MIDWEST SMART WORK ZONE DEPLOYMENT INITIATIVE

MwSWZDI

FHWA POOLED FUND STUDY

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White Lane Drop Arrows

Principle Investigator
Name Sanford Bernhardt, Kristin
Affiliation Lafayette College
Address Civil and Environmental Engineering
Lafayette College
Easton, PA 18042

Phone 610 330 5584
Fax
Email sanfordk@lafayette.edu

Vendor Name and Address
Advanced Traffic Markings
Ron Sims
PO Box H
Roanoke Rapids, NC 27870-8082
(252) 536-4940

Author(s) and Affiliation(s)

Supplemental Funding Agency Name and Address (if applicable)

Supplemental Notes

Abstract

ADVANCE LANE DROP ARROWS

Objectives

The primary goal of this evaluation was to determine the effectiveness of the arrows as located in the approach to a highway work zone. The arrows are intended for use both with stationary long-term work zones and with short-term moving projects. The specific research objectives were:

1. To test the effectiveness of the arrows in merging the traffic into one lane before the work zone starts;
2. To test and evaluate the effectiveness of the arrows in reducing the average speeds and speed variance approaching the work zone;
3. To determine whether the arrows changed the accident rate; and
4. To determine the ease of installation and removal, and the durability of the arrows.

Measures Of Effectiveness

The arrows were expected to provide an advance warning of the lane closure, to encourage motorists to reduce vehicle speed, to reduce the speed variance, to perform for the life of the project, and to be safe for motorists. Table 4-25 shows the measures of effectiveness associated with each objective. Lane distribution and speed measurements were disaggregated by vehicle type (passenger vehicles vs. non-passenger vehicles) and by time of day (day, night, and dawn/dusk).

TABLE 4-25 Measures of effectiveness.

Objective	Measures
Provide advance warnings	Lane distribution
Reduce speed	Mean speed 85th percentile speed Mean speed of fastest 15% of vehicles 10-mph pace
Reduce speed variance	Standard deviation of speed % of vehicles in 10-mph pace
Perform for life of project	Observed ease of installation Observed condition before removal Observed ease of removal
Provide for safety	Number of accidents related to arrows

Data Collection And Analysis Procedures

The field research was conducted at a stationary, long-term work zone on eastbound Interstate 70 (I-70) near Columbia, Missouri.

Site Description

The highway normally has a 70-mph speed limit, but the posted speed limit approaching the work zone was reduced first to 60-mph and then to 50-mph. Arrows were installed at three locations approaching the work zone (Figure 4-21).

The arrows, which were placed at a 45-degree angle to the travel direction, are approximately 8 feet long and 0.09 inches thick (Figure 4-22 and Figure 4-23). The large size of the arrows and their reflective white color provide visual and aural feedback to drivers.

The pavement-related work at this site included cold milling, pavement repair, and resurfacing. The average daily traffic was approximately 14,600 vehicles, with 25.6% non-passenger vehicles (three or more axles) in the eastbound direction of travel. The right lane (driving lane) was closed during the study.

Data Collection

Data were collected at four locations along the approach to the work zone, as shown in Figure 4-21, before the arrows were installed (before case), and again after the arrows were installed (after case). Vehicle speeds, volumes, and vehicle classifications were collected in 15-minute intervals. Due to breaks in the pneumatic tubes, it was not always possible to collect data at all four sites during all time periods, but approximately 24 hours of data were collected for both the before and after cases. The arrows were installed on April 12, 1999 and removed on April 19, 1999. Data for the analysis were collected on April 6, 1999 for the before case and on April 12-13, 1999 for the after case.

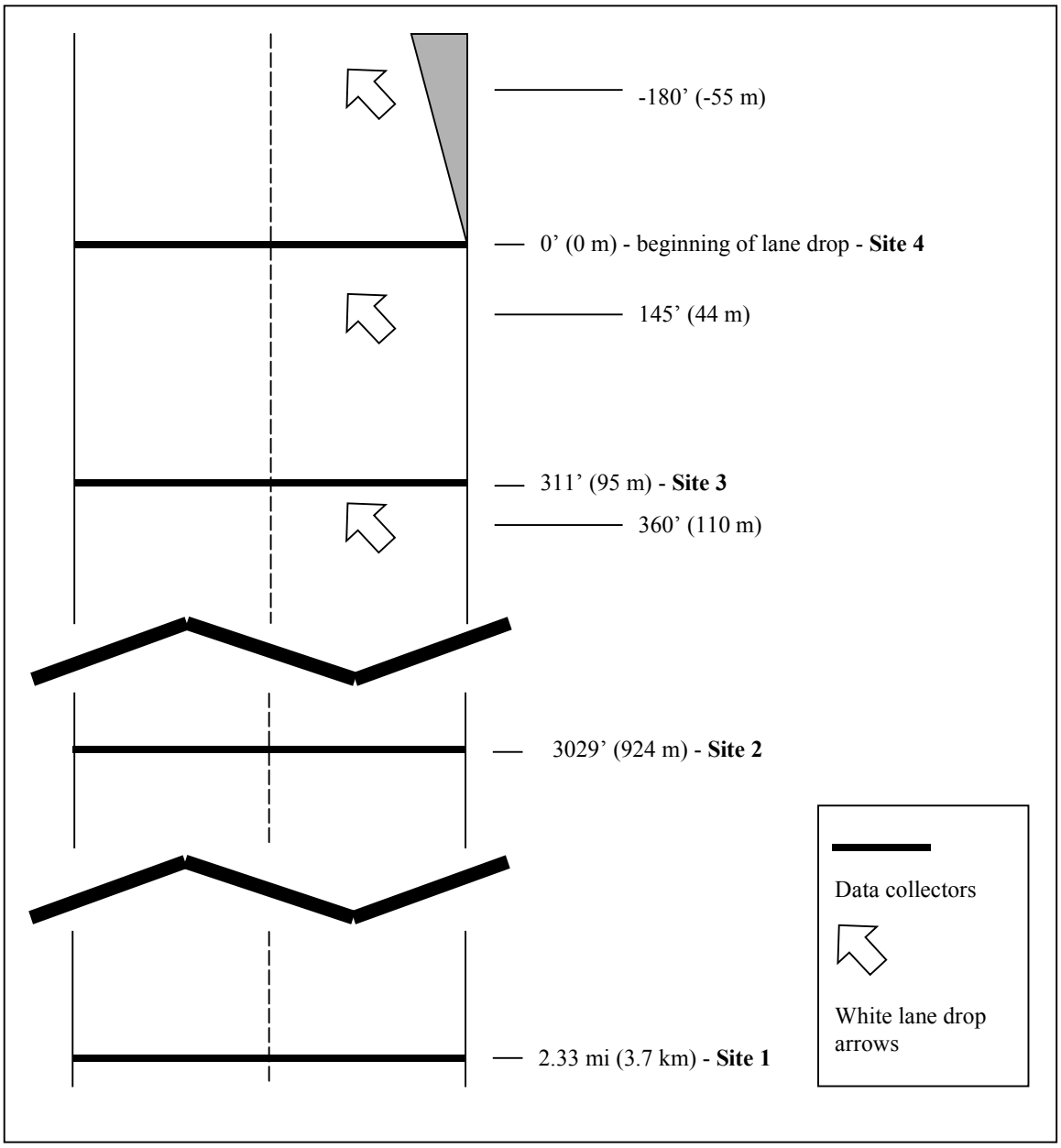

Figure 4-21 Schematic location of detectors and arrows in work zone.

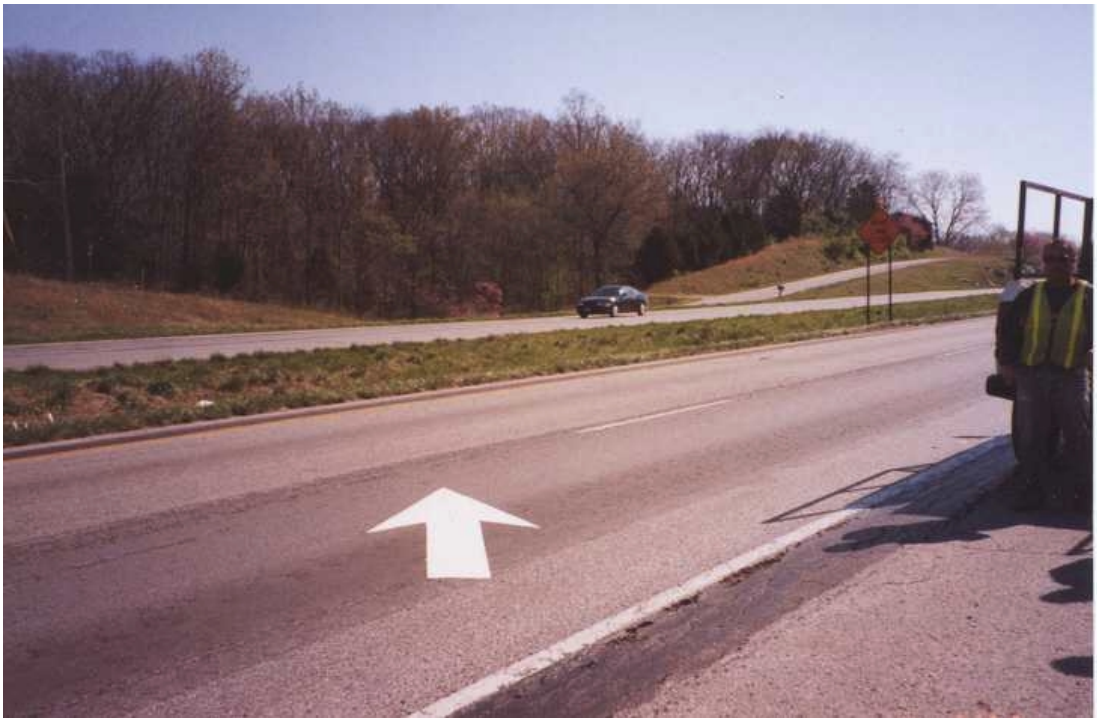

Figure 4-22 Lane drop arrow from shoulder.

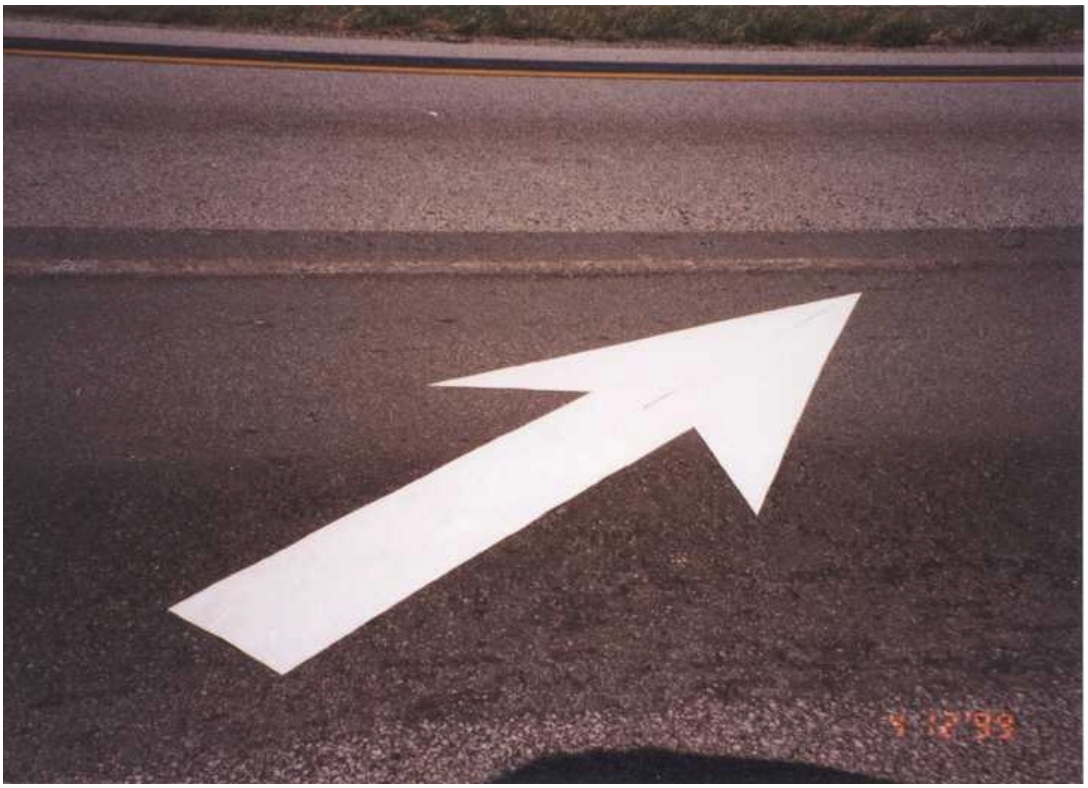

Figure 4-23 Lane drop arrow close-up.

Accident data were collected from one mile upstream of the first counter site through the end of the work zone. Observations were made regarding the ease of installing and removing the arrows and their durability.

Data Analysis

The primary measures of effectiveness used to analyze the data were lane distribution, mean speed, and speed variance upstream of the work zone. Along with these parameters, the percentage of vehicles below the speed limit, the 10-mph pace, the percentage of vehicles in the 10-mph pace, the 85th percentile speed**,** and the mean speed of the fastest 15% of vehicles were calculated to evaluate the traffic control devices in detail. The analysis examined the difference in the parameters before and after the device was installed. Significance testing of the parameters used a two-tailed Student's t-test with a *level* of significance $\alpha = 0.05$. An F-test was also conducted at the same level of significance to find any significant differences in the speed variance.

Each "before and after" comparison is a test of the hypothesis that the characteristic under study is the same in the before and after cases (i.e., the characteristic did not change). The level of significance (α) used was 0.05. This means that when there was no change, the test can be expected to reach that conclusion correctly (that there is no statistically significant difference) in 95% of the comparisons. However, in 5% of the cases in which there was no change, the test can be expected to indicate a statistically significant difference (this is called a Type I error).

The analysis methods, as well as classification procedures, were the same as those used to evaluate the removable orange rumble strips (Page 4-2).

Results

Results related to lane distribution, speed, speed variance, lane drop arrow performance, and safety are presented below. All comparisons described are the after case compared to the before case, and after cells that show a statistically significant difference from the before case (α= 0.05) are shaded in the Tables. A blank cell indicates that there were no such conditions observed, and a dash (–) indicates that it was not possible to calculate the particular parameter. For example, if only one vehicle was observed in a 15-minute interval, it would not be possible to calculate a standard deviation of speed.

Data collection sites 1, 2, 3, and 4 were 2.33 miles, 3029 feet, 311 feet, and 0 feet upstream from the beginning of the lane closure, respectively. Drivers at Sites 1 and 2 could not see the lane drop arrows, while drivers at Sites 3 and 4 would have passed over some of the arrows.

Lane Distribution

The lane distribution is considered to be improved in the after case if a lower percentage of vehicles is in the closed lane.

Figures 4-24-to 4-26 present profiles of the percentage of traffic remaining in the lane closed downstream. In all cases, at Site 1, the majority of traffic is in the right-side driving lane (the lane closed downstream). At Sites 2, 3, and 4 the majority of traffic is in the left side passing lane (the lane open downstream).

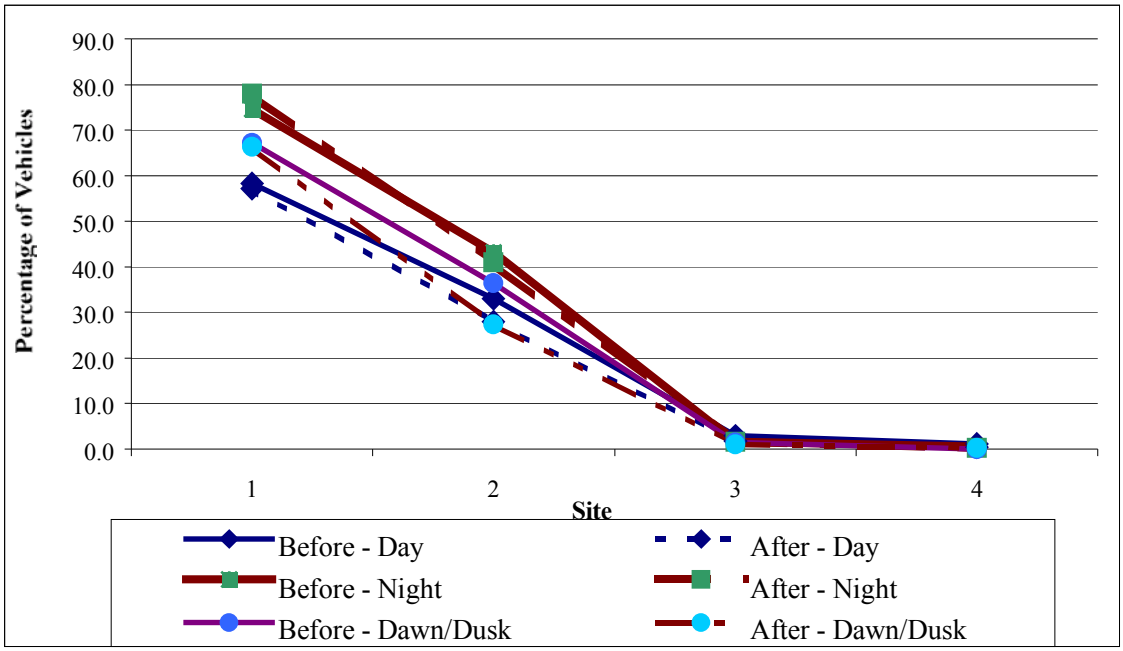

Figure 4-24 Profile of percentage of traffic in closed lane – *all vehicles.*

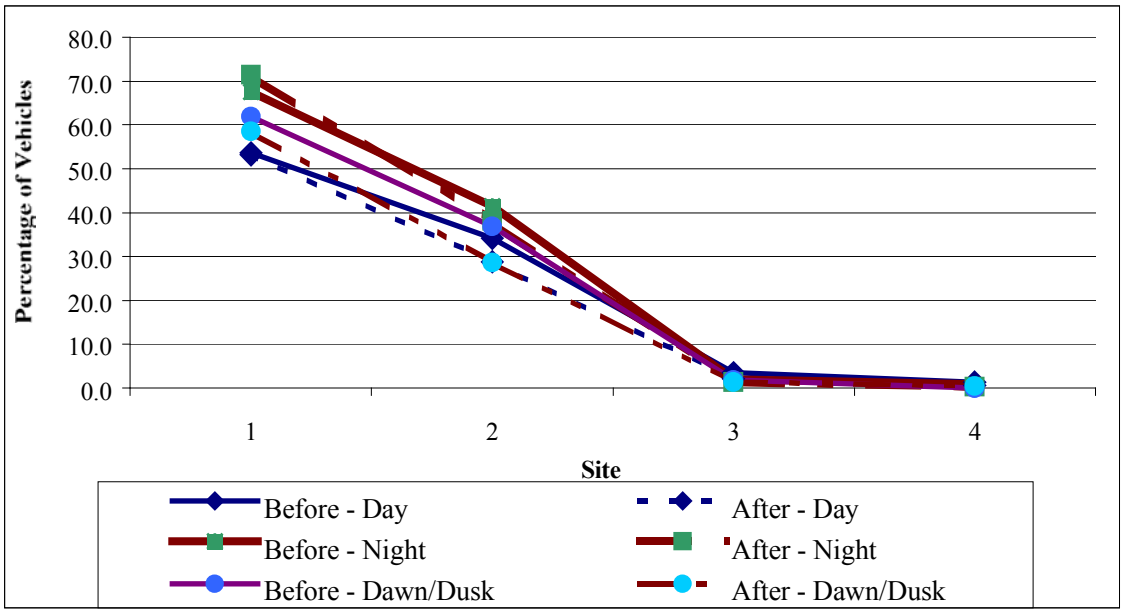

Figure 4-25 Profile of percentage of traffic in closed lane – *passenger vehicles.*

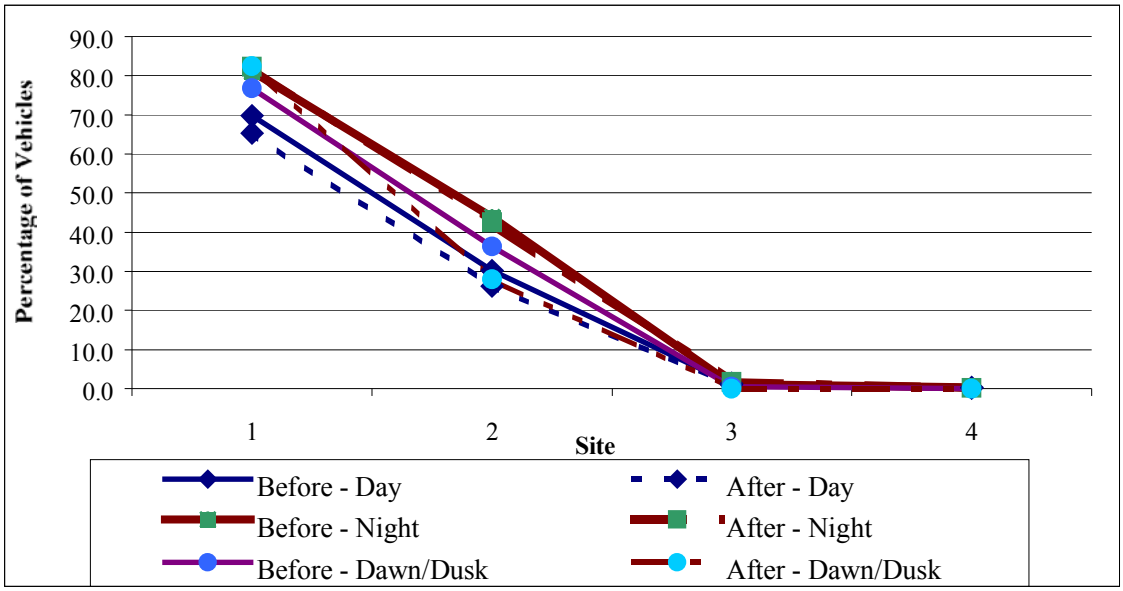

Figure 4-26 Profile of percentage of traffic in closed lane – *non-passenger vehicles.*

Tables 4-26 to 4-28 show the percentage of traffic remaining in the lane closed downstream during the day, night, and dawn/dusk.

During the day (Table 4-26), with uncongested conditions, lane distribution was somewhat worse at Site 1 and significantly better (for *all vehicles* and *passenger vehicles*) at Site 2 with the lane drop arrows. At both of these sites, motorists had not yet seen the lane drop arrows. At Sites 3 and 4, lane distribution was significantly improved with the lane drop arrows for *all vehicles* and *passenger vehicles*. During congested conditions, the lane drop arrows were associated with improved lane distribution of *all vehicles* and *passenger vehicles* at Site 3.

No significant differences between before and after lane distributions were found at night (Table 4-27).

No significant differences between before and after lane distributions were found during the dawn/dusk periods (Table 4-28).

Table 4-26 Percentage of traffic in closed lane – day.

Vehicle type	Case	Uncongested Conditions at Site				Congested Conditions at Site			
		1	2	3	4	1*	2*	3	4
All vehicles	**Before**	58.3	33.1	3.0	1.2			5.1	0.8
	After	57.1	**28.0**	**1.8**	**0.5**			**0.9**	0.4
Passenger vehicles	**Before**	53.6	34.1	3.6	1.4			6.2	0.9
	After	53.2	**28.8**	**2.1**	**0.6**			**0.7**	0.4
Non-passenger vehicles	**Before**	69.8	30.1	1.4	0.3			1.8	0.7
	After	65.4	26.2	1.1	0.2			1.5	0.5
* No congested conditions were observed at Sites 1 or 2									

Table 4-27 Percentage of traffic in closed lane – night.

Vehicle type	Case	Uncongested Conditions at Site*			
		1	2	3	4
All vehicles	Before	74.7	43.2	1.7	0.6
	After	78.1	41.0	1.6	0.3
Passenger vehicles	Before	67.5	41.5	2.0	0.8
	After	71.4	38.1	1.4	0.3
Non-passenger vehicles	Before	81.1	44.0	1.2	0.3
	After	82.2	42.5	1.7	0.2
* No congested conditions were observed					

Table 4-28 Percentage of traffic in closed lane – dawn/dusk.

Vehicle type	Case	Uncongested Conditions at Site*			
		1	2	3	4
All vehicles	Before	67.2	36.5	1.5	0.0
	After	66.4	27.3	1.0	0.3
Passenger vehicles	Before	61.9	36.8	1.8	0.0
	After	58.5	28.6	1.4	0.4
Non-passenger vehicles	Before	76.9	36.4	0.5	0.0
	After	82.4	28.0	0.0	0.0
* No congested conditions were observed					

Average Speed Characteristics

This section presents results for mean speed, percentage of vehicles below the speed limit, 10-mph pace, 85th percentile speed, and mean speed of the fastest 15% of vehicles during the day, night, and dawn/dusk. A lower mean speed, 10-mph pace, 85th percentile speed, and mean speed of the fastest 15% of vehicles are associated with improved conditions, as is an increase in the percentage of vehicles below the speed limit.

Mean Speeds

The mean speed profiles for the open lane indicate a mixed effect (Figures 4-27 to 4-29). Tables 4-29 to 4-31 show the results for mean speed for day, night, and dawn/dusk in the before and after cases. During the day, in uncongested conditions, the after case had several significantly higher speeds at Sites 1 and 2, where motorists could not see the lane drop arrows (Table 4-29). However, Site 4 had some significantly lower speeds. During congested conditions, at Sites 3 and 4 (where motorists had seen the arrows), the passing (open) lane had generally lower mean speeds.

At night (Table 4-30), the after case had significantly higher mean speeds at Sites 1 and 2, where motorists could not see the lane drop arrows. However, Site 3 and 4 had some significantly lower mean speeds in the passing (open) lane.

In the dawn/dusk periods (Table 4-31), mean speeds tended to be higher in the after case for Sites 1 and 2, where motorists could not see the lane drop arrows. However, mean speeds tended to be lower at Sites 3 and 4.

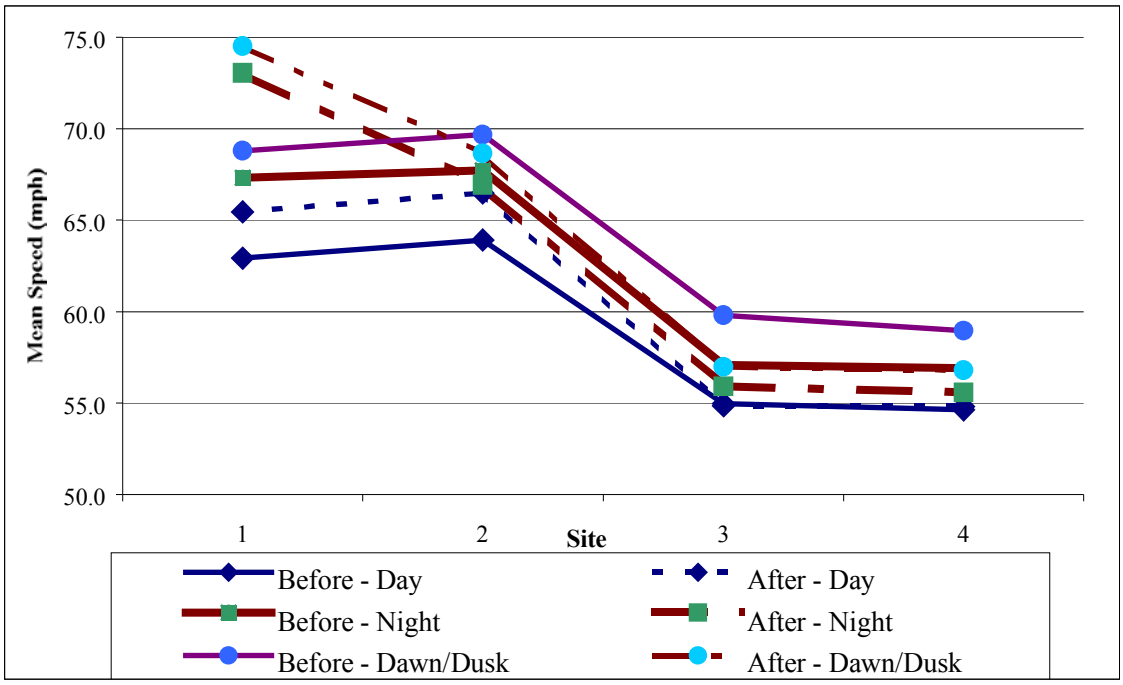

Figure 4-27 Mean speed profiles for open lane – *all vehicles.*

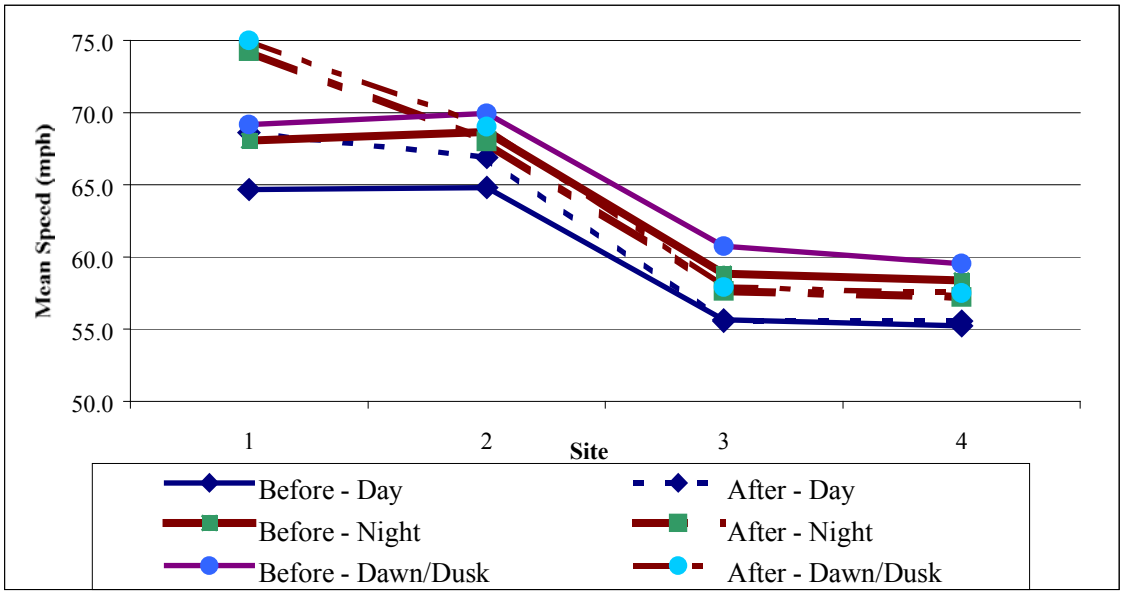

Figure 4-28 Mean speed profiles for open lane – *passenger vehicles.*

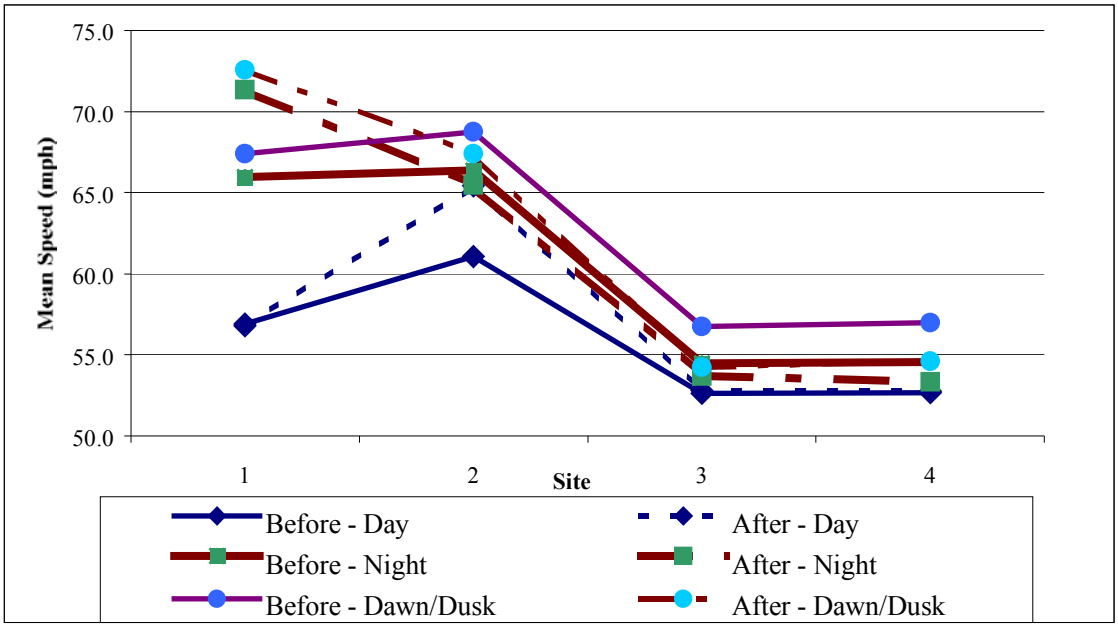

Figure 4-29 Mean speed profiles for open lane – *non-passenger vehicles.*

Table 4-29 Mean speeds – day.

Vehicle Type	Case	Lane	Uncongested Conditions at Site				Congested Conditions at Site			
			1	2	3	4	1*	2*	3	4
All vehicles	Before	Driving	64.0	66.8	56.4	53.9			33.3	30.6
		Passing	62.9	63.9	54.9	54.6			30.4	32.1
	After	Driving	**69.4**	**69.2**	54.0	**47.8**			29.1	30.0
		Passing	**65.5**	**66.5**	54.9	54.8			**24.7**	**29.6**
Passenger vehicles	Before	Driving	65.0	67.1	56.8	54.0			33.2	30.5
		Passing	64.7	64.8	55.7	55.2			31.1	32.8
	After	Driving	70.4	**69.8**	54.5	**49.2**			32.0	33.3
		Passing	68.6	**66.9**	55.6	**55.6**			**24.9**	**30.0**
Non-passenger vehicles	Before	Driving	62.2	65.3	52.9	53.0			34.0	31.5
		Passing	56.9	61.1	52.6	52.7			27.9	29.2
	After	Driving	**67.8**	**67.4**	51.3	**36.0**			25.1	20.0
		Passing	56.8	**65.4**	52.8	52.8			**23.7**	**27.7**
* No congested conditions were observed at Sites 1 or 2										

Table 4-30 Mean speeds – night.

Vehicle Type	Case	Lane	Uncongested Conditions at Site*			
			1	2	3	4
All vehicles	Before	Driving	63.9	66.3	57.0	52.2
		Passing	67.3	67.7	57.1	56.9
	After	Driving	**69.7**	**67.5**	58.1	52.3
		Passing	**73.0**	**66.9**	**55.9**	**55.6**
Passenger vehicles	Before	Driving	64.3	66.8	57.9	52.2
		Passing	68.1	68.7	58.9	58.4
	After	Driving	**70.9**	**68.6**	60.4	50.5
		Passing	**74.3**	**68.0**	**57.6**	**57.2**
Non-passenger vehicles	Before	Driving	63.5	65.7	55.1	52.0
		Passing	65.9	66.4	54.5	54.6
	After	Driving	**68.8**	**66.4**	**55.5**	54.7
		Passing	**71.3**	**65.5**	**53.7**	**53.3**
* No congested conditions were observed						

Table 4-31 Mean speeds – dawn/dusk.

Vehicle Type	Case	Lane	Uncongested Conditions at Site*			
			1	2	3	4
All vehicles	Before	Driving	65.0	69.2	61.5	
		Passing	68.8	69.7	59.8	59.0
	After	Driving	70.7	68.4	63.0	
		Passing	74.5	**68.6**	57.0	**56.8**
Passenger vehicles	Before	Driving	65.1	65.1	61.3	
		Passing	69.2	70.0	60.7	59.5
	After	Driving	**71.2**	**68.5**	63.0	
		Passing	**75.0**	**69.0**	**57.9**	**57.5**
Non-passenger vehicles	Before	Driving	64.8	66.5		
		Passing	67.4	68.8	56.7	57.0
	After	Driving	70.0	68.3		
		Passing	72.6	**67.4**	**54.2**	**54.6**
* No congested conditions were observed						

Percentage of Vehicles Below Speed Limit

Tables 4-32 to 4-34 show the percentage of vehicles in the closed lane in the after case. Speed limits were 60-mph at Site 1 and 50-mph at Sites 2, 3, and 4.

During the day (Table 4-32), in uncongested conditions, the percentage of vehicles below the speed limit tended to be somewhat improved in the after case at Sites 3 and 4. In congested conditions, Sites 3 and 4 showed improvement in the after case.

At night (Table 4-33), while Site 1 (where motorists could not see the lane drop arrows) showed poorer compliance with the speed limit in the after case, Sites 3 and 4 showed improvement.

In the dawn/dusk periods (Table 4-34), while Site 1 (where motorists could not see the lane drop arrows) showed poorer compliance with the speed limit in the after case, Sites 3 and 4 showed improvement.

Table 4-32 Percentage of vehicles below speed limit – day.

Vehicle Type	Case	Lane	Uncongested Conditions at Site				Congested Conditions at Site			
			1	2	3	4	1*	2*	3	4
All vehicles	Before	Driving	18.2	7.5	24.8	33.5			88.7	97.5
		Passing	11.9	11.4	23.9	26.0			92.2	89.3
	After	Driving	12.0	1.8	34.6	**58.3**			88.9	100.0
		Passing	11.6	3.2	25.6	25.5			**100.0**	96.8
Passenger vehicles	Before	Driving	17.7	6.8	23.8	33.6			88.3	96.9
		Passing	11.1	10.5	22.4	24.6			91.2	87.9
	After	Driving	12.2	1.9	35.5	**55.8**			88.1	100.0
		Passing	11.0	3.3	24.0	23.9			**100.0**	96.7
Non-passenger vehicles	Before	Driving	18.7	12.2	33.7	37.5			–	–
		Passing	14.8	16.2	29.4	31.8			95.7	95.4
	After	Driving	11.3	**1.6**	35.7	75.0			–	–
		Passing	13.4	**3.2**	30.2	30.1			**100.0**	97.8
* No congested conditions were observed at Sites 1 or 2										

Table 4-33 Percentage of vehicles below speed limit – night.

Vehicle Type	Case	Lane	Uncongested Conditions at Site*			
			1	2	3	4
All vehicles	Before	Driving	16.1	0.2	11.1	18.9
		Passing	4.2	0.2	16.3	15.5
	After	Driving	**2.7**	0.3	14.7	42.9
		Passing	**0.0**	0.3	19.6	**20.5**
Passenger vehicles	Before	Driving	16.9	0.3	6.7	19.2
		Passing	2.5	0.3	11.4	10.8
	After	Driving	**3.7**	0.3	7.1	50.0
		Passing	**0.0**	0.2	14.7	**15.1**
Non-passenger vehicles	Before	Driving	16.0	0.1	17.9	12.5
		Passing	5.5	0.0	21.9	21.5
	After	Driving	**1.7**	0.4	23.5	33.3
		Passing	**0.0**	0.5	25.3	**27.1**
* No congested conditions were observed						

Table 4-34 Percentage of vehicles below speed limit – dawn/dusk.

Vehicle Type	Case	Lane	Uncongested Conditions at Site*			
			1	2	3	4
All vehicles	Before	Driving	13.4	0.0	12.5	–
		Passing	1.7	0.0	6.2	7.5
	After	Driving	1.3	0.6	16.7	–
		Passing	0.5	0.0	17.1	**16.6**
Passenger vehicles	Before	Driving	16.1	16.1	12.5	–
		Passing	2.0	0.0	5.5	6.8
	After	Driving	**1.5**	**0.0**	16.7	–
		Passing	0.8	0.0	14.9	**14.7**
Non-passenger vehicles	Before	Driving	6.1	0.0	–	–
		Passing	0.0	0.0	70.4	10.5
	After	Driving	0.8	2.5	–	–
		Passing	0.0	0.0	71.7	**22.9**
* No congested conditions were observed						

10-mph Pace

The speed distributions (that is, the proportion of vehicles in each speed interval) were analyzed to determine whether a significant difference existed in the before and after distributions. Changes in the 10-mph pace are reported only when the changes in the distribution were significant.

Significant differences in the speed distributions occurred at Site 1 during both the day and night. In both cases, the 10-mph pace increased from 60-70 mph to 65-75 mph. No other significant differences in the distributions occurred.

85th Percentile Speeds

Tables 4-35 to 4-37 show the 85th percentile speeds for the before and after cases.

During the day (Table 4-35), in uncongested conditions, Sites 1 and 2 had higher 85th percentile speeds in the after case, while Sites 3 and 4 had lower speeds. Under congested conditions, Sites 3 and 4 generally showed lower 85th percentile speeds in the after case.

At night (Table 4-36), Sites 1 and 2 had generally higher speeds in the after case, while Sites 3 and 4 had uniformly lower speeds.

During the dawn/dusk periods (Table 4-37), Site 1 had uniformly higher 85th percentile speeds in the after case, while Site 4 exhibited uniformly lower speeds, and Site 3 showed mixed results.

Mean Speeds of the Fastest 15% of Vehicles

Table 4-38 to 4-40 show the mean speeds of the fastest 15% of vehicles for the before and after cases.

During the day (Table 4-38), in the after case for uncongested conditions, Sites 1 and 2 had higher mean speeds for the fastest 15% of vehicles. However, Sites 3 and 4 had uniformly lower speeds. Under congested conditions, Sites 3 and 4 had generally lower speeds.

Table 4-35 85th percentile speeds – day.

Vehicle Type	Case	Lane	Uncongested Conditions at Site				Congested Conditions at Site			
			1	2	3	4	1*	2*	3	4
All vehicles	Before	Driving	67.7	73.1	66.0	63.4			69.2	26.8
		Passing	69.9	72.8	64.9	64.3			68.5	47.4
	After	Driving	72.4	**75.9**	64.7	57.6			66.0	32.8
		Passing	72.6	74.6	64.0	63.6			67.5	**38.6**
Passenger vehicles	Before	Driving	68.4	73.8	66.2	64.5			44.0	27.1
		Passing	70.3	73.5	65.9	65.1			44.7	48.3
	After	Driving	73.4	**76.8**	64.4	57.2			33.1	24.9
		Passing	73.8	75.4	65.1	64.7			**34.6**	**38.6**
Non-passenger vehicles	Before	Driving	65.8	69.7	61.8	59.5			–	–
		Passing	67.4	69.8	61.4	61.1			32.3	35.7
	After	Driving	69.7	**72.8**	60.3	–			–	–
		Passing	70.1	72.5	60.1	60.3			25.7	38.0
* No congested conditions were observed at Sites 1 or 2										

Table 4-36 85th percentile speeds – night.

Vehicle Type	Case	Lane	Uncongested Conditions at Site*			
			1	2	3	4
All vehicles	Before	Driving	69.2	72.5	64.1	58.2
		Passing	72.4	74.6	65.4	64.9
	After	Driving	**75.3**	**73.7**	63.9	–
		Passing	**78.0**	73.8	**64.1**	**63.6**
Passenger vehicles	Before	Driving	70.2	73.5	63.8	54.3
		Passing	73.6	76.1	68.1	67.3
	After	Driving	**77.5**	**75.3**	65.2	–
		Passing	**78.7**	75.8	67.3	66.8
Non-passenger vehicles	Before	Driving	68.1	70.9	62.2	–
		Passing	70.5	72.0	61.0	61.2
	After	Driving	**73.9**	**72.2**	–	–
		Passing	**75.7**	71.3	**59.9**	**59.7**
* No congested conditions were observed						

Table 4-37 85th percentile speeds – dawn/dusk.

Vehicle Type	Case	Lane	Uncongested Conditions at Site*			
			1	2	3	4
All vehicles	Before	Driving	70.3	76.0	67.9	–
		Passing	74.1	76.4	67.7	66.7
	After	Driving	76.0	74.2	73.8	–
		Passing	79.7	75.1	64.5	**64.4**
Passenger vehicles	Before	Driving	70.8	70.8	67.0	–
		Passing	74.6	77.0	68.6	67.6
	After	Driving	**77.1**	**74.5**	73.8	–
		Passing	**79.7**	75.7	65.4	**65.1**
Non-passenger vehicles	Before	Driving	69.0	72.5	–	–
		Passing	72.4	74.3	62.9	62.8
	After	Driving	74.7	73.1	–	–
		Passing	78.3	72.9	**59.4**	60.7
* No congested conditions were observed						

Table 4-38 Mean speeds of fastest 15% of vehicles – day.

Vehicle Type	Case	Lane	Uncongested Conditions at Site				Congested Conditions at Site			
			1	2	3	4	1*	2*	3	4
All vehicles	Before	Driving	70.2	75.5	69.2	64.8			48.4	34.0
		Passing	72.3	75.3	68.5	68.0			48.9	51.5
	After	Driving	74.8	**78.3**	66.0	58.2			39.1	37.3
		Passing	76.2	77.1	67.5	67.2			36.5	**41.2**
Passenger vehicles	Before	Driving	70.9	76.1	69.5	65.6			48.1	34.2
		Passing	72.8	75.9	69.4	68.8			49.6	52.2
	After	Driving	75.7	**78.9**	65.5	**57.6**			39.7	31.2
		Passing	77.1	77.8	68.5	68.2			36.6	**41.3**
Non-passenger vehicles	Before	Driving	67.9	71.1	62.0	59.8			–	–
		Passing	69.3	71.7	63.7	63.6			44.0	45.6
	After	Driving	71.8	**74.4**	60.6				–	–
		Passing	73.2	74.3	62.6	62.8			35.1	40.1
* No congested conditions were observed at Sites 1 or 2										

At night (Table 4-39), Sites 1 and 2 tended to have higher mean speeds for the fastest 15% of vehicles. However, Sites 3 and 4 tended to have lower speeds.

During the dawn/dusk periods (Table 4-40), Site 1 had uniformly higher mean speeds for the fastest 15% of vehicles in the after case. However, Sites 3 and 4 tended to have lower speeds.

Characteristics Related to Speed Variance

This section presents the results for standard deviation of speed and percentage of vehicles traveling within the 10-mph pace during the day, night, and dawn/dusk. A decreased

standard deviation of speed and an increased percentage of vehicles traveling within the 10-mph pace indicate an improvement from the before to the after case.

Table 4-39 Mean speeds of fastest 15% of vehicles – night.

Vehicle Type	Case	Lane	Uncongested Conditions at Site*			
			1	2	3	4
All vehicles	Before	Driving	70.8	74.8	64.4	58.6
		Passing	74.1	76.7	69.0	68.6
	After	Driving	**77.3**	**75.9**	64.2	–
		Passing	**79.2**	76.3	**67.8**	**67.6**
Passenger vehicles	Before	Driving	71.8	75.8	64.1	54.6
		Passing	74.8	77.9	71.2	70.8
	After	Driving	**79.2**	76.9	65.5	–
		Passing	**79.5**	77.7	70.3	70.1
Non-passenger vehicles	Before	Driving	69.4	72.4	62.3	–
		Passing	71.1	73.5	63.1	63.2
	After	Driving	**75.3**	**73.6**	–	–
		Passing	**76.2**	72.8	**62.0**	**61.8**
* No congested conditions were observed						

Table 4-40 Mean speeds of fastest 15% of vehicles – dawn/dusk.

Vehicle Type	Case	Lane	Uncongested Conditions at Site*			
			1	2	3	4
All vehicles	Before	Driving	72.8	78.7	68.3	–
		Passing	76.3	78.5	70.3	69.7
	After	Driving	77.8	**76.5**	74.1	–
		Passing	81.0	77.4	67.9	**67.5**
Passenger vehicles	Before	Driving	73.1	73.1	67.3	–
		Passing	76.8	78.9	71.0	70.4
	After	Driving	**78.6**	**76.8**	74.1	–
		Passing	**81.1**	78.0	68.9	**68.4**
Non-passenger vehicles	Before	Driving	71.3	74.1	–	–
		Passing	73.1	76.0	65.5	65.0
	After	Driving	76.1	75.1	–	–
		Passing	79.1	74.8	**61.4**	62.4
* No congested conditions were observed						

Standard Deviation of Speed

Figures 4-30 to 4-32 illustrate how the standard deviation of speed in the open lane varied between the cases for the four sites. In general, standard deviation increased from Site 1 to Site 3.

During the day and night periods, standard deviation of speed tended to improve at Sites 3 and 4 when the arrows were in place.

Table 4-41 to 4-43 show the standard deviations of speed at the four sites in the before and after cases.

During the day (Table 4-41), in the after case with uncongested conditions, Site 4 had uniformly lower standard deviations of speed. Under congested conditions, standard deviations of speed were uniformly improved (lower) at Sites 3 and 4.

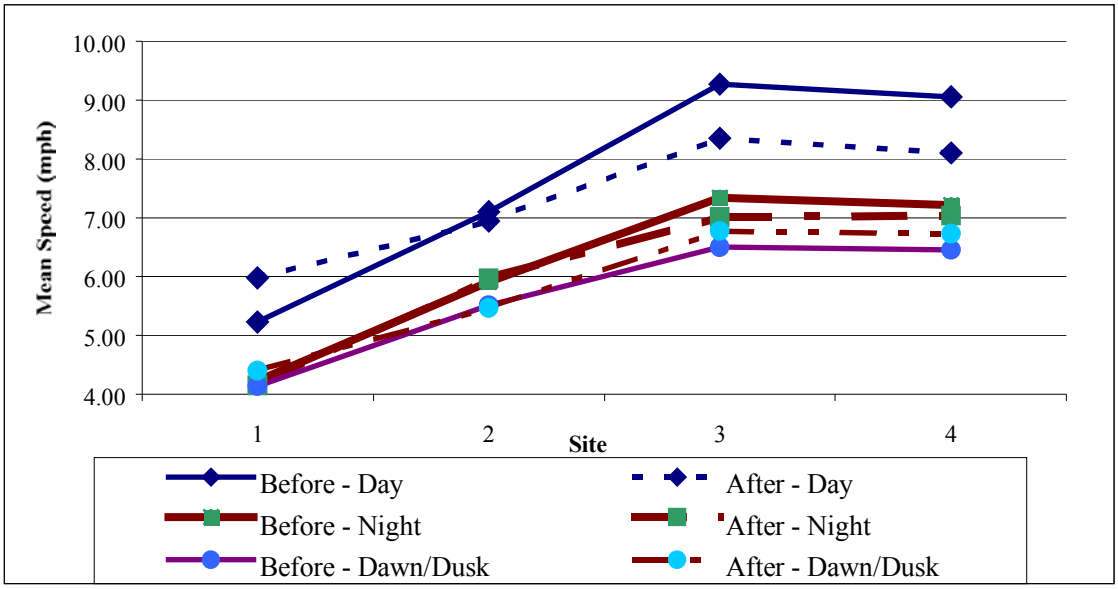

Figure 4-30 Standard deviation of mean speed profiles for open lane – *all vehicles*

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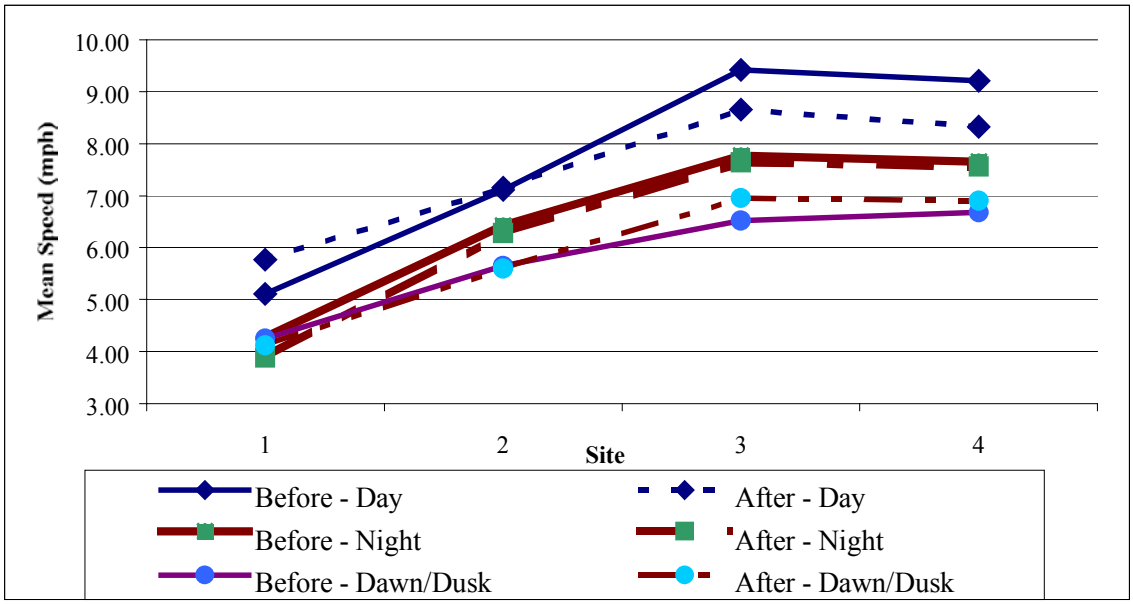

Figure 4-31 Standard deviation of mean speed profiles for open lane – *passenger vehicles.*

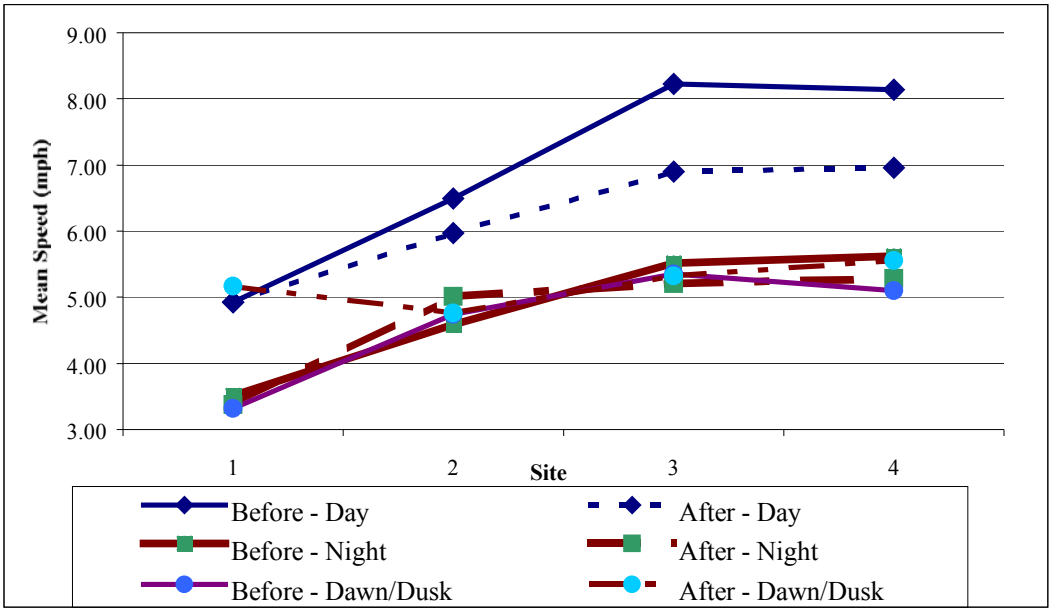

Figure 4-32 Standard deviation of mean speed profiles for open lane – *non-passenger vehicles.*

Table 4-41 Standard deviation of speed – day.

Vehicle Type	Case	Lane	Uncongested Conditions at Site				Congested Conditions at Site			
			1	2	3	4	1*	2*	3	4
All vehicles	Before	Driving	5.09	6.14	10.07	10.73			12.88	9.41
		Passing	5.22	7.10	9.27	9.06			11.37	12.09
	After	Driving	5.24	6.13	10.02	6.23			8.27	5.22
		Passing	5.98	6.94	8.36	8.10			6.74	8.08
Passenger vehicles	Before	Driving	5.35	6.26	10.11	10.6			11.44	9.11
		Passing	5.11	7.11	9.42	9.2			11.66	12.43
	After	Driving	5.32	6.26	9.41	6.0			7.93	**1.57**
		Passing	5.77	7.15	8.66	8.3			6.84	8.08
Non-passenger vehicles	Before	Driving	4.33	4.93	4.79	4.24			12.12	16.26
		Passing	4.92	6.50	8.23	8.14			9.83	10.08
	After	Driving	4.46	5.13	5.96	0.00			5.37	0.00
		Passing	4.93	5.97	6.90	6.96			6.21	7.94
* No congested conditions were observed at Sites 1 or 2										

At night (Table 4-42), little difference was found between the before and after conditions.

During the dawn/dusk periods (Table 4-43), little difference was found between the before and after conditions.

Percentage of Vehicles Traveling within the 10-mph Pace

Tables 4-44 to 4-46 show the percentage of vehicles traveling within the 10-mph pace for the before and after cases. For congested conditions, the plurality of vehicle speeds fell below 30-mph (i.e. in the 1-30 mph interval); therefore, it was impossible to calculate a 10-mph pace.

During the day (Table 4-44), little difference was found between the before and after cases under uncongested conditions.

Table 4-42 Standard deviation of speed – night.

Vehicle Type	Case	Lane	Uncongested Conditions at Site*			
			1	2	3	4
All vehicles	Before	Driving	4.29	5.62	5.51	4.68
		Passing	4.22	5.90	7.34	7.22
	After	Driving	4.91	5.54	3.76	0.00
		Passing	4.14	5.96	7.02	7.04
Passenger vehicles	Before	Driving	4.88	6.22	4.94	3.47
		Passing	4.28	6.43	7.77	7.65
	After	Driving	5.54	5.73	4.04	0.00
		Passing	3.88	6.29	7.63	7.57
Non-passenger vehicles	Before	Driving	3.52	4.48	2.17	4.24
		Passing	3.51	4.59	5.52	5.63
	After	Driving	4.09	4.84	0.00	0.00
		Passing	3.38	5.01	5.21	5.28
* No congested conditions were observed						

Table 4-43 Standard deviation of speed – dawn/dusk.

Vehicle Type	Case	Lane	Uncongested Conditions at Site*			
			1	2	3	4
All vehicles	Before	Driving	4.86	6.36	6.13	–
		Passing	4.14	5.51	6.50	6.46
	After	Driving	4.49	5.56	9.83	–
		Passing	4.40	5.47	6.77	6.72
Passenger vehicles	Before	Driving	5.20	5.20	5.85	–
		Passing	4.26	5.66	6.51	6.68
	After	Driving	4.70	5.68	9.83	–
		Passing	4.11	5.60	6.95	6.90
Non-passenger vehicles	Before	Driving	4.09	4.90	–	–
		Passing	3.32	4.75	5.35	5.10
	After	Driving	4.01	4.83	–	–
		Passing	5.17	4.76	5.32	5.55
* No congested conditions were observed						

Table 4-44 Percentage of vehicles within 10-mph pace – day.

Vehicle Type	Case	Lane	Uncongested Conditions at Site			
			1	2	3	4
All vehicles	Before	Driving	73.7	59.9	53.3	52.8
		Passing	76.0	58.6	47.1	48.3
	After	Driving	69.7	61.9	55.2	57.3
		Passing	78.2	58.0	49.7	51.1
Passenger vehicles	Before	Driving	70.6	58.8	54.5	52.9
		Passing	76.3	57.9	46.3	46.8
	After	Driving	69.7	60.9	56.8	58.3
		Passing	79.9	57.3	48.2	49.2
Non-passenger vehicles	Before	Driving	81.3	71.9	52.8	50.0
		Passing	84.6	64.7	54.5	55.0
	After	Driving	76.9	69.2	61.1	–
		Passing	77.9	65.2	60.4	59.4

At night (Table 4-45), while some significant differences were found at Sites 1 and 2, no significant differences or patterns were found at Sites 3 and 4.

During the dawn/dusk periods (Table 4-46), little difference was found between the before and after conditions.

Arrow Performance

The traffic control contractor's personnel laid out the arrows, walked on the surface area of the arrows to apply pressure, then rolled their pickup truck tires over the surface area (Figures 4-33 to 4-35). The installation process, including a temporary lane closure, required approximately two hours for a two-person team. The arrows remained in good condition for seven days. Arrow removal required approximately two hours (including a temporary lane closure) for a two-person team with no special tools and exhibited no particular difficulties.

Table 4-45 Percentage of vehicles within 10-mph pace – night.

Vehicle Type	Case	Lane	Uncongested Conditions at Site			
			1	2	3	4
All vehicles	Before	Driving	79.8	68.3	72.3	70.0
		Passing	79.5	63.5	54.7	57.4
	After	Driving	**72.6**	70.5	72.7	–
		Passing	77.7	64.1	56.9	57.0
Passenger vehicles	Before	Driving	75.7	62.2	74.0	77.8
		Passing	79.5	61.1	51.8	55.7
	After	Driving	**66.5**	**70.3**	71.4	–
		Passing	80.7	60.6	52.3	53.4
Non-passenger vehicles	Before	Driving	85.3	78.2	50.0	–
		Passing	87.6	75.4	65.9	66.1
	After	Driving	**79.0**	74.5	–	–
		Passing	87.0	72.4	68.7	67.5

Table 4-46 Percentage of vehicles within 10-mph pace – dawn/dusk

Vehicle Type	Case	Lane	Uncongested Conditions at Site			
			1	2	3	4
All vehicles	Before	Driving	76.4	60.7	66.7	–
		Passing	77.2	64.0	55.9	58.1
	After	Driving	75.0	**69.3**	37.5	–
		Passing	80.2	64.8	54.6	55.2
Passenger vehicles	Before	Driving	71.2	71.2	66.7	–
		Passing	77.5	63.1	56.4	55.0
	After	Driving	73.5	68.3	37.5	–
		Passing	82.5	63.8	52.6	52.8
Non-passenger vehicles	Before	Driving	89.4	72.7	–	–
		Passing	89.2	75.5	70.4	69.3
	After	Driving	78.0	79.7	–	–
		Passing	78.3	72.4	71.7	66.9

Figure 4-33 Arrow installation.

Figure 4-34 Arrow installation.

Figure 4-35 Arrow installation.

Safety

The time periods when the lane drop arrows were in place were too short to indicate a statistically significant reduction in accidents. However, a sharp rise in accidents could indicate that the arrows are hazardous. No accidents were found to have occurred because of the lane drop arrows. The arrows were expected to help the drivers still in the closed lane to change lanes, which would be expected to cause a changing lane accident. No lane changing accidents occurred while the arrows were in place.

Conclusions

This study examined the effect of lane drop arrows on lane distributions, vehicle speeds, and vehicle conflicts at a long-term work zone in Missouri. The arrows were primarily intended to reduce traffic speeds, speed variability, and the percentage of vehicles in the closed lane. The data analysis examined the difference in the parameters before and after the lane drop arrows were installed. The primary measures of effectiveness were lane distributions, speed mean, and speed variance; however, other parameters were also studied for significance in the evaluation of the traffic control devices. For the before and after studies, the analysis took into consideration the effects of time of day and class of vehicle.

The lane drop arrows were associated with improved lane distributions at Sites 3 and 4 during the day. In general, the arrows were associated with improved mean, 85^{th} percentile, and mean speeds of the fastest 15% of vehicles. The standard deviation of speed apparently improved in the daytime when the arrows were in place.

Recommendations

The results of this study indicate that the removable lane drop arrows can be expected to encourage earlier merging when two freeway lanes are reduced to one for a work zone. Speeds near the arrows can be expected to decrease, and the standard deviation of speed within the lane can also be expected to decrease. The primary costs of the rumble strips include the material, several hours of labor for installation and removal, and any additional traffic delay or hazard caused by the temporary lane closures required for installation and removal.