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Impact of Edge Lines on Safety of Rural Two-Lane Highways

by

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16. Abstract

This report documents the results of the project for “Impact of Edge Lines on Safety of Rural Two Lane Highways.” This research project was initiated in the effort of compliance with the updated version of the Manual on Uniform Traffic Control Devices (MUTCD Millennium Edition, 2000) in the subject of edge line implementation in Louisiana. The objective of this study is to investigate if the marking of edge lines on rural narrow two-lane highways would result in any negative effect on drivers’ behavior that in turn may debase highway safety. The before-and-after measurements show that: (a) edge lines help drivers confine their traveling path, particularly at night, and (b) edge lines have no or little effect on drivers’ operating speed. Conclusively, this study found that the presence of edge lines has a positive impact and the magnitude of the impact is influenced by such factors as roadway width, operating speed, time of the day, frequency of heavy vehicles, pavement condition, roadway alignment, and traffic in the opposing direction. The results obtained from this project can serve as a guideline for implementation by transportation agencies in Louisiana for general conformance with the MUTCD on edge line markings for narrow rural roadways.

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ABSTRACT

This research project was initiated to comply with the updated version of the Manual on Uniform Traffic Control Devices (MUTCD Millennium Edition, 2000) regarding edge line implementation in Louisiana. The objective of this study was to investigate if marking edge lines on rural narrow two-lane highways would result in any negative effect on drivers behavior that could in turn decrease highway safety. The before-and-after measurements show that: (a) edge lines help drivers confine their traveling path, particularly at night, and (b) edge lines have little or no effect on drivers' operating speed. This study found that the presence of edge lines has a positive impact and that the magnitude of the impact is influenced by such factors as roadway width, operating speed, time of the day, frequency of heavy vehicles, pavement condition, roadway alignment, and traffic in the opposition direction. The results from this project provide a guideline that Louisiana transportation agencies can implement for general conformance with the MUTCD on edge line markings for narrow rural roadways.

ACKNOWLEDGEMENTS

This project was supported by the Louisiana Department of Transportation and Development (LADOTD) through the Louisiana Transportation Research Center (LTRC). The help and guidance received throughout this project from the project review committee is gratefully acknowledged.

IMPLEMENTATION STATEMENT

The implementation of this project as a tool to enhance highway safety should lead to the establishment of an internal policy on edge line marking for Louisiana's rural narrow two-lane highway system. The results and recommendations presented in this report can be used by LADOTD'S traffic division for the funding and prioritizing of projects on the two-lane highway system. In particular, LADOTD and its jurisdictional transportation agencies can apply the outcome of this project on their rural highways to a comprehensive highway safety improvement plan.

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INTRODUCTION

Rural two-lane highways in Louisiana carry one-third of the total vehicle miles traveled (VMT) and have experienced a considerably high percentage of fatal crashes. Each year, more than half of all fatal crashes have occurred on this type of highway, where the dominant crash types are head-on collision and running-off-roadways (ROR). Strategic studies have been conducted accordingly to address this problem.

Proper pavement marking would be an inexpensive countermeasure to reduce incidents. Marking edge lines is expected to provide a visual guide, which would help confine vehicles within the traveled lane. The effects of edge lines were documented in a number of past studies, and the Manual on Uniform Traffic Control Devices (MUTCD) provides the guidelines for edge line implementation. However, rural two-lane highways with narrower lane widths caused concern, namely the presence of edge lines would influence drivers to operate closer to the centerline, increasing the risks of head-on and sideswipe crashes. While LaDOTD makes efforts to comply with the updated MUTCD, concerns arise on the installation of edge lines on narrow rural two-lane highways. It has been widely suspected that edge lines on narrow roadways may make motorists operate vehicles closer to the centerline, and thus increase the risk of head-on and sideswipe collisions.

This study demonstrated the impact of edge line markings on rural narrow highways and recommended a guideline for the application of edge line markings on rural highways in Louisiana. It focused on two-lane highways between 20 and 22 feet wide. The proposed guideline may be adopted for implementation by the Louisiana Department of Transportation and Development (LADOTD) to conform the updated MUTCD on the edge line markings of rural narrow roadways.

OBJECTIVES

The goal of this project was to determine if the implementation of edge lines on narrow rural roadways has any negative impact on driver behavior that affects highway safety. Specifically, the objectives were to:

- Review and document the results of past and present research and the current practices for the application of edge line marking on narrow rural two-lane highways,
- Investigate the impact of edge line marking on the wheel tracking of vehicles under various roadway alignment and traffic conditions,
- Examine the potential tort liability arising from the implementation of edge line markings on narrow two-lane highways, and
- Develop a recommended guideline for the application of edge line markings on two-lane highways in Louisiana.

SCOPE OF WORK

The study was conducted on the selected rural two-lane highways in Louisiana that are between 20 and 22 feet wide. The variables considered in the analysis were highway geometry (pavement width, pavement condition, road alignment, and degree of curvature) and traffic conditions (traffic volume, operating speed, and percentage of heavy vehicles).

METHODOLOGY

Project Background

The two-lane highway is the oldest and most common type of roadway in the U.S. Many of them were constructed under standards that have become obsolete. Although rural two-lane highways in Louisiana carry only about 34 percent of total vehicle-miles traveled, these highways experience the highest percentage of fatal crashes from running-off-roadway and head-on collisions. Analysis of the Louisiana state highway crash data reveals that, on average, between 2000 and 2003, 50 percent of total fatal crashes occurred on rural two-lane highways; 69 percent of those were classified as a running-off-roadway and 62 percent as head-on collisions. As clearly shown in Table 1, rural two-lane highways experience a high frequency of running-off-roadway and head-on collisions crashes. These crash types on two-lane highways are typically more fatal than those on other types of highways.

Generally, motorists rely on a complex series of visual cues to safely navigate on highways. Traffic control devices are a significant source of information for motorists. The Manual on Uniform Traffic Control Devices (MUTCD) defines the standards adopted by public agencies to install and maintain traffic control devices on all streets and highways. The MUTCD ensures that public agencies apply traffic signs, signals and pavement markings in a uniform manner so that the cues provided to motorists are consistent throughout the country. To incorporate new technical advances and to clarify standards, the MUTCD has undergone numerous updates. The latest edition, the Millennium edition of MUTCD, has several important changes that require compliance by state DOTs and other public agencies responsible for erecting and maintaining traffic control devices [1].

Table 1

Crash statistics in Louisiana highway system

	All State Highways		Rural Two-lane Highways	
	All Crashes	Fatal Crashes	All Crashes	Fatal Crashes
Year 2000				
All Types of Crashes	77,361	658	18,687(24%)	342 (52%)
Head-on	10,495	237	5,739 (55%)	155 (65%)
Run-off-roadway	7,307	234	4,447(61%)	161(69%)
Year 2001				
All Types of Crashes	86204	696	18357(21%)	334(48%)
Head-on	12339	267	6326(51%)	168(63%)
Run-off-roadway	8187	235	4823(59%)	154(66%)
Year 2002				
All Types of Crashes	99943	658	19057(19%)	344(52%)
Head-on	13966	262	6930(50%)	162(62%)
Run-off-roadway	8632	225	5190(60%)	161(72%)
Year 2003				
All Types of Crashes	96219	649	17893(19%)	321(49%)
Head-on	14198	280	6878(48%)	166(59%)
Run-off-roadway	8336	225	4930(59%)	151(67%)

One of the updates in the Millennium MUTCD concerns the application of edge line markings on rural arterial roadways. In particular, Section 3B.07 of the MUTCD requires the use of edge line markings on rural arterials with a traveled way of 20-feet or more in width and an ADT of 6,000 vehicles per day or greater (see Appendix A). Previous editions of the MUTCD were less specific regarding the actual criteria for the application of edge lines[2].

In response to the previous editions of the MUTCD, (LADOTD) developed an internal policy in response to the previous editions of the MUTCD to place the edge lines on roadways that are 22feet wider regardless of ADT [3]. Considering the total mileage (5,096 miles) of existing narrow rural roadways with a traveled width between 20 and 22feet in the state highway system, LaDOTD's roadway striping program requires additional resources to comply with the Millennium edition of the MUTCD.

In addition to monetary, staffing, and equipment concerns, compliance with the requirement on edge lines on rural roadways may or may not improve highway safety. Edge lines on narrow roadways may make motorists operate vehicles closer to the centerline, resulting in an increased risk of head-on and sideswipe collisions. Therefore, a thorough investigation of this concern and a study on the legal liability of edge line marking implementation are necessary before LADOTD generates a policy and implements the new edge line requirement contained in the latest edition of MUTCD.

Past Studies on the Impact of Edge Lines

Many past studies have investigated the impact of edge line markings on lateral placement of vehicles, operating speed, crashes, and drivers' comfort level. The following introduces the literature that provides an insight into the impact of edge line markings on highway safety.

In 1958, Thomas conducted a study on rural 24-foot surfaces in Louisiana [4]. The purpose of the study was to determine the effect, if any, that a dashed or continuous line at various distances from the pavement edge has on the lateral placement of vehicles. The study was conducted on four test sections-each being on tangent alignment in a rural area. Vehicle speed and type of vehicle were observed separately during daylight and darkness by various maneuvers, such as free moving, meeting, and passing at each of the locations.

This study showed that the psychological effect on a majority of vehicle drivers is the only benefit from pavement edge lines. The tendency of vehicles to move towards the center of edge-striped pavements did not appear significantly enough large to create any abnormal hazard on a 24-foot surface, as shown in figure 1. In 1960, the author repeated the study at a different location in Louisiana [5]. One of the additions to the previous study was the inclusion of a 20foot wide tangent roadway section. While the study on 24-foot surfaces yielded the same result as the previous study, the study on 20-foot tangent sections showed that for free–flowing vehicles, both passenger cars and commercial vehicles moved closer to the centerline. This tendency to move closer to the centerline after the marking of edge lines was also present when passenger cars met other passenger cars traveling in the other direction.

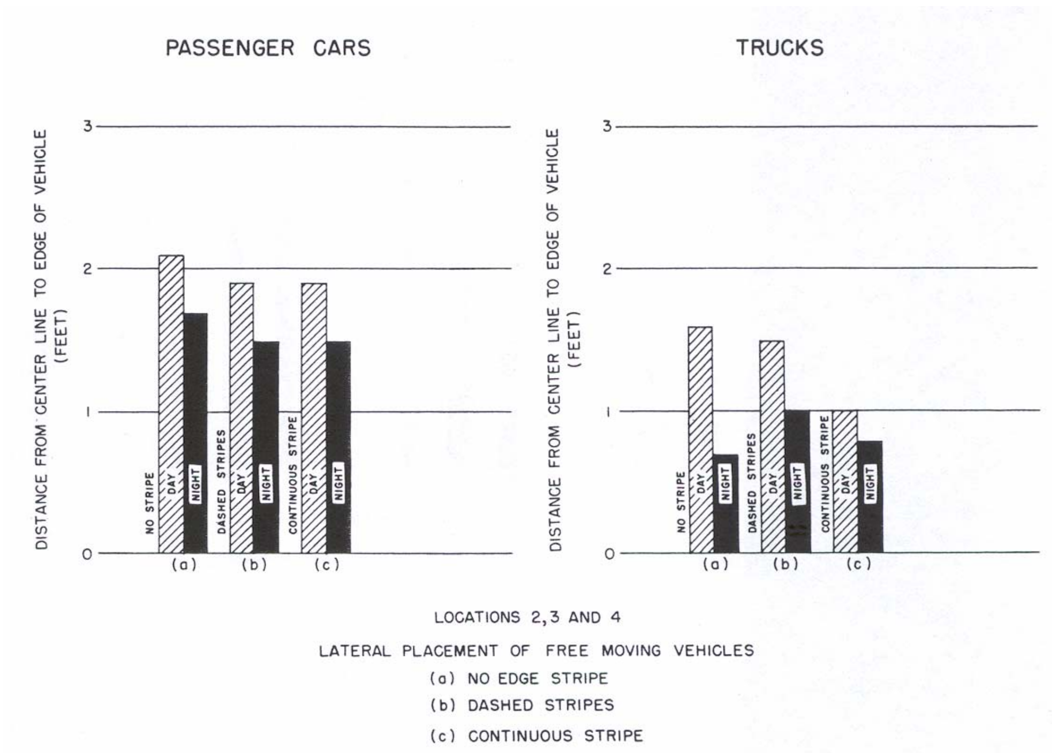


Figure 1
Lateral placement on various edge line configurations (source: [4])

The Ohio Department of Highways studied the effect of pavement edge marking on crashes with nine pairs of rural two-lane highways in 1960 [6]. It concluded the use of pavement edge markings resulted in a significant reduction in fatal and injury-causing crashes. Crashes at intersections, alleys, and driveways were significantly reduced but crashes between access points showed no significant change. Neither was there a significant change in daytime crashes. Nighttime crashes were reduced, but the change was statistically insignificant.

The movement of vehicles to a more centralized position was also found in the Connecticut and Missouri studies. In 1969, the Missouri State Highway Department investigated the effects of edge line stripping on driver behavior and found that vehicles generally tend to move closer to the centerline of the pavement after applying a four inch edge line under the free moving traffic conditions, assuming no interference from other vehicles [7]. They concluded that edge lines had no significant effect on average speeds, and the results were inconclusive regarding increased driver comfort after edge lining. In 1971 his study on two one-mile sections of narrow rural roads in Montgomery County, Maryland, Hassan found that vehicle placement was closer to the centerline of the pavement during the daylight after edge lines were placed for both roads [8].

In 2003, Steyvers and Waard studied the impact of edge line markings on vehicles' lateral position on narrow rural roadways in the Netherlands and concluded that edge lines may improve driving behavior on narrow rural roadways [9]. Because drivers took a more central position without dangerous negative side effects and crossed road edges less frequently, they caused less damage and less dangerous situations. They also mentioned that no problems were encountered with oncoming vehicles on the edge-lined roadways, as the vehicles in both the lanes moved to the side. This happened even though the edge lines let the vehicles move closer to the center of the road. The driving speed increased on edge-lined roadways, compared with the unlined roadways. They also mentioned in their literature review that in Louisiana, edge lines did not lead to a more central road position during daylight, but this effect was found at night

In 2002, Dewar and Olson [10] reported in their study that the lane width is an important factor influencing drivers' behavior[10]. They found that there is greater lateral displacement of vehicles on roads with narrow lanes, in comparison with roads having wider lanes. They reported that this was due to drivers' tendency to respond more to the nearness to the lane edge and suggest the marking of edge lines on narrow lanes.

In summary, many studies have concluded that drivers tended to operate closer to the centerline where edge lines were marked; however, the impact of edge lines on highway safety was not significant, or the data were inconclusive.

Crash Analysis

This section presents the results of crash analysis by lane width to investigate crash patterns on narrower highways. The analysis was conducted with the Louisiana State Highway crash data and the Louisiana Highway Needs data obtained from LADOTD. In this project, the study scope was limited to roadways with lanes between 20 and 22feet wide. Both directional lanes were assumed to be the same width. Table 2 tabulates the total mileage and vehicle-mile traveled (VMT) by lane width. The VMT was computed using equation 1, and the weighted ADT was determined as the average ADT for all road control sections by using equation 2.

$$VMT = \sum_i (Road\ Length_i \times ADT_i \times 365) \qquad (1)$$

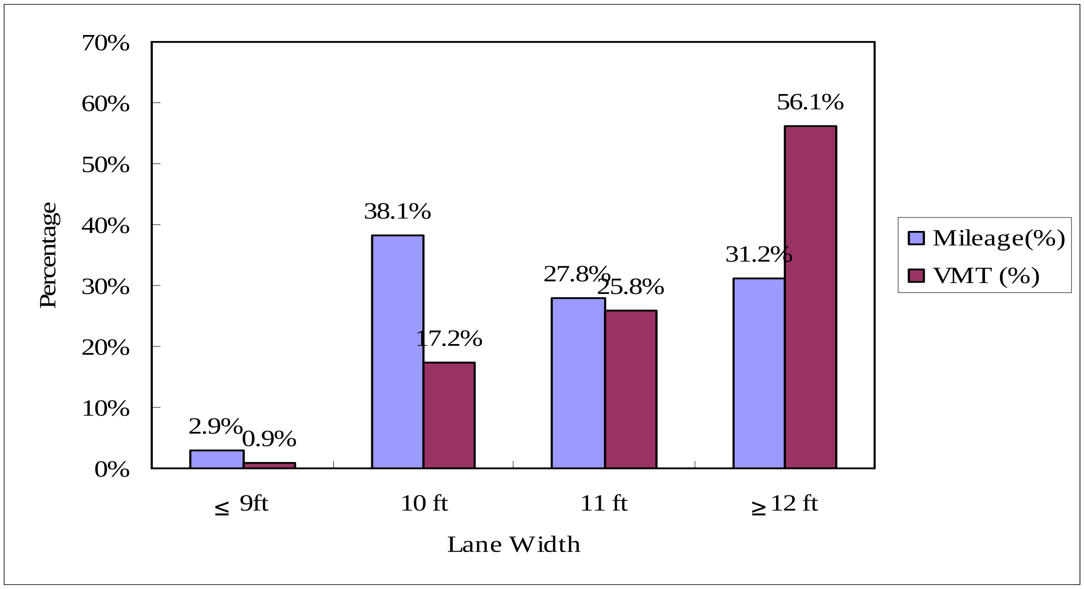
$$Weighted\ ADT = \frac{VMT}{\sum_i Road\ Length_i} \qquad (2)$$

Table 2

Statistics of total mileage and VMT of Louisiana rural two-lane highways

Lane Width	Mileage	VMT (Billion)	Weighted Average ADT
Less than or equal to 9 ft	384.9 (2.9%)	0.11 (0.9%)	714.6
10 ft	5096.5 (38.1%)	2.20 (17.2%)	1086.0
11 ft	3718.4 (27.8%)	3.03 (25.8%)	2231.6
More than or Equal to 12 ft	4169.7 (31.2%)	6.58 (56.1%)	4322.5

The percentages of the total mileage and VMT by lane width are plotted in figure 2. It shows that rural two-lane highways with lane widths of 10-feet represent 38.1 percent of the total number of two-lane rural highway but they carry only 17.2 percent of VMT. The highways with lane widths of 12-feet represent 31.2 percent of the total two-lane rural highway but carry more than half of the total VMT. Wider roadways are associated with the higher weighted ADT as shown in table 2.



Total mileage of rural two-lane highways: 13,369 mile (2002)

Figure 2
Percentage of total mileage and VMT by lane width

The Louisiana highway system recorded around 77,361 crashes in 2000. Of these crashes, 35 percent occurred in rural areas and 27 percent on two-lane rural highways, as shown in table 3. The analysis concentrated on three common types of crashes-running-off-roadway (ROR), head-on collision, and sideswipe collision with the opposite direction traffic.

The number of crashes were converted to percentages and plotted in figure 3 to compare the crash patterns between each category of lane width. The ROR crash was dominate on the rural highways with narrower lane widths. While the percentage of head-on collision was slightly higher in the most narrow roadways, the percentage of sideswipe crashes in the most narrow roadways was similar to the wider roadways.

Table 3

Number of crashes in rural two-lane highways by lane width

Year 2000	<= 9 ft	1.0 ft	11 ft	>= 12 ft	Total
All Crashes (Rural 2-lane Highway)	156	3213	5304	10072	18745
ROR (Rural 2-lane Highway)	45	1112	1386	1858	4401
Head-on (Rural 2-lane Highway)	9	102	211	241	563
Sideswipe (Rural 2-lane Highway)	2	98	138	308	546

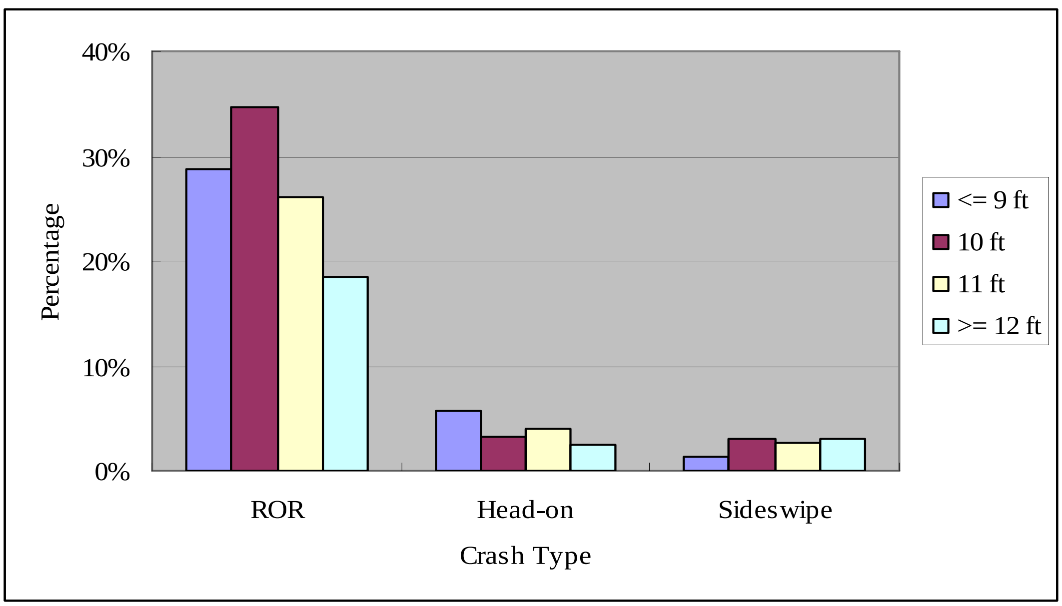


Figure 3
Percentage of crashes by crash type and lane width

While the crashes considered in table 3 and figure 3 include all severity levels, such as property damage only (PDO), injury crashes, and fatal crashes, figure 4 plots only fatal crashes. No fatal crash was reported on the roadways with lane widths of 9-feet or less.

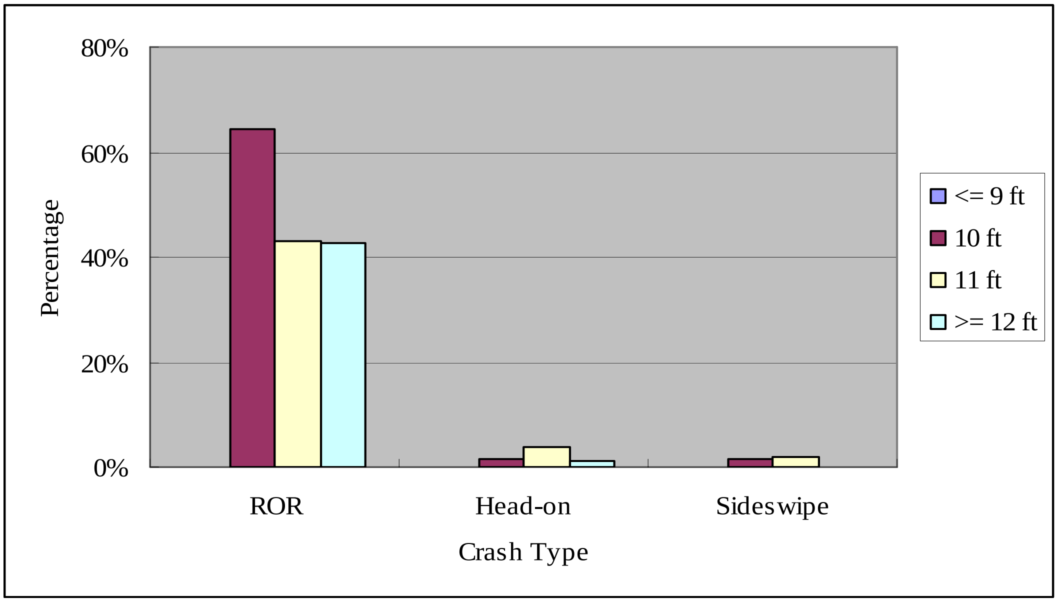


Figure 4
Percentage of fatal crashes by crash type and lane width

It is clear that 10-foot lane width roadways have the higher percentage of running-off-roadway, about 65 percent of all types of crashes, compared to the other categories of roadways. While 9-feet lane width roadways had a higher percentage of head-on crashes than did the other roadways, none of these crashes was reported as fatal. The roadways with 11-feet lane widths had a higher percentage of fatal head-on crashes. Fatal sideswipe crashes were evenly distributed between 10-feet and 11-feet lane width roadways, while no such crash was reported on the other lane widths.

In addition to crash frequency, crash rate, defined in Equation 3, is widely used in safety analysis.

$$Crash\ Rate = \frac{Number\ of\ Crashes \times 10^6}{ADT \times Length \times 365} \quad (3)$$

The results show that roadways with 9-foot wide lanes have a high rate of head-on collisions, as shown in Figure 5, but they have a fatal crash rate of zero, as shown in Figure 6. In terms of both crash rate of all severity levels and fatal crash rate running-off-roadway crashes had the highest crash rate, on 10-foot wide lanes. The incidence of ROR crashes decreased as the lane width became wider.

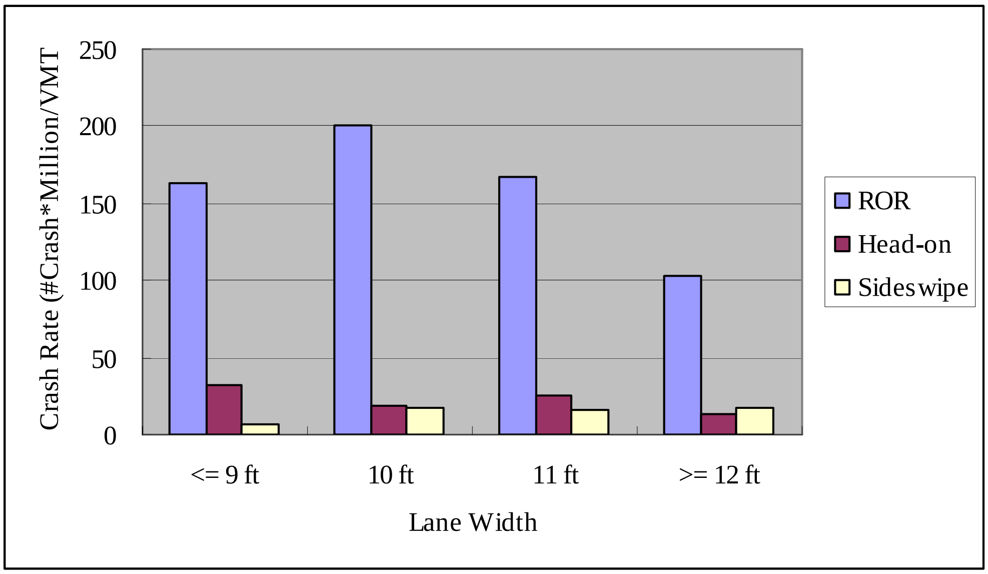


Figure 5
Crash rate by crash type and lane width

The two types of crash rate analyses do not indicate that narrower rural two-lane roadways have significantly more head-on or sideswipe crashes, whether fatal or not, than wider rural two-lane roadways, excluding the 9-foot wide lane, which had a slightly higher rate of head-on crashes, as seen in Figure 5.

Figure 6. Fatal crash rate by crash type and lane width

Measure of Drivers' Behavioral Changes

Pavement markings are a significant cue for motorists to safely navigate the state highways. A driver looking at pavement markings on the roadway can react in many ways. With respect to the edge line, a driver could do the following.

- Move closer to the road edge,
- Move closer to the centerline or even pass over the centerline, or
- Maintain his/her path with a centralized position in the traveled lane.

- Such factors as speed, vehicle composition, lane width, and driver alertness could all be responsible for the driver behavior described above; thus, discussions will focus on identifying the variables that should be measured for meaningful analysis.

- Vehicles' lateral position measured from either center line or edge line,
- 24-hour traffic volume counted for each direction,
- Average speed or the 85th percentile speed of vehicles for each direction,

- Percentage of heavy vehicles for each direction, and
- Roadway width.

In addition to these variables, the study considered other variables that could be influential before and after edge line treatment, such as roadside condition, edge-drop, and pavement condition (patches, ruts, and etc).

STUDY SITES

The safety of the data collection crew was the dominant factor in the site selection. All pavements in the study were between 20 and 22 feet wide. In reality, many variables can affect a vehicle's lateral position on narrow roadways. These variables include land use adjacent to the highway, type of traffic control devices, pavement conditions, ADT, weather, and lighting conditions. To stay within the scope of the project, this study focused mainly on geometric features while maintaining other variables at the selected sites as uniform as possible. For instance, all selected sites had the same speed limits.

Louisiana's highway NEEDS data was reviewed to identify such highway sections. Ten sites were selected, including seven highway sections that have tangent road alignment and three sites that have horizontal curvature. Those sites are located in Acadia Parish and St. Martin Parish as shown in figure 7. Table 4 briefly describes the selected sites.

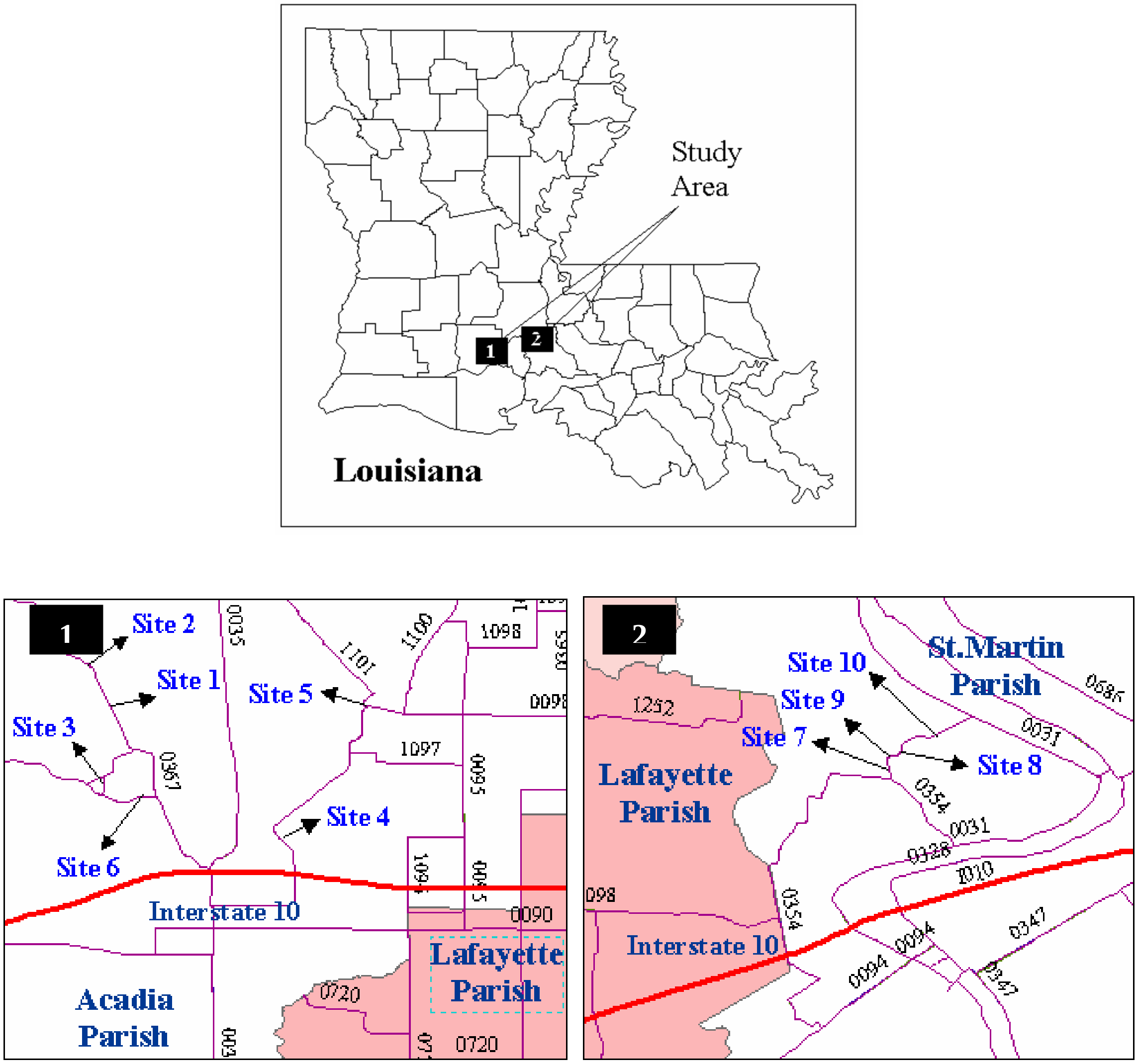


Figure 7
Study sites

Table 4

Attributes of the study sites

Site ID	State Highway	Alignment	Speed Limit	Pavement Width	Pavement Condition
Site 1	LA367	Tangent	55 MPH	20	Good
Site 2	LA367	Curved	55 MPH	24	Good
Site 3	LA 1113	Tangent	55 MPH	18.5	Poor
Site 4	LA 98	Tangent	55 MPH	20	Good
Site 5	LA 98	Curved	55 MPH	20	Good
Site 6	LA 98	Tangent	55 MPH	21	Good
Site 7	LA 354	Tangent	55MPH	21	Poor
Site 8	LA 354	Tangent	55 MPH*	20	Fair
Site 9	LA 354	Curved	55 MPH*	20	Fair
Site 10	LA 354	Tangent	55MPH	20.5	Good

* Advisory speed limit of 45 MPH

Data Collection Methods Explored

The field data collection was the most critical time consuming part of this study. Data was collected on each site during two time periods: before and after the application of the edge lines. Before edge lines were placed, existing roadway characteristics were collected at each site, and input into a spreadsheet to assure accuracy of actual geometrical alignment. To develop a suitable traffic data collection method, three different data collection methods were evaluated: (1) videotaping traffic and then analyzing with an image-sensing processor in the lab, (2) spreading sand on the pavement to measure the wheel path from the road edge, and (3) installing tubes of different lengths transversally on the roadway to measure the lateral position of vehicles. These methods are described in detail in the following sections.

Image-Sensing System

The state-of-the-art image-sensing system technology allows real-time traffic data collection without requiring substantial human interaction with traffic. It records video images of the traffic flow for various roadway facilities. The video images serve as input to an image detecting processor that analyzes the video signals and calculates the desired traffic parameters. The technology has been widely used particularly for video detection at signalized intersections and at traffic control centers that remotely monitor traffic by analyzing the signal received from camera.

The research team at the University of Louisiana at Lafayette developed an image-sensing system with a portable traffic data collector. The system consists of a video camera, image-sensing processor (Auto Scope®, MVP2000 model), and a personal computer. Auxiliary parts include a TV-monitor, VCR, camera mounting devices, and so forth. The video image can be analyzed in real-time by connecting the camera with the image-sensing processor directly or can be recorded on video tapes and analyzed with the processor later in the lab.

The system was tailored for this study and evaluated to determine the accuracy of detecting the encroachment patterns on the curve and tangent segments. A series of pilot studies were performed on selected local roads on Louisiana State highways. Measurements of 0.5-foot, 1-foot, 3-foot and 8-foot offsets were made from the edge of traveled-way (ETW) within the curve or tangent section, as illustrated in figure 8. This detects an encroachment distance from the centerline. To record images, the camera was mounted on top of a 25-foot pole

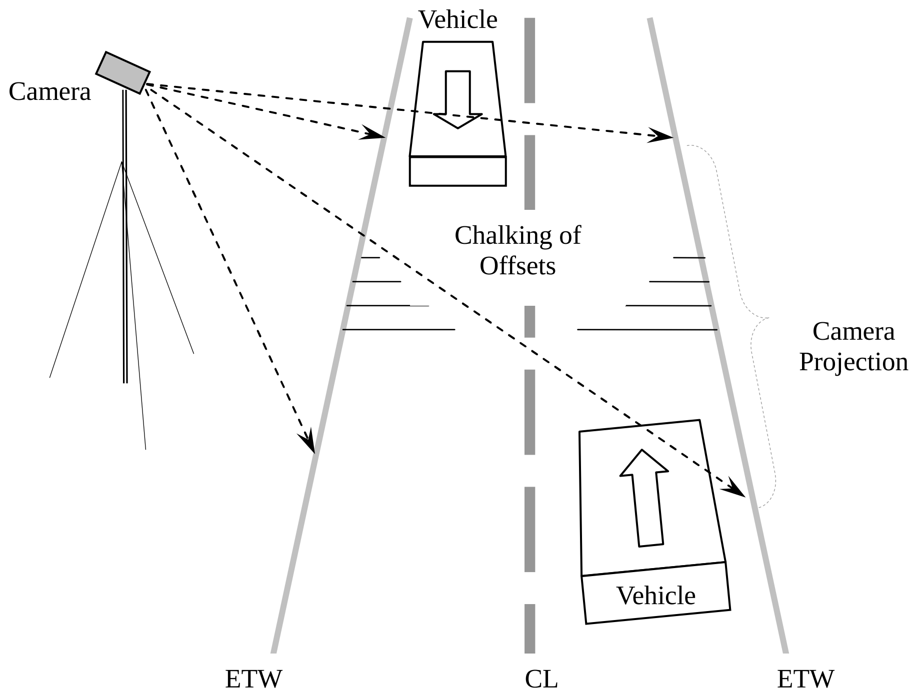


Figure 8
Video recording in the field for the image-sensing method

The average camera height during the test phase was 13feet and the pole was fixed on the road shoulder approximately 5feet away from the road edge for the safety of the crew and camera. A field of view measuring 45feet long and 22feet wide was physically marked on the road using paint and the same calibrated on the still video image shown in figure 9.The data obtained show that, on the left lane, 53 vehicles passed over the 8-foot detector, 35 passed over the 3-foot detector, and 2 passed over both the 0.5-foot and 1-foot detectors. On the right lane, 99 vehicles passed over both the 8-foot and 3-foot detectors.

Figure 9
Electric detector operation on recorded video image

The nature of the distribution of vehicle counts on the left lane was anticipated, as the videotape showed that vehicles moved closer to the centerline than to the edge line. The same cannot be said on the nature of the distribution of vehicle counts on the right lane as the traffic in the right lane (which is the farther lane on the videotape) was moving in the receding direction with respect to the camera, and the lack of visibility regarding the vehicle tire position, in the right lane, was further aggravated by a side view image.

While this study could have collected traffic data successfully in several locations using the image-sensing devices, the quality of data would be governed by some constraints that the research team could not control. The most uncontrollable variable was weather. Wind swayed the camera, resulting in image shaking and preventing precise detection of vehicle position on the pavement. The movement of shadows during the day also caused problems in detection of vehicle position. Additionally, driver behavior may have been influenced by the presence of roadside cameras. The camera was difficult to hide from the drivers' view on open rural highways. Drivers decelerated, altered their vehicle's lateral position, or stopped a passing maneuver in response to the camera's presence. Vandalism or theft of the exposed camera was a security concern that also factored into the decision process. Considering all these factors, the research team concluded the image-sensing method was not suitable for this study.

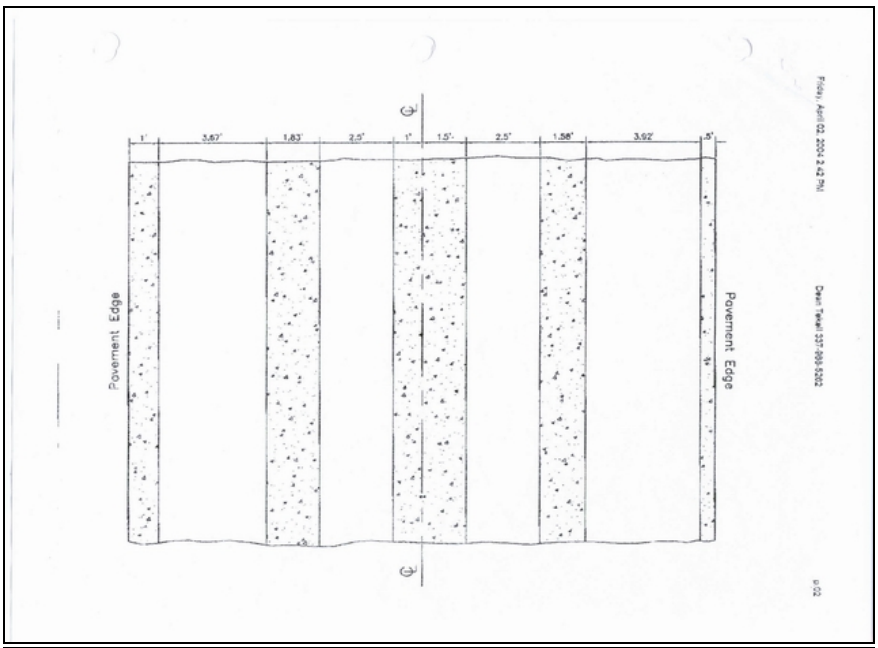
Sand Spread

Proposed by Gulf Engineers and Consultants, this method would obtain the wheel path that remained on the sand uniformly spread on the pavement. As vehicles pass by, their wheel paths in the sand provided a measure of the average travel path with respect to the centerline and edge of traveled way. Figure 10 shows sand scattered by traffic eight hours after spreading and the measures of the wheel paths.

This method was determined to be a straightforward method to measure the average lateral position of vehicles, as well as easy to apply and cost-effective. However, it needs to be supplemented by extra efforts to obtain other traffic parameters such as traffic volume and vehicular speed. Moreover, concerns that sand could decrease tire friction with the road surface arose during the test phase. As a result, the use of sand was discontinued.

(a) Spreading Sand

(b) After 8 hours



(c) Measure of wheel paths

Figure 10
Use of sand to measure wheel paths

Road Tubes

Road tubes are widely used to count traffic. The tubes are generally laid on the pavement perpendicular to the direction of traffic and connected a counter. As each set of axles strike the road tubes, the counter receives air-pulses from the tubes and analyzes pulses as programmed.

A data collection methodology was developed for this study by using three sets of traffic data counters (Jamar Technologies, TRAX Plus I series). Various pilot studies were preformed to ensure the accuracy of the measurements. First, traffic was videotaped on a local roadway where tube detectors were laid out; traffic counts and vehicle classification were then evaluated by monitoring the recorded videotapes. Also, a test vehicle equipped with a global positioning system (GPS) unit was used to evaluate the accuracy of speed measurement. This method was also evaluated to see if it produces the same outcome when a tube is hit by either one wheel or both wheels (left and right wheels) of a vehicle. These preliminary tests showed satisfactory results.

Figure 11 illustrates the layout of tubes for the study. The target lane is the lane being studied. Counter I was connected with tube S1 (1-foot extension from ETW) and tube S2 (2-foot extension from ETW). Both tubes counted vehicles traveling 1-foot and 2-feet away from ETW, respectively. Counter II connected to two tubes, C1 and C2, which counted vehicles crossing over the centerline while traveling in target lane. Tube T1, T2, T3, and T4 connected to Counter III were used to collect other traffic data including traffic volume, speed, and vehicle classes.

The four dotted squares in figure 11 represent passing vehicles' lateral positions for which the tube layout was designed to measure:

- Vehicles driving within 0 to1 feet from road edge,
- Vehicles driving within 1 to 2 feet from road edge,
- Vehicle driving 2 feet away from road edge and not crossing the centerline, and
- Vehicles crossing over the centerline.

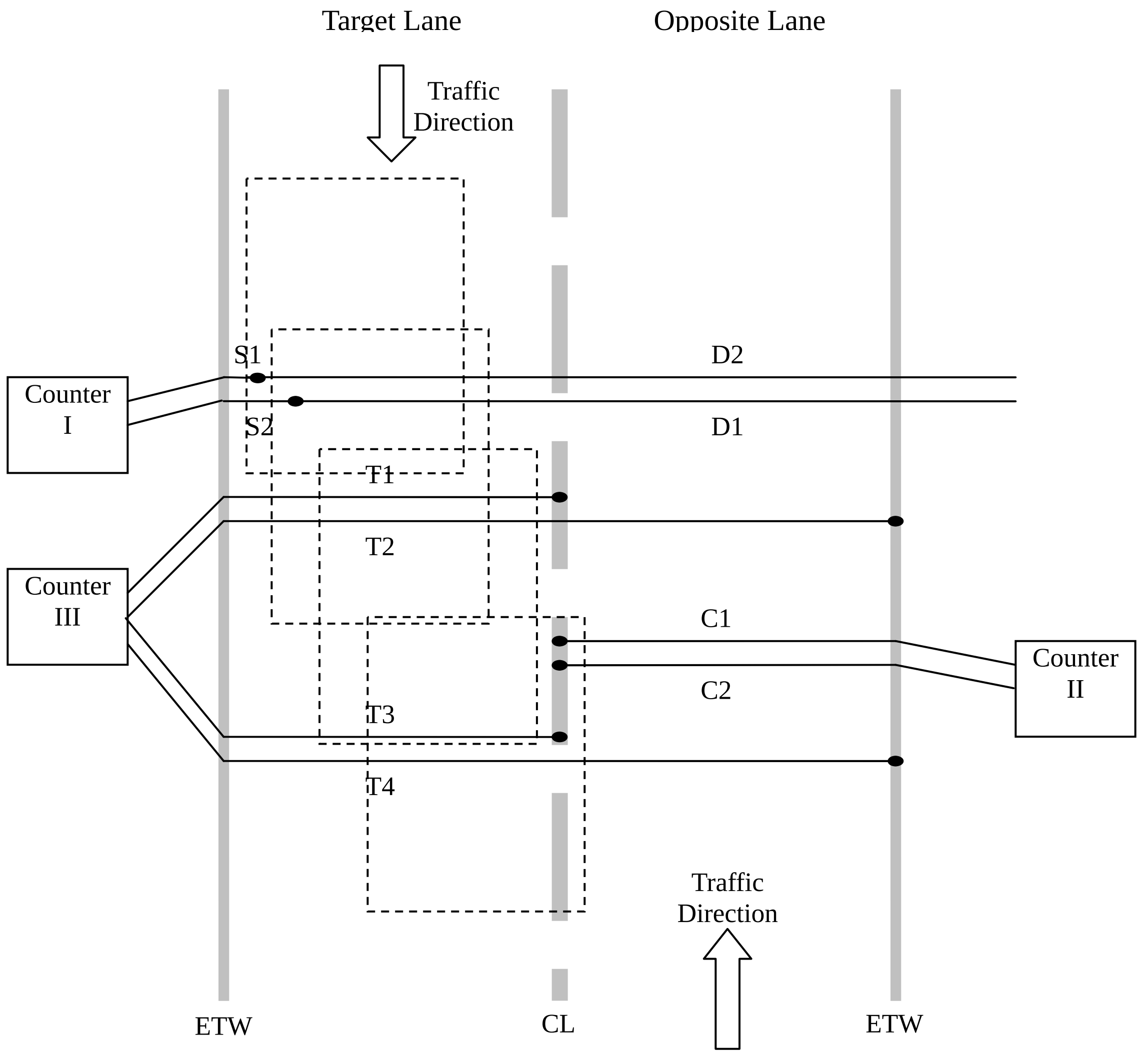


Figure 11
Tube layout diagram

In addition to that, the following information was obtained for the analysis.

- The total number of vehicles passing through target lane (from tube T1 and T3),
- The total number of vehicles passing through opposite lane (from tube T2 and T4),
- The speed of vehicles passing through target lane (from tube T1 and T3),
- The speed of vehicles passing through opposite lane (from tube T2 and T4),
- The classification of vehicles passing through target lane (from tube T1 and T3),
- The classification of vehicles passing through opposite lane (from tube T2 and T4).

The use of road tubes was determined to be advantageous over other methodologies because it: (a) is relatively free from weather conditions, e.g., rain and wind, compared to the other two methods, (b) allows data collection for a long period of time, and (c) has been used by highway agencies in the past. The research team did experience some failure in collecting data with this method, mainly because traffic and weather caused a tube to fail to adhere to the pavement.

Table 5 summarizes the performance of the three methodologies, where the rankings are relative values. Taking all the factors into consideration, the tube detector is clearly the best data collection method for this project.

Table 5

Evaluation of data collection methodologies

	Sand Spread	Image Sensing	Tube Detector
Operation	Easy	Difficult	Intermediate
Operating Cost	Low	High	Intermediate
Amount of Information	Low (vehicle position only)	High (volume, speed, class, vehicle position, and videos)	High (volume, speed, class, vehicle position)
Data Quality	Low	Intermediate	High
Operating Duration	Not defined	Short (maximum 4 hours, non-applicable in nighttime)	Long (several days)
Intrusiveness	Medium (awareness of sand on the pavement)	High (wind, lighting, awareness of camera on the roadside)	Low (precision of tube layout)
Potential Liability	High	High	Low

Results of Vehicles' Lateral Position Analysis

At each site, the data were collected continuously for at least 24 hours for 2 time periods: before and after edge line markings. The whole analysis is illustrated in figure 12.

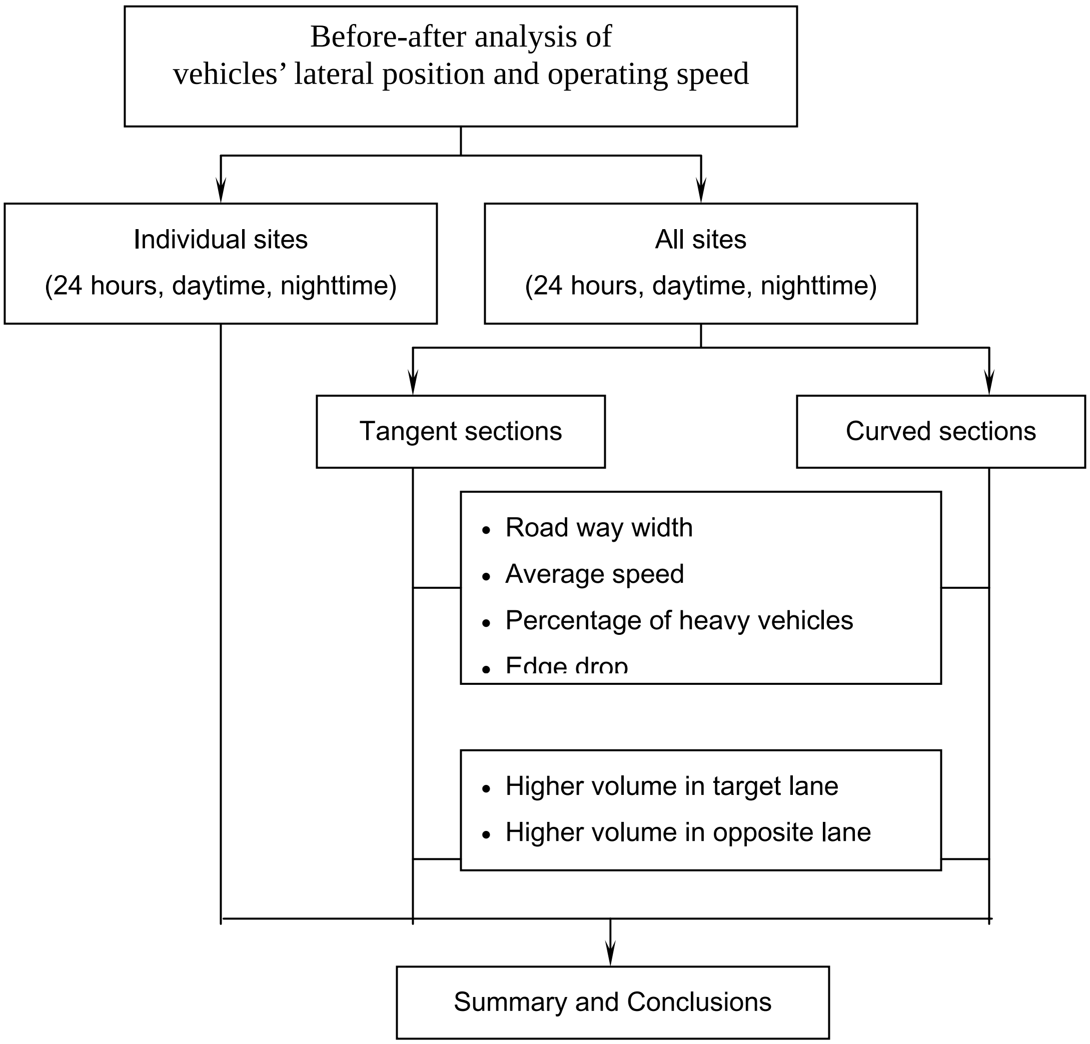


Figure 12
Architecture of the analyses

The main objective was to find the changes in vehicles' lateral position and operating speed after edge line markings. As described earlier, the lateral clearance measures consisted of traffic counts of 0-1 feet, 1-2 feet, 2feet-centerline, and crossing the center line, where the summation of accounts makes the total traffic of the target lane. Considering that the edge lines would affect driver behavior differently during the day and at night, this study considers two separately. Similarly, curved sections were analyzed separately from tangent sections.

This study also investigated the impact of roadway width, vehicular speed, heavy vehicle frequency, pavement edge drop, and daily traffic volume on a vehicle's lateral position before and after the edge line was applied. This analysis may help identify road sections where edge line implementation is desirable. Because vehicles may have to execute an evasive maneuver when they meet oncoming vehicles from opposing direction, traffic volume in the opposing lane was also investigated. The results are presented at the end of this chapter.

Average Daily Traffic and Operating Speed

Figure 13 and figure 14 compare the ADT and average speed of the 10 sites before and after application of the edge line markings. Figure 13 shows slight differences in 24-hour traffic between the two time periods. The small differences are expected, considering the variations in traffic volume by day of the week.

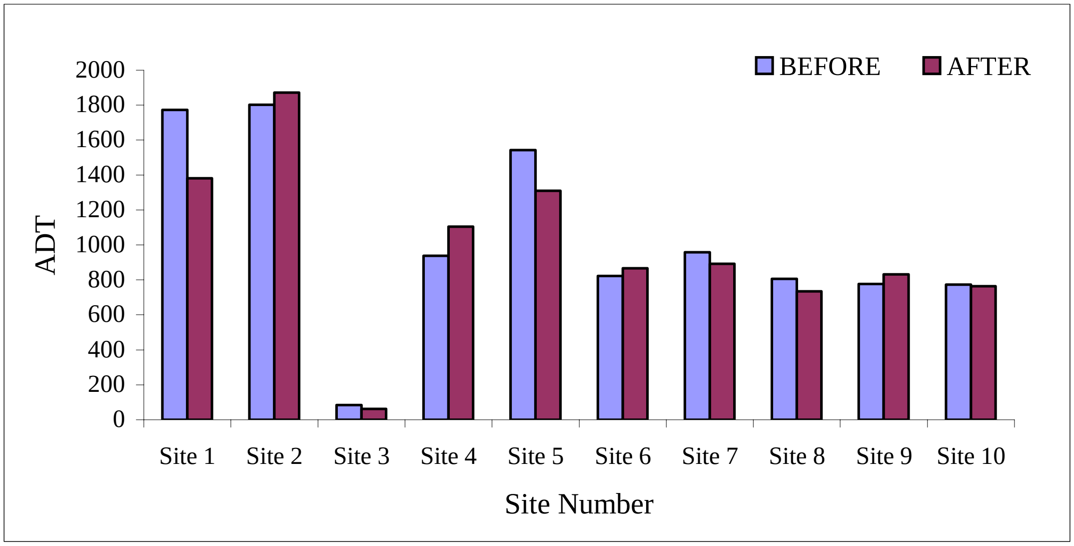


Figure 13

Estimated daily traffic

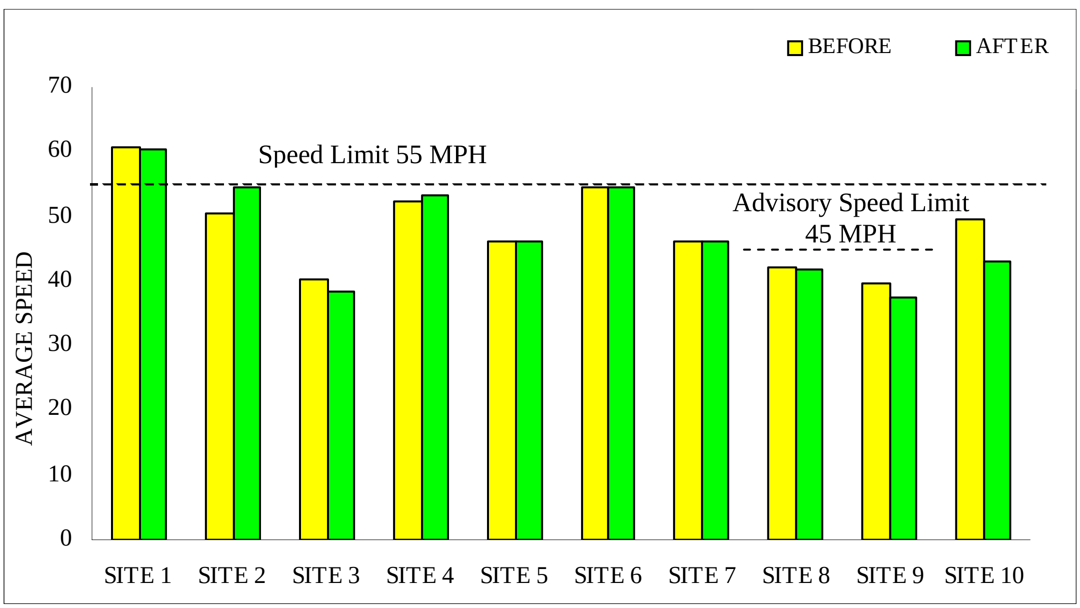


Figure 14
Average speeds (before and after)

Figure 14 shows little or no change in the average speeds after the application of edge lines.

Change of Vehicles' Lateral Position

Detecting any changes in vehicles' lateral position was the focus of the analysis. A decrease in both the edge line (0-1 feet) and the centerline count was desirable, because it would imply vehicles were traveling in a more centralized position within the lane.

Figure 15 shows a summary of the changes on all sites, where CL ± and 1 FT ± indicate an increase or decrease in the centerline and edge count, respectively. The horizontal axis, change in percentage of centerline count (CL), was calculated as the percentage difference in centerline count between the before and after periods, N_A-N_B. If the percentage of centerline counts increases after edge-lining, then the N_A-N_B is positive. Similarly, the vertical axis, change in percentage of 0-1 ft count (1 FT), was calculated as the percentage difference in 0-1 foot count between before and after periods. If the percentage of 0-1 foot counts increases after edge-lining, then the N_A-N_B is positive.

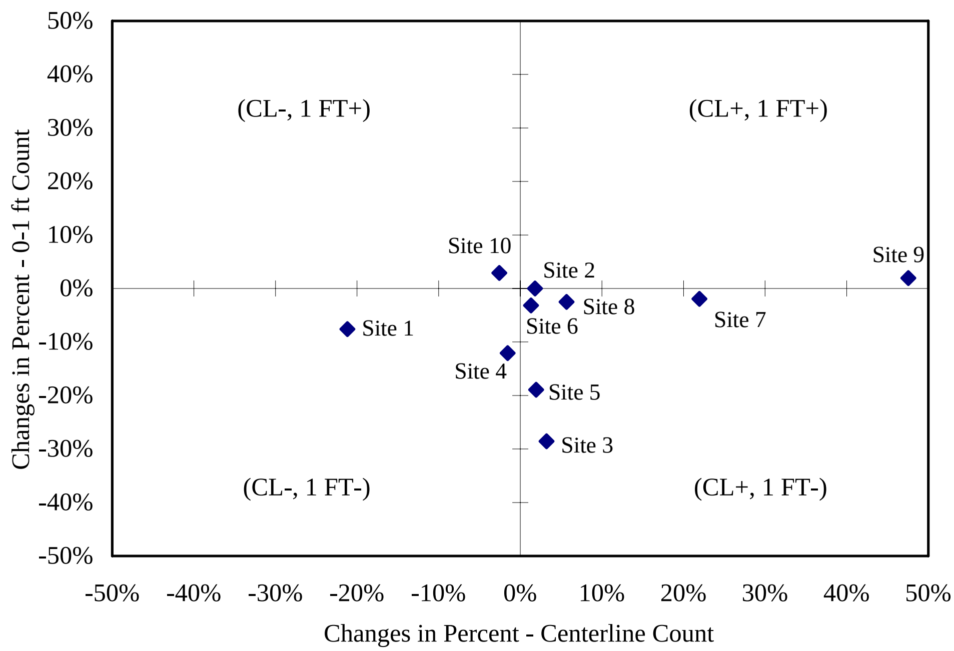


Figure 15-a
Vehicles' position change (24-hours)

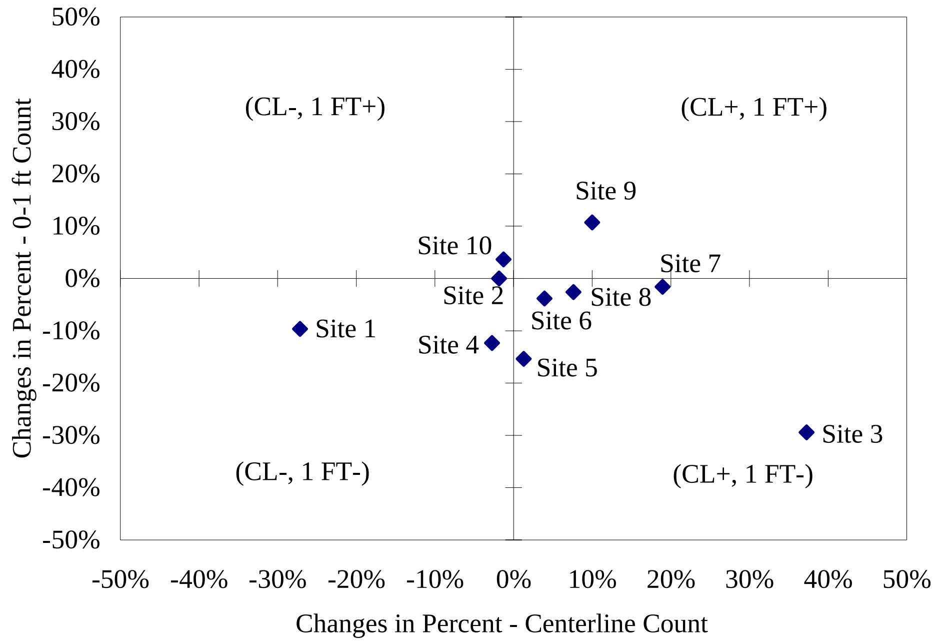


Figure 15-b
Vehicles' position change (daytime)

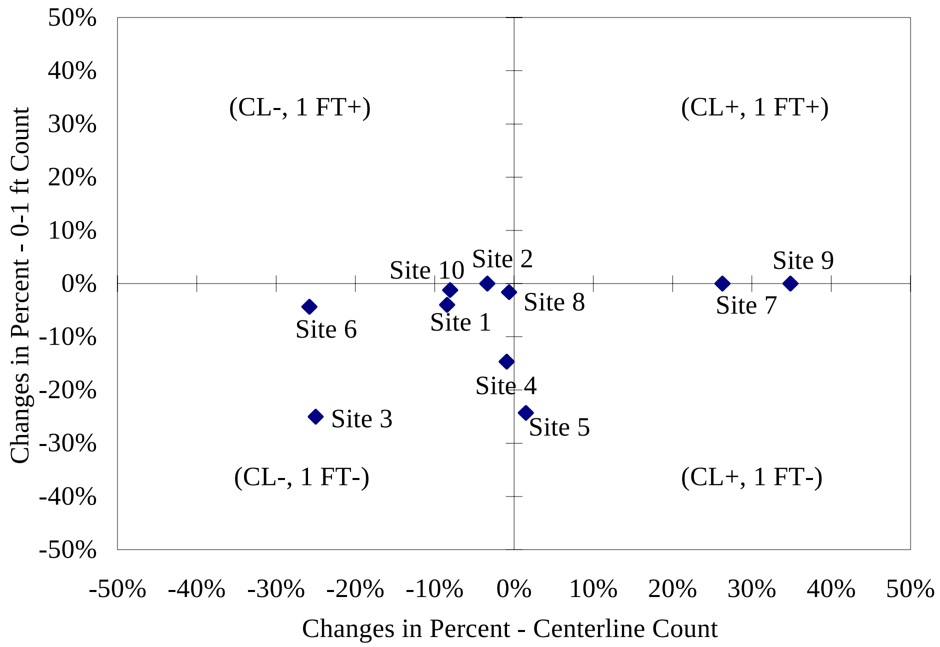


Figure 15-c
Vehicles' position change (nighttime)

Based on the definition, the differences calculated as N_A-N_B could fall into one of four quadrants shown in figure 15. The data points closer to the horizontal and vertical axes indicate that the percentage change between the before and after time periods is only marginal. Ideally, all 10 sites would fall in the third quadrants.

For example, figure 15 shows that Site 1 falls in the third quadrant during the daytime, nighttime, 24-hour time periods. This means that, the percentages of both vehicles driving across the centerline and those driving closer to the road edge have decreased for this site. Likewise, Site 9 belongs to the first quadrant during the 24-hours and daytime periods, meaning that the percentages of vehicles driving across the centerline and those passing closer to the road edge increased, while at night, only the percentage centerline count increased after edge-lining.

Tangent Sections

The data analysis was performed separately for tangent and curved sections for three time periods: 24-hours, daytime, and nighttime. The before and after edge line data were analyzed to determine any changes in the following:

- The number of vehicles passing close to the road edge,
- The number of vehicles passing over the centerline,
- The number of vehicles passing neither close to the road edge nor over the centerline, and
- The average operating speeds.

The daytime hours were 7:00 AM to 5:00 PM, and the nighttime hours were 7:00 PM to 5:00 AM. The four twilight hours are excluded. The seven tangent sections were analyzed to detect any change in the before and after counts of 0-1 foot, 1-2 feet, between 2-feet and centerline, over centerline counts, and average speeds. The first step involved analyzing the complete data (24-hours) obtained on all tangent sites considering the lighting conditions. The next step involved division of the tangent sections into similar groups by the following parameters:

- Roadway width less than or equal to 20-feet vs. greater than 20-feet,
- Average speed less than or equal to 50 MPH vs. higher than 50 MPH,
- Percentage of heavy vehicles less than or equal to 10 percent vs. greater than 10 percent,
- Roadways with edge drop vs. without edge drop, and
- Good vs. poor pavement condition.

Figure 16 shows a comparison of lateral position distribution and average speed for all tangent sections considering 24-hours, daytime and nighttime data. A decrease in the 0-1 foot counts indicates a reduction in the percentage of vehicles passing close to the road edge. The charts also show a slight decrease in the percentage of vehicles passing over the centerline and an increase in the "between 2-feet to centerline" count, indicating that the edge lines are causing vehicles not to pass close to the road edge and over the centerline.

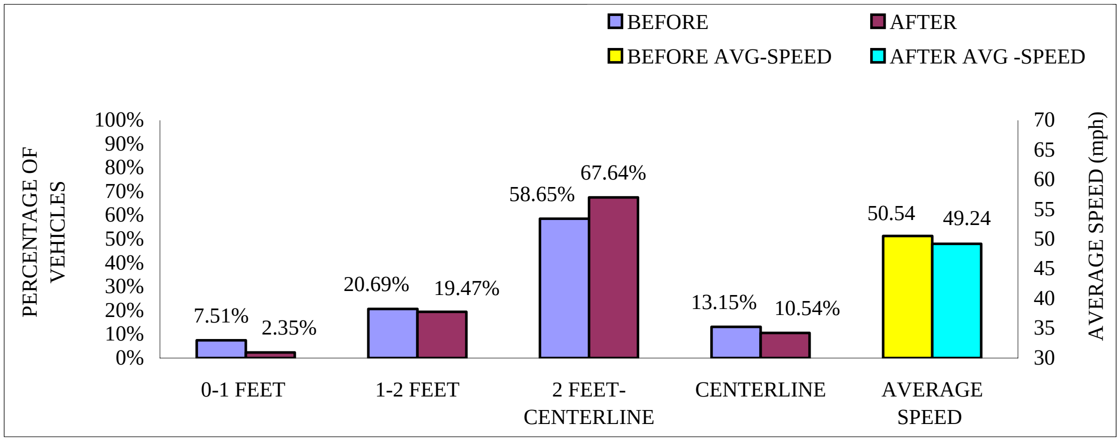


Figure 16-a
Tangent sites (24 hours)

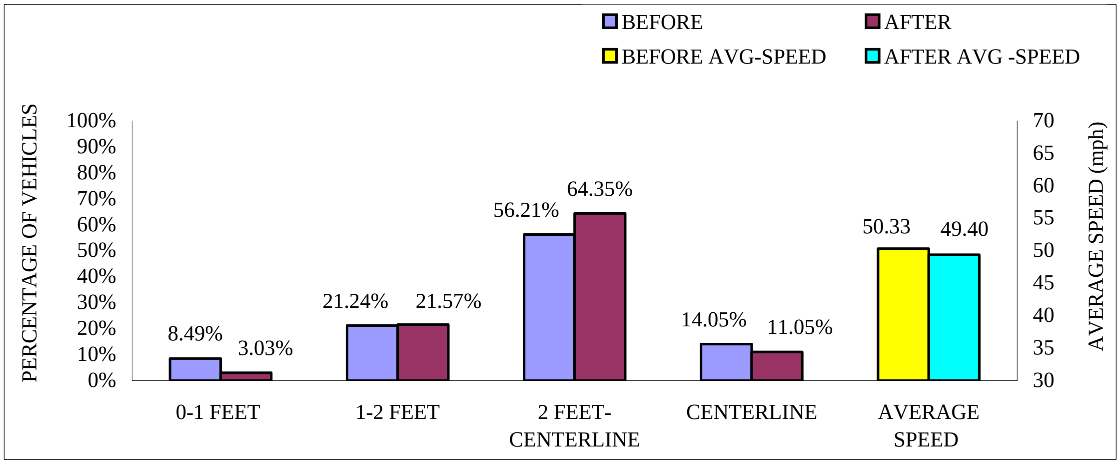


Figure 16-b
Tangent sites (daytime)

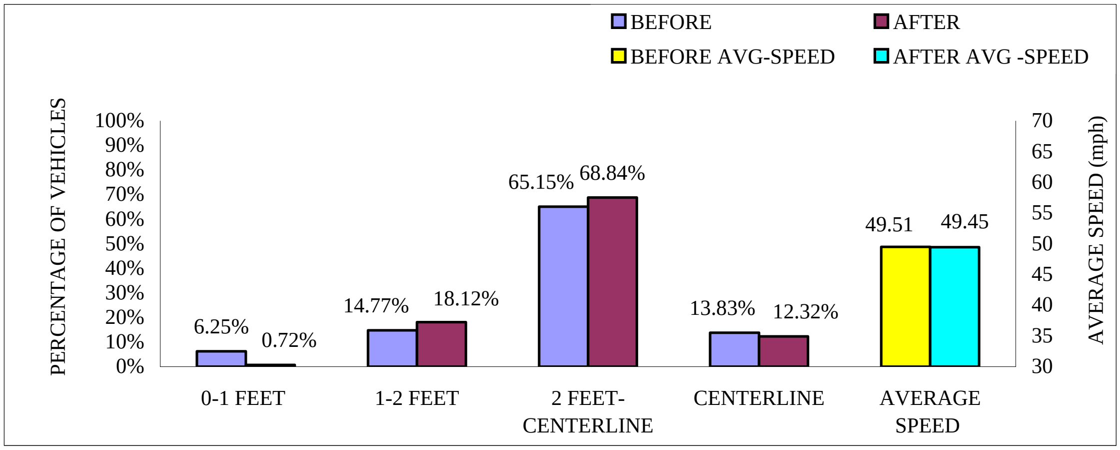


Figure 16-c
Tangent sites (nighttime)

Figure 17 shows more clearly that vehicles traveled in a more centralized position within the lane (between 1ft from road edge and the centerline) after edge line markings. During the data collection phase, the study team found that the edge line in Site 7 was not marked properly, i.e., the edge line began only 40-feet ahead of where the “before” data was collected, as shown in figure 18. At other locations, edge lines began at least a quarter mile ahead of the location to give drivers sufficient time to adjust to the newly installed edge line. This might have caused an unusual maneuver at Site 7.

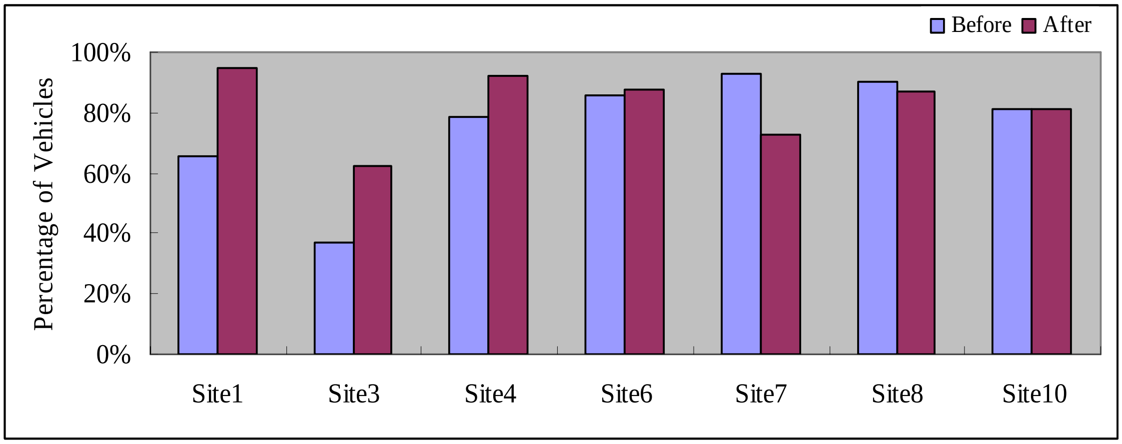


Figure 17
Between 1-foot and centerline counts (24 hours)

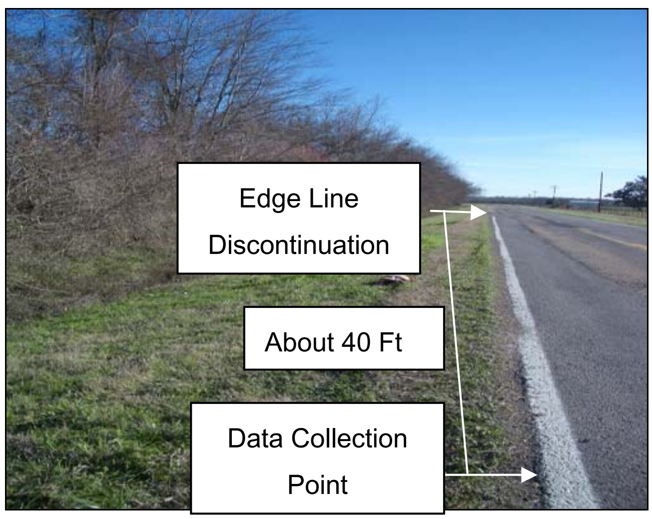
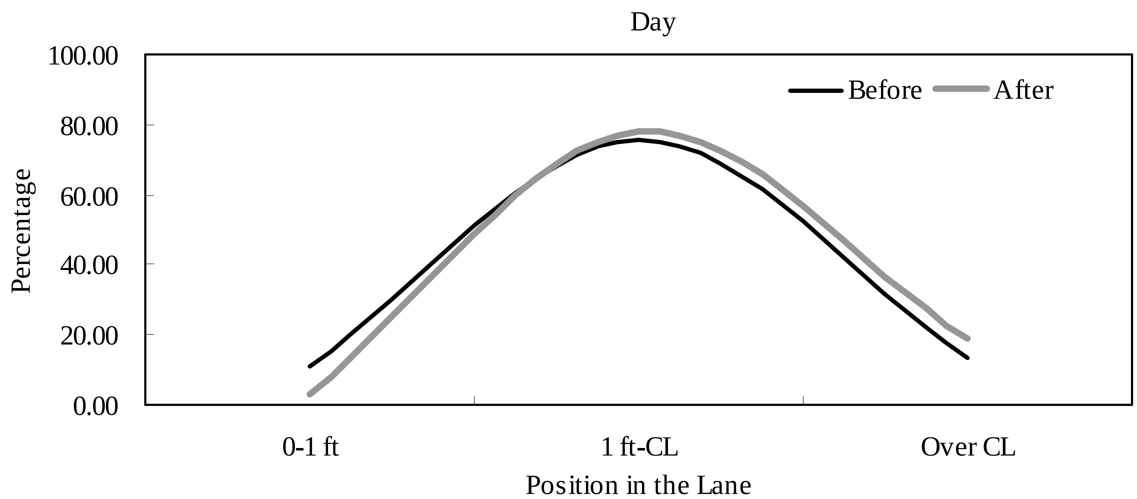


Figure 18
Edge line marking at site 7

Figure 19 draws the distribution of average lateral placement of vehicles from 7 tangent sites. Two plots show the distribution of daytime and nighttime positions separately. In daytime, there was a shift toward the centerline (shift to the right) after the application of edge lines; fewer vehicles traveled closer to the road edge, and more vehicles crossed the centerline. However at night, the distribution was more concentrated in the middle of the lane, implying that vehicles maintained a more central position in the roadway. The two plots clearly indicate the effect of edge lines on drivers' lateral position on tangent roadways.



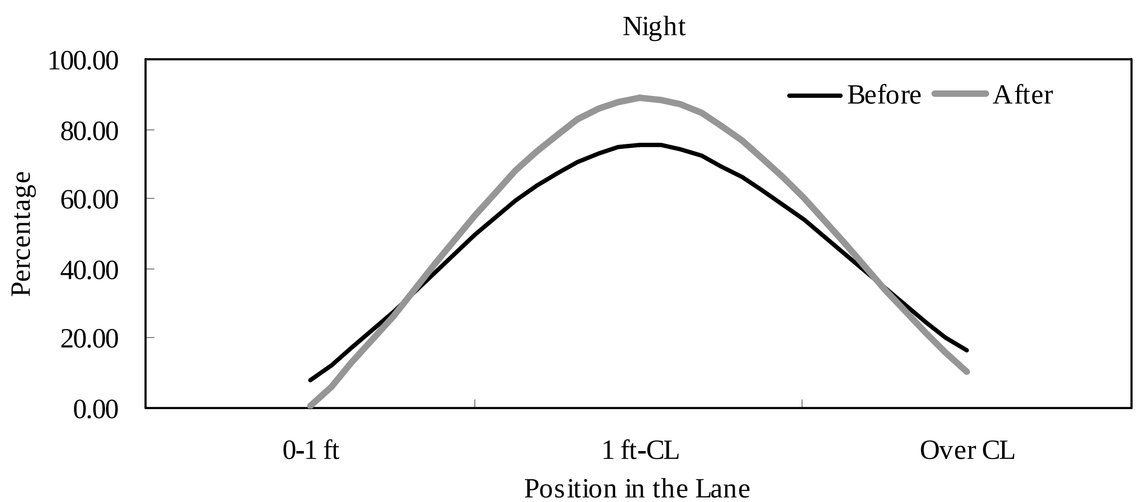


Figure 19
Distribution of vehicles' lateral position

The risk of having a daytime sideswipe collision may increase on narrow two-lane highways with edge lines because of the shift shown in figure 19. This is due to an overhang of the vehicle body, i.e. fenders.

A sideswipe collision could be possible even if the wheel paths of two directional vehicles do not cross the centerline. This is due to an overhang of the vehicle body, ex., fenders. It was measured that the average overhang of vehicles was 2.4 inches with the maximum of 3.5 inches from a sample of 17 vehicles. As seen in Figure 18, because the lateral position is near normally distributed, it can be assumed that the risk of sideswipe collision would decrease as the vehicles crossing centerline decrease.

Curved Sections

This portion of the study was conducted on three curved sections, Site 2, Site 5, and Site 9. Sites 2 and 9 are grouped together as they have the outer lane as the target lane. Site 5 is studied separately because which has the inner lane is its target lane, as seen in figure 20.

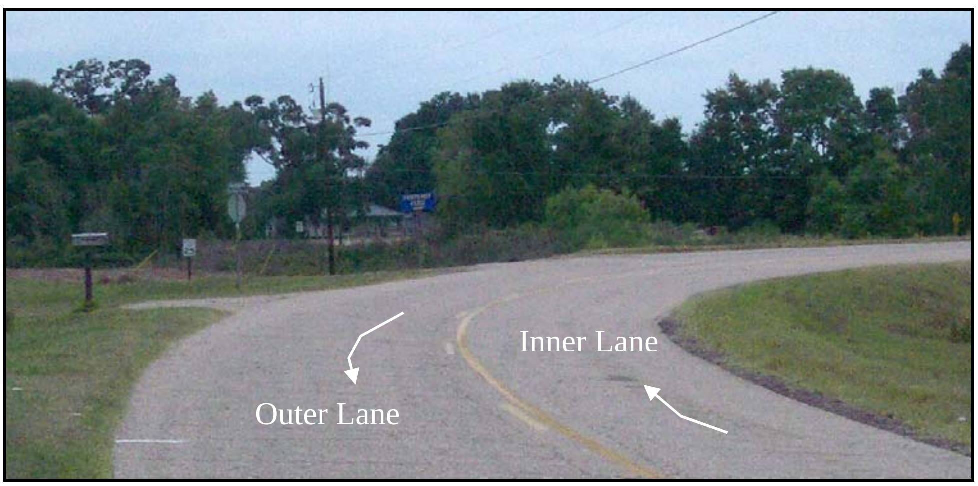


Figure 20
The inner lane and outer lane on a curved section of a roadway

Analysis of Inner Lane. Figure 21 shows a comparison of vehicles' lateral position distribution and average speed during 24-hours, daytime, and nighttime data on curved sections with the inner lane as the target lane. The 24-hours, daytime, and nighttime plots all show a decrease in the percentage between the 0-1-foot count and the 2-feet to centerline count. The percentage of 1-2 feet counts shows an increase, and the centerline count shows a marginal increase. Before the application of edge lines the vehicles may have moved very close to the road edge while negotiating the inner lane of a curve. The application of edge lines shows a decrease in the 0-1 foot count and an increase in the 1-2 feet count, indicating that the while negotiating the inner lane of this curved section, drivers are still driving close to the road edge because they are aware of edge lines.

Analysis of Outer Lane. Similar charts are plotted in figure 22 for the outer lanes of two curved sections. Before the application of edge lines, drivers negotiating, the outer lane of curved sections tended to cross over the centerline, and this trend increased after the marking of edge lines. The speeds also increased after the marking of edge lines.

Summary of the Results on Curved Sections

In general, while negotiating a curved section of a roadway, drivers tended to move closer to the centerline when driving in the outer lane, and closer to the road edge when driving in the inner lane. The application of edge lines increased the tendency to cross over the centerline from the outer lane; drivers in the inner lane were consciously aware of the road edges, and not moving as close to the road edge as they did before the edge-lining. The average speed of vehicles in the outer lane increased slightly while the average speed of vehicles traveling in the inner lane decreased slightly.

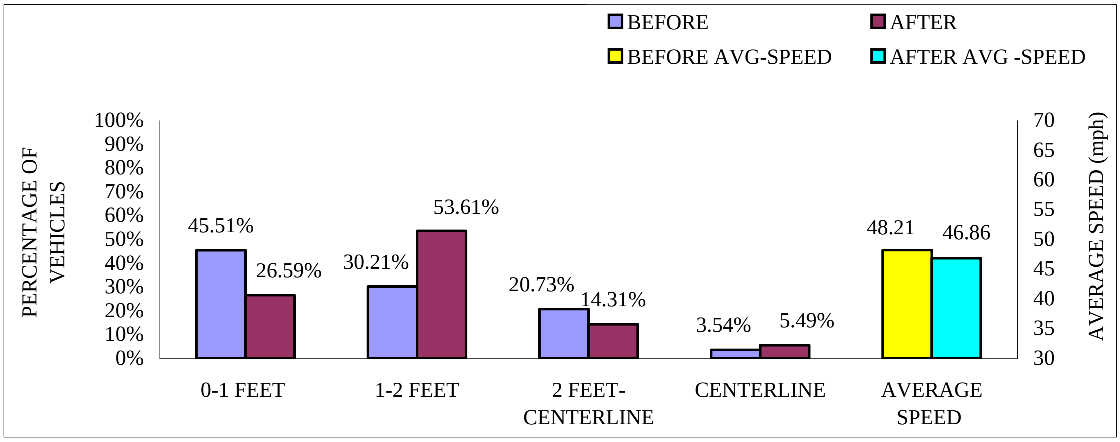


Figure 21-a
Inner lane of curved site (24-hours)

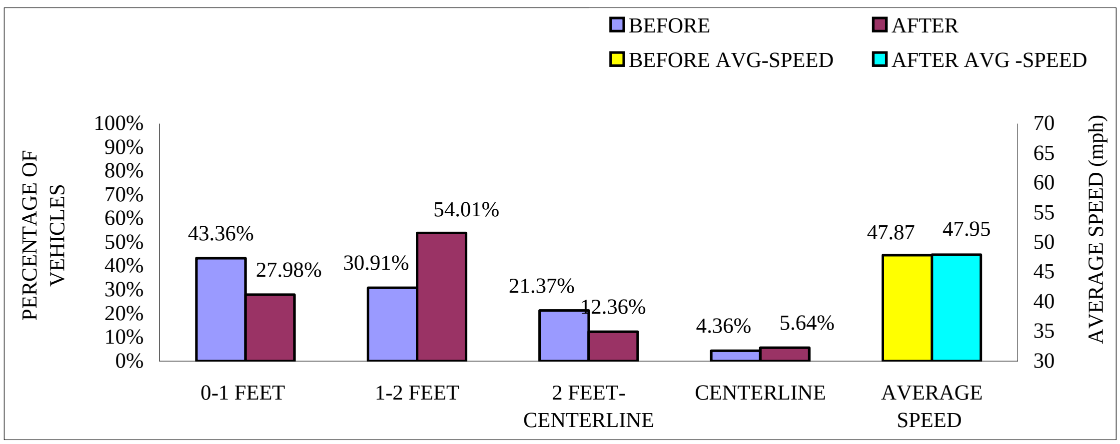


Figure 21-b
Inner lane of curved site (daytime)

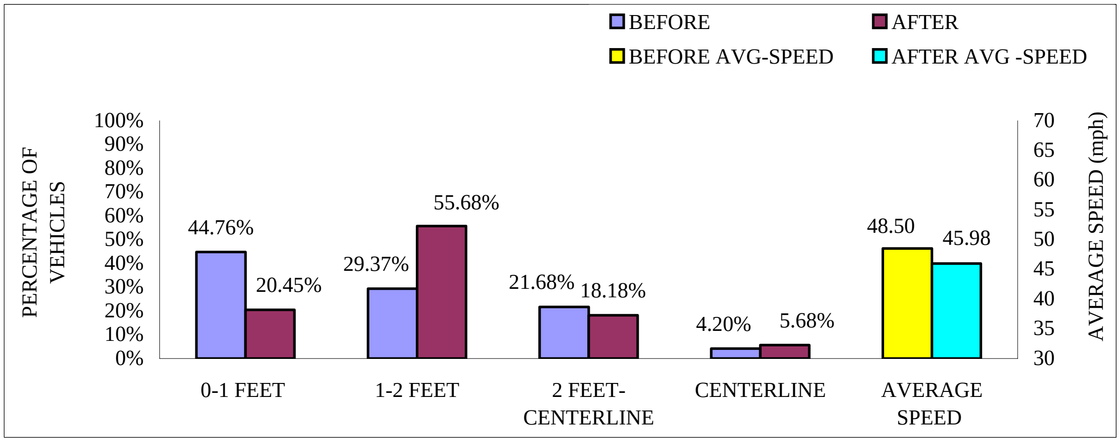


Figure 21-c
Inner lane of curved site (nighttime)

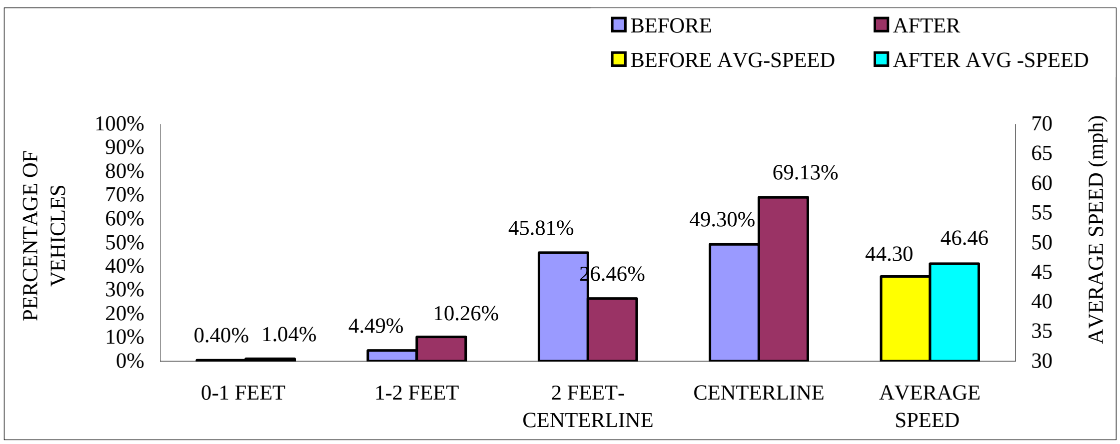


Figure 22-a
Outer lane of curved sites (24-hours)

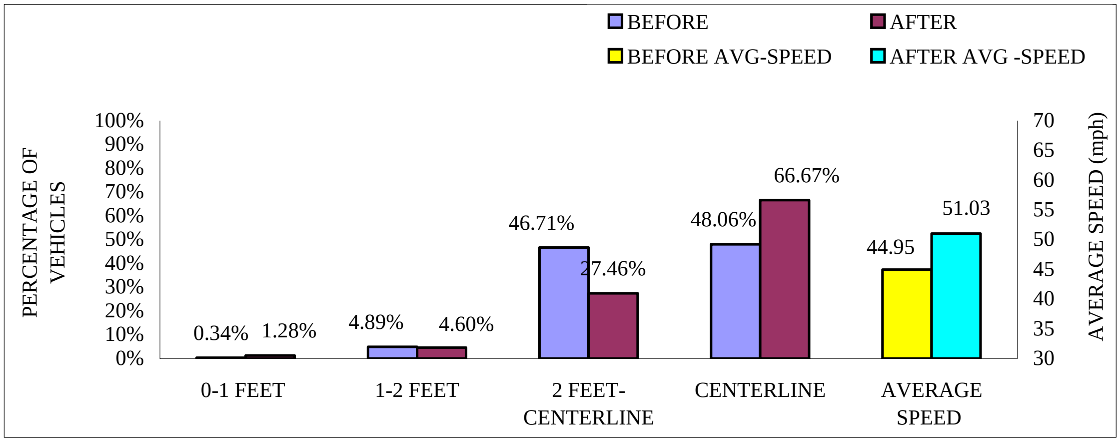


Figure 22-b
Outer lane of curved sites (daytime)

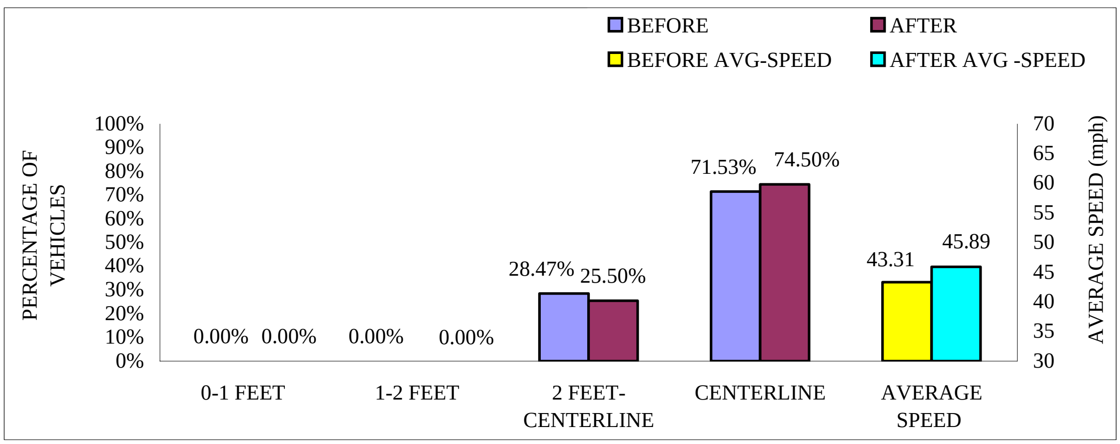


Figure 22-c
Outer lane of curved sites (nighttime)

Other Factors

Roadway Width. The seven tangent sections are divided into two groups based on the roadway widths. The first group was greater than 20-feet, and the second group was less than or equal to 20-feet. Sites 6, 7, and10 fall into the first group, and sites 1, 3, 4, and 8 fall into the other (see table 4 for roadway widths). Figure 23 shows a comparison of vehicles' lateral position distributions and average speeds during three time periods.

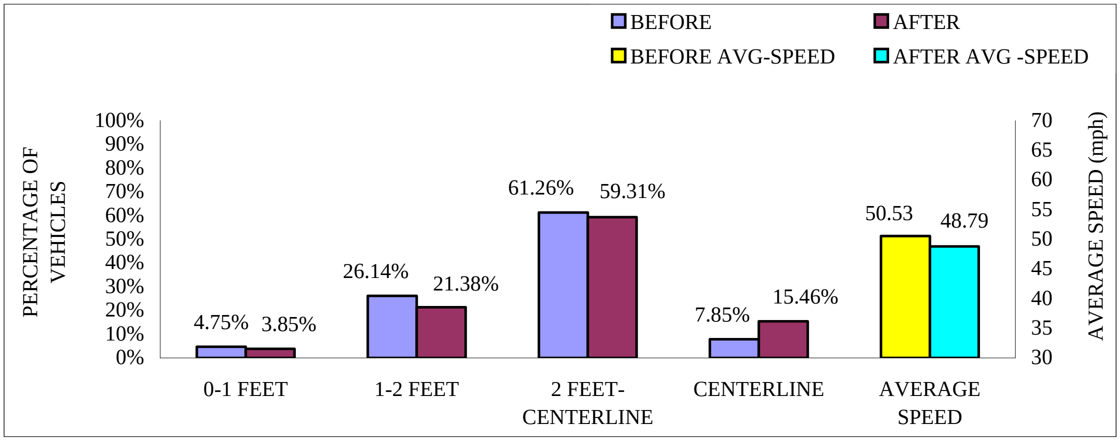


Figure 23-a
Roadway width greater than 20-feet (24-hours)

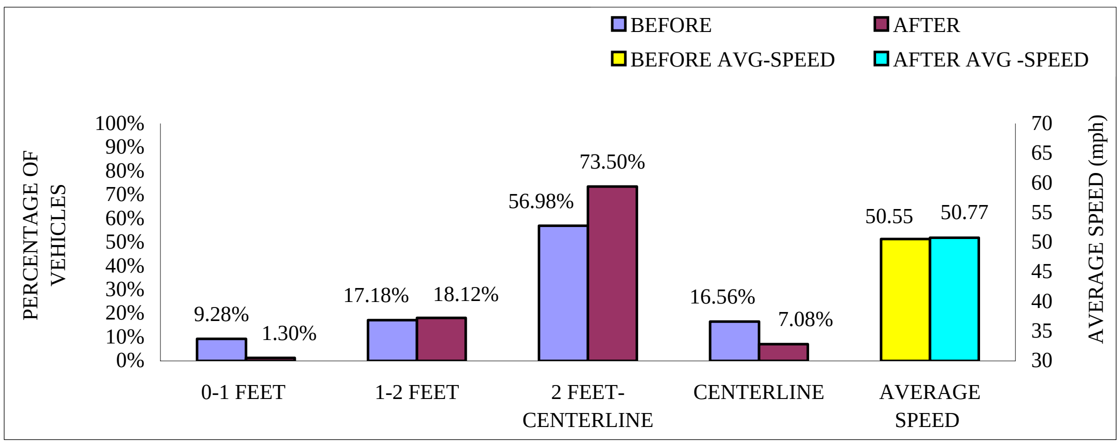


Figure 23-b
Roadway width less than or equal to 20-feet (24-hours)

Figure 23 shows that edge lines on roadways 20-feet wide or narrower, decreases the percentage of vehicles both passing close to the road edge and passing over centerline. On the roadways wider than 20-feet, the results were different. These plots indicated a decrease in the percentage of vehicles passing close to the road edge and the percentage of vehicles passing neither close to the road edge nor over the centerline. However the percentage of vehicles passing over the centerline shows an increase. Similar charts are plotted considering daytime (figure 24) and nighttime conditions (figure 25).

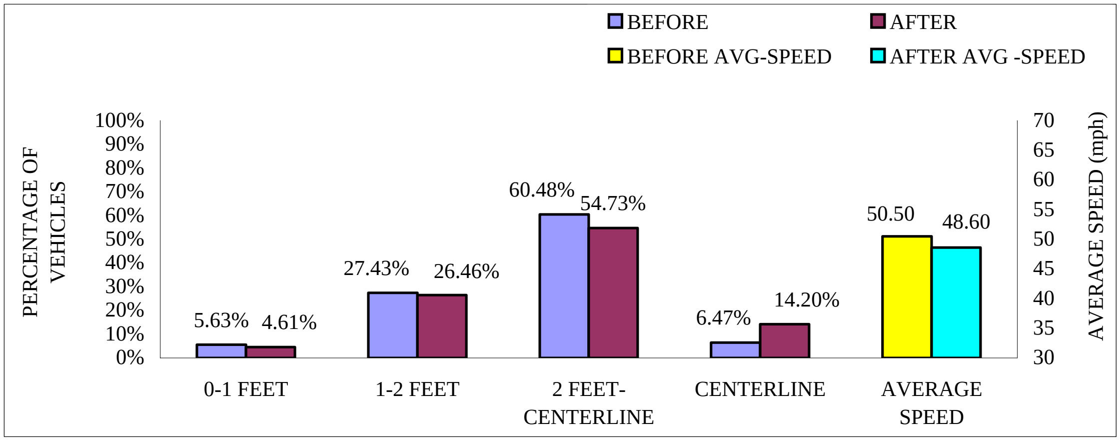


Figure 24-a
Roadway Width Greater Than 20-feet (Daytime)

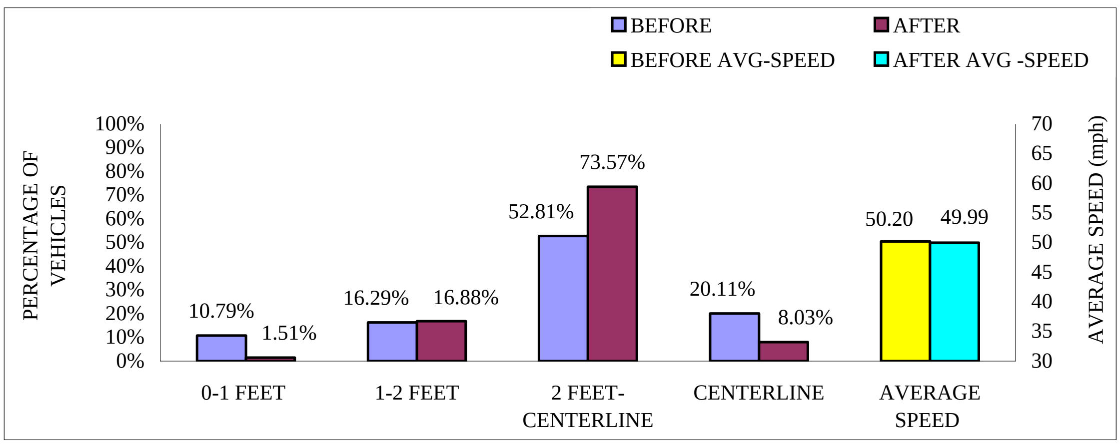


Figure 24-b
Roadway width less than or equal to 20-feet (daytime)

The daytime plots for roadways 20 feet wide or less indicate a decrease in the percentage of vehicles passing close to the road edge and passing over centerline and an increase in the percentage of vehicles traveling between 2-feet and the centerline.

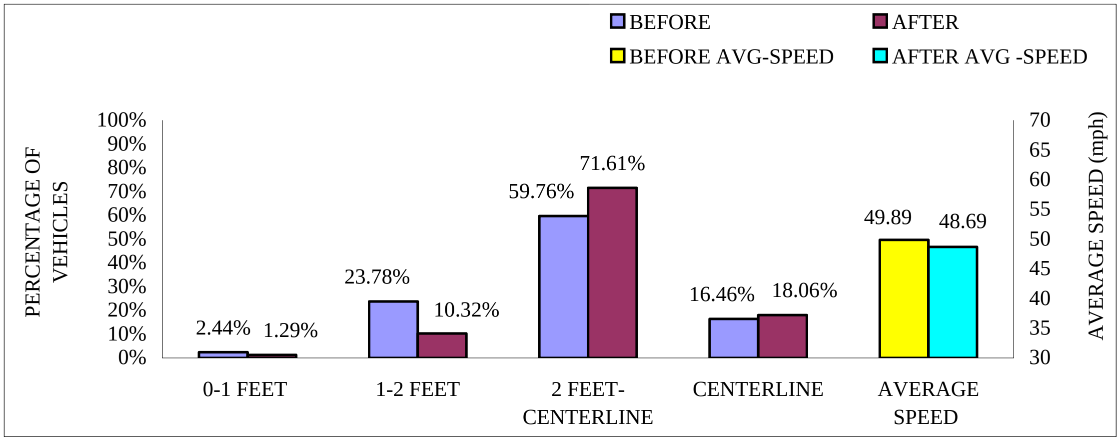


Figure 25-a
Roadway width greater than 20-feet (nighttime)

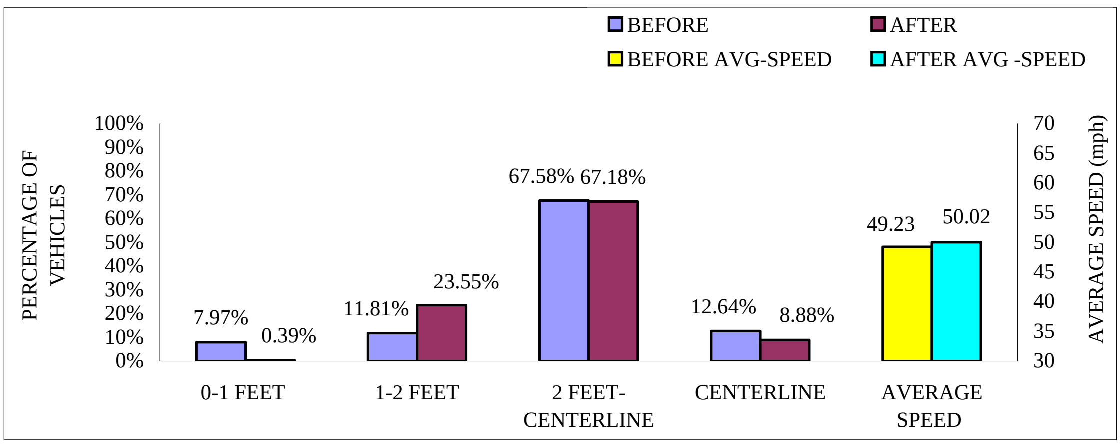


Figure 25-b
Roadway width less than or equal to 20-feet (nighttime)

At nighttime, the 1-2 feet counts increased and the 0-1 foot counts decreased. At night, vehicles on roadways 20 feet wide or narrower are more likely to stay within the travel lane. Daytime plots for roadways wider than 20-feet show a clear shift to the centerline.

In summary, the application of edge lines on roadways 20 feet wide or narrower is effective in reducing the percentage of vehicles passing close to the road edge and over centerline. However on roadways wider than 20-feet, the marking of edge lines decreased the percentage of vehicles passing close to the road edge but increased the percentage of vehicles passing over the centerline. The average speed shows no definite change.

Operating Speed. In this phase of the analysis, the seven tangent sections were divided into two groups based on the recorded average operating speed. The first group involved sites with recorded average operating speeds less than or equal to 50 MPH and another group involved sites with recorded average operating speeds greater than 50 MPH. Sites 1, 4, and 6 fall in the first group and sites 3, 7, 8, and 10 fall in the second group. The following figures show a comparison of before and after data for the two groups considering the 24 hours, daytime, and nighttime conditions.

The plots in figure 26, show that on sites with average speeds greater than 50 MPH, the marking of edge lines reduced the percentage of vehicles passing close to the road edge and over the centerline. There is a decrease in the percentages of the centerline, 0-1 foot, and 1-2 feet counts, and an increase in the percentage of between 2-feet to centerline count). On sites with average speeds less than 50 MPH, the percentage of vehicles passing over the centerline increased slightly although the percentage of vehicles passing close to the road edge decreased. In general, edge lines were effective in reducing the percentage of vehicles passing close to the road edge irrespective of the average operating speed, but at speeds lower than 50 MPH, the vehicles moved towards the centerline. Similar charts are plotted for daytime (figure 27) and nighttime data (figure 28).

The daytime and nighttime data show a trend similar to the 24-hour data. In summary, the presence of edge lines caused drivers to move away from the road edge, and at higher speeds the presence of edge lines did not result in an increase in the number of vehicles crossing over the centerline.

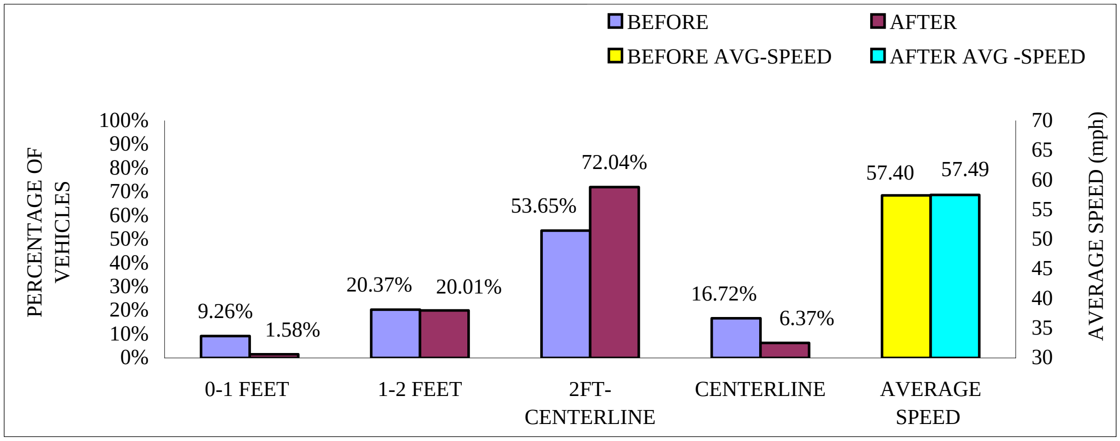


Figure 26-a
Average speed greater than 50 MPH (24-hours)

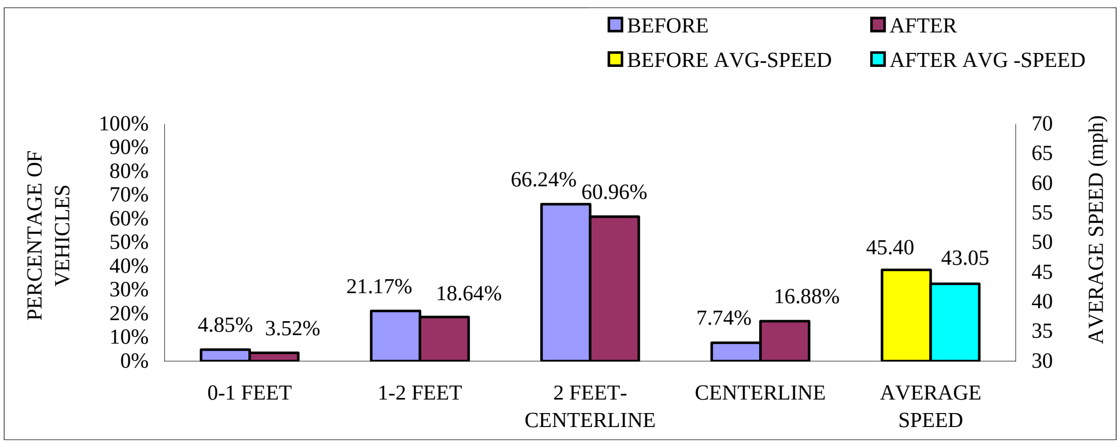


Figure 26-b
Average speed less than or equal to 50 MPH (24-hours)

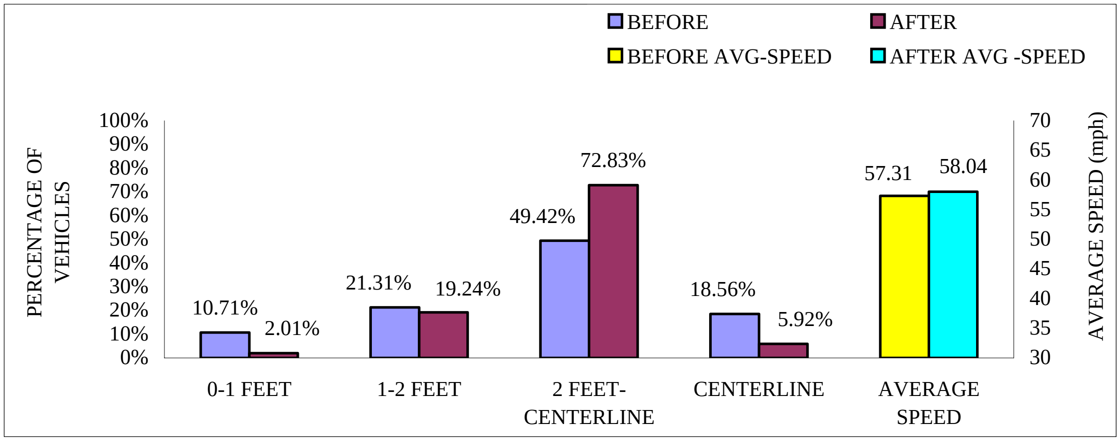


Figure 27-a
Average speed greater than 50 MPH (daytime)

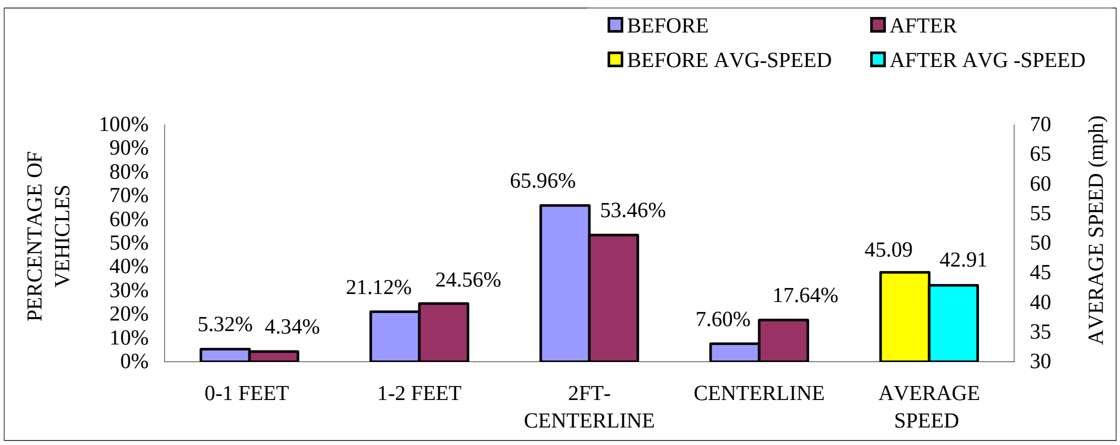


Figure 27-b
Average speed less than or equal To 50 MPH (daytime)

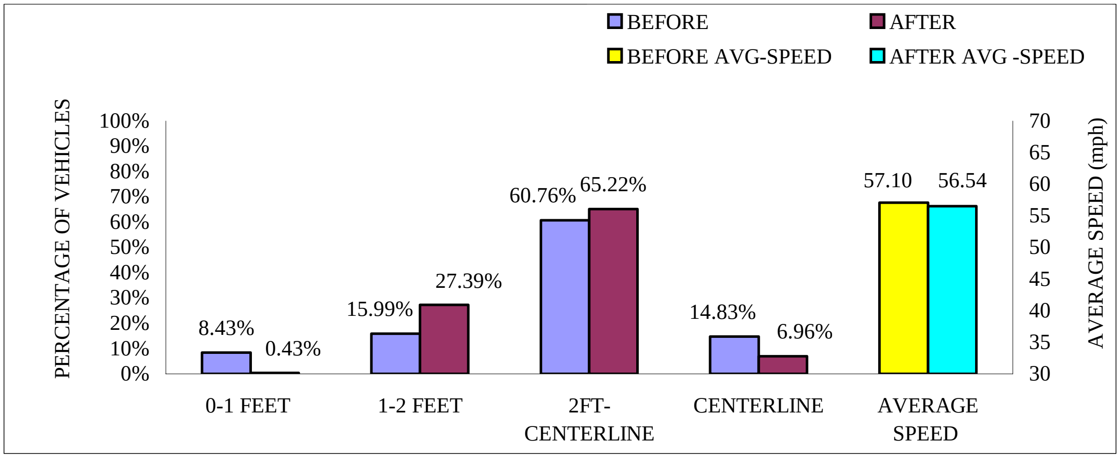


Figure 28-a
Average speed greater than 50 MPH (nighttime)

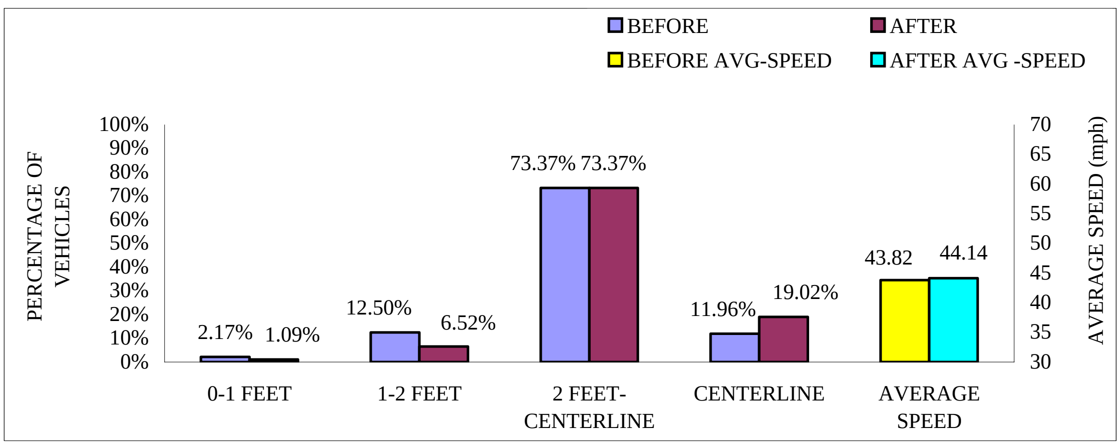


Figure 28-b
Average speed less than or equal to 50 MPH (nighttime)

Heavy Vehicles. The seven tangent sections are separated into two groups based on the percentage of heavy vehicles. Those sites with a percentage of heavy vehicles less than or equal to 10 percent are grouped together, and sites with percentage of heavy vehicles higher than 10 percent fall into the second group. Sites 1 and 10 fall into the first group, and sites 3, 4, 6, 7, and 8 into the second group. The following charts are plotted comparing the before and after data for the two groups considering 24 hours data, daytime, and nighttime conditions.

Figure 29 shows an increase in the percentage of vehicles passing close to the centerline, regardless of the percentage of heavy vehicles. The charts also show that as the percentage of heavy vehicles increase, the percentage of vehicles passing over centerline increases. Similar charts were plotted for daytime and nighttime data.

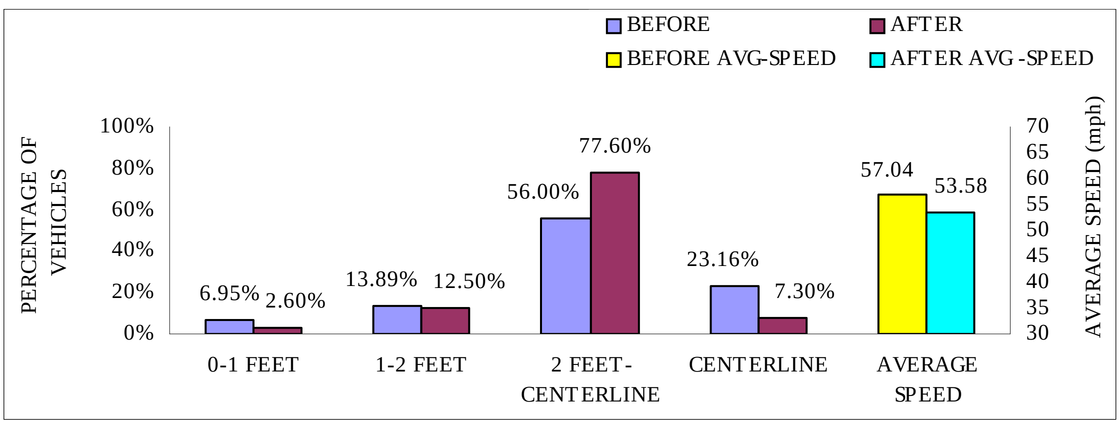


Figure 29-a
Heavy vehicles less than or equal to 10 percent (24-hours)

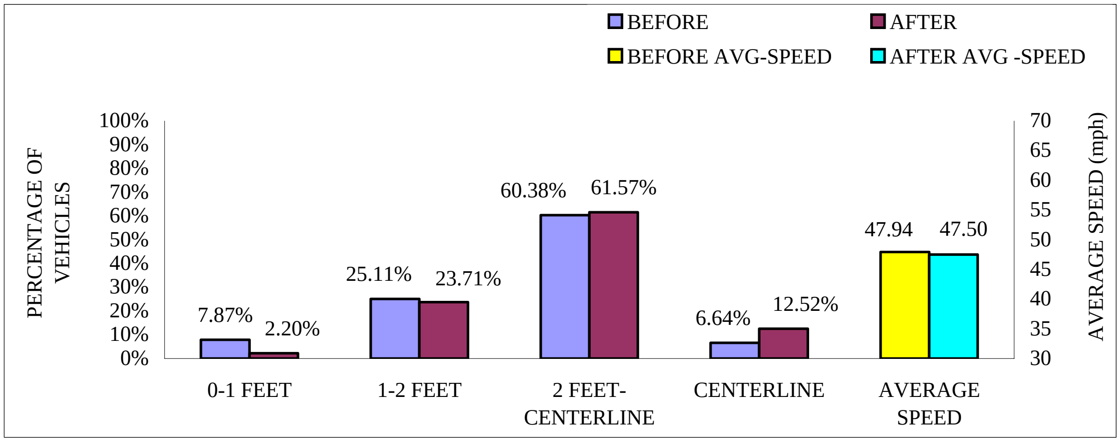


Figure 29-b
Heavy vehicles greater than 10 percent (24-hours)

The daytime charts shown in figure 30 indicate a trend similar to the 24-hour charts. The nighttime charts for sites with a low percentage of heavy vehicles, shown in Figure 31 indicate results different from the 24-hour charts and the daytime charts. The nighttime plots for sites with high percentage of heavy vehicles show results similar as to the 24-hours and the daytime charts.

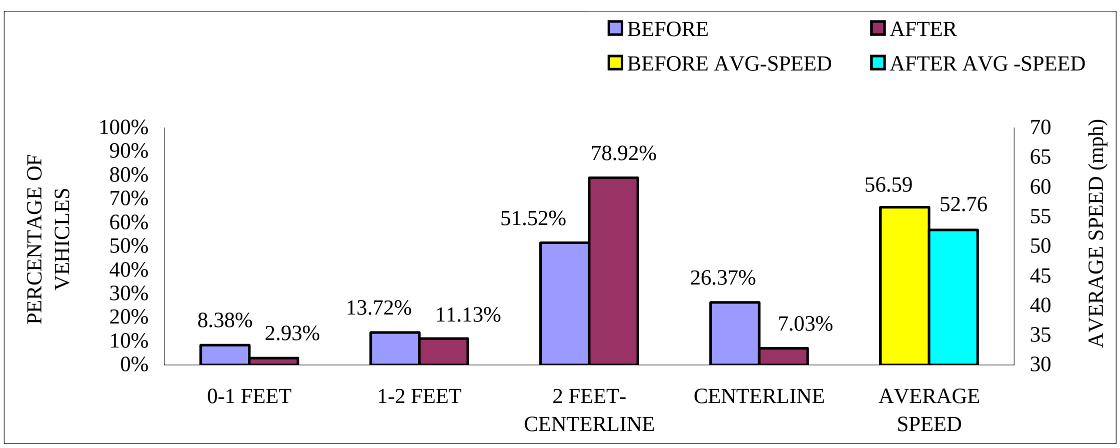


Figure 30-a
Heavy vehicles less than or equal to 10 percent (daytime)

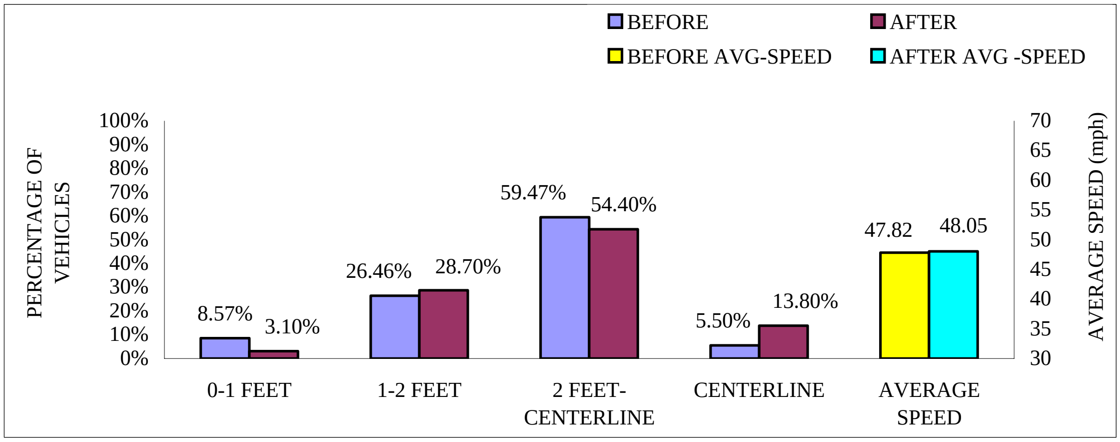


Figure 30-b
Heavy vehicles greater than 10 percent (daytime)

Figures 29, 30, and 31, show that the edge lines are effective in reducing the percentage of vehicles passing close to the road edge, which is a welcome result. It implies the possible reduction of run-off-roadway crashes. The same can't be said regarding the effect of edge lines on the percentage of vehicles passing over the centerline. The edge lines show no effect on the average operating speed.

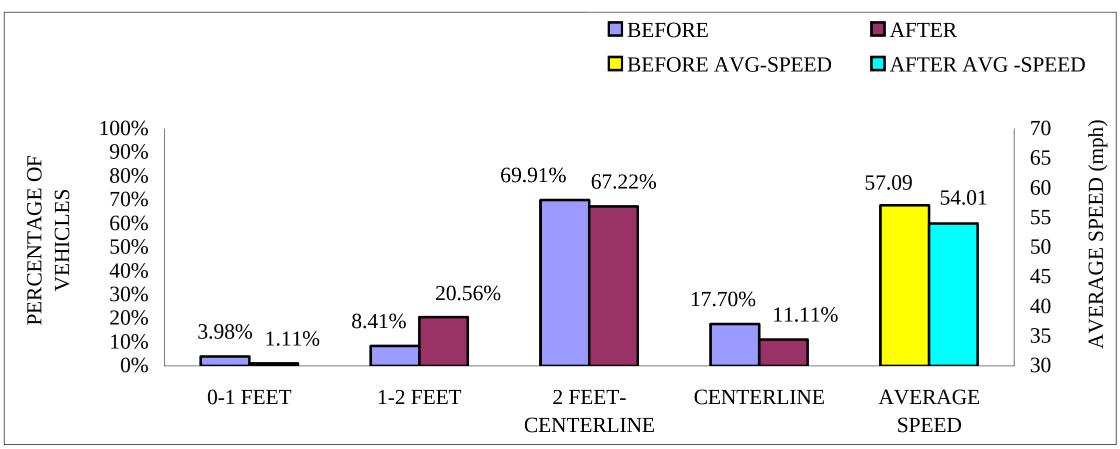


Figure 31-a
Heavy vehicles less than or equal to 10 percent (nighttime)

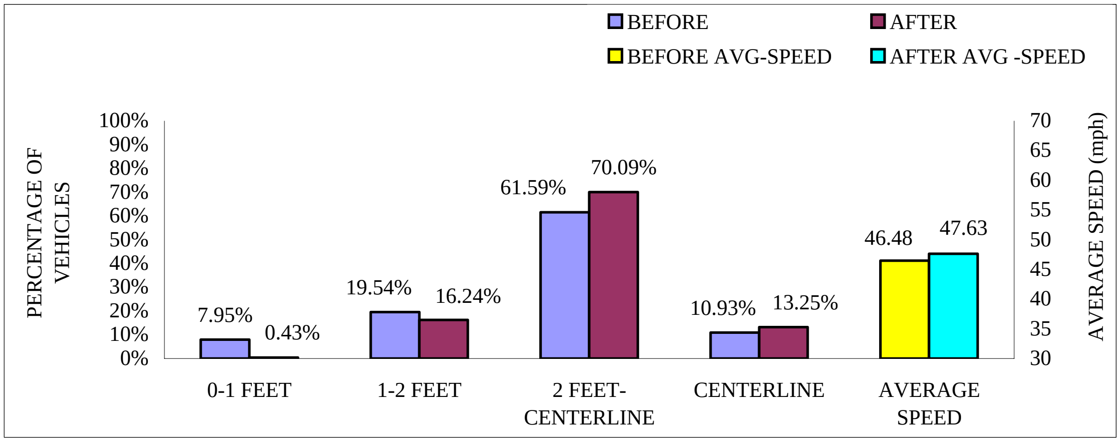


Figure 31-b
Heavy vehicles greater than 10 percent (nighttime)

Pavement Edge Drop. Some of the test sites had pavement edge drop, a difference of elevation between the edge of the pavement and the shoulder surface as shown in Figure 32. This factor likely has some influence on vehicles' lateral position. Hence, the sites with edge drop and without edge drop were grouped into two categories, and the before and after data was analyzed comparing these two categories.

Figure 32
Pavement edge drop

Figure 33 shows that, irrespective of edge drop, the 0-1 foot count decreased indicating a decrease in the percentage of vehicles passing close to the road edge. On roadways with edge drop, the percentage 1-2 feet count decreases in the 24-hours and daytime periods shown in figure 34. It increases at nighttime although the percentage of 0-1 foot count decreased, as shown in Figure 35. The percentage of vehicles crossing the centerline decreases on roadways with edge drop and increases on roadways without edge drop. Therefore, after the application of edge lines on roads without edge drop, vehicles tended to move towards the centerline or road edge (indicated by an increase in the percentage of 1-2 feet count), whereas the application of edge lines on roadways with edge drop was effective in reducing the percentage of vehicles passing over centerline and those traveling close to the road edge.

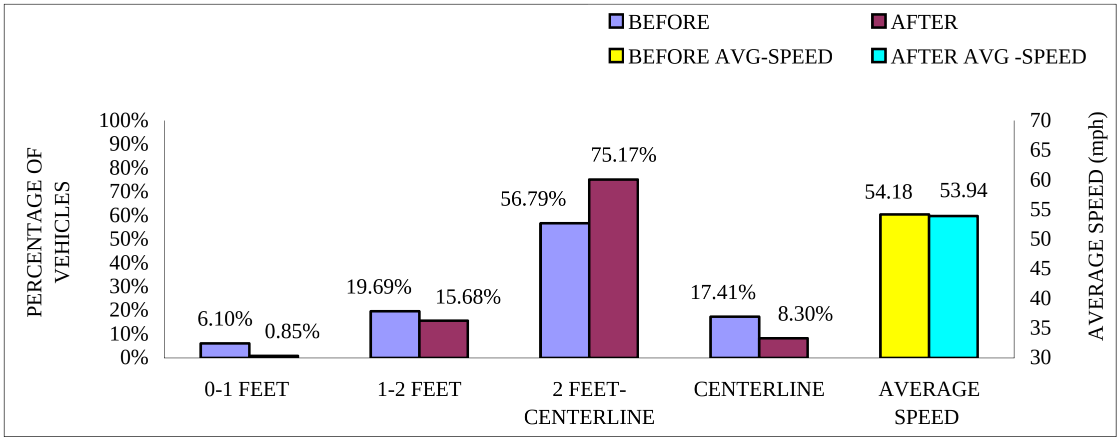


Figure 33-a
With edge drop (24-hours)

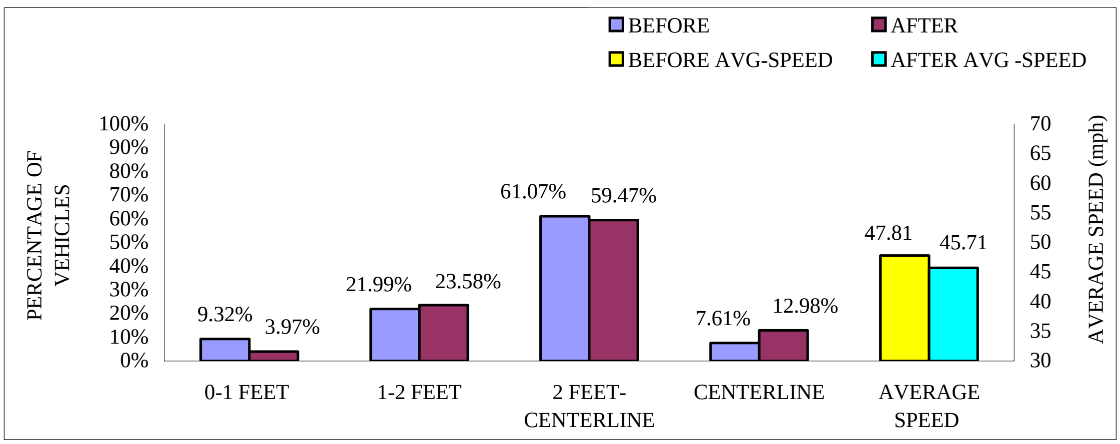


Figure 33-b
Without edge drop (24-hours)

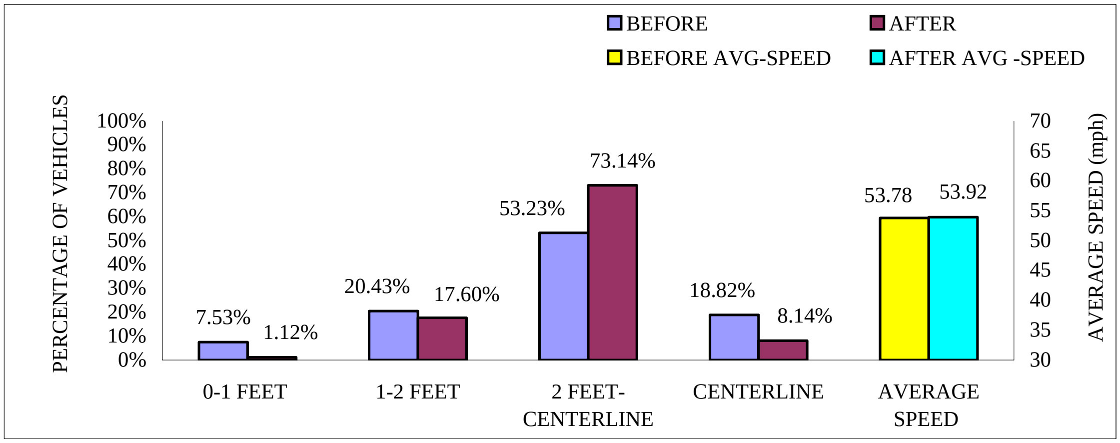


Figure 34-a
With edge drop (daytime)

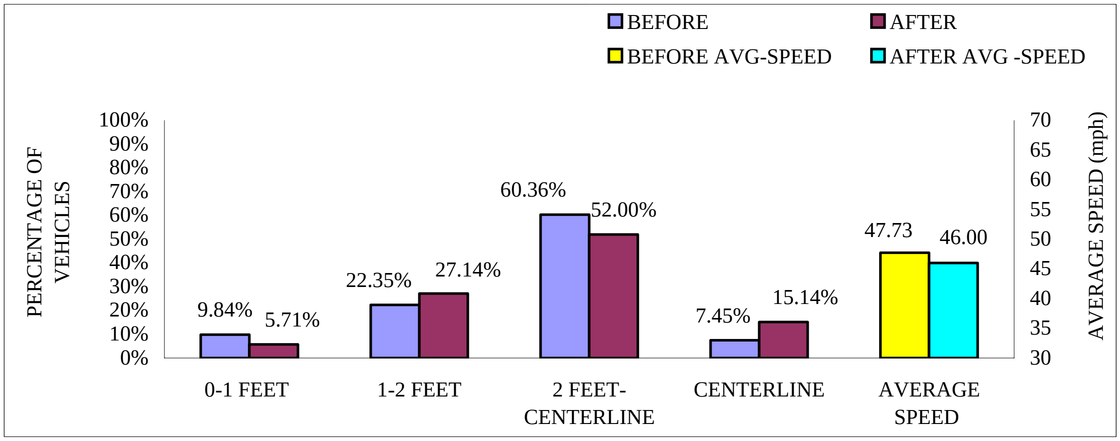


Figure 34-b
Without edge drop (daytime)

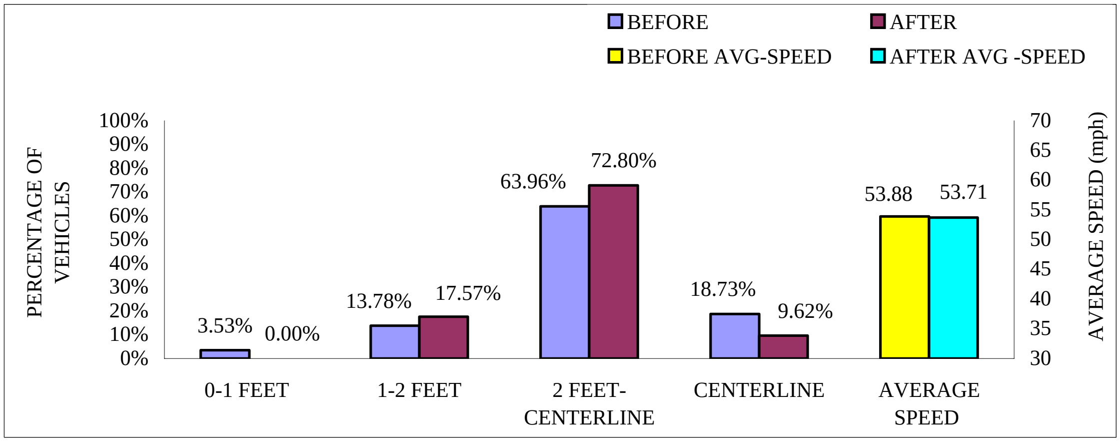


Figure 35-a
With edge drop (nighttime)

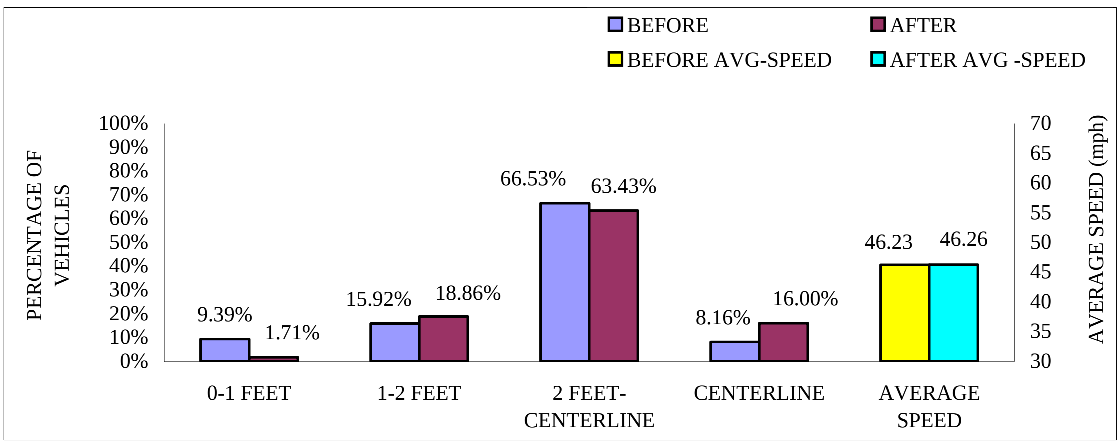


Figure 35-b
Without edge drop (nighttime)

Pavement Condition. Some drivers tend to alter their travel paths on deteriorated pavement. Such pavement is characterized by severe cracks, patches, or potholes as seen in figure 36. Based on manual observations, seven study sites (tangent sites) were classified into two groups by their pavement condition. The fair condition group includes sites 1, 4, 6, and 10, and sites 3, 7, and 8 fall into the poor pavement condition group. Figure 37 compares how vehicles' lateral positions were affected after edge line marking with respect to the pavement condition.

(a) Favorable Condition (LA 367)

(b) Cracks (LA 1113)

(c) Pothole (LA 354)

(d) Deteriorated Overlay (LA 354)

(e) Cracked Pavement Edge (LA 354)

(f) Pavement Patch (LA 354)

Figure 36   Various pavement conditions

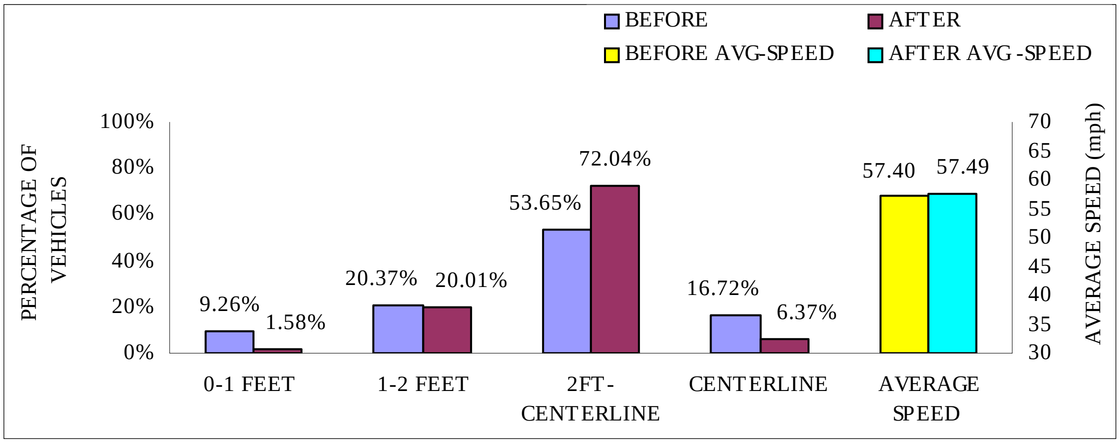


Figure 37-a
Good pavement condition (24 hours)

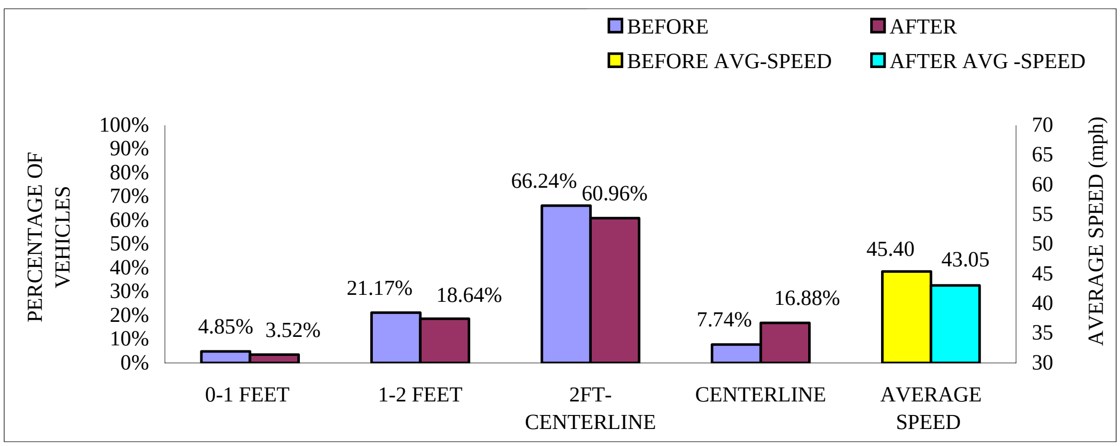


Figure 37-b
Poor pavement condition (24 hours)

The charts indicate that when 24-hour data is considered, after the application of edge lines on sites with good pavement condition, vehicles tended to stay in their lane. This is indicated by a decrease in the centerline count and 0-1 foot and 1-2 feet counts. And on sites with poor pavement condition, vehicles moved over the centerline. Regardless of the pavement condition, vehicles moved away from the road edge after the marking of edge lines. Similar charts are plotted to study vehicles' lateral position during the day and at night as shown in figure 37 and figure 38, respectively.

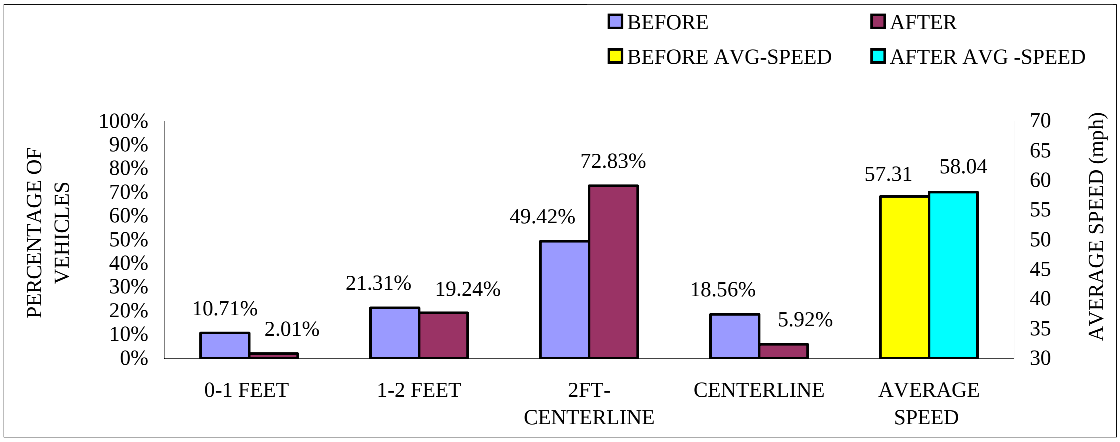


Figure 38-a
Good pavement condition (daytime)

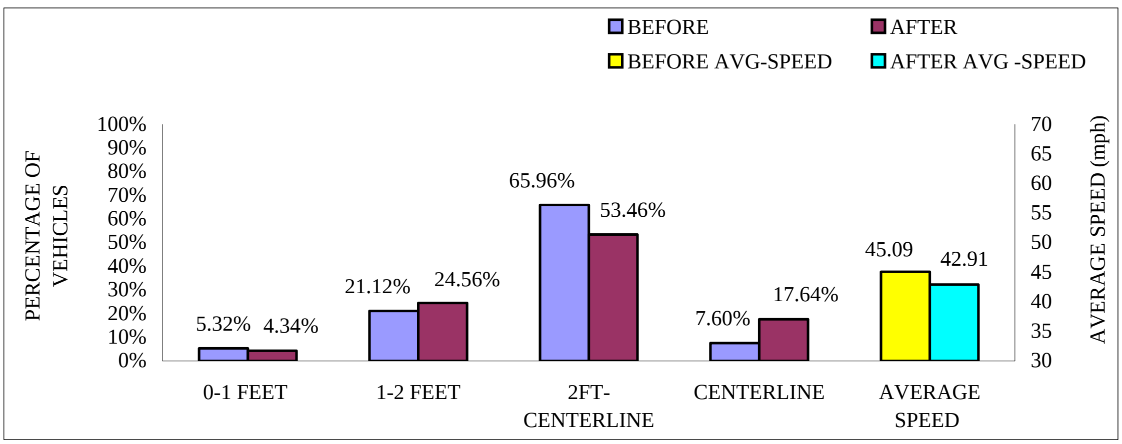


Figure 38-b
Poor pavement condition (daytime)

Similar conclusions could be drawn from the daytime and nighttime analysis. In general, on sites with good pavement condition, edge lines were effective in inducing a more favorable lateral position and causing the driver to move away from the road edge. But on sites with poor pavement condition, the edge lines caused drivers to move away from the road edge and over the centerline, which is not intended. This could indicate potential increase in head-on collisions when edge line markings are applied to narrow roadways with poor pavement conditions.

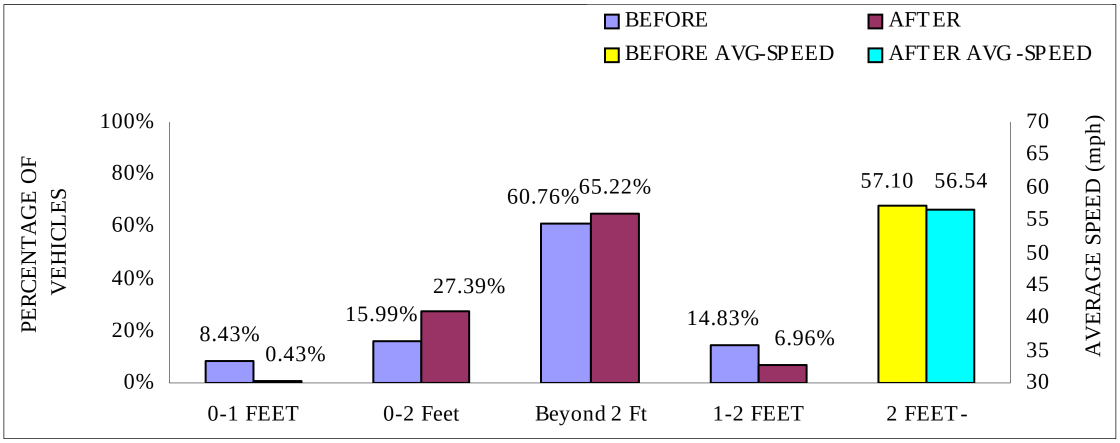


Figure 39-a
Good pavement condition (nighttime)

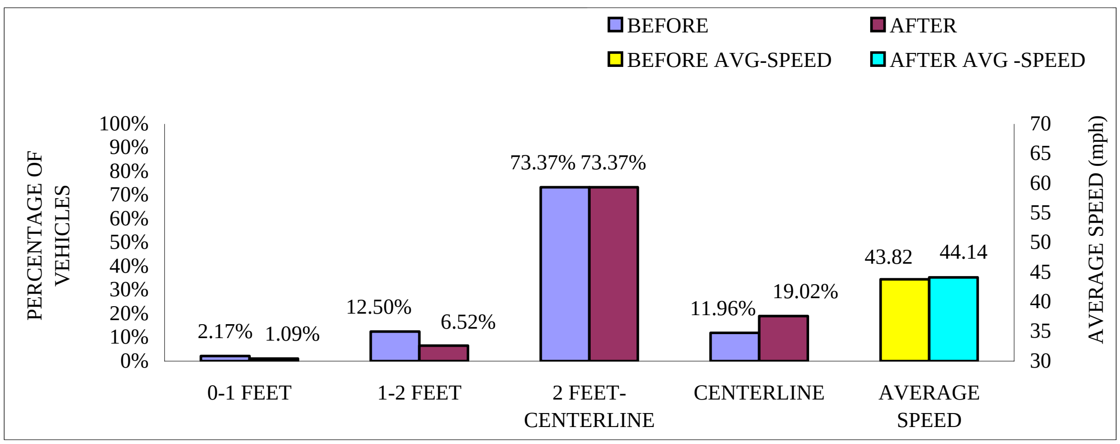


Figure 39-b
Poor pavement condition (nighttime)

Vehicles' Lateral Position Based on Traffic Interactions.

A vehicle interacts with vehicles traveling in the opposite direction, particularly on undivided narrow two-lane highways. Even if passing is not allowed, interactions between vehicles alter driving behavior. Thus, it was necessary to investigate the effect of edge lines on lateral placement of vehicles at different levels of vehicle interaction. This study focused on two types of interaction: vehicle interaction with other vehicles in the same direction; and vehicles interaction with vehicles traveling in the opposite direction. Because the traffic data was collected at 15-minute intervals, capturing the moment of interaction was not viable. This study considered traffic counts of the 15-minute intervals to determine the higher level of interaction periods. The minimum average time headway of 30 seconds per vehicle (flow rate of 120 vehicles per hour per lane) was chosen to classify a time interval as a high volume interval. In doing so, higher volume intervals with the corresponding time period of both before and after edge line data, as shown in the example below, were selected for the analysis.

Example: The interval between 5:15 PM and 5:30 PM from the “before” data set of LA 354, and the interval between 5:15 PM and 5:30 PM from the “after” data set of LA 354 are classified as high volume interval because of more than 30 vehicles being recorded at each location.

Figure 40-a shows that at high volume intervals of the target lane (higher interaction in the same traveled lane), the percentage of vehicles passing closer to the road edge as well as crossing the centerline decreased after edge line installation. Figure 40-b shows that with high opposing traffic volume all the vehicles at target lane operate completely within the travel lane, i.e., neither closer to the road edge nor across the centerline. In other words, when the chance of meeting oncoming vehicles from the opposing direction is higher, vehicles maintained a more centralized position within the travel lanes that had edge lines. When comparing the two types of interaction, the effect of edge lines is more apparent in the interaction with oncoming traffic. This is a welcome result since it reduces the chance of vehicles having head-on collisions and running- off- roadway.

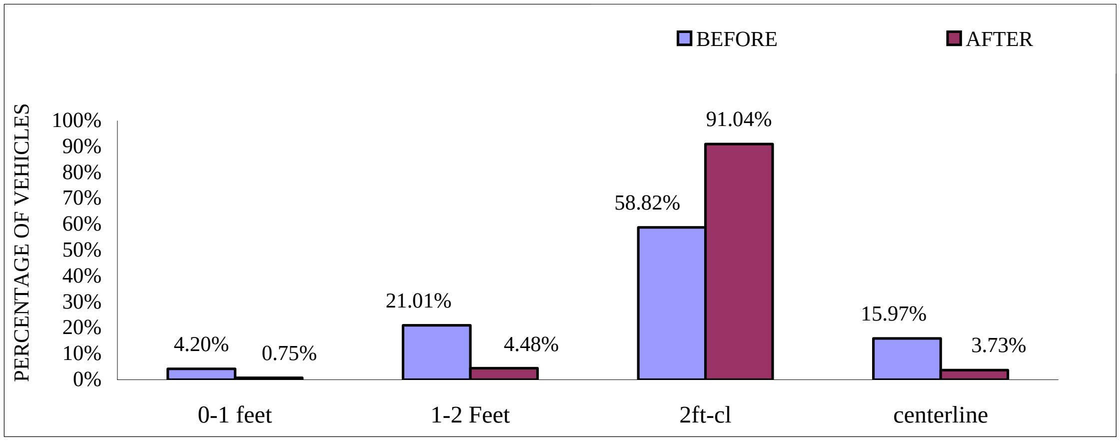


Figure 40-a
Position change when higher interaction in the traveled lane

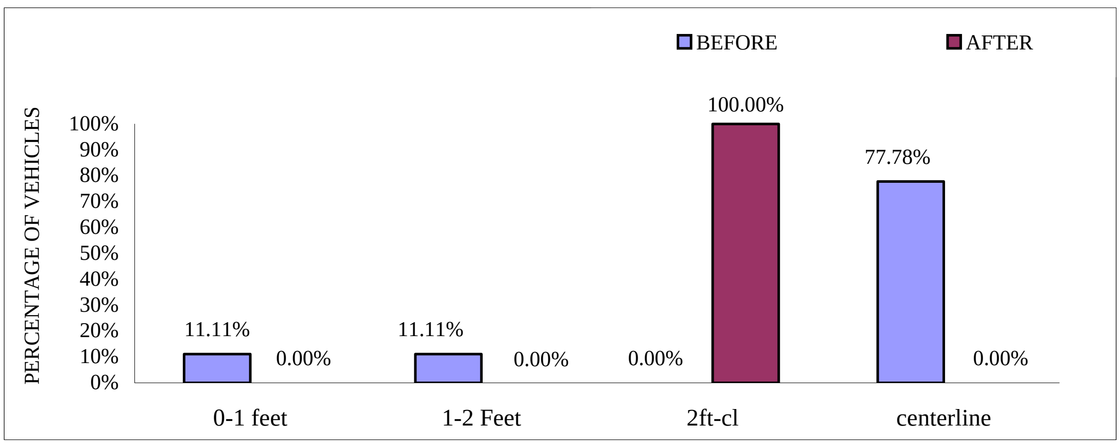


Figure 40-b
Position change when higher interaction with oncoming traffic

TORT LIABILITY: LEGAL IMPLICATIONS

For many years, the Louisiana Department of Transportation and Development has provided edge lines for its two lane roadways that are 22 feet or wider. This policy was consistent with the Manual on Uniform Traffic Control Devices (MUTCD), through the 1988 edition. Section 3B-6 Pavement Edge Lines of the 1988 edition established no requirement for the application of edge lines to rural two lane roadways of any class or width. Only through its EDSM (Engineering Directives and Standards Manual) did DOTD developed the policy to mark two lane roadways with widths of 22-feet or more [3].

However, beginning with the Millennium edition of the MUTCD published in December 2000, the MUTCD has stated that edge line markings shall be placed on rural arterials with a traveled way of 20-feet or more in width and an ADT of 6,000 vehicles per day or greater. Additionally, the Millennium edition stated that rural arterials and collectors with a traveled way of 20 feet or more in width and an ADT of 3,000 vehicles per day or greater should receive an edge line. The latest edition of the MUTCD (2003) applicable to edge lines is reprinted below.

Section 3B.06 <u>Edge Line Pavement Markings</u>

Standard:

> If used, edge line pavement markings shall delineate the right or left edges of a roadway.
>
> Except for dotted edge line extensions (see Section 3B.08), edge line markings shall not be continued through intersections or major driveways.
>
> If used on the roadways of divided highways or one-way streets, or on any ramp in the direction of travel, left edge line pavement markings shall consist of a normal solid yellow line to delineate the left edge of a roadway or to indicate driving or passing restrictions left of these markings.
>
> If used, the right edge line pavement markings shall consist of a normal solid white line to delineate the right edge of the roadway.

Guidance:

> Edge line markings should not be broken for minor driveways.

Support:

Edge line markings have unique value as visual references to guide road users during adverse weather and visibility conditions.

Option:

Wide solid edge line markings may be used for greater emphasis.

Section 3B.07 Warrants for Use of Edge Lines

Standard:

Edge line markings shall be placed on paved streets or highways with the following characteristics:

A. Freeways;

B. Expressways; and

C. Rural arterials with a traveled way of 6.1 m (20 ft) or more in width and an ADT of 6,000 vehicles per day or greater.

Guidance:

Edge line markings should be placed on paved streets or highways with the following characteristics:

A. Rural arterials and collectors with a traveled way of 6.1 m (20 ft) or more in width and an ADT of 3,000 vehicles per day or greater.

B. At other paved streets and highways where an engineering study indicates a need for edge line markings.

Edge line markings should not be placed where an engineering study or engineering judgment indicates that providing them is likely to decrease safety.

Option:

Edge line markings may be placed on streets and highways with or without centerline markings.

Edge line markings may be excluded, based on engineering judgment, for reasons such as if the traveled way edges are delineated by curbs, parking, bicycle lanes, or other markings.

Edge line markings may be used where edge delineation is desirable to minimize unnecessary driving on paved shoulders or on refuge areas that have lesser structural pavement strength than the adjacent roadway.

When used in the MUTCD, the text headings shall be defined as follows:

1. Standard—a statement of required, mandatory, or specifically prohibitive practice regarding a traffic control device. All standards are labeled, and the text appears in bold type. The verb shall is typically used. Standards are sometimes modified by Options.

2. Guidance—a statement of recommended, but not mandatory, practice in typical situations, with deviations allowed if engineering judgment or engineering study indicates the deviation to be appropriate. All Guidance statements are labeled, and the text appears in unbold type. The verb should is typically used. Guidance statements are sometimes modified by Options.

3. Option—a statement of practice that is a permissive condition and carries no requirement or recommendation. Options may contain allowable modifications to a Standard or Guidance. All Option statements are labeled, and the text appears in unbold type. The verb may is typically used.

4. Support—an informational statement that does not convey any degree of mandate, recommendation, authorization, prohibition, or enforceable condition. Support statements are labeled, and the text appears in unbold type. The verbs shall, should, and may are not used in Support statements.

Several other items and definitions within the MUTCD are also helpful in the analysis of legal implications of edge line markings. These include:

Section 1A.09 Engineering Study and Engineering Judgment

Standard:

This Manual describes the application of traffic control devices, but shall not be a legal requirement for their installation.

Guidance:

The decision to use a particular device at a particular location should be made on the basis of either an engineering study or the application of engineering judgment. Thus, while this Manual provides Standards,

Guidance, and Options for design and application of traffic control devices, this Manual should not be considered a substitute for engineering judgment.

Engineering judgment should be exercised in the selection and application of traffic control devices, as well as in the location and design of the roads and streets that the devices complement. Jurisdictions with responsibility for traffic control that do not have engineers on their staffs should seek engineering assistance from others, such as the State transportation agency, their County, a nearby large City, or a traffic engineering consultant.

Section 1A.13 Definitions of Words and Phrases in This Manual

Standard:

> Unless otherwise defined herein, or in the other Parts of this Manual, definitions contained in the most recent edition of the "Uniform Vehicle Code," "AASHTO Transportation Glossary (Highway Definitions)," and other publications specified in Section 1A.11 are also incorporated and adopted by reference.

The following words and phrases, when used in this Manual, shall have the following meanings:

25. Engineering Judgment—the evaluation of available pertinent information, and the application of appropriate principles, Standards, Guidance, and practices as contained in this Manual and other sources, for the purpose of deciding upon the applicability, design, operation, or installation of a traffic control device. Engineering judgment shall be exercised by an engineer, or by an individual working under the supervision of an engineer, through the application of procedures and criteria established by the engineer. Documentation of engineering judgment is not required.
26. Engineering Study—the comprehensive analysis and evaluation of available pertinent information, and the application of appropriate principles, Standards, Guidance, and practices as contained in this Manual and other sources, for the purpose of deciding upon the applicability, design, operation, or installation of a traffic control device. An engineering study shall be performed by an engineer, or by an individual working under the supervision of an engineer, through the application of procedures and criteria established by the engineer. An engineering study shall be documented.

Armed with this information, the study results, and experience in the practical application of edge line markings, the researchers concluded that the State of Louisiana DOTD should revise its Engineering Directives and Standards Manual to permit the marking of rural highways in accordance with the latest edition of the MUTCD (2003).

CONCLUSIONS

The following are the major findings from this project:

- With edge lines, centralization of vehicles' position is more apparent during nighttime, which reduces the risk of ROR and head-on collisions.
- Edge line markings generally cause drivers to operate their vehicles away from the road edge, irrespective of the roadway alignment.
- Magnitude of the impact of edge line markings is influenced by roadway width, operating speed, time of the day, frequency of heavy vehicles, pavement condition, roadway alignment, and traffic from the opposite direction.
- Due to the limited number of curved sections, the impact of edge line for horizontal curves are not conclusive
- Edge lines have no or little effect on the average operating speed

The before-and-after measurements show that the edge line has a positive impact on rural narrow two-lane highways in Louisiana particularly at night. The additional in-depth study is necessary for curve sections. The qualitative safety effect in terms of number of crashes before-and-after edge line should be monitored and documented as a continuation of this project.

RECOMMENDATIONS

This project has demonstrated the positive impact that edge lines have on vehicular lateral position on narrow rural two-lane highways in Louisiana. However, the actual impact of this position change on the number and severity of crashes on Louisiana highways is not clear and is beyond the scope of this study. It is also not financially feasible to implement an edge line requirement on all narrow rural two-lane highways in Louisiana at one time. To warrant the implementation process, the actual safety improvement must be known. For that, we recommend the results of this study be implemented in phases by first validating the benefit of placing edge lines on narrow rural two-lane highways in Louisiana as follows.

1. Select 30-50 segments with overall high crash frequency rates for three consecutive years (2002-2005).
2. Select 30-50 segments with high ROR and head-on crash frequency rates for three consecutive years.
3. Implement edge lines on these selected segments.
4. Observe the crash statistics for at least two years after the edge line implementation.
5. Conduct before-and-after statistical analysis to validate the effect of edge lines on the crash frequency, crash type, and severity distributions.

The results of this analysis will provide much needed information on the crash reduction aspect of edge lines on rural two-lane highways in Louisiana and will provide a strong foundation for further implementation statewide. To our knowledge, this validation work has not been conducted elsewhere.

REFERENCES

[1] Federal Highway Administration, *Manual on Uniform Traffic Control Devices, Millennium Edition*, U.S. Department of Transportation, Washington D.C. (2000)

[2] Federal Highway Administration, *Manual on Uniform Traffic Control Devices, 1988 Edition*, U.S. Department of Transportation, Washington D.C. (1988)

[3] Louisiana Department of Transportation and Development, *Engineering Directives and Standards Manual (EDSM) Vol. VI, Chapter 4, Section 1, Directive 1, Pavement Markings*, LaDOTD Office of Engineering, Baton Rouge (1994)

[4] Thomas, I. L., *Pavement Edge Lines on Twenty-Four Foot Surfaces in Louisiana*, Highway Research Board Bulletin, Washington D.C. (1958), pp. 12-20

[5] Thomas, I. L., Taylor, W. T., Effect of Edge Striping on Traffic Operations, Highway Research Board Bulletin, Washington D.C. (1960), pp. 11-15

[6] Musick, J. V., *Effect of Pavement Edge Marking on Two-Lane Rural State Highways in Ohio*, Highway Research Board Bulletin 266, National Research Council, Washington, D.C. (1960)

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[8] Hassan, Z. Y., *Effect of Edge Marking on Narrow Rural Roads*, Consortium of Universities/Urban Transportation Center, Washington, D.C. (1971)

[9] Steyvers, F.J.J.M., De Waard, D., Road-Edge Delineation in Rural Areas: Effects on Driving Behavior, *Ergonomics*, Vol. 43, No 2, Groningen, The Netherlands (2000), pp. 223-238

[10] Olson, P. L., Dewar, R. E., *Introduction. In: Human Factors in Traffic Safety*, Lawyers & Judges Publishing Company, Arizona (2002), pp. 1-12

ACRONYMS, ABBREVIATIONS, & SYMBOLS

MUTCD	Manual on Traffic Control Devices
ADT	Average Daily Traffic
CASTS	Center for the Analysis of Spatial and Temporal Systems
DOT	Department of Transportation
LaDOTD	Louisiana Department of Transportation and Development
LTRC	Louisiana Transportation Research Center
ETW	Edge of Traveled Way
TL	Target Lane
OL	Opposite Lane
CL	Centerline
MPH	Miles Per Hour

APPENDICES

Appendix A: MUTCD Guidelines on Edge Lines (the Millennium Edition)

Appendix B: Analysis of Individual Sections

Appendix C: FHWA Vehicle Classification Scheme F

Appendix A: MUTCD Guidelines on Edge Lines (the Millennium Edition)

Section 3B.06: Edge Line Pavement Markings

Standard:

- If used, edge line pavement markings shall delineate the right or left edges of a roadway.
- Except for dotted edge line extensions (see Section 3B.08), edge line markings shall not be continued through intersections or major driveways.
- If used on the roadways of divided highways or one-way streets, or on any ramp in the direction of travel, left edge line pavement markings shall consist of a normal solid yellow line to delineate the left edge of a roadway or to indicate driving or passing restrictions left of these markings.
- If used, the right edge line pavement markings shall consist of a normal solid white line to delineate the right edge of the roadway.

Guidance:

Edge line markings should not be broken for minor driveways.

Support:

Edge line markings have unique value as visual references to guide road users during adverse weather and visibility conditions.

Option:

Wide solid edge line markings may be used for greater emphasis.

Appendix A (Continued):

Section 3B.07: Warrants for Use of Edge Lines

Standard:

Edge line markings shall be placed on paved streets or highways with the following characteristics:

A. Freeways;

B. Expressways; and

C. Rural arterials with a traveled way of 6.1 m (20 ft) or more in width and an ADT of 6,000 vehicles per day or greater.

Guidance:

Edge line markings should be placed on paved streets or highways with the following characteristics:

A. Rural arterials and collectors with a traveled way of 6.1 m (20 ft) or more in width and an ADT of 3,000 vehicles per day or greater.

B. At other paved streets and highways where an engineering study indicates a need for edge line markings.

Edge line markings should not be placed where an engineering study or engineering judgment indicates that providing them is likely to decrease safety.

Option:

Edge line markings may be placed on streets and highways with or without centerline markings.

Edge line markings may be excluded, based on engineering judgment, for reasons such as if the traveled way edges are delineated by curbs, parking, bicycle lanes, or other markings.

Edge line markings may be used where edge delineation is desirable to minimize unnecessary driving on paved shoulders or on refuge areas that have lesser structural pavement strength than the adjacent roadway.

Appendix B: Analysis of Individual Sections

<u>Site 1</u>

- LA 367, tangent alignment
- Good pavement condition, slight rutting
- Single dashed centerline with reflectors
- 5-inch edge drop on both sides of the road
- Long sight distance for the driver

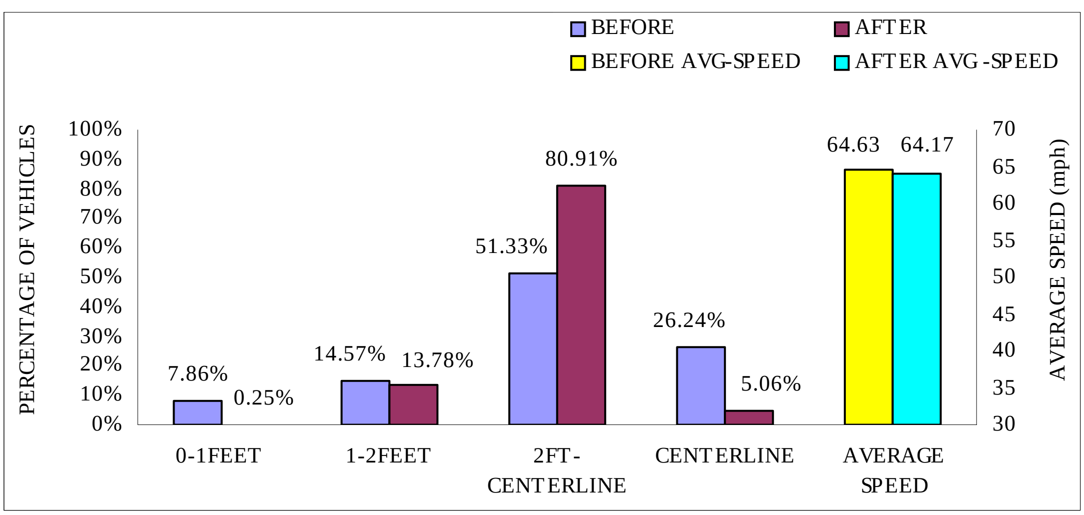


Figure B.1
Before vs. after on site 1

Appendix B (Continued):

Site 2

- LA 367, curved alignment
- Good pavement surface condition
- Rutting at a few places
- Passing allowed on the opposite lane
- The target lane is the outer lane of the curve

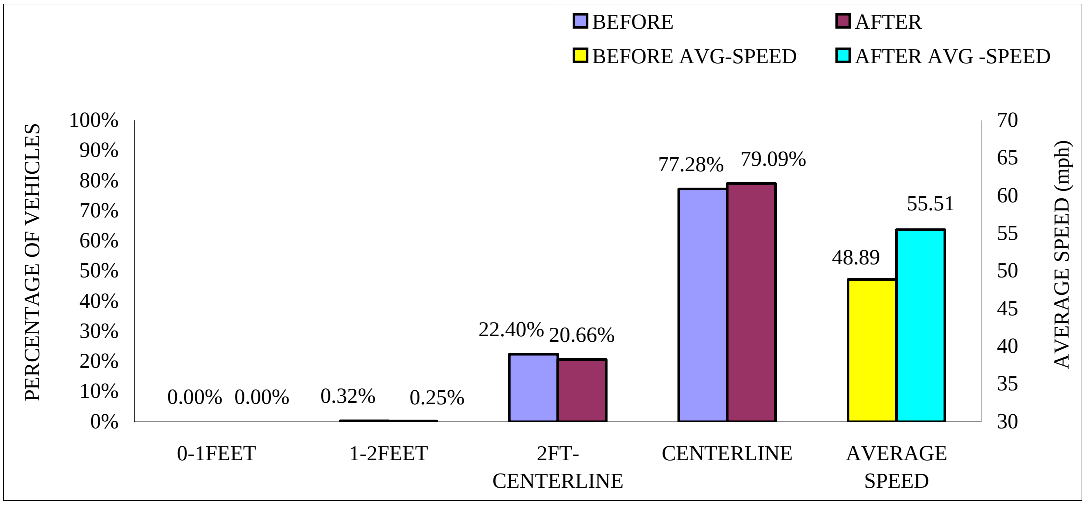


Figure B.2
Before vs. after on site 2

Appendix B (Continued):

Site 3

- LA 1113, tangent alignment
- Poor pavement surface condition
- Passing not allowed
- Has reflectors along the centerline
- Long sight distance
- Very low ADT and narrowest road width considered in this study (18.5 ft)

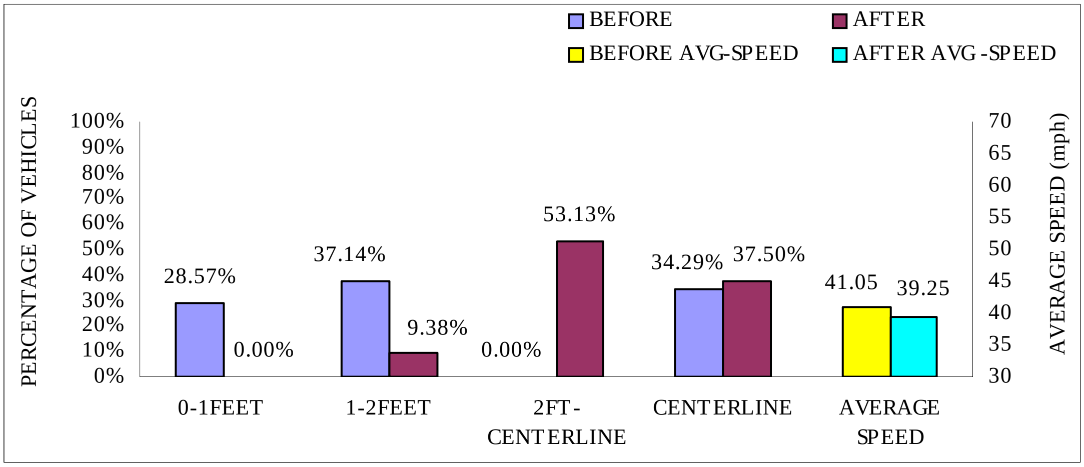


Figure B.3
Before vs. after on site 3

Appendix B (Continued):

Site 4

- LA 98, tangent alignment
- Good pavement surface condition
- Reflectors along the centerline
- Passing not allowed
- Long sight distance

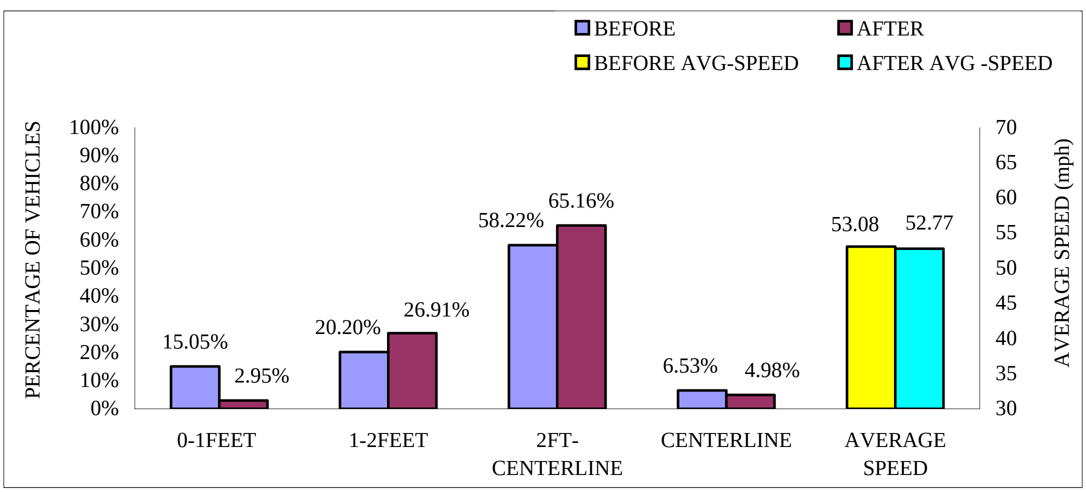


Figure B.4
Before vs. after on site 4

Appendix B (Continued):

<u>Site 5</u>

- LA 98, curved alignment
- Good pavement surface condition with a slight rutting
- Passing allowed on the opposite lane
- Target lane as the inner lane of the curve
- Fairly enough sight distance

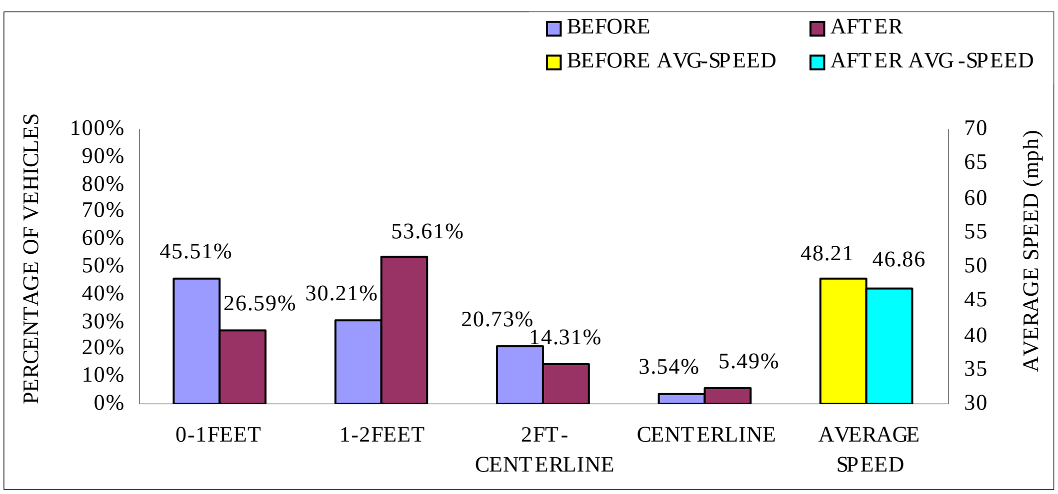


Figure B.5
Before vs. after on site 5

Appendix B (Continued):

Site 6

- LA 98, tangent alignment
- Good pavement surface condition
- A little rutting
- Passing not allowed
- Fairly enough sight distance

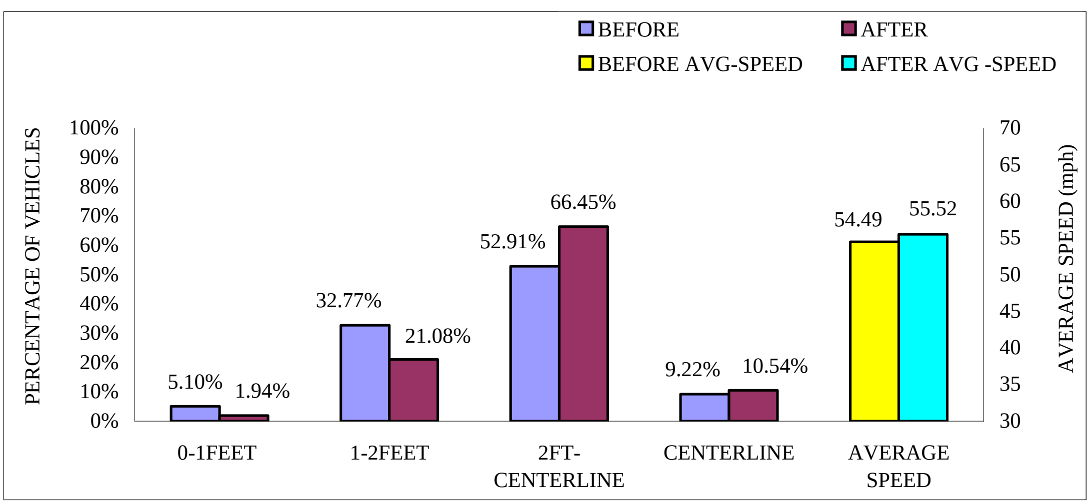


Figure B.6
Before vs. after on site 6

Appendix B (Continued):

<u>Site 7</u>

- LA 354, tangent alignment
- The pavement surface is quite rough: substantial rutting and patches on both lanes
- Reflectors along the centerline, slightly damaged
- Passing allowed in the opposite lane
- Fairly enough sight distance

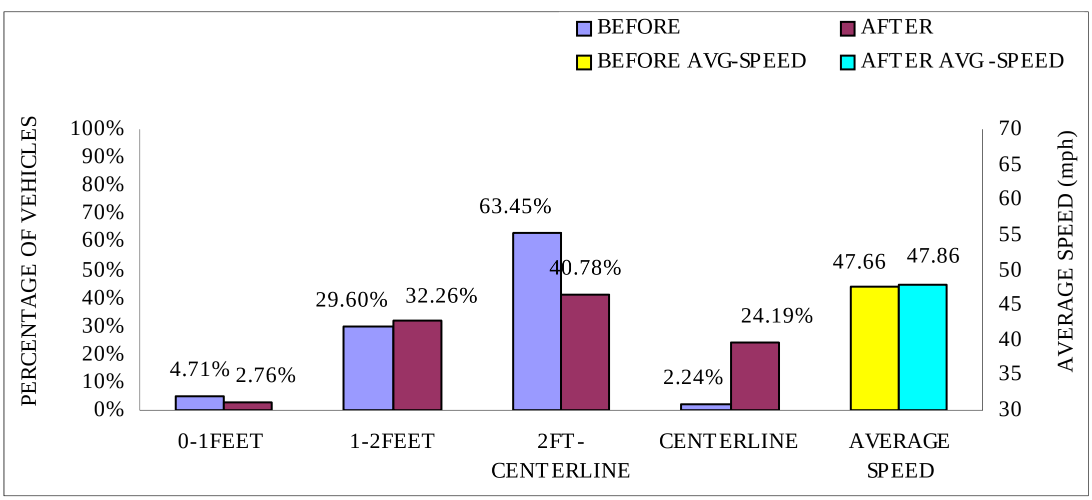


Figure B.7
Before vs. after on site 7

Appendix B (Continued):

Site 8

- LA 354, tangent alignment (on a S-curve)
- Located in the middle of two consequent horizontal curves, called as an S-curve
- Fair pavement surface condition with cracks and patches in a few places
- Short sight distance
- 45 MPH of an advisory speed limit

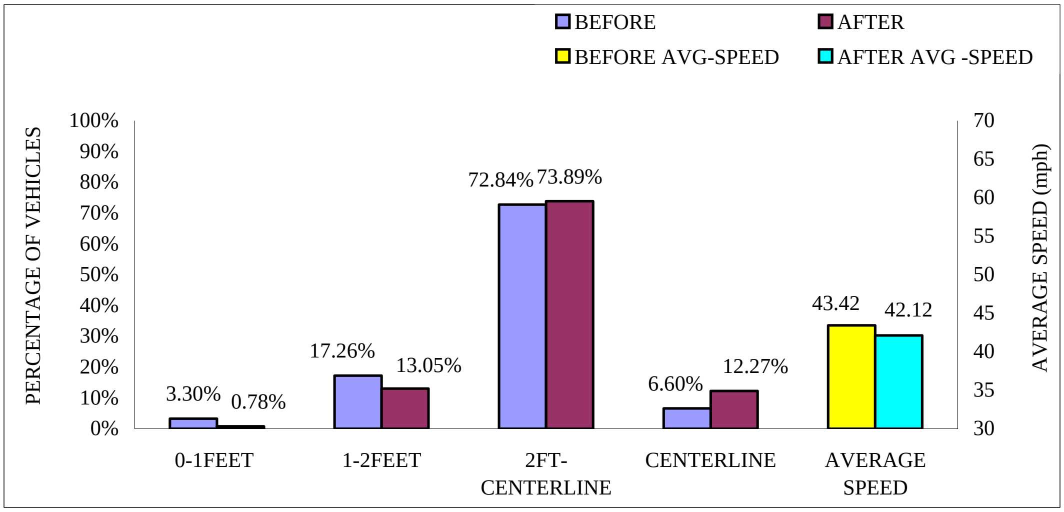


Figure B.8
Before vs. after on site 8

Appendix B (Continued):

<u>Site 9</u>

- LA 354, curved alignment
- Located at one of the bends on an S-curve
- The target lane as the outer curve on the section
- Fair pavement surface condition with a little cracks and patches on the on both lanes
- Short sight distance
- 45 MPH of an advisory speed limit

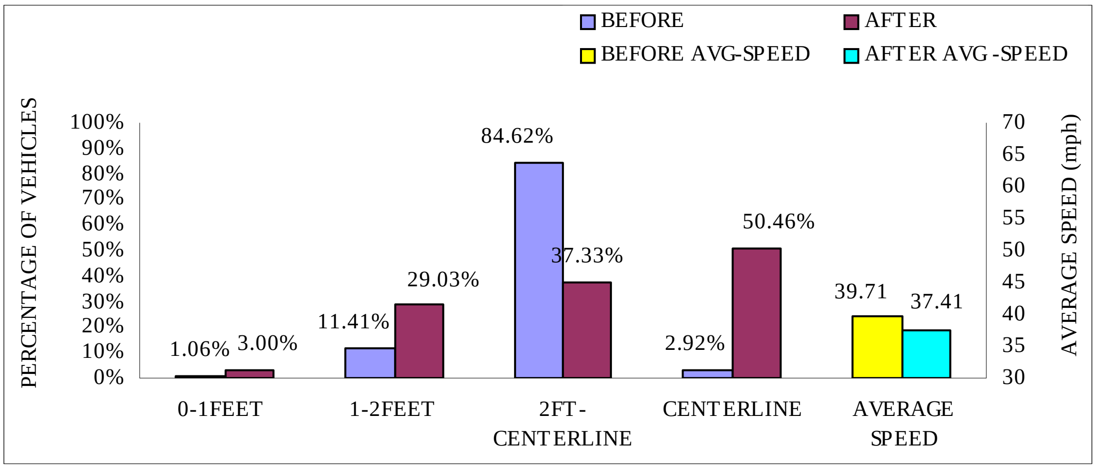


Figure B.9

Before vs. after on site 9

Appendix B (Continued):

<u>Site 10</u>

- LA 354, tangent section
- Moderate pavement surface condition
- Overlaid surface with a bit damage, therefore a little unevenness.
- Reflectors along the centerline
- Fairly enough sight distance

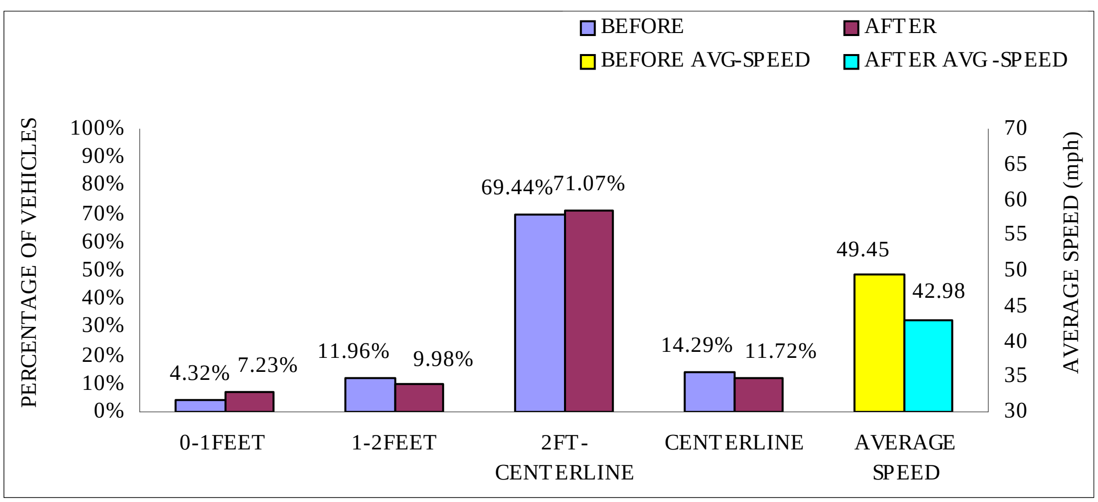
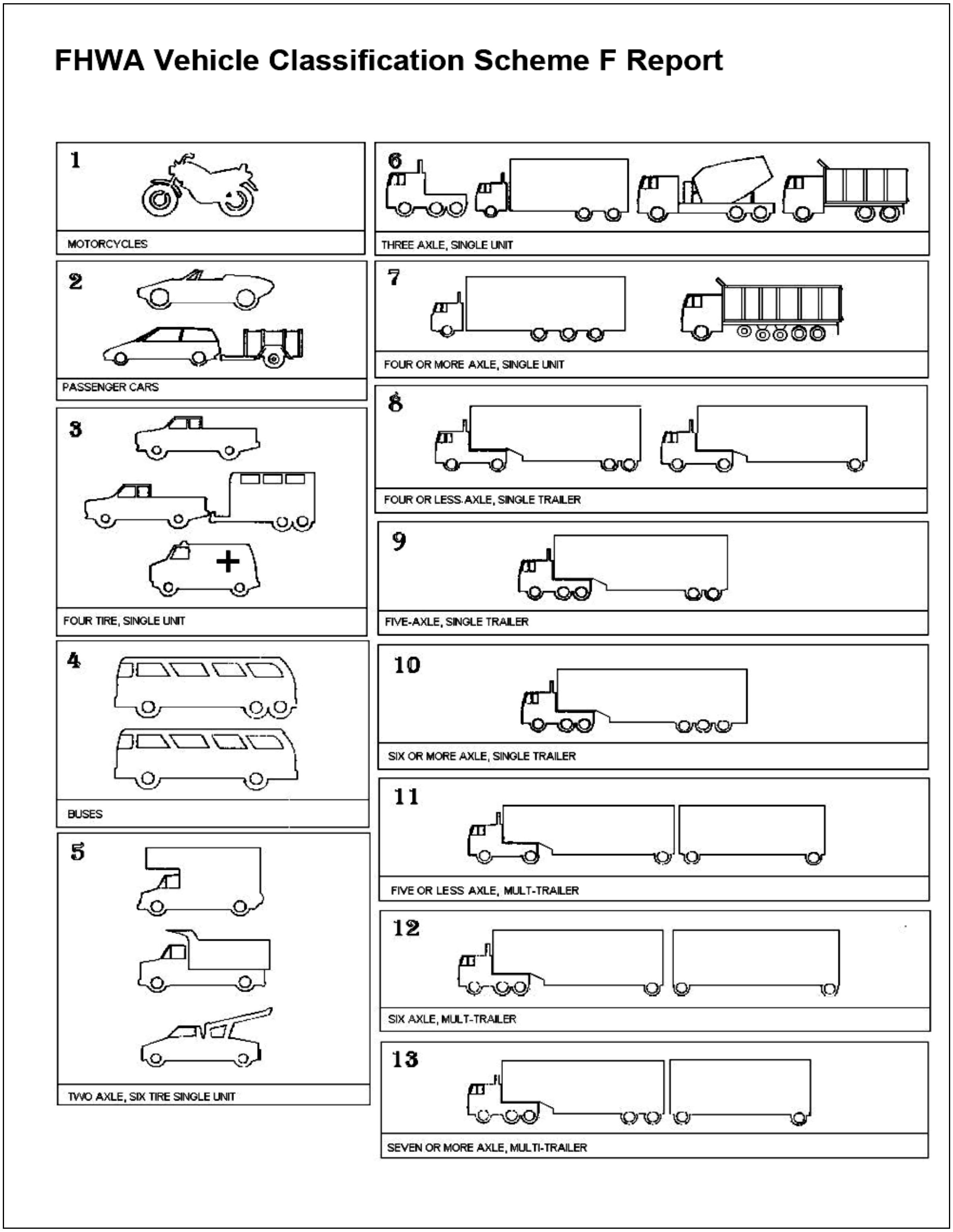


Figure B.10

Before vs. after on site 10

Appendix C: FHWA Vehicle Classification Scheme F



Appendix C (Continued):

Class 1: Motorcycles

All two or three wheeled motorized vehicles. Typical vehicles in this category have saddle type seats and are steered by handlebars rather than wheels. This category includes motorcycles, motor scooters, mopeds, motor-powered bicycles, and three-wheeled motorcycles.

Class 2: Passenger Cars

All sedans, coupes, and station wagons manufactured primarily for the purpose of carrying passengers and including those passenger cars pulling recreational or other light trailers.

Class 3: Other Two-Axle, Four-Tire, Single Unit Vehicles

All two-axle, four-tire, vehicles other than passenger cars. Included in this classification are pickups, panels, vans, and other vehicles such as campers, motor homes, ambulances, hearses, carryalls, and minibuses. Other two-axle, four-tire single unit vehicles pulling recreational or other light trailers are included in this classification.

Class 4: Buses

All vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles. This category includes only traditional buses (including school buses) functioning as passenger-carrying vehicles. Modified buses should be considered to be trucks and be appropriately classified.

Note: In reporting information on trucks the following criteria should be used:

a. Truck tractor units traveling without a trailer will be considered single unit trucks.

b. A truck tractor unit pulling other such units in a “saddle mount” configuration will be considered as one single unit truck and will be defined only by axles on the pulling unit.

c. Vehicles shall be defined by the number of axles in contact with the roadway. Therefore, “floating” axles are counted only when in the down position.

d. The term “trailer” includes both semi- and full trailers.

Class 5: Two-Axle, Six-Tire, Single Unit Trucks

All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., having two axles and dual rear wheels.

Class 6: Three-axle Single unit Trucks

All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., having three axles.

Class 7: Four or More Axle Single Unit Trucks

All trucks on a single frame with four or more axles.

Class 8: Four or Less Axle Single Trailer Trucks

All vehicles with four or less axles consisting of two units, one of which is a tractor or straight truck power unit.

Class 9: Five-Axle Single Trailer Trucks

All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.

Class 10: Six or More Axle Single Trailer Trucks

All vehicles with six or more axles consisting of two units, one of which is a tractor or straight truck power unit.

Class 11: Five or Less Axle Multi-Trailer Trucks

All vehicles with five or less axles consisting of three or more units, one of which is a tractor or straight truck power unit

Class 12: Six-Axle Multi-Trailer Trucks

All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit.

Class 13: Seven or More Axle Multi-Trailer Trucks

All vehicles with seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit.

Class 14: Will be defined by ODOT personnel for special studies.

Class 15: Will by default identify any vehicle, which does not conform to the classification criteria for Class 1 through Class 14.