

# SWZDI

## Smart Work Zone Deployment Initiative

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<b>EVALUATION OF EARLY MERGE STATIC WORK ZONE SIGNING IN OKLAHOMA</b>		
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Abstract <p>This research examined the safety and operational benefits of having traffic merge early into the open lane prior to a work zone merge area. A 2007 law in Oklahoma adopted the use of additional "STATE LAW MERGE NOW" static signing in the advance warning areas approximately 1/2-mile upstream from freeway merge areas. Work zones that were continuations from the 2006 construction season did not use this signing, while new work zones did. This provided a unique opportunity to compare the impact of early merge signing in actual work zone environments. Measures of effectiveness examined included the number and percentage of traffic that remained in the closed lane and the number of conflicts that occurred at the merge area.</p> <p>It was found that the early merge signs did not appear to reduce the percentage of vehicles that remained in the closed lane. However, at least for right-lane closures, there appeared to be a significant benefit to using the STATE LAW MERGE NOW signing to reduce the number of observed conflicts at the merge area. This was evident when the hourly volumes were more than 550 vph. It seemed likely that although the early merge signs themselves did not improve early merging, the signs seemed to encourage drivers to consider earlier how they would make their merge maneuver, so when they reached the merge area the drivers that must merge were more likely to be able to make the merge without the need to vie for position against other drivers.</p>		



# **EVALUATION OF EARLY MERGE STATIC WORK ZONE SIGNING IN OKLAHOMA**

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## **DISCLAIMER**

This research was performed in cooperation with the Smart Work Zone Deployment initiative, a Federal Highway Administration (FHWA) pooled fund study administered by the Iowa Department of Transportation. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Smart Work Zone Deployment Initiative, the Iowa Department of Transportation, or the FHWA. This report does not constitute a standard, specification, or regulation. The engineer in charge of the study was Dr. Steven D. Schrock, Kansas P.E. #18989.

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# 1. INTRODUCTION

Highway work zone merge areas continue to be areas of potential safety problems, as multiple lanes of traffic vie for position in advance of lane reductions. As traffic volumes continue to increase, additional pressures will be placed on highway agencies to move traffic safely through highway work zones. One potentially beneficial strategy used in several states is known as the Early Merge Left Concept (EMLC).

This strategy is an effort by highway departments on four-lane highway sections such as median separated Interstate sections to utilize two theories of traffic to improve flow through the work zone. First, additional signing or other measures in the advance warning area are used to encourage traffic to move traffic out of the lane to be closed. This is meant to decrease the occurrence of drivers waiting to merge into the open lane until right at the merge point, which should result in fewer forced merges and improved traffic flow at the merge. One potential drawback to a high compliance of drivers moving early into the open lane is that some aggressive drivers may see the lack of traffic in the lane to be closed as an invitation to move into the empty lane and speed to the merge point. In order to combat this, the EMLC contains a second traffic calming theory: the left lane is always the open lane, which means drivers in the right lane must move left as they approach the merge. Any aggressive driver that wants to use the empty lane as a passing lane must therefore pass traffic on the right. There is anecdotal evidence that drivers are more reluctant to pass on the right, as it violates their experiences that faster traffic should be in the left lane(s). Figure 1 shows images of how these theories are meant to combine to improve traffic flow.

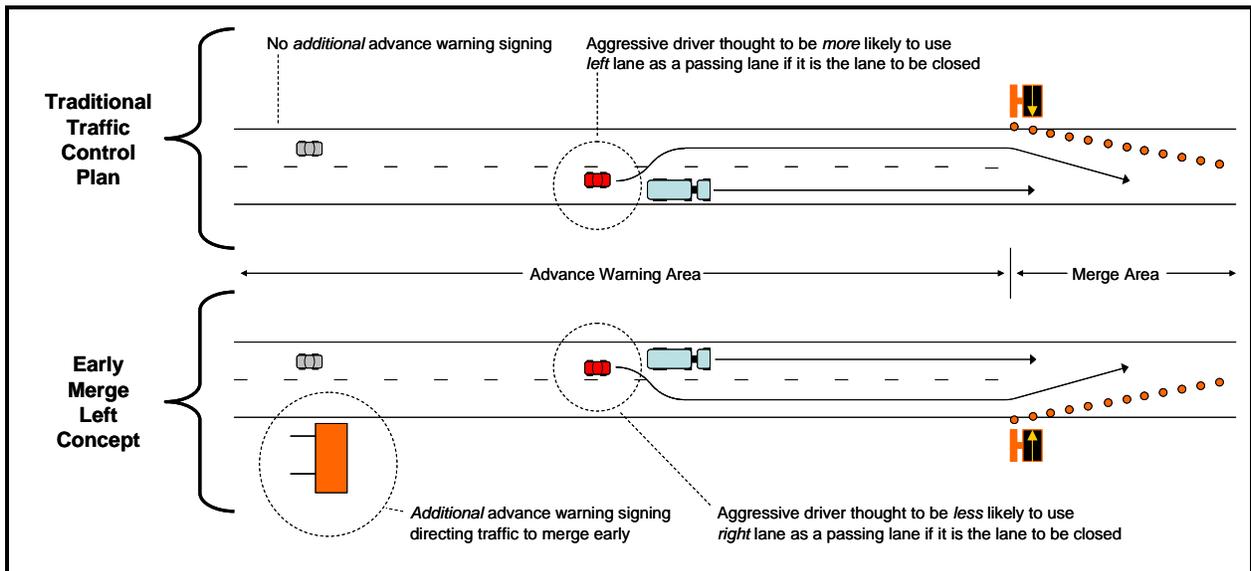
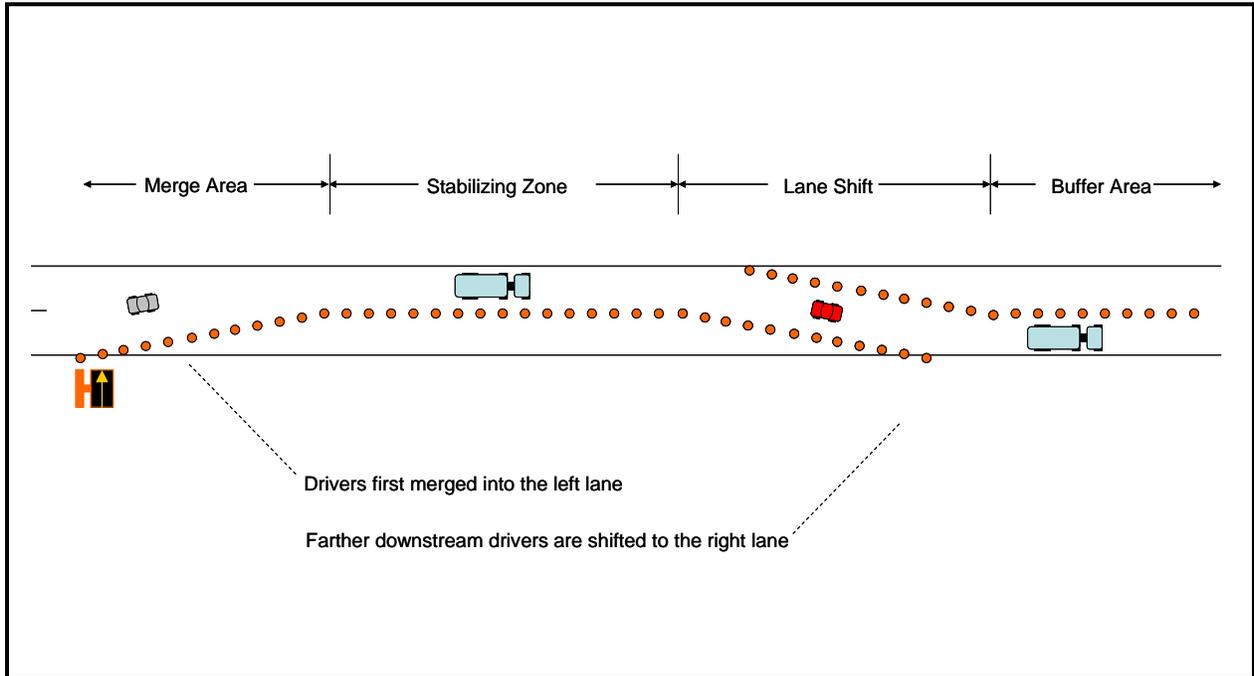


FIGURE 1 The early merge left concept.

One extension of the EMLC is what to do with situations where the left lane is to be closed. While traditional work zone traffic control plans would simply close the left lane and move traffic into the right lane, this is counter to the second theory of the EMLC. To accommodate times when work requires the closure of the left lane, the EMLC would still move traffic into the left lane, but after the merge area would shift traffic back to the right lane. This concept is also known as the Iowa Weave, and is shown in Figure 2.



**FIGURE 2 Example of an Iowa weave traffic control plan.**

## **RESEARCH OBJECTIVE**

This research examined the potential safety and operational benefits of having traffic merge into the left lane far upstream of a work zone lane closure where one lane of a two-lane freeway section is closed. It is believed that if highway agencies can get a larger proportion of drivers to move earlier out of the lane that will be closed and discourage aggressive drivers from using the lane as a passing lane there is a potential for fewer merge point conflicts, resulting in fewer merge area crashes and improved traffic operations.

This research examined four work zones in the State of Oklahoma, where a 2007 law adopted the use of additional “STATE LAW MERGE NOW” signing in the advance warning areas upstream from the merge point as shown in Figures 2 and 3. Work zones that were continuations from the 2006 construction season did not use this signing, while new work zones did. This provided a unique opportunity to research the potential impact of early merge signing in actual work zone environments.



**FIGURE 2 Oklahoma early merge sign directing traffic to the right.**



**FIGURE 3 Oklahoma early merge sign directing traffic to the left.**

Oklahoma law did not specify the use of an Iowa Weave-type secondary lane shift, so some work zones used a traffic control plan like that shown in Figure 1 (e.g., when the right lane was to be closed), and some used the mirror image (when the left lane was to be closed). The work zones were organized into the two-by-two matrix for study as shown in Figure 4.

		Lane Closure Type	
		Left Lane Closure	Right Lane Closure
Early Merge Sign Present?	Yes	I-35 NB @ Perry, OK	I-40 WB @ Weatherford, OK
	No	US-81 SB @ El Reno, OK	I-35 SB @ Blackwell, OK

**FIGURE 4 Matrix of work zone configurations studied in this research.**

## WORK PLAN

This research was conducted in two phases. Phase I (Tasks 1-3) involved an examination of the state of the literature and the state of the art regarding the use of work zone early merge strategies. Phase II (Tasks 4-6) involved field data collection, reduction, and analysis of traffic conditions at several work zones in Oklahoma. The work plan consisted of the following 6 tasks:

- Task 1: Literature Review
- Task 2: DOT Telephone Survey
- Task 3: Examination of EMLC Traffic Control Requirements
- Task 4: Field Data Collection
- Task 5: Field Data Reduction and Analysis of Results

- Task 6: Report Preparation

The literature review is presented in Chapter 2; the results of the DOT telephone survey and the examination of the traffic control requirements are presented in Chapter 3; field data collection and reduction is discussed in Chapter 4; the analysis is presented in Chapter 5; and findings and discussions of future research are presented in Chapter 6.



## 2. LITERATURE REVIEW

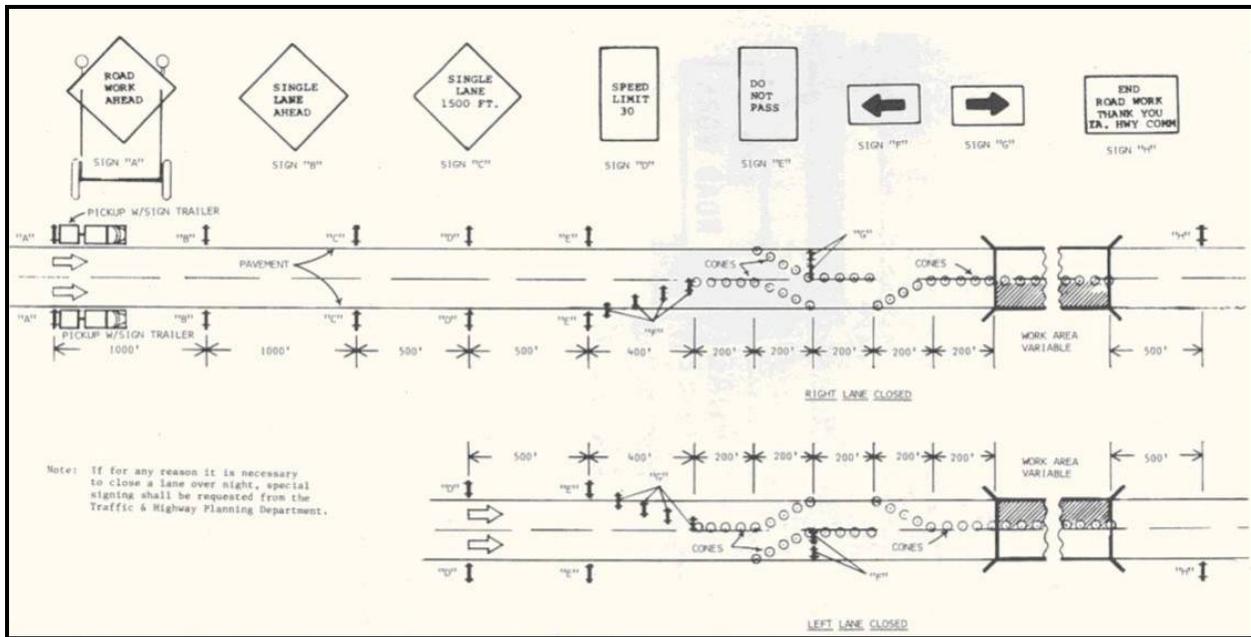
There are several sources in the literature that address the concept of an early merge strategy. For example, using microsimulation, Nemeth and Rouphail found that merge control strategies that make extensive use of the early merge concept significantly reduced the frequency of forced merges, especially in higher traffic volumes (1). Other researchers found that not all aspects of early merge strategies was positive; Mousa, et al. found that travel times could be increased when early merge strategies are used, by forcing faster traffic into a slower traffic stream (2). This has led other researchers to ponder that when early merge control strategies are used there may be an increase in the likelihood of drivers using the lane to be closed, as a strategy to prevent an increase in a driver's travel time (3).

Perhaps the most extensive early merge strategy that has been implemented is the Indiana Lane Merge concept, developed by the Indiana Department of Transportation as a way of improving safety and traffic flow (4). The core of the system is a series of changeable message signs in the advance warning area coupled with speed sensors to detect the speed of adjacent traffic. When a queue develops upstream from the merge area, the sensors detect the slow-moving traffic and display "DO NOT PASS" information on the upstream changeable message signs. There are also static signs stating that it is illegal to pass in a no passing zone, there is in effect a variable-length no passing zone created that matches the length of the existing queue. In the system deployed in the late 1990's in Indiana, this dynamic no-passing zone extended up to 2.5 miles upstream from the merge area. When studied for operational effects, it was found by Tarko, et al. that while compliance with the merge strategy was good the strategy did not increase throughput, and that travel times increased (4).

### IOWA WEAVE

One version of the merge strategy that is related is the Iowa Weave, which includes more than one weave area. The term Iowa Weave is evidence that this lane closure method was initially introduced in the state of Iowa. The actual date of this new introduction is not known; however, it was estimated in the year prior to 1969 based on the literature (5). When it was first introduced, there were two Iowa weave lane closures setups: left-hand merge with lane shift, and right-hand merge with lane shift. Figure 5 shows the original Iowa Weave lane closures described. This pattern was initially designed to control speeds but the use was subsequently discontinued by Iowa after the introduction of median crossovers and two-lane, two-way operation in work zone lane closures.

In an early review of the Iowa Weave concept, Brewer conducted research to examine both the left-hand merge and right-hand merge Iowa weave setting on arterial roads in Des Moines, Iowa (6). Brewer used two different methods to collect the data: video camera observation and enoscopes (flash boxes). Video cameras were used to record data on weaving and merging at the advance warning area. In addition, the license plates of all vehicles sampled were recorded to classify these vehicles into different categories: Iowa same county, Iowa-other-than-local, and out-of-state. Meanwhile, the enoscopes were placed in the work areas behind the barricades to collect vehicle speeds.



**FIGURE 5 Original concept of the Iowa Weave traffic control plan (5).**

Brewer found that this weaving pattern was highly effective in visible construction sites, with more than 50 percent of all vehicles sampled traveling below the posted temporary speed limit of 30 mph, whereas in construction sites where the Iowa Weave was not used, the posted speed limit compliance of all vehicles sampled was found to be less than 20 percent (6). The chosen speed limit of 30 mph was considered by Brewer as the desirable speed where vehicles should be constricted. In this research, Brewer concluded that no excessive driver confusion was found in the use of this weave pattern, even though three vehicles were found performing unusual maneuvers in the advance warning area.

Since the introduction of the Iowa weave, many Departments of Transportation (DOTs) have experimented with this new weave pattern. Iowa, North Carolina, and Tennessee along with Arkansas have each used the Iowa weave lane closure setting in their freeways. Based on the instructional bulletin by the Tennessee DOT on the use of the Iowa Weave, TDOT requires all of their interstate construction and maintenance projects to review and include the use of the merge left where lane closure is applicable (7). However, the following criteria are cited by TDOT before determining its use:

- Projects on rural interstates should include the merge left concept.
- Projects on urban interstates will be reviewed for merge left concept considering factors such as number of lanes, interchange spacing, and proximity to major splits.
- Other controlled access facilities will be considered on a case-by-case basis.

In North Carolina, this weave pattern was first borrowed from the Iowa DOT after a tractor-trailer breached the approach taper and buffer zone in a work zone on I-77, and struck the construction personnel (8). The Iowa Weave was subsequently adopted to control traffic in high

speed, medium volume work zones. The main purpose of this adoption by NCDOT was to enhance the safety of construction personnel when any breaching by errant vehicles occurred.

### **Characteristics of the Iowa Weave**

In the 1990s, Lorscheider and Dixon examined the effect of the Iowa weave by evaluating the speeds at the advance of warning, end of taper, weave and lane closure areas on both the rural and urban freeways (8). In this study, the Vehicle Magnetic Imaging traffic counters were utilized to monitor the vehicle speeds in the project area. The only concern observed in this device was the limitation of detecting vehicles traveling above the upper threshold of 15-80 mph. However, Lorscheider and Dixon explained that this limitation could be amended by using the newly revised software from the manufacturer. The results of this research showed that this weave pattern is effective in reducing the speeds of motorists in work zones despite the finding that it increases driver confusion in the urban settings. The authors also added that the use of this weave pattern should be limited to rural freeways. In addition, it was found that the speed reduction resulting from the weave section dissipated within 0.75 mile. Nonetheless, Lorscheider and Dixon stated that this unique design was a great tool to protect workers as it directed motorists to drive through the merging taper and stabilizing zone on the left lane before channelizing them over to the right lane to avoid the actual work area ahead of them.

Lorscheider and Dixon further concluded that the Iowa weave could be a great time-saving method for contractors in construction work zones even though some drivers were confused by the direction of the advance signs that led them to the lane that was closed. Depending on the size of the work zones, a lane closure involving an advance warning area on an urban freeway can take up to two hours to set up and remove. Furthermore, contractors are often permitted to have a ten-hour window at night to set up the lane closures. With such regulation, contractors can spend substantial amount of the time installing and removing the lane closures, but by using the Iowa Weave, contractors can remove the weave section, which normally takes less than twenty minutes, and leave the entire length of the lane closures in an extended straight buffer area. The Iowa Weave also helps eliminate the use of right lane closures, which requires the relocation of advance warning signs and reduces driver confusion to motorists that drive by the area on a routine basis.

Lorscheider and Dixon also indicated that the Iowa weave can be used on three-lane, one-way work zones, by closing two lanes and allowing vehicles to weave through the center lane to the far side of the work zone. When the construction workers signal the need for the lane closure to be swapped to the opposite side, the weave section is again removed, leaving the two lane closures with an extended buffer (transformed to conventional lane closure). There are two additional benefits observed in using this method over the two-lane, one-way weave pattern. First, the three-lane, one-way weave pattern allows an additional buffer area between the workers and the open travel lane. Second, this technique also provides additional time for the contractors to remove the lane closure in the center lane. With proper attention, contractors can place the buffer zone and a weave at the midpoint of the work zone to facilitate two different construction activities on two separate lanes concurrently. For example, contractors can pave the end of the first lane while cold milling the second lane. However, Lorscheider and Dixon recommended that the three-lane work zone setup be examined with extra care as this type of closure increases driver confusion.

In the most recent literature on the Iowa Weave, Zhu and Saccomanno (9) conducted research to compare both the left-hand closure and right-hand closure, while proposing and comparing a more channelized lane closure layout or the Iowa weave on the three-lane freeway. The focus of this research, however, was to examine the safety implications of these lane closure methods by measuring two traffic-flow characteristics using the microlevel simulation INTEGRATION: uncomfortable deceleration and speed variances. Based on the simulation results of this research, it was found that the right-hand closure appears to be safer than the left-hand closure, whereas the proposed layout on a three-lane freeway segment was found to be safer than both the left-hand closure and right-hand lane closure. Zhu and Saccomanno also explained that the proposed layout helped to avoid high-risk lane changing that could occur on the higher-speed left lane than the lower-speed right lane. In terms of positive guidance, Zhu and Saccomanno found that this layout helped reduce the uncertainty associated with lane closure merging by reducing the choices that drivers have to make in lane closures and increase driver awareness (10).

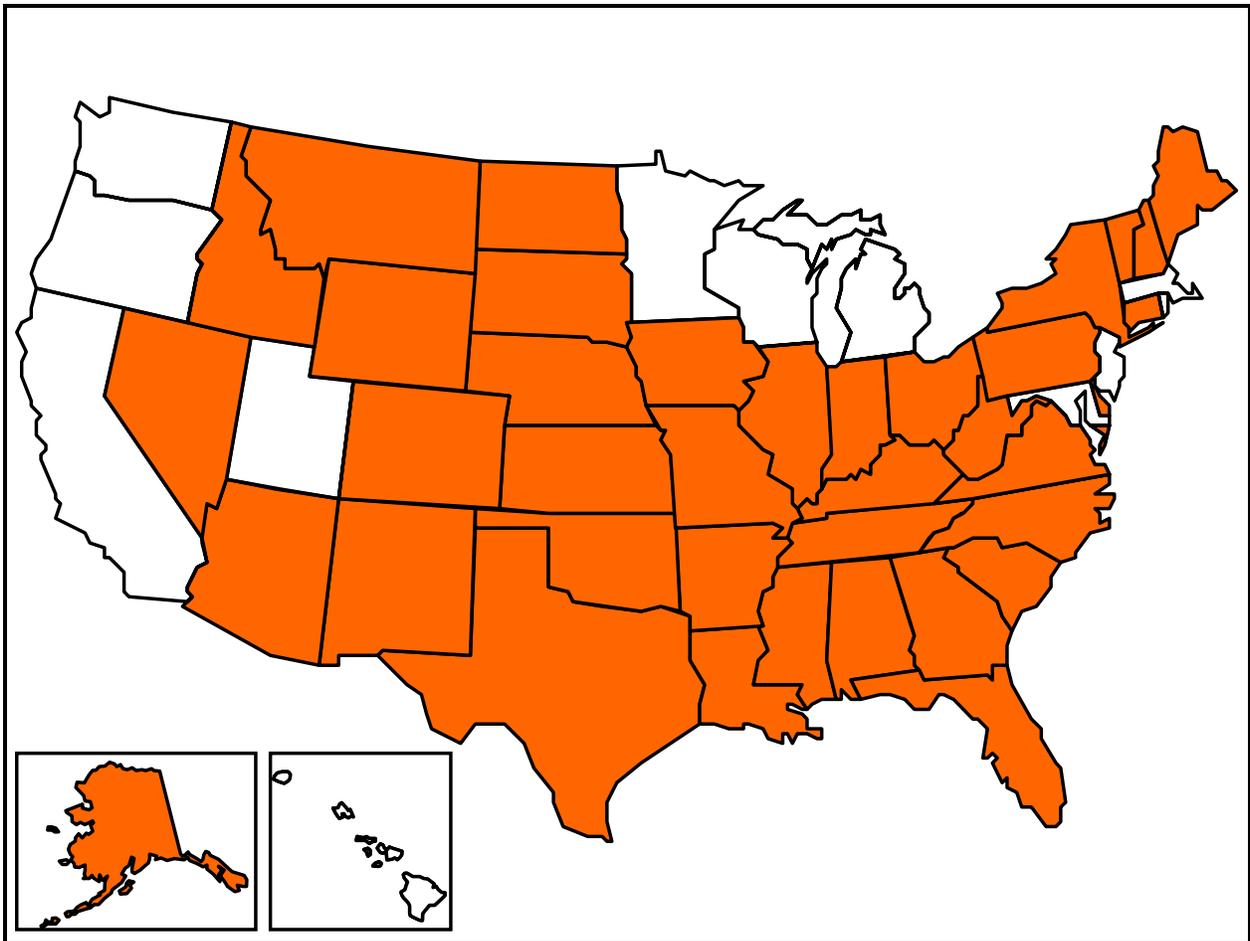
The following are the key findings of Zhu and Saccomanno's research:

- A lower number of uncomfortable decelerations were observed in the advance warning area, buffer and work areas of the proposed layout (the Iowa Weave).
- The results were consistent in both of the studied flow rates of 2,800 vph and 3,600 vph.
- Overall, a higher number of uncomfortable decelerations was obtained for the current left hand closure.
- The safety advantages of the Iowa Weave layout compared to the conventional right-hand closure was not as pronounced as the left-hand closure.
- Significant differences were observed between the Iowa Weave layout and the conventional left-hand closure in speed variances.
- The Iowa Weave layout and the conventional right-hand closure appeared to result in similar speed variances.

### 3. DOT TELEPHONE SURVEY

Telephone contact was made with 38 state departments of transportation to determine their use of early merge strategies in long term work zones. The states contacted are shown in Figure 6. This represented 76 percent of all state DOTs nationally, and was considered to be a representative sample by the authors. The purpose of the telephone survey was to determine:

- The extent that states use an early merge system,
- Under what conditions and traffic volumes they are used, and
- Perceptions of the advantages and disadvantages of their use.



**FIGURE 6** State departments of transportation surveyed by telephone.

The survey found that the vast majority of states (36 of 38, or 95 percent of those surveyed) do not use an early merge system. Two states (5 percent of those surveyed) indicated the use of early merge strategies were Indiana and Louisiana. Note that at the time of the survey the state

of Oklahoma had not yet implemented the “STATE LAW MERGE NOW” signing. If the survey results are updated to reflect this fact then 3 states (8 percent of those surveyed) made some use of an early merge strategy. Indiana indicated good results from their early merge strategy, but indicated that due to the equipment requirements (see discussion in the Literature Review chapter) it was only used at high-profile work zones.

There were also three states that indicated that they currently make use of the Iowa Weave strategy: Arkansas, North Carolina, and Tennessee. The Tennessee DOT indicated that they make use of the Iowa Weave - merging all traffic to the left lane and then (if needed) shifting traffic back to the right lane - at short term nighttime lane closures on their interstate system. The Arkansas Highway and Transportation Department indicated that they used a similar strategy but reserved its use for major reconstruction projects on Interstate highways. Engineers from these transportation departments indicated that the main benefit of the Iowa Weave appeared to be improved efficiency from their contractors because when the work space was shifted from one lane to the other there were few traffic control changes required. Additionally, the engineers believed that by always initially shifting traffic to the left that driver confusion was minimized, but no studies have been done to date to confirm this.

While few states appear to be utilizing the early merge strategy, it was interesting to note that the late merge strategy is a much more commonly used strategy that is being experimented by the states. Seven states (18 percent of those surveyed) indicated that they have made use of the late merge or the dynamic late merge strategy, at least at specific locations. One of the main benefits cited by engineers is that the late merge strategy is effective in reducing queue lengths, so the likelihood of a queue extending beyond the advance warning area is reduced.

## 4. FIELD DATA COLLECTION

Field data were collected over fifteen days in July and August 2007 at four freeway work zones in Oklahoma. Specifically, the following locations were studied:

- I-35 Northbound at Perry, OK
- US-81 Southbound at El Reno, OK
- I-40 WB at Weatherford, OK
- I-35 Southbound at Blackwell, OK

While efforts were made to select work zone locations that were as similar as possible, the research team ultimately had to choose from the projects that were available at the time of the research. So while the work zone locations had many similarities there were also some differences that could not be eliminated from the study. Similarities between these study sites included:

- Four-lane Interstate-type cross-sections with grass medians,
- High-speed traffic,
- Long-term work zones that had not changed traffic control in the weeks prior to the study,
- Rural locations, and
- Terrain (only varied between flat to slight rolling hills at all sites).

Unavoidable differences between these locations included:

- Nature of the construction activities being performed,
- Percentages of heavy trucks, and
- Traffic volumes.

Video trailers were utilized to collect the data, as shown in Figures 7 and 8. Trailers were always installed in pairs, one with a view of the work zone merge area and another approximately 1/2-mile upstream to view traffic prior to drivers viewing the STATE LAW MERGE NOW sign, which was positioned just after the LEFT (RIGHT) LANE CLOSED 1/2 MILE signing. Whenever possible, these trailers were positioned behind roadside guide signs or just past bridge abutments to minimize changes in driver behavior due to their noticing the trailers. Of course this was not always possible and in these cases the trailers were positioned laterally as far as possible from the roadside.



**FIGURE 7** Data collection trailer used for data collection, positioned behind guide sign.



**FIGURE 8** The same data collection trailer as viewed from the traveled way.

## DATA REDUCTION

The objective of the data reduction process was to condense the large amount of video recorded during data collection into numerical traffic data which could be analyzed statistically. Nearly 200 hours of digital video were recorded onto an external hard drive. The video data were broken down into many files of various lengths by the recording device itself. A log was made of these video files organized by location and date. Each of these video files was watched carefully by research assistants using this log as a guide.

The video files were viewed using video playback software. At locations where traffic volume was significantly less or those which had a broader viewing area, the video speed was increased in order to reduce the time required to review the video data. Multiple-tally denominator traffic counters were used during the viewing process to tally the lane-by-lane traffic counts. At both downstream and upstream video locations, traffic counts were collected for the left lane and right lane for both cars and trucks. For the downstream locations, the number of conflicts and cars/trucks exiting were also collected. A conflict was defined as a potential driving hazard caused by or affecting one or more vehicles upon entering the work zone, and was considered an indication of the crash potential observed in the traffic stream. Conflicts did not reflect the number of vehicles involved in the hazardous condition, only that a conflict occurred. The following conditions were used as conflict indicators while reviewing the videos:

- A vehicle at or near the merge area in the lane about to be closed attempting to enter the open lane while another vehicle was present in the open lane (i.e., two or more vehicles were “jockeying” for position);
- A vehicle striking a traffic control device such as a cone or barrel, or visibly trying to avoid a collision with such a device;
- Brake lights were seen from one or more vehicles as a direct result of another vehicle’s actions; and
- Any other erratic driving behavior that appeared to increase the likelihood of a crash.

Lane-by-lane volumes and the number of conflicts were recorded in five-minute increments, which were later compiled into 15-minute increments. These 15-minute interval data, separated by date and location, were used as the basis for the data analysis.

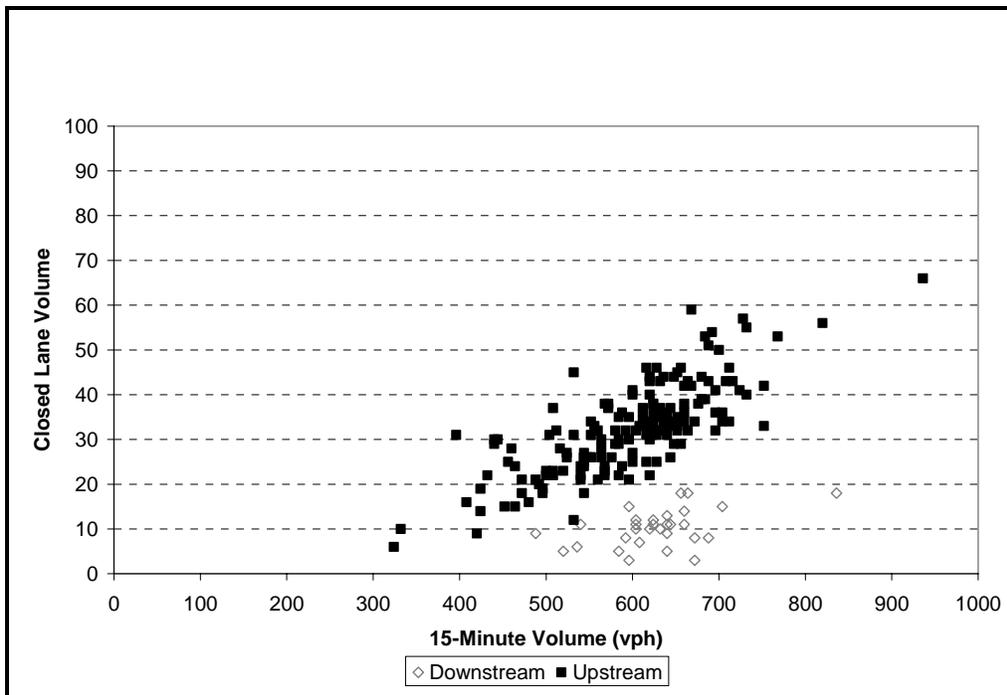


## 5. ANALYSIS

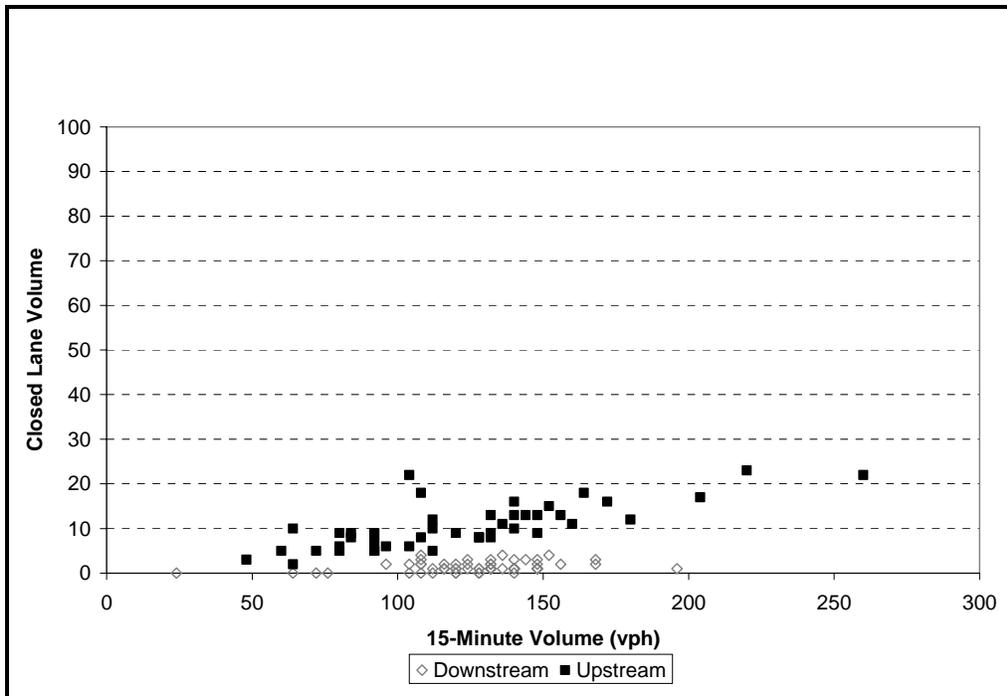
Two changes in behavior could reasonably be expected to result from the STATE LAW MERGE NOW signing. First, if drivers followed the sign's directions it would be less likely that vehicles would remain in the lane to be closed. Second, even if drivers did not change lanes earlier they may be more likely to position themselves to more easily make the lane change when they reached the merge point. This could result in fewer forced merges or other aggressive behavior noted above.

### CLOSED LANE VOLUMES

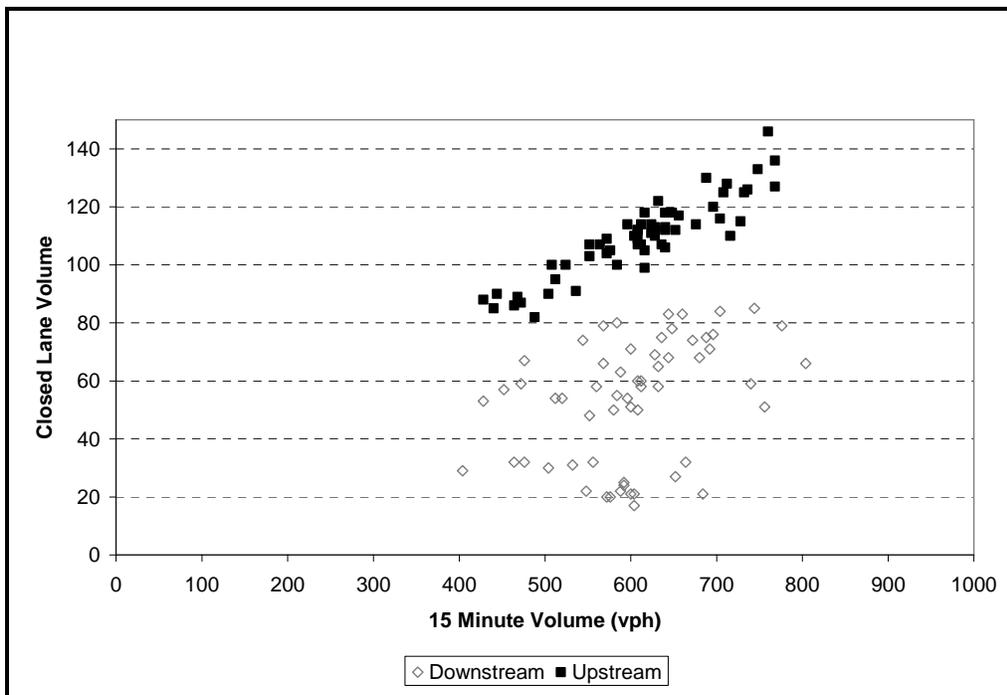
Figures 9 through 12 show the 15-minute traffic volumes for each of the locations studied. As expected, there were in all cases more vehicles in the lane to be closed when observed at the upstream location and fewer when the merge area was reached. Also not surprising was the fact that the volume of traffic in the closed lane tended to increase as the overall traffic volumes increased. In order to account for this in the analysis the data were transformed from raw volumes to percentage of traffic in the closed lane as the dependent variable, as shown in Figures 13 through 16. This transformation appeared to satisfactorily reduce or eliminate the volume factor from impacting the closed lane traffic when expressed as a percentage. This allowed a direct comparison between the four different work zone merge area types (left or right lane, with or without the early merge signing).



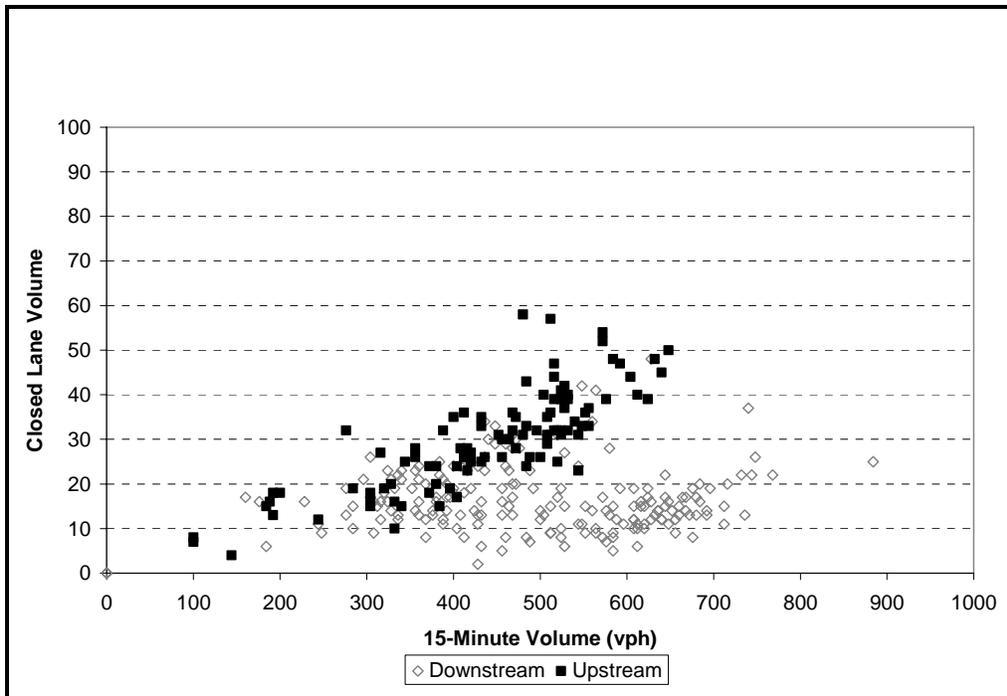
**FIGURE 9** Observed closed lane volumes when the left lane was closed and the early merge signing present (location: Perry, Oklahoma).



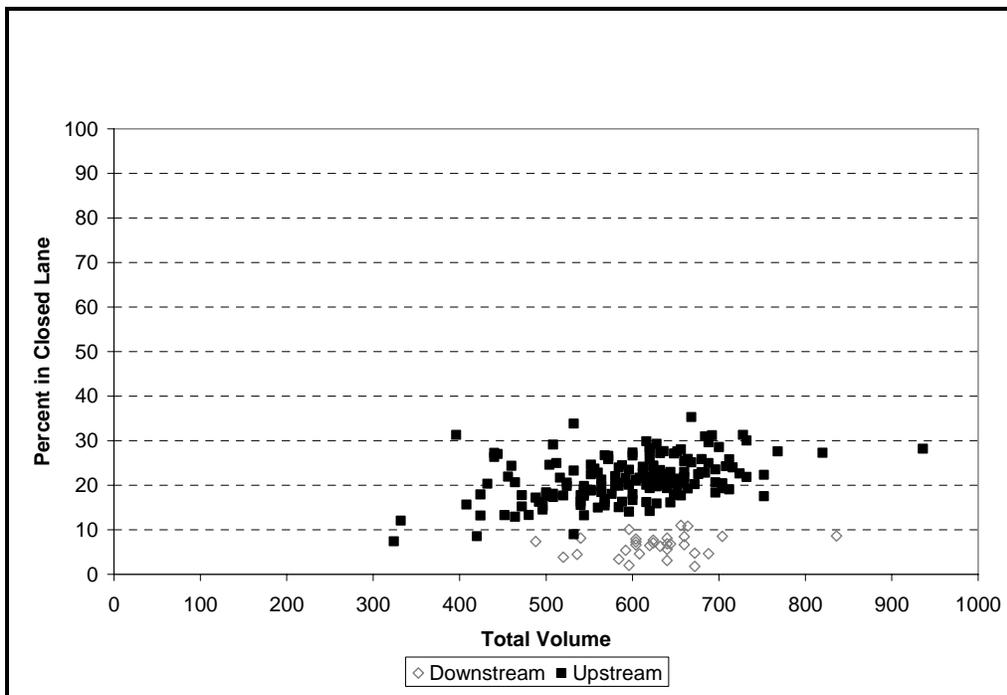
**FIGURE 10** Observed closed lane volumes when the left lane was closed and the early merge signing not present (location: El Reno, Oklahoma).



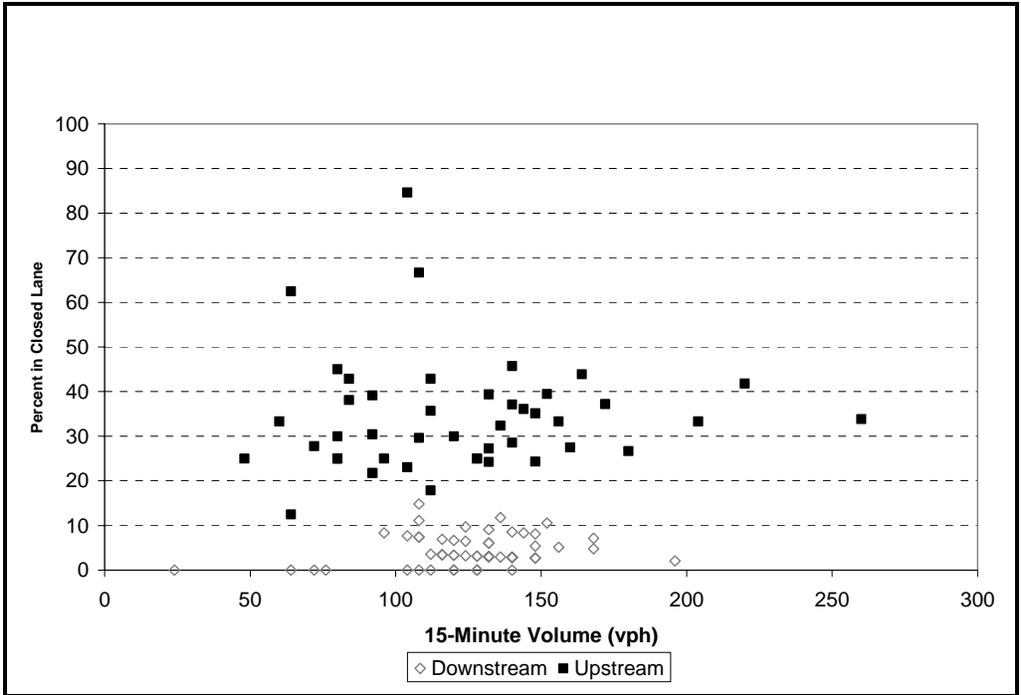
**FIGURE 11** Observed closed lane volumes when the right lane was closed and the early merge signing present (location: Weatherford, Oklahoma).



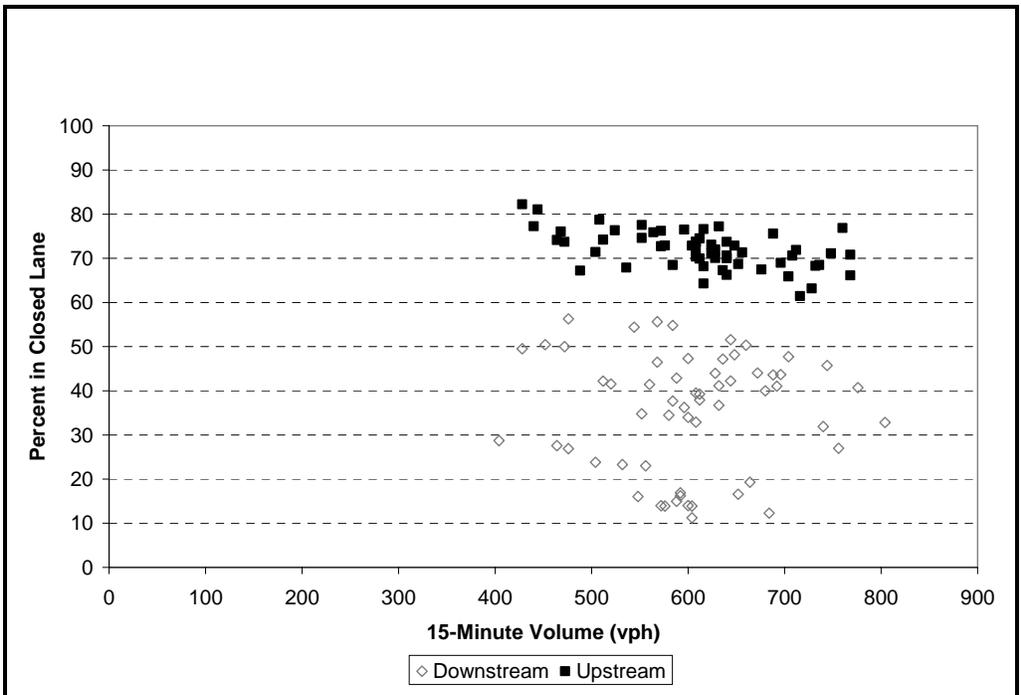
**FIGURE 12** Observed closed lane volumes when the right lane was closed and the early merge signing not present (location: Blackwell, Oklahoma).



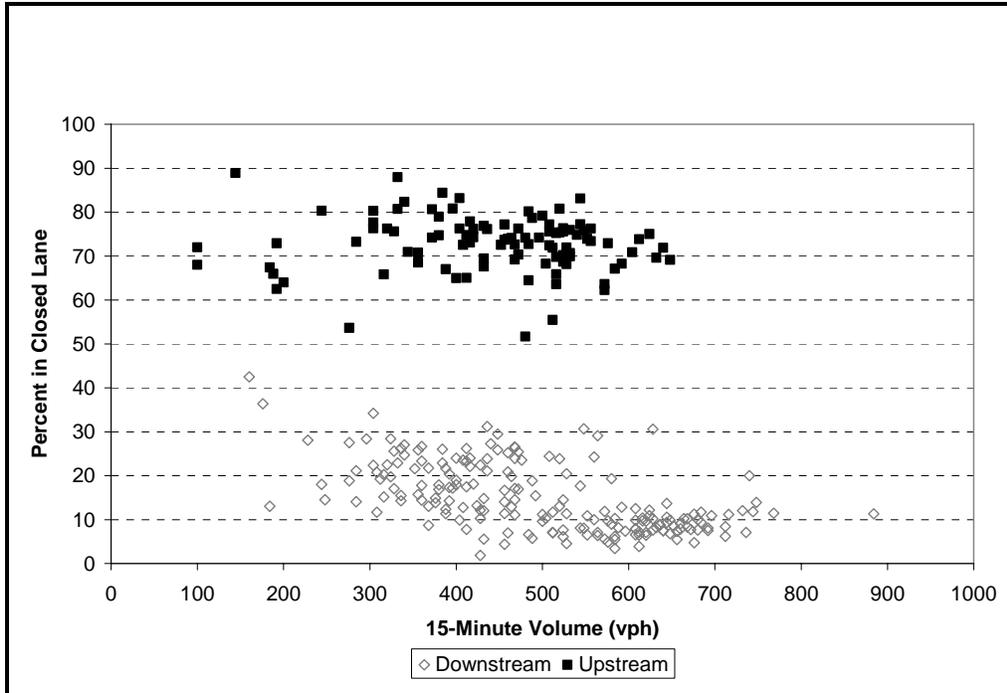
**FIGURE 13** Percent of traffic in the closed lane when the left lane was closed and the early merge signing present (location: Perry, Oklahoma).



**FIGURE 14** Percent of traffic in the closed lane when the left lane was closed and the early merge signing not present (location: El Reno, Oklahoma).



**FIGURE 15** Percent of traffic in the closed lane when the right lane was closed and the early merge signing present (location: Weatherford, Oklahoma).



**FIGURE 16 Percent of traffic in the closed lane when the right lane was closed and the early merge signing not present (location: Blackwell, Oklahoma).**

Table 1 shows the statistical analysis of the percent of traffic in the closed lanes at the merge point. The left-lane merge setups were compared to see if there was a difference between the locations that did and did not have the early merge signing. It was found that the location that did *not* have the early merge signing had a significantly lower percentage of traffic in the closed lane. When the right-lane merge setups were compared the same result was found: the location that did *not* have the early merge signing had a significantly lower percentage of traffic in the closed lane. This is the opposite of the intent of the signs, and is an indication that these signs are not having the desired effect, at least at the most basic level of legal compliance.

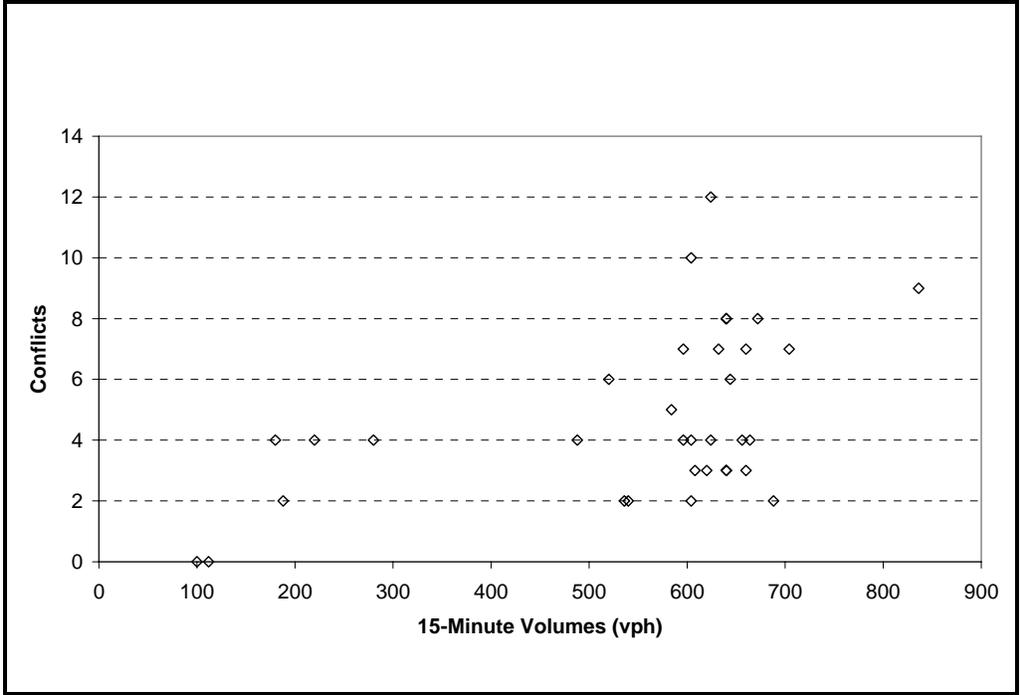
**TABLE 1 Average Percent of Traffic in Closed Lanes**

<b>Merge and Sign Condition</b>	<b>Location</b>	<b>Average Percent of Traffic in Closed Lane at Merge Point</b>	<b>Standard Deviation</b>	<b>Sample Size</b>	<b>95 Percent C.I. (%)</b>	<b>Sig. Diff?</b>
Left-Lane Closure with Early Merge Signing Present	Perry	6.5	2.36	30	(5.7, 7.3)	Yes
Left-Lane Closure without Early Merge Signing Present	El Reno	4.4	3.57	55	(3.4, 5.3)	
Right-Lane Closure with Early Merge Signing Present	Weatherford	35.5	13.1	59	(32.1, 38.8)	Yes
Right-Lane Closure without Early Merge Signing Present	Blackwell	14.9	7.67	196	(13.8, 16.0)	

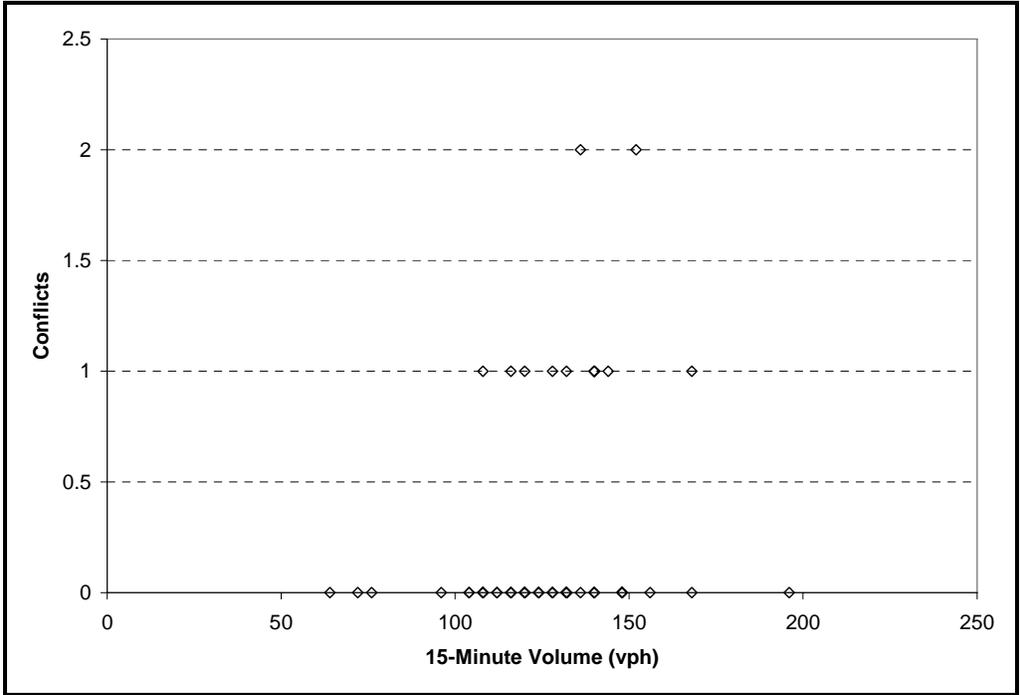
**MERGE AREA CONFLICTS**

The second manner in which early merge signing could be expected to affect traffic was the number of observed conflicts at the merge point of the work zones. Conflict analysis was considered to be a surrogate for crash analysis, as it documents instances of two or more vehicles in close proximity whose drivers are vying for the same space. While crashes are rare events, conflicts occur with more frequency; high-conflict locations can be assumed to be more likely to be crash-prone locations as well.

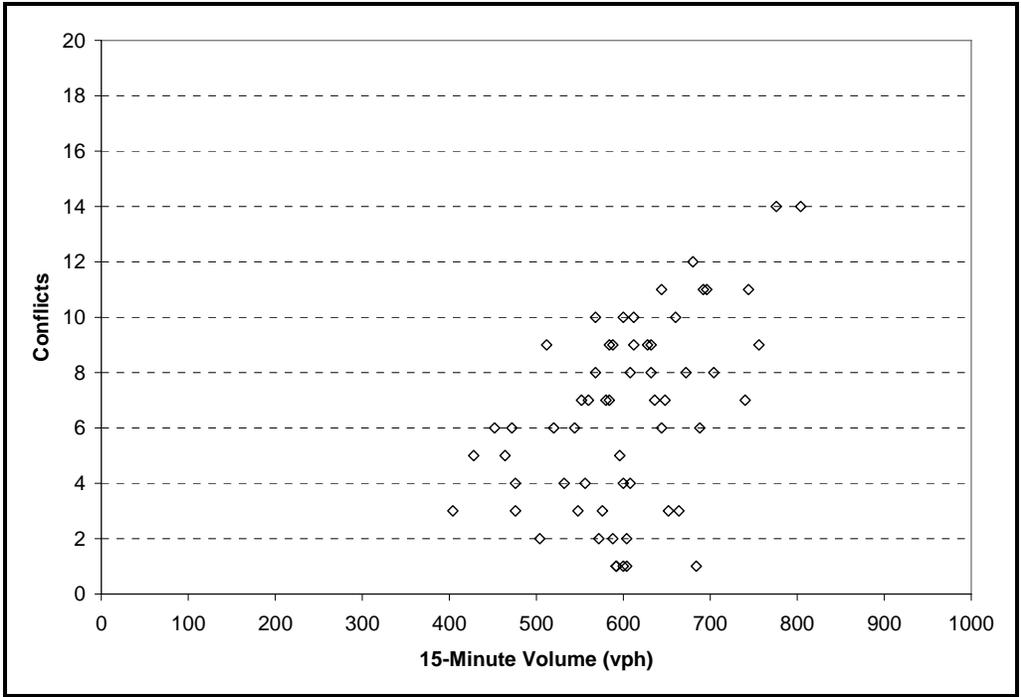
The observed conflicts plotted against the 15-minute volume for each location are shown in Figures 17 through 20. As in the analysis of the closed lane volumes it can be seen that as the 15-minute volumes increase the number of conflicts tends to also increase. Again, this is not an unexpected result, as it makes sense that as there are more vehicles on the roadway there would be more opportunities for vehicle paths to come into conflict. To account for this, a log10 transform was performed on these data, with the transformed data shown in Figures 21 through 24.



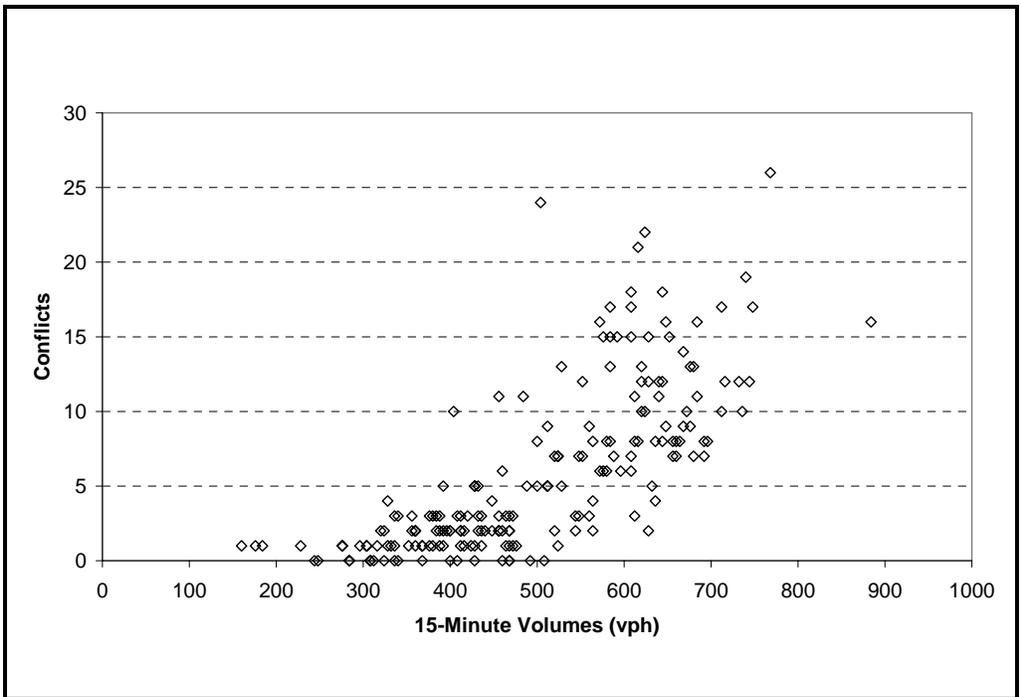
**FIGURE 17 Merge area conflicts when the left lane was closed and the early merge signing present (location: Perry, Oklahoma).**



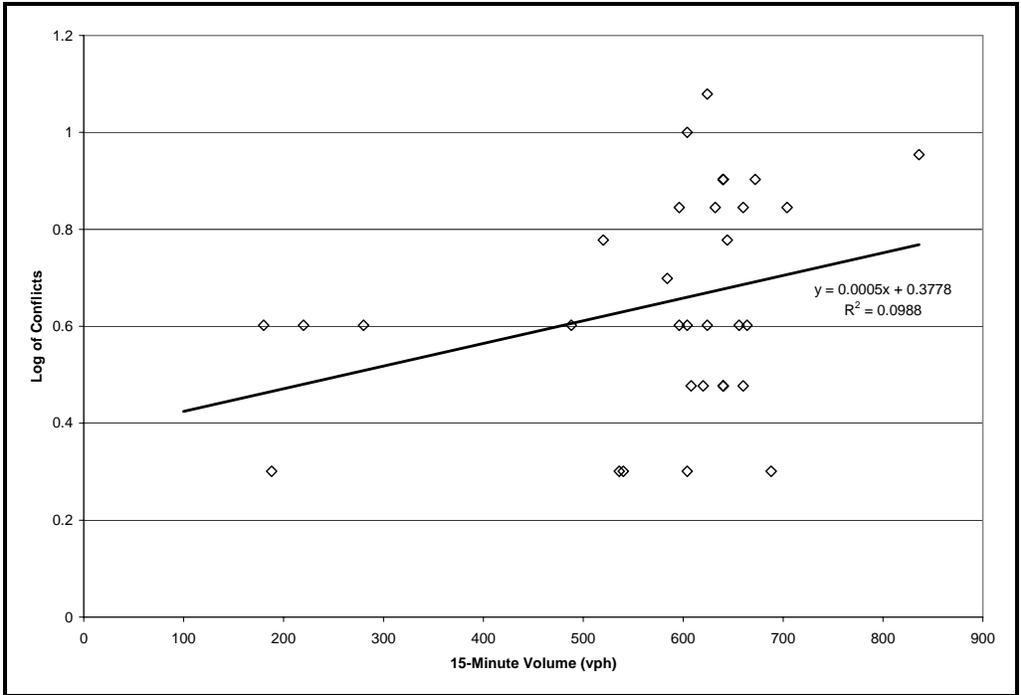
**FIGURE 18 Merge area conflicts when the left lane was closed and the early merge signing not present (location: El Reno, Oklahoma).**



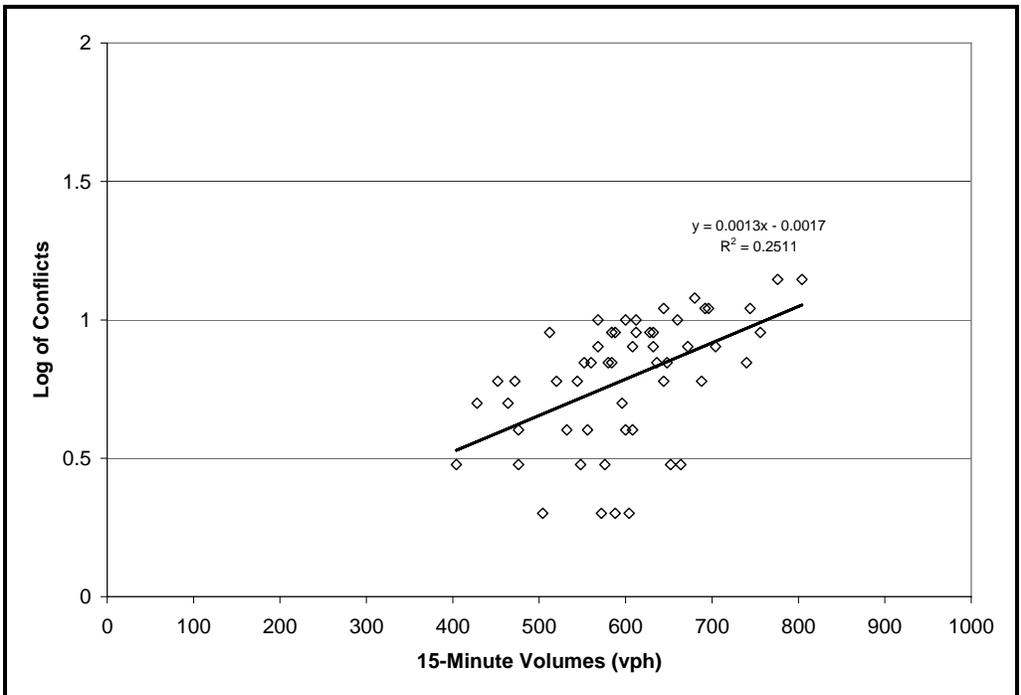
**FIGURE 19** Merge area conflicts when the right lane was closed and the early merge signing present (location: Weatherford, Oklahoma).



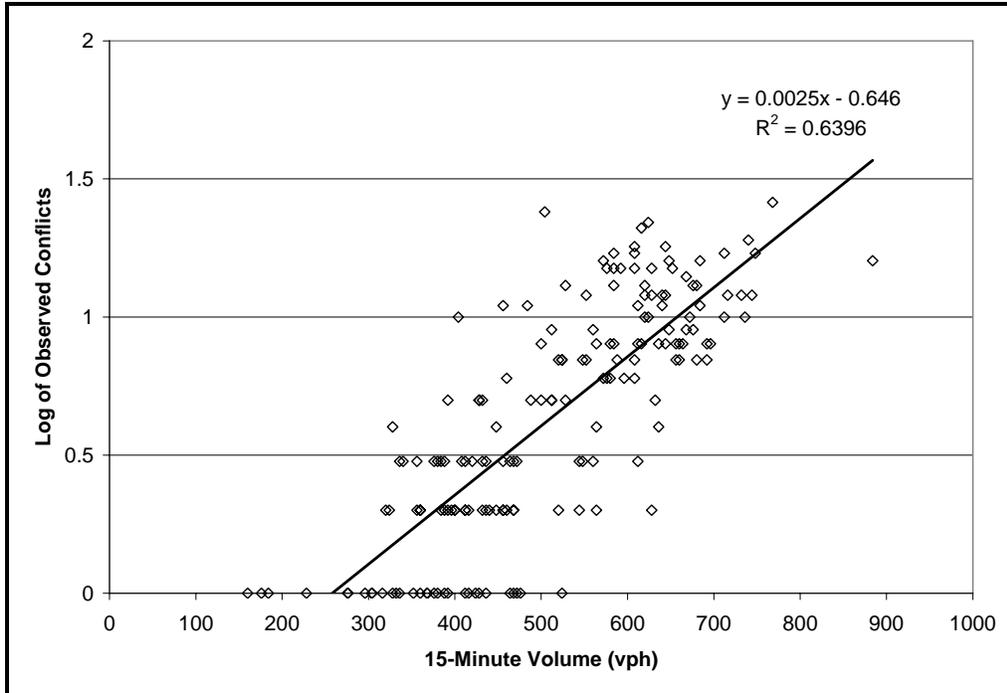
**FIGURE 20** Merge area conflicts when the right lane was closed and the early merge signing not present (location: Blackwell, Oklahoma).



**FIGURE 21** Log transform of merge area conflicts when the left lane was closed and the early merge signing present (location: Perry, Oklahoma).



**FIGURE 22** Log transform of merge area conflicts when the right lane was closed and the early merge signing present (location: Weatherford, Oklahoma).



**FIGURE 23 Log transform of merge area conflicts when the right lane was closed and the early merge signing not present (location: Blackwell, Oklahoma).**

Note that any 15-minute time periods with no conflicts had to be removed from this transformation, as the  $\log_{10}(0) = -\infty$ , there would be no useful way to interpret the results. The log transform of the data resulted in an issue with the location where the left lane was closed and the early merge signing was not present (e.g., El Reno, Oklahoma). Because of the low observed volumes a large proportion of the time periods were without conflicts, so the small dataset that remained limited the usefulness of this analysis at this location. As a result, no transformation of the El Reno data was performed, meaning that there was no satisfactory method to compare the two locations with left-lane closures (e.g., Perry and El Reno). The remaining analysis in this chapter then focused solely on the two right-lane closures (e.g., Weatherford and Blackwell).

A general linear model of the transformed data for the two right-lane closures was constructed, taking the form:

$$\text{Log}(y) = B_0 + B_1x_1 + B_2x_2 + B_3x_1x_2 \quad (1)$$

Where:

$y$  = observed conflicts,

$x_1$  = 15-minute volume (vph), and

$x_2$  = location (no early merge sign present (Blackwell) = 0,  
early merge sign present (Weatherford) = 1).

Multiple regression analysis was performed with the ANOVA results shown in Table 2 and the Coefficient results in Table 3. The results indicate that there was a significant difference between the two regression lines, and that each of the coefficients in the general linear model were also significant. The revised model was then rewritten as:

$$\text{Log}(y) = -0.6460 + 0.0025x_1 + 0.6443x_2 - 0.0012x_1x_2 \quad (2)$$

Taking the antilog of both sides of this equation yields:

$$y = 10^{(-0.6460 + 0.0025x_1 + 0.6443x_2 - 0.0012x_1x_2)} \quad (3)$$

**TABLE 2 Regression Output Testing the Difference between the Presence or Absence of Early Merge Signing at Two Right-Lane Work Zone Closures**

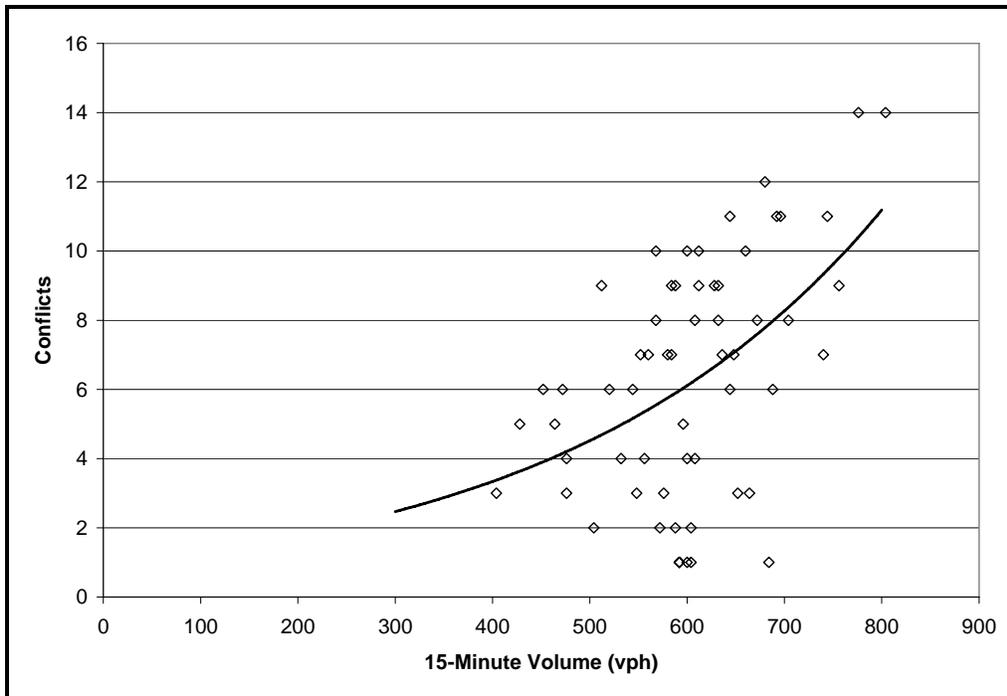
Source	df	SS	MS	F	P-value
Regression	3	21.2395	7.0798	120.858	> 0.0001
Residual	224	13.1219	0.0586		
Total	227	34.3613			

**TABLE 3 Regression Output for Test of Coefficient Significance**

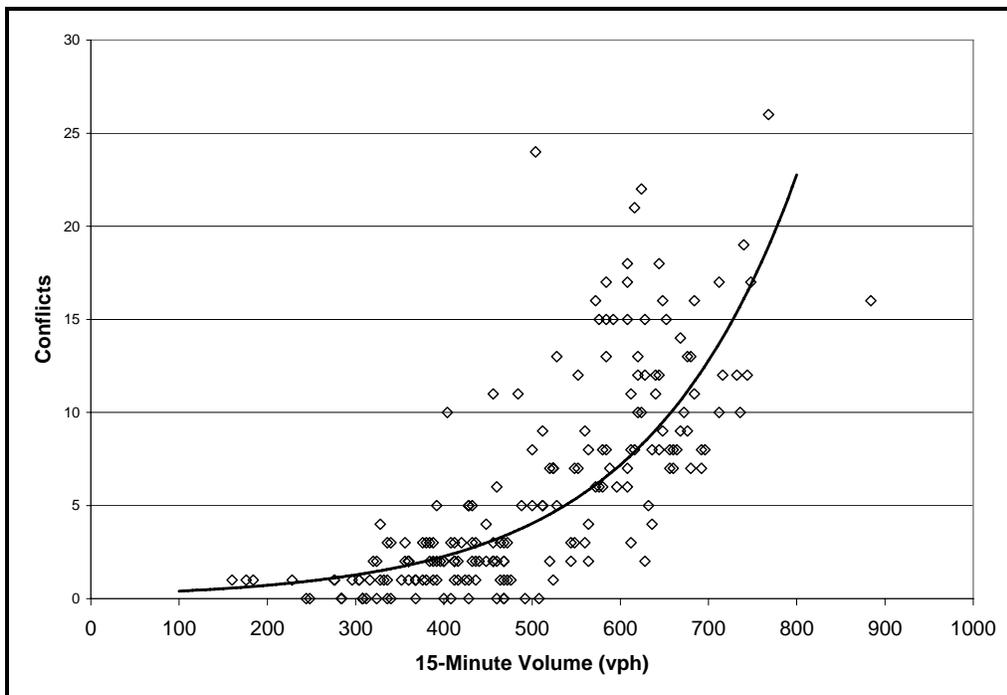
	Coefficient	Standard Error	t-Statistic	P-value
B <sub>0</sub>	-0.6460	0.0724	-8.9221	> 0.0001
B <sub>1</sub>	0.0025	0.0001	18.2853	> 0.0001
B <sub>2</sub>	0.6443	0.2417	2.6664	0.0082
B <sub>3</sub>	-0.0012	0.0004	-2.9498	0.0035

When equation 3 was plotted through the observed conflicts for the two right-lane closure locations it can be seen that the equations fit the datasets well, as shown in Figures 24 and 25. When the two equations were plotted together in Figure 26 it can be shown that when the traffic volumes are below about 550 vph there is little difference in the number of observed conflicts. However, as the volume rises above 550 vph the location without the STATE LAW MERGE NOW signing experienced a much higher increase in observed conflicts, while the site that had the signing had a smaller number. There appears to be a relationship then, between the presence of the early merge signing and the number of observed conflicts when traffic volumes exceed 550 vph.

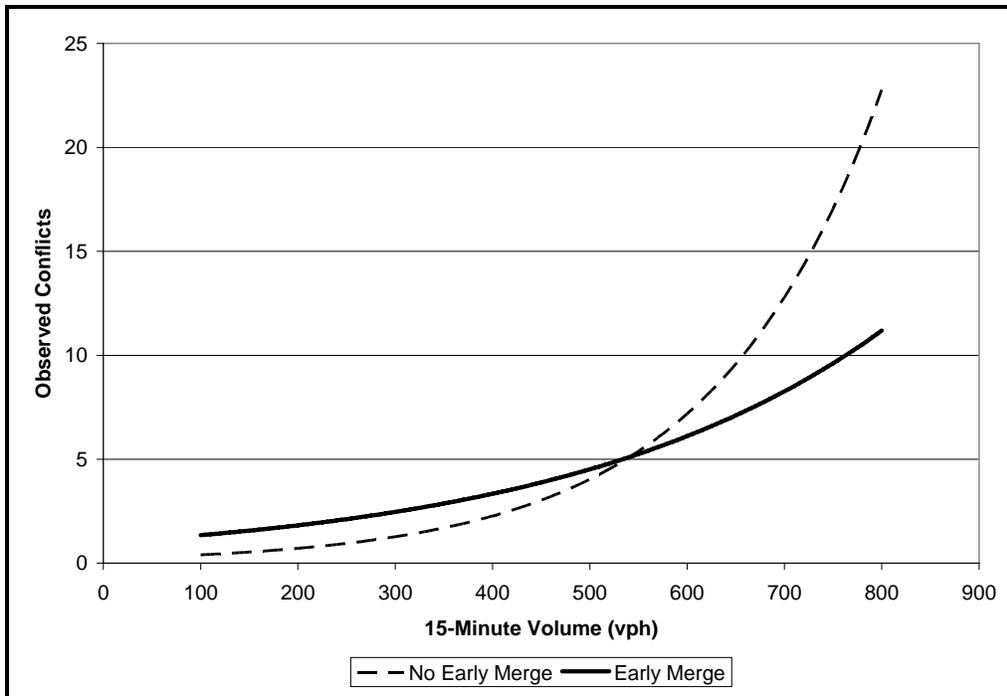
A discussion of the findings and future work is presented in the next chapter.



**FIGURE 24 Merge area conflicts when the right lane was closed and the early merge signing present with regression line shown (location: Weatherford, Oklahoma).**



**FIGURE 25 Merge area conflicts when the right lane was closed and the early merge signing not present with regression line shown (location: Blackwell, Oklahoma).**



**FIGURE 26 Comparison of regression models of conflicts versus volume for right-lane closures.**



## 6. FINDINGS AND DISCUSSION OF FUTURE RESEARCH

The following findings were found as a result of this research:

- The STATE LAW MERGE NOW signing in place at work zones in Oklahoma does not appear to reduce the percentage of vehicles that remain in the closed lane. In fact, the percentage of vehicles that remained in the closed lane for a given merge setup was actually higher at the work zones that had the signing than those that did not. This is not to say that the signs themselves had no effect, but simply that no beneficial relationship was observed. It is possible that some other factor may have obscured any benefit.
- At least for right-lane closures, there appeared to be a significant benefit to using the STATE LAW MERGE NOW signing to reduce the number of observed conflicts at the merge point. This was evident when the hourly volumes were more than 550 vph.

It is possible then that although the signs themselves do not promote legal compliance by getting drivers out of the lane to be closed before then reach the merge point, it is possible that the signs still have a benefit. The sign may encourage drivers to begin considering how they will make their merge maneuver, so that by the time the merge point is reached the drivers that must merge are more likely to be able to make the merge without the need to vie for position against other drivers. If this finding can be extended to other work zone locations the use of early merge signs of this type could have a benefit for the driving public.

### FUTURE RESEARCH NEEDS

There were several unanswered questions that remain after concluding this research. First, the El Reno location provided very low traffic volumes compared to the other study locations, and so a lack of a suitable location for the left-lane closure without the STATE LAW MERGE NOW signing limited the analysis of left lane closures. It would be interesting to see if the conflict analysis findings of the right-lane closures can be extended to left-lane closures.

Second, in order to provide an improved confidence in the results there is a need to collect additional data, preferably from a large number of work zone locations. This would alleviate any concerns that there were some site-specific factors that were not considered in this research that may have impacted the results in some way.

Third, it would be useful to study the placement of these signs. Currently, ODOT requirements are to place these signs about 1/2- mile from the merge point. It would be interesting to know if different sign placement could result in different driver behaviors. Naturally, as this would require cooperation with whatever department of transportation has jurisdiction of the work zone, this approach would require increased planning and cooperation.



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