single site investigated, the obedience of drivers to this type of hazard warning was more effective than to signing alone. At the very least, transverse striping alerts drivers to the upcoming hazard more effectively than signing does. Further use of this traffic-control method may be warranted at locations at which excessive speeds have contributed to accidents.*

Denton (1973) studied a transverse bar pattern applied to an approach to the Newbridge Roundabout in the county of Midlothian, Scotland. The pattern, detailed by Denton (1971) for the Road Research Laboratory, consisted of 0.6 m (2 ft) wide yellow stripes, which stretched from edge line to edge line on the approach side of the divided roadway.

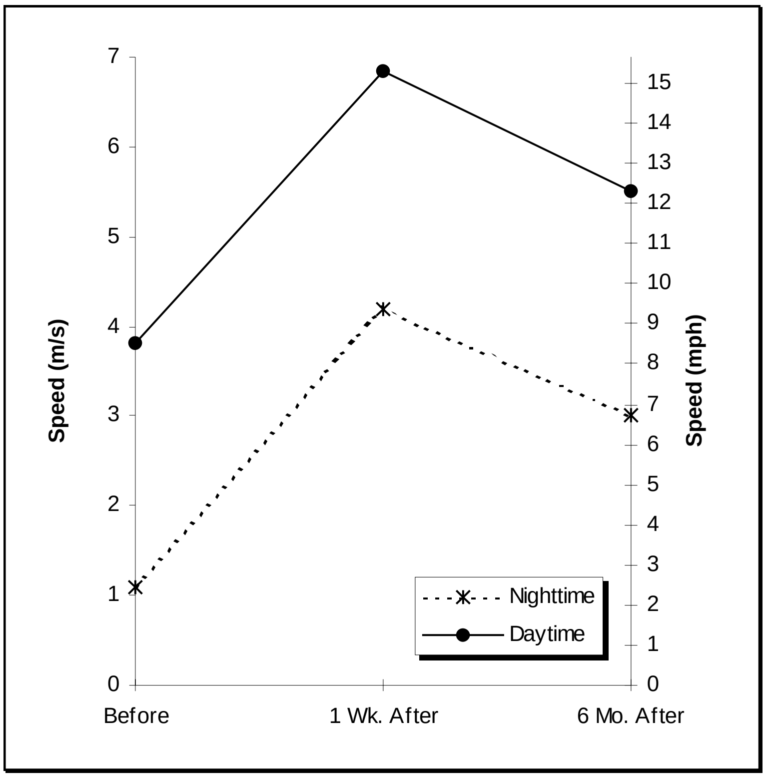


Figure 2. Average speed reductions.

In all, 90 stripes were applied, with spacing decreasing exponentially from 6 m (20 ft) to a minimum of 3 m (10 ft).

As can be seen from Table 1 and Table 2, the pattern had a significant effect on both mean and 85th percentile speeds. Figure 3 shows a comparison of the speed distributions before and after the installation for one of the time periods observed. Each of the observed time periods showed a similar reduction in speed variation after the installation of the pattern. Additionally, there were 14 accidents during the 12 months prior to the installation, and only 2 during the 16 months following the installation. While the time frame is still too short for findings from the accident data to be conclusive, these intermediate results are very promising.

Table 1. Mean speeds before and after with percent reduction, units are km/h (mph).

	7-9 am		2-4 pm		6-8 pm		MEAN	
Before	59.1	(36.7)	57.8	(35.9)	54.9	(34.1)	57.0	(35.4)
After	42.2	(26.2)	45.2	(28.1)	44.7	(27.8)	44.1	(27.4)
% reduction	28.6%		21.7%		18.5%		22.6%	

Table 2. 85th percentile speeds before and after with percent reduction, units are km/h (mph).

	7-9 am		2-4 pm		6-8 pm		MEAN	
Before	77.4	(48.1)	75.9	(47.2)	72.4	(45.0)	75.1	(46.7)
After	50.8	(31.6)	54.1	(33.6)	53.7	(33.4)	52.8	(32.8)
% reduction	34.3%		28.8%		25.8%		29.8%	

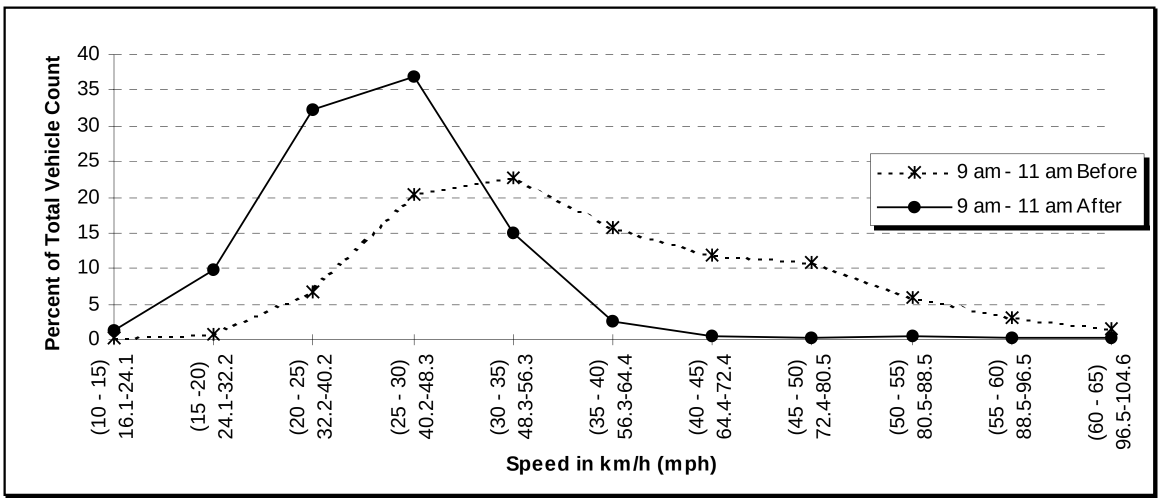


Figure 3. Before and after speed distribution for 9 am to 11 am.

In proving ground tests, Richards et al (1985b) found that, compared to rumble strips and effective lane width reduction, transverse striping resulted in relatively low speed variations, with standard deviations ranging from 7.10 to 9.69 km/h (4.41 to 6.02 mph). Other values are shown in Table 3 for comparison.

Table 3. Effects of work zone speed control treatments on standard deviations.

	Standard Deviation, km/h (mph)				
Treatment	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**
Effective Lane Width Reduction (N=18)					
Striping	12.5 (7.7)	16.2 (10.0)	15.2 (9.5)	11.6 (7.2)	7.8 (4.8)
Cones	9.5 (5.9)	12.3 (7.6)	13.0 (8.0)	9.6 (6.0)	8.8 (5.4)
Barrels	13.2 (8.2)	18.5 (11.5)	20.4 (12.7)	18.4 (11.4)	16.3 (10.2)
Transverse Striping (N=17)					
Full Width	8.4 (5.2)	7.3 (4.5)	7.0 (4.4)	7.8 (4.8)	9.5 (5.9)
Shoulder Only	8.2 (5.1)	7.4 (4.6)	7.2 (4.4)	7.7 (4.8)	9.1 (5.6)
Herringbone	5.6 (3.4)	7.5 (4.7)	9.6 (6.0)	9.5 (5.9)	9.1 (5.6)
Rumble Strips (N=18)					
Individual Strips	11.6 (7.2)	13.1 (8.1)	14.6 (9.0)	16.4 (10.2)	14.7 (9.1)
Cluster w/Equal Spacing	6.7 (4.1)	10.8 (6.7)	12.3 (7.6)	13.0 (8.1)	10.8 (6.7)
Cluster w/Unequal Spacing	14.8 (9.2)	14.6 (9.0)	14.2 (8.8)	14.7 (9.1)	13.0 (8.1)

Our Experiment:

We will test the transverse bars in the work zone associated with the I-70 roadway reconstruction project 70-99 K-5628-01 in Wabaunsee County. This stretch of rural interstate is four lanes divided by a grass median. The terrain is fairly flat and featureless. The westbound lanes will be closed and reconstructed while two-way traffic runs on the eastbound lanes. After the westbound lanes are reconstructed, the eastbound lanes will be closed and reconstructed. The project will be completed in the 1999 construction season. We will perform the experiment using the following sequence:

1. Measure the existing speed. Prior to the installation of the transverse bars, speed detection loops will be installed in both eastbound lanes and westbound lanes beyond the extent of the construction on both ends. Speeds will be measured for two weeks prior to the installation of the transverse bars. The speed monitoring will be done as discretely as possible and avoiding inclement weather so that best representative data is gathered.
2. Install the transverse bars and continue measuring speed. Before the westbound lanes are closed, install the transverse bars in what will become, during construction, the eastbound lane of the two-way traffic. Data will be collected throughout the approximately four months that the westbound lanes will be closed. The data will later be analyzed to detemine what effect (if any) the bars had on vehicle speeds. After the westbound lanes are reconstructed all the experimental pavement markings will be removed.

3. Monitor speeds while two-way traffic is running on the newly constructed westbound lanes. This will be the control data. Standard work zone traffic control shall be used. At this point no experimental pavement markings will be on the project. Speed data will be collected and combined over the remainder of the construction project. The data will be compared to that collected during the time the transverse bars were on the pavement. This will indicate the amount of speed reduction induced by the bars.

Agreement to Remove in Case of Hazard:

If at any time during the experiment it should be deemed by KDOT or FHWA officials that the experimental pavement markings directly or indirectly constitute a safety hazard to the motoring public the contractor shall remove them immediately and restore the work zone to MUTCD compliance.

Agreement to Provide Results:

This project will last approximately one construction season. We will provide FHWA, HTO-20, a copy of the final results within three months of completion of the experiment.

If you have any questions, please contact me at (785) 296-3843. Thank you.

Sincerely,

James E. Tobaben
Chief of Transportation Planning

JET:MAV:CWB:PAB

CC: Mike Crow
Dean Testa
Jim Brewer
Eric Meyer
Richard McReynolds
Matt Volz

References:

AGENT, K. R. (1980), "Transverse Pavement Markings for Speed Control and Accident Reduction," *Transportation Research Record 773*, 11-14

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DENTON, G. G. (1973), "The Influence of Visual Pattern on Perceived Speed at Newbridge MB Midlothian," *Transport and Road Research Laboratory Report LR531*, Crowthorne, Berkshire.

LIEBEL, D. L., & BOWRON, D. J. (1984), “Use of Optical Speed Bars’ to Reduce Accidents- the Calgary Experience,” *Proceedings of the International Transport Congress*, pp. A27-A38, Ottawa, Canada.

RICHARDS, S. H., WUNDERLICH, R. C., DUDEK, C. L. & BRACKETT, R. Q. (1985b), “Improvements and New Concepts for Traffic Control in Work Zones, Volume 4, Speed Control on Work Zones,” *FHWA/RD-85/037*, Federal Highway Administration.

APPENDIX C: PROJECT CHRONOLOGY

1996	
December 1996	PTP Proposal Drafted

1997	
May 12, 1997	Contract signed with KU for "A Comprehensive Literature Review of Perceptual Countermeasures to Speeding." $20,000.
May 23, 1997	FHWA Work order (DTFH71-97-PTP-KS-24) executed. $25,000.
August 21-22, 1997	Literature review results presented at PTP Conference in St. Joseph, Missouri.
October 23, 1997	Progress report submitted by KU.
November 7, 1997	Preliminary test recommendations delivered.

1998	
June 1998	Construction project selected for evaluation site (K-5628-01).
June 8, 1998	Potential pattern designs presented to project oversight committee.
June 10, 1998	Type 1 (removable) pavement markings chosen for stripe application, using a manufacturer-recommended adhesive primer.
June 16, 1998	Surveyed volunteers regarding potential pattern designs.
June 19, 1998	Phasing, Layout, and dimensions provided to KDOT.
August 7, 1998	MUTCD Request for Experimentation submitted to FHWA
October 1998	Contractor moves start date to early March. Low pavement temperatures would prevent adequate adhesion of stripes and traffic detection hardware. Test is moved to Phase II.
November 30, 1998	K-TRAN pre-proposal submitted to fund evaluation of test data.

1999

February 11, 1999	Phasing, layout, and dimensions revised to for application in Phase II of construction project.
June 1, 1999	Meeting held to plan data collection specifics.
June 1999	Test hoses set out on I70 east of Wabaunsee county.
June 16, 1999	Stripes laid out by contractor.
June 17, 1999	Stripes painted by contractor.
June 25, 1999	Data collection equipment deployed. 11:00AM, several hoses damaged by a power broom ~2:00 PM, roadway is opened to traffic
June 29, 1999	One hose at Data Pt 1 WB was cut Both hoses at Data Pt 10 WB and leading hose at Data Pt 10 EB were broken free of the roadway. Trailing hose at Data Pt 7 WB had water in it and was not transmitting impulses Data collection unit at Data Pt 8 WB was full of water and consequently pulled.
June 30, 1999	Data Pt 5 EB water in hose
July 16, 1999	Data Pts 7 and 8 WB--water in counters Data Pts 1 and 2 EB--download errors result in loss of data
July 27, 1999	Data collection complete.

2000

July 2000	Final report submitted

APPENDIX D: RAY TRACING

When a person views a scene, light sources, such as the Sun, a light bulb or a headlight, emit light rays which hit objects and are reflected and refracted. Light rays that are reflected to the person's pupils make up what the person sees. The amount or strength of the rays that reach the pupils determines the brightness with which the object is seen. Similarly, a camera is a means of recording on film the light rays reflected by objects in a scene.

In the world of computer graphics, *ray tracing* is a technique that creates an image by simulating light sources, light rays, objects and a camera. When creating a photographic image, the camera sees what the photographer sees, whatever objects and lights are present. When creating, or rendering, an image on a computer using ray tracing, every light and every object must be described in a way that the computer software can interpret. For example, an object might be described as a red box, 4 units in each direction (i.e., a cube), with one corner located at the origin, or <0, 0, 0> in three-dimensional rectangular coordinates, and the opposite corner located at <4, 4, -4>. Another object might be described as a sphere centered at <7, 0, 0> with a radius of 2 units and a mirror-like surface, perhaps a steel ball. In the right hands, a ray tracer can create photo-realistic images, imitating very complex shadings and reflections.

In high-end rendering packages, the objects in a scene are typically described graphically, through a CAD-like interface. In less expensive, though not necessarily poorer quality, packages, scenes are often described in a text file, using keywords and three-dimensional rectangular coordinates. A camera and light sources may also be defined. In principle, ray tracing follows the light rays emitted by light sources as they travel through a scene, reflecting, refracting, and diffusing off objects. As light bounces off of objects at different angles, contrast is produced between areas that reflect different amounts of light to the camera.

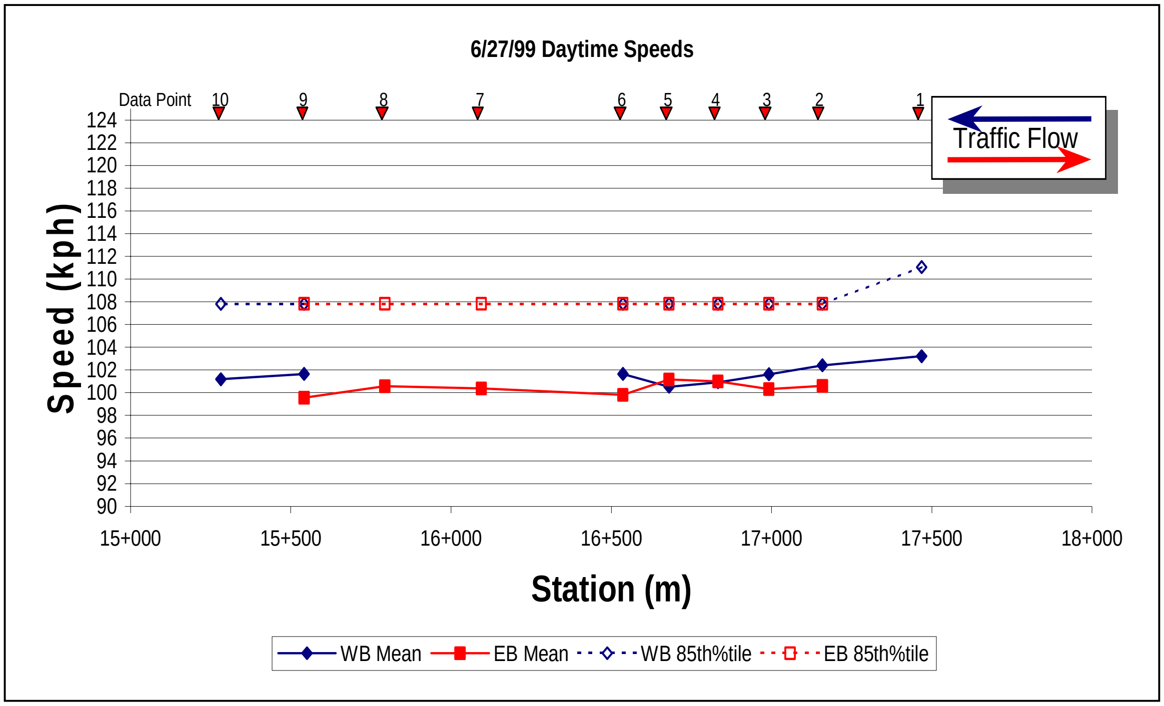
For example, an object's description must include its position, shape, size and some information about the surface of the object, such as its color, reflectivity or texture. A typical light source has a type (e.g., a point light might represent a bare light bulb, or a spotlight might represent a headlight beam), a location, a color, and an intensity. Finally, there must be a point from which the scene is viewed, usually represented by a camera with a specific location given by *X*, *Y*, and *Z* coordinates, and lens characteristics.

Once the scene is described, rays are shot into the scene and thousands of calculations are carried out to determine which rays make it from a light source to the camera, what each ray's color and intensity is when it arrives, and which direction it was traveling at the time. The final direction of travel reveals where in the final image that light ray will appear.

APPENDIX E: SIMULATION DESCRIPTIONS

ID	Multiplier	Exponent	Bars/s	Distance	Leading	Work Zone Pattern Type	Deceleration (Stripe Spacing) Model	Pylon Spacings	% of Pavement Covered	Description
1	3		2	1028	Y	Y				Stripes
2	1	1	2	673 ft	Y	Uniform	Linear	Uniform	4.7%	
3	3		1	1028	Y	Y				Stripes
4	3		2	1028	n/a	N				Tubes, Orange
5	3		2	1028	n/a	N				Tubes, alternating orange and yellow
6	n/a	n/a	n/a	n/a	Y	n/a	n/a	Uniform	0.0%	Tubes, orange with yellow at graduated intervals
7	3		2	1028	N	N				Stripes
8	3	1	2	1014 ft	Y	Uniform	Linear	Uniform	7.0%	Full stripes, night
9	2		2	702	Y	Y				Stripes
10	3		2	702	Y	Y				Stripes
11	3		2	702	Y	Y				Stripes, graduated work zone patterns
12	1	1	2	1006 ft	Y	Uniform	Linear	Uniform	4.7%	
13	1	1	1	1050 ft	Y	Uniform	Linear	Uniform	2.5%	
14	2	1	2	1013 ft	Y	Uniform	Linear	Uniform	5.6%	
15	3	1	2	1006 ft	Y	Uniform	Linear	Uniform	7.1%	
16	2	2	2	1000 ft	Y	Uniform	Exponential	Uniform	5.5%	
17	2	3	2	1010 ft	Y	Uniform	Exponential	Uniform	5.6%	
18	2	1	2	1002 ft	Y	Uniform	Linearly Stepped	Uniform	5.8%	Linearly stepped deceleration
19	2	2	2	1031 ft	Y	Uniform	Exponentially Stepped	Uniform	5.7%	Exponentially stepped deceleration
20	2	2	2	1000 ft	Y	Graduated	Exponential	Uniform	5.5%	Graduated work zone pattern
21	2	2	2	1000 ft	Y	Graduated	Exponential	Graduated	5.5%	Graduated pylon spacings (match stripes)
22	2	2	2	1000 ft	Y	Graduated	Exponential	Uniform	5.5%	Split Stripes
23	2	2	2	1000 ft	Y	Graduated	Exponential	Uniform	5.5%	Nighttime, Split stripes
24	2	2	2	1000 ft	Y	Graduated	Exponential	Graduated	0.0%	tubes, orange
25	2	2	2	1000 ft	Y	Graduated	Exponential	Graduated	0.0%	tubes, orange and yellow
26	2	2	2	1000 ft	N	Graduated	Exponential	Uniform	5.5%	
27	2	2	2	1010 ft	Y	Graduated	Exponential	Uniform	5.5%	Chevron, 30
28	2	3	2	1007 ft	Y	Graduated	Exponential	Uniform	8.3%	Chevron, 45
29	8	0.5	2.25	1302 ft	N	n/a	Inverse Exp	Uniform	11.3%	Ito, adapted
30	6	1	4.1	1325 ft	N	n/a	Linear	Uniform	13.4%	British bar
31	8	0.5	2.25	1302 ft	N	n/a	Inverse Exp	n/a	11.3%	Ito, original
32	3	2	2	1011 ft	Y	Uniform	Exponential	Uniform	6.9%	
33	4	2	2	1000 ft	Y	Uniform	Exponential	Uniform	9.2%	
34	3	2	3	1008 ft	Y	Uniform	Exponential	Uniform	10.3%	
35	3	2	2.00	1012 ft	Y	Uniform	Exponential	Uniform	6.9%	Slow from 70 to 60 mph in Primary Pattern
36	3	1.5	2	1015 ft	Y	Uniform	Exponential	Uniform	7.0%	
37	3	2	2.00	1008 ft	Y	Uniform	Exponential	Uniform	6.9%	60 mph
38	3	3	2	1011 ft	Y	Uniform	Exponential	Uniform	6.9%	
39	2	2	2	1000 ft	Y	Uniform	Exponential	Uniform	5.5%	Tighter Work Zone Pattern (25 ft)
40	3	2	2	1011 ft	Y	Uniform	Exponential	Uniform	6.9%	Work Zone spacing of 25 ft
41	3	2	2	1011 ft	Y	Uniform	Exponential	Uniform	6.9%	Work Zone spacing of 20 ft

APPENDIX F: DATA POINT COMPARISONS, DAYTIME



6/27/1999 Daytime (Sunday)

WB

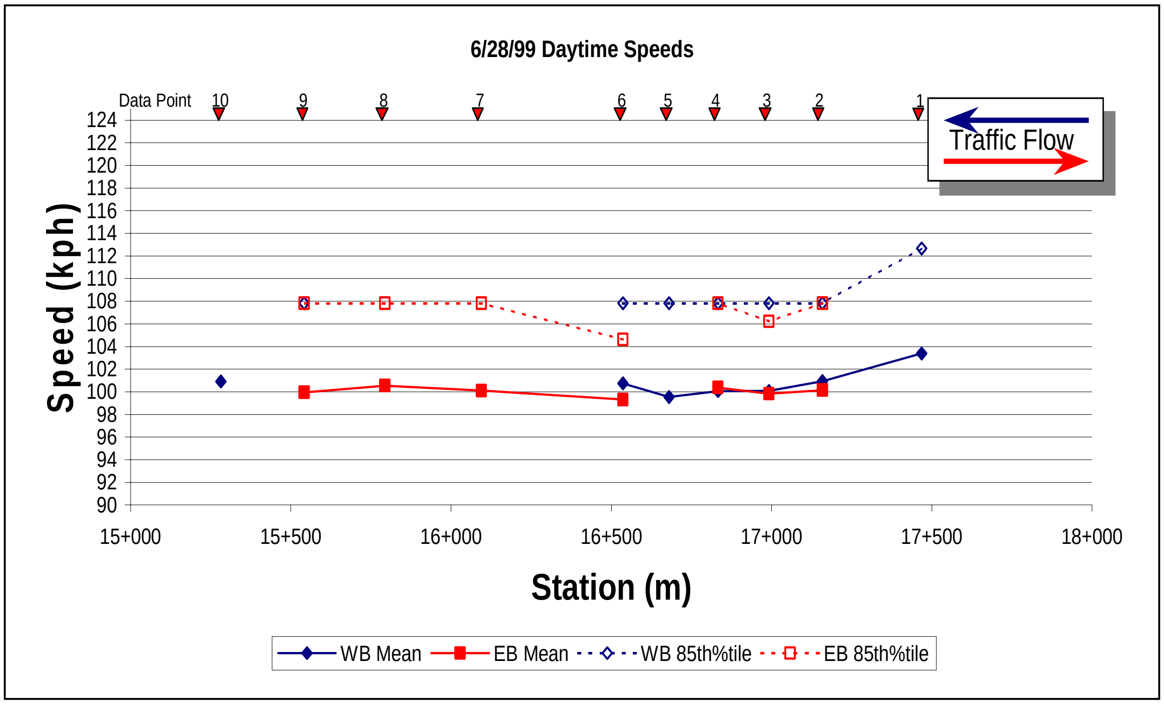
Data Point	1	2	3	4	5	6	7	8	9	10
Mean	103.2	102.4	101.6	100.9	100.5	101.7			101.7	101.2
Standard Error	0.15	0.15	0.15	0.15	0.14	0.15			0.14	0.15
Mode	99.8	99.8	99.8	99.8	99.8	99.8			99.8	99.8
Standard Deviation	7.7	7.4	7.3	7.2	7.1	7.2			6.8	7.0
85th%tile Speed	111.0	107.8	107.8	107.8	107.8	107.8			107.8	107.8
Minimum	70.8	69.2	61.2	61.2	67.6	69.2			67.6	69.2
Maximum	140.0	140.0	133.6	127.1	133.6	127.1			127.1	127.1
Count	2568	2511	2474	2420	2405	2395			2231	2186

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean		100.6	100.3	101.0	101.2	99.8	100.4	100.6	99.5	
Standard Error		0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.15	
Mode		99.8	99.8	99.8	99.8	99.8	99.8	99.8	99.8	
Standard Deviation		6.2	6.2	6.3	6.4	6.4	6.5	6.6	7.0	
85th%tile Speed		107.8	107.8	107.8	107.8	107.8	107.8	107.8	107.8	
Minimum		75.6	72.4	75.6	75.6	41.8	70.8	70.8	67.6	
Maximum		140.0	133.6	133.6	140.0	133.6	140.0	133.6	133.6	
Count		1895	1907	1921	1959	1965	2006	2038	2056	

*All values except "Count" are in kilometers per hour (kph).



6/28/1999 Daytime **(Monday)**
WB

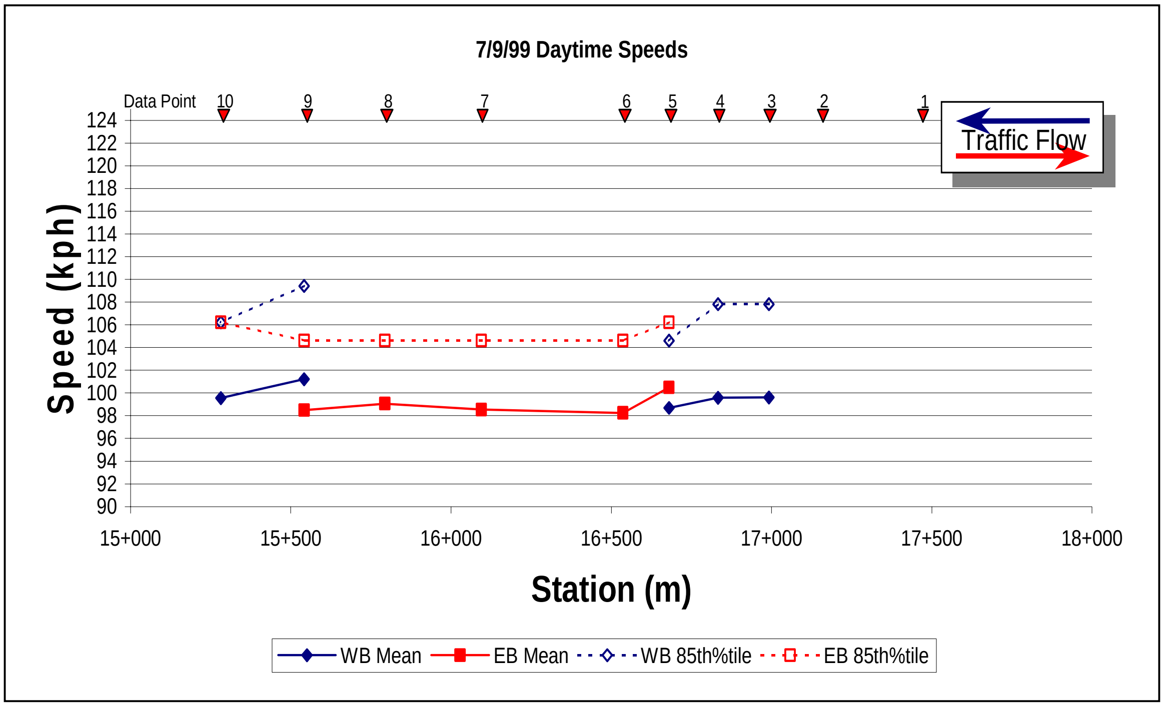
Data Point	1	2	3	4	5	6	7	8	9	10
Mean	103.4	100.9	100.1	100.1	99.5	100.7			100.9	
Standard Error	0.34	0.15	0.15	0.15	0.14	0.15			0.15	
Mode	99.8	99.8	99.8	99.8	99.8	99.8			99.8	
Standard Deviation	9.0	7.6	7.6	7.5	7.0	7.3			7.3	
85th%tile Speed	112.7	107.8	107.8	107.8	107.8	107.8			107.8	
Minimum	69.2	70.8	41.8	46.7	48.3	70.8			75.6	
Maximum	157.7	140.0	140.0	140.0	128.7	133.6			140.0	
Count	695	2502	2480	2457	2443	2419			2257	

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean		100.2	99.8	100.4		99.3	100.1	100.5	99.9	
Standard Error		0.14	0.14	0.14		0.14	0.15	0.14	0.14	
Mode		99.8	99.8	99.8		99.8	99.8	99.8	99.8	
Standard Deviation		6.3	6.2	6.3		6.4	6.8	6.5	6.5	
85th%tile Speed		107.8	106.2	107.8		104.6	107.8	107.8	107.8	
Minimum		80.5	77.2	80.5		77.2	77.2	77.2	74.0	
Maximum		133.6	128.7	133.6		128.7	140.0	133.6	128.7	
Count		1922	1935	1945		1975	2031	2064	2101	

*All values except "Count" are in kilometers per hour (kph).



7/9/1999 Daytime **(Friday)**
WB

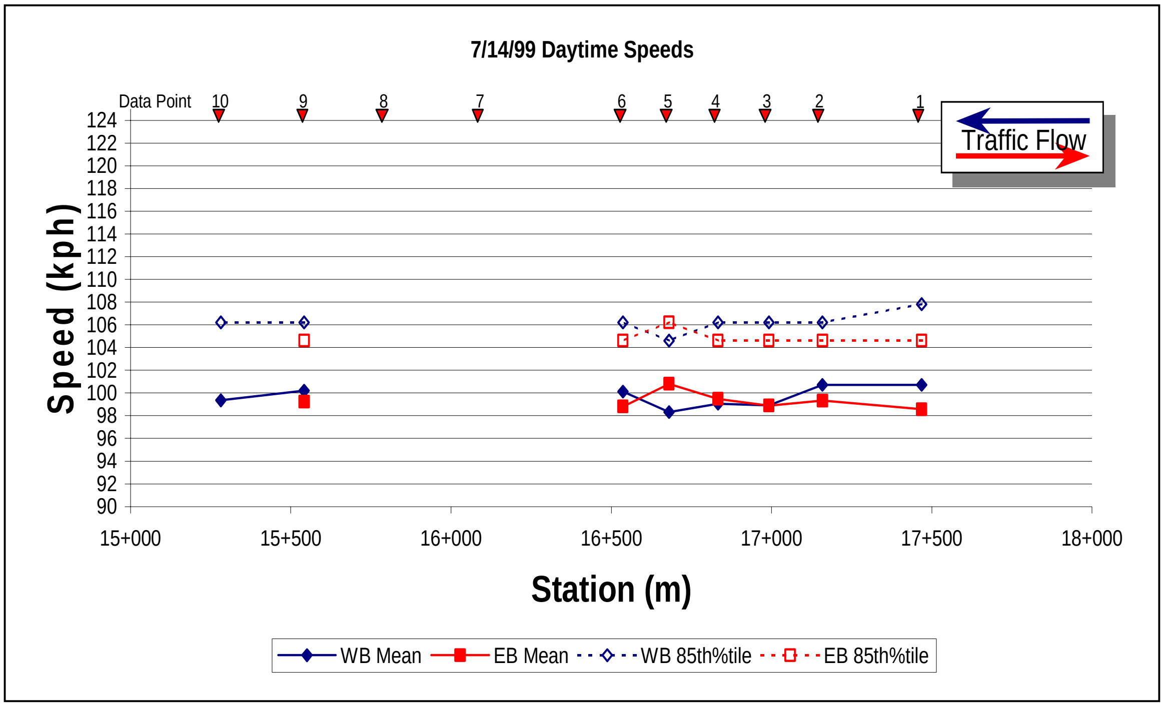
Data Point	*1*	*2*	*3*	*4*	*5*	6	7	8	9	*10*
Mean			99.6	99.6	98.7				101.2	99.5
Standard Error			0.14	0.14	0.13				0.16	0.17
Mode			99.8	99.8	96.6				99.8	99.8
Standard Deviation			7.0	6.8	6.4				7.4	7.0
85th%tile Speed			107.8	107.8	104.6				109.4	106.2
Minimum			64.4	64.4	57.9				74.0	49.9
Maximum			133.6	133.6	127.1				128.7	133.6
Count			2546	2523	2499				2269	1658

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	*1*	*2*	*3*	*4*	*5*	6	7	8	9	*10*
Mean					100.5	98.3	98.5	99.1	98.5	
Standard Error					0.14	0.14	0.14	0.14	0.13	
Mode					99.8	96.6	96.6	96.6	96.6	
Standard Deviation					6.2	6.0	6.1	6.0	6.0	
85th%tile Speed					106.2	104.6	104.6	104.6	104.6	106.2
Minimum					62.8	54.7	49.9	67.6	72.4	
Maximum					144.8	140.0	130.4	125.5	122.3	
Count					2072	1864	1820	1817	2110	

*All values except "Count" are in kilometers per hour (kph).



7/14/1999 Daytime (Wednesday)

WB

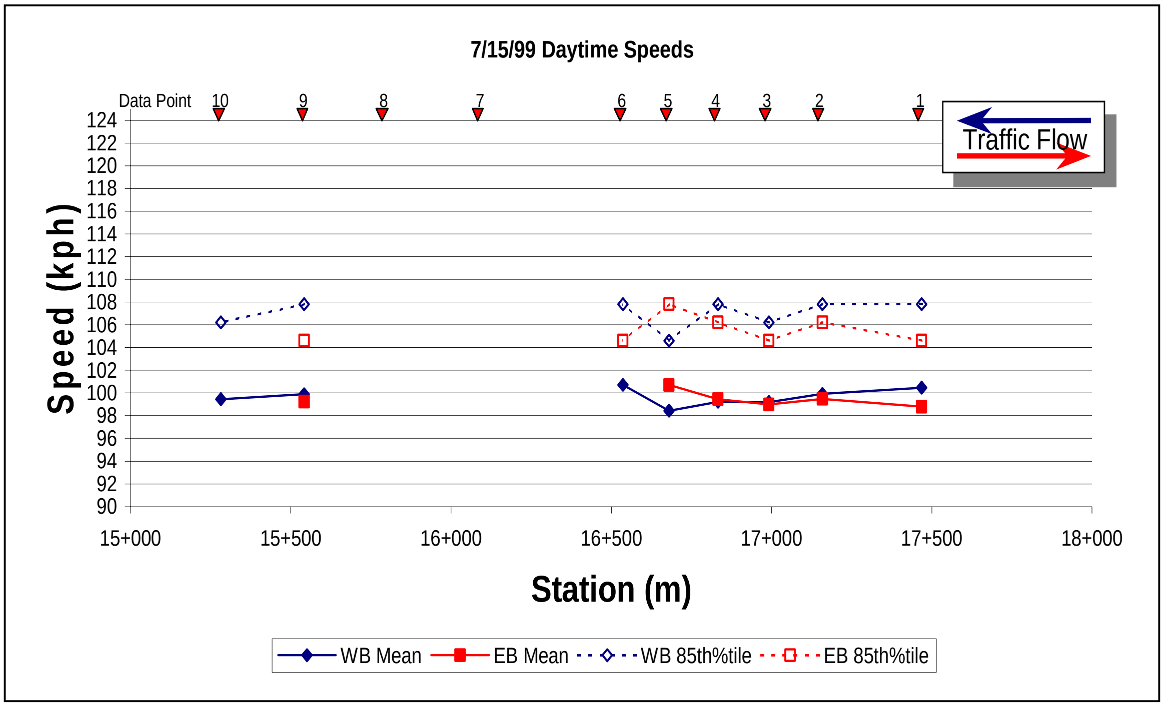
Data Point	1	2	3	4	5	6	7	8	9	10
Mean	100.7	99.7	98.9	99.1	98.3	100.1			100.2	99.4
Standard Error	0.21	0.14	0.14	0.14	0.14	0.16			0.13	0.19
Mode	99.8	99.8	96.6	96.6	96.6	99.8			99.8	99.8
Standard Deviation	8.9	7.2	7.0	7.0	6.7	7.1			6.3	7.9
85th%tile Speed	107.8	106.2	106.2	106.2	104.6	106.2			106.2	106.2
Minimum	45.1	48.3	49.9	40.2	53.1	61.2			75.6	45.1
Maximum	160.9	125.5	125.5	127.1	125.5	170.6			127.1	133.6
Count	1882	2493	2459	2434	2432	1952			2249	1725

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	98.6	99.3	98.9	99.5	100.8	98.8			99.2	
Standard Error	0.13	0.13	0.13	0.13	0.13	0.13			0.12	
Mode	96.6	96.6	96.6	96.6	99.8	96.6			96.6	
Standard Deviation	5.5	5.7	5.6	5.7	6.0	5.7			5.7	
85th%tile Speed	104.6	104.6	104.6	104.6	106.2	104.6			104.6	
Minimum	66.0	64.4	66.0	61.2	51.5	57.9			64.4	
Maximum	130.4	133.6	133.6	130.4	127.1	133.6			136.8	
Count	1914	1943	1947	1977	2007	2010			2125	

*All values except "Count" are in kilometers per hour (kph).



7/15/1999 Daytime (Thursday)
WB

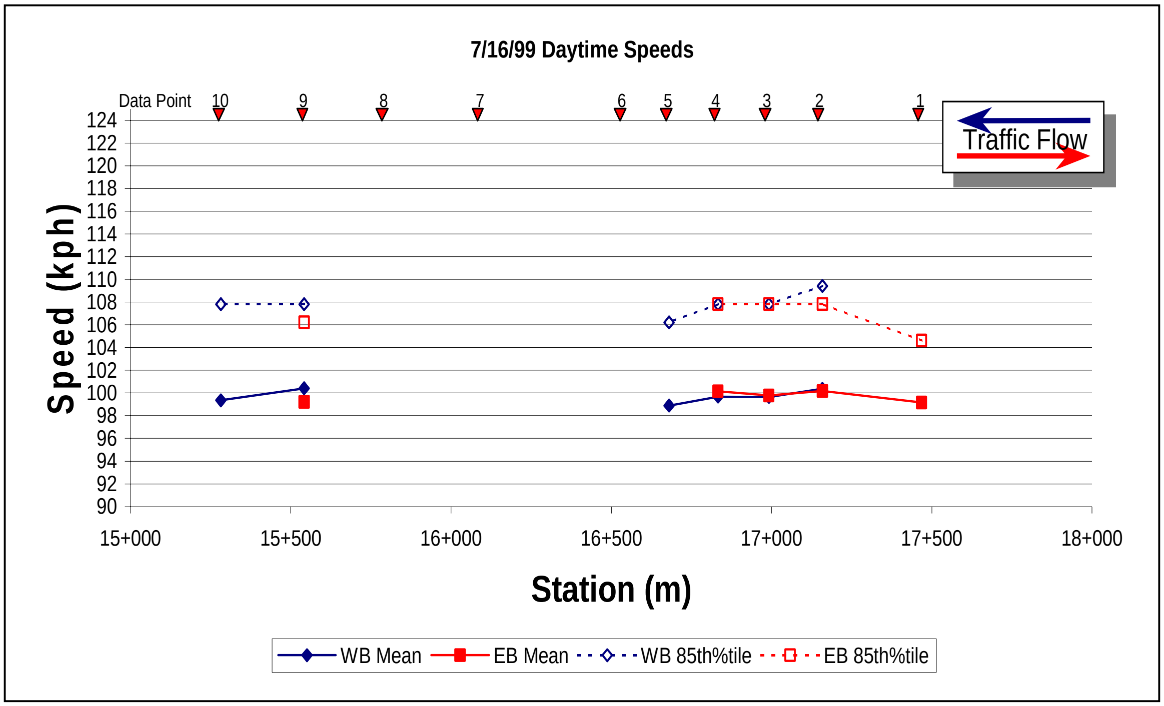
Data Point	1	2	3	4	5	6	7	8	9	10
Mean	100.5	99.9	99.2	99.2	98.4	100.7			99.9	99.4
Standard Error	0.18	0.13	0.13	0.13	0.12	0.19			0.13	0.18
Mode	99.8	99.8	99.8	99.8	99.8	99.8			99.8	99.8
Standard Deviation	8.1	6.7	6.5	6.5	6.2	6.7			6.1	7.8
85th%tile Speed	107.8	107.8	106.2	107.8	104.6	107.8			107.8	106.2
Minimum	57.9	74.0	72.4	64.4	72.4	64.4			72.4	43.5
Maximum	175.4	164.2	127.1	127.1	127.1	140.0			127.1	201.2
Count	2062	2596	2558	2533	2538	1228			2322	1868

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	98.8	99.5	99.0	99.5	100.7	98.7			99.2	
Standard Error	0.13	0.13	0.13	0.13	0.13	0.13			0.13	
Mode	99.8	99.8	99.8	99.8	99.8	99.8			99.8	
Standard Deviation	5.8	5.8	5.8	5.9	6.1	5.8			5.9	
85th%tile Speed	104.6	106.2	104.6	106.2	107.8	104.6			104.6	
Minimum	77.2	80.5	77.2	66.0	74.0	77.2			74.0	
Maximum	127.1	127.1	127.1	122.3	127.1	127.1			127.1	
Count	1959	2008	2004	2020	2031	2033			2135	

*All values except "Count" are in kilometers per hour (kph).



7/16/1999 Daytime (Friday)

WB

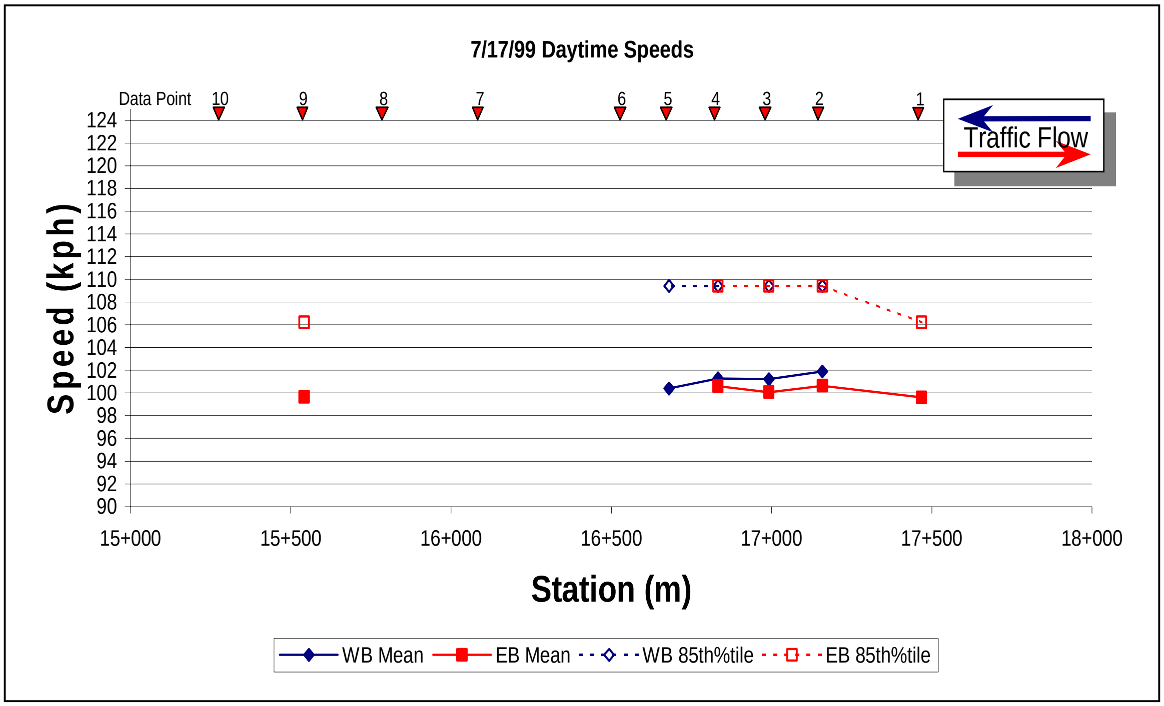
Data Point	1	2	3	4	5	6	7	8	9	10
Mean		100.4	99.7	99.7	98.9				100.4	99.4
Standard Error		0.15	0.15	0.15	0.15				0.15	0.18
Mode		99.8	99.8	99.8	99.8				99.8	99.8
Standard Deviation		7.8	7.5	7.5	7.3				7.3	7.9
85th%tile Speed		109.4	107.8	107.8	106.2				107.8	107.8
Minimum		62.8	72.4	75.6	74.0				75.6	48.3
Maximum		140.0	128.7	140.0	140.0				140.0	140.0
Count		2590	2546	2523	2505				2333	2059

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	99.1	100.2	99.8	100.1					99.2	
Standard Error	0.14	0.14	0.14	0.14					0.14	
Mode	99.8	99.8	99.8	99.8					99.8	
Standard Deviation	6.3	6.5	6.4	6.5					6.7	
85th%tile Speed	104.6	107.8	107.8	107.8					106.2	
Minimum	62.8	66.0	66.0	67.6					57.9	
Maximum	127.1	128.7	140.0	140.0					140.0	
Count	2063	2096	2122	2123					2240	

*All values except "Count" are in kilometers per hour (kph).



7/17/1999 Daytime (Saturday)

WB

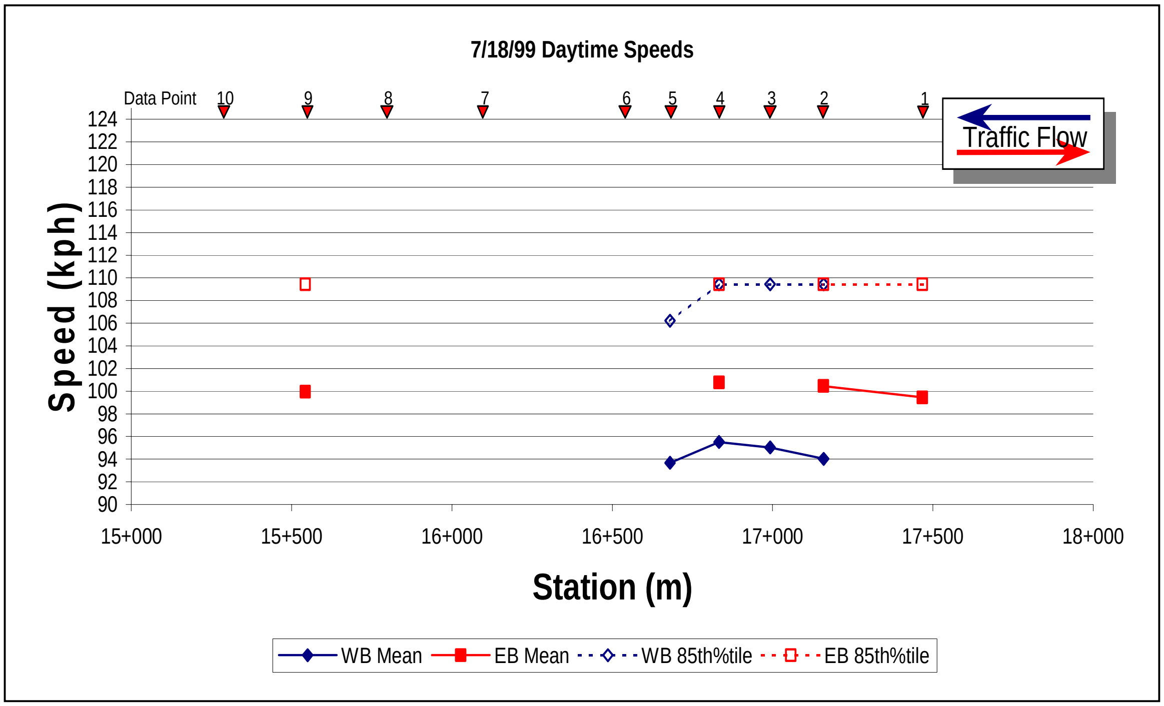
Data Point	1	2	3	4	5	6	7	8	9	10
Mean		101.9	101.2	101.3	100.4					
Standard Error		0.17	0.17	0.16	0.17					
Mode		99.8	99.8	99.8	99.8					
Standard Deviation		8.5	8.4	8.1	8.1					
85th%tile Speed		109.4	109.4	109.4	109.4					
Minimum		56.3	77.2	74.0	67.6					
Maximum		140.0	140.0	140.0	140.0					
Count		2523	2475	2432	2403					

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	99.6	100.6	100.1	100.6					99.7	
Standard Error	0.15	0.15	0.15	0.16					0.15	
Mode	99.8	99.8	99.8	99.8					99.8	
Standard Deviation	6.7	6.8	6.8	7.1					7.0	
85th%tile Speed	106.2	109.4	109.4	109.4					106.2	
Minimum	70.8	82.1	77.2	77.2					64.4	
Maximum	128.7	128.7	117.5	128.7					128.7	
Count	1969	2012	1981	2004					2092	

*All values except "Count" are in kilometers per hour (kph).



7/18/1999 Daytime **(Sunday)**

WB

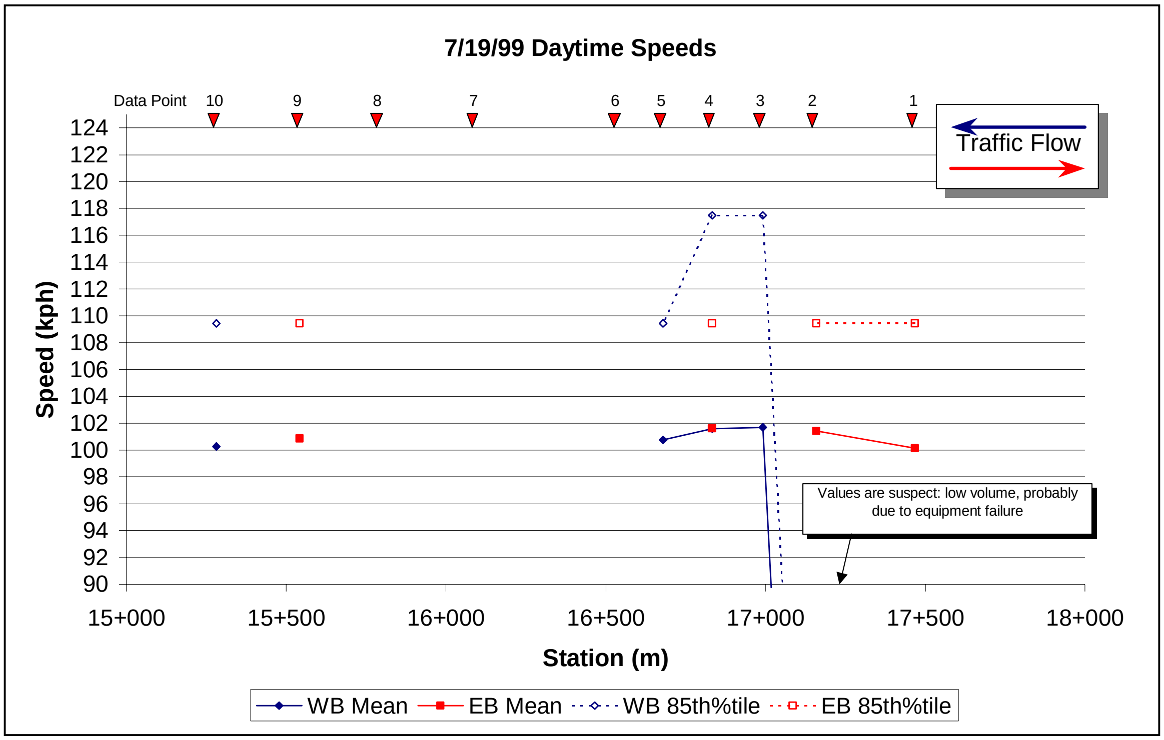
Data Point	1	2	3	4	5	6	7	8	9	10
Mean		94.0	95.0	95.5	93.7					
Standard Error		0.48	0.38	0.40	0.43					
Mode		99.8	99.8	99.8	99.8					
Standard Deviation		21.7	17.9	17.8	19.2					
85th%tile Speed		109.4	109.4	109.4	106.2					
Minimum		16.1	17.7	17.7	17.7					
Maximum		140.0	128.7	175.4	175.4					
Count		2075	2174	1979	1949					

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	99.4	100.5		100.8					100.0	
Standard Error	0.18	0.20		0.19					0.18	
Mode	99.8	99.8		99.8					99.8	
Standard Deviation	7.7	8.3		8.2					8.0	
85th%tile Speed	109.4	109.4		109.4					109.4	
Minimum	67.6	49.9		72.4					74.0	
Maximum	128.7	140.0		140.0					128.7	
Count	1759	1771		1799					1892	

*All values except "Count" are in kilometers per hour (kph).



7/19/1999 Daytime (Monday)

WB

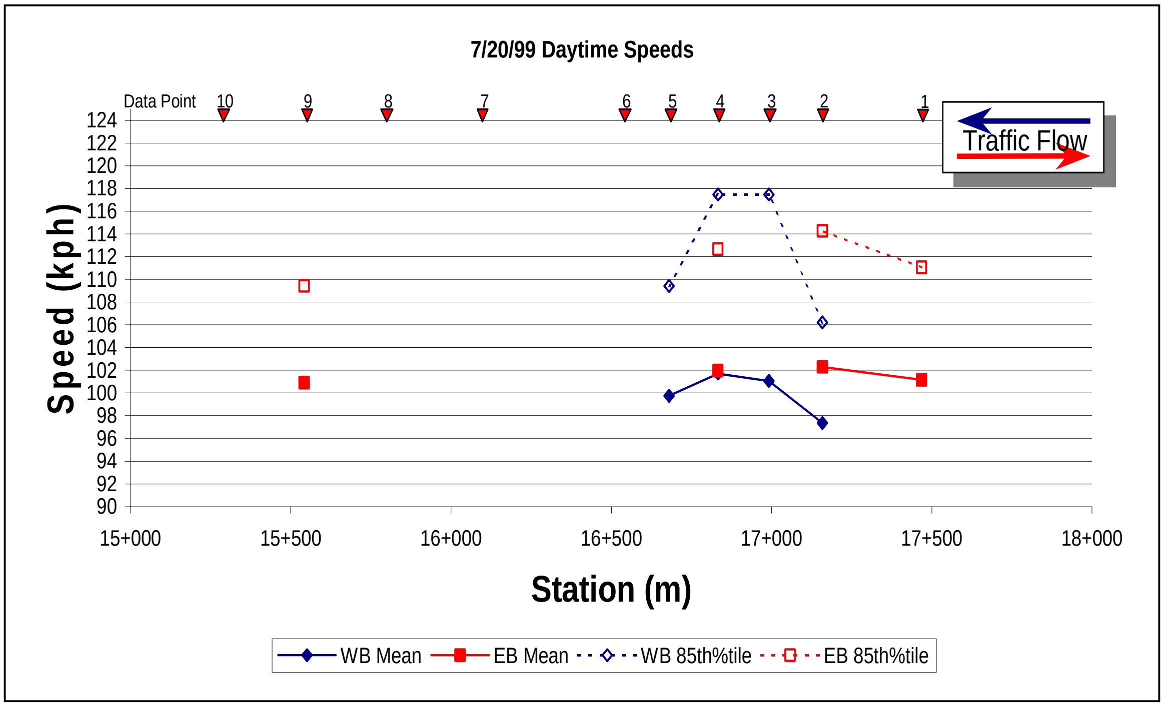
Data Point	*1*	*2*	*3*	*4*	*5*	6	7	8	9	*10*
Mean		25.5	101.7	101.6	100.7					100.3
Standard Error		0.61	0.20	0.20	0.20					0.27
Mode		17.7	103.0	103.0	103.0					99.8
Standard Deviation		9.9	9.5	9.4	9.3					9.9
85th%tile Speed		41.8	117.5	117.5	109.4					109.4
Minimum		16.1	70.8	57.9	70.8					57.9
Maximum		54.7	146.5	146.5	146.5					175.4
Count		262	2292	2293	2253					1367

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	*1*	*2*	*3*	*4*	5	6	7	8	9	*10*
Mean	100.1	101.4		101.6					100.9	
Standard Error	0.19	0.19		0.19					0.19	
Mode	99.8	99.8		99.8					99.8	
Standard Deviation	8.3	8.1		8.3					8.6	
85th%tile Speed	109.4	109.4		109.4					109.4	
Minimum	46.7	70.8		77.2					70.8	
Maximum	175.4	146.5		175.4					146.5	
Count	1854	1888		1915					2028	

*All values except "Count" are in kilometers per hour (kph).



7/20/1999 Daytime (Tuesday)
WB

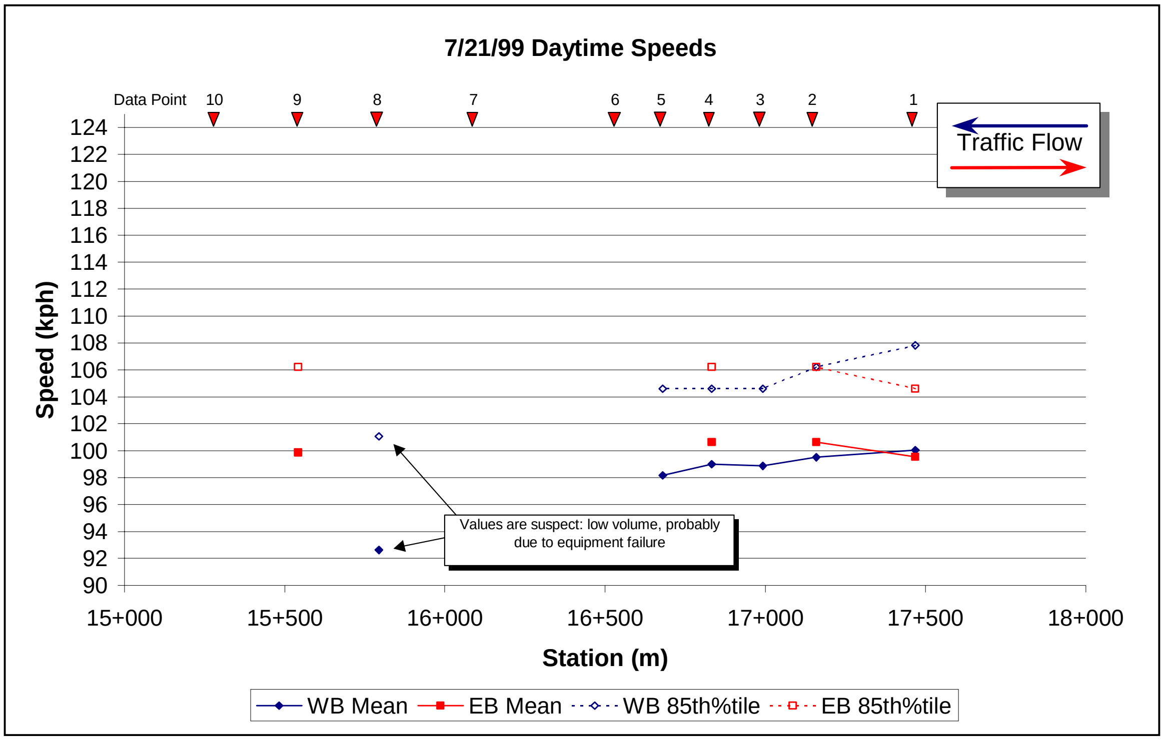
Data Point	*1*	*2*	*3*	*4*	5	6	7	8	9	*10*
Mean		97.4	101.0	101.7	99.7					
Standard Error		0.37	0.34	0.54	0.32					
Mode		99.8	103.0	103.0	103.0					
Standard Deviation		14.4	10.6	10.8	10.4					
85th%tile Speed		106.2	117.5	117.5	109.4					
Minimum		16.1	70.8	62.8	57.9					
Maximum		138.4	146.5	117.5	175.4					
Count		1501	964	401	1047					

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	*1*	*2*	*3*	*4*	5	6	7	8	9	*10*
Mean	101.2	102.3		102.0					100.9	
Standard Error	0.24	0.21		0.23					0.21	
Mode	103.0	103.0		103.0					103.0	
Standard Deviation	9.3	8.9		9.7					9.1	
85th%tile Speed	111.0	114.3		112.7					109.4	
Minimum	0.0	75.6		0.0					0.0	
Maximum	146.5	146.5		146.5					125.5	
Count	1487	1796		1821					1914	

*All values except "Count" are in kilometers per hour (kph).



7/21/1999 Daytime (Wednesday)
WB

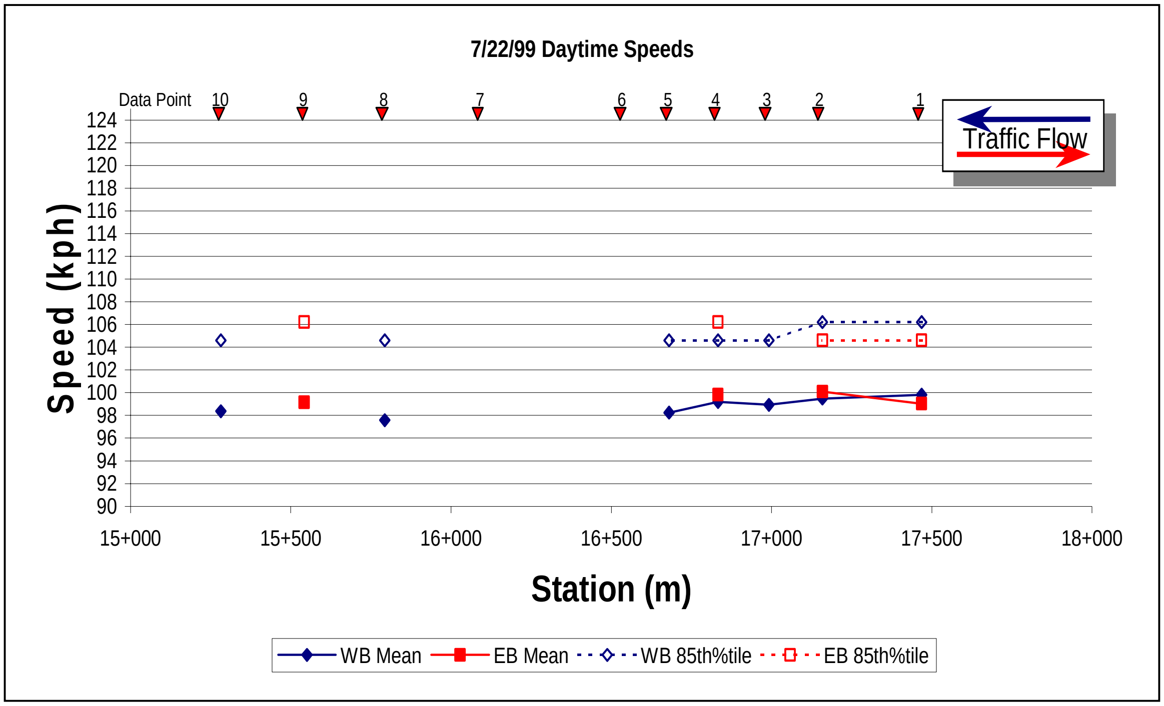
Data Point	1	2	3	4	5	6	7	8	9	10
Mean	100.0	99.5	98.9	99.0	98.2			92.6		
Standard Error	0.19	0.13	0.13	0.14	0.13			0.61		
Mode	99.8	99.8	99.8	96.6	96.6			99.8		
Standard Deviation	7.7	6.7	6.6	6.7	6.3			11.1		
85th%tile Speed	107.8	106.2	104.6	104.6	104.6			101.1		
Minimum	54.7	54.7	56.3	61.2	66.0			38.6		
Maximum	140.0	133.6	130.4	133.6	133.6			117.5		
Count	1652	2460	2430	2415	2396			329		

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	99.5	100.6		100.6					99.9	
Standard Error	0.14	0.13		0.13					0.13	
Mode	99.8	99.8		99.8					96.6	
Standard Deviation	6.0	6.0		6.0					5.9	
85th%tile Speed	104.6	106.2		106.2					106.2	
Minimum	82.1	80.5		78.9					75.6	
Maximum	133.6	140.0		133.6					125.5	
Count	1927	1962		2002					2108	

*All values except "Count" are in kilometers per hour (kph).



7/22/1999 Daytime (Thursday)
WB

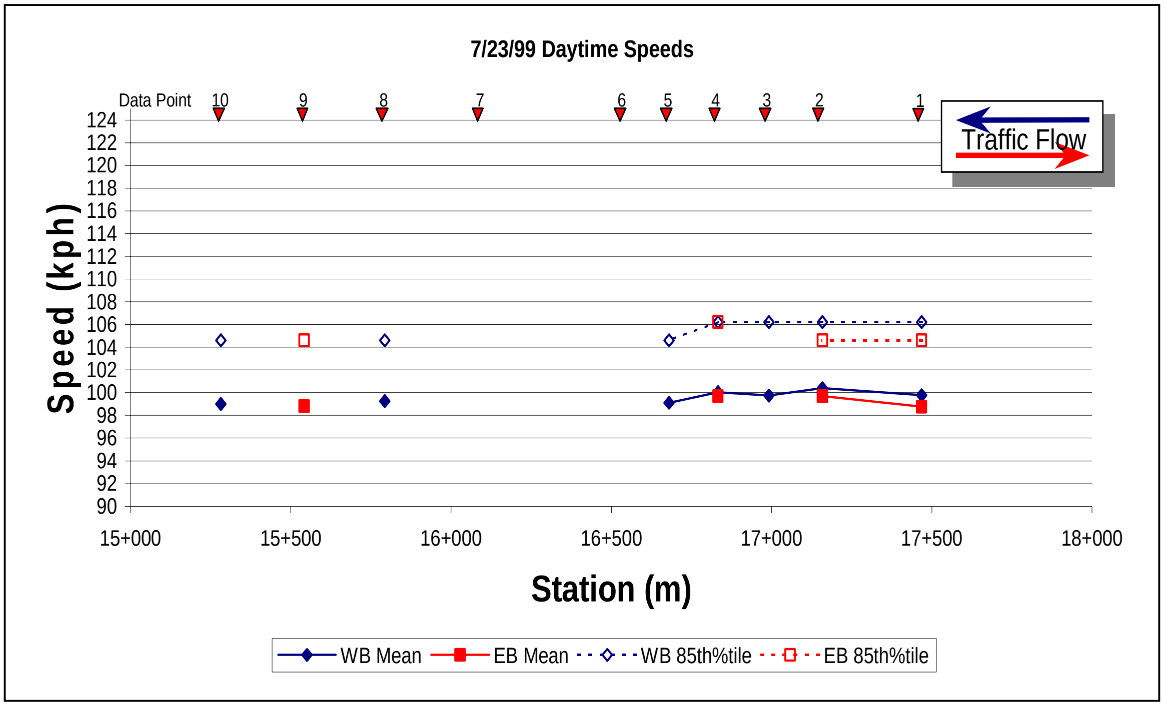
Data Point	1	2	3	4	5	6	7	8	9	10
Mean	99.8	99.5	98.9	99.2	98.2			97.6		98.4
Standard Error	0.20	0.14	0.13	0.13	0.14			0.20		0.21
Mode	99.8	99.8	96.6	96.6	96.6			96.6		98.2
Standard Deviation	8.1	7.1	6.6	6.6	6.6			8.0		7.1
85th%tile Speed	106.2	106.2	104.6	104.6	104.6			104.6		104.6
Minimum	0.0	0.0	0.0	0.0	0.0			0.0		43.5
Maximum	201.2	133.6	132.0	127.1	125.5			122.3		130.4
Count	1605	2508	2468	2458	2401			1580		1113

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	99.0	100.1		99.8					99.2	
Standard Error	0.13	0.12		0.13					0.13	
Mode	99.8	99.8		99.8					99.8	
Standard Deviation	5.7	5.4		6.0					6.2	
85th%tile Speed	104.6	104.6		106.2					106.2	
Minimum	66.0	66.0		51.5					54.7	
Maximum	122.3	125.5		127.1					127.1	
Count	1937	1944		1987					2146	

*All values except "Count" are in kilometers per hour (kph).



7/23/1999 Daytime **(Friday)**
WB

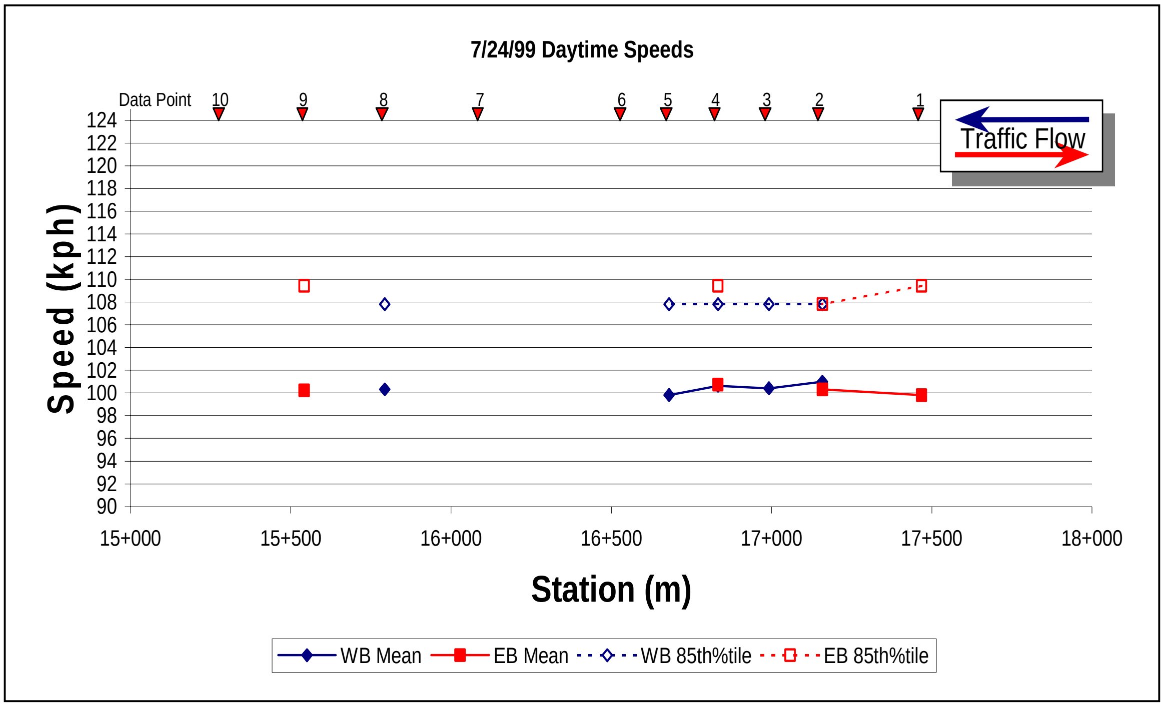
Data Point	***1***	***2***	***3***	***4***	***5***	***6***	***7***	**8**	**9**	***10***
Mean	99.8	100.4	99.7	100.0	99.1			99.3		99.0
Standard Error	0.22	0.14	0.14	0.14	0.13			0.14		0.18
Mode	99.8	96.6	96.6	96.6	96.6			96.6		99.8
Standard Deviation	7.9	6.8	6.7	6.7	6.5			6.3		7.4
85th%tile Speed	106.2	106.2	106.2	106.2	104.6			104.6		104.6
Minimum	54.7	61.2	69.2	75.6	74.0			54.7		48.3
Maximum	144.8	133.6	133.6	133.6	133.6			122.3		140.0
Count	1334	2451	2409	2386	2375			2063		1629

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	***1***	***2***	***3***	***4***	**5**	**6**	**7**	**8**	**9**	***10***
Mean	98.8	99.7		99.7					98.8	
Standard Error	0.14	0.13		0.14					0.14	
Mode	99.8	99.8		99.8					99.8	
Standard Deviation	6.1	5.7		6.3					6.7	
85th%tile Speed	104.6	104.6		106.2					104.6	
Minimum	67.6	74.0		74.0					56.3	
Maximum	127.1	127.1		140.0					127.1	
Count	1925	1941		1997					2136	

*All values except "Count" are in kilometers per hour (kph).



7/24/1999 Daytime (Saturday)

WB

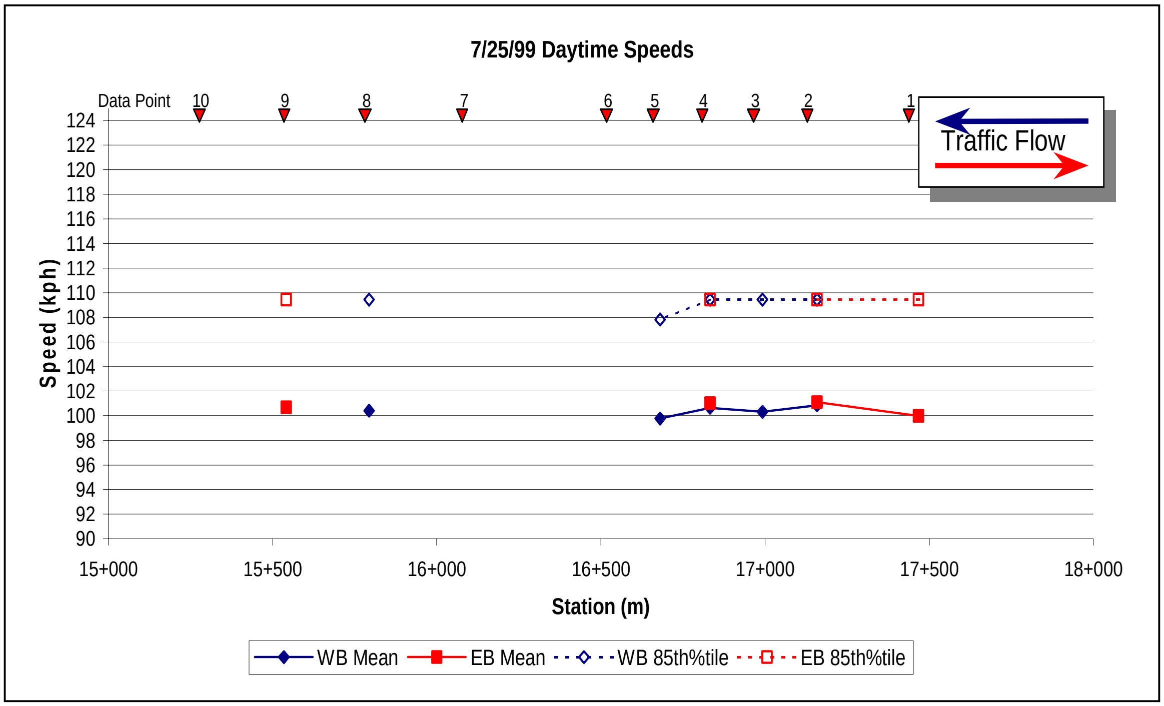
Data Point	***1***	***2***	***3***	***4***	***5***	**6**	**7**	**8**	**9**	***10***
Mean		101.0	100.4	100.6	99.8			100.3		
Standard Error		0.14	0.14	0.14	0.13			0.13		
Mode		99.8	99.8	99.8	99.8			99.8		
Standard Deviation		7.0	6.8	6.9	6.6			6.5		
85th%tile Speed		107.8	107.8	107.8	107.8			107.8		
Minimum		62.8	69.2	57.9	74.0			77.2		
Maximum		140.0	140.0	148.1	140.0			140.0		
Count		2544	2507	2493	2476			2301		

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	***1***	***2***	***3***	***4***	**5**	**6**	**7**	**8**	**9**	***10***
Mean	99.8	100.3		100.7					100.2	
Standard Error	0.17	0.14		0.17					0.16	
Mode	99.8	99.8		99.8					99.8	
Standard Deviation	7.4	6.1		7.5					7.3	
85th%tile Speed	109.4	107.8		109.4					109.4	
Minimum	45.1	43.5		45.1					70.8	
Maximum	128.7	122.3		157.7					128.7	
Count	1897	1941		1986					2098	

*All values except "Count" are in kilometers per hour (kph).



7/25/1999 Daytime (Sunday)

WB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean		100.9	100.3	100.6	99.8			100.4		
Standard Error		0.15	0.15	0.15	0.15			0.15		
Mode		99.8	99.8	99.8	99.8			99.8		
Standard Deviation		7.7	7.6	7.6	7.4			7.3		
85th%tile Speed		109.4	109.4	109.4	107.8			109.4		
Minimum		54.7	70.8	70.8	69.2			70.8		
Maximum		140.0	146.5	128.7	140.0			140.0		
Count		2545	2506	2478	2439			2321		

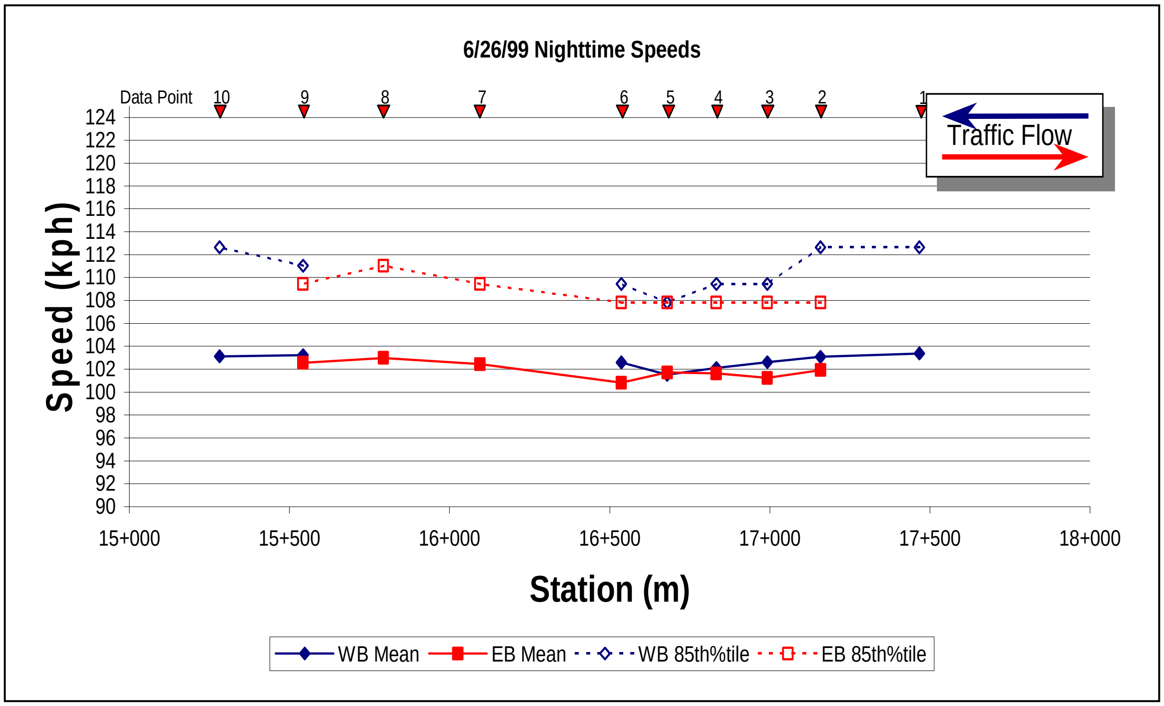
*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	100.0	101.1		101.0					100.7	
Standard Error	0.16	0.17		0.17					0.16	
Mode	99.8	99.8		99.8					99.8	
Standard Deviation	7.0	7.2		7.5					7.4	
85th%tile Speed	109.4	109.4		109.4					109.4	
Minimum	74.0	72.4		46.7					70.8	
Maximum	128.7	140.0		128.7					140.0	
Count	1863	1895		1910					2054	

*All values except "Count" are in kilometers per hour (kph).

APPENDIX G: DATA POINT COMPARISONS, NIGHTTIME



6/26/99 Nighttime (Saturday)

WB

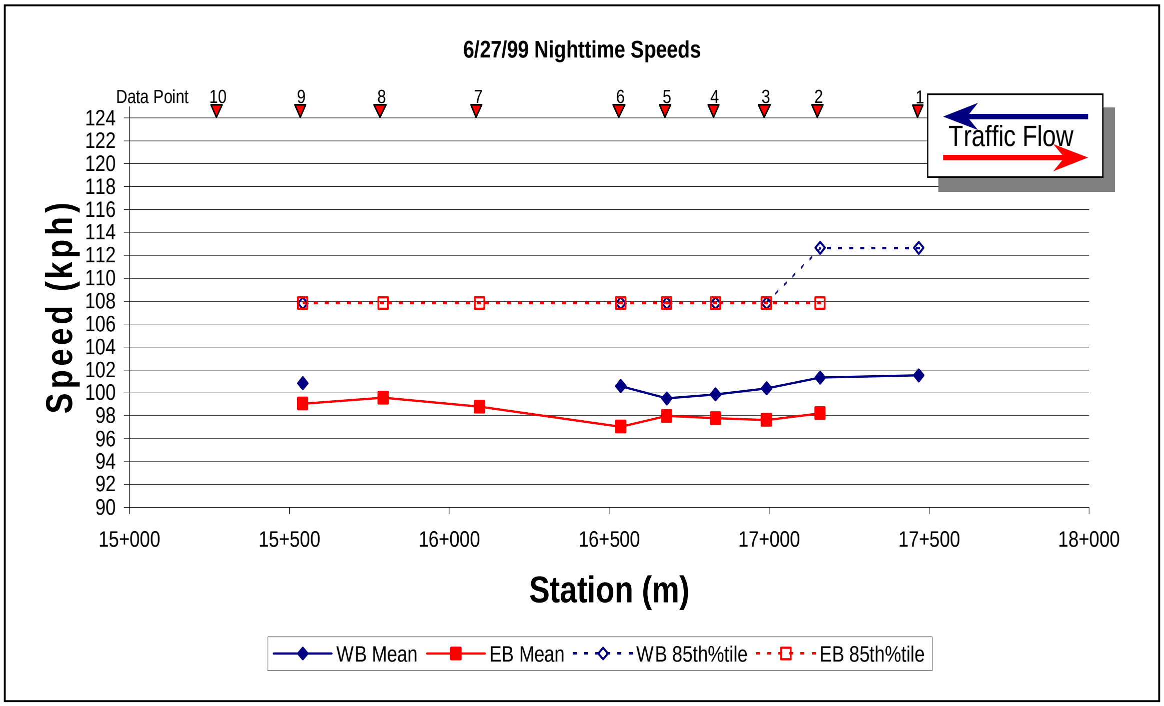
Data Point	1	2	3	4	5	6	7	8	9	10
Mean	103.4	103.1	102.6	102.1	101.5	102.6			103.2	103.1
Standard Error	0.22	0.22	0.22	0.23	0.22	0.22			0.23	0.24
Mode	99.8	99.8	99.8	99.8	99.8	99.8			99.8	99.8
Standard Deviation	8.2	8.2	8.1	8.2	8.0	8.1			8.0	8.2
85th%tile Speed	112.7	112.7	109.4	109.4	107.8	109.4			111.0	112.7
Minimum	70.8	70.8	70.8	67.6	67.6	69.2			77.2	77.2
Maximum	140.0	136.8	140.0	140.0	133.6	133.6			140.0	159.3
Count	1355	1324	1315	1285	1284	1285			1235	1222

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean		101.9	101.2	101.6	101.7	100.8	102.4	103.0	102.6	
Standard Error		0.23	0.23	0.24	0.23	0.23	0.23	0.23	0.23	
Mode		99.8	99.8	99.8	99.8	99.8	99.8	99.8	99.8	
Standard Deviation		7.4	7.3	7.7	7.6	7.5	7.6	7.7	7.6	
85th%tile Speed		107.8	107.8	107.8	107.8	107.8	109.4	111.0	109.4	
Minimum		77.2	75.6	75.6	77.2	77.2	78.9	80.5	75.6	
Maximum		130.4	127.1	130.4	133.6	133.6	133.6	136.8	136.8	
Count		1057	1060	1060	1076	1086	1103	1106	1115	

*All values except "Count" are in kilometers per hour (kph).



6/27/99 Nighttime **(Sunday)**

WB

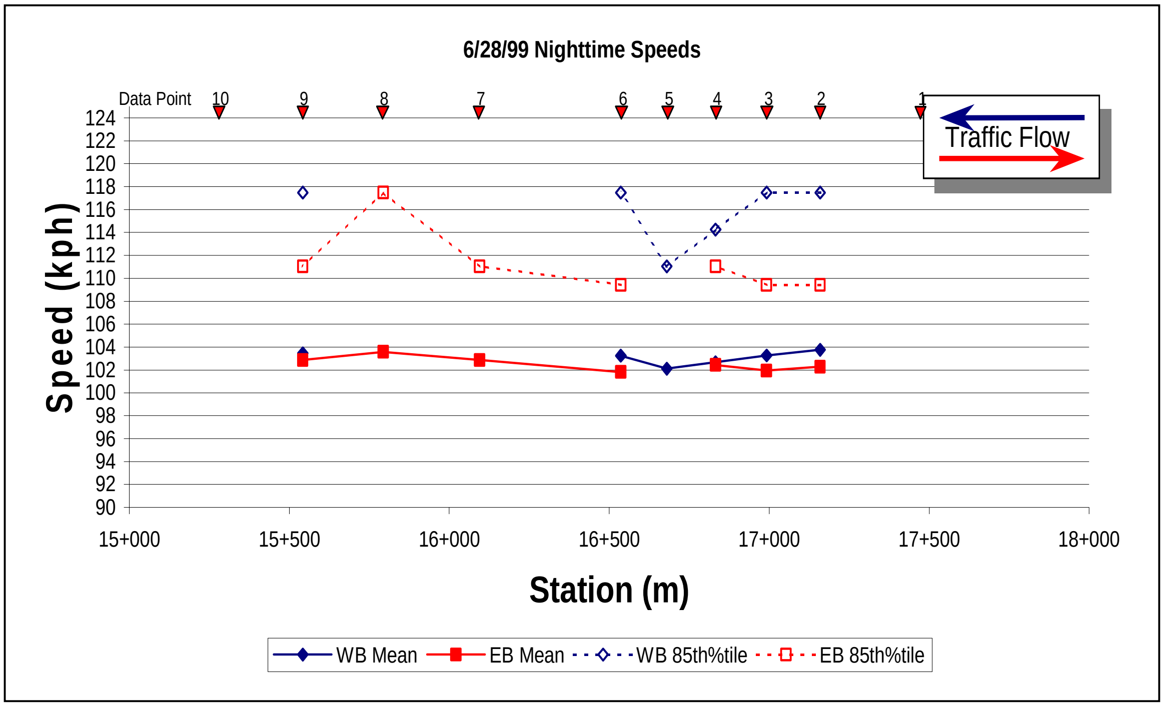
Data Point	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	***10***
Mean	101.5	101.3	100.4	99.9	99.5	100.6			100.8	
Standard Error	0.33	0.32	0.31	0.31	0.30	0.31			0.32	
Mode	99.8	99.8	99.8	99.8	99.8	99.8			99.8	
Standard Deviation	11.3	10.9	10.7	10.5	10.3	10.5			10.7	
85th%tile Speed	112.7	112.7	107.8	107.8	107.8	107.8			107.8	
Minimum	48.3	53.1	41.8	51.5	51.5	56.3			54.7	
Maximum	140.0	140.0	140.0	140.0	140.0	140.0			140.0	
Count	1202	1179	1168	1162	1156	1158			1137	

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Mean		98.2	97.6	97.8	98.0	97.1	98.8	99.6	99.1	
Standard Error		0.30	0.30	0.30	0.30	0.29	0.29	0.28	0.28	
Mode		99.8	99.8	99.8	99.8	99.8	99.8	99.8	99.8	
Standard Deviation		10.0	10.0	10.1	10.3	10.0	10.0	9.8	9.6	
85th%tile Speed		107.8	107.8	107.8	107.8	107.8	107.8	107.8	107.8	
Minimum		54.7	56.3	53.1	46.7	45.1	54.7	57.9	57.9	
Maximum		133.6	140.0	133.6	140.0	140.0	133.6	133.6	127.1	
Count		1131	1138	1145	1157	1163	1178	1184	1192	

*All values except "Count" are in kilometers per hour (kph).



6/28/99 Nighttime **(Monday)**

WB

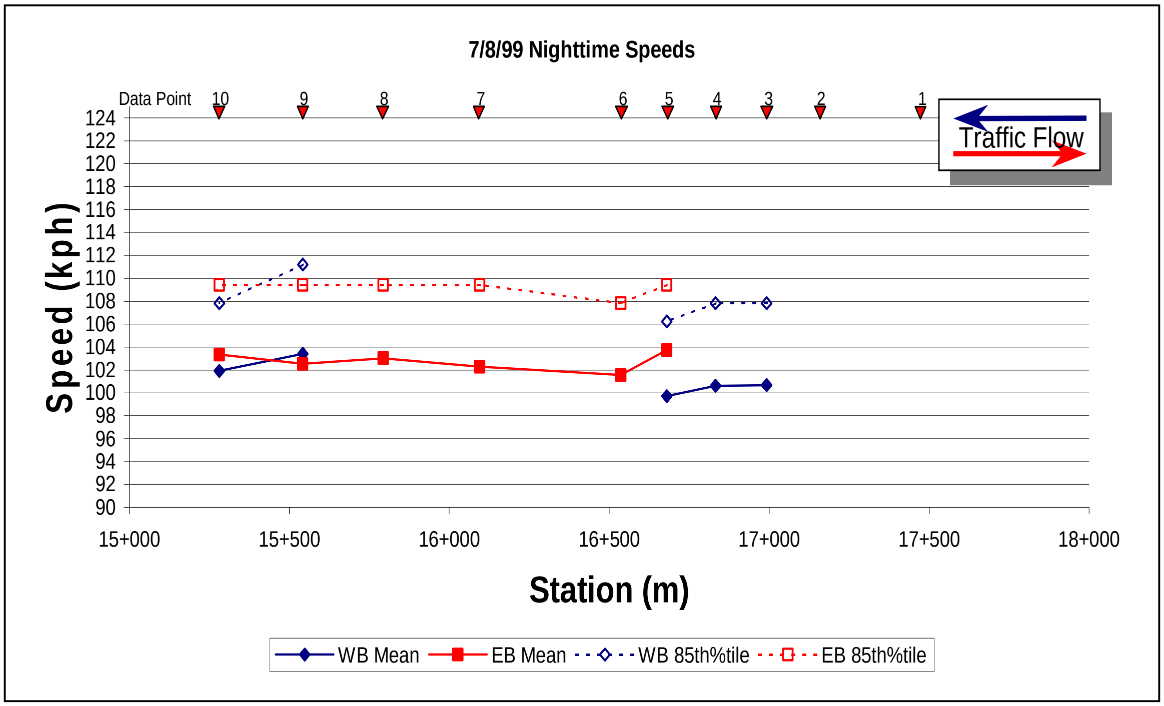
Data Point	1	2	3	4	5	6	7	8	9	10
Mean		103.7	103.3	102.7	102.1	103.2			103.5	
Standard Error		0.26	0.26	0.26	0.25	0.27			0.27	
Mode		99.8	99.8	99.8	99.8	99.8			99.8	
Standard Deviation		9.0	9.0	8.8	8.5	8.9			8.7	
85th%tile Speed		117.5	117.5	114.3	111.0	117.5			117.5	
Minimum		74.0	77.2	77.2	80.5	77.2			70.8	
Maximum		128.7	140.0	140.0	140.0	140.0			140.0	
Count		1170	1157	1143	1136	1129			1085	

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean		102.3	101.9	102.4		101.8	102.9	103.6	102.9	
Standard Error		0.25	0.25	0.26		0.26	0.26	0.27	0.26	
Mode		99.8	99.8	99.8		99.8	99.8	99.8	99.8	
Standard Deviation		7.8	8.0	8.1		8.3	8.5	8.9	8.7	
85th%tile Speed		109.4	109.4	111.0		109.4	111.0	117.5	111.0	
Minimum		77.2	72.4	70.8		74.0	61.2	57.9	64.4	
Maximum		140.0	140.0	140.0		140.0	140.0	140.0	140.0	
Count		1007	1008	1017		1022	1040	1053	1071	

*All values except "Count" are in kilometers per hour (kph).



7/8/99 Nighttime (Thursday)

WB

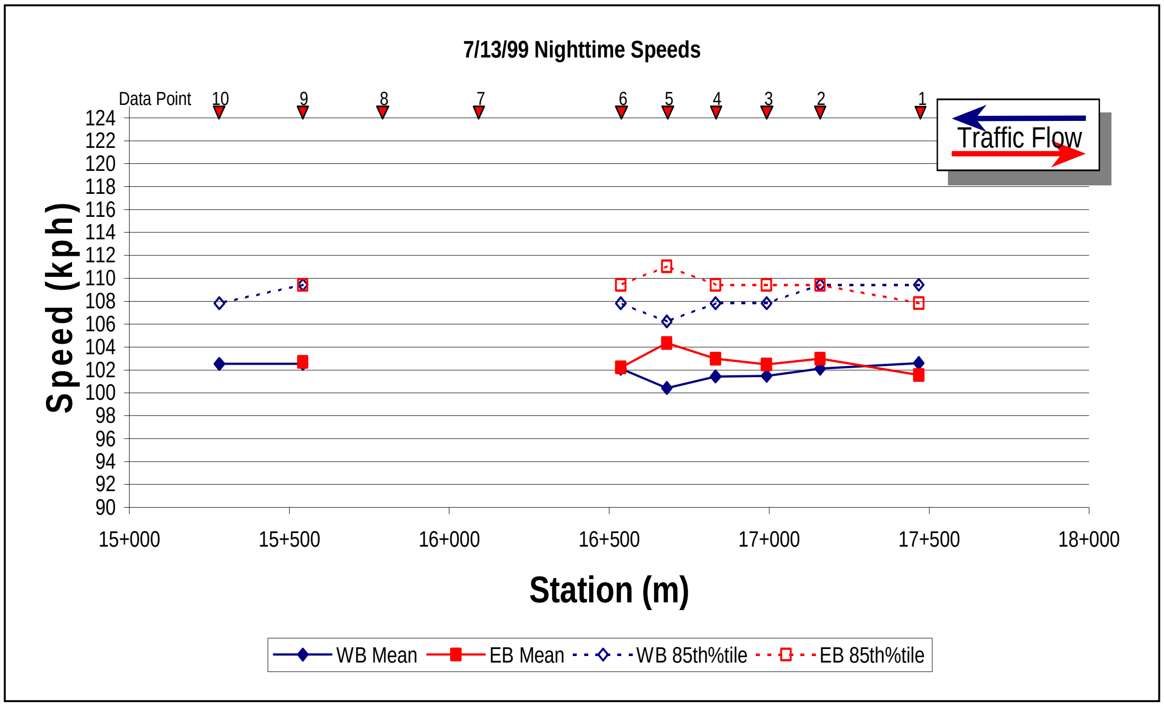
Data Point	1	2	3	4	5	6	7	8	9	10
Mean			100.7	100.6	99.7				103.4	101.9
Standard Error			0.22	0.22	0.21				0.23	0.20
Mode			99.8	99.8	99.8				99.8	101.4
Standard Deviation			7.9	7.8	7.4				8.0	7.0
85th%tile Speed			107.8	107.8	106.2				111.2	107.8
Minimum			61.2	64.4	64.4				64.4	69.2
Maximum			140.0	133.6	130.4				140.0	138.4
Count			1248	1239	1237				1247	1168

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean					103.7	101.5	102.3	103.0	102.5	103.3
Standard Error					0.22	0.21	0.22	0.21	0.20	0.20
Mode					99.8	99.8	98.2	99.8	99.8	101.4
Standard Deviation					7.2	7.1	7.2	7.0	6.9	6.8
85th%tile Speed					109.4	107.8	109.4	109.4	109.4	109.4
Minimum					67.6	66.0	66.0	69.2	67.6	67.6
Maximum					136.8	136.8	144.8	141.6	138.4	132.0
Count					1072	1083	1110	1132	1146	1133

*All values except "Count" are in kilometers per hour (kph).



7/13/99 Nighttime (Tuesday)

WB

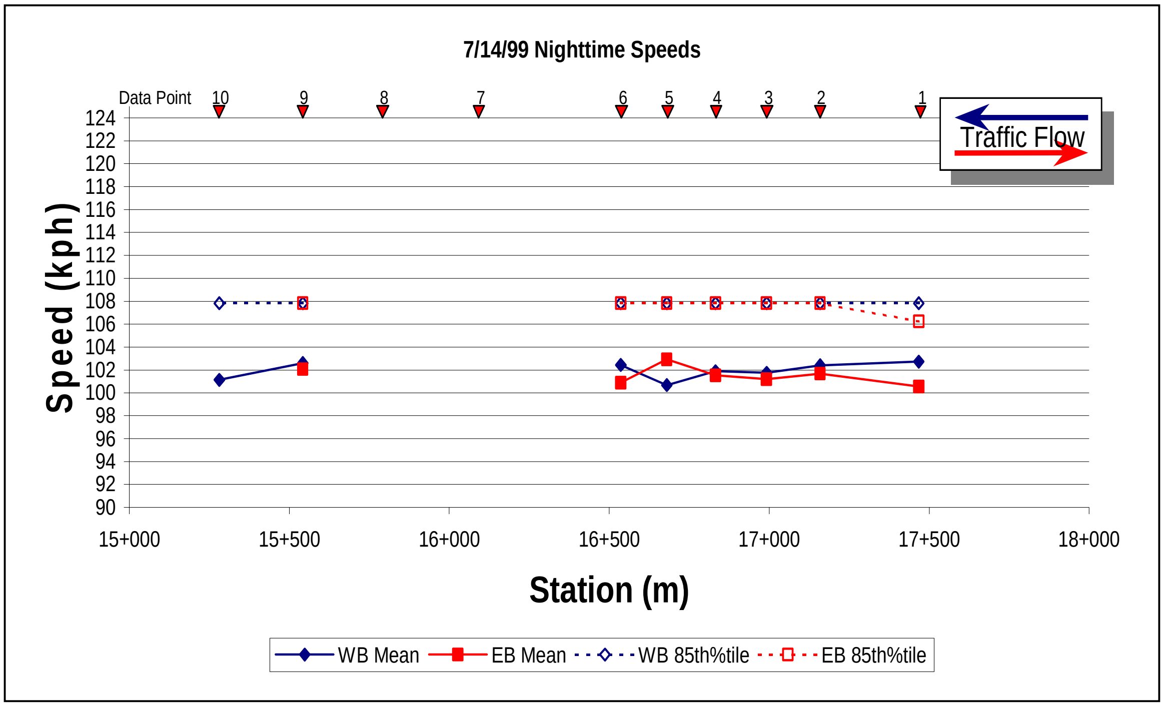
Data Point	1	2	3	4	5	6	7	8	9	10
Mean	102.6	102.1	101.5	101.4	100.4	102.1			102.5	102.0
Standard Error	0.24	0.21	0.21	0.21	0.20	0.21			0.21	0.27
Mode	99.8	99.8	99.8	98.2	98.2	99.8			99.8	99.8
Standard Deviation	7.7	7.2	7.1	7.1	7.0	7.1			7.0	7.3
85th%tile Speed	109.4	109.4	107.8	107.8	106.2	107.8			109.4	107.8
Minimum	49.9	74.0	74.0	69.2	53.1	72.4			69.2	59.5
Maximum	140.0	140.0	136.8	136.8	133.6	140.0			140.0	144.8
Count	1060	1185	1179	1166	1165	1155			1120	764

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	101.5	103.0	102.5	103.0	104.3	102.2			102.7	
Standard Error	0.23	0.24	0.23	0.24	0.25	0.24			0.23	
Mode	99.8	101.4	99.8	101.4	101.4	99.8			98.2	
Standard Deviation	7.1	7.3	7.2	7.4	7.7	7.3			7.2	
85th%tile Speed	107.8	109.4	109.4	109.4	111.0	109.4			109.4	
Minimum	77.2	82.1	83.7	82.1	83.7	80.5			78.9	
Maximum	177.0	183.5	178.6	177.0	178.6	165.8			138.4	
Count	941	949	952	951	960	955			985	

*All values except "Count" are in kilometers per hour (kph).



7/14/99 Nighttime (Wednesday)

WB

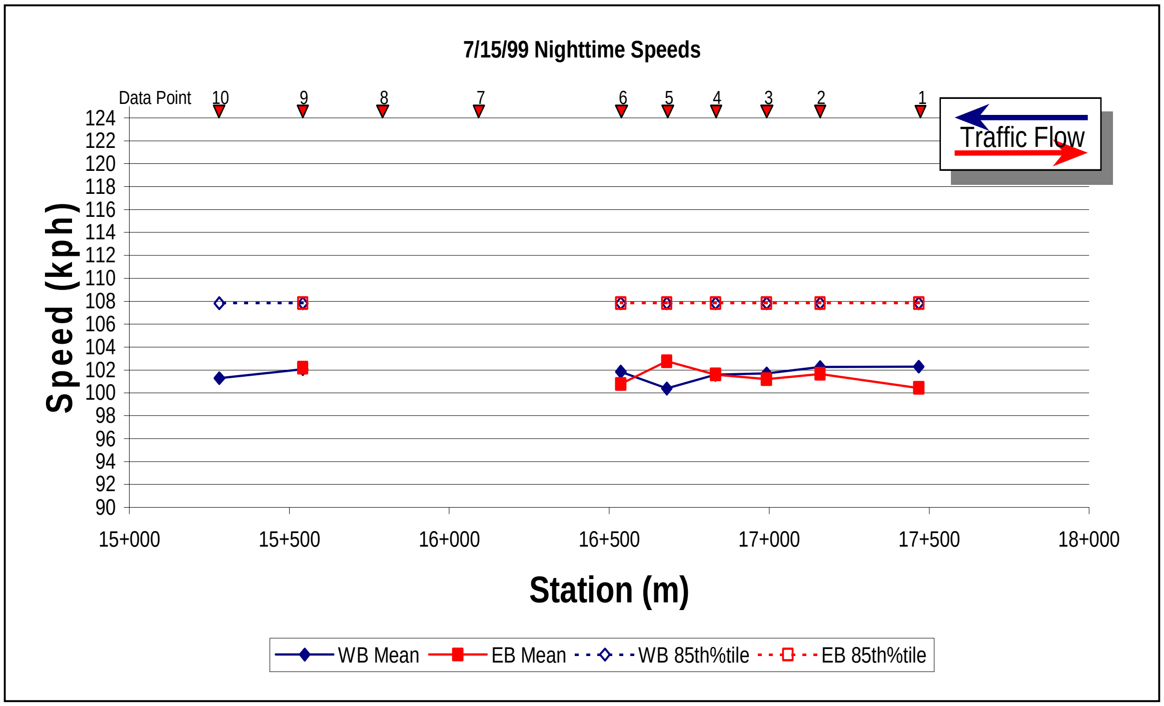
Data Point	1	2	3	4	5	6	7	8	9	10
Mean	102.7	102.4	101.8	101.9	100.7	102.4			102.6	101.1
Standard Error	0.25	0.22	0.21	0.22	0.21	0.22			0.21	0.35
Mode	99.8	99.8	99.8	99.8	99.8	99.8			99.8	99.8
Standard Deviation	8.0	7.8	7.6	7.7	7.4	7.8			7.2	9.2
85th%tile Speed	107.8	107.8	107.8	107.8	107.8	107.8			107.8	107.8
Minimum	45.1	74.0	74.0	74.0	77.2	72.4			77.2	48.3
Maximum	140.0	148.1	140.0	140.0	148.1	148.1			140.0	175.4
Count	1058	1286	1276	1268	1268	1208			1227	685

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	100.6	101.7	101.2	101.5	102.9	100.9			102.1	
Standard Error	0.23	0.22	0.22	0.22	0.23	0.22			0.22	
Mode	99.8	99.8	99.8	99.8	99.8	99.8			99.8	
Standard Deviation	7.1	7.0	7.0	7.0	7.2	6.9			7.0	
85th%tile Speed	106.2	107.8	107.8	107.8	107.8	107.8			107.8	
Minimum	72.4	72.4	70.8	70.8	69.2	69.2			74.0	
Maximum	156.1	144.8	151.3	160.9	165.8	148.1			127.1	
Count	969	983	984	983	988	993			1028	

*All values except "Count" are in kilometers per hour (kph).



7/15/99 Nighttime (Thursday)

WB

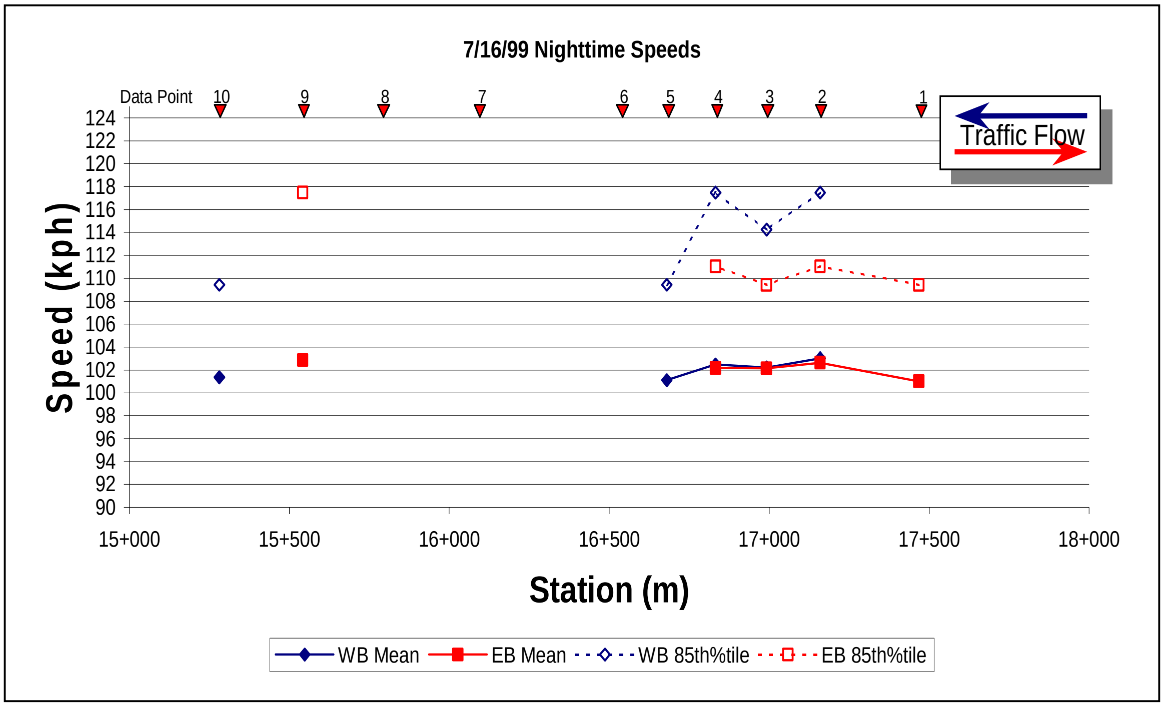
Data Point	1	2	3	4	5	6	7	8	9	10
Mean	102.3	102.3	101.7	101.6	100.4	101.8			102.1	101.3
Standard Error	0.27	0.22	0.22	0.22	0.21	0.21			0.21	0.26
Mode	99.8	99.8	99.8	99.8	99.8	99.8			99.8	99.8
Standard Deviation	8.4	7.7	7.7	7.7	7.5	7.6			7.1	7.3
85th%tile Speed	107.8	107.8	107.8	107.8	107.8	107.8			107.8	107.8
Minimum	46.7	70.8	70.8	69.2	70.8	70.8			69.2	56.3
Maximum	140.0	127.1	140.0	140.0	133.6	140.0			133.6	127.1
Count	937	1261	1262	1250	1249	1243			1188	806

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	100.4	101.6	101.2	101.6	102.7	100.8			102.2	
Standard Error	0.22	0.23	0.22	0.23	0.24	0.23			0.23	
Mode	99.8	99.8	99.8	99.8	99.8	99.8			99.8	
Standard Deviation	7.0	7.3	7.2	7.4	7.6	7.5			7.5	
85th%tile Speed	107.8	107.8	107.8	107.8	107.8	107.8			107.8	
Minimum	74.0	74.0	77.2	74.0	74.0	70.8			77.2	
Maximum	140.0	140.0	148.1	148.1	156.1	148.1			148.1	
Count	1022	1028	1026	1038	1051	1050			1081	

*All values except "Count" are in kilometers per hour (kph).



7/16/99 Nighttime **(Friday)**

WB

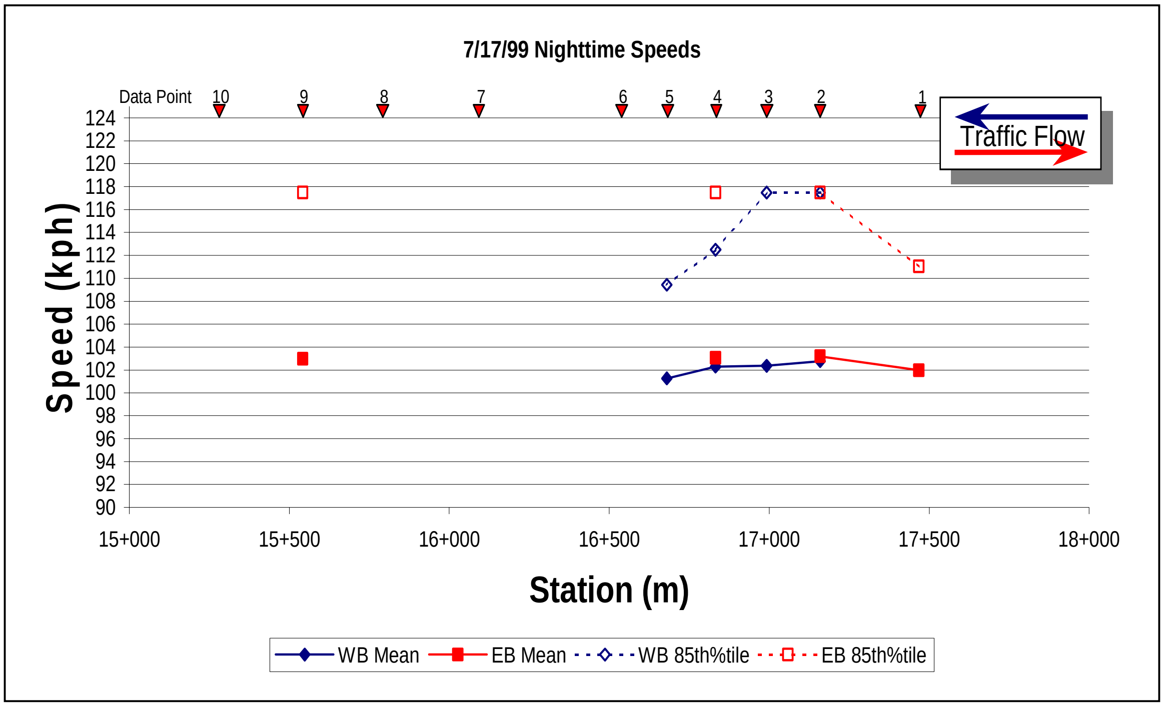
Data Point	*1*	*2*	*3*	*4*	*5*	6	7	8	9	*10*
Mean		103.0	102.2	102.5	101.1					101.4
Standard Error		0.25	0.25	0.25	0.24					0.27
Mode		99.8	99.8	99.8	99.8					99.8
Standard Deviation		9.3	9.2	9.4	8.9					8.3
85th%tile Speed		117.5	114.3	117.5	109.4					109.4
Minimum		67.6	66.0	69.2	69.2					61.2
Maximum		140.0	140.0	140.0	140.0					128.7
Count		1384	1371	1365	1358					932

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	*1*	*2*	*3*	*4*	*5*	6	7	8	9	*10*
Mean	101.0	102.6	102.1	102.2					102.9	
Standard Error	0.27	0.26	0.26	0.27					0.27	
Mode	99.8	99.8	99.8	99.8					99.8	
Standard Deviation	8.6	8.5	8.6	8.7					9.1	
85th%tile Speed	109.4	111.0	109.4	111.0					117.5	
Minimum	72.4	77.2	67.6	70.8					74.0	
Maximum	140.0	140.0	140.0	140.0					140.0	
Count	1039	1053	1055	1056					1118	

*All values except "Count" are in kilometers per hour (kph).



7/17/99 Nighttime (Saturday)

WB

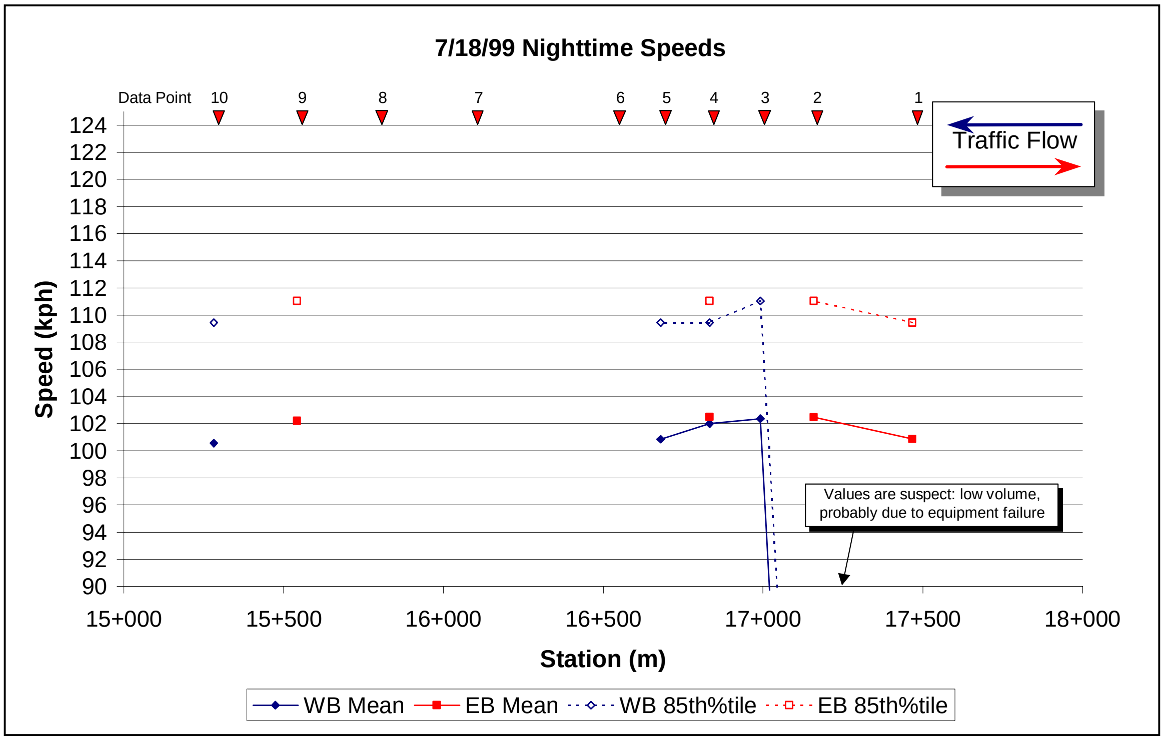
Data Point	1	2	3	4	5	6	7	8	9	10
Mean		102.8	102.4	102.3	101.3					
Standard Error		0.25	0.25	0.25	0.25					
Mode		99.8	99.8	99.8	99.8					
Standard Deviation		9.3	9.3	9.1	9.0					
85th%tile Speed		117.5	117.5	112.5	109.4					
Minimum		70.8	70.8	70.8	74.0					
Maximum		175.4	157.7	140.0	175.4					
Count		1360	1349	1335	1323					

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	102.0	103.2		103.1					103.0	
Standard Error	0.30	0.30		0.30					0.30	
Mode	99.8	99.8		99.8					99.8	
Standard Deviation	9.2	9.2		9.2					9.5	
85th%tile Speed	111.0	117.5		117.5					117.5	
Minimum	77.2	77.2		77.2					49.9	
Maximum	140.0	140.0		140.0					140.0	
Count	939	946		948					976	

*All values except "Count" are in kilometers per hour (kph).



7/18/99 Nighttime (Sunday)
WB

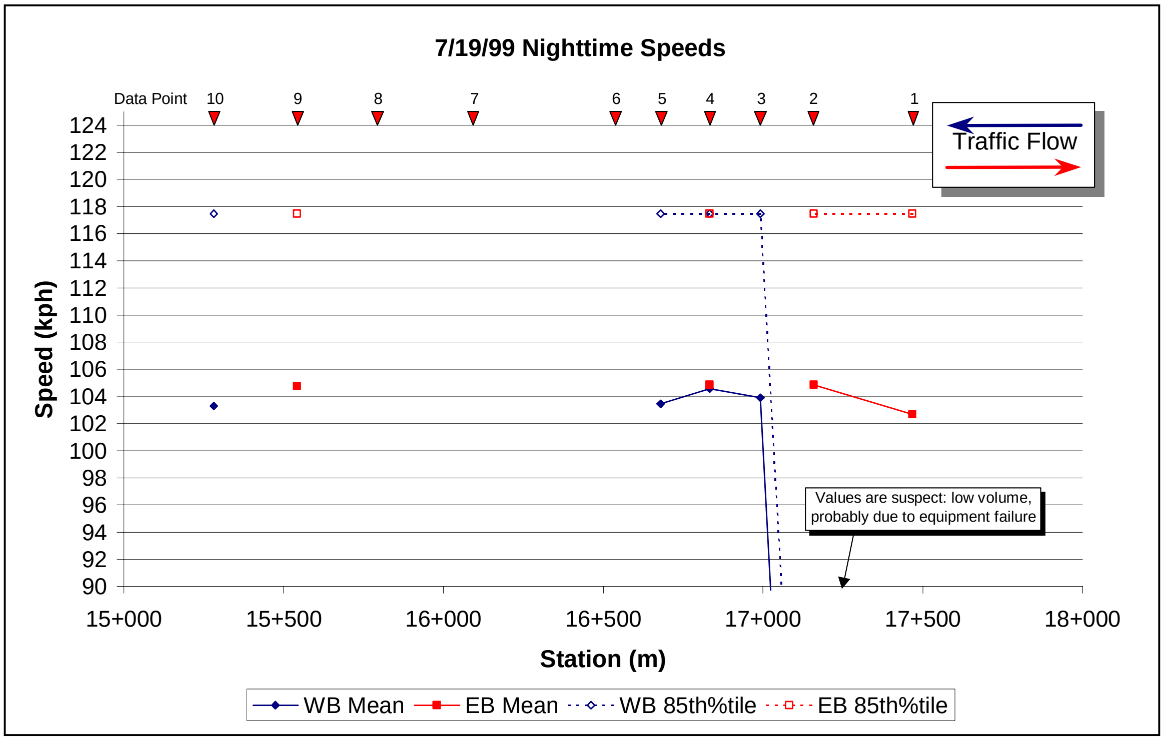
Data Point	*1*	*2*	*3*	*4*	*5*	6	7	8	9	*10*
Mean		29.4	102.4	102.0	100.8					100.6
Standard Error		1.39	0.24	0.24	0.22					0.35
Mode		27.4	99.8	99.8	99.8					99.8
Standard Deviation		11.6	8.9	8.7	8.2					8.5
85th%tile Speed		43.5	111.0	109.4	109.4					109.4
Minimum		16.1	57.9	56.3	54.7					64.4
Maximum		56.3	140.0	140.0	140.0					140.0
Count		70	1344	1351	1347					586

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	*1*	*2*	*3*	*4*	5	6	7	8	9	*10*
Mean	100.9	102.5		102.5					102.2	
Standard Error	0.27	0.27		0.27					0.26	
Mode	99.8	99.8		99.8					99.8	
Standard Deviation	8.6	8.9		8.8					8.7	
85th%tile Speed	109.4	111.0		111.0					111.0	
Minimum	74.0	77.2		54.7					72.4	
Maximum	140.0	140.0		140.0					140.0	
Count	1021	1042		1032					1089	

*All values except "Count" are in kilometers per hour (kph).



7/19/99 Nighttime (Monday)

WB

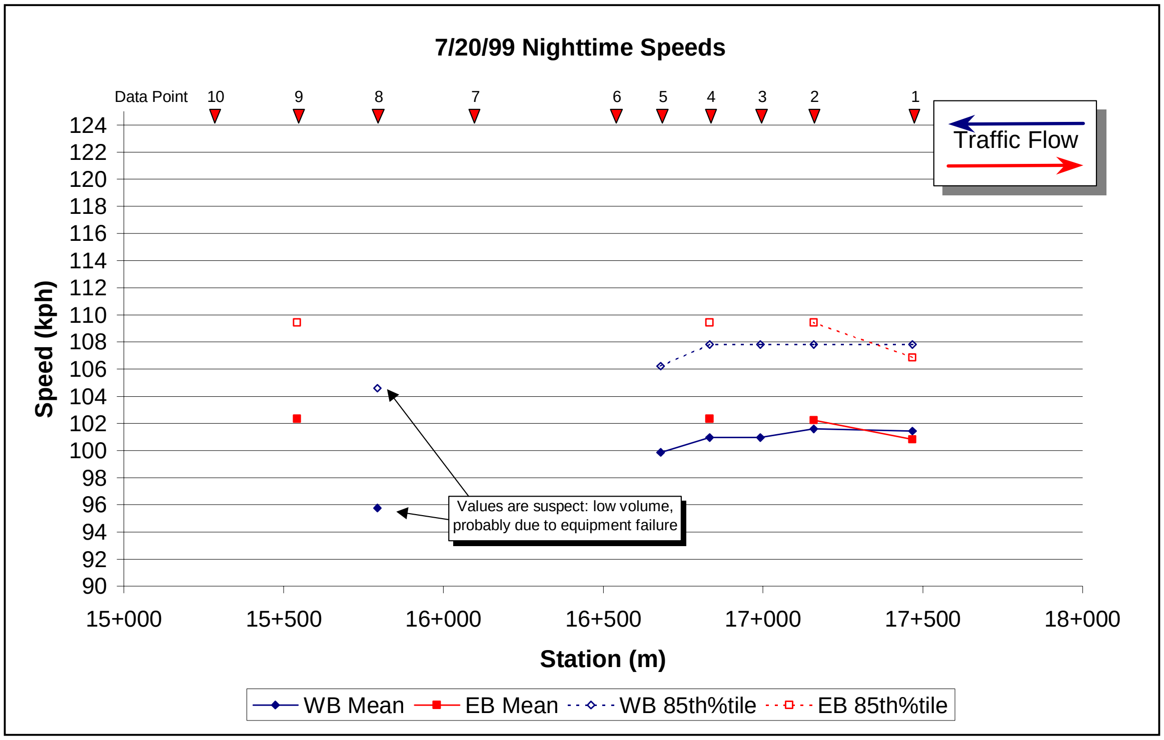
Data Point	1	2	3	4	5	6	7	8	9	10
Mean		30.8	103.9	104.6	103.5					103.3
Standard Error		1.49	0.33	0.34	0.33					0.50
Mode		27.4	103.0	103.0	103.0					103.0
Standard Deviation		13.2	10.9	11.3	10.6					11.5
85th%tile Speed		48.1	117.5	117.5	117.5					117.5
Minimum		16.1	57.9	70.8	70.8					49.9
Maximum		64.4	146.5	175.4	146.5					146.5
Count		78	1082	1086	1042					533

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	102.7	104.9		104.9					104.8	
Standard Error	0.35	0.36		0.36					0.34	
Mode	103.0	103.0		103.0					103.0	
Standard Deviation	10.1	10.5		10.2					10.2	
85th%tile Speed	117.5	117.5		117.5					117.5	
Minimum	78.9	78.9		78.9					49.9	
Maximum	146.5	146.5		175.4					146.5	
Count	816	861		825					883	

*All values except "Count" are in kilometers per hour (kph).



7/20/99 Nighttime (Tuesday)

WB

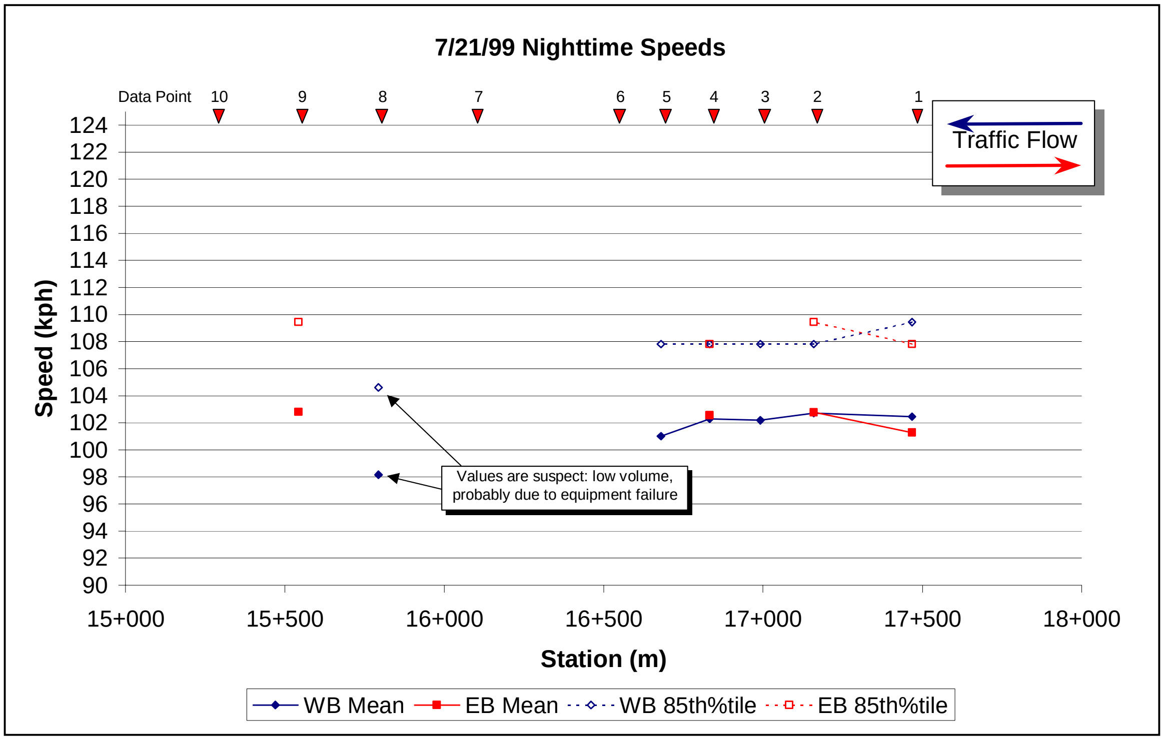
Data Point	1	2	3	4	5	6	7	8	9	10
Mean	101.4	101.6	101.0	100.9	99.9			95.8		
Standard Error	0.30	0.21	0.21	0.21	0.20			0.79		
Mode	99.8	99.8	99.8	99.8	96.6			96.6		
Standard Deviation	7.7	7.3	7.2	7.2	6.8			11.5		
85th%tile Speed	107.8	107.8	107.8	107.8	106.2			104.6		
Minimum	72.4	74.0	74.0	75.6	75.6			40.2		
Maximum	136.8	132.0	133.6	133.6	133.6			120.7		
Count	677	1208	1195	1183	1173			214		

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	100.8	102.2		102.3					102.3	
Standard Error	0.21	0.21		0.22					0.22	
Mode	96.6	98.2		98.2					98.2	
Standard Deviation	6.6	6.6		6.7					7.0	
85th%tile Speed	106.9	109.4		109.4					109.4	
Minimum	80.5	75.6		78.9					83.7	
Maximum	130.4	128.7		138.4					132.0	
Count	945	956		961					1015	

*All values except "Count" are in kilometers per hour (kph).



7/21/99 Nighttime (Wednesday)
WB

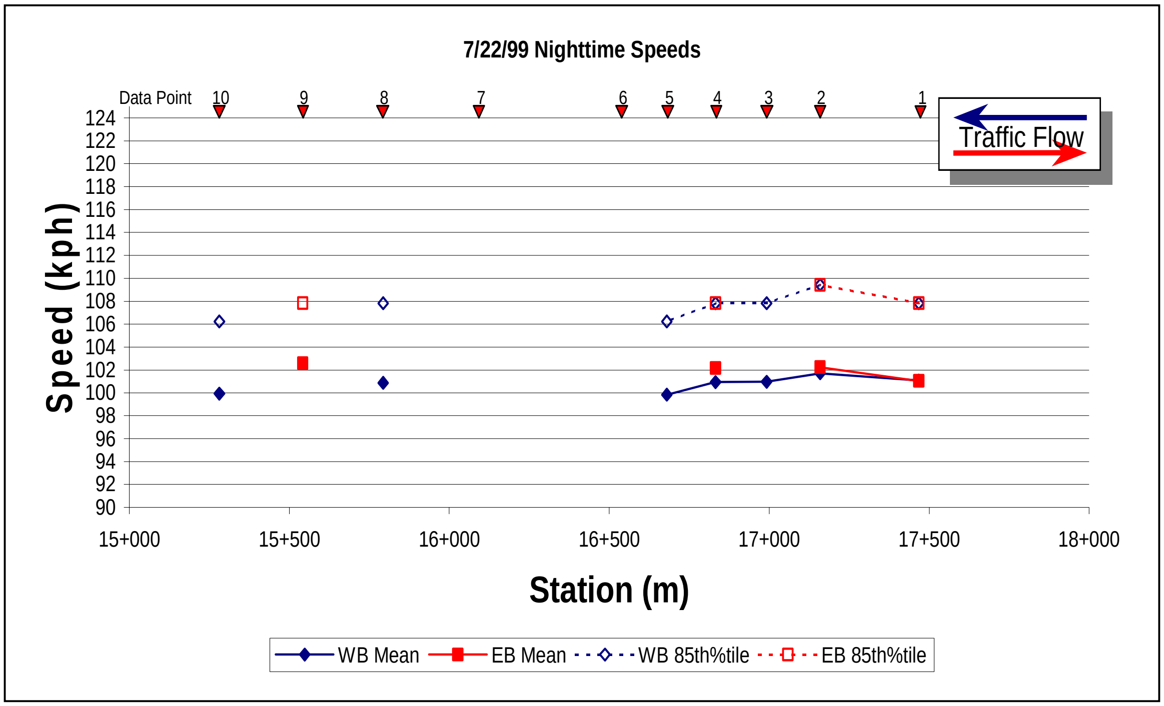
Data Point	1	2	3	4	5	6	7	8	9	10
Mean	102.5	102.7	102.2	102.3	101.0			98.2		
Standard Error	0.35	0.21	0.21	0.21	0.21			0.52		
Mode	99.8	99.8	99.8	99.8	99.8			99.8		
Standard Deviation	8.5	7.6	7.6	7.6	7.4			7.9		
85th%tile Speed	109.4	107.8	107.8	107.8	107.8			104.6		
Minimum	61.2	77.2	77.2	77.2	77.2			43.5		
Maximum	151.3	151.3	151.3	144.8	140.0			122.3		
Count	596	1266	1263	1263	1263			233		

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	101.3	102.8		102.6					102.8	
Standard Error	0.23	0.23		0.23					0.23	
Mode	99.8	99.8		99.8					99.8	
Standard Deviation	7.1	7.3		7.4					7.4	
85th%tile Speed	107.8	109.4		107.8					109.4	
Minimum	77.2	77.2		77.2					80.5	
Maximum	136.8	140.0		140.0					136.8	
Count	989	998		1008					1054	

*All values except "Count" are in kilometers per hour (kph).



7/22/99 Nighttime (Thursday)

WB

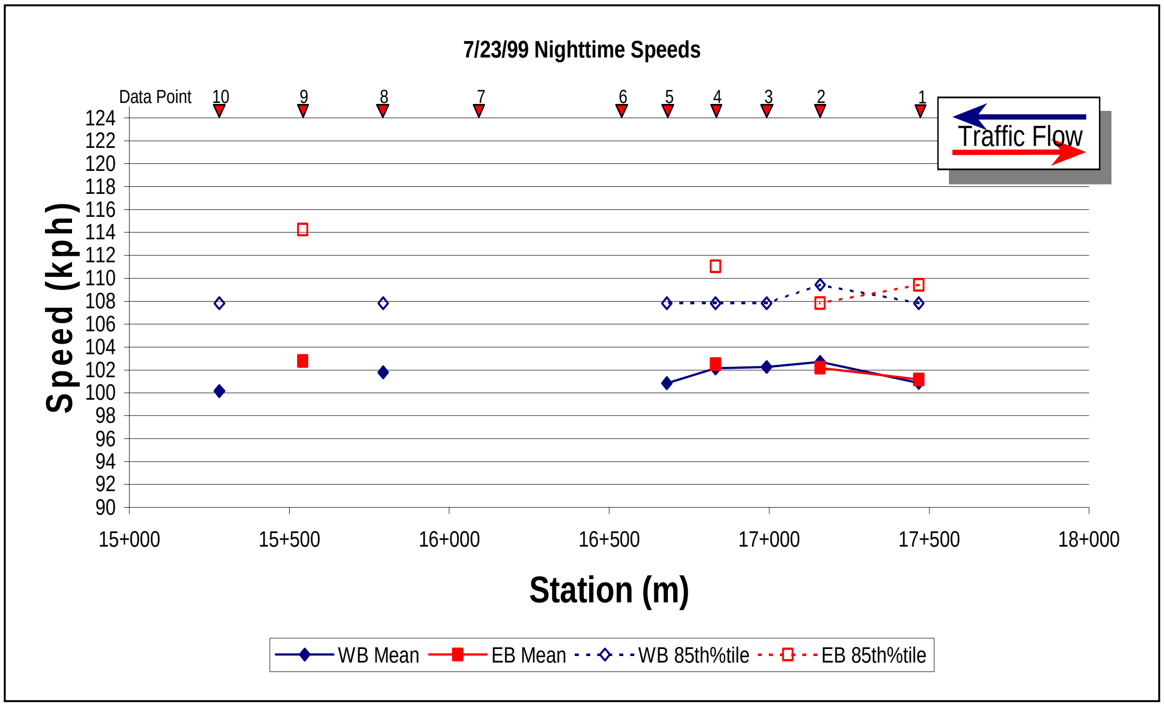
Data Point	1	2	3	4	5	6	7	8	9	10
Mean	101.1	101.7	101.0	100.9	99.8			100.9		99.9
Standard Error	0.34	0.20	0.20	0.20	0.19			0.19		0.39
Mode	98.2	99.8	99.8	99.8	98.2			99.8		96.6
Standard Deviation	8.6	7.4	7.3	7.4	7.0			6.9		8.6
85th%tile Speed	107.8	109.4	107.8	107.8	106.2			107.8		106.2
Minimum	45.1	66.0	75.6	75.6	77.2			78.9		45.1
Maximum	132.0	130.4	132.0	136.8	133.6			133.6		128.7
Count	644	1362	1343	1329	1325			1280		485

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	101.0	102.2		102.2					102.6	
Standard Error	0.22	0.22		0.23					0.22	
Mode	99.8	99.8		99.8					99.8	
Standard Deviation	7.1	7.1		7.4					7.5	
85th%tile Speed	107.8	109.4		107.8					107.8	
Minimum	82.1	77.2		80.5					80.5	
Maximum	140.0	136.8		140.0					133.6	
Count	1063	1073		1063					1141	

*All values except "Count" are in kilometers per hour (kph).



7/23/99 Nighttime **(Friday)**

WB

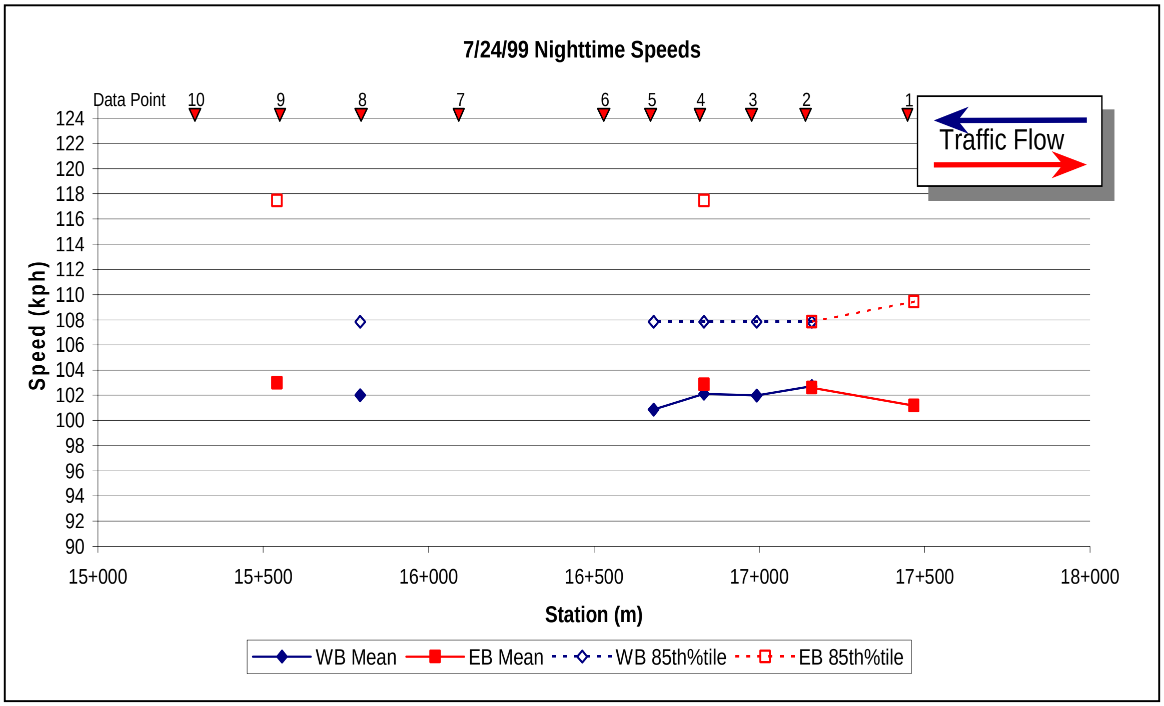
Data Point	***1***	***2***	***3***	***4***	***5***	***6***	***7***	**8**	**9**	***10***
Mean	100.9	102.7	102.3	102.1	100.8			101.8		100.2
Standard Error	0.37	0.23	0.22	0.22	0.21			0.22		0.31
Mode	99.8	99.8	99.8	99.8	99.8			99.8		99.8
Standard Deviation	8.8	8.8	8.6	8.4	8.1			8.3		8.4
85th%tile Speed	107.8	109.4	107.8	107.8	107.8			107.8		107.8
Minimum	57.9	56.3	69.2	67.6	64.4			64.4		57.9
Maximum	127.1	148.1	148.1	148.1	140.0			148.1		140.0
Count	546	1480	1462	1450	1435			1372		725

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	***1***	***2***	***3***	***4***	**5**	**6**	**7**	**8**	**9**	***10***
Mean	101.2	102.2		102.5					102.8	
Standard Error	0.28	0.24		0.28					0.26	
Mode	99.8	99.8		99.8					99.8	
Standard Deviation	9.1	8.0		9.2					9.0	
85th%tile Speed	109.4	107.8		111.0					114.3	
Minimum	48.3	67.6		74.0					70.8	
Maximum	157.7	148.1		175.4					157.7	
Count	1085	1107		1110					1168	

*All values except "Count" are in kilometers per hour (kph).



7/24/99 Nighttime **(Saturday)**
WB

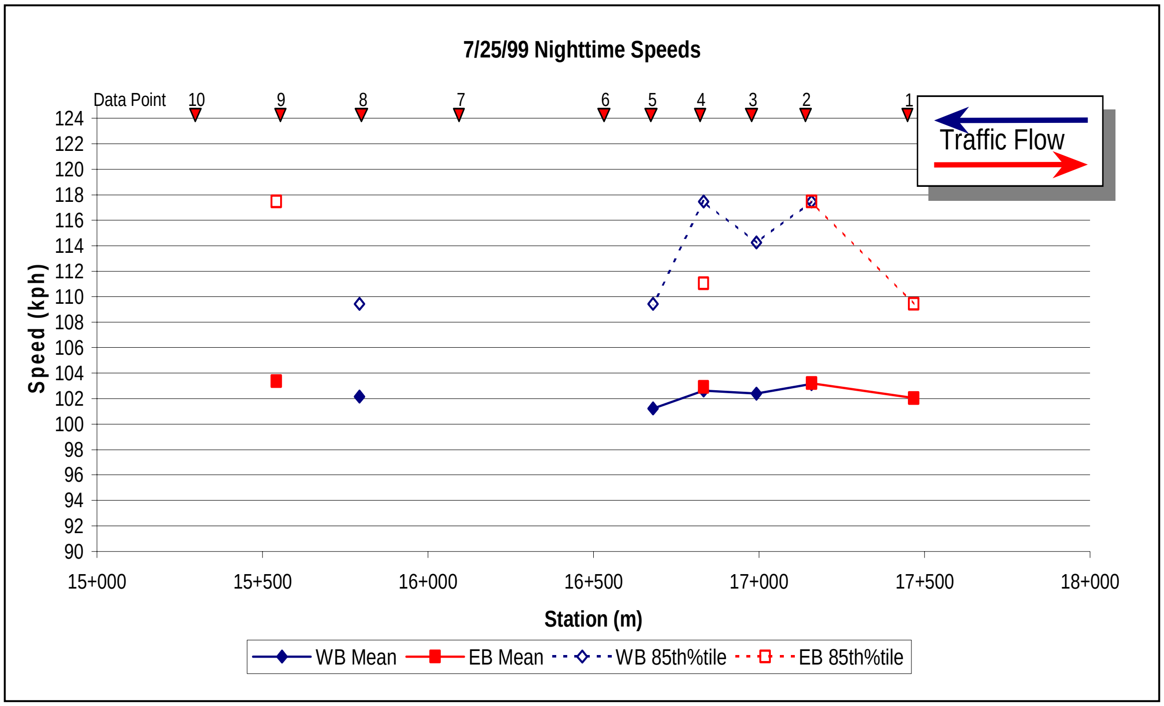
Data Point	1	2	3	4	5	6	7	8	9	10
Mean		102.7	102.0	102.1	100.9			102.0		
Standard Error		0.23	0.22	0.23	0.22			0.22		
Mode		99.8	99.8	99.8	99.8			99.8		
Standard Deviation		8.3	8.1	8.4	8.0			8.0		
85th%tile Speed		107.8	107.8	107.8	107.8			107.8		
Minimum		70.8	69.2	70.8	66.0			67.6		
Maximum		148.1	140.0	148.1	156.1			140.0		
Count		1367	1365	1360	1352			1315		

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	1	2	3	4	5	6	7	8	9	10
Mean	101.2	102.6		102.9					103.0	
Standard Error	0.28	0.25		0.29					0.27	
Mode	99.8	99.8		99.8					99.8	
Standard Deviation	8.9	7.9		9.2					8.9	
85th%tile Speed	109.4	107.8		117.5					117.5	
Minimum	72.4	75.6		74.0					77.2	
Maximum	140.0	148.1		140.0					140.0	
Count	1003	1016		1021					1065	

*All values except "Count" are in kilometers per hour (kph).



7/25/99 Nighttime **(Sunday)**

WB

Data Point	*1*	*2*	*3*	*4*	*5*	6	7	8	9	*10*
Mean		103.1	102.4	102.6	101.2			102.2		
Standard Error		0.25	0.24	0.25	0.23			0.24		
Mode		99.8	99.8	99.8	99.8			99.8		
Standard Deviation		9.1	8.6	8.9	8.3			8.4		
85th%tile Speed		117.5	114.3	117.5	109.4			109.4		
Minimum		77.2	77.2	77.2	77.2			77.2		
Maximum		140.0	128.7	140.0	140.0			140.0		
Count		1329	1323	1313	1302			1268		

*All values except "Count" are in kilometers per hour (kph).

EB

Data Point	*1*	*2*	*3*	*4*	5	6	7	8	9	*10*
Mean	102.0	103.2		102.9					103.4	
Standard Error	0.27	0.27		0.26					0.26	
Mode	99.8	99.8		99.8					99.8	
Standard Deviation	8.6	8.7		8.4					8.7	
85th%tile Speed	109.4	117.5		111.0					117.5	
Minimum	77.2	82.1		82.1					77.2	
Maximum	140.0	140.0		130.4					140.0	
Count	1041	1050		1064					1126	

*All values except "Count" are in kilometers per hour (kph).

APPENDIX H: ANOVA PARAMETER VALUES

Data Summary, Daylight, Passenger Cars				
			(WZ Lim: 97 kph)	
Description	Mean	85th %-ile	%Speeding	Std Dev
Data Pt 1	102.4	109.4	75%	7.7
Data Pt 2	101.6	109.4	71%	7.0
Data Pt 3	101.0	107.8	70%	6.9
Data Pt 4	100.9	107.8	69%	6.8
Data Pt 5	99.7	106.2	62%	6.5
Data Pt 6	101.2	107.8	71%	6.7
Data Pt 9	101.0	107.8	71%	6.2
	(kph)	(kph)		(kph)

Comparisons With Previous Data Point, Daylight, Passenger Cars								
			Total			Before	After	Total
Description	P	F	Count	Sum	SumSq	SS	SS	SS
Data Pt 2	0.000	13.78	5169	527091	54037234.8	160854	127374	288996
Data Pt 3	0.007	7.40	5015	508062	51720407.6	127374	121709	249451
Data Pt 4	0.367	0.81	4951	499790	50689752.9	121709	115597	237345
Data Pt 5	0.000	39.67	4933	494556	49806038.6	115597	107082	224471
Data Pt 6	0.000	62.96	4898	491790	49601494.3	107082	112820	222731
Data Pt 9	0.356	0.85	4636	468643	47574038.6	112820	87180	200037
			(vehicles)	(kph)				

Data Summary, Daylight, Heavy Vehicles				
			(WZ Lim: 97 kph)	
Description	Mean	85th %-ile	%Speeding	Std Dev
Data Pt 1	98.9	104.6	59%	7.0
Data Pt 2	98.7	104.6	57%	6.2
Data Pt 3	98.0	104.6	53%	6.1
Data Pt 4	97.5	104.6	50%	6.1
Data Pt 5	96.3	103.0	41%	5.9
Data Pt 6	97.9	104.6	52%	6.1
Data Pt 9	98.8	104.6	59%	6.1
	(kph)	(kph)		(kph)

Comparisons With Previous Data Point, Daylight, Heavy Vehicles								
			Total			Before	After	Total
Description	P	F	Count	Sum	SumSq	SS	SS	SS
Data Pt 2	0.578	0.31	1497	147905	14680311.6	37429	29687	67129
Data Pt 3	0.025	5.03	1511	148602	14673357.5	29687	28946	58828
Data Pt 4	0.142	2.16	1497	146336	14362217	28946	28421	57450
Data Pt 5	0.000	13.82	1447	140266	13651016.7	28421	25373	54308
Data Pt 6	0.000	23.78	1447	140541	13704683.8	25373	28313	54570
Data Pt 9	0.007	7.38	1457	143248	14139413.3	28313	27149	55744
			(vehicles)	(kph)				

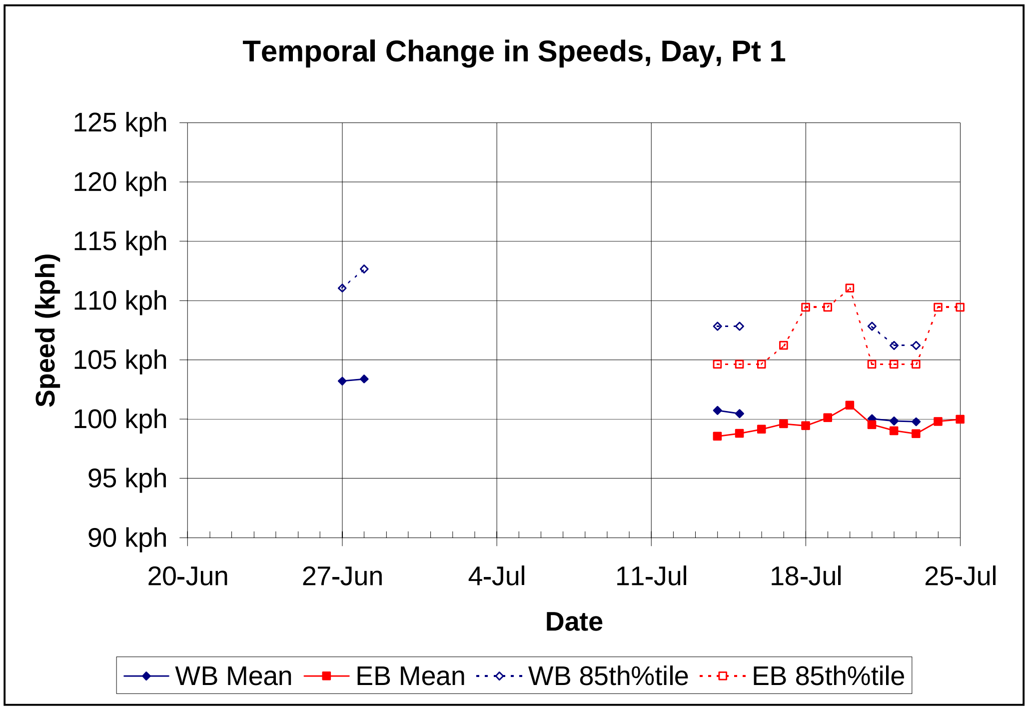
Data Summary, Nighttime, Passenger Cars				
			(WZ Lim: 97 kph)	
Description	Mean	85th %-ile	%Speeding	Std Dev
Data Pt 1	103.7	112.7	78%	8.9
Data Pt 2	103.4	112.7	77%	8.7
Data Pt 3	102.8	111.0	76%	8.6
Data Pt 4	102.7	111.0	75%	8.6
Data Pt 5	101.3	109.4	70%	8.3
Data Pt 6	103.0	111.0	76%	8.6
Data Pt 9	103.2	111.0	76%	8.6
	(kph)	(kph)		(kph)

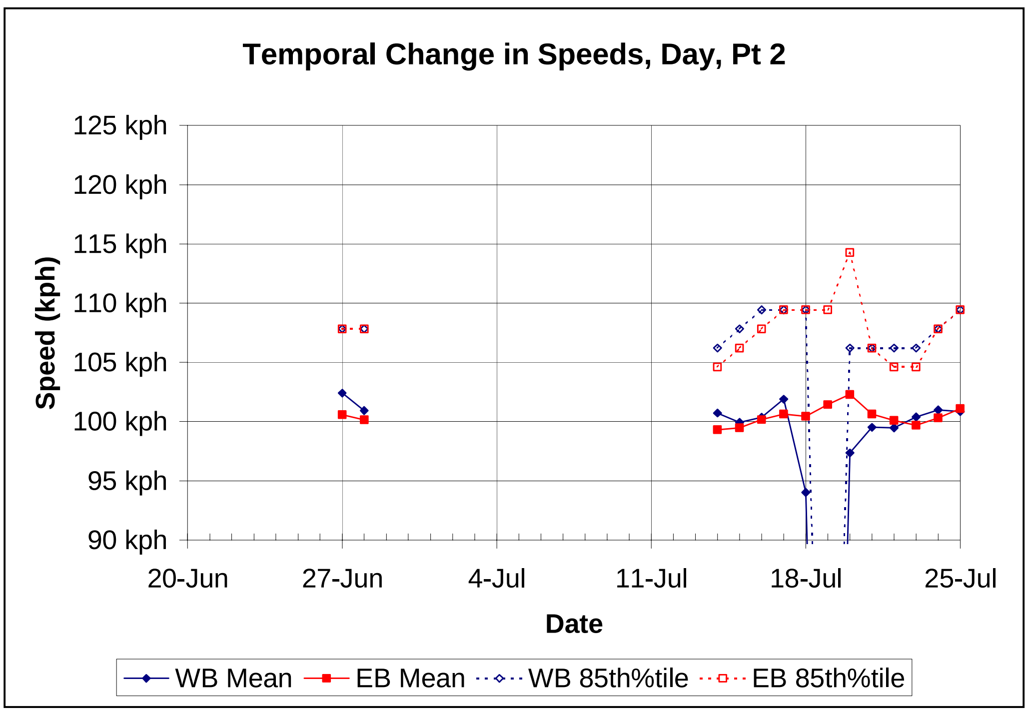
Comparisons With Previous Data Point, Nighttime, Passenger Cars									
			Total			Before	After	Total
Description	P	F	Count	Sum	SumSq	SS	SS	SS
Data Pt 2	0.265	1.24	3413	353349	36851612.2	138605	130535	269238
Data Pt 3	0.072	3.23	3369	347309	36060321.6	130535	125516	256298
Data Pt 4	0.786	0.07	3348	344102	35616804.2	125516	125061	250583
Data Pt 5	0.000	22.15	3328	339597	34897494.6	125061	117468	244145
Data Pt 6	0.000	30.06	3310	338136	34786280.5	117468	124023	243686
Data Pt 9	0.407	0.69	3238	333828	34660870.7	124023	120173	244248
			(vehicles)	(kph)				

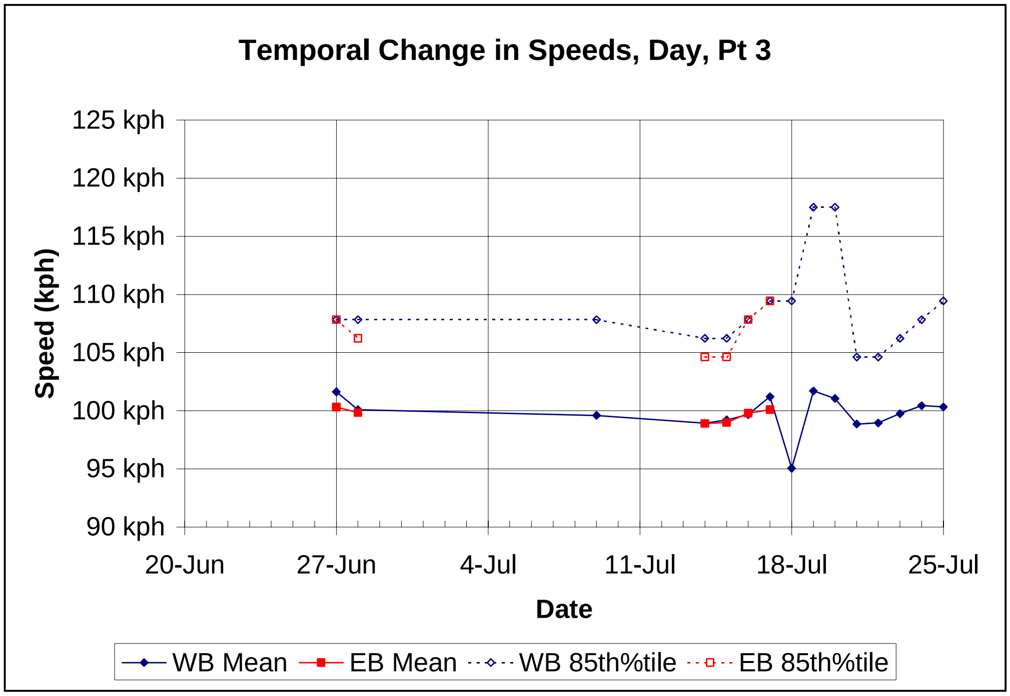
Data Summary, Nighttime, Heavy Vehicles				
			(WZ Lim: 97 kph)	
Description	Mean	85th %-ile	%Speeding	Std Dev
Data Pt 1	101.1	107.8	74%	7.0
Data Pt 2	100.9	107.8	71%	6.9
Data Pt 3	100.2	106.2	67%	6.8
Data Pt 4	100.1	106.2	67%	6.7
Data Pt 5	99.0	104.6	60%	6.4
Data Pt 6	100.3	106.2	70%	6.5
Data Pt 9	101.3	107.8	77%	6.6
	(kph)	(kph)		(kph)

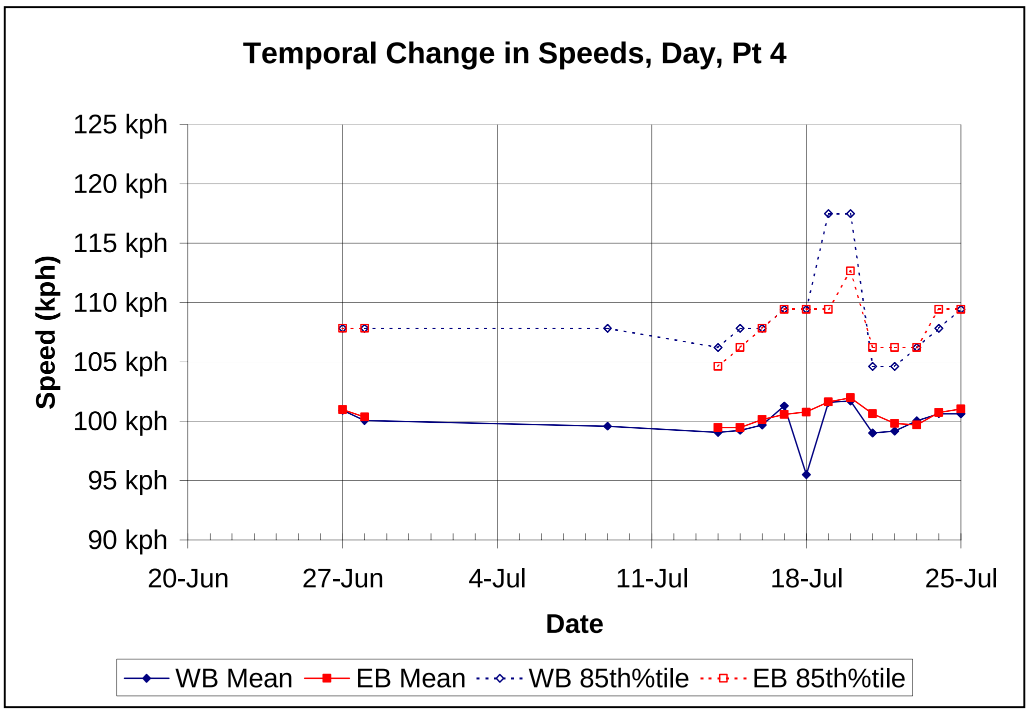
Comparisons With Previous Data Point, Nighttime, Heavy Vehicles								
			Total			Before	After	Total
Description	P	F	Count	Sum	SumSq	SS	SS	SS
Data Pt 2	0.625	0.24	1151	116241	11795984.3	28717	27862	56591
Data Pt 3	0.088	2.91	1159	116531	11772026.9	27862	27484	55485
Data Pt 4	0.742	0.11	1149	115052	11574460	27484	26550	54039
Data Pt 5	0.006	7.64	1113	110771	11074203.8	26550	22833	49723
Data Pt 6	0.000	12.23	1102	109825	10992935.2	22833	24478	47837
Data Pt 9	0.019	5.56	1105	111394	11278577.2	24478	24337	49061
			(vehicles)	(kph)				

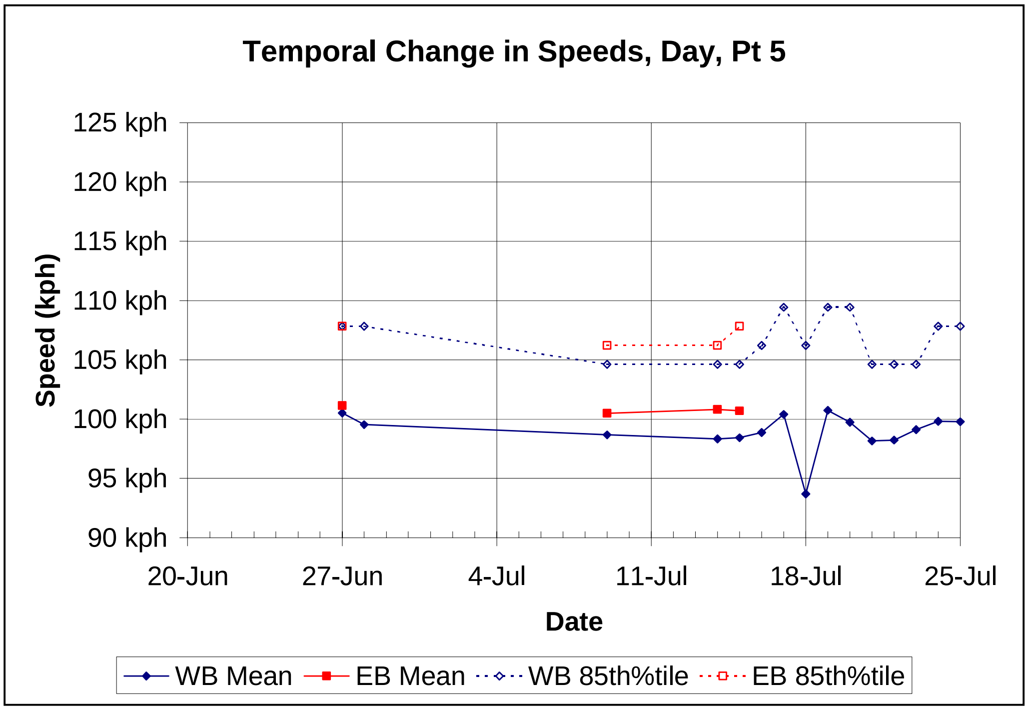
APPENDIX I: TEMPORAL DATA, DAYTIME

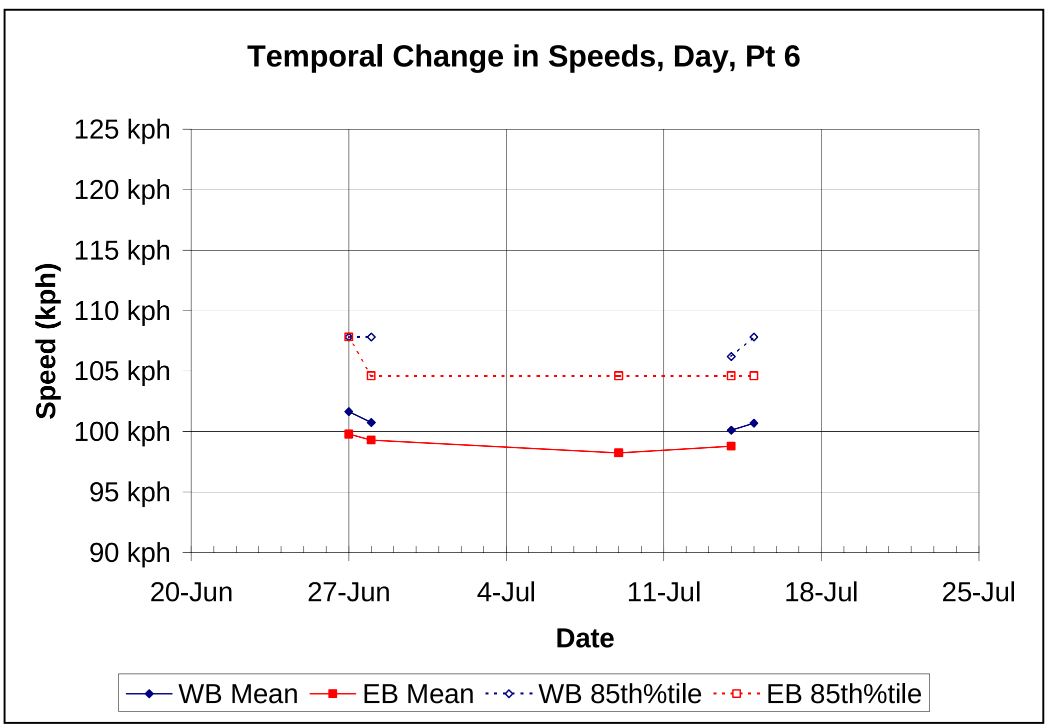


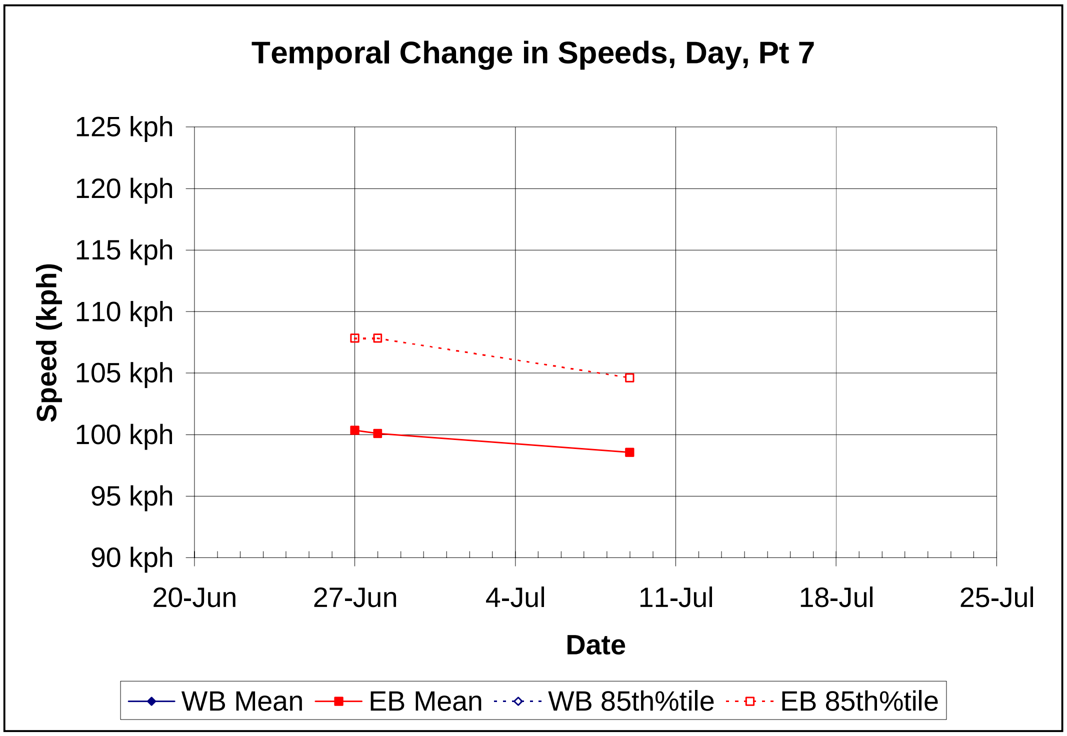


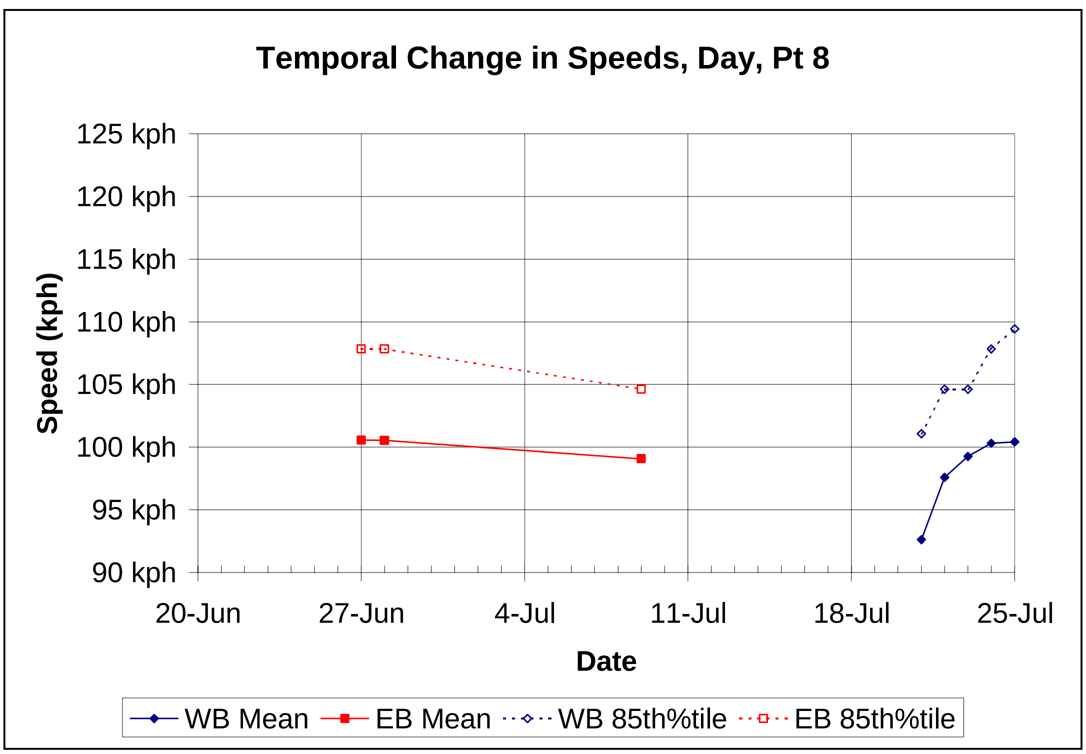

Temporal Change in Speeds, Day, Pt 3
Speed (kph)
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile

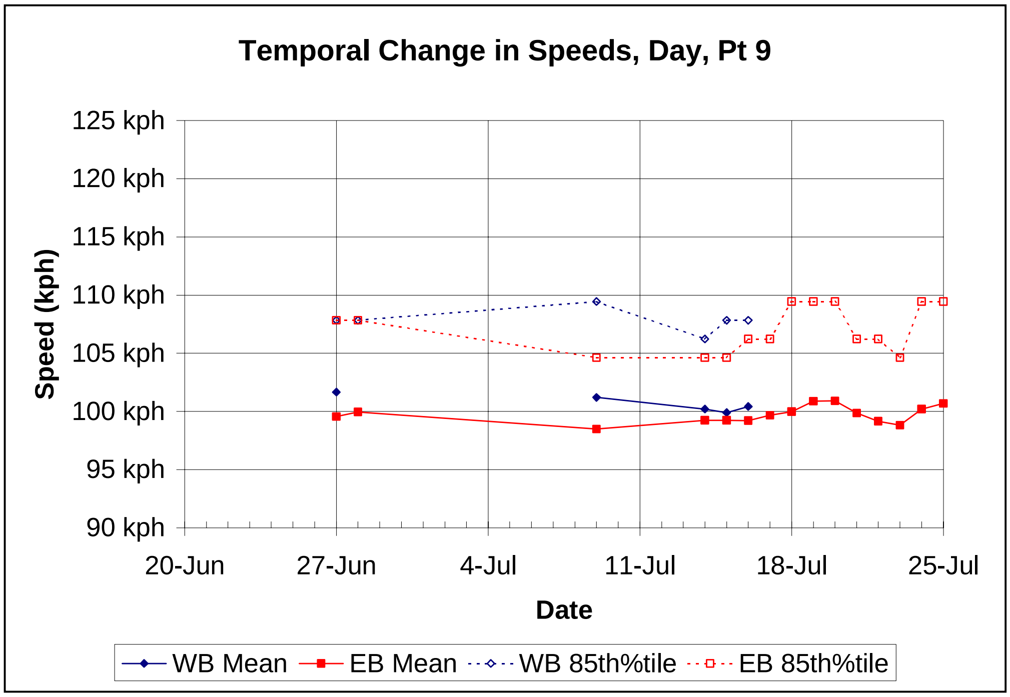

Temporal Change in Speeds, Day, Pt 4
Speed (kph)
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile

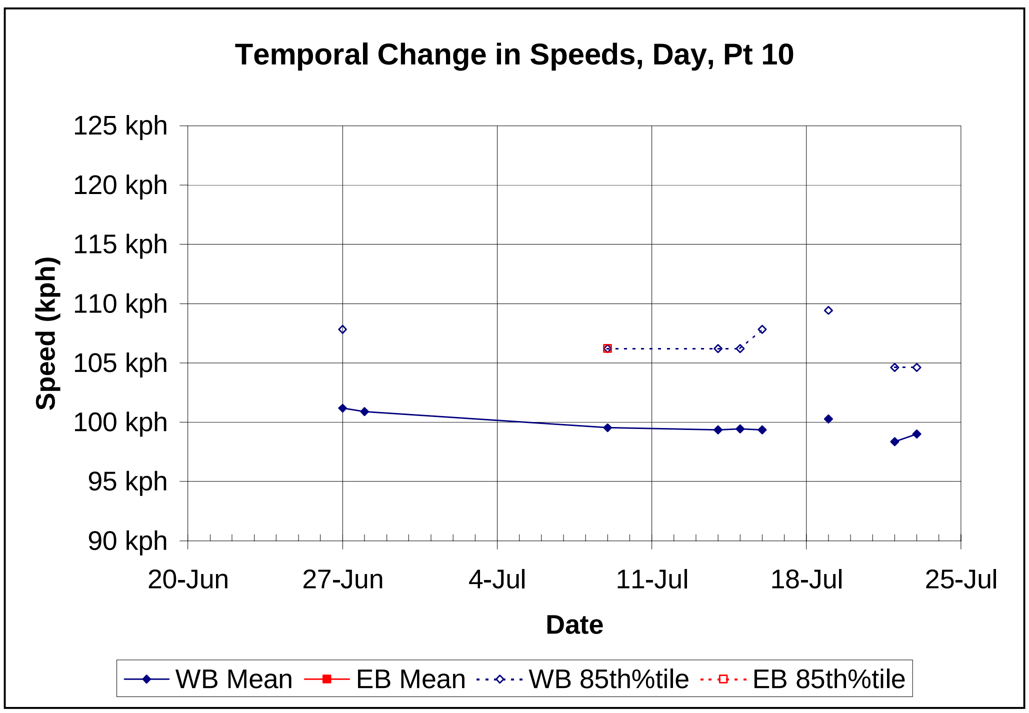

Temporal Change in Speeds, Day, Pt 5
Speed (kph)
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile

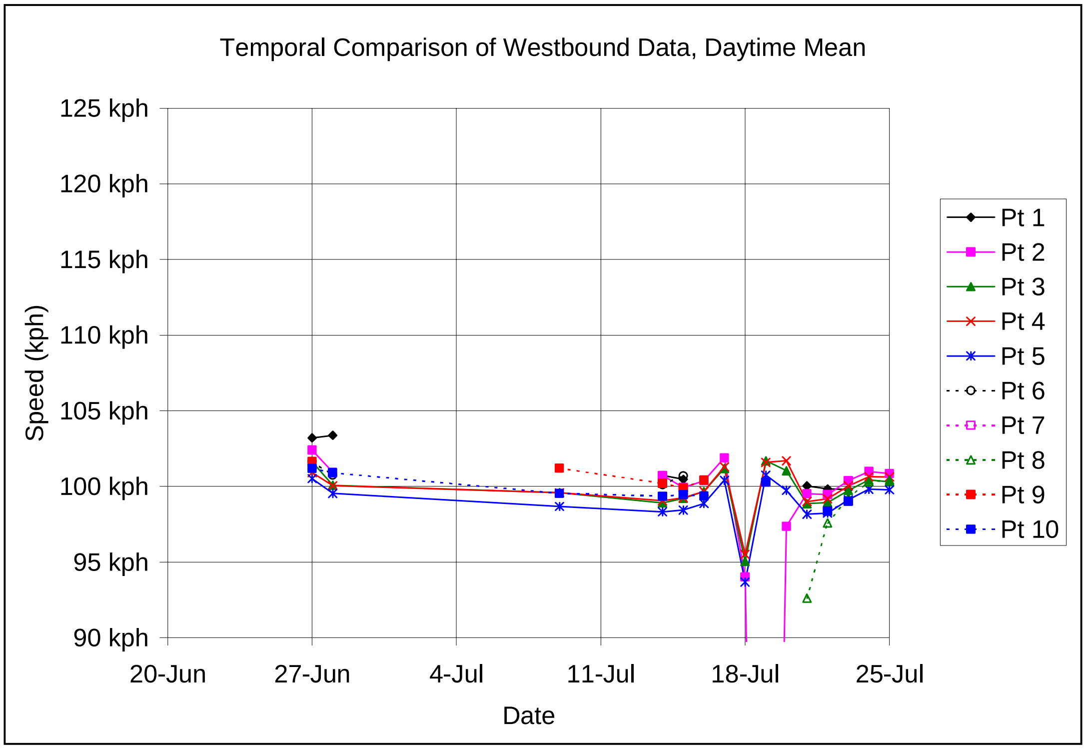

Temporal Change in Speeds, Day, Pt 6
Speed (kph)
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile

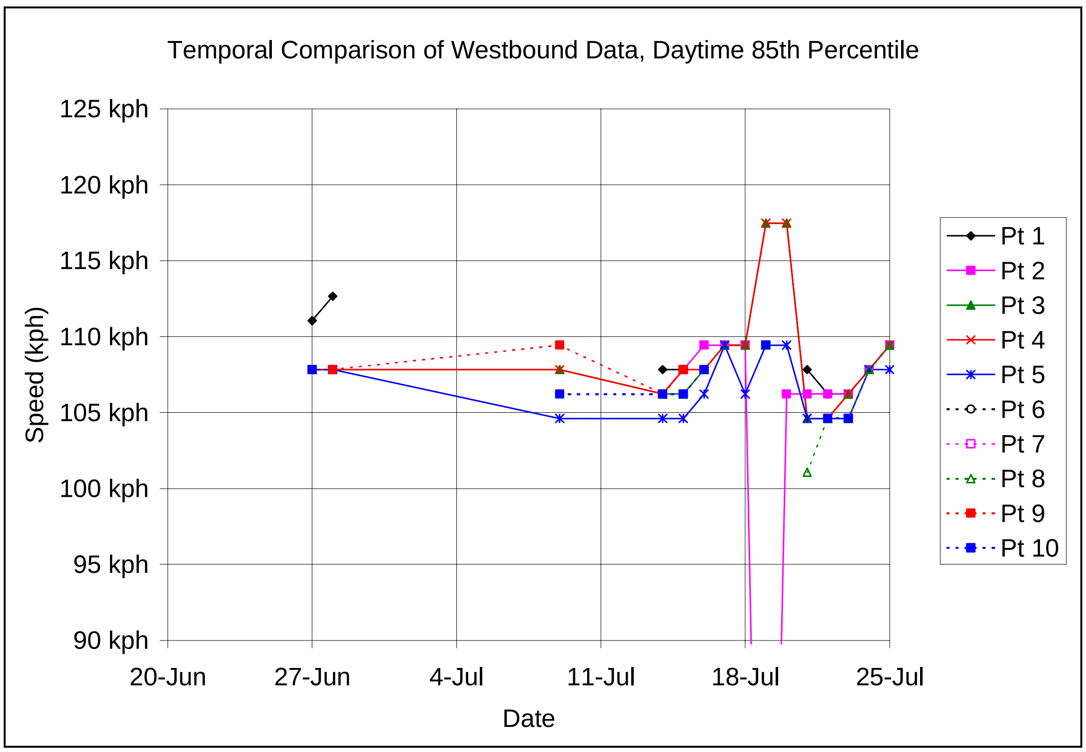

Temporal Change in Speeds, Day, Pt 7
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
Speed (kph)
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile

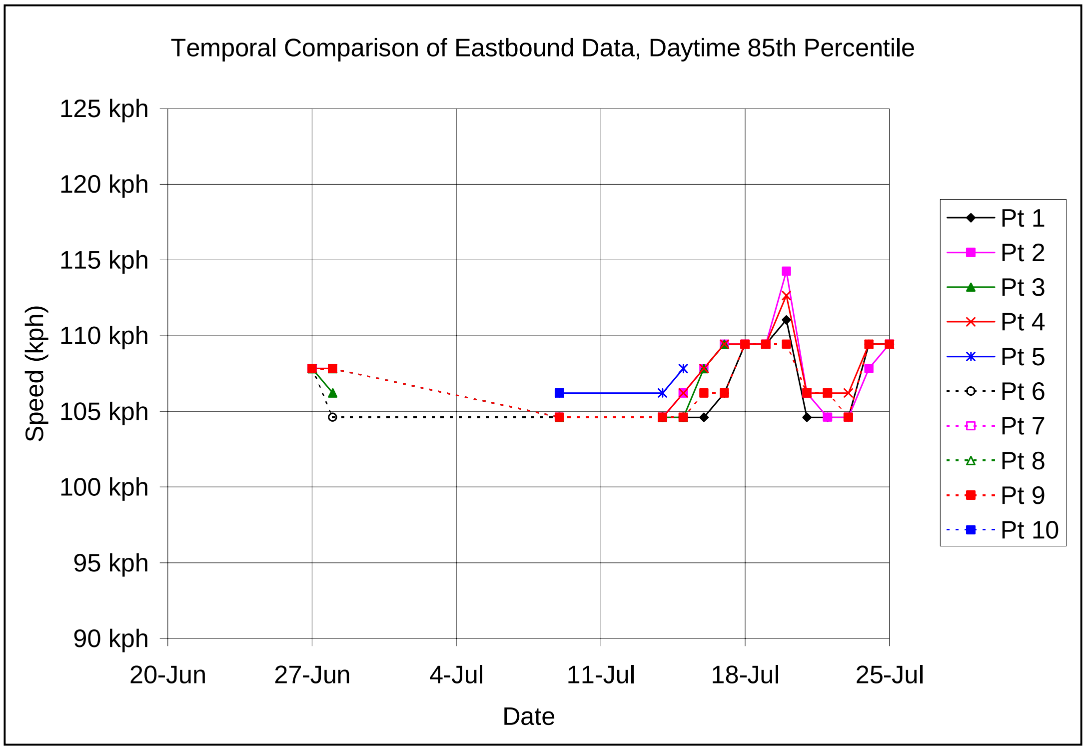

Temporal Change in Speeds, Day, Pt 8
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
Speed (kph)
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile

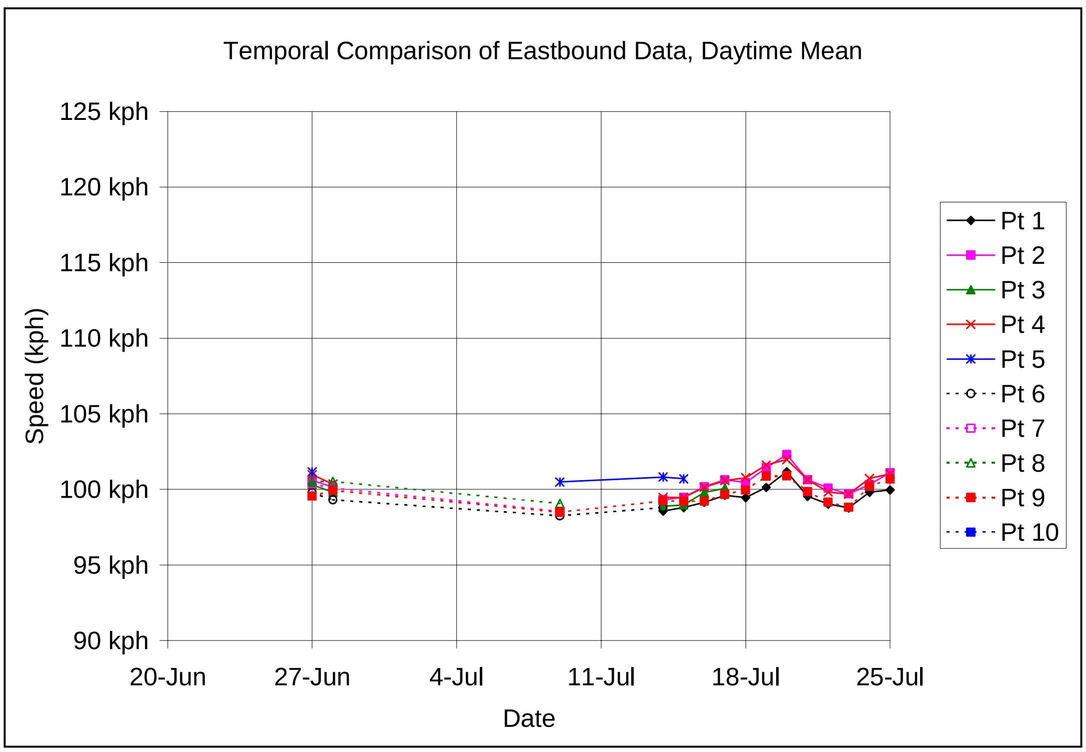

Temporal Change in Speeds, Day, Pt 9
Speed (kph)
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile


Temporal Change in Speeds, Day, Pt 10
Speed (kph)
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile

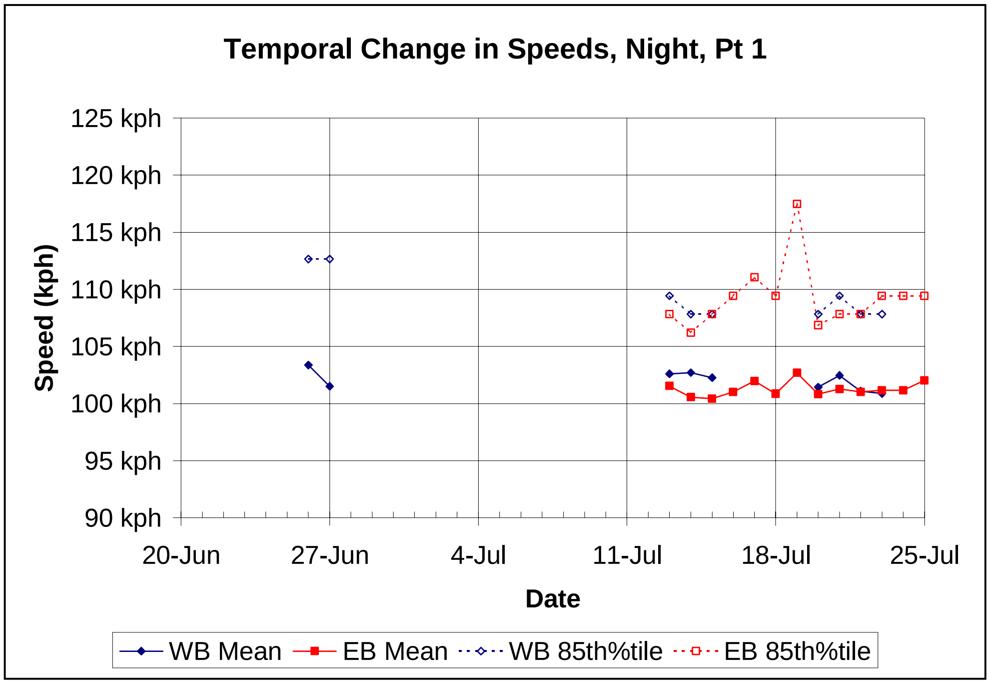

Temporal Comparison of Westbound Data, Daytime Mean
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
Speed (kph)
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
Pt 1
Pt 2
Pt 3
Pt 4
Pt 5
Pt 6
Pt 7
Pt 8
Pt 9
Pt 10

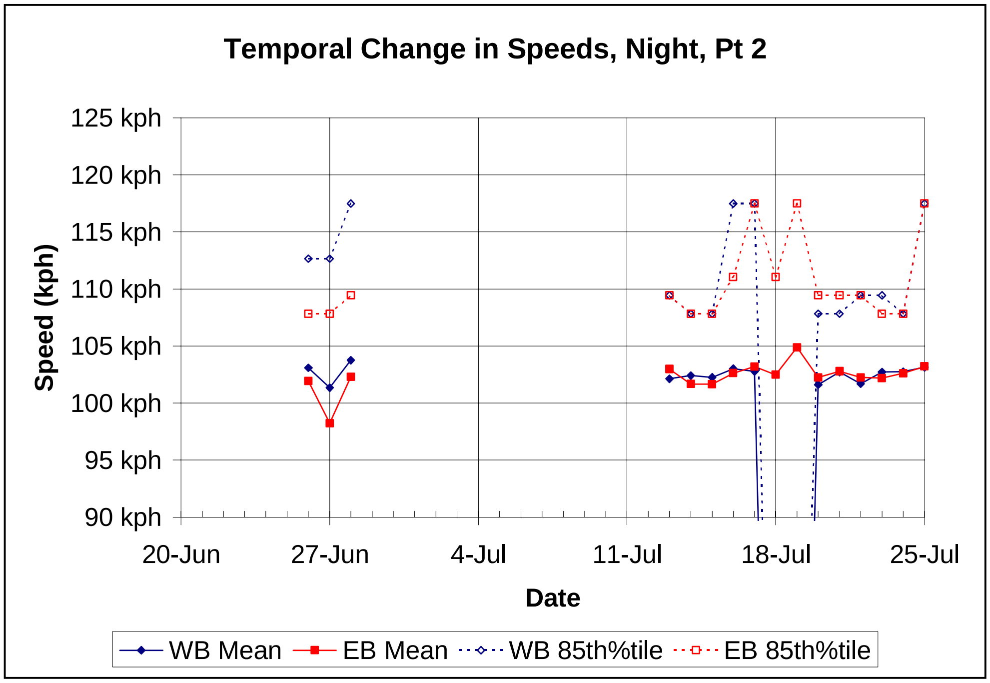

Temporal Comparison of Westbound Data, Daytime 85th Percentile
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
Speed (kph)
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
Pt 1
Pt 2
Pt 3
Pt 4
Pt 5
Pt 6
Pt 7
Pt 8
Pt 9
Pt 10

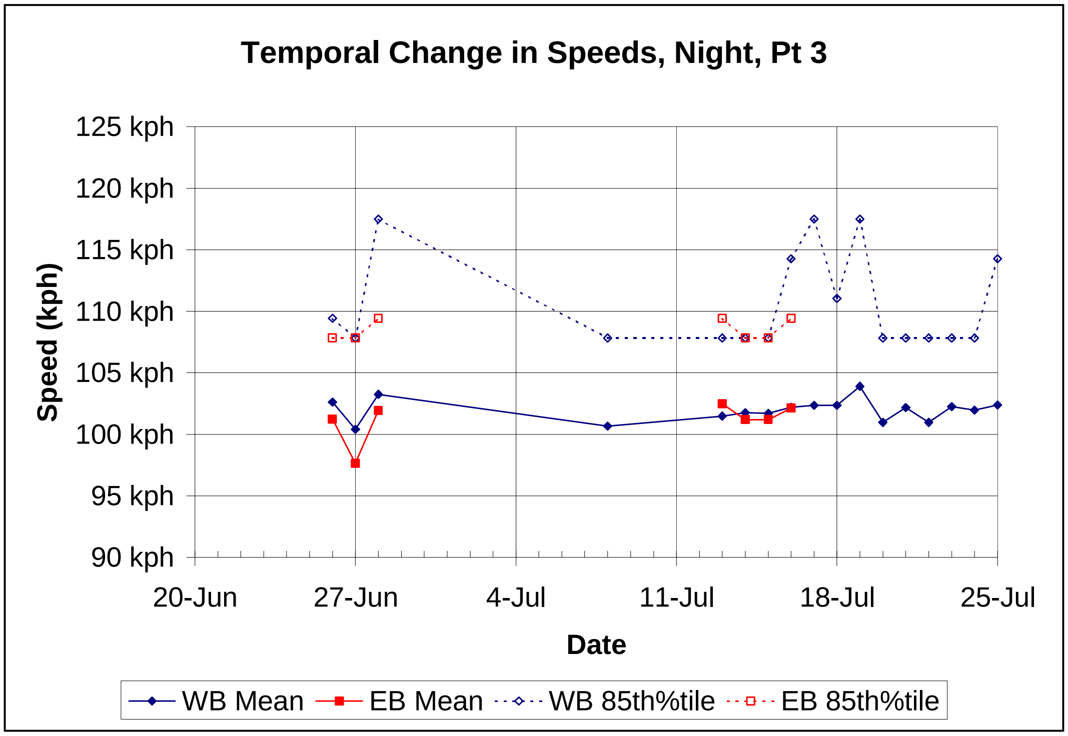

Temporal Comparison of Eastbound Data, Daytime 85th Percentile
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
Speed (kph)
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
Pt 1
Pt 2
Pt 3
Pt 4
Pt 5
Pt 6
Pt 7
Pt 8
Pt 9
Pt 10

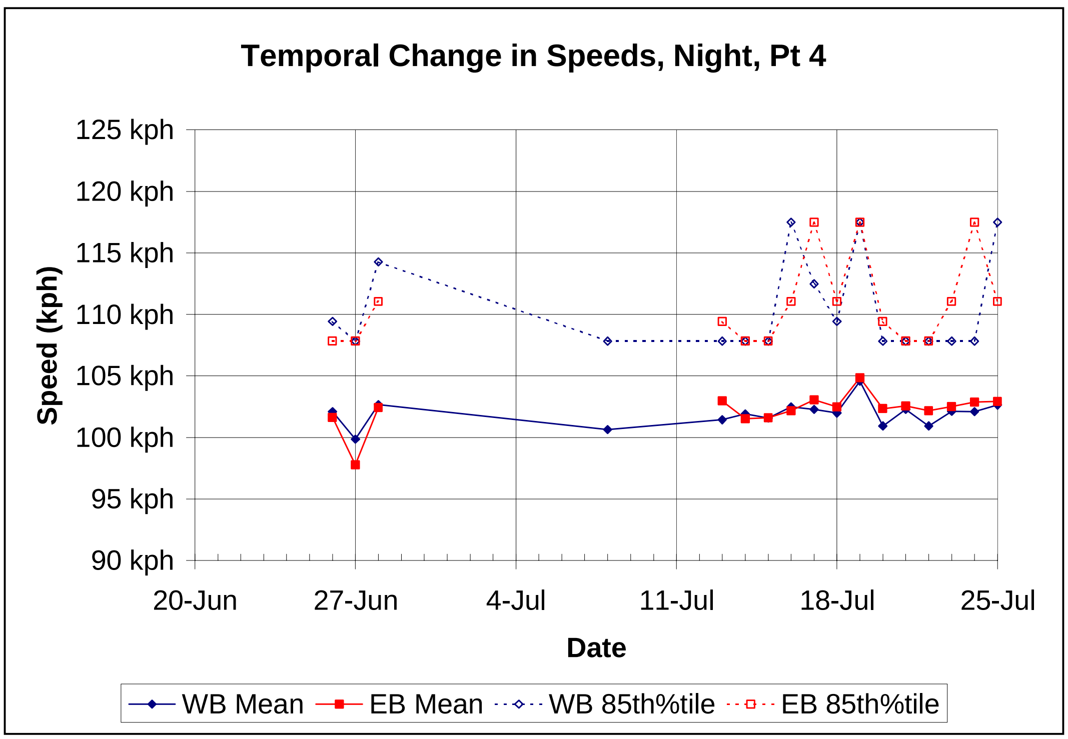

Temporal Comparison of Eastbound Data, Daytime Mean
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
Speed (kph)
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
Pt 1
Pt 2
Pt 3
Pt 4
Pt 5
Pt 6
Pt 7
Pt 8
Pt 9
Pt 10

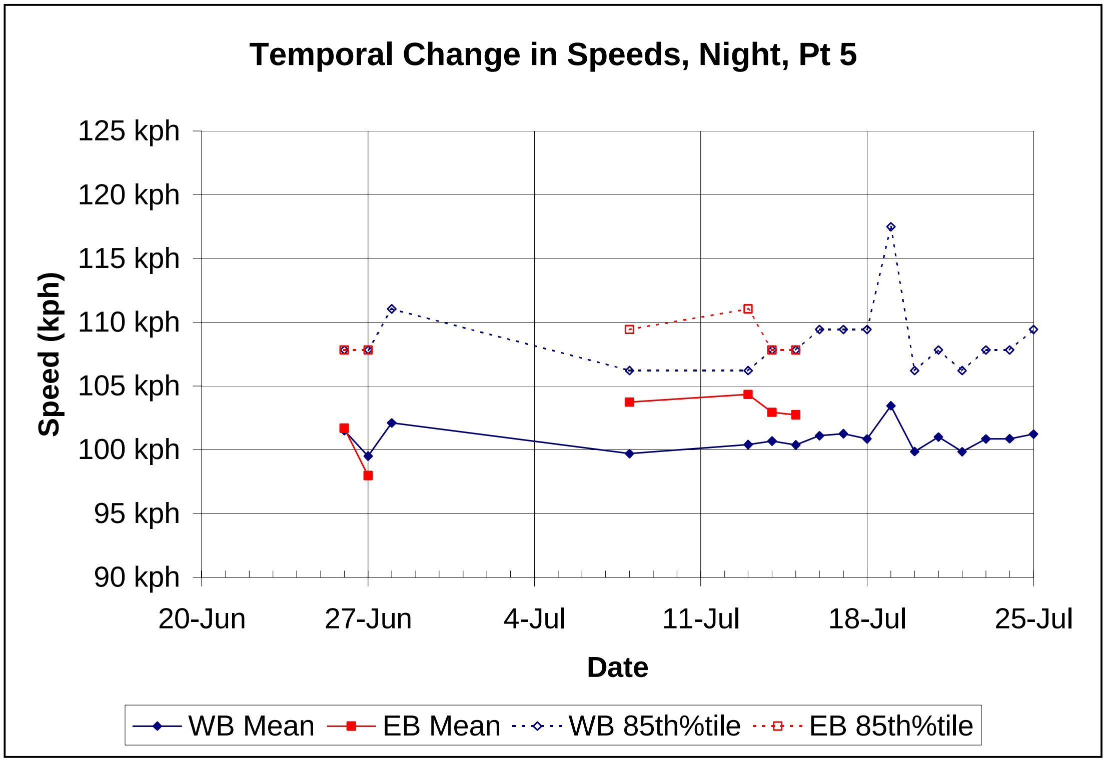
APPENDIX J: TEMPORAL DATA, NIGHTTIME

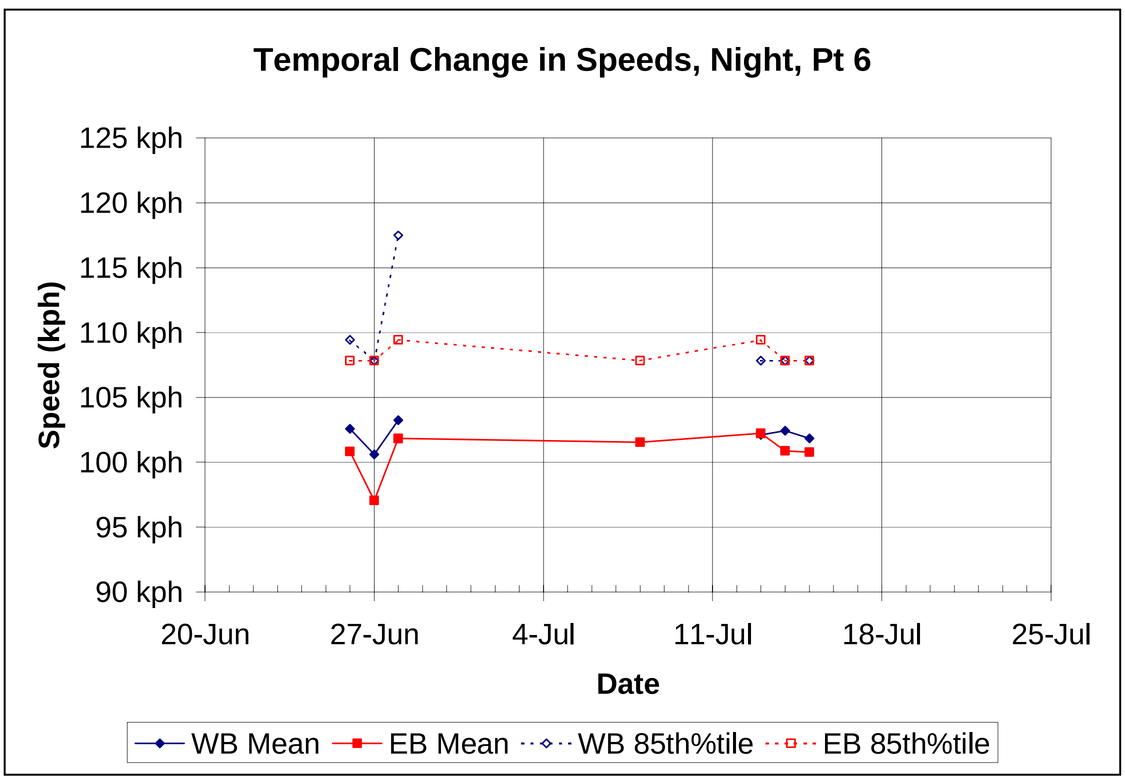


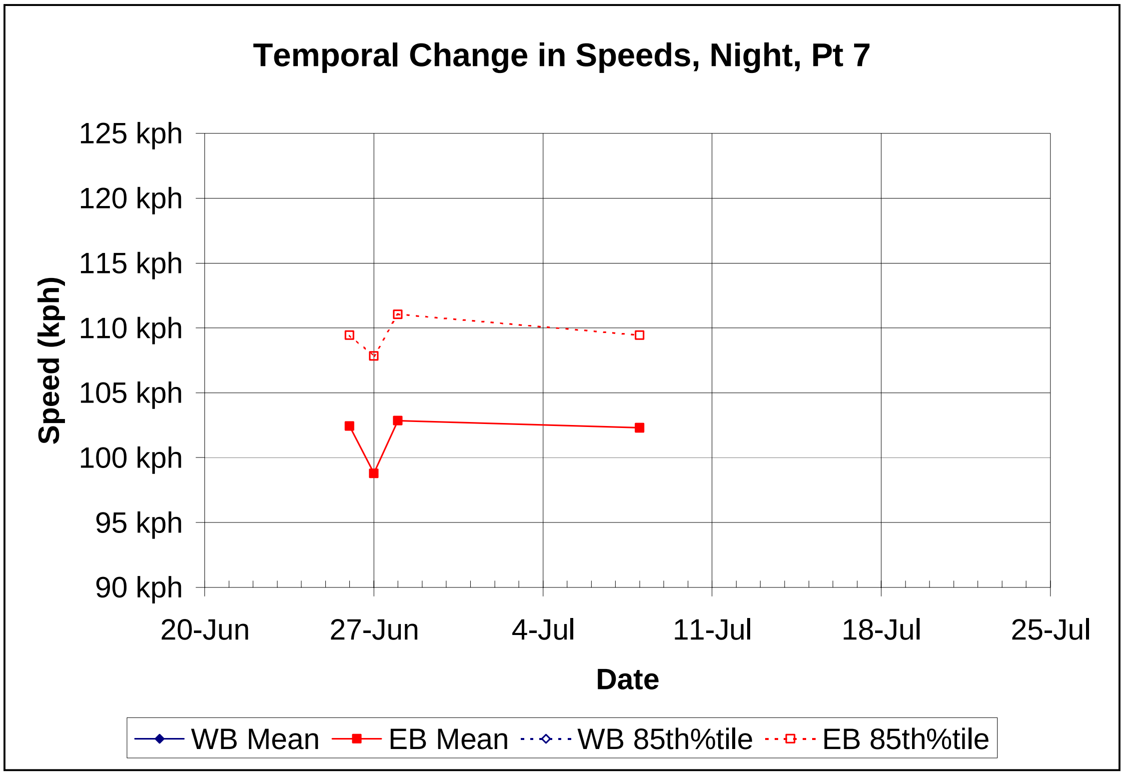


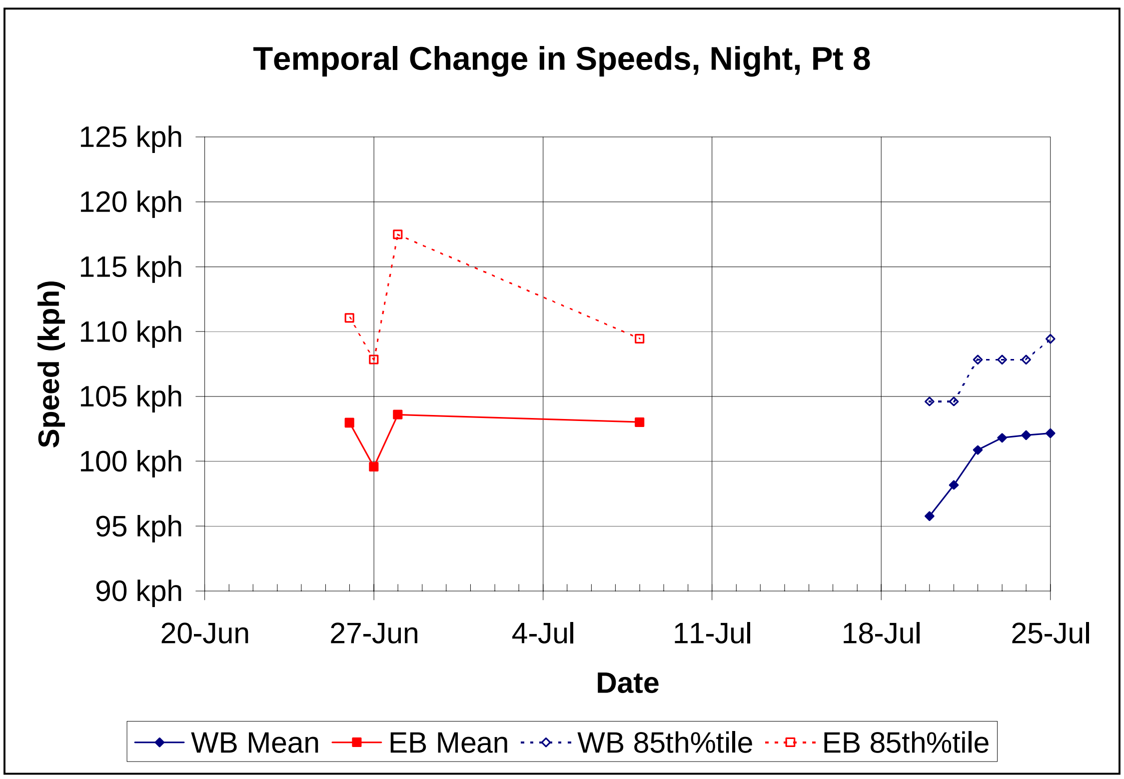

Temporal Change in Speeds, Night, Pt 3
Speed (kph)
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile

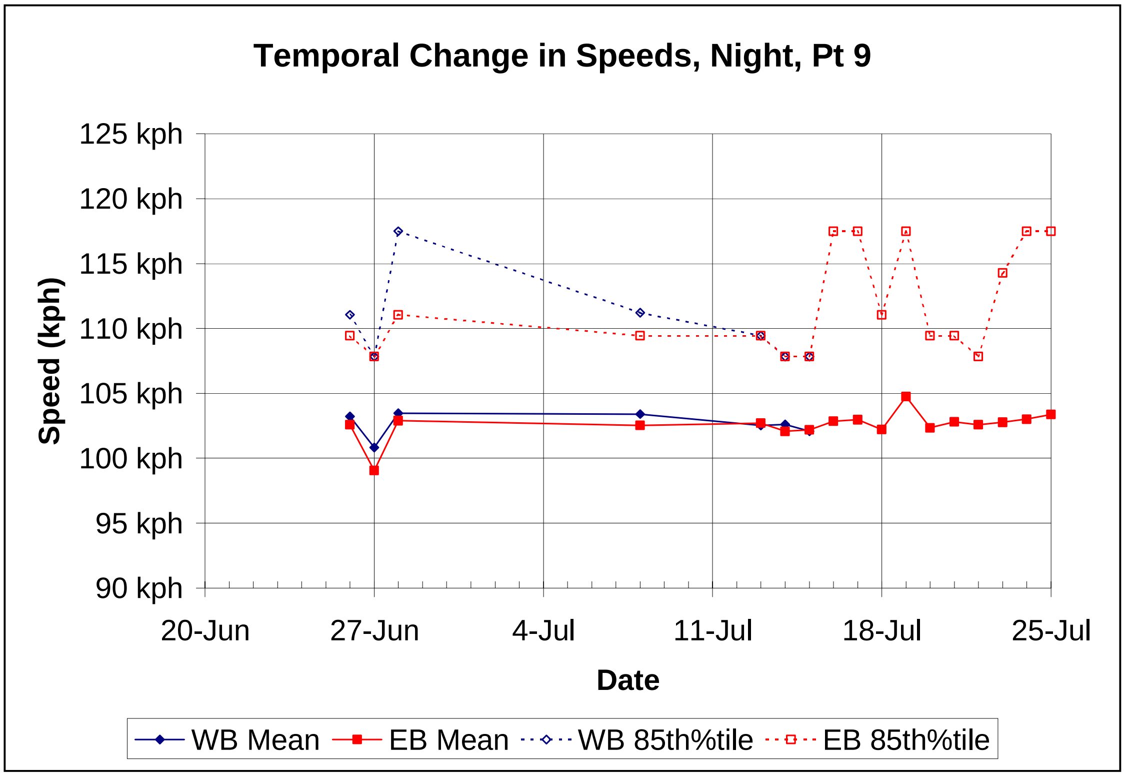

Temporal Change in Speeds, Night, Pt 4
Speed (kph)
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile

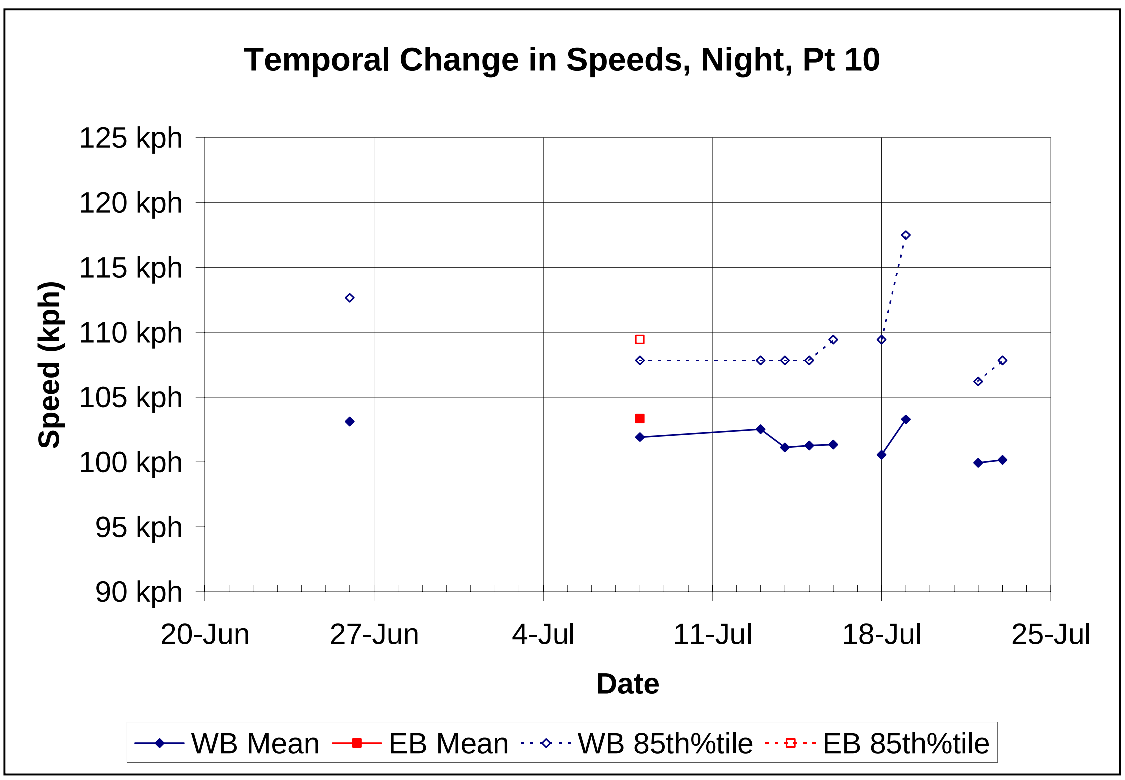

Temporal Change in Speeds, Night, Pt 5
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
Speed (kph)
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile

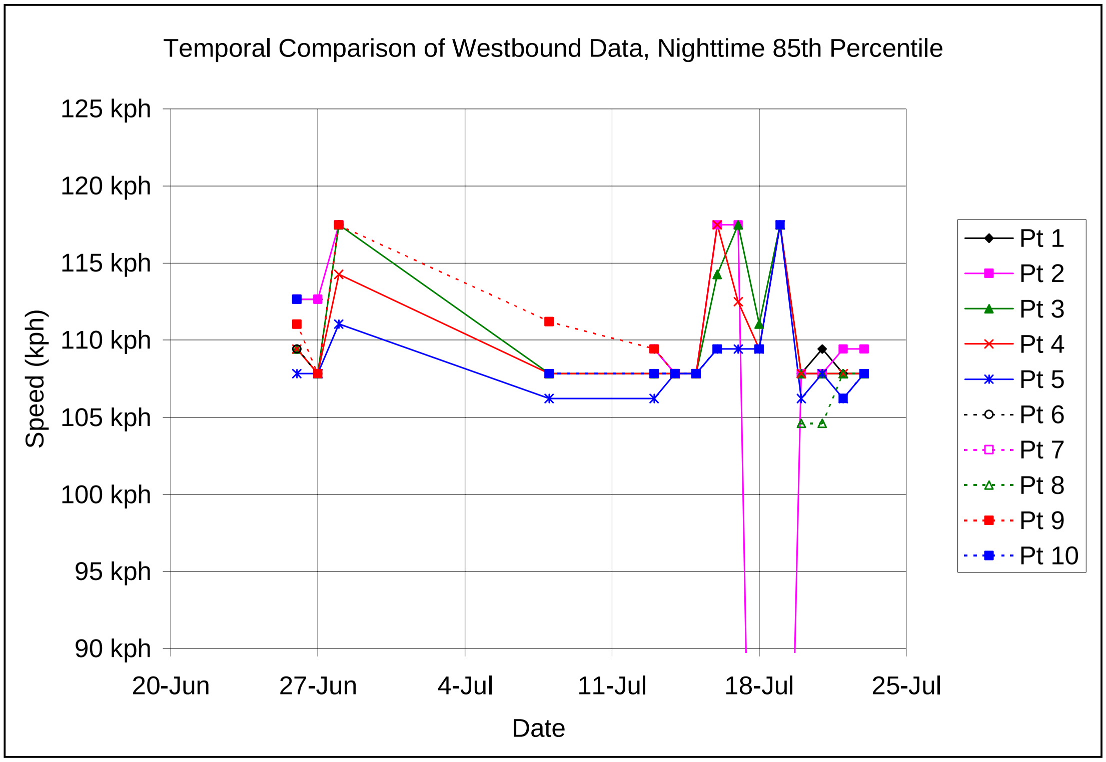

Temporal Change in Speeds, Night, Pt 6
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
Speed (kph)
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile

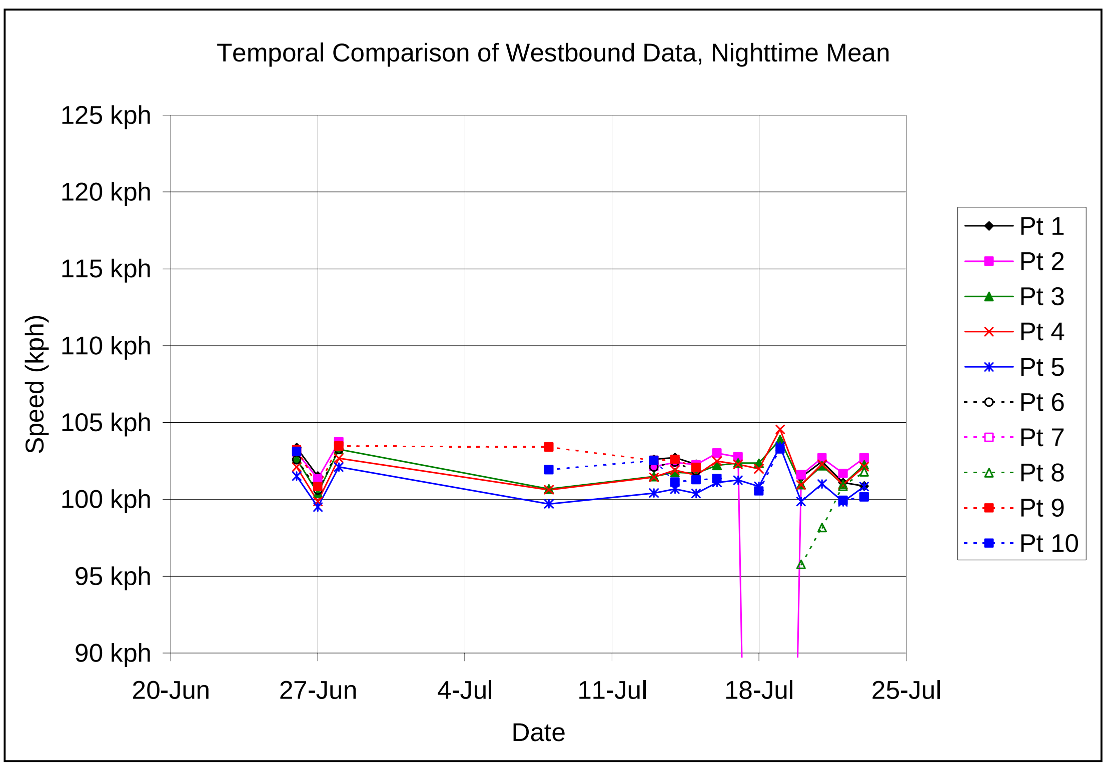

Temporal Change in Speeds, Night, Pt 7
Speed (kph)
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile

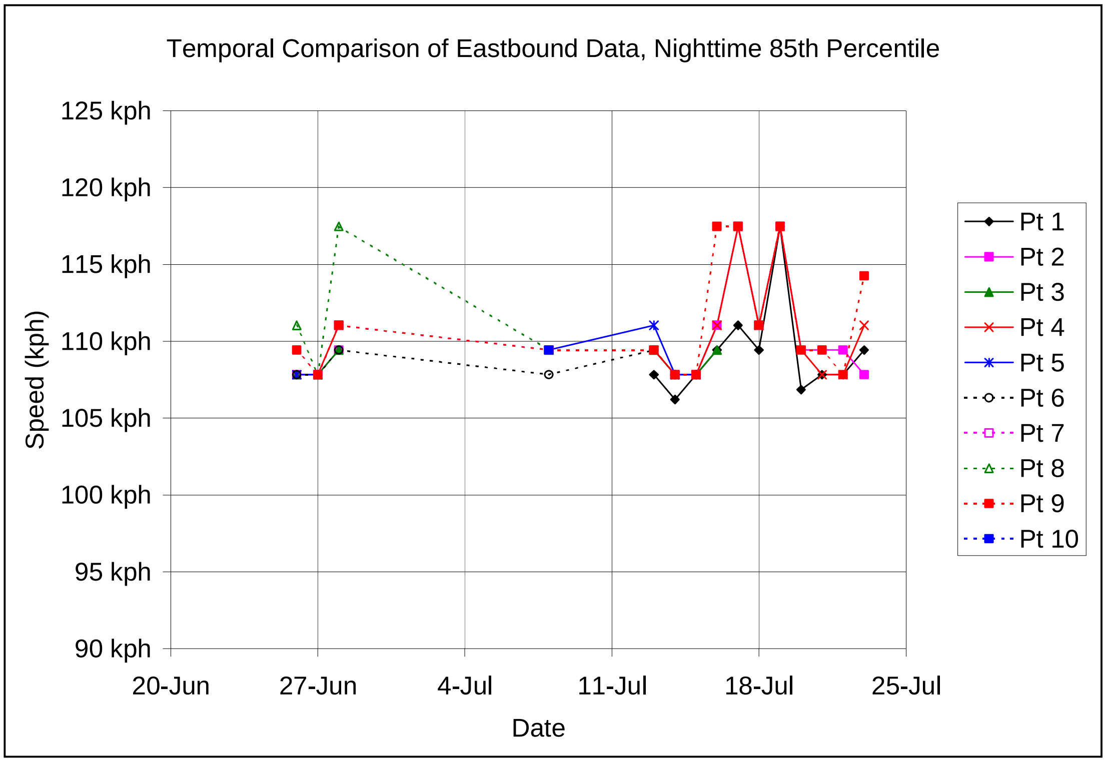

Temporal Change in Speeds, Night, Pt 8
Speed (kph)
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile

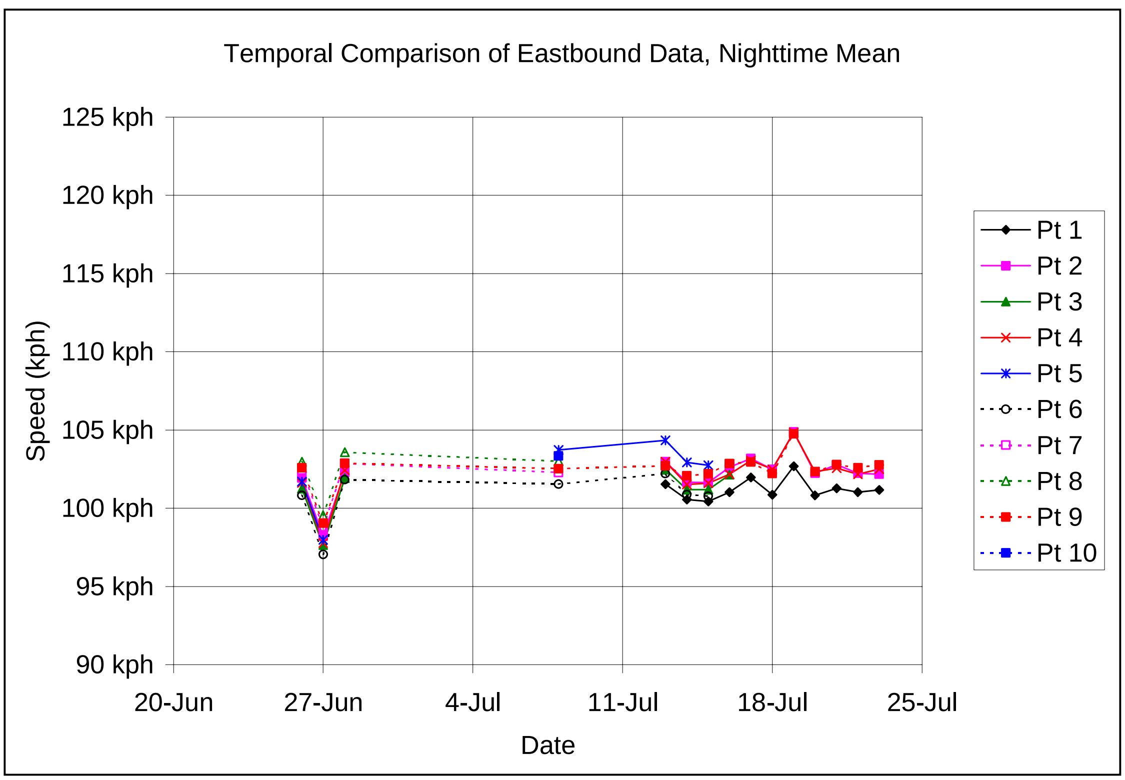

Temporal Change in Speeds, Night, Pt 9
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
Speed (kph)
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile


Temporal Change in Speeds, Night, Pt 10
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
Speed (kph)
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
WB Mean
EB Mean
WB 85th%tile
EB 85th%tile


Temporal Comparison of Westbound Data, Nighttime 85th Percentile
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
Speed (kph)
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
Pt 1
Pt 2
Pt 3
Pt 4
Pt 5
Pt 6
Pt 7
Pt 8
Pt 9
Pt 10


Temporal Comparison of Westbound Data, Nighttime Mean
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
Speed (kph)
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
Pt 1
Pt 2
Pt 3
Pt 4
Pt 5
Pt 6
Pt 7
Pt 8
Pt 9
Pt 10


Temporal Comparison of Eastbound Data, Nighttime 85th Percentile
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
Speed (kph)
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
Pt 1
Pt 2
Pt 3
Pt 4
Pt 5
Pt 6
Pt 7
Pt 8
Pt 9
Pt 10


Temporal Comparison of Eastbound Data, Nighttime Mean
125 kph
120 kph
115 kph
110 kph
105 kph
100 kph
95 kph
90 kph
Speed (kph)
20-Jun
27-Jun
4-Jul
11-Jul
18-Jul
25-Jul
Date
Pt 1
Pt 2
Pt 3
Pt 4
Pt 5
Pt 6
Pt 7
Pt 8
Pt 9
Pt 10

APPENDIX K: SPEED REDUCTION DATA

Daytime (6/26/99, 12:00pm to 6/26/99, 2:00pm)			
Total records	1656		
Full records	1490	90%	Pct matched at all 6 data points
Full FF records	331	22%	Pct of full recs with >=5 sec headway
Cars	252		
Trucks	79	24%	Pct trucks (FF only)

Nighttime (6/25/99, 10:00pm to 6/26/99, 5:00am)			
Total records	1520		
Full records	1241	82%	Pct matched at all 6 data points
Full FF records	703	57%	Pct of full recs with >=5 sec headway
Cars	536		
Trucks	167	24%	Pct trucks (FF only)

	Speed (kph)					
Data Point	1	2	3	4	5	6
Count	252	252	252	252	252	252
Min	49.8	85.4	85.0	85.4	84.3	85.6
Max	121.4	122.1	121.1	120.2	120.2	122.1
Median	100.2	100.1	99.3	99.9	98.7	99.8
Average	100.9	100.7	100.3	100.2	99.2	100.6
Conf Int (95%)	0.9	0.8	0.8	0.8	0.8	0.8
StdDev	7.3	6.3	6.2	6.1	6.1	6.4
85th %ile	108.2	107.7	106.6	106.5	105.2	106.6

	Cumulative Speed Change (kph)				
Data Point	1-2	1-3	1-4	1-5	1-6
Min	-15.5	-17.3	-13.3	-14.8	-18.6
Max	38.9	40.3	43.6	44.4	46.7
Median	-0.2	-0.4	-0.5	-1.4	0.0
Average	-0.2	-0.6	-0.7	-1.7	-0.3
Conf Int (95%)	0.4	0.5	0.5	0.6	0.6
StdDev	3.6	4.3	4.4	4.6	5.1
Correlation (r)	-0.49	-0.52	-0.55	-0.55	-0.50

Cars, Daytime

	Speed (kph)					
Data Point	1	2	3	4	5	6
Count	536	536	536	536	536	536
Min	80.9	80.3	80.3	80.4	80.0	81.5
Max	137.0	135.3	134.9	135.0	134.3	144.7
Median	103.8	103.8	103.1	102.9	101.5	103.3
Average	105.0	104.7	104.3	104.2	103.1	104.7
Conf Int (95%)	0.7	0.7	0.7	0.7	0.7	0.7
StdDev	8.1	8.3	8.2	8.3	8.1	8.5
85th %ile	113.2	113.2	112.6	112.5	111.3	112.9

	Cumulative Speed Change (kph)				
Data Point	1-2	1-3	1-4	1-5	1-6
Min	-14.6	-23.9	-22.1	-21.3	-20.1
Max	9.3	11.1	12.8	21.7	32.1
Median	-0.4	-0.5	-0.4	-1.5	0.0
Average	-0.3	-0.8	-0.8	-2.0	-0.4
Conf Int (95%)	0.2	0.3	0.3	0.3	0.4
StdDev	2.4	3.3	3.8	4.0	4.3
Correlation (r)	-0.10	-0.17	-0.19	-0.24	-0.18

Cars, Nighttime

Speed (kph)						
Data Point	**1**	**2**	**3**	**4**	**5**	**6**
Count	79	79	79	79	79	79
Min	82.9	83.2	84.2	84.1	81.3	80.9
Max	110.0	109.3	108.4	108.4	106.2	110.5
Median	98.4	98.1	97.6	96.9	96.6	97.8
Average	98.4	98.0	97.4	97.3	96.3	97.6
Conf Int (95%)	1.3	1.3	1.3	1.3	1.3	1.3
StdDev	5.7	5.8	5.8	5.8	5.6	5.8
85th %ile	104.3	103.7	103.6	104.0	102.5	103.5

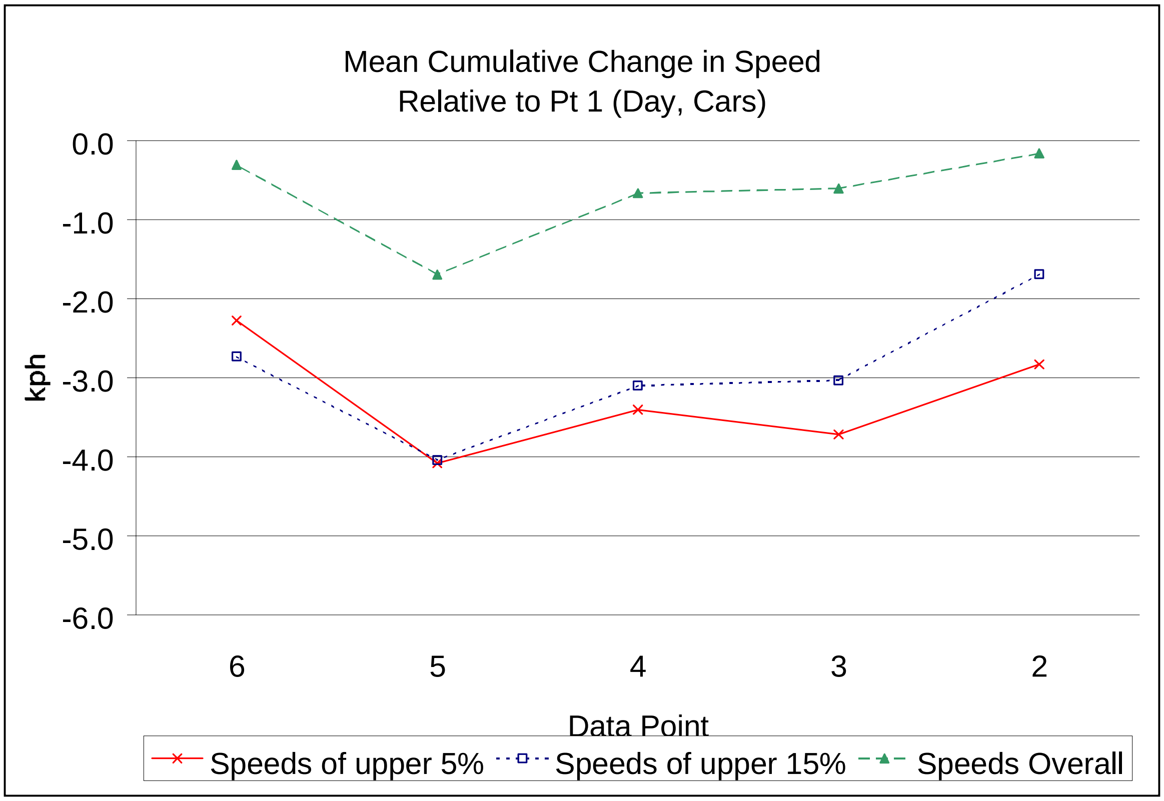
Cumulative Speed Change (kph)					
Data Point	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**
Min	-6.9	-10.2	-9.1	-11.7	-13.3
Max	3.7	4.2	5.9	6.1	9.4
Median	-0.3	-0.4	-0.2	-1.2	-0.1
Average	-0.3	-1.0	-1.1	-2.1	-0.8
Conf Int (95%)	0.4	0.5	0.6	0.7	0.7
StdDev	1.8	2.4	2.8	2.9	3.2
Correlation (r)	-0.08	-0.18	-0.21	-0.31	-0.26

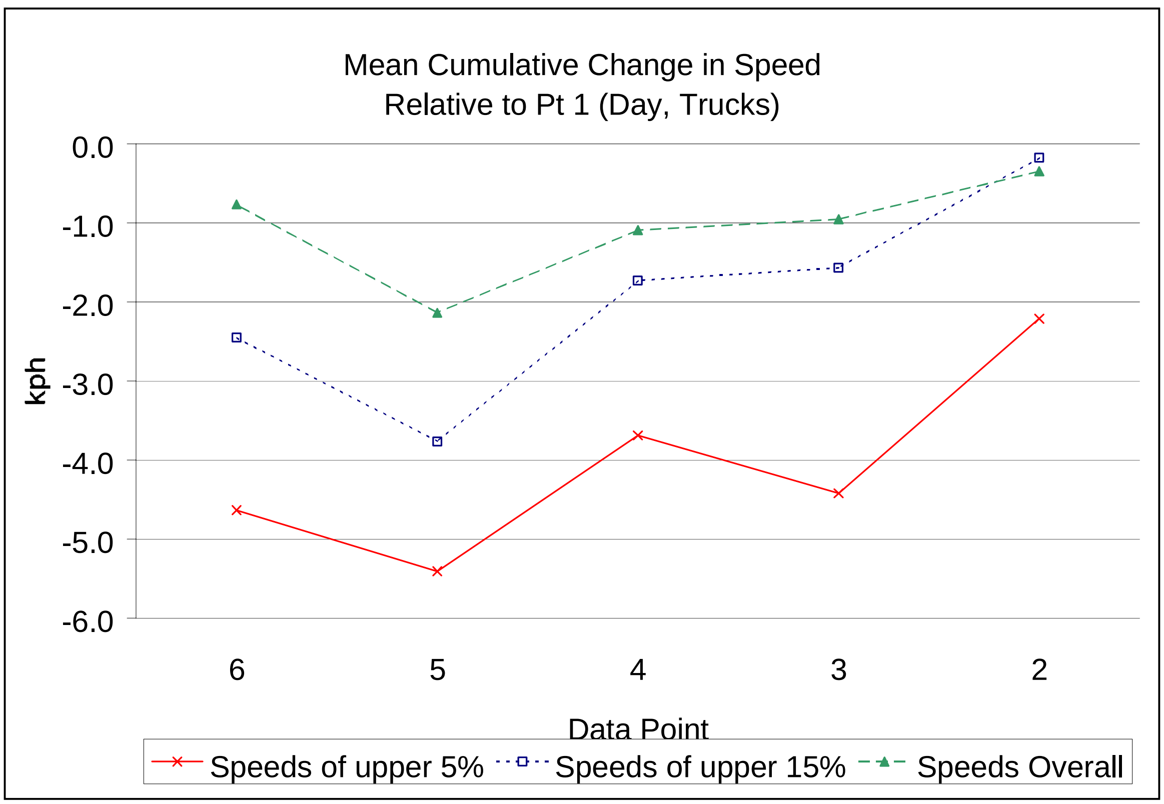
Heavy Vehicles, Daytime

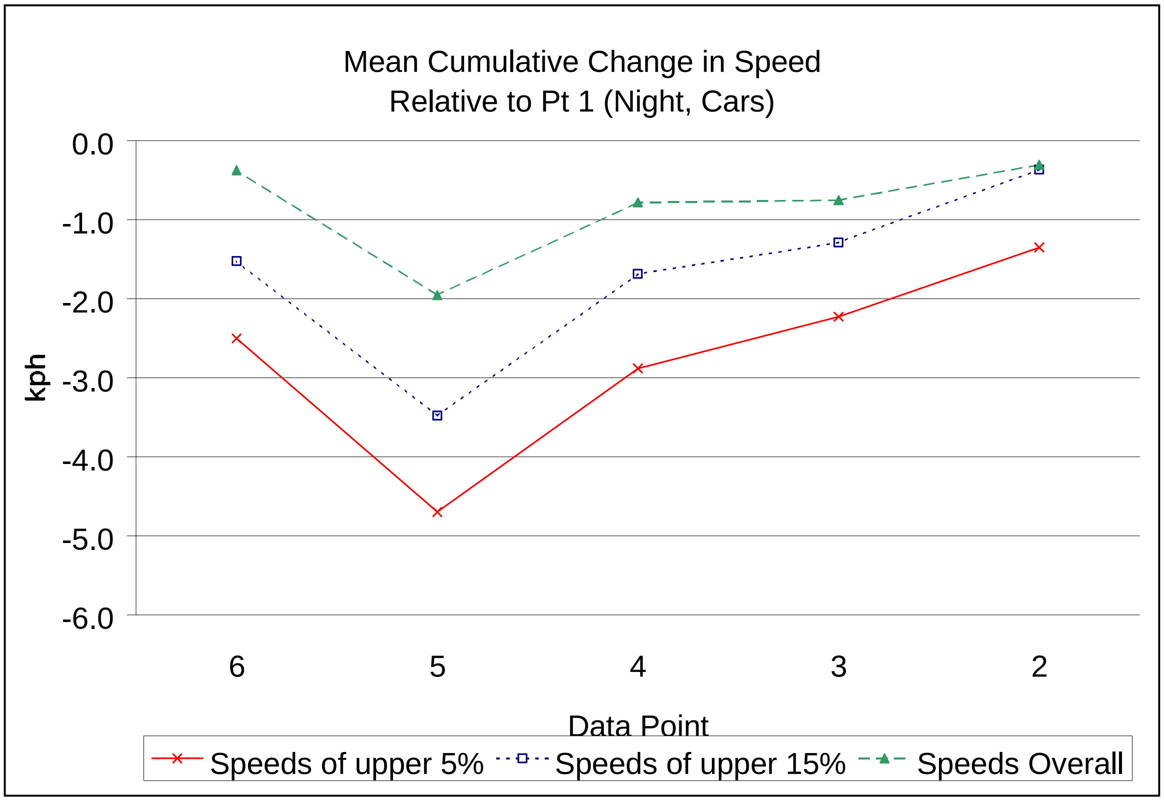
Speed (kph)						
Data Point	**1**	**2**	**3**	**4**	**5**	**6**
Count	167	167	167	167	167	167
Min	85.3	84.8	84.1	84.6	84.0	84.9
Max	128.2	127.1	127.4	128.0	126.2	128.5
Median	101.0	100.9	100.3	100.1	98.8	100.2
Average	101.7	101.4	101.0	100.8	99.6	101.2
Conf Int (95%)	1.1	1.1	1.1	1.1	1.1	1.1
StdDev	6.9	7.0	7.2	7.3	7.0	7.0
85th %ile	106.8	107.0	106.3	106.1	105.3	106.7

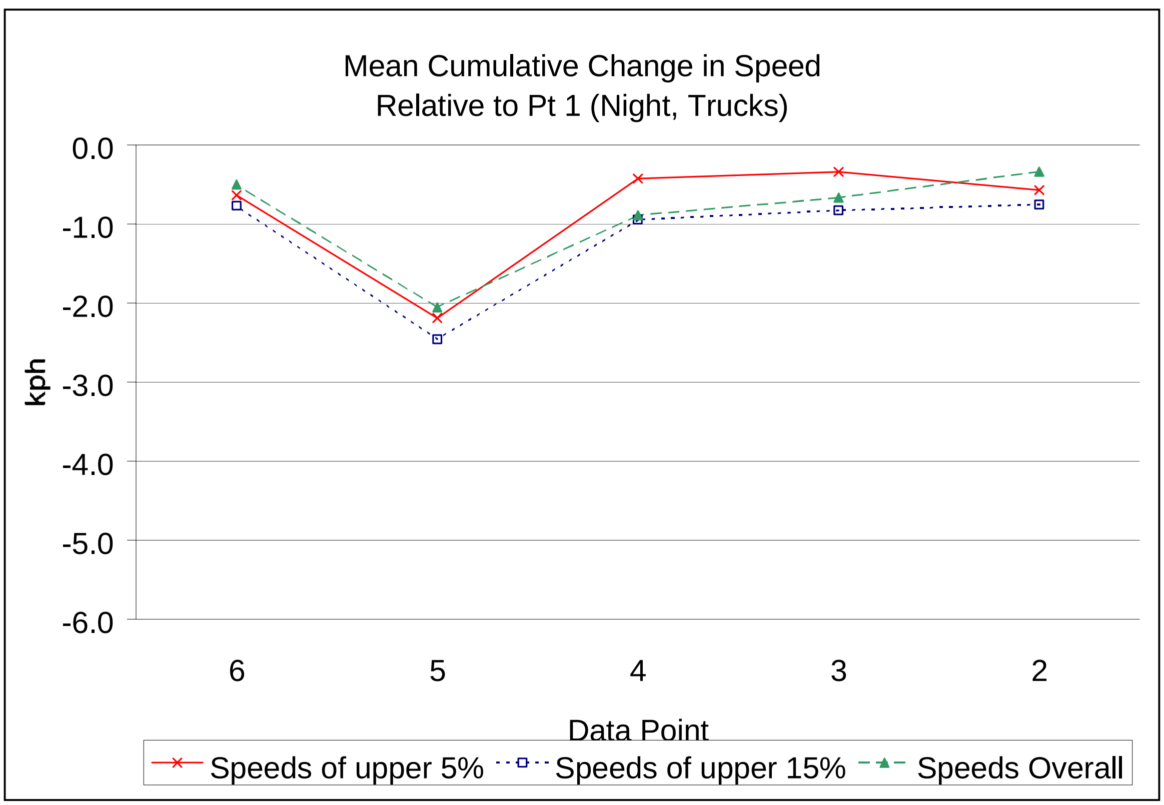
Cumulative Speed Change (kph)					
Data Point	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**
Min	-6.9	-7.8	-7.7	-9.9	-8.6
Max	10.4	6.0	7.8	7.3	8.2
Median	-0.4	-0.5	-0.5	-1.6	-0.2
Average	-0.3	-0.7	-0.9	-2.1	-0.5
Conf Int (95%)	0.3	0.3	0.4	0.4	0.4
StdDev	1.7	2.0	2.3	2.5	2.6
Correlation (r)	-0.08	0.00	0.01	-0.13	-0.15

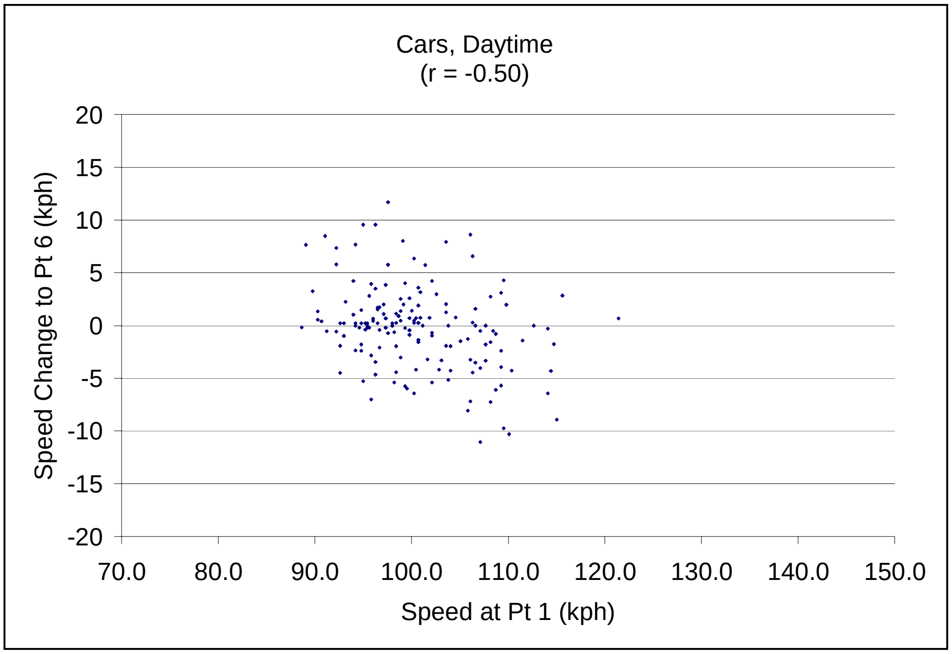
Heavy Vehicles, Nighttime

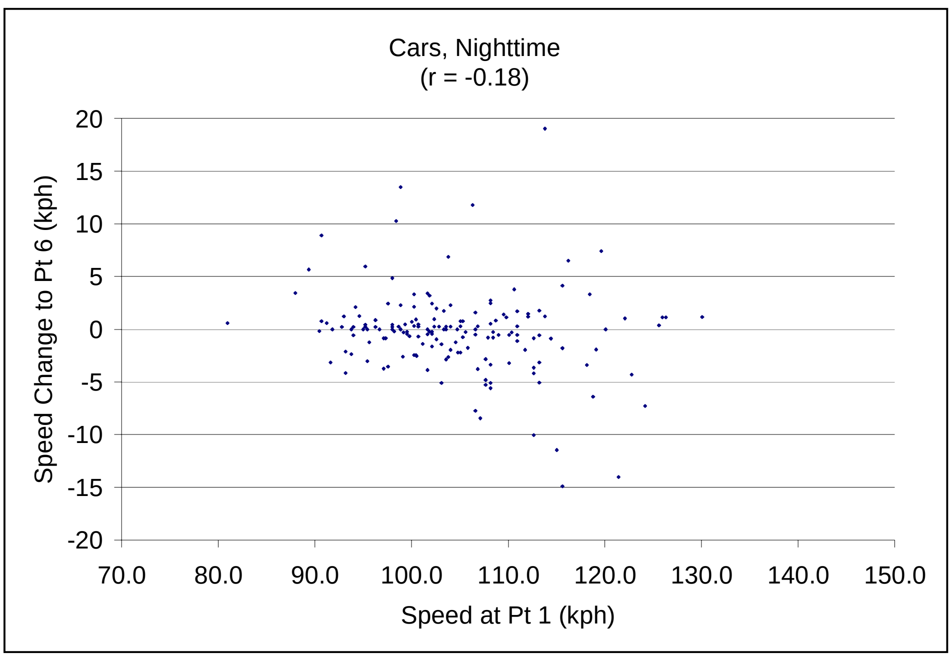

Mean Cumulative Change in Speed
Relative to Pt 1 (Day, Cars)
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
kph
6
5
4
3
2
Data Point
Speeds of upper 5%
Speeds of upper 15%
Speeds Overall

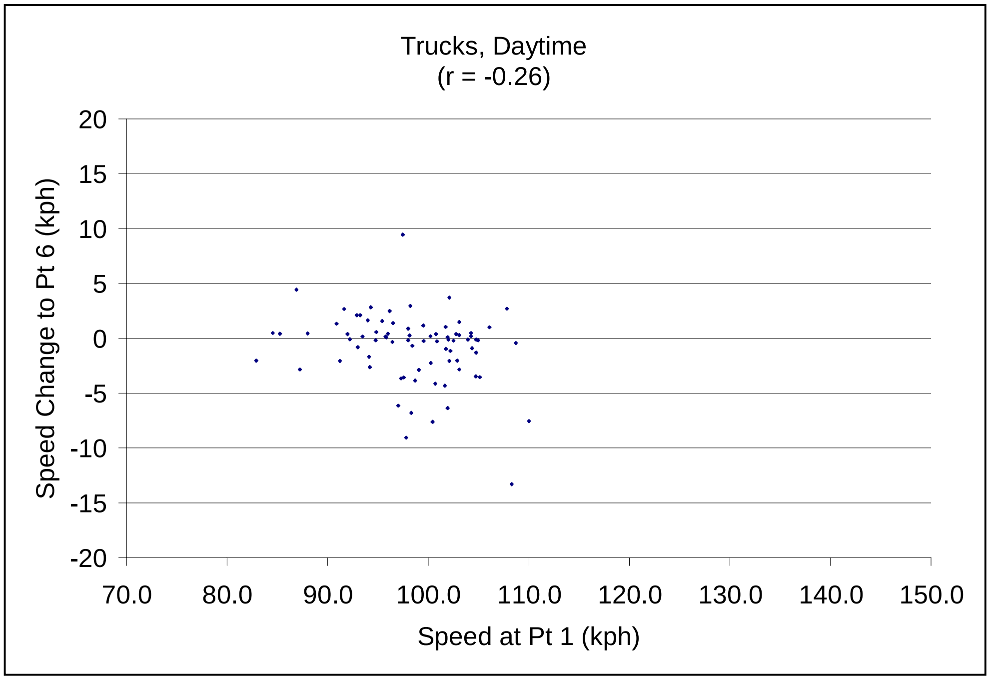

Mean Cumulative Change in Speed
Relative to Pt 1 (Day, Trucks)
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
kph
6
5
4
3
2
Data Point
Speeds of upper 5%
Speeds of upper 15%
Speeds Overall

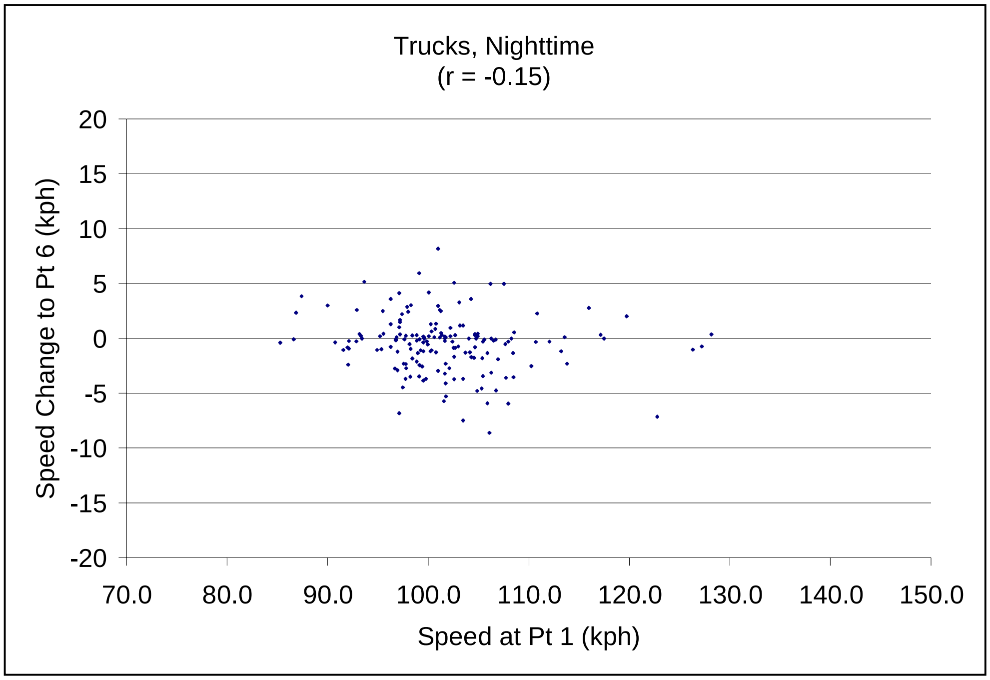

Mean Cumulative Change in Speed
Relative to Pt 1 (Night, Cars)
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
kph
6
5
4
3
2
Data Point
Speeds of upper 5%
Speeds of upper 15%
Speeds Overall


Mean Cumulative Change in Speed
Relative to Pt 1 (Night, Trucks)
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
kph
6
5
4
3
2
Data Point
Speeds of upper 5%
Speeds of upper 15%
Speeds Overall

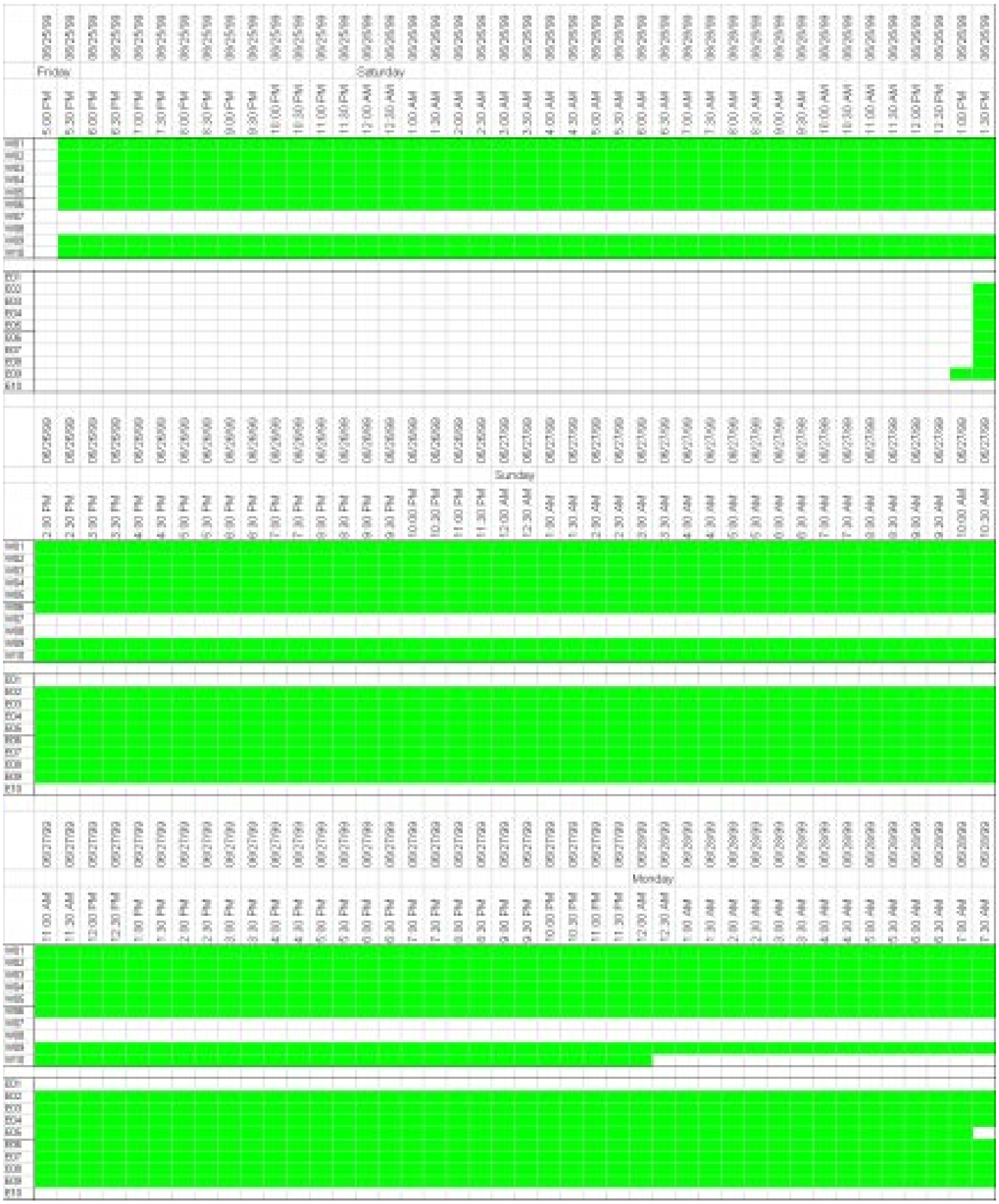

Cars, Daytime
(r = -0.50)
Speed Change to Pt 6 (kph)
20
15
10
5
0
-5
-10
-15
-20
70.0
80.0
90.0
100.0
110.0
120.0
130.0
140.0
150.0
Speed at Pt 1 (kph)


Cars, Nighttime
(r = -0.18)
Speed Change to Pt 6 (kph)
20
15
10
5
0
-5
-10
-15
-20
70.0
80.0
90.0
100.0
110.0
120.0
130.0
140.0
150.0
Speed at Pt 1 (kph)

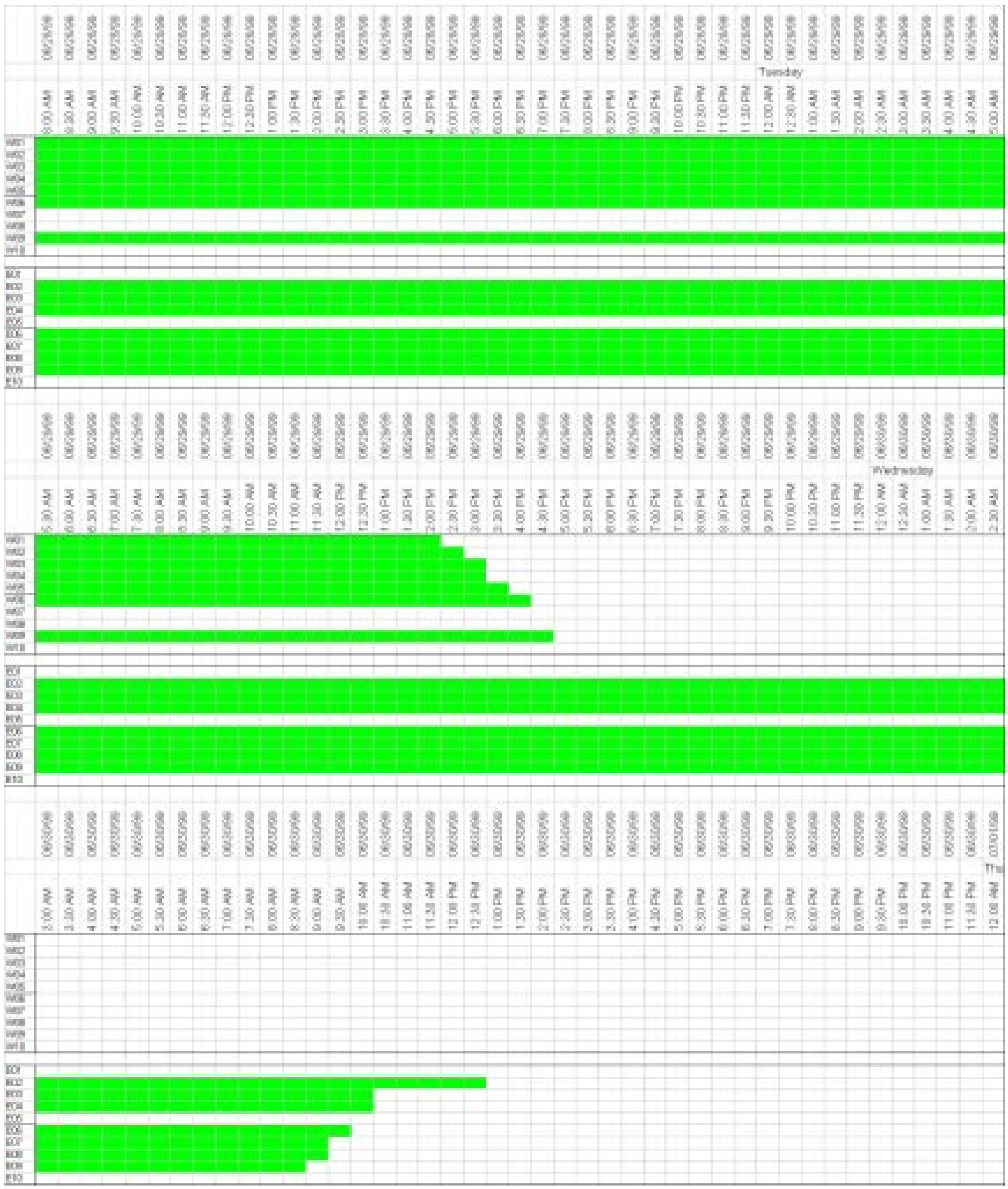

Trucks, Daytime
(r = -0.26)
Speed Change to Pt 6 (kph)
20
15
10
5
0
-5
-10
-15
-20
70.0
80.0
90.0
100.0
110.0
120.0
130.0
140.0
150.0
Speed at Pt 1 (kph)


Trucks, Nighttime
(r = -0.15)
Speed Change to Pt 6 (kph)
20
15
10
5
0
-5
-10
-15
-20
70.0
80.0
90.0
100.0
110.0
120.0
130.0
140.0
150.0
Speed at Pt 1 (kph)

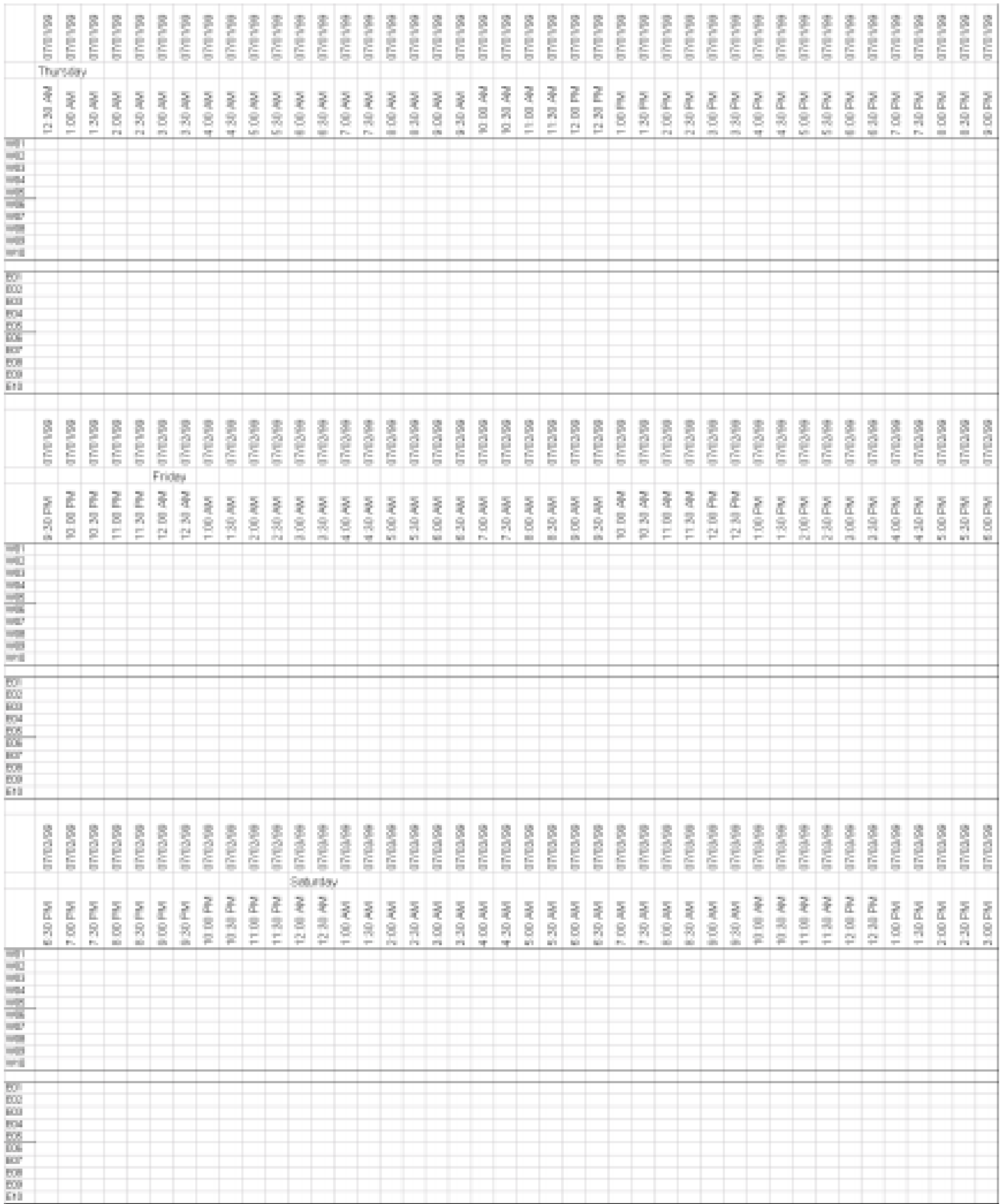
APPENDIX L: DATA COLLECTION TIMELINE



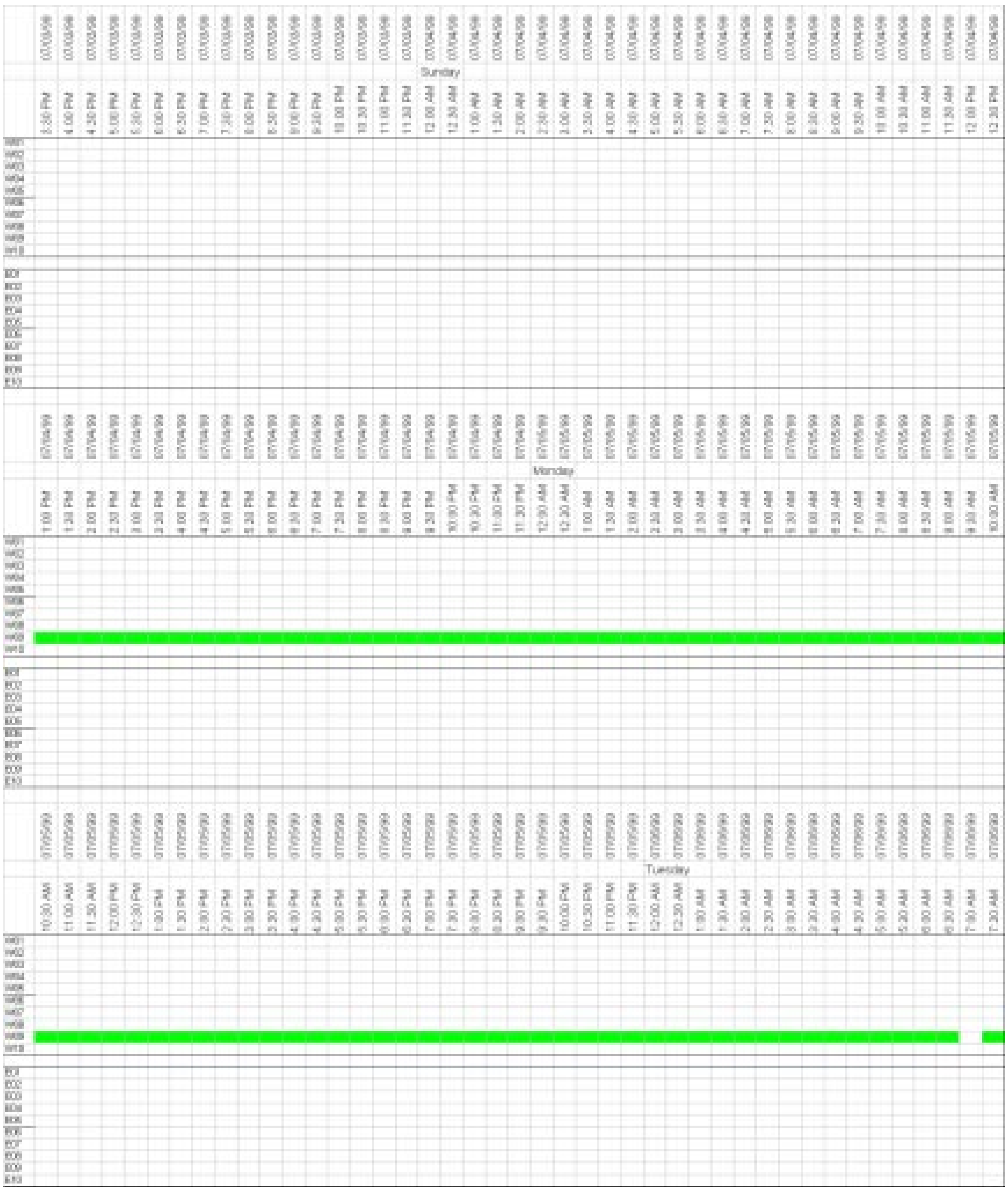
Data Collection Timeline (Continued)



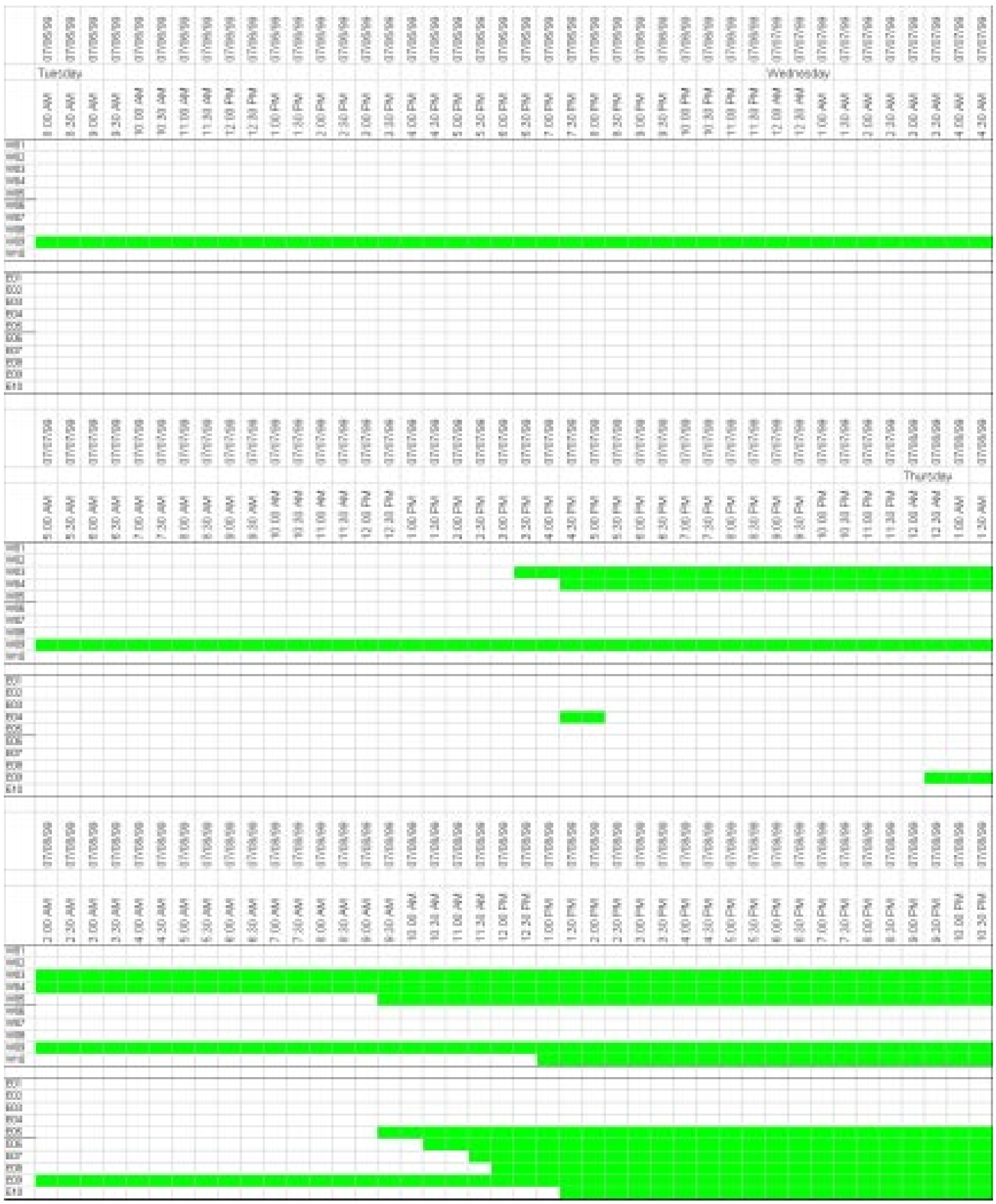
Data Collection Timeline (Continued)



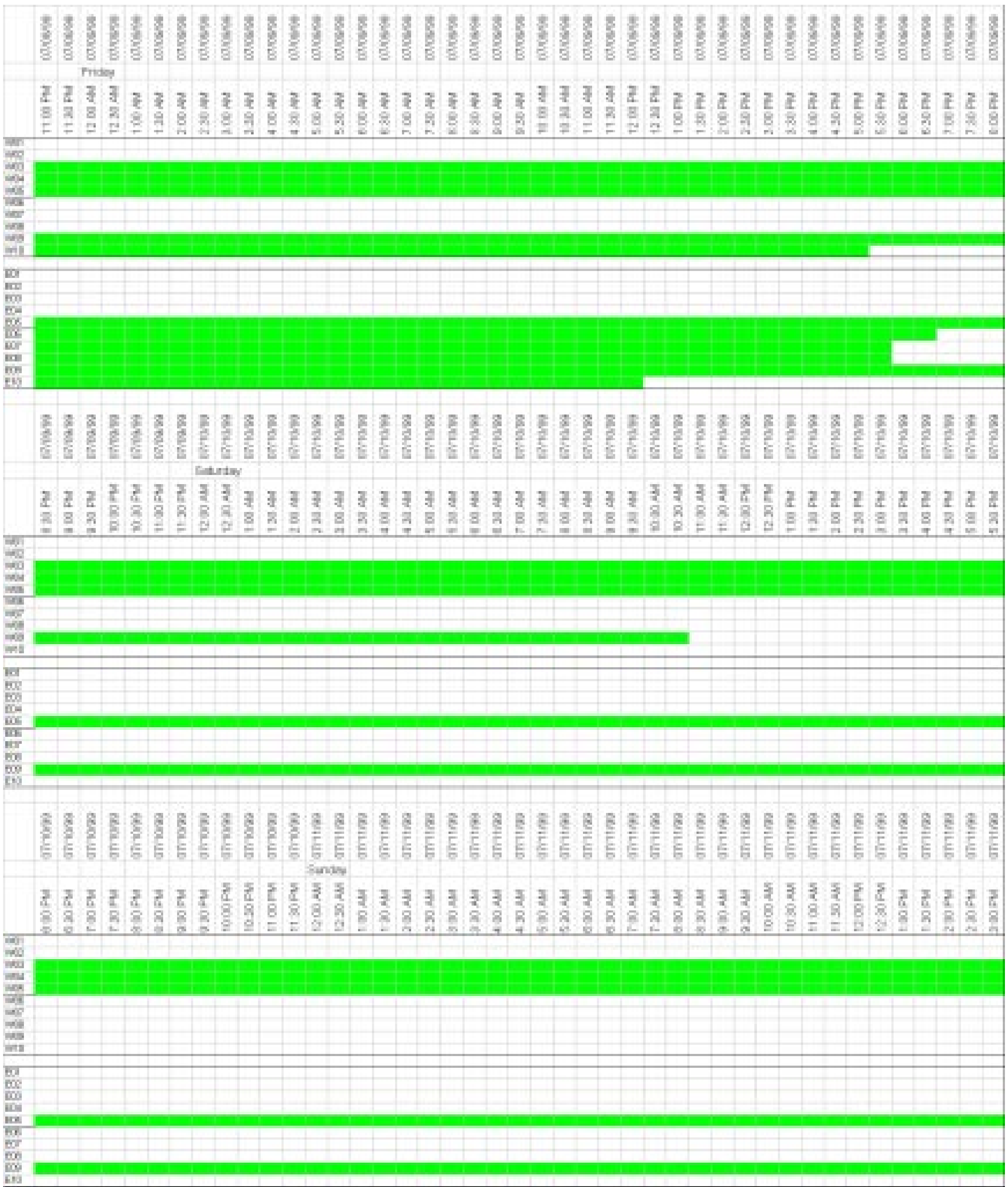
Data Collection Timeline (Continued)



Data Collection Timeline (Continued)



Data Collection Timeline (Continued)



Data Collection Timeline (Continued)

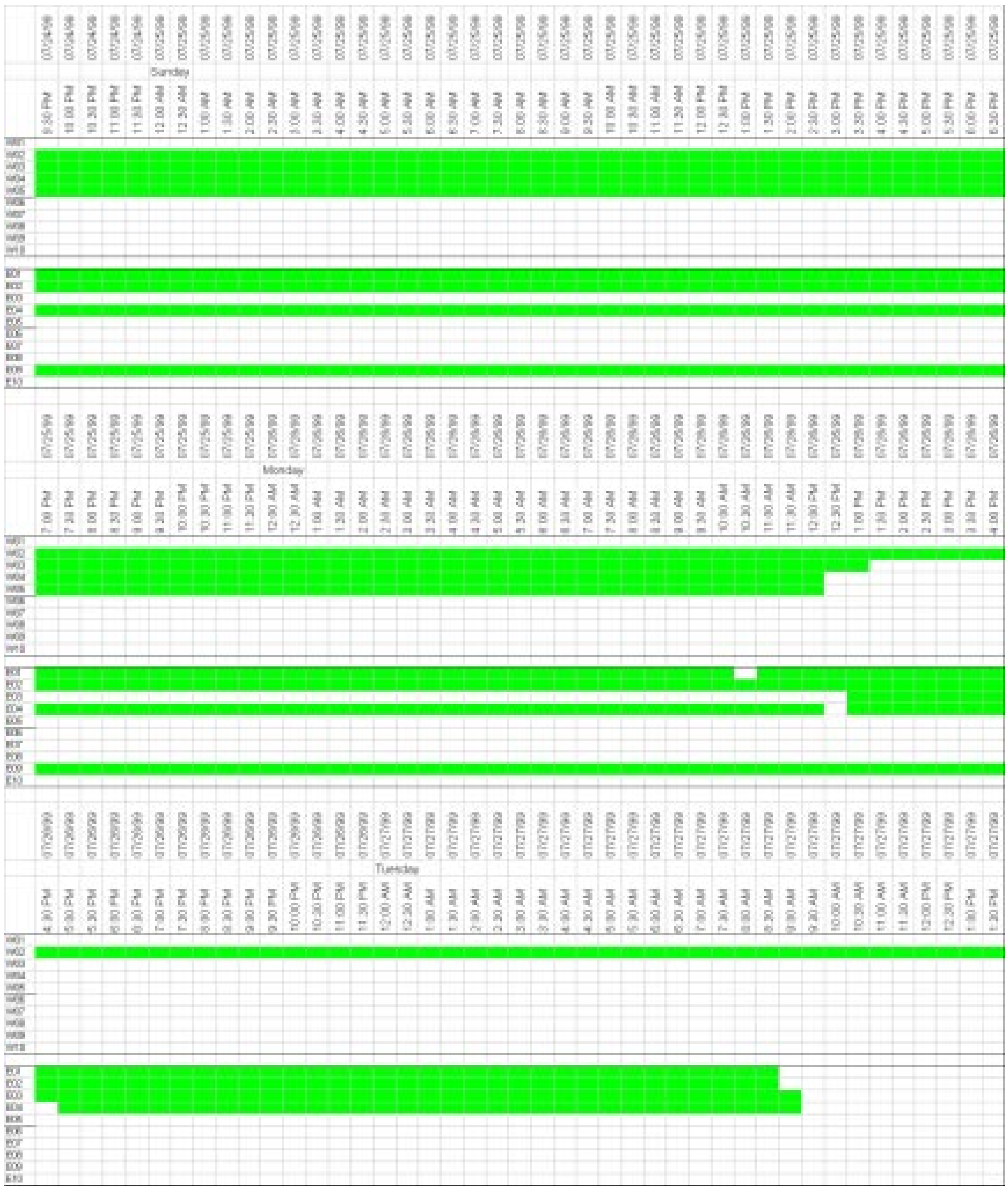
Data Collection Timeline (Continued)

Data Collection Timeline (Continued)

Data Collection Timeline (Continued)

Data Collection Timeline (Continued)

Data Collection Timeline (Continued)



Data Collection Timeline (Continued)