Evaluation of Work Zone Split Traffic Symbol Sign

Final Report
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16. Abstract

Effective signage that is easily understood facilitates safe driving through a work zone. While the guidance for work zone signage in the Manual on Uniform Traffic Control Devices (MUTCD) is suitable for many conditions, there may be instances where alternative signage may be more effective at enhancing safety. This project evaluated the use of alternative signage for closure of a middle lane in a freeway work zone on a bridge rehabilitation project on I-170 in St. Louis, Missouri. The alternative signage displays the lane arrangement in a single sign, while the MUTCD recommends using two signs to direct the movements to the left and the right sides of the work area. The evaluation of the alternative signage included stakeholder and driver surveys, operational and safety analyses, and the collection and analysis of field videos to assess driver behavior.

The analysis of field videos showed that drivers may have adapted to the alternative signs because the rate of lane changes decreased between the early and late periods of construction. Stakeholder interviews found that personnel from the Missouri Department of Transportation (MoDOT) and the contractor generally thought that the alternative sign communicated information more clearly but had mixed opinions on whether the use of the sign improved safety. Drivers did not express any concerns regarding the use of the alternative sign through a website that collects feedback on MoDOT work zones. A review of crash data found that crash patterns during the work zone period were similar to the crash patterns before the work zone was in place, and the use of the alternative sign did not appear to be a contributing factor in any work zone crashes. Analysis of Regional Integrated Transportation Information System (RITIS) traffic data found that use of the alternative sign did not have an impact on travel times in the vicinity of the work zone. Overall, the evaluation found that the alternative sign communicates information clearly and does not cause any adverse impacts to work zone safety and operations.

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EXECUTIVE SUMMARY

Effective signage that is easily understood facilitates safe driving through a work zone. The Manual on Uniform Traffic Control Devices (MUTCD) (FHWA 2009) provides guidance on signage for temporary traffic control (TTC) in work zones. While the MUTCD guidance is suitable for many conditions, there may be instances where alternative signage may be more effective at enhancing safety.

In this project, the use of alternative signage for closure of a middle lane in a freeway work zone was evaluated based on its implementation at a work zone for a Missouri bridge rehabilitation project on I-170 near I-70 in December 2016. The work zone activity called for the shifting of three lanes, two lanes around one side and one lane around the other side of the work area. MUTCD signs W1-4 and W1-4b are shown in Figure ES.1, while the alternative sign tested in this study is shown in Figure ES.2. The alternative signage presented in Figure ES.2 displays the lane arrangement in a single sign.

FHWA 2009

Figure ES.1. Horizontal alignment warning signs from MUTCD Section 6F

Figure ES.2. Alternative warning signs evaluated in this project

The evaluation included the following components:

- Collection and analysis of field videos to assess driver behavior
- Stakeholder interviews with Missouri Department of Transportation (MoDOT) personnel and contractors to understand their perception of the alternative signage
- Investigation of driver responses on MoDOT’s “Rate Our Work Zones” website
- Collection and analysis of crash data for the work zone period and the time period before the work zone was implemented

- Collection and processing of the Regional Integrated Transportation Information System (RITIS) travel time data to investigate operational impacts.

Both stationary and drive-through videos were collected from the work zone for 20 analysis periods based on the stage of construction (early or late construction), direction (northbound or southbound), and time of day (a.m. peak, p.m. peak, nighttime, weekday midday, and weekend midday). As determined from the drive-through videos, the average distance at which the sign became visible was around 1,637 ft in the northbound direction and around 1,043 ft in the southbound direction. These distances were based on a travel speed of 45 mph at the speed limit and travel times of 24.8 seconds in the northbound direction and 15.8 seconds in the southbound direction. These lead times indicate that the sign was sufficiently visible to drivers.

Stationary videos for four views from three camera locations in the work zone were recorded, and the videos from two of these views were processed manually to obtain data regarding traffic counts, lane changes, and unusual driver behavior. It was not necessary to process the videos from the other two views. Traffic counts by lane for each analysis period were generated from the analysis of the two videos. A total of 32,350 vehicles were counted during the 20 analysis periods. The flow rates for the a.m. and p.m. peaks were approximately 30 to 40 percent higher than the flow rates during midday on a weekday. The nighttime flow rates were generally the lowest, although the weekend flow rates were lowest for the northbound late construction period. The middle lane had the highest traffic counts for most of the analysis periods.

Lane changes over the 20 analysis periods were also processed from the videos. The results show that most lane changing activity occurred between the outside and middle lanes. The gore point was also located between the outside and middle lanes. Thus, the majority of the lane changing activity occurred at the gore point location. In addition, the average lane change rate generally decreased between the early and late construction periods. The percentage of vehicles starting in the outside lane before the work zone that remained in the outside lane increased from 73.8 percent in the early construction period to 85.7 percent in the late construction period. The decrease in lane changing activity during the later stages of construction may be due to drivers becoming more familiar with the work zone layout and signage as construction progressed. On average, vehicles changed lanes 8.32 seconds after the split sign and 7.97 seconds before the gore point. The locations of the lane changes relative to the split sign and gore point remained unchanged throughout the period of time when the split sign was in place.

Some unusual driver behavior was observed in the videos, including aggressive lane changes before and at the beginning of the gore point, vehicles driving across the lane closure area, and vehicles being stranded in the gore. The unusual driver behavior generally appeared to be related to aggressive driving and not to the presence of the alternative sign.

The general consensus of the MoDOT personnel and contractors who participated in the stakeholder interviews was that the alternative sign was a positive option because it communicated information more clearly than the MUTCD signs. However, the respondents had different perceptions on the impacts of the sign on work zone safety for drivers and construction workers. Some respondents thought the alternative sign improved safety while others indicated that the safety level was the same because they did not think that drivers pay attention to the signs. Respondents did not think that the use of the alternative sign had any effect on work zone delays. The interviewees, both MODOT and contractor staff, were generally positive in their assessment of the alternative sign.

The survey responses from MoDOT's "Rate our Work Zones" survey were reviewed to determine if drivers gave any feedback regarding the use of the alternative signs. Drivers who completed the survey did not express any concerns regarding the use of the new split signs on the I-170 project.

Crash data from 2015 and 2016 were reviewed to assess possible safety impacts of the use of the alternative signage. A total of 265 crashes occurred in 2015 and 2016 on this section of I-170 between I-70 and St. Charles Rock Road. The most common types of crashes were rear-end, out of control, and passing crashes. The number of crashes generally decreased from 2015 to 2016, and there were 13 crashes on this section of I-170 while the work zone was in place. The crash patterns during the work zone period were similar to the crash patterns before the work zone was in place. Almost all of the crashes during the work zone period were due to lane changing, passing, or rear-end collisions, although there was one crash caused by a vehicle losing control. A detailed review of the crash reports found that the use of the alternative sign did not appear to be a contributing factor to any of these crashes.

Travel time data from RITIS were processed to assess any operational impacts due to the use of the alternative sign. Travel time analysis was conducted on the I-170 work zone segment and in the vicinity of the work zone segment, including sections of I-170 upstream and downstream from the work zone and adjacent routes (I-70 and Natural Bridge Road). The analysis compared travel times during the period the alternative sign was in place (October 27, 2016 to November 16, 2016) with the time period from one year earlier. The results showed that there were no significant travel time differences between the two time periods. Thus, the use of the alternative sign did not have any adverse impacts on operations in the vicinity of the work zone.

The investigation of the use of the alternative sign on the I-170 project found that the alternative sign has great potential for use on freeway work zones with lane closures in the middle lane. The stakeholders believed that it communicated information more effectively to drivers, and the use of the sign did not appear to create any adverse impacts on operations or safety.

CHAPTER 1. INTRODUCTION

1.1 Motivation

The Manual on Uniform Traffic Control Devices (MUTCD) (FHWA 2009) provides guidance on signage for temporary traffic control (TTC) in work zones. While the MUTCD guidance is suitable for many conditions, there may be instances where alternative signage may be more effective at enhancing safety. For example, consider the signage for a single freeway lane closure at the taper of a work zone. Section 6F.24 in the MUTCD (FHWA 2009) recommends the option of using a graphical lane closed sign, W4-2, while the Missouri Department of Transportation (MoDOT) uses alternative signage consisting of a MERGE/arrow sign on the closed-lane side and a RIGHT LANE CLOSED sign on the other side. A recent field study conducted by Edara and Sun (2014) found that MoDOT's alternative signage was more effective than the MUTCD signage with 11 percent more vehicles merging earlier into the open lane.

This project investigated the effectiveness of alternative signage for closure of a middle lane on a freeway. This research was performed at the work zone for the Missouri bridge rehabilitation project J6I2104 on I-70 at I-170. For this work zone, MoDOT used alternatives to the MUTCD W1-4 and W1-4b signs. The project, located in the St. Louis District, involved shifting three lanes, two lanes around one side and one lane around the other side of the work area. One concern with the standard MUTCD signage is that the traveling public must process both signs at the same time to understand how many lanes are available to travel around the work area. If drivers miss one sign due to vehicles blocking the view, they may think they have only one option and may make an aggressive lane shift to move into a perceived open lane instead of continuing in their original lane. The single alternative sign would inform the driver of all available lanes around the work area.

The primary objective of this project was to assess how well drivers responded to the alternative warning signs. The performance was measured qualitatively via surveys and interviews of users, contractors, and MoDOT personnel and quantitatively by using video monitoring, crash analysis, and travel time analysis.

1.2 Overview of MUTCD Guidance on Warning Signs

Section 6F.16 of the MUTCD (FHWA 2009) provides guidance on the function, design, and application of warning signs in TTC zones. Warning signs notify users of specific situations or conditions on or adjacent to a roadway that might not otherwise be apparent. W1-4 and W1-4b (see Figure 1.1) are part of this family of warning signs directing traffic through work zones.

FHWA 2009

Figure 1.1. Horizontal alignment warning signs from MUTCD Section 6F

W1-4b contains an upward-pointing black arrow that slants diagonally up and to the right and then straightens to a vertical direction. W1-4 shows two side-by-side upward-pointing black arrows that slant diagonally up and to the left and then straighten to a vertical direction. The combination of W1-4 and W1-4b notifies travelers that three contiguous lanes are being split into separate single lane (lane 1) and dual lanes (lanes 2 and 3). Alternately, the lane split can occur between lanes 2 and 3 into separate dual lanes (lanes 1 and 2) and single lane (lane 3).

As shown in Figure 1.1, drivers must notice both signs to understand that three lanes are open. If the drivers miss one of the two signs, they may incorrectly assume only one or only two lanes are open. The alternative signage presented in Figure 1.2.a eliminates that confusion by displaying the lane arrangement in a single sign. The optional sign in Figure 1.2.b can be placed at the end of work area when the lanes revert back to their original configuration.

Figure 1.2.a. Alternative warning sign evaluated in this project

Figure 1.2.b. Optional alternative warning sign

1.3 Overview of I-170 Work Zone

A work zone located on I-170 south of I-70 was selected as an ideal field site for investigating the use of the alternative warning signs. Figure 1.3 illustrates the general location of the work zone split traffic symbol sign project relative to the surrounding area.

Imagery © 2016 Google Map data © 2016 Google

Figure 1.3. Work zone site location map

The work zone was part of MoDOT project J6I2104, which included 12 bridge rehabilitations at the interchange of I-70 and I-170. The work zone began on November 30, 2016 and ended on December 31, 2016.

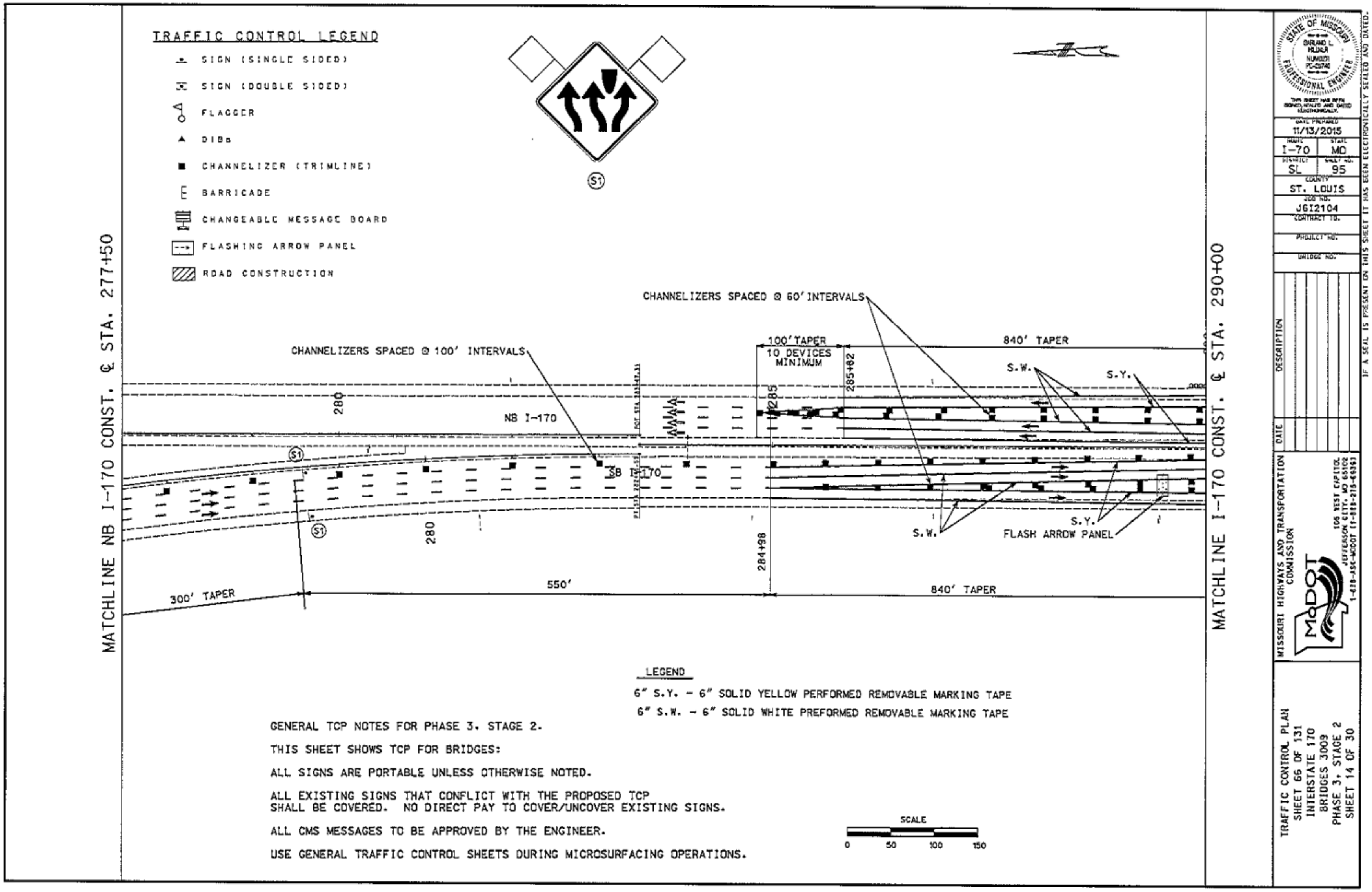
The work zone was divided into three stages, with the alternative split signs in use during the second stage. As shown in the construction schedule in Table 1.1, the southbound work zone split sign was posted December 7, 2016 and the northbound split sign was posted December 10, 2016.

Table 1.1. Work zone split sign (Stage 2) construction schedule for December 2016

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Dec 4	Dec 5	Dec 6	Dec 7 SB Day 1	Dec 8 SB Day 2	Dec 9 SB Day 3	Dec 10 SB Day 4 NB Day 1
Dec 11 SB Day 5 NB Day 2	Dec 12 SB Day 6 NB Day 3	Dec 13 SB Day 7 NB Day 4	Dec 14 SB Day 8 NB Day 5	Dec 15 SB Day 9 NB Day 6	Dec 16 SB Day 10 NB Day 7	Dec 17 SB Day 11 NB Day 8
Dec 18 SB Day 12 NB Day 9	Dec 19 SB Day 13 NB Day 10	Dec 20 SB Day 14 NB Day 11	Dec 21 SB Day 15 NB Day 12	Dec 22	Dec 23	Dec 24

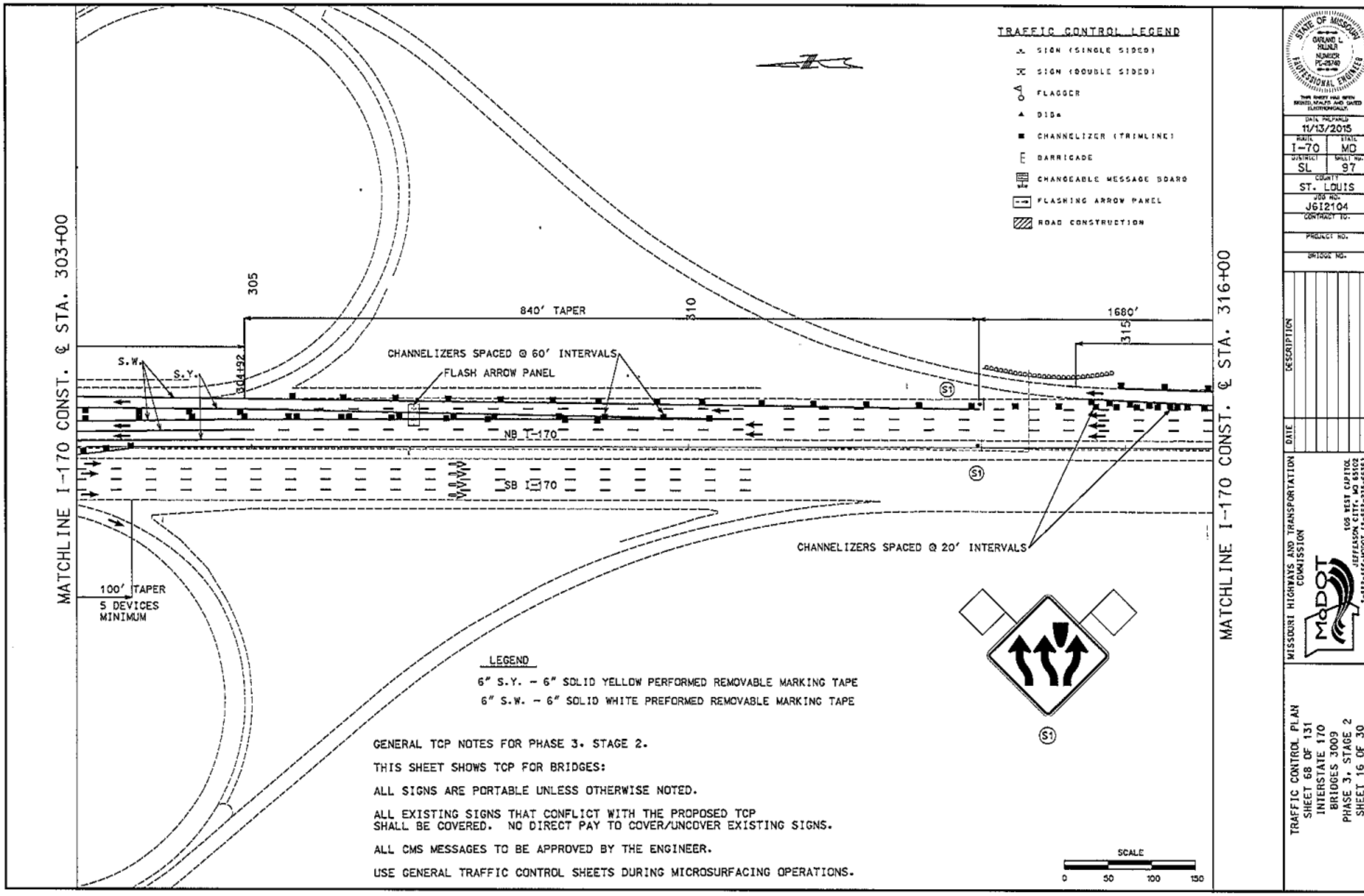
Both signs were removed on December 21, 2016. During the second stage of the project, one lane of traffic (lane 3) shifted to the right while two lanes of traffic (lanes 1 and 2) shifted to the left.

Figures 1.4 and 1.5 are sheets from the project traffic control plans that show the layout of the signage and markings in the split area. As shown in the figures, channelizers, white and yellow preformed removable marking tape, and an arrow board were used along with the split sign to delineate the vehicle paths for each lane.



MoDOT 2015a

Figure 1.4. Traffic control plan and signage for southbound I-170



MoDOT 2015a

Figure 1.5. Traffic control plan and signage for northbound I-170

The split sign was placed in advance of the gore point (Figure 1.6), while an arrow board was placed near the split itself in the northbound direction (Figure 1.7).

Figure 1.6. Work zone split sign on northbound I-170

Figure 1.7. Gore point on northbound I-170

In the field deployment, the optional sign shown in Figure 1.2.b was not utilized. The lanes tapered over a length of 840 ft at the beginning of the split.

1.4 Methodology Overview

Both qualitative and quantitative measures were used to evaluate the effectiveness of the alternative signs. The methods used for the assessment are as follows:

- Collection and analysis of drive-through videos to understand the driver's perspective and evaluate sign visibility
- Collection and processing of stationary videos to assess driver behavior
- Stakeholder interviews with contractor and MoDOT personnel to learn their views on the effectiveness of the signs
- Driver survey to obtain opinions about the signs' effectiveness from drivers who travelled through the work zone
- Analysis of crash data for the work zone period and time period prior to the work zone commencement
- Travel time analysis for the work zone period and time period prior to the work zone commencement

The rest of this report is as follows. Chapter 2 presents the methodology and results for the drive-through and stationary videos. The stakeholder interviews are discussed in Chapter 3, while the driver survey is described in Chapter 4. The crash data and travel time analyses are presented in Chapters 5 and 6, respectively. Chapter 7 includes the conclusions and summary of findings from the research.

CHAPTER 2. VIDEO DATA COLLECTION AND ANALYSIS

To help gain insights into driver behavior with the new signs, video data were collected and analyzed. The video data included both drive-through videos and stationary videos. The drive-through videos were used to help understand the driver's perspective of the signs and evaluate sign visibility. Stationary videos were analyzed to derive traffic counts and to evaluate driver behavior, including lane changes and unusual vehicle maneuvers.

2.1 Overview of Video Data

Video data of traffic entering the work zone area were collected during three separate video collection sessions: (1) prior to the placement of the split traffic symbol signs, (2) after the placement of the split traffic symbol signs when drivers were adapting to the new traffic patterns, and (3) before the removal of the split traffic symbol signs when drivers had adapted to the work zone traffic patterns.

During each of the video collection sessions, data were collected during five different traffic periods to capture driver behavior during diverse traffic conditions. The data collection periods were typically as follows:

1. Weekday a.m. commute period (7:00 to 9:00 a.m.)
2. Weekday midday commute period (11:00 to 1:00 p.m.)
3. Weekday p.m. commute period (4:00 to 6:00 p.m.)
4. Weekday nighttime commute period (8:00 to 10:00 p.m.)
5. Weekend commute period (11:00 to 1:00 p.m.)

To make the best use of the data collection efforts, video recording time periods were chosen based on peak hour traffic times. The traffic volume during the one-hour-long recording time was estimated for each scenario, as shown in Table 2.1. As noted, it was anticipated that a 20 percent diversion of traffic off of I-170 was to be expected due to the disruption of traffic flow during construction.

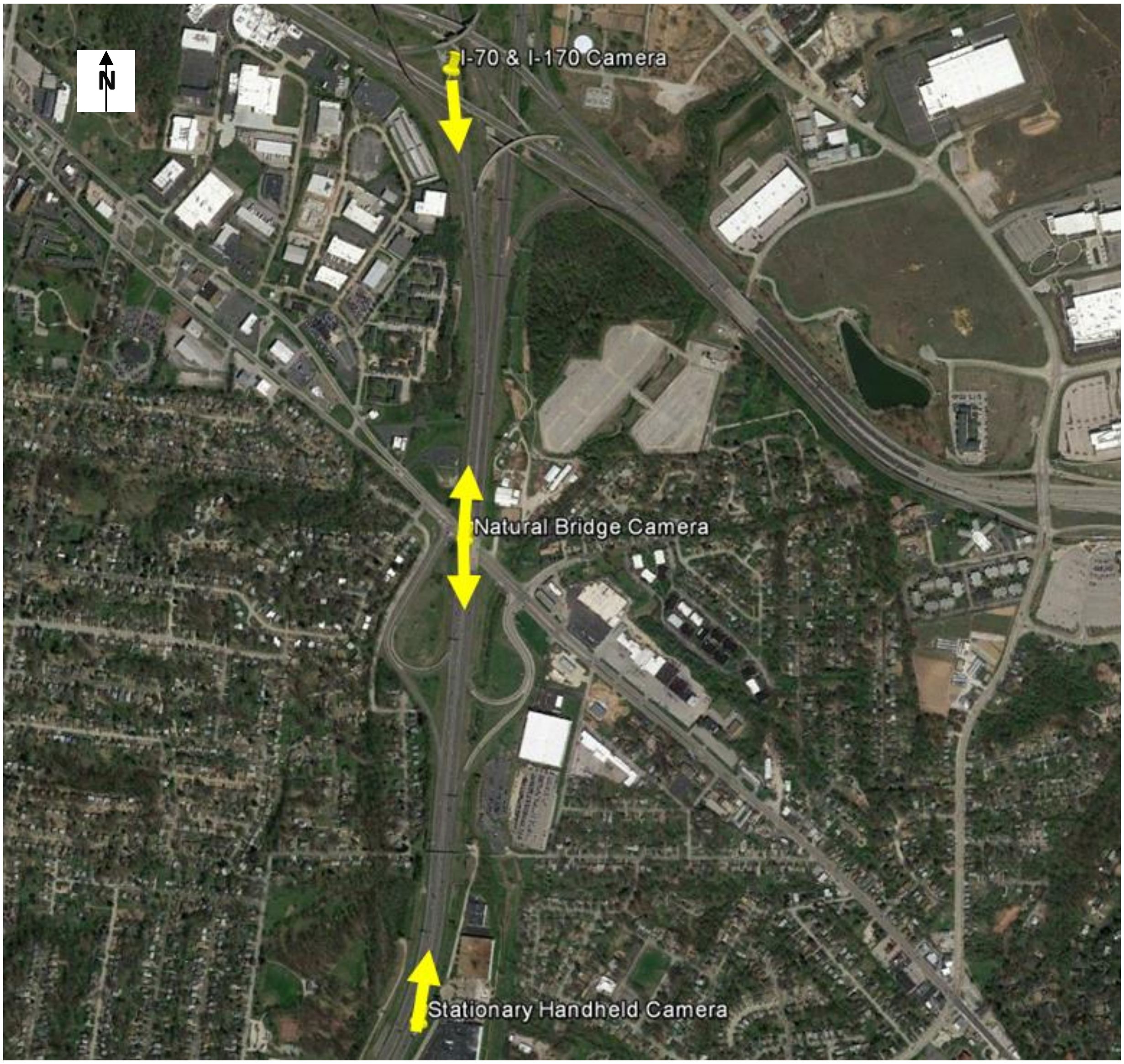
Table 2.1. Work zone split sign (Stage 2) data collection schedule

Scenario	Duration	Time	Day	Typical Hourly Volume	Expected Vehicle Capture*
northbound a.m.	1 Hour	7-8 a.m.	Tue-Thurs	5,192	4,154
northbound p.m.	1 Hour	4-5 p.m.	Tue-Thurs	6,099	4,879
northbound midday	1 Hour	12-1 p.m.	Tue-Thurs	3,543	2,834
northbound nighttime period	1 Hour	8-9 p.m.	Tue-Thurs	2,793	2,234
northbound weekend	1 Hour	12-1 p.m.	Sat-Sun	3,242	2,594
southbound a.m.	1 Hour	7-8 a.m.	Tue-Thurs	5,840	4,672
southbound p.m.	1 Hour	4-5 p.m.	Tue-Thurs	4,744	3,795
southbound midday	1 Hour	12-1 p.m.	Tue-Thurs	3,563	2,850
southbound nighttime period	1 Hour	8-9 p.m.	Tue-Thurs	2,175	1,740
southbound weekend	1 Hour	12-1 p.m.	Sat-Sun	3,417	2,734

*Note: Expected vehicle capture rate assumes 20% diversion of traffic off of I-170 during construction. Video data were collected prior to placement, post-placement, and before removal of work zone split traffic symbol signs for each scenario.

Two types of cameras were used for data collection. One type was the permanent MoDOT CCTV cameras and the other type was portable cameras deployed on tripods. Camera placements and fields of view were determined based on field topography and conditions, including side slopes, visual obstructions, and camera personnel safety. There were three camera/vantage points selected for data collection. One camera location showed views in both directions. Thus, there were a total of four camera views.

Two of the three camera locations used were the CCTV traffic cameras. Figure 2.1 illustrates the camera locations and viewpoints with respect to the video data collection.



Imagery © 2016 Google Map data © 2016 Google

Figure 2.1. Camera locations and views map

The far north camera (I-70 and I-170) was a MoDOT stationary camera used to record the southbound rear view of traffic entering the work zone. The middle camera (Natural Bridge Camera) was also a MoDOT stationary camera used to record the southbound front view and northbound front view of traffic entering the work zones. The far south camera was a portable camera located within MoDOT's right-of-way to record the northbound rear view of traffic entering the work zone. Existing preset settings of MoDOT CCTV cameras were used for recording; however, the handheld cameras required mounting setup. Also, all of the cameras used could record only one direction of travel at a time.

Screenshots from the four camera views are shown in Figures 2.2 through 2.5. The northbound back and southbound front views were used for the video analysis because they provided the best views of traffic approaching the work zone.

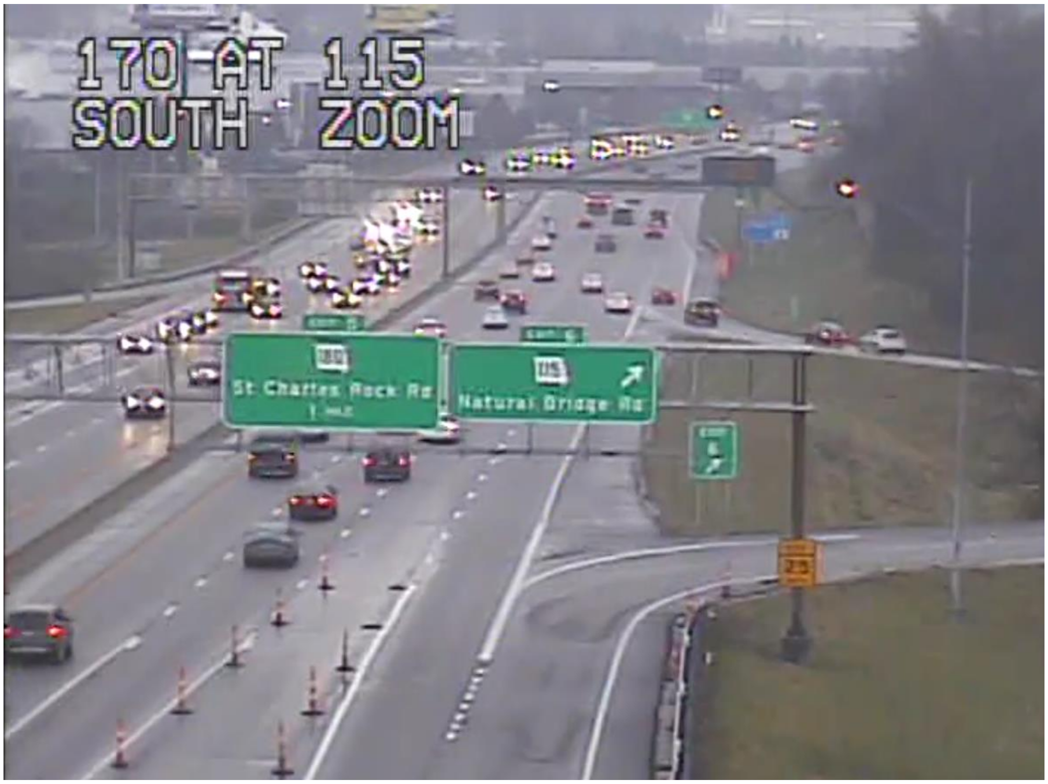


Figure 2.2. Screenshot of northbound front view stationary video

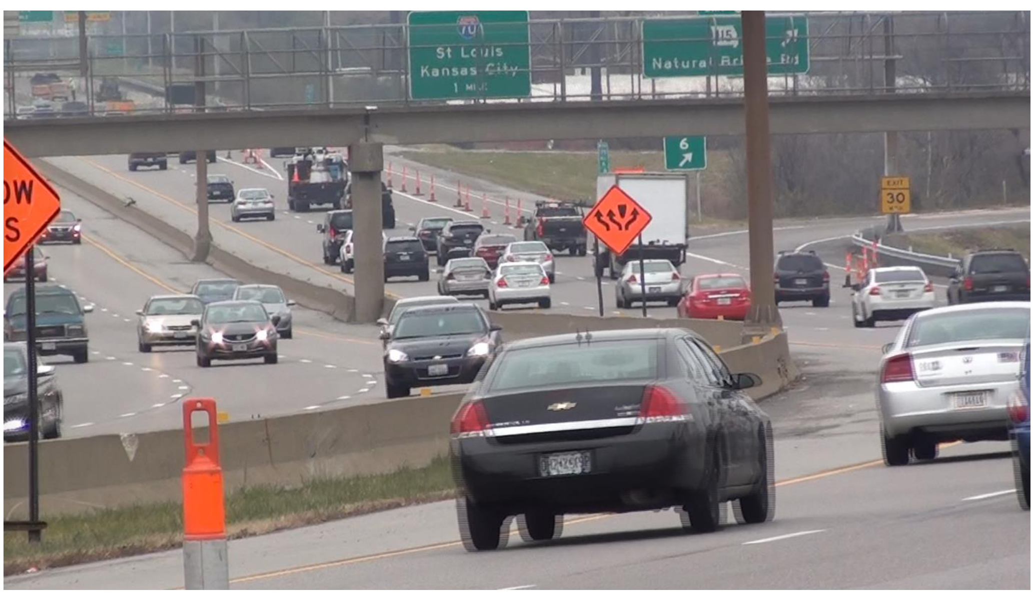


Figure 2.3. Screenshot of northbound back view stationary video

Figure 2.4. Screenshot of southbound front view stationary video

Figure 2.5. Screenshot of southbound back view stationary video

In addition to the stationary cameras, two cameras were mounted inside a test vehicle to capture views of drivers travelling through the work zone. A GoPro HERO5 Black 4K Ultra HD Action Camera was mounted to the center rear view mirror inside the vehicle to capture a side view of vehicles progressing through the work zone, and a handheld recording camera was mounted to the passenger seat to capture a driving view of vehicles progressing through the work zone. A minimum of two drive-through videos per scenario were captured. A total of 60 drive-through videos were collected during the earlier construction period, while 48 drive-through videos were collected during the later construction period. Sample screenshots for the videos can be seen in Figures 2.6 through 2.9.

Figure 2.6. Screenshot of front view northbound drive-through video

Figure 2.7. Screenshot of side view northbound drive-through video

Figure 2.8. Screenshot of front view southbound drive-through video

Figure 2.9. Screenshot of front view southbound drive-through video

2.2 Video Data Collection

The video data collection was completed in three separate sessions: pre-placement, post-placement, and before removal of the work zone split traffic symbol signs. The methods and activities undertaken for each session are described in the following sections.

2.2.1 Pre-placement of Signs Data Collection Session

Prior to the placement of the split traffic signs, video data were collected to capture a base record of drivers' natural behavior before the interruption in traffic movements during the abovementioned traffic periods. Data collection for the pre-placement session began November 30, 2016 and ended December 6, 2016.

During this session, approximately 20 hours of stationary video recordings and 47 drive-through video runs were collected. Figures 2.10, 2.11, and 2.12 show screenshot examples of videos collected during each data collection period in the northbound direction. The receding field of view shows the traffic traveling away from the camera.

Figure 2.10. Screenshots from northbound cameras before split sign placement (11/30/2016)

Figure 2.11. Screenshot from northbound camera before split sign placement (12/3/2016)

Figure 2.12. Screenshots from northbound cameras before split sign placement (12/6/2016)

Figure 2.13 shows screenshot examples of the drive-through camera views during the northbound a.m. peak commute period**.**

Figure 2.13. Screenshots from northbound drive-through cameras before split sign placement (12/6/2016)

2.2.2 Early Construction with Signs Data Collection Session

After placement of the split traffic signs, video data were collected to ascertain how drivers were adjusting to the new signs. Driver behavior, such as aggressive lane changes, erratic driving maneuvers, and/or significant speed variation, was noted. Data collection for this session began December 7, 2016 and ended December 14, 2016.

During this session, approximately 20 hours of stationary video recordings and 60 drive-through video runs were collected. Figures 2.14 and 2.15 are screenshot examples of traffic during each data collection period from the southbound direction camera position. The approaching field of view shows traffic traveling towards the camera.

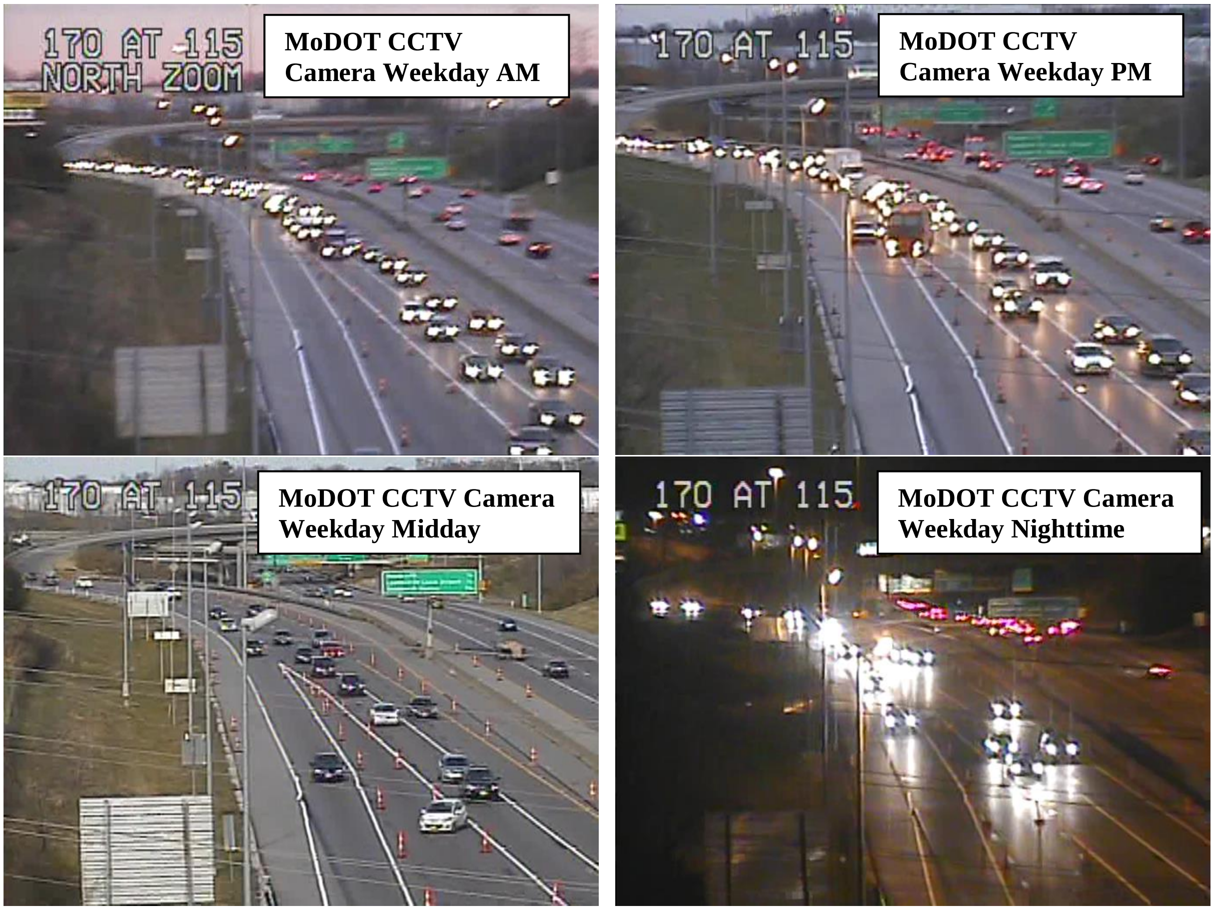


Figure 2.14. Screenshots from southbound cameras during early construction with split signs (12/7/2016)

Figure 2.15. Screenshots from southbound cameras during early construction with split signs (12/10/2016)

Figure 2.16 shows screenshot examples of the drive-through camera views during the southbound a.m. peak commute period.

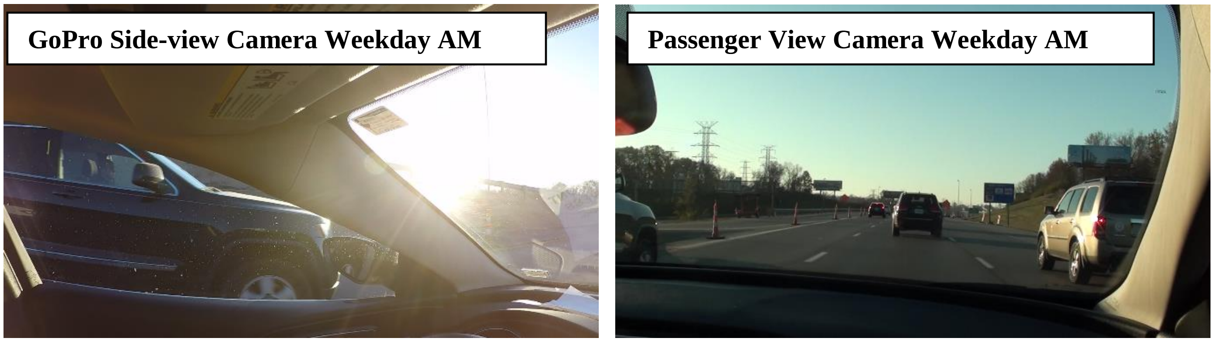


Figure 2.16. Screenshots from southbound drive-through cameras during early construction with split signs (12/8/2016)

2.2.3 Late Construction with Signs Data Collection Session

Before the removal of the split traffic signs, video data were collected to confirm whether drivers had adjusted to the interruption in traffic movements. Data collection for this session began December 11, 2016 and ended December 18, 2016.

During this session, approximately 21 hours of stationary video recordings and 48 drive-through video runs were collected. Figures 2.17 and 2.18 show screenshot examples of traffic during each data collection period from the northbound camera position. The receding field of view shows the traffic traveling away from the camera.

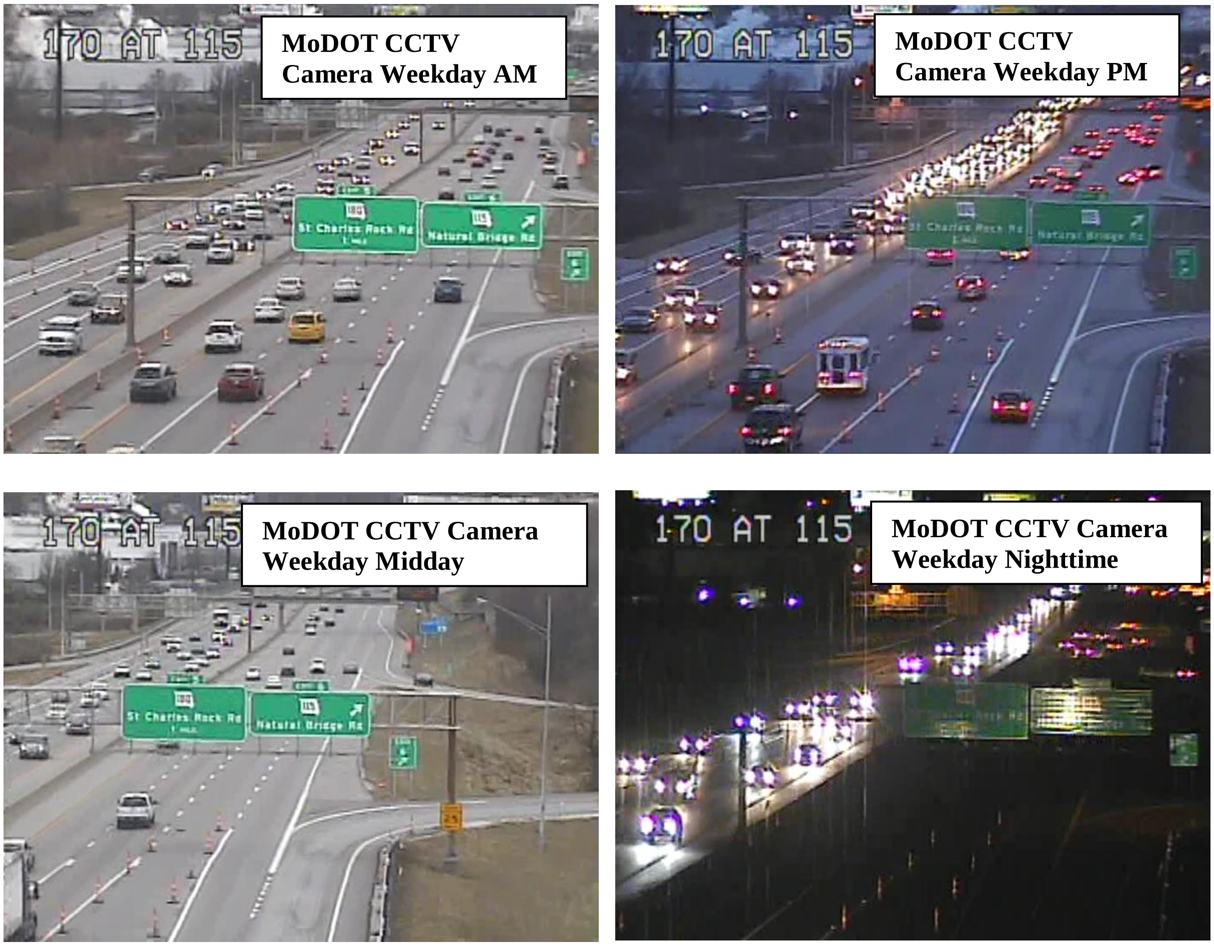


Figure 2.17. Screenshots from northbound cameras during late construction with split signs (12/15/2016)

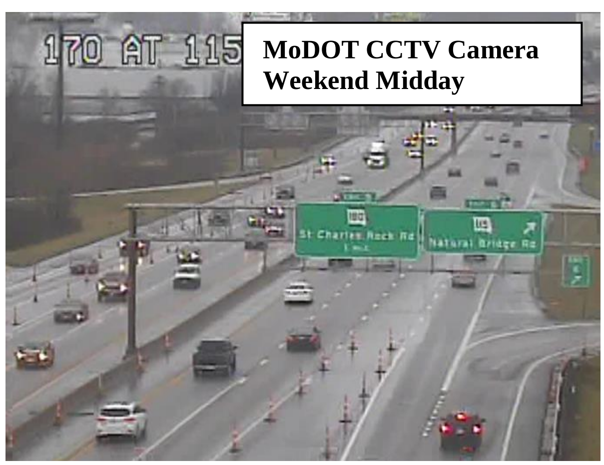


Figure 2.18. Screenshots from northbound cameras during late construction with split signs (12/17/2016)

Figure 2.19 shows screenshot examples of the drive-through camera views during a weekday evening.

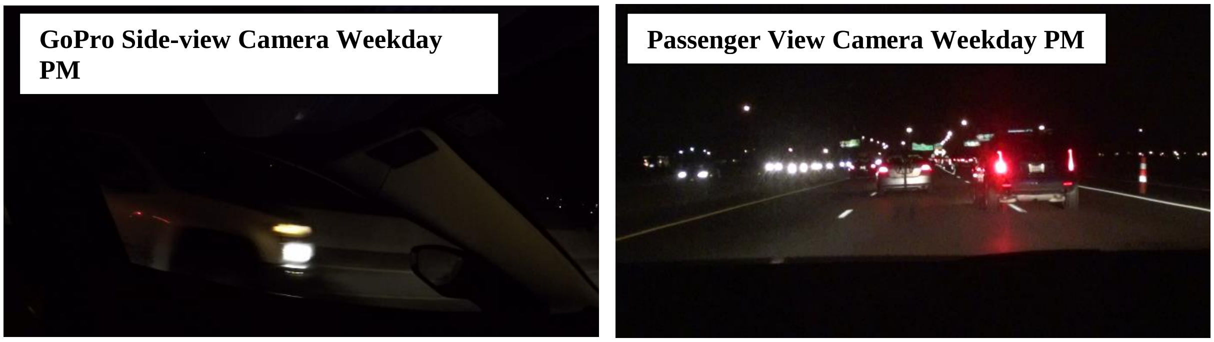


Figure 2.19. Screenshots from northbound drive-through cameras during late construction with split signs (12/15/2016)

2.3 Analysis of Video Data

Both the stationary and drive-through field videos were processed visually to generate traffic counts and assess how drivers reacted to the new signs. The evaluation of driver behavior included lane changes and aggressive driver maneuvers. In addition, the visibility of the signs was estimated from the drive-through videos.

2.3.1 Time Periods

Table 2.2 summarizes the time periods that were used for the analysis.

Table 2.2. Summary of video monitoring time periods used for analysis

Time Period ID	Direction	Construction Period	Traffic Period	Drive-Through Video Date	Stationary Video Date
1	NB	early	a.m. peak	12/13/16	12/13/16
2	NB	early	p.m. peak	12/13/16	12/13/16
3	NB	early	midday	12/14/16	12/13/16
4	NB	early	night	12/13/16	12/13/16
5	NB	early	weekend	12/11/16	12/11/16
6	SB	early	a.m. peak	12/9/16	12/7/16
7	SB	early	p.m. peak	12/8/16	12/7/16
8	SB	early	midday	12/9/16	12/7/16
9	SB	early	night	12/8/16	12/7/16
10	SB	early	weekend	12/11/16	12/10/16
11	NB	late	a.m. peak	12/15/16	12/15/16
12	NB	late	p.m. peak	12/15/16	12/14/16
13	NB	late	midday	12/15/16	12/15/16
14	NB	late	night	12/15/16	12/15/16
15	NB	late	weekend	12/18/16	12/18/18
16	SB	late	a.m. peak	12/13/16	12/13/16
17	SB	late	p.m. peak	12/13/16	12/13/16
18	SB	late	midday	12/14/16	12/13/16
19	SB	late	night	12/13/16	12/13/16
20	SB	late	weekend	12/18/16	12/11/16

These time periods account for two directions. In addition, driver behavior during the earlier and later stages of the work zone was analyzed separately to determine if drivers behaved differently after becoming familiar with the new work zone split signs.

2.3.2 Performance Measures

2.3.2.1 Performance Measures for Drive-Through Videos

The drive-through videos were used to understand the driver's perspective, observe any unusual driver behavior, and assess the visibility of the sign. The following time stamps were recorded from the front view videos: time stamp at which the split sign was first visible to the driver, time stamp when the vehicle passed the split sign, and time stamp when the vehicle passed the gore point. These time stamps were used to calculate the time headway for sign visibility and the travel time from the split sign to the gore nose. The time headway for sign visibility was calculated as the difference between the times when the vehicle passed the split sign and when the split sign first became visible. The travel time between the gore nose and split sign was calculated as the difference between the times when the vehicle passed the gore point and the split sign.

2.3.2.2 Performance Measures for Stationary Videos

Various performance measures were obtained through the visual processing of the stationary videos. These performance measures are as follows:

- Vehicle counts by lane
- Number of lane changes by initial and final lane
- Time headway between lane change location and split sign
- Time headway between lane change location and gore point

For each of the 20 video monitoring time periods, vehicle counts by lane were recorded in 5-minute intervals until a minimum of 1,500 vehicles were counted for each time period. Once 1,500 vehicles were counted, the traffic counts were completed for the current 5-minute interval. In addition, the following data were recorded for each lane change in advance of the work zone: initial lane position, final lane position, time stamp when lane changing vehicle passed the split sign, time stamp when the vehicle started to change lanes, and time stamp when the lane changing vehicle passed the gore point. These data were used to derive the total number of lane changes, their distribution by lane, and the location of the lane changes relative to the split sign and gore nose. The analysis period for the lane changing corresponded to the period of time for the vehicle counts.

In addition to these performance measures, any unusual driver behavior such as aggressive lane changes was noted for the time period during which the traffic counts were recorded. The time stamp for the unusual driver behavior was recorded, and screenshots were captured for each event.

2.4 Results of Video Data Analysis

2.4.1 Sign Visibility

The results for sign visibility and the travel time between the sign and the gore point based on the drive-through videos are shown in Table 2.3.

Table 2.3. Results for sign visibility from drive-through videos

	Time headway for sign visibility (s)	Travel time between sign and gore point (s)
	Northbound	
Average	24.8	17.2
Standard Deviation	4.0	2.2
Minimum	20.3	15.2
Maximum	35.0	24.1
Number of Observations	24	
	Southbound	
Average	15.8	8.6
Standard Deviation	4.2	3.3
Minimum	11.8	5.4
Maximum	31.7	21.3
Number of Observations	29	
	Overall	
Average	19.9	12.5
Standard Deviation	6.1	5.1
Minimum	11.8	5.4
Maximum	35.0	24.1
Number of Observations	53	

As shown in the table, the average time at which the sign became visible was 24.8 seconds in the northbound direction and 15.8 seconds in the southbound direction. Based on the work zone speed limit of 45 mph, these time headways correspond to distances of 1637 ft and 1043 ft, respectively. These results indicate that the sign was sufficiently visible to drivers considering the guidance provided by the US Sign Council (Bertucci 2006). The sign became visible earlier in the northbound direction than the southbound direction. This could be due to differences in sight distance or horizontal curvature. The average travel time between the split sign and gore point was 17.2 seconds in the northbound direction and 8.6 seconds in the southbound direction. The higher travel time for the northbound direction could be caused by differences in travel conditions during the time that the video was recorded or possible differences in where the sign was placed relative to the gore point.

2.4.2 Traffic Counts

Table 2.4 summarizes the results for the traffic flows derived from the counts in units of vehicles per hour (vph).

Table 2.4. Observed traffic flows

Time Period ID	Direction	Construction Period	Traffic Period	Duration of Counts (min)	Flow rate (vph)			
					Lane 3*	Lane 2*	Lane 1*	Total
1	NB	early	a.m. peak	25	1106	1310	1510	3926
2	NB	early	p.m. peak	25	1128	1399	1531	4058
3	NB	early	midday	33	710	1220	1028	2958
4	NB	early	night	45	499	1059	681	2239
5	NB	early	weekend	35	590	1089	914	2592
6	SB	early	a.m. peak	25	168	1687	1793	3648
7	SB	early	p.m. peak	25	418	1824	1560	3802
8	SB	early	midday	40	426	1559	884	2868
9	SB	early	night	55	193	981	464	1637
10	SB	early	weekend	35	490	1479	926	2895
11	NB	late	a.m. peak	20	1287	1590	1650	4527
12	NB	late	p.m. peak	20	1218	1896	1950	5064
13	NB	late	midday	33	765	1207	1115	3087
14	NB	late	night	30	764	1292	972	3028
15	NB	late	weekend	45	567	892	583	2041
16	SB	late	a.m. peak	25	1001	1570	1687	4258
17	SB	late	p.m. peak	25	691	1658	1502	3852
18	SB	late	midday	35	502	1406	941	2849
19	SB	late	night	62	273	777	353	1402
20	SB	late	weekend	40	381	1259	744	2384

* Note: Lane 1 adjacent to median, lane 2 middle, lane 3 adjacent to outside shoulder

The flow rates for the a.m. and p.m. peaks were approximately 30 to 40 percent higher than the flow rates during midday on a weekday. The nighttime flow rates were generally the lowest, although the weekend flow rates were lowest for the northbound late construction period. The middle lane had the highest traffic counts for most of the analysis periods. The high flow rates for all time periods confirm that I-170 is a busy urban freeway corridor.

2.4.3 Lane Changes

Table 2.5 summarizes the results for the number of lane changes per hour before the gore point by initial and final lane. Lane 1 is the median lane, lane 2 is the middle lane, and lane 3 is the outside lane.

Table 2.5. Observed lane changes before gore point

Time Period ID	Direction	Construction Period	Traffic Period	Rate of Lane Changes Per Hour (veh/hr) (Initial Lane – Final Lane) 3 - 2*	3 - 1*	2 - 3*	2 - 1*	1 - 3*	1 - 2*	Lane Changes (veh/hr)
1	NB	early	a.m. peak	137	0	180	77	2	89	485
2	NB	early	p.m. peak	115	2	79	34	14	36	281
3	NB	early	midday	90	12	107	86	14	47	355
4	NB	early	night	131	0	99	59	0	56	344
5	NB	early	weekend	213	0	177	115	0	75	579
6	SB	early	a.m. peak	149	0	38	48	0	24	259
7	SB	early	p.m. peak	182	0	110	84	0	12	389
8	SB	early	midday	215	0	71	86	0	15	386
9	SB	early	night	68	0	58	20	0	13	158
10	SB	early	weekend	199	0	51	48	0	22	321
11	NB	late	a.m. peak	54	0	99	117	0	114	384
12	NB	late	p.m. peak	39	0	45	33	0	81	198
13	NB	late	midday	56	0	78	107	0	78	319
14	NB	late	night	112	0	102	62	0	52	328
15	NB	late	weekend	73	0	112	99	0	41	325
16	SB	late	a.m. peak	86	2	26	5	7	2	130
17	SB	late	p.m. peak	216	0	79	43	0	14	353
18	SB	late	midday	178	9	45	3	0	5	240
19	SB	late	night	72	0	18	1	0	0	91
20	SB	late	weekend	170	0	50	15	5	6	245
Average (Early Construction)				**150**	**1**	**97**	**65**	**3**	**39**	**356**
Standard Deviation (Early Construction)				**51**	**4**	**49**	**29**	**6**	**27**	**117**
Average (Late Construction)				**106**	**1**	**65**	**49**	**1**	**39**	**261**
Standard Deviation (Late Construction)				**61**	**3**	**33**	**45**	**3**	**41**	**98**
Average (All Time Periods)				**128**	**1**	**81**	**57**	**2**	**39**	**308**
Standard Deviation (All Time Periods)				**59**	**3**	**44**	**38**	**4**	**34**	**116**

* Note: Lane 1 adjacent to median, lane 2 middle, lane 3 adjacent to outside shoulder

The results show that most lane changing activity occurred between the outside and middle lanes. The gore point was also located between the outside and middle lane. Therefore, the majority of the lane changing activity occurred where the gore point was located. Frequent lane changes also occurred between the middle lane and the median lane. In addition, the average lane change rate generally decreased between the early construction period and the late construction period.

To further investigate differences in lane changing activity during the early and late construction periods, the difference in lane change rate was calculated for each combination of initial and final lane, direction, and time of day. The results for this analysis are shown in Table 2.6.

Table 2.6. Percent change in lane change rate by time period

Direction	Traffic Period	Percent Change in Lane Change Rate**					
		3 - 2*	**3 - 1***	**2 - 3***	**2 - 1***	**1 - 3***	**1 – 2***
NB	a.m. peak	-60.5	***	-45.0	52.3	-100.0	28.4
NB	p.m. peak	-66.1	-100.0	-43.2	-1.8	-100.0	125.0
NB	midday	-37.3	-100.0	-27.3	24.8	-100.0	66.7
NB	night	-15.8	***	3.4	5.7	***	-7.1
NB	weekend	-65.5	***	-36.6	-14.1	***	-45.2
SB	a.m. peak	-41.9	***	-31.3	-90.0	***	-90.0
SB	p.m. peak	18.4	***	-28.3	-48.6	***	20.0
SB	midday	-16.9	***	-36.8	-96.0	***	-65.7
SB	night	6.6	***	-69.7	-95.0	***	-100.0
SB	weekend	-14.8	***	-3.7	-68.8	***	-73.1
All Time Periods		-29.5	-22.1	-32.7	-25.9	-61.6	1.2

* Note: Lane 1 adjacent to median, lane 2 middle, lane 3 adjacent to outside shoulder
** Note: Negative value indicates decrease from early construction to late construction
*** Note: No lane changes in early construction period

In comparing the late construction time period to the early construction time period, it can be seen that the rate of lane changing from the outside lane to the middle lane decreased for all time periods except for the southbound p.m. peak and nighttime periods. The rate of lane changing from the middle lane to the outside lane also decreased for all time periods except for the northbound nighttime period. Lane changes between the middle and median lanes also generally decreased during the latter stages of construction although they increased during the northbound a.m. peak and daytime periods.

Tables 2.5 and 2.6 show that the lane changing activity generally decreased toward the end of the time period when the work zone was in place. This result may be due to drivers becoming more familiar with the work zone layout and signage as construction progressed.

Table 2.7 shows the distribution of lane changes for each time period.

Table 2.7. Distribution of lane changes by time period

Time Period ID	Direction	Construction Period	Traffic Period	Total No. of Lane Changes	Duration (min)	Percent of Total Lane Changes (Initial Lane – Final Lane) 3-2*	3-1*	2-3*	2-1*	1-3*	1–2*
1	NB	early	a.m. peak	202	25	28.2	0.0	37.1	15.8	0.5	18.3
2	NB	early	p.m. peak	117	25	41.0	0.9	28.2	12.0	5.1	12.8
3	NB	early	midday	182	31	25.3	3.3	30.2	24.2	3.8	13.2
4	NB	early	night	258	45	38.0	0.0	28.7	17.1	0.0	16.3
5	NB	early	weekend	338	35	36.7	0.0	30.5	19.8	0.0	13.0
6	SB	early	a.m. peak	108	25	57.4	0.0	14.8	18.5	0.0	9.3
7	SB	early	p.m. peak	162	25	46.9	0.0	28.4	21.6	0.0	3.1
8	SB	early	midday	257	40	55.6	0.0	18.3	22.2	0.0	3.9
9	SB	early	night	145	55	42.8	0.0	36.6	12.4	0.0	8.3
10	SB	early	weekend	187	35	62.0	0.0	16.0	15.0	0.0	7.0
11	NB	late	a.m. peak	128	20	14.1	0.0	25.8	30.5	0.0	29.7
12	NB	late	p.m. peak	66	20	19.7	0.0	22.7	16.7	0.0	40.9
13	NB	late	midday	176	33	17.6	0.0	24.4	33.5	0.0	24.4
14	NB	late	night	164	30	34.1	0.0	31.1	18.9	0.0	15.9
15	NB	late	weekend	244	45	22.5	0.0	34.4	30.3	0.0	12.7
16	SB	late	a.m. peak	54	25	66.7	1.9	20.4	3.7	5.6	1.9
17	SB	late	p.m. peak	147	25	61.2	0.0	22.4	12.2	0.0	4.1
18	SB	late	midday	140	35	74.3	3.6	18.6	1.4	0.0	2.1
19	SB	late	night	93	62	79.6	0.0	19.4	1.1	0.0	0.0
20	SB	late	weekend	163	40	69.3	0.0	20.2	6.1	1.8	2.5
Early Construction Time Periods				**1956**	**341**	**42.1**	**0.4**	**27.3**	**18.4**	**0.9**	**10.9**
Late Construction Time Periods				**1375**	**335**	**40.5**	**0.4**	**25.0**	**18.6**	**0.4**	**15.1**
All Time Periods				**3331**	**675**	**41.4**	**0.4**	**26.3**	**18.5**	**0.7**	**12.7**

* Note: Lane 1 adjacent to median, lane 2 middle, lane 3 adjacent to outside shoulder

These results again show that lane changes predominantly occurred between the outside and middle lanes. Approximately 40 percent of the lane changes were from the outside lane to the middle lane during both the early construction and late construction time periods, while approximately 25 percent of the lane changes were from the middle lane to the outside lane. An additional 30 percent of the lane changes were between the median and middle lanes. Relatively few lane changes of more than one lane occurred.

The distribution of vehicles by initial and final lane is provided in Table 2.8.

Table 2.8. Distribution of vehicles by initial and final lane

				Percent of Vehicles by Initial and Final Lane								
				Initial Lane 3*			Initial Lane 2*			Initial Lane 1*		
				Final Lane			Final Lane			Final Lane		
Time Period ID	**Direction**	**Construction Period**	**Traffic Period**	**3***	**2***	**1***	**3***	**2***	**1***	**3***	**2***	**1***
1	NB	early	a.m. peak	87.6	12.4	0.0	13.7	80.4	5.9	0.2	5.9	94.0
2	NB	early	p.m. peak	89.6	10.2	0.2	5.7	91.9	2.4	0.9	2.4	96.7
3	NB	early	midday	86.6	11.9	1.6	8.3	85.1	6.6	1.3	4.3	94.5
4	NB	early	night	73.8	26.2	0.0	9.3	85.1	5.5	0.0	8.2	91.8
5	NB	early	weekend	64.0	36.0	0.0	16.2	73.2	10.6	0.0	8.3	91.7
6	SB	early	a.m. peak	11.4	88.6	0.0	2.3	94.9	2.8	0.0	1.3	98.7
7	SB	early	p.m. peak	56.3	43.7	0.0	6.1	89.3	4.6	0.0	0.8	99.2
8	SB	early	midday	49.6	50.4	0.0	4.5	90.0	5.5	0.0	1.7	98.3
9	SB	early	night	65.0	35.0	0.0	5.9	92.1	2.0	0.0	2.8	97.2
10	SB	early	weekend	59.4	40.6	0.0	3.5	93.3	3.2	0.0	2.4	97.6
11	NB	late	a.m. peak	95.8	4.2	0.0	6.2	86.4	7.4	0.0	6.9	93.1
12	NB	late	p.m. peak	96.8	3.2	0.0	2.4	95.9	1.7	0.0	4.2	95.8
13	NB	late	midday	92.7	7.3	0.0	6.5	84.7	8.9	0.0	7.0	93.0
14	NB	late	night	85.3	14.7	0.0	7.9	87.3	4.8	0.0	5.3	94.7
15	NB	late	weekend	87.1	12.9	0.0	12.6	76.4	11.1	0.0	7.1	92.9
16	SB	late	a.m. peak	91.1	8.6	0.2	1.7	98.0	0.3	0.4	0.1	99.4
17	SB	late	p.m. peak	68.8	31.3	0.0	4.8	92.6	2.6	0.0	1.0	99.0
18	SB	late	midday	62.8	35.5	1.7	3.2	96.6	0.2	0.0	0.5	99.5
19	SB	late	night	73.6	26.4	0.0	2.3	97.6	0.1	0.0	0.0	100.0
20	SB	late	weekend	55.5	44.5	0.0	3.9	94.9	1.2	0.6	0.8	98.6
Early Construction Time Periods				**73.8**	**25.9**	**0.2**	**7.1**	**88.1**	**4.8**	**0.3**	**3.4**	**96.3**
Late Construction Time Periods				**85.7**	**14.2**	**0.1**	**4.8**	**91.6**	**3.6**	**0.1**	**3.4**	**96.5**
All Time Periods				**80.5**	**19.3**	**0.2**	**6.0**	**89.9**	**4.2**	**0.2**	**3.4**	**96.4**

* Note: Lane 1 adjacent to median, lane 2 middle, lane 3 adjacent to outside shoulder

The table confirms that lane changing decreased during the later construction period, especially lane changing from the outside lane. The percentage of vehicles starting in the outside lane before the work zone that remained in the outside lane increased from 73.8 percent in the early construction period to 85.7 percent in the late construction period. Conversely, 25.9 and 14.2 percent of these vehicles switched to the middle lane in the early and late construction periods, respectively. The percentage of middle lane vehicles remaining in the middle lane increased from 88.1 percent to 91.6 percent between the early construction and late construction periods. Lane changes by vehicles in the median lane were relatively infrequent, in that approximately 96 percent of these vehicles remained in the median lane during both the early construction and late construction time periods. The results from Table 2.8 indicate that drivers may have become more familiar with the work zone layout and signage as the construction progressed and therefore tended to stay in their lane more frequently than during the early stages of the work zone implementation.

In addition to the number of lane changes by lane, the locations of the lane changes relative to the split sign and gore point were also analyzed. Table 2.9 summarizes the time headways between the lane change and split sign and between the lane change and the gore point.

Table 2.9. Time headways for lane changes before gore point

Time Period ID	Direction	Construction Period	Traffic Period	Gap from Lane Change to Gore Point (sec)**		Gap from Sign to Lane Change (sec)	
				Average	Std. Dev.	Average	Std. Dev.
1	NB	early	a.m. peak	9.37	5.33	13.12	8.68
2	NB	early	p.m. peak	8.39	6.63	19.88	7.50
3	NB	early	midday	7.26	3.36	8.26	3.82
4	NB	early	night	6.72	4.18	11.26	7.03
5	NB	early	weekend	9.09	4.18	7.62	5.31
6	SB	early	a.m. peak	4.45	3.01	7.14	4.33
7	SB	early	p.m. peak	4.20	2.72	5.45	4.19
8	SB	early	midday	3.16	4.06	3.57	2.09
9	SB	early	night	2.56	1.42	3.58	1.70
10	SB	early	weekend	2.93	1.79	3.79	1.86
11	NB	late	a.m. peak	8.59	4.74	7.55	4.27
12	NB	late	p.m. peak	12.28	8.89	18.98	8.82
13	NB	late	midday	6.79	3.86	8.12	4.27
14	NB	late	night	7.92	4.33	9.29	5.25
15	NB	late	weekend	8.40	4.19	7.96	4.76
16	SB	late	a.m. peak	6.08	3.37	4.17	2.52
17	SB	late	p.m. peak	3.63	1.88	6.16	2.27
18	SB	late	midday	2.74	1.12	2.90	1.29
19	SB	late	night	2.32	1.14	8.35	1.46
20	SB	late	weekend	2.82	1.42	9.29	2.42
	Early Time Periods			**7.97**	**6.75**	**6.08**	**4.71**
	Late Time Periods			**7.98**	**5.18**	**6.09**	**4.71**
	All Time Periods			**7.97**	**3.58**	**8.32**	**4.19**

* Note: Lane 1 adjacent to outside shoulder, lane 2 middle, lane 3 adjacent to median,
** For lane changes after split sign

On average, vehicles changed lanes 8.32 seconds after the split sign and 7.97 seconds before the gore point. Based on the work zone speed limit of 45 mph, these time headways correspond to distances of 549 ft and 526 ft, respectively. In comparing the values between the early and late construction time periods, it can be seen that the average values for both time headways are nearly identical. This result indicates that the locations of the lane changes relative to the split sign and gore point remained unchanged throughout the period of time when the alternative split sign was in place.

2.4.4 Driver Behavior

Some unusual driver behavior was observed in the videos, including aggressive lane changes before and at the gore point, vehicles driving across the lane closure area, and vehicles being stranded in the gore. Several aggressive lane changes before the gore point were observed. Examples of these are shown in Figures 2.20 and 2.21.

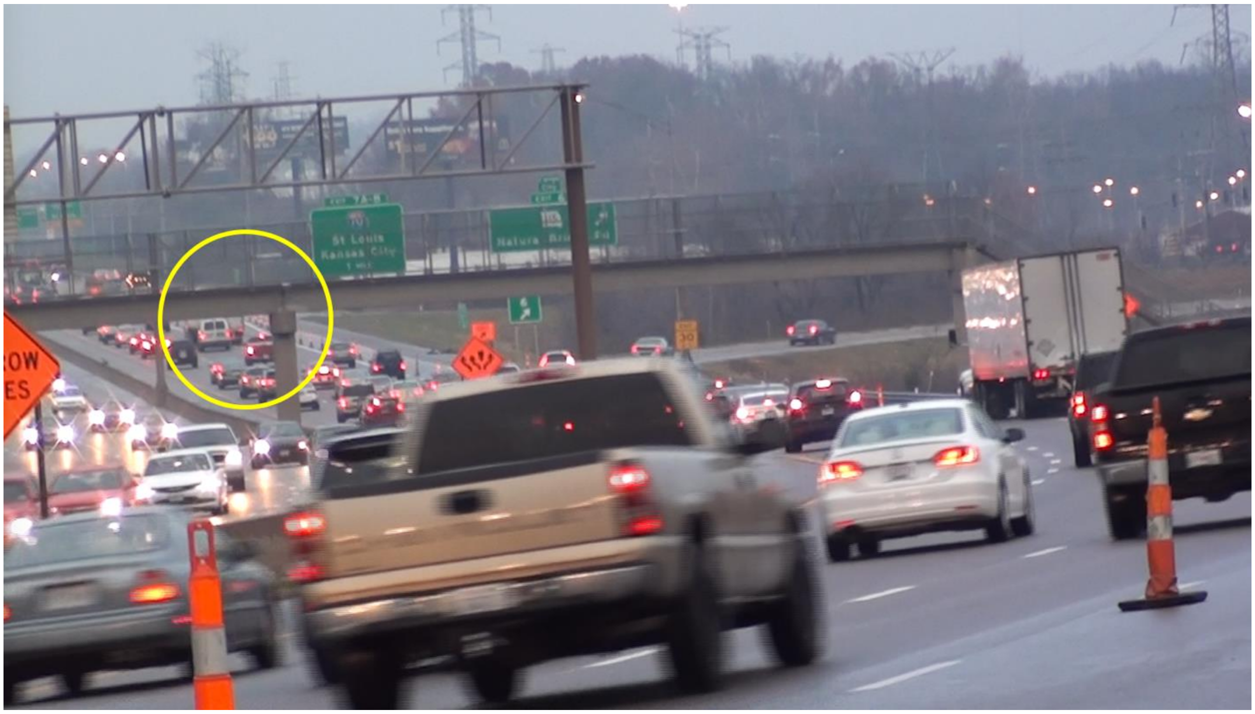


Figure 2.20. Tractor-trailer making aggressive lane change causing queue (early construction, northbound, morning peak)

Figure 2.21. Tractor-trailer making aggressive lane change causing following vehicle to change lanes (early construction, northbound, morning peak)

In the event shown in Figure 2.20, a tractor-trailer made an aggressive lane change from the outside lane to middle lane and caused a vehicle queue to develop. In another event (Figure 2.21), a tractor-trailer suddenly changed lanes and applied the brakes, causing the vehicle following behind to move into a different lane.

Several aggressive lane changes near the gore were captured in the videos. Examples of these events are shown in Figures 2.22 and 2.23. In both examples, vehicles traveled within the triangular gore area by traversing solid white lines.

Figure 2.22. Lane change near the gore example 1 (late construction, southbound, midday)

Figure 2.23. Lane change near the gore example 2 (late construction, southbound, midday)

Several events in which vehicles drove through the lane closure area were observed in the videos. Examples of these events are shown in Figures 2.24 through 2.26. Multiple vehicles can be seen driving through the lane closure area in Figure 2.26.

Figure 2.24. Vehicle driving through lane closure area to outside lane (early construction, southbound, midday)

Figure 2.25. Vehicle driving through lane closure area to middle lane (early construction, southbound, midday)

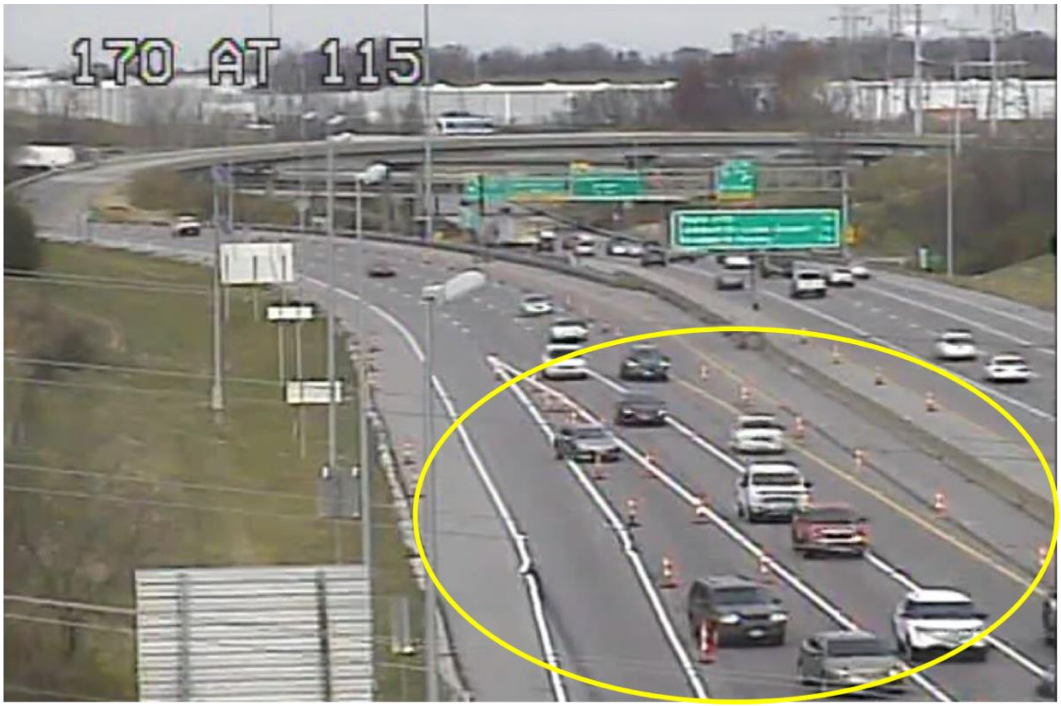


Figure 2.26. Multiple vehicles driving through lane closure area (early construction, southbound, midday)

During the processing of the drive-through videos, an event in which a vehicle was stopped in the gore area was observed. A screenshot of this event is shown in Figure 2.27.

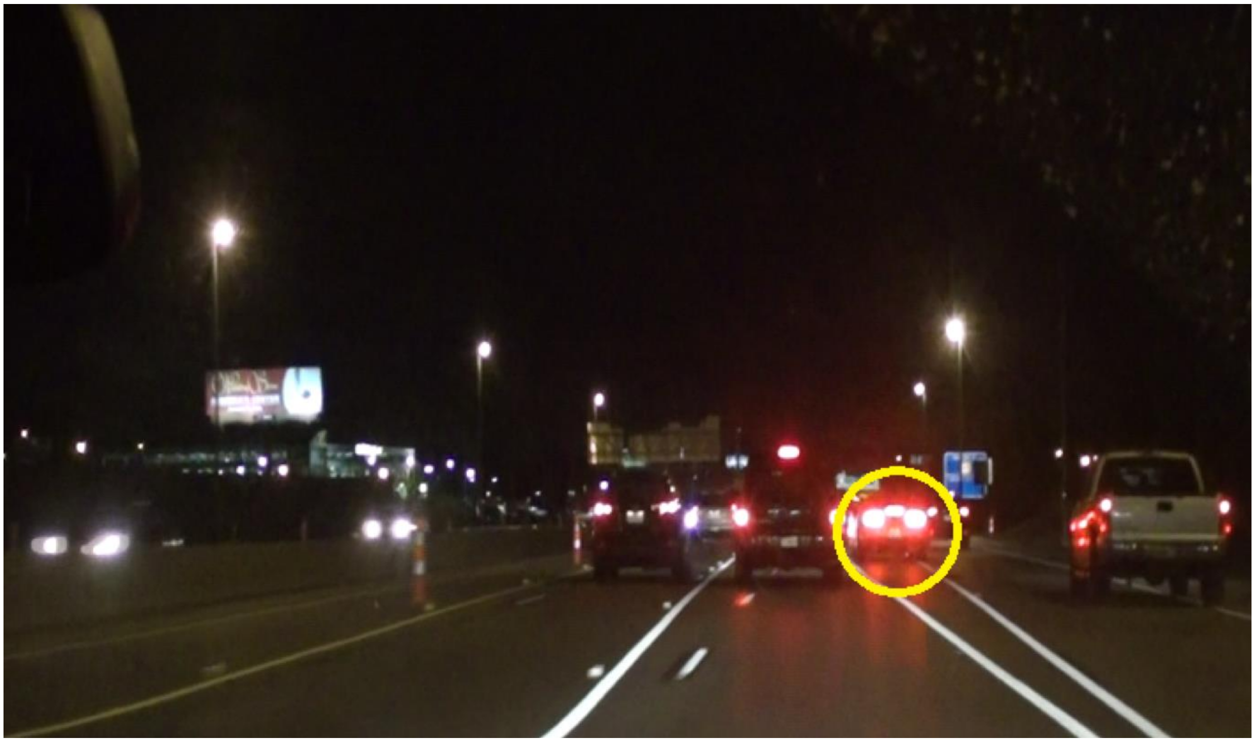


Figure 2.27. Vehicle stopped in gore area (late construction, southbound, night)

2.4.5 Summary of Results of Video Data Analysis

Overall, the results of the video analysis showed that the number of lane changes decreased from the early construction period to the late construction period. The most frequent lane changing occurred between the outside and middle lanes. The reduction in lane changing behavior could be due to driver acclimation to the work zone, including the work zone split sign. While the rate of lane changing decreased, the locations of the lane changes relative to the alternative sign and the gore point remained the same. Several types of unusual driver behavior such as aggressive lane changes before and at the gore point, vehicles driving across the lane closure area, and vehicles being stranded in the gore area were observed in the videos. The unusual driver behavior generally appears to be related to aggressive driving and not to the presence of the alternative sign.

CHAPTER 3. STAKEHOLDER INTERVIEWS

3.1 Overview and Methodology

To gain further insights into the possible impacts of using the alternative sign, the research team conducted interviews with stakeholders for the project. Two groups of stakeholders were involved in the investigation of the work zone split traffic signs: the contractor personnel group and MoDOT personnel group. In total, there were four contractors and five MoDOT personnel respondents interviewed within each group for the investigation. The purpose of the interviews was to obtain the perspectives of the two groups on the effectiveness of the signs. Each person responded to a set of questions tailored towards their experience, knowledge, and usage of the split traffic work zone signs. Their responses were reported and documented.

In contrast to the stakeholders' participation described in the proposal, which anticipated two rounds of interviews—one after the placement of the signs and the other before the removal of the signs—only one round of interviews was completed due to the shortness of the construction schedule.

The interviews included questions about the interviewees' experience with work zones containing middle lane closures, their observations of driver behavior under both the MUTCD sign and the alternative sign, and their opinions on whether the use of the alternative sign helped to improve safety. Interviewees were also asked if they had any suggestions for ways in which the implementation of the alternative sign could be improved. A complete list of interview questions is shown in Table 3.1.

Table 3.1. List of questions for stakeholder interviews

No.	Question
1	For how long has the alternative sign been in place in the work zone?
2	How many work zones have you been involved with in which lanes are available around both sides of a work zone? (Answer: 0, 1-3, 4-10, 10 or more)
3*	Have you driven through the work zone?
4*	As a driver, do you think that the alternative sign was more or less effective than the MUTCD sign in getting your attention and communicating information? Please explain.
5	How frequently would you estimate that you have observed the following types of driving behavior while the alternative sign has been in place? (Answers: never, rarely, sometimes, frequently) a. Aggressive lane changes b. Erratic driver maneuvers c. Driver honking horn
6	Based on your experience, how frequently would you estimate that you have observed the following types of driving behavior in similar work zones with the MUTCD sign configuration? (Answers: never, rarely, sometimes, frequently) a. Aggressive lane changes b. Erratic driver maneuvers c. Driver honking horn
7	Compare work zone safety for drivers between the alternative signage and the MUTCD signage. Answers: {Alternative is much safer} {Alternative is safer} {Same} {MUTCD is safer} {MUTCD is much safer} Please explain your answer.
8	Compare work zone safety for <u>construction workers</u> between the alternative signage and the MUTCD signage. Answers: {Alternative is much safer} {Alternative is safer} {Same} {MUTCD is safer} {MUTCD is much safer} Please explain your answer.
9	Do you feel that work zone delay for drivers has increased, decreased, or remained the same with the use of the alternative signage versus the use of the MUTCD signage? Please explain your answer.
10	With the alternative sign, have you observed any differences in driver behavior between nighttime and daytime? If so, please describe these differences.
11	Were there any differences in your experiences with implementing the alternative sign and the MUTCD sign? If yes, please describe these differences.
12	Do you have any concerns regarding the use of the alternative sign? If yes, please describe your concerns.
13	Do you have any suggestions for ways in which the implementation of the alternative sign could be improved? If so, please describe.

No.	Question
14	Have you received any feedback from your staff regarding the alternative sign? If yes, please describe this feedback.
15	Have you noticed any changes in driver behavior during the time that the signs have been in place? If so, please describe.
16	Do you have any other comments regarding this study?

* Questions that were only asked of MoDOT personnel

3.2 Summary of Results

3.2.1 Results from Interviews with MoDOT Personnel

The interview responses from MoDOT personnel are summarized in Table 3.2.

Table 3.2. Summary of interview responses from MoDOT personnel

Question No.	Respondent ID				
	M-1	M-2	M-3	M-4	M-5
1	1 week	13 days	1 week	1 week	5 days
2	1-5	1-5	5-10	1-5	
3	yes	yes	yes	yes	yes
4	alternative more information	alternative easier to understand	alternative clear direction	alternative more effective more information	alternative more effective gives whole picture
5	sometimes sometimes sometimes	sometimes never never	sometimes sometimes rarely	sometimes sometimes rarely	sometimes sometimes never
6	sometimes sometimes sometimes	frequently sometimes rarely	sometimes sometimes rarely	sometimes sometimes rarely	frequently frequently sometimes
7	alternative safer (more information)	alternative safer (easy to understand)	same (alternative is less confusing)	same (more info but drivers pay no attention)	alternative
8	same (drivers drive badly either way)	alternative safer (easy to understand)	same	same (more info but drivers pay no attention)	same/alternative safer
9	same (high volume)	same no effect	same	same	same capacity is the same
10	no	no	no	no	only observed during daytime
11	no	no	no	no	no experience with MUTCD Sign
12	no	no	no, clear for driver	no	no
13	no	no	no	no	no
14	no	no	favorable from MoDOT	no	no
15	n/a	n/a	no	no	no
16	n/a	no	no	no	no

The results indicate that 80 percent of the MoDOT respondents had experience with work zones in which lanes are available around both sides of the work zone, while one respondent did not answer this question. All of the respondents drove through the work zone and thought that the alternative sign was more effective than the MUTCD sign at getting their attention and communicating information. As for driver behavior with the new sign, all respondents sometimes observed aggressive lane changes while 80 percent of respondents sometimes observed erratic driver maneuvers. Drivers honking their horns was seen less frequently; 40 percent of MoDOT respondents never observed this behavior and 40 percent rarely observed it. For driver behavior with the MUTCD sign, 40 percent of MoDOT respondents frequently observed aggressive lane changes while 60 percent observed these changes sometimes. MoDOT respondents also indicated that they observed erratic driver maneuvers frequently (20 percent) or sometimes (80 percent). Instances of drivers honking their horns were observed sometimes (40 percent) or rarely (60 percent) by the MoDOT respondents.

The MoDOT respondents were somewhat divided on the comparison of perceived safety between the alternative and MUTCD signs. The majority (60 percent) of MoDOT respondents thought that the alternative sign was safer for drivers because they perceived that it provided more information. However, 40 percent of respondents felt that the alternative sign and MUTCD sign provided the same level of work zone safety for drivers. One respondent expressed the opinion that the signs provide the same level of safety because drivers do not pay attention to the signs. For construction worker safety, 80 percent of respondents indicated that the two signs provided the same level of safety. Reasons provided for this belief included the opinion that drivers do not pay attention to the signs and drivers still drive badly regardless of the signage. The remaining respondents (20 percent) indicated that the alternative sign was safer for construction workers with one reason given being that it was easy to understand.

All of the MoDOT respondents indicated that the work zone delay was the same for both the alternative signage and the MUTCD signage. Most of the respondents (80 percent) did not observe any differences in driver behavior between nighttime and daytime, while one respondent had only observed the work zone during the daytime. None of the respondents with familiarity in using both signs noted any differences in their experience with implementing them. The MoDOT respondents did not notice any changes in driver behavior during the time that the signs were in place. Finally, the MoDOT respondents did not express any additional concerns regarding the use of the alternative signs.

3.2.2 Results from Interviews with Contractor Personnel

Table 3.3 summarizes the interview responses from the contractor personnel.

Table 3.3. Summary of interview responses from contractor personnel

Question No.	Respondent ID C-1	C-2	C-3	C-4
1	1 week	2 weeks	3 weeks	2 weeks
2	1-3	1-3	10 or more	1-3
3	n/a	n/a	n/a	n/a
4	n/a	n/a	n/a	n/a
5	often often often	often often often	hourly hourly hourly	often often often
6	frequently frequently frequently	frequently frequently sometimes	hourly hourly hourly	often often often
7	alternative much safer (easier to read-less choices)	same	same (no attention)	alternative much safer (better visual)
8	same (no one pays attention unless it is late)		same (no attention)	alternative much safer (better visual)
9	same	same	same	same
10	no	no	night is better	no
11	no	no	no	no
12	no	no	no MUTCD is better	no
13	no	no	warning sign before	no
14	no	no	no	like it better
15	no	no		no
16	no	no		no

All of the contractors indicated that they have been involved with work zones in which lanes are available around both sides of the work zone. The contractor respondents indicated that they observed aggressive lane changes, erratic driver maneuvers, and drivers honking their horns hourly (25 percent) or often (75 percent) with the alternative sign in place. For driver behavior with the MUTCD sign, 75 percent of the contractors frequently or often observed aggressive lane changes, while 25 percent observed them sometimes. The contractor respondents also noticed erratic driver maneuvers frequently or often (75 percent) or hourly (25 percent). Instances of the drivers honking their horns were observed often or frequently (50 percent), hourly (25 percent), or sometimes (25 percent) by the contractors.

The contractors were evenly split on their perception of whether the alternative sign was safer for drivers or provided the same level of safety as the MUTCD sign. Some contractors felt that the alternative provided clearer visuals, while others believed that drivers do not pay attention to the signs. One contractor (25 percent) responded that the alternative sign was safer for construction workers because it provided better visual information, while two contractors (50 percent) indicated that the two signs provided the same level of safety for construction workers because drivers do not pay attention to the signs.

All of the contractor respondents indicated that the work zone delay was the same for the alternative signs and MUTCD signs. Most of the respondents (75 percent) did not observe any differences in driver behavior between nighttime and daytime, while one respondent thought that driver behavior was better at night. The contractor respondents did not note any differences in their experience with implementing the alternative signs and the MUTCD signs, and they did not observe any changes in driver behavior during the time that the signs were in place. One contractor indicated that his or her staff liked the alternative sign better, while another contractor expressed the opinion that the MUTCD sign is better. Regarding suggestions for improvement of the implementation of the alternative sign, one contractor suggested the use of another warning sign before the work zone.

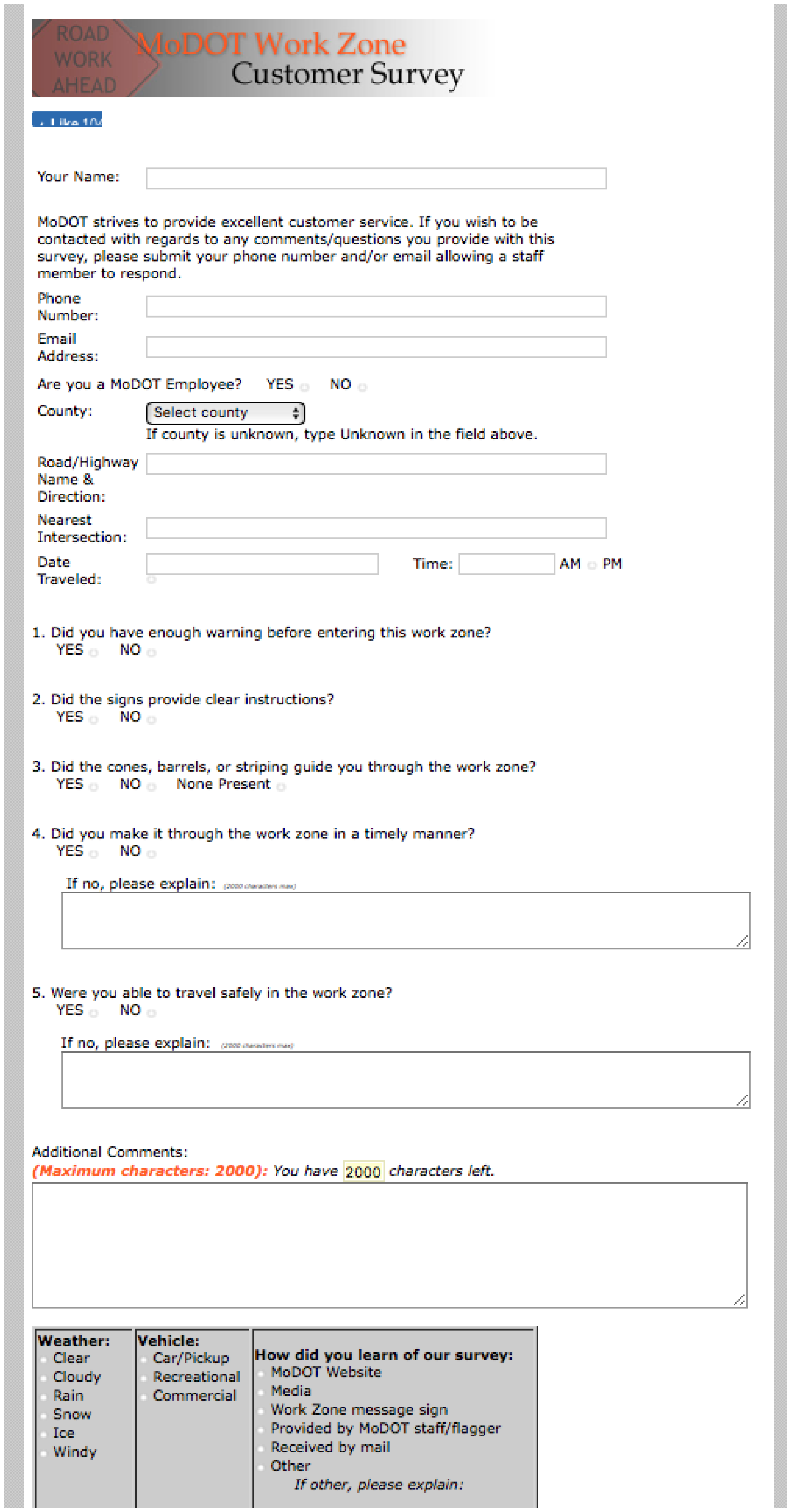
3.2.3 Overall Summary of Stakeholder Interview Results

The overall results from the interviews with both MoDOT and contractor personnel can be summarized as follows:

- Respondents generally thought that the alternative sign was a good idea but were divided on whether the use of the alternative sign improved work zone safety for drivers and construction workers when compared to the MUTCD sign. Some respondents thought the alternative sign improved safety because they perceived that it communicated information more clearly and was easier to understand. Other respondents indicated that the level of safety was the same because they do not think that drivers pay attention to the signs.
- Based on the responses, the use of the alternative sign has no effect on work zone delay.
- Interviewees believed that the use of the alternative sign has almost no effect on the driving behavior of people because the rates of aggressive lane changes, erratic maneuvers, and horn honking are much the same with the alternative sign and the MUTCD sign.
- Changes in driver behavior during the time that the alternative signs were in place were not observed by the respondents.
- Feedback from MoDOT and contractor staff regarding the use of the alternative sign was generally positive.

CHAPTER 4. DRIVER SURVEY

The research team also sought the opinions of another important stakeholder group, drivers. MoDOT's "Rate Our Work Zones" survey (MoDOT 2013) is a web-based work zone customer survey that records driver perceptions of work zones across Missouri. As shown in Figure 4.1, the survey asks drivers to comment on the timeliness of warning of work zone presence; clarity of signs, striping, and other temporary traffic control devices; and perception of delay and safety while driving through the work zone.


ROAD WORK AHEAD

MoDOT Work Zone Customer Survey

Your Name:

MoDOT strives to provide excellent customer service. If you wish to be contacted with regards to any comments/questions you provide with this survey, please submit your phone number and/or email allowing a staff member to respond.

Phone Number:

Email Address:

Are you a MoDOT Employee? YES NO

County: Select county

If county is unknown, type Unknown in the field above.

Road/Highway Name & Direction:

Nearest Intersection:

Date Traveled: Time: AM PM

1. Did you have enough warning before entering this work zone?
YES NO

2. Did the signs provide clear instructions?
YES NO

3. Did the cones, barrels, or striping guide you through the work zone?
YES NO None Present

4. Did you make it through the work zone in a timely manner?
YES NO

If no, please explain: (2000 characters max)

5. Were you able to travel safely in the work zone?
YES NO

If no, please explain: (2000 characters max)

Additional Comments:
(Maximum characters: 2000): You have 2000 *characters left.*

Weather:
- Clear
- Cloudy
- Rain
- Snow
- Ice
- Windy

Vehicle:
- Car/Pickup
- Recreational
- Commercial

How did you learn of our survey:
- MoDOT Website
- Media
- Work Zone message sign
- Provided by MoDOT staff/flagger
- Received by mail
- Other

If other, please explain:

MoDOT 2013

Figure 4.1. MoDOT "Rate Our Work Zones" survey

The research team requested the survey responses from MoDOT for December 2016 from the St. Louis region. There were only two survey responses for the St. Louis region in the month of December 2016. These responses concerned work zones on US 40 and I-44. Therefore, drivers did not express any concerns regarding the use of the new split signs on the I-170 project in the survey.

CHAPTER 5. CRASH DATA ANALYSIS

5.1 Overview and Methodology

Another important aspect of evaluating the alternative sign was to assess its possible safety impacts. While the stakeholder interviews provided some insights into the perceived safety of the alternative sign, an analysis of crash data was also performed to provide a quantitative evaluation of the possible safety impacts of the alternative sign. The key question to be answered was whether the use of the alternative sign was a factor in any of the crashes that occurred in the work zone.

To perform this evaluation, crash data were reviewed for the work zone period as well as a period of time before the work zone was implemented. Understanding the crash patterns for this section of I-170 before the work zone was in effect constituted an important part of the safety evaluation. Crash data for the period beginning January 1, 2015 and ending November 29, 2016 were used to evaluate safety under non-work zone conditions. The use of this earlier period allowed for comparison of crashes in the months and year before the work zone was in effect to the crashes that occurred during the work zone period.

The crash data analysis has some limitations. The sample size is relatively small, and exposure variables such as annual average daily traffic (AADT) were not included in the analysis. The analysis looked at observed crashes instead of expected crashes. Thus, the analysis could be subject to the effects of random variations in crashes. An analysis based on the Highway Safety Manual (AASHTO 2010) was outside the project scope. Despite these limitations, the analysis provided some information regarding the safety effects of the alternative sign.

Crash data were retrieved using the Accident Browser module of the MoDOT Transportation Management System (TMS) database. Data for all crashes that occurred in this section of I-170 between January 1, 2015 and December 31, 2016 were retrieved using the Accident Browser. The study area encompassed I-170 between the I-70 interchange and the St. Charles Rock Rd. interchange. The geographic limits used for the Accident Browser queries are shown in Figures 5.1 through 5.4.

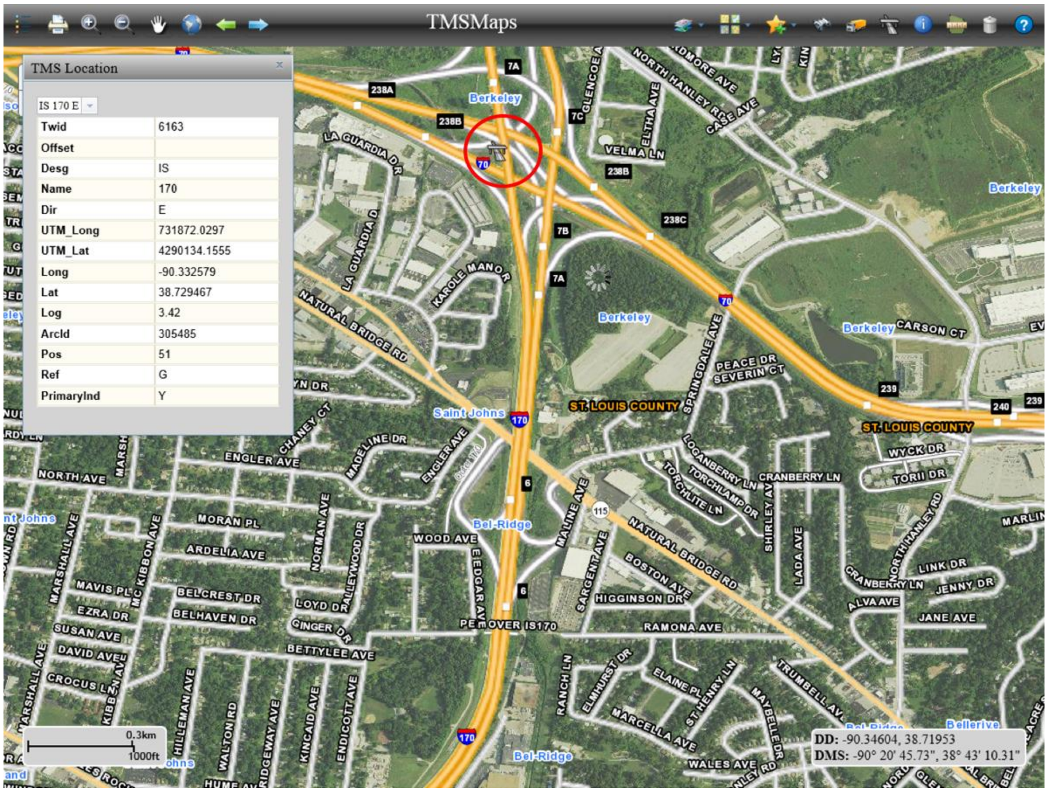


Figure 5.1. Beginning of southbound I-170 segment for safety analysis

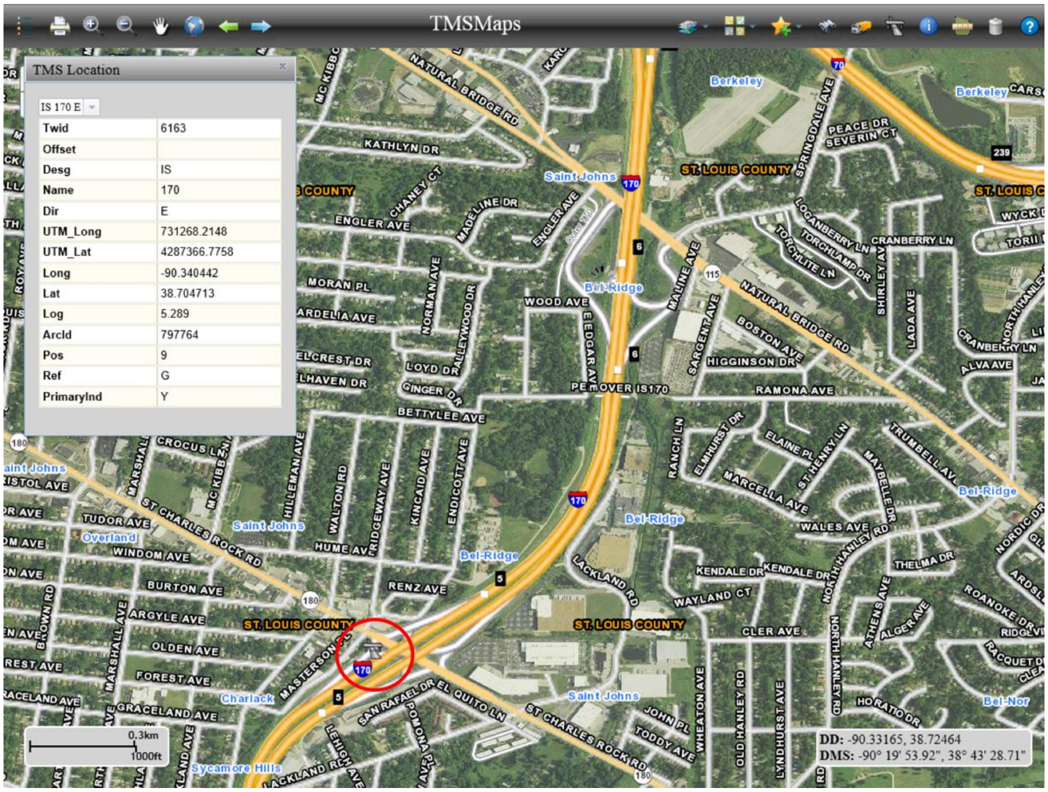


Figure 5.2. End of southbound I-170 segment for safety analysis

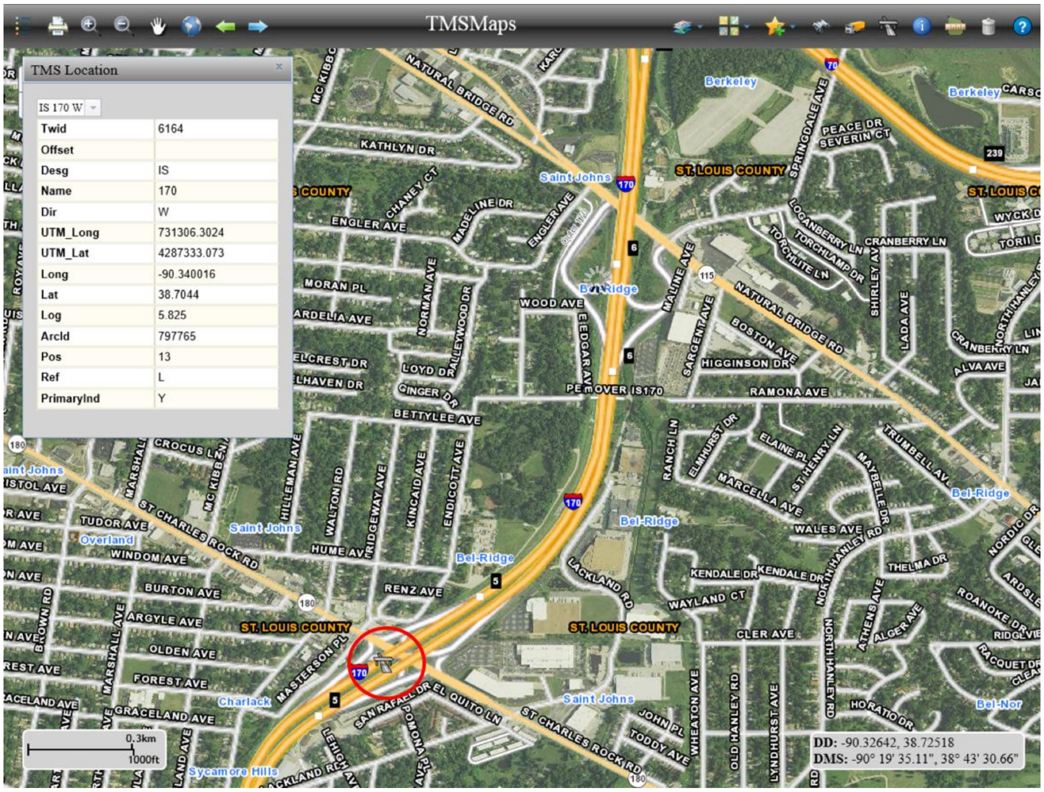


Figure 5.3. Beginning of northbound I-170 segment for safety analysis

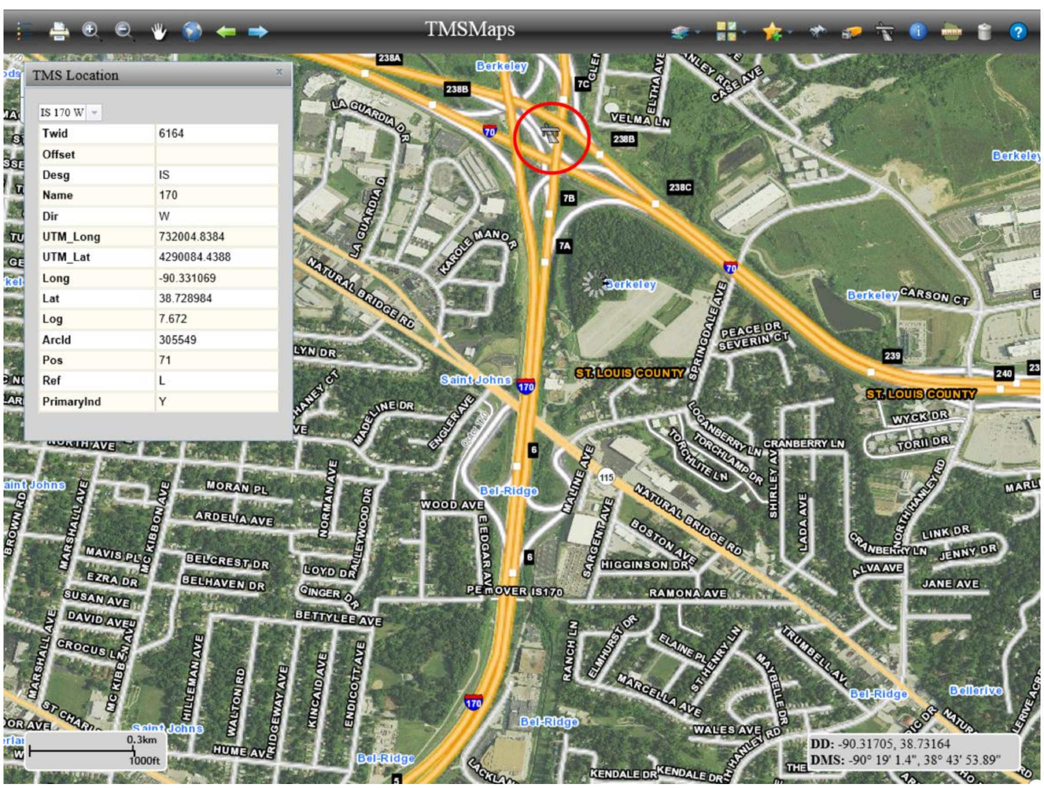


Figure 5.4. End of northbound I-170 segment for safety analysis

It should be noted that the directions are coded in TMS as eastbound and westbound, but I-170 is actually signed as northbound and southbound in this location. The northbound direction corresponds to westbound in TMS while the southbound direction corresponds to eastbound in TMS.

The Accident Browser output contained information regarding crash characteristics such as date, severity, type of crash, light conditions, and weather conditions. Output for some of the fields for all of the crashes that occurred in the study area during 2015 and 2016 is provided in Appendix A. This information was used to identify general trends regarding crash circumstances. In addition, crash reports for all of these crashes were obtained. The reports were reviewed to obtain more details on the contributing circumstances of these crashes with particular focus on the crashes that occurred during the work zone period.

5.2 Results of Crash Data Analysis

5.2.1 Overall Results for 2015 and 2016

5.2.1.1 Crashes in 2015 and 2016 on I-170 southbound

A total of 96 crashes occurred in the study area on I-170 southbound during 2015 and 2016, including 2 crashes on ramps at the I-70 interchange. As shown in Table 5.1 and Figure 5.5, the highest number of crashes occurred in January, February, and April of 2015. The number of crashes by month in 2016 compared to 2015 was lower for all months except for August and December.

Table 5.1. Crashes by month for I-170 southbound

Month	2015	2016
January	7	0
February	8	3
March	6	3
April	7	1
May	6	2
June	6	3
July	4	1
August	2	3
September	3	3
October	6	1
November	6	4
December	5	6
Total	**66**	**30**

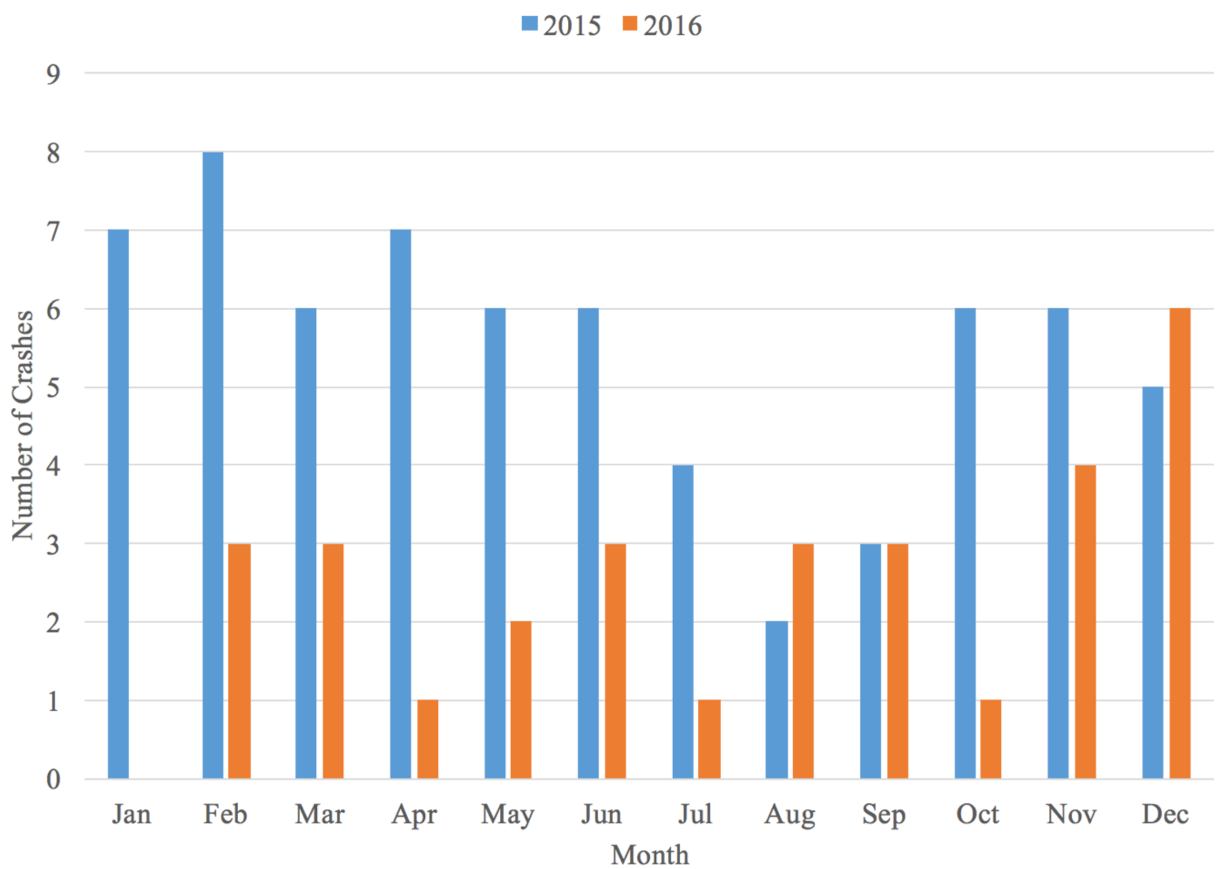


Figure 5.5. Crashes by month for I-170 southbound

The most common types of crashes were rear-end crashes, with 25 crashes in 2015 and 13 crashes in 2016, followed by passing and out of control crashes. A graph of crashes by type is shown in Figure 5.6. As shown in the figure, the rates for rear-end and out of control crashes decreased considerably in 2016 compared to 2015.

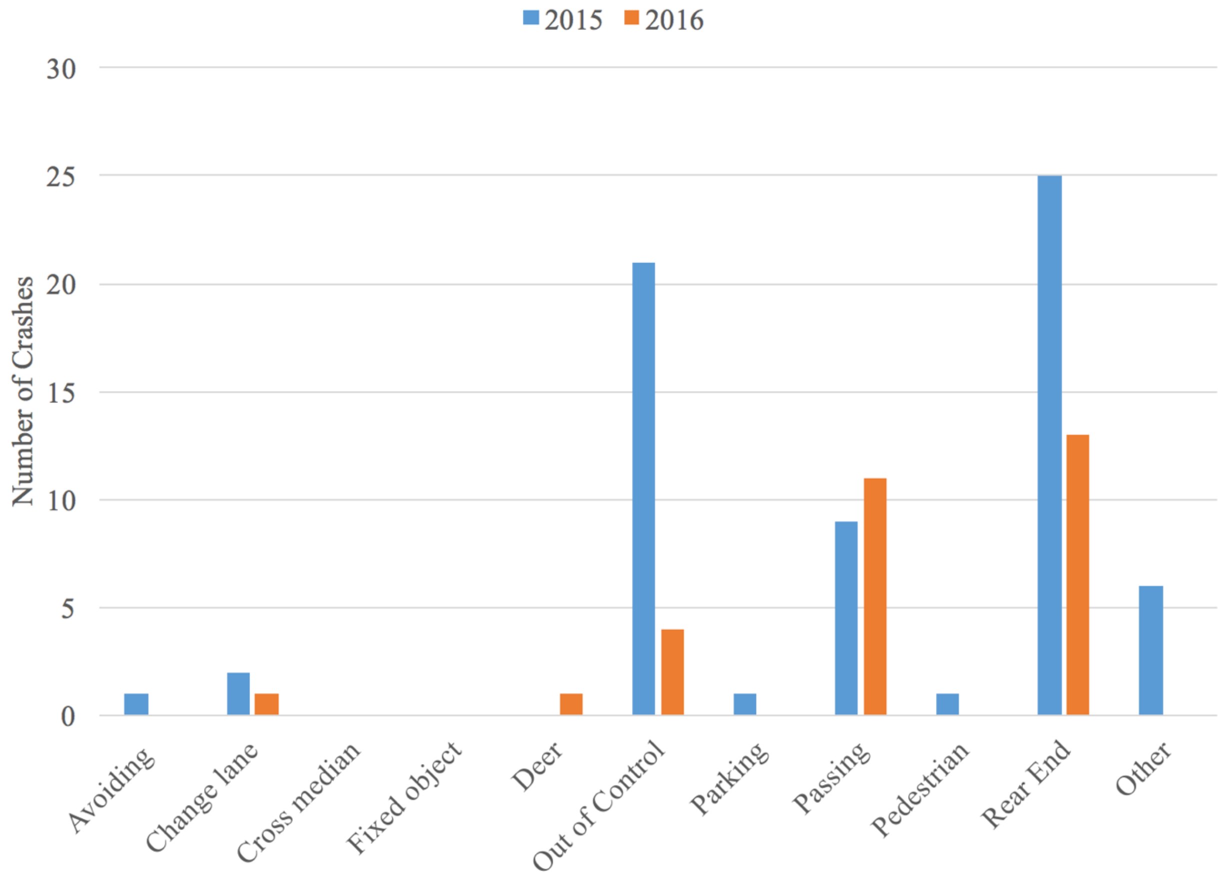


Figure 5.6. Crashes by type for I-170 southbound

Figure 5.7 shows a graph of crashes by severity for I-170 southbound. More than 80 percent of crashes were property damage only (PDO) crashes. There were three disabling injury crashes in 2015.

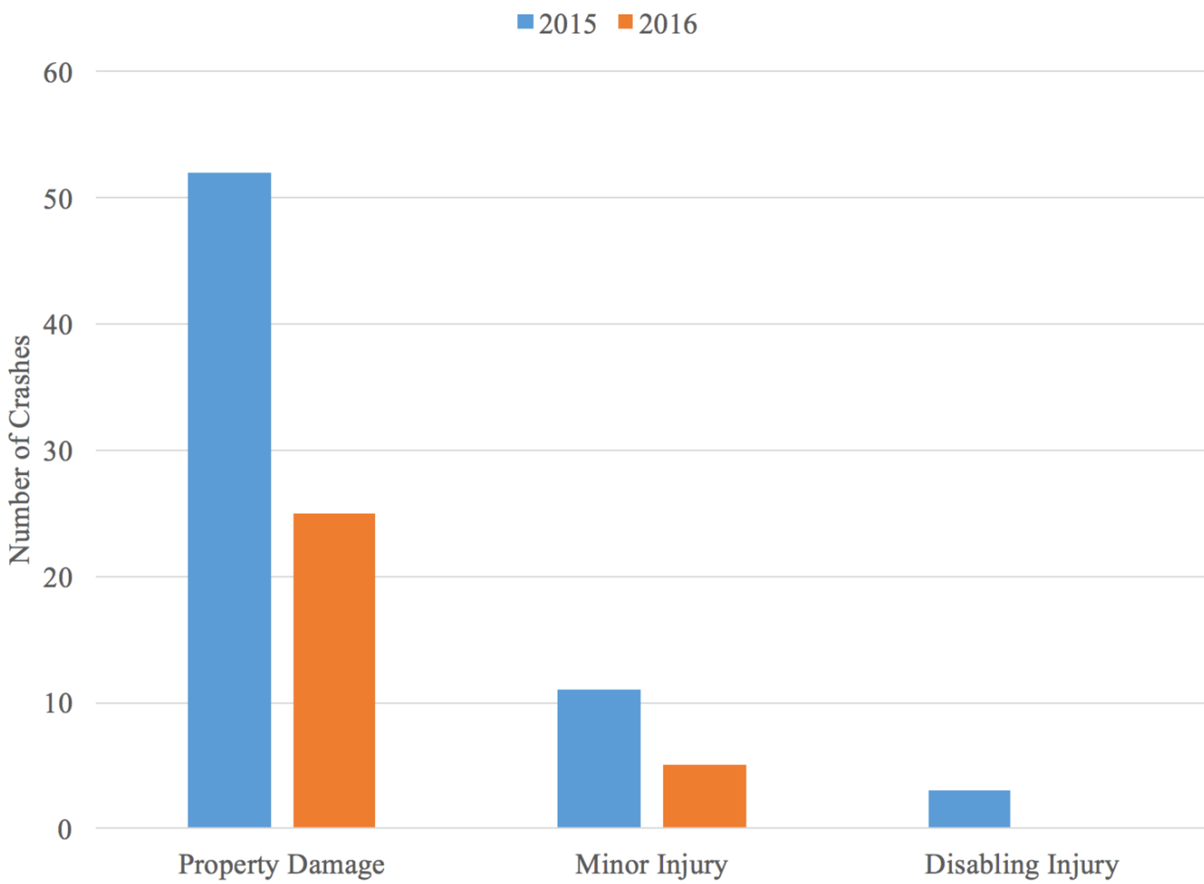


Figure 5.7. Crashes by severity for I-170 southbound

The distribution of crashes by light condition is shown in Figure 5.8. Most of the crashes occurred in daylight.

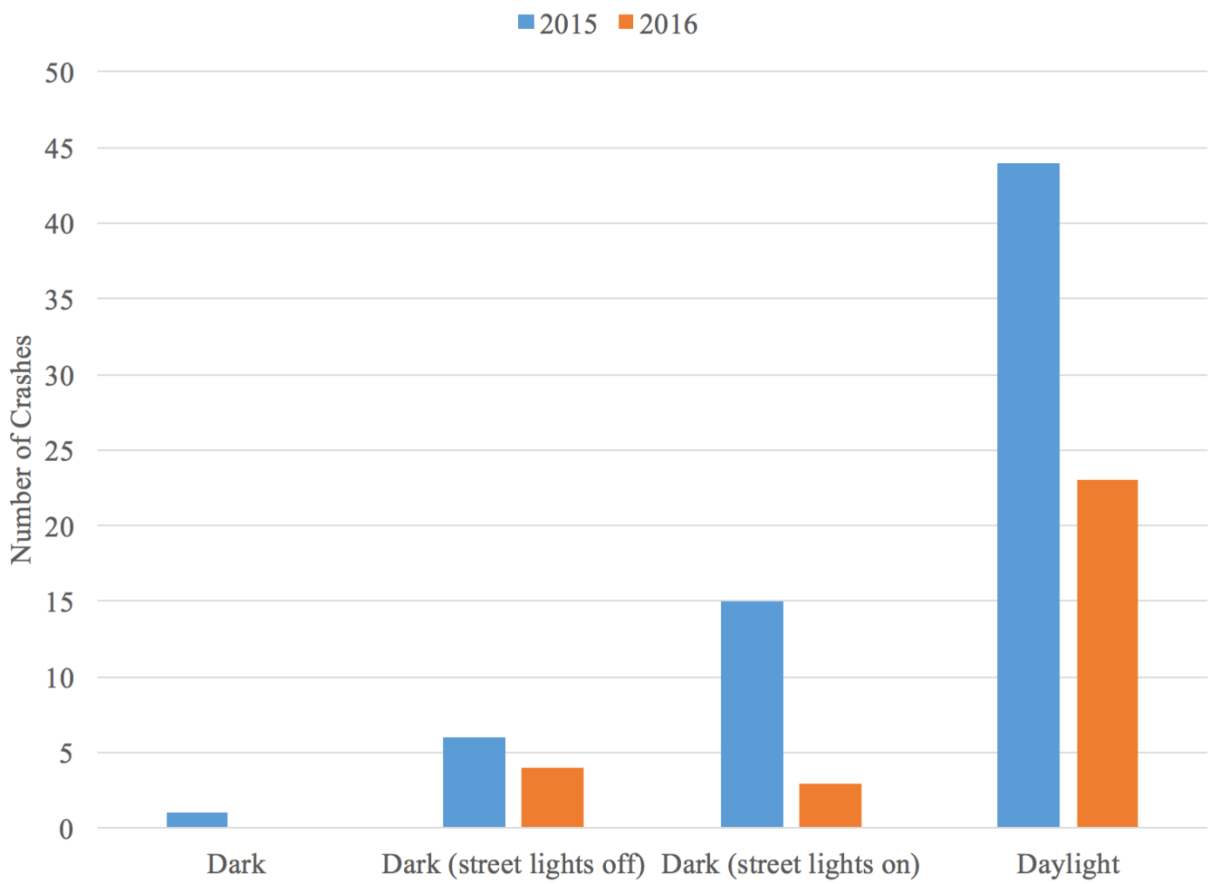


Figure 5.8. Crashes by light condition for I-170 southbound

The distribution of crashes by road surface condition is shown in Figure 5.9. Approximately 75 percent of the crashes occurred in dry conditions.

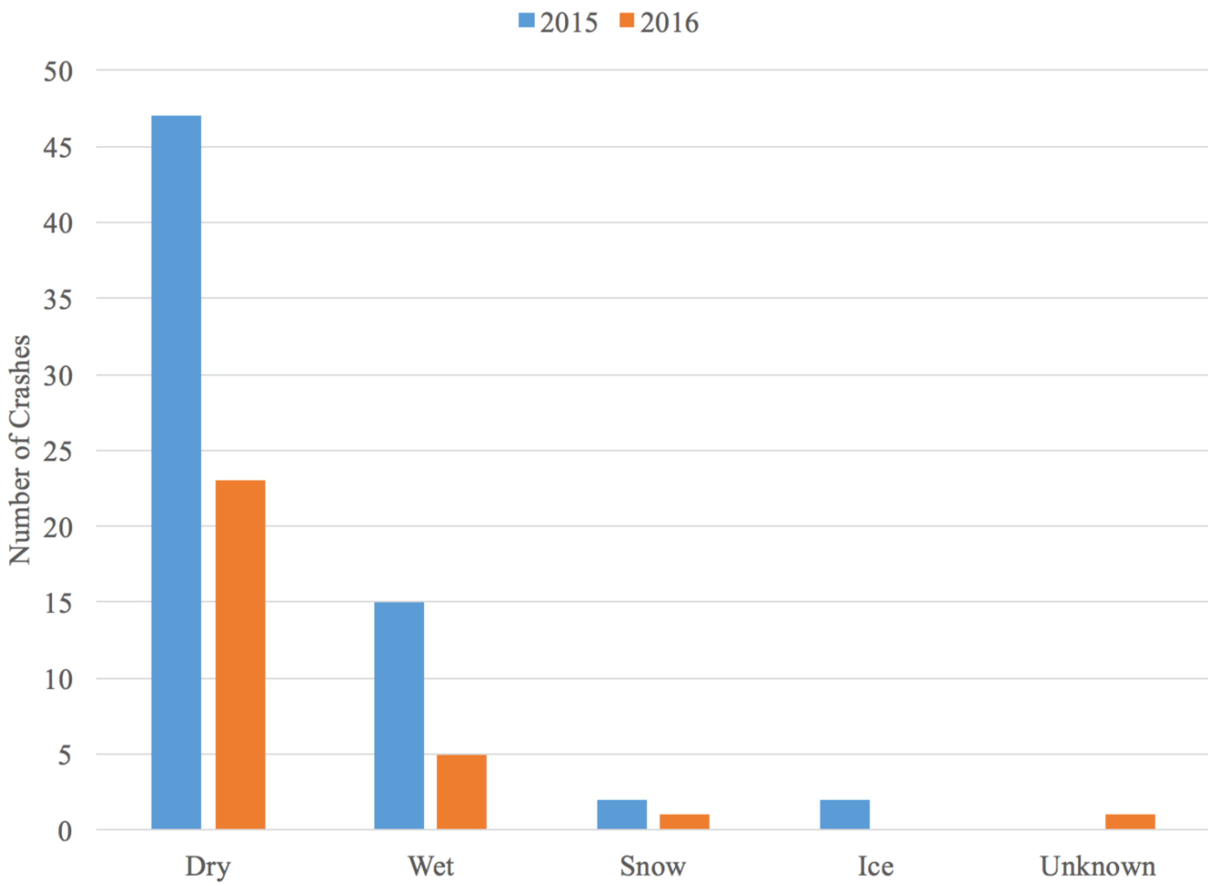


Figure 5.9. Crashes by road surface condition for I-170 southbound

5.2.1.2 Crashes in 2015 and 2016 on I-170 northbound

A total of 169 crashes occurred in the study area on I-170 northbound during 2015 and 2016, including two crashes on ramps at the I-70 interchange. As shown in Table 5.2 and Figure 5.10, the highest number of crashes occurred in September 2015 and November 2015. The number of crashes by month in 2016 compared to 2015 was the same or lower for most months except for January, March, and August.

Table 5.2. Crashes by month for I-170 northbound

Month	2015	2016
January	5	8
February	12	10
March	5	7
April	12	4
May	8	5
June	4	4
July	7	5
August	4	7
September	14	3
October	7	6
November	17	7
December	4	4
Total	**99**	**70**

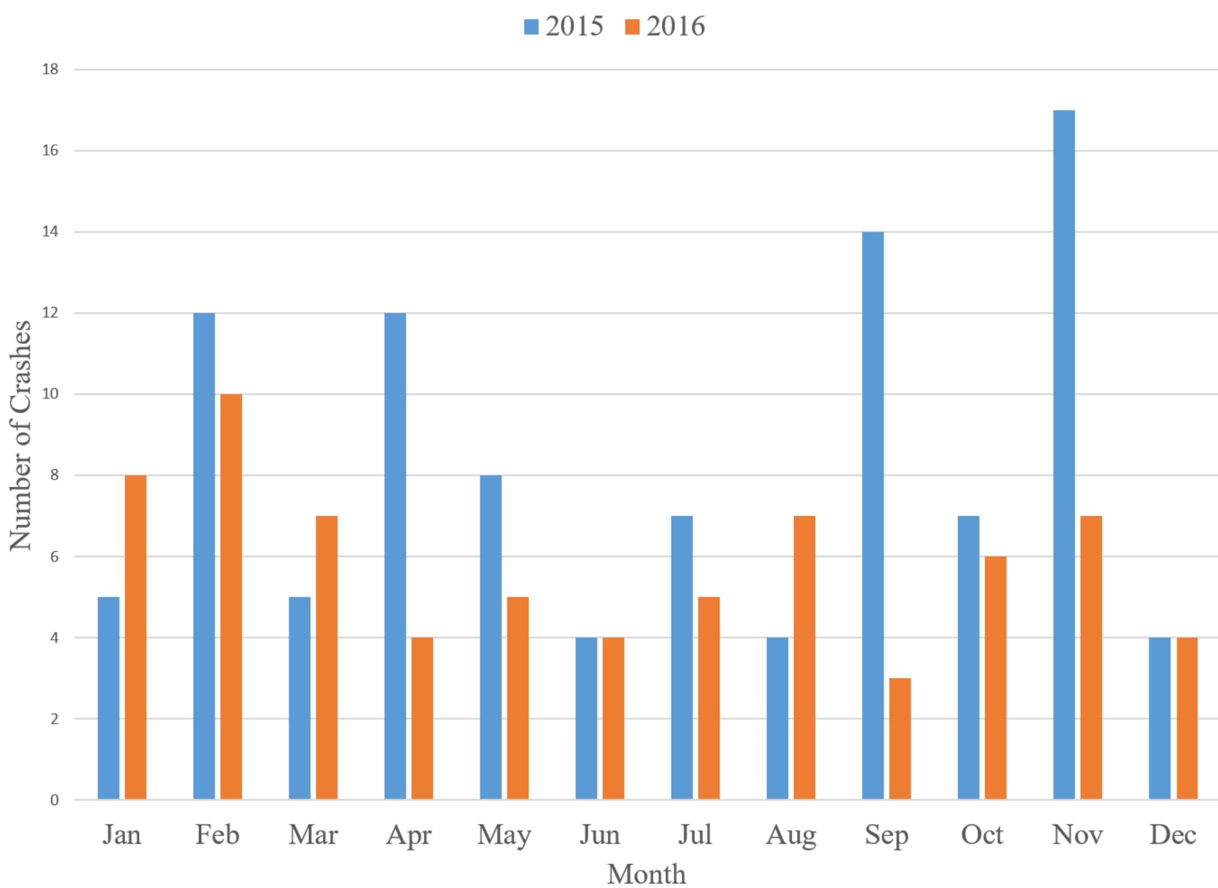


Figure 5.10. Crashes by month for I-170 northbound

The most common types of crashes were rear-end crashes, with 51 crashes in 2015 and 35 crashes in 2016, followed by passing and out of control crashes. Figure 5.11 shows the distribution of crashes by type for I-170 northbound. As shown in the graph, the rates for rear-end and passing crashes decreased considerably in 2016 compared to 2015, while the number of out of control crashes remained the same.

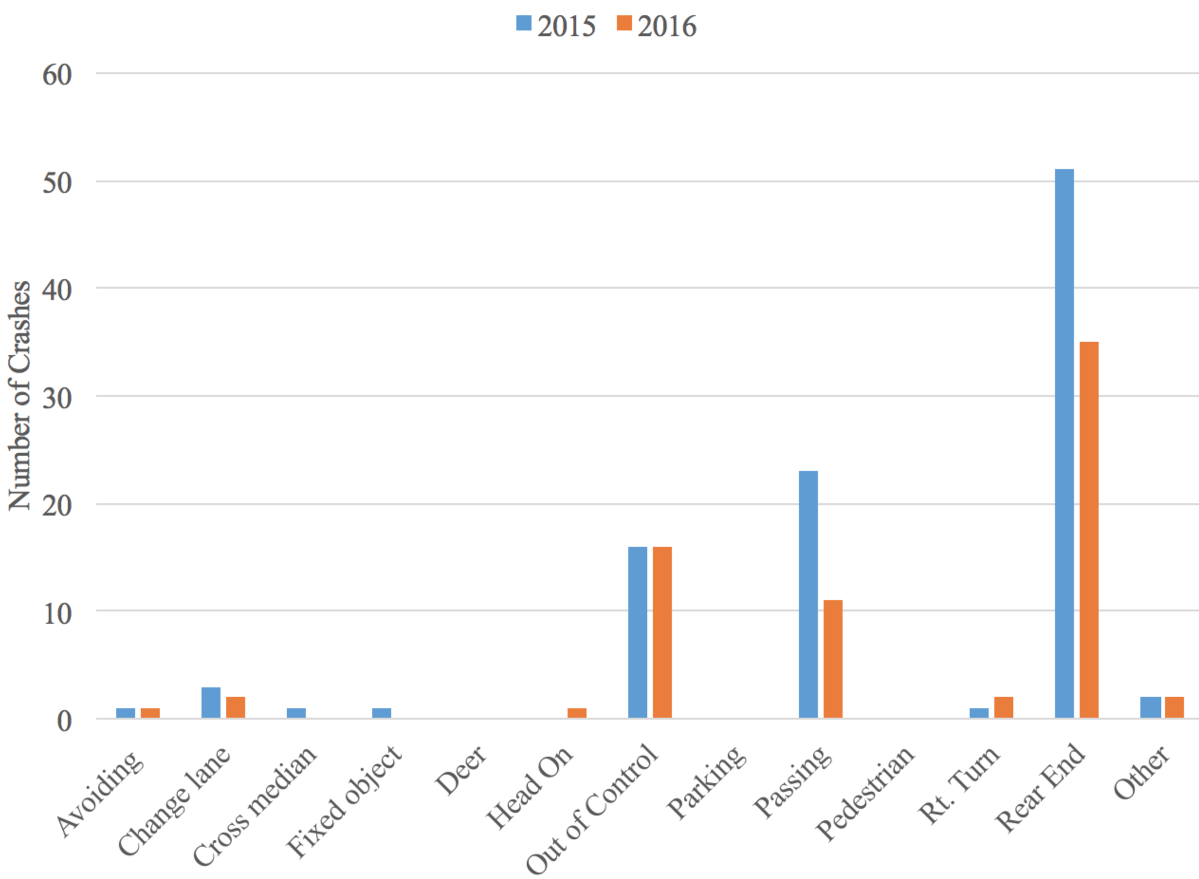


Figure 5.11. Crashes by type for I-170 northbound

Figure 5.12 shows a graph of crashes by severity. Approximately 75 percent of crashes were PDO crashes. There were three disabling injury crashes in both 2015 and 2016.

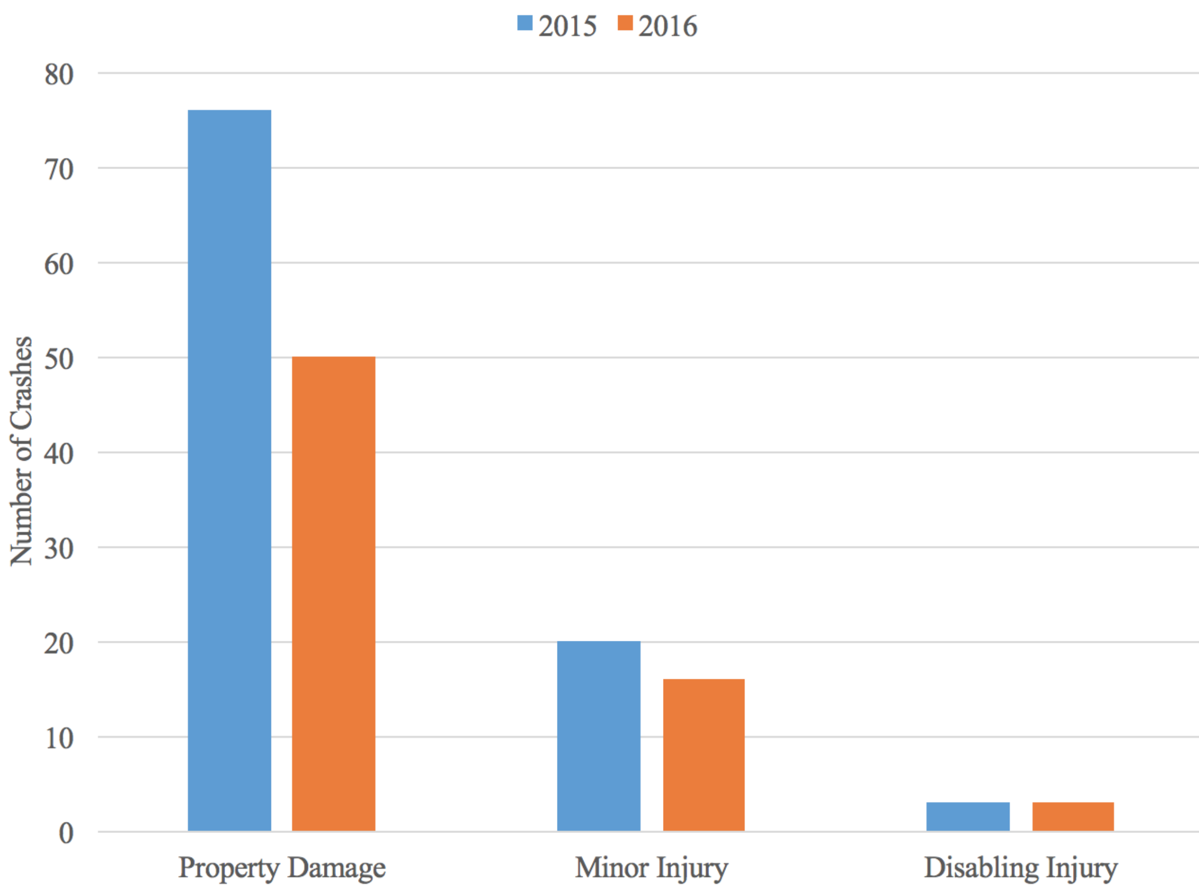


Figure 5.12. Crashes by severity for I-170 northbound

Figure 5.13 shows the distribution of crashes by light condition. More than 70 percent of the crashes occurred in daylight.

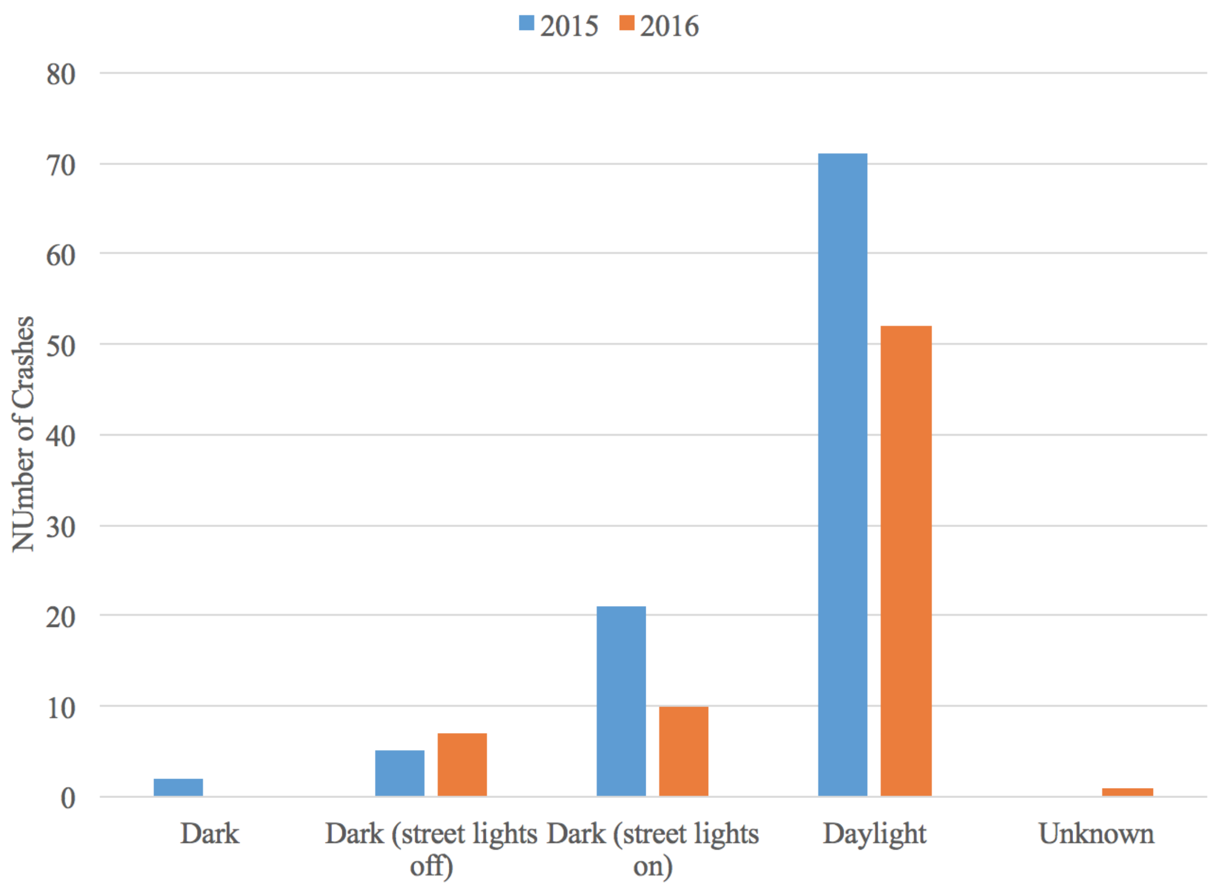


Figure 5.13. Crashes by light condition for I-170 northbound

The distribution of crashes by road surface condition is shown in Figure 5.14. Approximately 75 percent of the crashes occurred in dry conditions.

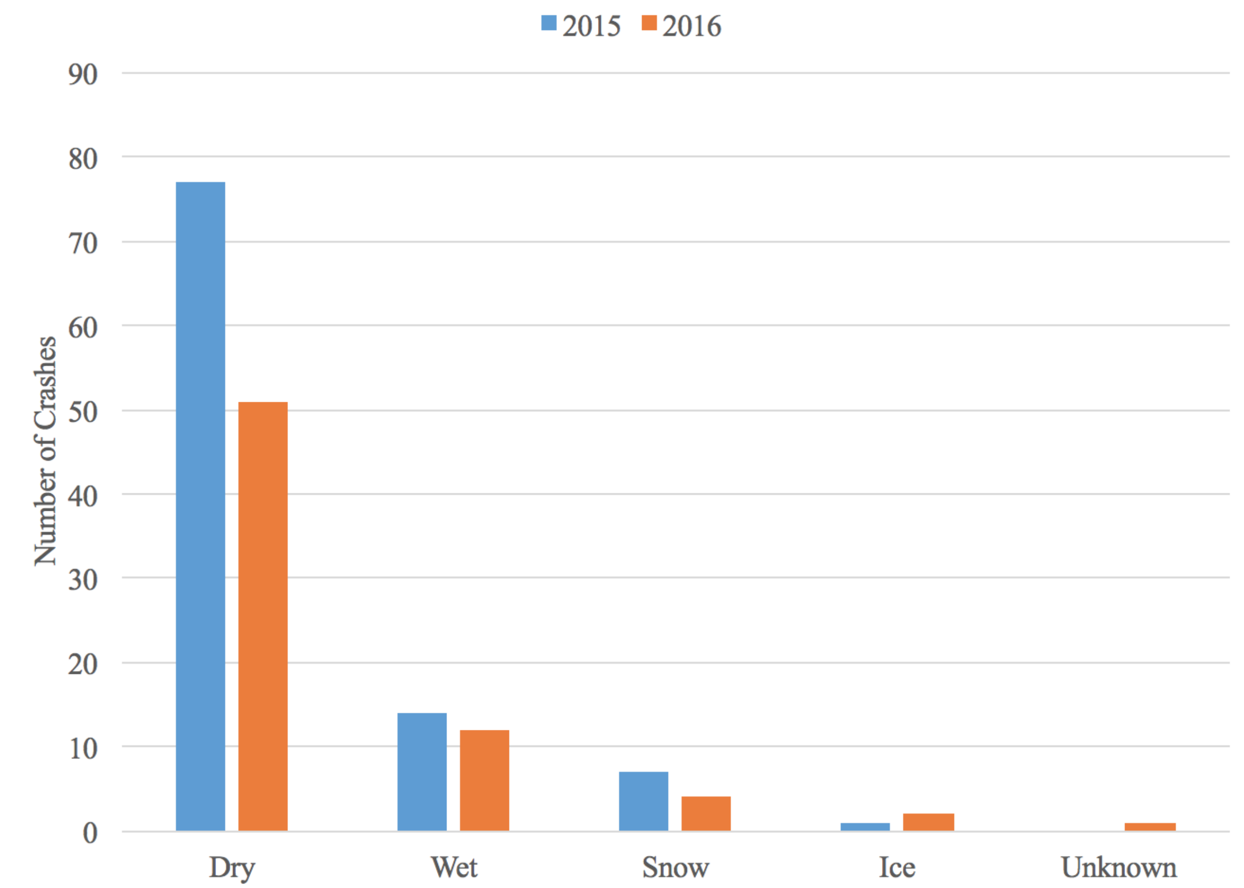


Figure 5.14. Crashes by road surface condition for I-170 northbound

5.2.2 Crashes during Work Zone Period

A total of 13 crashes occurred in the study area when the work zone was in place between November 30 and December 31, 2016. The crashes are summarized in Table 5.3 and Table 5.4 and contain the dates for when the work zone and alternative sign were in effect.

Table 5.3. Summary of crashes during work zone period

Travelway	Log	Crash Class	Date	Severity Rating*	Description
IS 170 E	4.015	PASSING	12/1/2016	PDO	Vehicles collided on side near closed lane area for work zone.
IS 170 E	4.614	PASSING	12/8/2016	PDO	Collision during lane change.
IS 170 E	3.695	PASSING	12/19/2016	PDO	Lane encroachment. Unclear if crash occurred near EB I-70 entrance ramp or just before construction gore point.
IS 170 E	3.558	REAR-END	12/21/2016	MI	Rear-end collision due to traffic slowdown.
IS 170 E	3.862	PASSING	12/23/2016	PDO	Collision during lane change in traffic slowdown.
IS 170 E	3.583	OUT OF CONTROL	12/27/2016	MI	Vehicle swerved to avoid striking a squirrel and struck guardrail.
IS 170 W	7.124	REAR-END	11/30/2016	PDO	Rear-end collision in stopped traffic.
IS 170 W	7.473	REAR-END	11/30/2016	PDO	Rear-end collision in stopped traffic.
IS 170 W	7.548	REAR-END	11/30/2016	PDO	Rear-end collision due to another driver who was driving recklessly.
IS 170 W	7.049	REAR-END	12/12/2016	PDO	Rear-end collision after vehicle followed construction truck into work area.
IS 170 W	5.869	PASSING	12/16/2016	I	Vehicle slid on ice, causing collision with another vehicle.
IS 170 W	6.943	CHANGING LANE	12/19/2016	MI	Vehicle collision due to lane change in advance of split in icy road conditions.
IS 170 W	6.558	REAR-END	12/20/2016	PDO	Rear-end collision in heavy work zone traffic.

IS = Interstate
* PDO = Property Damage Only, MI = Minor Injury, I = Injury

Table 5.4. Dates for work zone and alternative sign

Direction	Begin Work Zone	Begin Alternative Sign	End Alternative Sign	End Work Zone
northbound (westbound)	12/1/2016	12/10/2016	12/21/2016	12/30/2016
southbound (eastbound)	11/30/2016	12/7/2016	12/21/2016	12/31/2016

Figure 5.15 shows the distribution of these crashes by type.

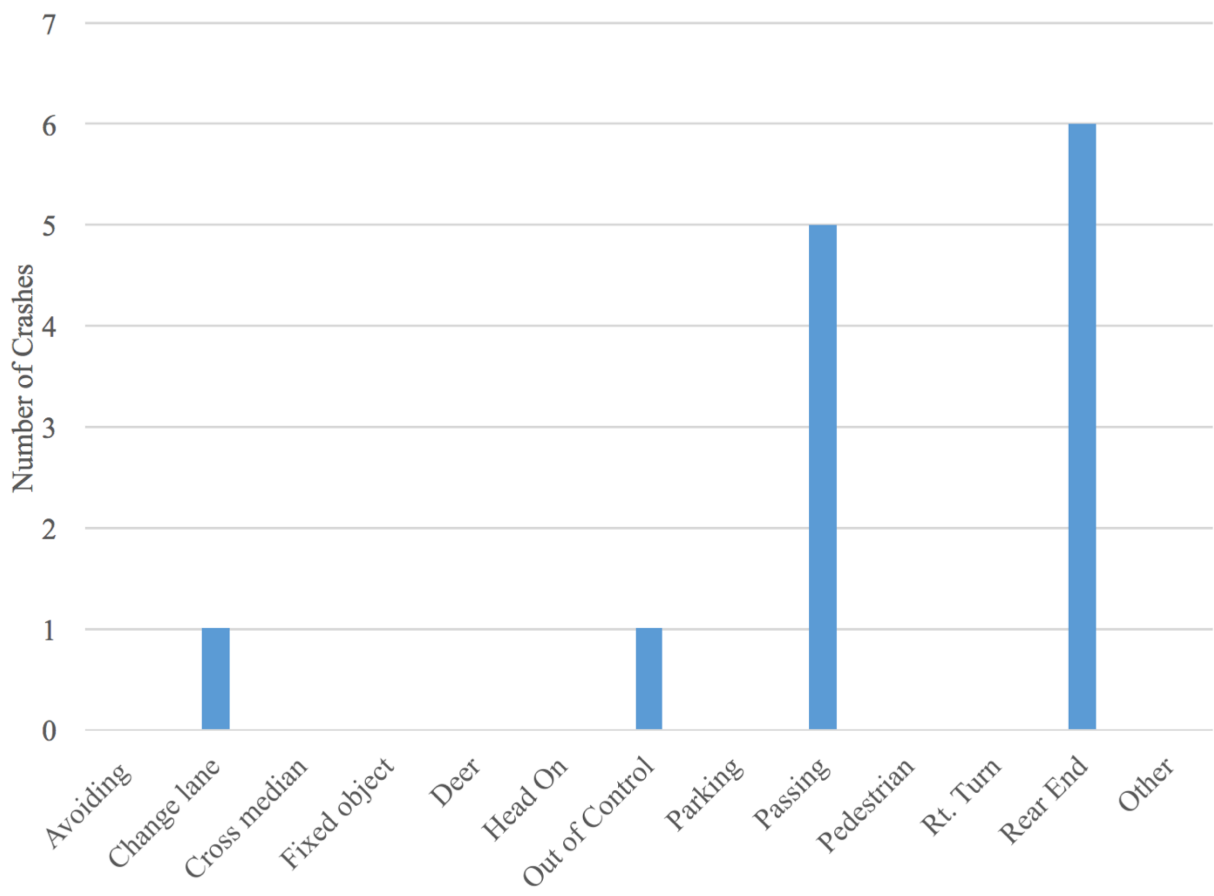


Figure 5.15. Crashes during work zone period by type

As shown in the figure, almost all of the crashes involved lane changing, passing, or rear-end collision, although there was one crash caused by a vehicle losing control. The crash patterns during the work zone period were similar to the crash patterns before the work zone was in place. Additional information regarding the crashes may be found in Appendix A.

Three of the crashes occurred in heavy traffic conditions on northbound I-170 on November 30, 2016, when the work zone was only in place on southbound I-170. The remaining four crashes on northbound I-170 occurred during the time period when the alternative sign was in place. Factors that contributed to these crashes included heavy traffic conditions, icy road conditions, lane changing, and a vehicle following a construction truck into the work area. The crash on northbound I-170 on December 19, 2016 occurred as a result of a collision between vehicles during a lane change maneuver in advance of the work zone split. However, the road conditions at the time of the crash were icy, and there is no indication in the crash report that driver confusion or the use of the alternative sign was a contributing factor in the crash.

A total of six crashes occurred on southbound I-170 between November 30 and December 31, 2016, with three of the crashes taking place while the alternative sign was in place. Two of the six crashes occurred during traffic slowdowns, while another crash was caused by a vehicle swerving to avoid a collision with a squirrel. One crash happened near the lane closure area before the alternative sign was in place. Two of the crashes that occurred while the alternative sign was being used were due to lane encroachment, while the third crash was a rear-end collision during a traffic slowdown. There is no indication from the crash reports that driver confusion or the use of the alternative sign played a role in any of these crashes.

5.3 Summary of Results of Crash Data Analysis

It does not appear that the use of the alternative split sign affected the crash patterns on this section of I-170. The number of crashes in 2016 was generally lower than the number of crashes in 2015. On southbound I-170, there was one more crash in December 2016 compared to December 2015, and there were two more crashes in December 2016 compared to November 2016. These variations are likely due to the random fluctuations in the number of crashes. On northbound I-170, the number of crashes per month remained the same between December 2015 and December 2016. In addition, there were three fewer crashes in December 2016 compared to November 2016. In reviewing the combined crash statistics in both directions, there was one more crash in December 2016 compared to December 2015 and one less crash in December 2016 compared to November 2016.

The predominant types of crashes that occurred on this stretch of I-170 during the non-work zone period were rear-end, passing, and out of control. This crash pattern mirrors the types of crashes that occurred during the work zone period from November 30, 2016 to December 31, 2016. During the work zone period, 46 percent of the crashes were rear-end and 38 percent were passing. A total of 13 crashes occurred during this time period, although three of these crashes took place on northbound I-170 when the work zone was only in place on southbound I-170. While there were some crashes due to lane changing or passing when the alternative sign was in place, the use of the alternative sign does not appear to have been a contributing factor to these crashes based on the information contained in the crash reports.

CHAPTER 6. TRAVEL TIME ANALYSIS

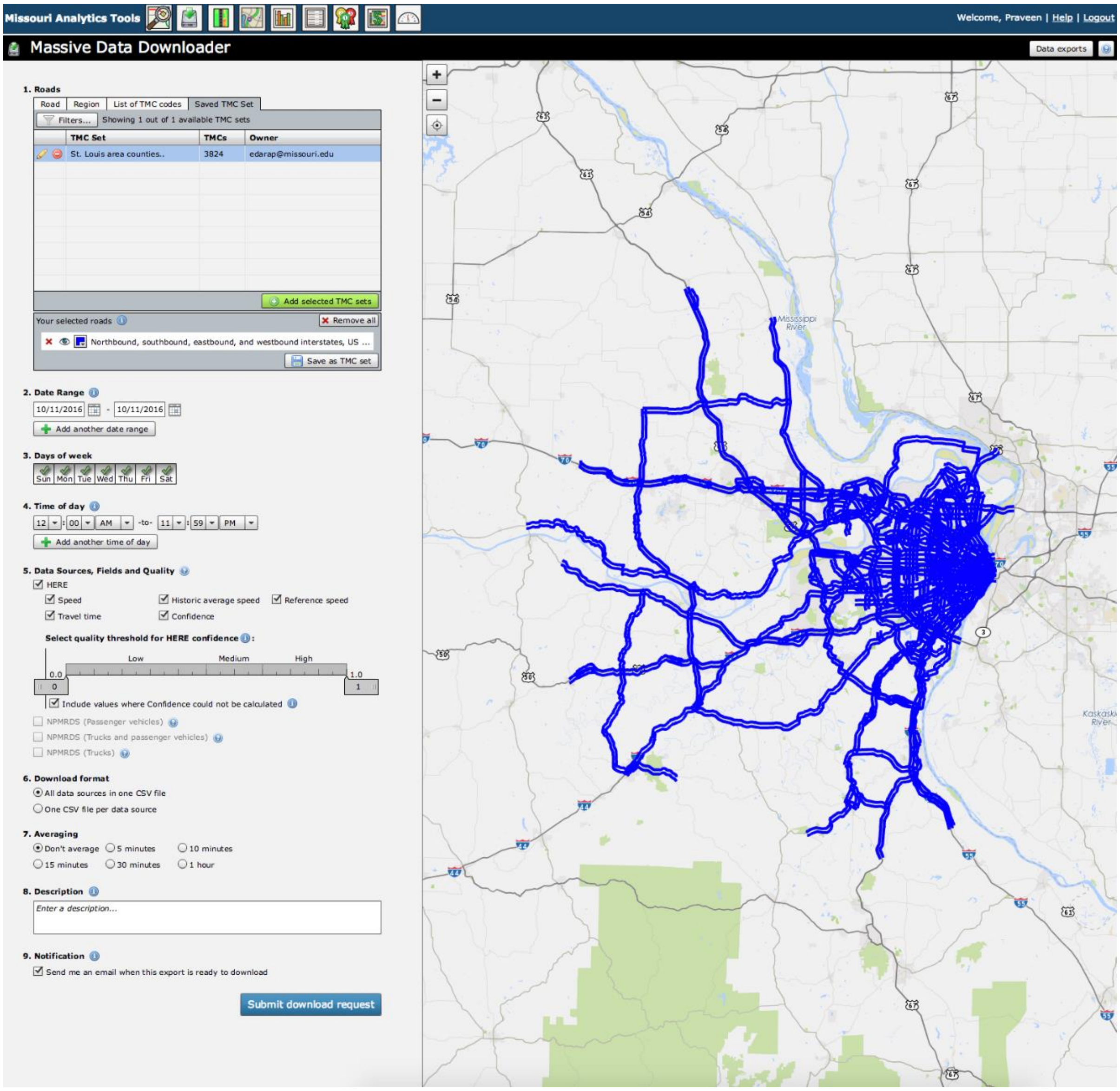
6.1 Introduction

In addition to the safety analysis, the operations of the work zone with the alternative sign were assessed. To perform this analysis, travel times between the work zone period with the alternative sign and the non-work zone period were compared. As previously shown in Table 5.4, the alternative sign was in place on southbound I-170 for 15 days (between December 7 and December 21, 2016) and on northbound I-170 for 12 days (between December 10 and December 21, 2016).

6.2 Travel Time Data

To analyze the travel time impacts for the presence of the work zone and alternative work zone split signage, adjacent segments around the work zone location (within a two-mile radius) were queried from the RITIS database. (MoDOT obtains travel data from RITIS for various roadways in Missouri.) Travel time data from RITIS were used on a previous project to develop a data-driven traffic impact assessment tool for work zones (Edara et al. 2017).

Figure 6.1 shows a screenshot of a RITIS data query window, including a coverage map of the St. Louis area and criteria for the query, including date, time, duration, and data format.



Edara et al. 2017

Figure 6.1. RITIS data query interface and detector deployment in St. Louis area

The query output, as shown in Figure 6.2, includes travel time, speed, and traffic message channel (TMC) codes used to identify the segments.

tmc_code	measurement_tstamp	speed	average_speed	reference_speed	travel_time_minutes	confidence
119-12871	01/01/2015 12:00:18 AM	31.69	30.97	25	0.69	0.7
119N13546	01/01/2015 12:00:18 AM	37.9	34.77	33	0.08	0.7
119P13325	01/01/2015 12:00:18 AM	24.86	24.85	45	0.28	0.7
119N04183	01/01/2015 12:00:18 AM	56.15	48.62	52	0.8	0.85
119-12859	01/01/2015 12:00:18 AM	39.15	43.25	36	0.52	0.7
119P13630	01/01/2015 12:00:18 AM	23.61	28.23	26	0.15	0.7
119N13621	01/01/2015 12:00:18 AM	34.18	34.18	27	0.08	0.7
119-13434	01/01/2015 12:00:18 AM	20.51	25.54	19	0.59	0.7

tmc	road	direction	intersection	state	county	zip	start latitude	start longitude	end latitude	end longitude	miles	road order
119+13650	Bellefontaine Rd	NORTHBOUND	I-270/Dunn Rd	MO	ST LOUIS	63137	38.74948	-90.22402	38.76942	-90.22088	1.38731	6
119P13650	Bellefontaine Rd	NORTHBOUND	I-270/Dunn Rd	MO	ST LOUIS	63138	38.76942	-90.22088	38.77023	-90.22074	0.056411	7
119-13650	Bellefontaine Rd	SOUTHBOUND	I-270/Dunn Rd	MO	ST LOUIS	63138	38.79406	-90.21385	38.77023	-90.22074	1.68779	2
119N13650	Bellefontaine Rd	SOUTHBOUND	I-270/Dunn Rd	MO	ST LOUIS	63138	38.77023	-90.22074	38.76942	-90.22088	0.056411	3
119+13508	Big Bend Rd	EASTBOUND	I-270	MO	ST LOUIS	63122	38.5672	-90.47614	38.56711	-90.44095	2.06902	6
119P13508	Big Bend Rd	EASTBOUND	I-270	MO	ST LOUIS	63122	38.56711	-90.44095	38.56735	-90.43921	0.095707	7
119-13508	Big Bend Rd	WESTBOUND	I-270	MO	ST LOUIS	63122	38.56696	-90.43079	38.56735	-90.43921	0.45771	8
119N13508	Big Bend Rd	WESTBOUND	I-270	MO	ST LOUIS	63122	38.56735	-90.43921	38.56711	-90.44095	0.095707	9
119+13618	Dorsett Rd	EASTBOUND	I-270	MO	ST LOUIS	63043	38.71454	-90.45399	38.71454	-90.44833	0.306022	3
119P13618	Dorsett Rd	EASTBOUND	I-270	MO	ST LOUIS	63043	38.71454	-90.44626	38.71454	-90.44833	0.113363	4

Edara et al. 2017

Figure 6.2. Screenshot of RITIS output

As shown in the top part of Figure 6.2, there are seven fields for the travel time and speed information: TMC code, time stamp, speed, average speed, reference speed, travel time, and confidence level. The RITIS output also includes descriptive information for the unique TMS codes for RITIS segments, including TMC code, road, direction, intersection, state, county, zip, start and end latitude/longitude, segment miles, and road order, as shown in the bottom part of Figure 6.2.

The time stamp field includes both the date (month, day, and year) and time of day (hour, minute, and second). There are three speeds that are provided as output by RITIS: prevailing speed, historical average speed, and reference speed (free flow speed). Figure 6.3 provides additional details regarding the speed measures, travel time, and confidence levels.

Data Types

Vendor-Provided Data

Speed — The current estimated harmonic mean speed for the roadway segment in miles per hour.

Travel Time — Time it will take to drive along the roadway segment (Distance Traveled / Speed).

Reference Speed — The calculated "free flow" mean speed for the roadway segment in miles per hour. This attribute is calculated based upon the 85th-percentile point of the observed speeds on that segment for all time periods, which establishes a reliable proxy for the speed of traffic at free-flow for that segment.

Historic Average Speed — The historical average speed for the roadway segment for that hour of the day and day of the week in miles per hour.

Comparative Speed — Measured speed as a percentage of the historic average speed for this time of day and day of week.

Congestion — Measured speed as a percentage of the free flow speed.

Historic Average Congestion — Historic average speed as a percentage of the free flow speed for this time of day and day of week.

Confidence — This is a simple confidence factor.

- Between 0.7 and 1.0 (including 1.0) - high confidence, based on real-time data for that specific segment
- Between 0.5 and 0.7 (including 0.7) - medium confidence, based on a combination of historic and real-time data
- Between 0.0 and 0.5 (including 0.5) - lower confidence, based primarily on road reference speeds

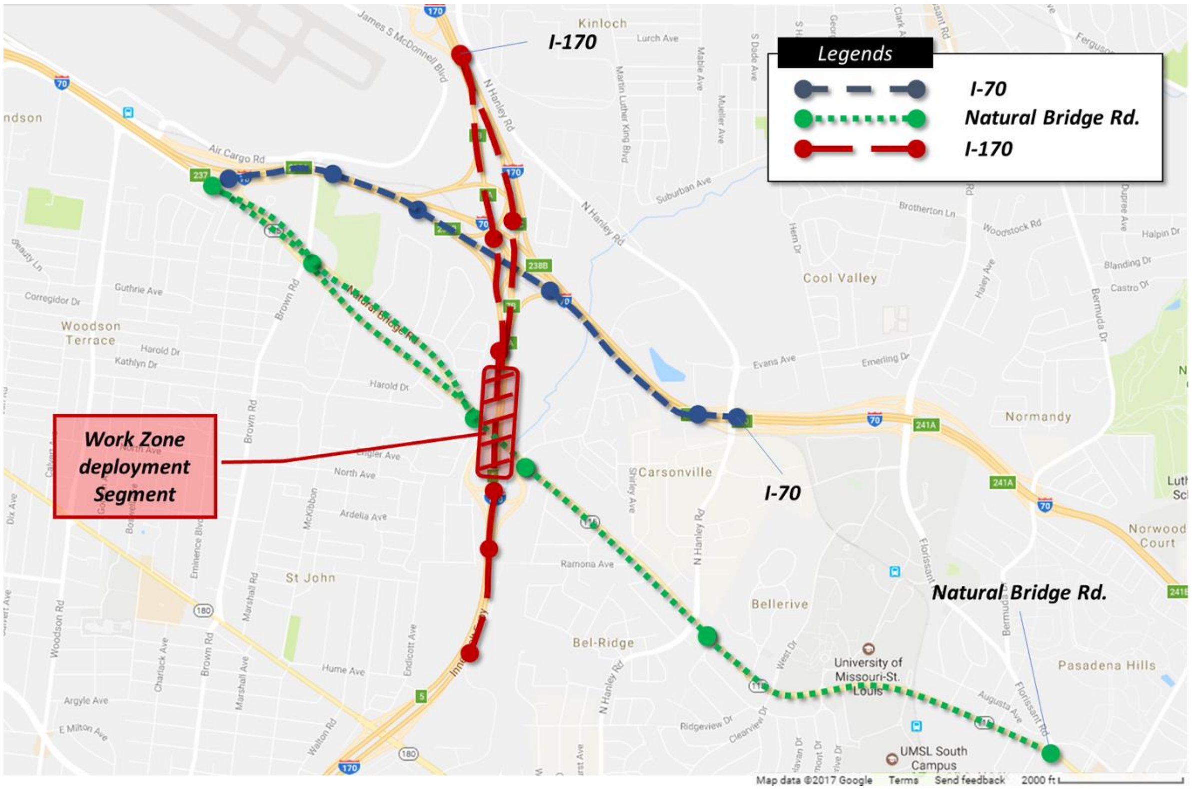
Edara et al. 2017

Figure 6.3. RITIS data description

6.3 Study Area

Travel time analysis was conducted on the I-170 work zone segment and in the vicinity of the work zone segment, including sections of I-170 upstream and downstream from the work zone and adjacent routes. There are two major adjacent routes that intersect I-170 in the vicinity of the work zone: I-70 on the north end of the work zone segment and Natural Bridge Road on the south end of the work zone segment.

The study area, including I-170 and the identified adjacent segments, is shown in Figure 6.4. Each green, red, or blue dot on the map represents the RITIS sensor segment.



Google Maps

Figure 6.4. Study area for operational analysis using RITIS

The AADT values for these routes are presented in Table 6.1. I-70 and I-170 have quite similar AADT values for both total traffic and number of trucks.

Table 6.1. AADT for the study routes in 2015

Route	Traffic	Truck
I-170	113,253	15,440
I-70	133,231	11,613*
Natural Bridge Road	13,017	NA

*A closest upstream/downstream observation
Source: MoDOT 2015b

6.4 Performance Measurement for Travel Time Analysis

Two measures using historical information were utilized for quantifying the operational impacts of the work zone: travel time difference analysis based on historical three-week average travel time for the segment (HATT) and travel time difference analysis based on travel time for the segment one year ago (HYTT). Since the HATT needs to include travel time information for only non-work zone days, the three weeks prior the first day of work zone, between October 27, 2016 and November 16, 2016, were used. The time period between November 17 and 29, 2016 was excluded from the analysis because it was expected that travel patterns would be different due to the Thanksgiving holiday.

The average travel time difference per mile is calculated using the following equation:

$$\left[\sum_{t=1}^{T}\left(\frac{\mathrm{WZ\ TT}_t - \mathrm{HATT}_t}{S}\right)\right] / n_T \tag{6.1}$$

where

S is segment length

WZ TT_t is the travel time when work zone was present

HATT_t is the historical average travel time computed by averaging the travel times in the past three weeks for the same segment, same time of day, and day of the week

n_T is the number of observations completed within the work zone duration

Travel time difference from the travel time one year ago was calculated by replacing the HATT_t with travel time from a year ago in Equation 6.1 and is denoted by HYTT_t.

RITIS provides travel time information for every minute, and both HATT and HYTT were calculated for all times of day (i.e., 24 hours in each day). The dates used for the HATT and HYTT analyses are shown in Table 6.2.

Table 6.2. Dates used for HATT and HYTT analyses

Route	Direction	Dates for HATT	Dates for HYTT
I-170	NB	10/27/2016 - 11/16/2016	12/12/2015 - 12/23/2015
I-170	SB	10/27/2016 - 11/16/2016	12/9/2015 - 12/23/2015
I-70	EB	10/27/2016 - 11/16/2016	12/9/2015 - 12/23/2015
I-70	WB	10/27/2016 - 11/16/2016	12/12/2015 - 12/23/2015
Natural Bridge Rd.	EB	10/27/2016 - 11/16/2016	12/9/2015 - 12/23/2015
Natural Bridge Rd.	WB	10/27/2016 - 11/16/2016	12/12/2015 - 12/23/2015

6.5 Travel Time Analysis

The computed HATT and HYTT values are presented in Table 6.3, and each average HATT and HYTT during the work zone schedule is shown in Figure 6.5 and Figure 6.6.

Table 6.3. Calculated HATT and HYTT differences (seconds per mile)

			HATT					**HYTT**				
Routes	**Direction**	**Analysis**	***2_nd UPS***	***1_st UPS***	***Work Zone***	***1_st DS***	***2_nd DS***	***2_nd UPS***	***1_st UPS***	***Work Zone***	***1_st DS***	***2_nd DS***
I-170	*NB*	*Ave*	6.63	6.60	3.47	3.46	2.54	7.59	7.48	3.26	3.29	2.36
		STD	4.44	4.42	4.27	4.29	3.55	3.25	3.23	3.43	3.47	2.51
		Max	13.60	13.59	17.10	17.17	13.82	15.00	14.94	14.49	14.65	10.25
		Min	0.00	0.00	0.00	0.00	0.00	3.16	3.05	0.70	0.70	0.69
	SB	*Ave*	12.08	12.15	10.06	10.17	3.92	12.93	13.03	11.25	11.42	3.87
		STD	9.61	9.63	8.37	8.41	3.41	7.91	7.91	6.66	6.66	2.00
		Max	25.79	25.83	26.42	26.56	12.27	25.86	25.98	24.47	24.64	8.36
		Min	0.00	0.00	0.00	0.00	0.00	0.92	0.97	3.26	3.44	1.73
I-70	*EB*	*Ave*	4.97	4.85	5.22	5.21	6.23	4.97	4.82	4.82	4.80	6.32
		STD	6.37	6.31	7.39	7.38	10.41	6.00	5.97	7.08	7.07	10.01
		Max	18.96	18.84	25.92	25.92	41.25	19.18	19.04	25.78	25.71	40.97
		Min	0.00	0.00	0.00	0.00	0.00	0.98	0.87	0.65	0.60	0.92
	WB	*Ave*	2.37	2.55	2.57	4.47	4.44	3.90	5.02	4.87	3.97	3.94
		STD	4.14	4.90	4.93	6.71	6.69	3.91	4.34	4.37	4.43	4.41
		Max	14.94	17.28	17.29	23.93	23.93	15.36	17.40	17.27	17.78	17.79
		Min	0.00	0.00	0.00	0.00	0.00	0.96	1.18	1.09	0.53	0.54
Natural Bridge Road	*EB*	*Ave*	5.89	7.78	7.71	17.78	15.69	7.12	8.00	7.87	20.43	18.04
		STD	3.59	5.37	5.33	10.74	13.10	2.25	2.71	2.68	6.63	12.47
		Max	11.88	17.77	17.62	28.56	45.47	12.96	13.67	13.22	31.96	52.26
		Min	0.00	0.00	0.00	0.00	0.00	4.75	4.60	4.51	12.54	0.12
	*WB**	*Ave*	5.87	10.00	9.12	15.39	6.35	9.19	-	-	-	-
		STD	3.69	6.45	6.01	9.44	5.01	2.92	-	-	-	-
		Max	11.96	20.88	19.87	30.51	18.48	14.89	-	-	-	-
		Min	0.00	0.00	0.00	0.00	0.00	4.41	-	-	-	-

* Westbound of Natural Bridge Road had no records for the days of interest in 2015.

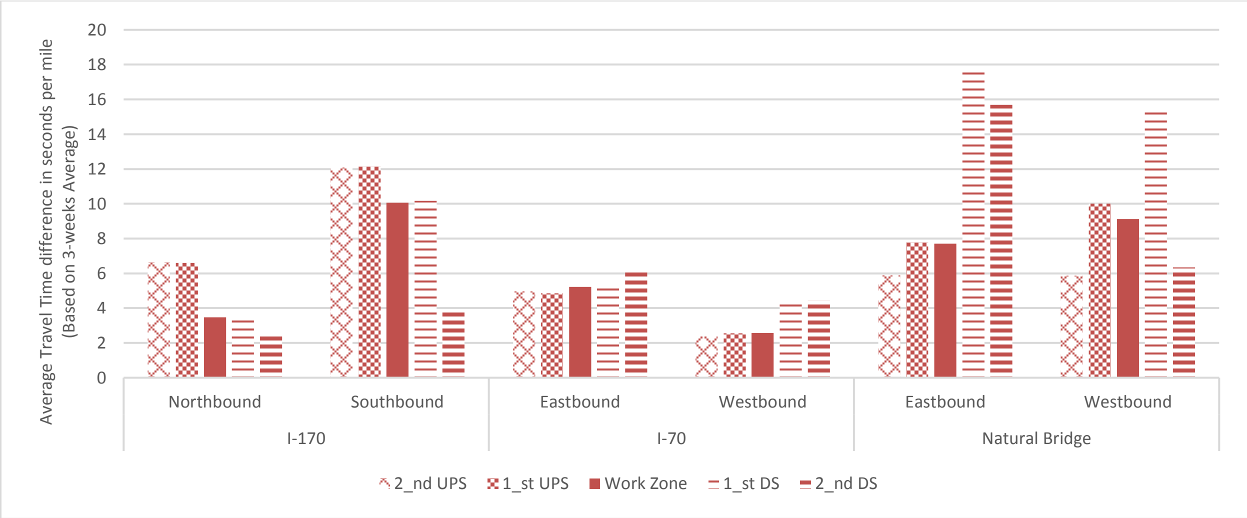


Figure 6.5. Average travel time difference from three-week average travel time (HATT)

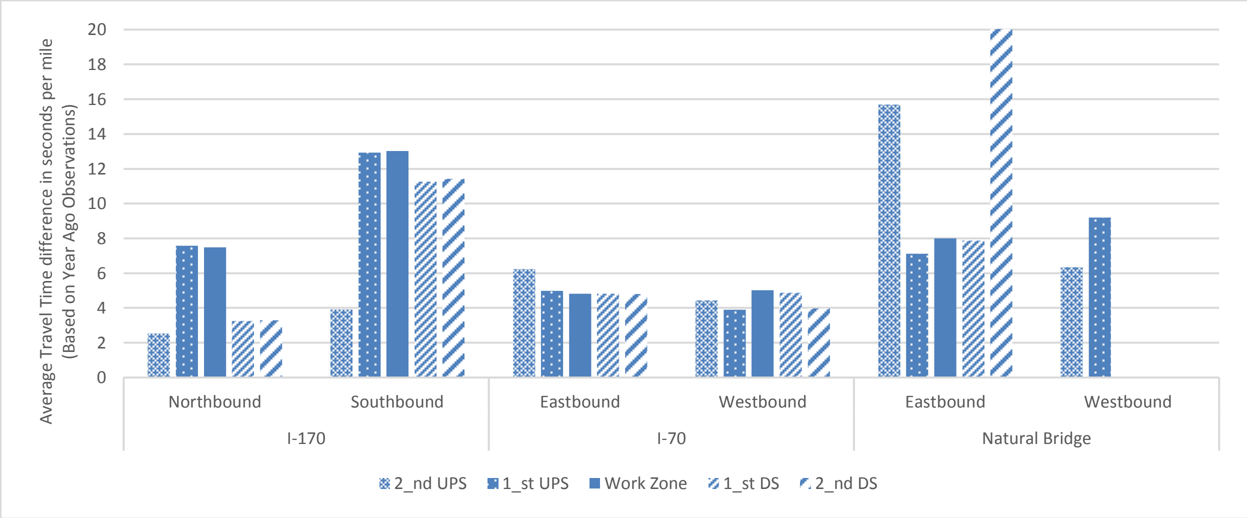


Figure 6.6. Average travel time difference from year ago travel time (HYTT)

Figure 6.5 shows HATT while Figure 6.6 shows HYTT. For simplicity, travel times from the second upstream segments through the second downstream segments are presented. The results show that there was a minor travel time increase of a few seconds during the time that the alternative sign was present in the work zone. The small increase had minimal impact on travel times through the work zone. I-170 had higher travel time differences than I-70, and I-170 southbound had higher travel time differences than I-170 northbound. The travel time differences on Natural Bridge Road were also higher than the travel time differences on I-70. From these results, it can be concluded that the use of the alternative sign in the work zone did not significantly affect operations on I-170 or its adjacent corridors.

CHAPTER 7. CONCLUSIONS

In this project, the use of alternative signage for closure of a middle lane in a freeway work zone was evaluated based on its implementation at the work zone for the Missouri bridge rehabilitation project J6I2104 on I-I70 between I-70 and Natural Bridge Road. The work zone included the shifting of three lanes, two lanes around one side of the work area and one lane around the other side. The evaluation of the alternative signage included the collection and analysis of field videos to assess driver behavior, stakeholder interviews, driver surveys, and operational and safety analyses. The findings from the study can be summarized as follows:

- Drivers seemed to generally accept the alternative signage because no concerns regarding the use of the sign were submitted through the MoDOT driver survey website.
- The use of the alternative sign did not create any adverse safety impacts. Crash patterns during the work zone period were similar to the crash patterns before the work zone was in place, and the use of the alternative sign did not appear to be a contributing factor in any work zone crashes.
- Lane changing behavior decreased as the construction progressed.
- Instances of aggressive driver behavior were observed in the videos, but these instances do not appear to be related to the use of the alternative sign.
- The use of the alternative sign did not cause any adverse operational impacts in the work zone and surrounding area.
- MoDOT personnel and contractors familiar with the project believed that the sign helped to communicate information clearly but had mixed perceptions on whether the use of the sign improved safety. Some respondents believed that drivers simply do not pay attention to signs.

In summary, the investigation of the use of the alternative sign on the I-170 project found that the alternative sign has great potential for use on freeway work zones with lane closures in the middle lane. The stakeholders believed that it communicated information more effectively to drivers, and the use of the sign did not appear to create any adverse impacts for operations or safety.

REFERENCES

AASHTO. 2010. *Highway Safety Manual (HSM) 2010.* American Association of State Highway and Transportation Officials, Washington, DC.

Bertucci, A. 2006. *Sign Legibility Rules of Thumb*. US Sign Council, Bristol, PA.

Edara, P., Y. Chang, C. Sun, and H. Brown. 2017. *Data-Driven Traffic Impact Assessment Tool for Work Zones*. Smart Work Zone Deployment Initiative. Iowa Department of Transportation and Midwest Transportation Center, Ames, IA.

Edara, P., C. Sun, and Z. Zhu. 2014. *Investigation of Alternative Work Zone Merging Sign Configurations*. Missouri Department of Transportation, Jefferson City, MO.

FHWA. 2009. *Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD).* Federal Highway Administration, Washington, DC.

MoDOT. 2013. *MoDOT Work Zone Customer Survey*. Missouri Department of Transportation, Jefferson City, MO. http://www.modot.org/workzones/Comments.htm. Accessed April 25, 2017.

MoDOT. 2015a. *Construction Plans for Job No. J6I2104, Route 70, St. Louis County*. Missouri Department of Transportation, Jefferson City, MO.

MoDOT. 2015b. *Traffic Volume Map*. Missouri Department of Transportation, Jefferson City, MO. http://www.modot.org/safety/trafficvolumemaps.htm. Accessed April 17, 2017.

APPENDIX A: CRASH DATA OUTPUT

Table A.1. TMS Accident Browser output from selected fields for 2015 and 2016 crashes

Travelway	Log	Crash Class	Date	Severity Rating	Light Cond	Road Surf Cond	Weather Cond
IS 170 E	5.249	CHANGING LANE	1/1/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	ICE	FREEZING
IS 170 E	3.449	OUT OF CONTROL	1/3/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	WET	RAIN
IS 170 E	4.808	OUT OF CONTROL	1/16/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLOUDY
IS 170 E	5.134	PASSING	1/16/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.203	OUT OF CONTROL	1/19/2015	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.09	OUT OF CONTROL	1/22/2015	DISABLING INJURY	DARK W/ STREET LIGHTS OFF	DRY	CLEAR
IS 170 E	5.246	REAR-END	1/23/2015	MINOR INJURY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 E	3.553	OUT OF CONTROL	2/1/2015	MINOR INJURY	DAYLIGHT	WET	RAIN
IS 170 E	4.303	PARKING OR PARKED CAR	2/1/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS OFF	WET	FREEZING
IS 170 E	3.457	PASSING	2/11/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	5.151	OUT OF CONTROL	2/20/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	ICE	RAIN
IS 170 E	4.066	PASSING	2/24/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 E	3.58	OUT OF CONTROL	2/26/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	SNOW	SNOW
IS 170 E	3.449	OUT OF CONTROL	2/27/2015	MINOR INJURY	DARK W/ STREET LIGHTS ON	DRY	CLOUDY
IS 170 E	5.141	OTHER	2/28/2015	MINOR INJURY	DAYLIGHT	SNOW	CLOUDY
IS 170 E	4.084	OUT OF CONTROL	3/9/2015	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.076	REAR-END	3/9/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.123	REAR-END	3/10/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	RAIN
IS 170 E	4.18	OUT OF CONTROL	3/10/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 E	5.16	REAR-END	3/14/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	WET	RAIN
IS 170 E	4.678	CHANGING LANE	3/30/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR

Travelway	Log	Crash Class	Date	Severity Rating	Light Cond	Road Surf Cond	Weather Cond
IS 170 E	5.255	OUT OF CONTROL	4/1/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	5.265	OUT OF CONTROL	4/13/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	CLOUDY
IS 170 E	3.439	REAR-END	4/13/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	RAIN
IS 170 E	5.246	REAR-END	4/18/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	3.477	OUT OF CONTROL	4/25/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	RAIN
IS 170 E	5.246	REAR-END	4/27/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	5.227	REAR-END	4/28/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	5.246	REAR-END	5/6/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.191	REAR-END	5/6/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	3.872	REAR-END	5/6/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	5.283	PASSING	5/19/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.746	OUT OF CONTROL	5/21/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.897	REAR-END	5/28/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS OFF	DRY	CLEAR
IS 170 E	4.191	REAR-END	6/7/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 E	4.468	OTHER	6/8/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.124	OTHER	6/12/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.05	OUT OF CONTROL	6/13/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.047	PASSING	6/19/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	RAIN
IS 170 E	3.958	OTHER	6/25/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	3.477	REAR-END	7/9/2015	MINOR INJURY	DAYLIGHT	WET	CLEAR
IS 170 E	4.085	PASSING	7/23/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.099	REAR-END	7/28/2015	MINOR INJURY	DAYLIGHT	DRY	CLOUDY
IS 170 E	4.064	REAR-END	7/30/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	3.477	REAR-END	8/11/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	3.439	PASSING	8/27/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	3.449	PASSING	9/5/2015	DISABLING INJURY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.48	OTHER	9/25/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	CLOUDY
IS 170 E	3.46	REAR-END	9/30/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	UNKNOWN
IS 170 E	5.255	REAR-END	10/1/2015	MINOR INJURY	DAYLIGHT	DRY	CLEAR

Travelway	Log	Crash Class	Date	Severity Rating	Light Cond	Road Surf Cond	Weather Cond
IS 170 E	4.984	OTHER	10/4/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 E	3.591	REAR-END	10/13/2015	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 E	3.601	OUT OF CONTROL	10/22/2015	DISABLING INJURY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.061	PEDESTRIAN	10/24/2015	MINOR INJURY	DARK W/ STREET LIGHTS OFF	DRY	CLOUDY
IS 170 E	5.208	OUT OF CONTROL	10/30/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLOUDY
IS 170 E	4.555	AVOIDING	11/19/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	3.467	REAR-END	11/20/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	3.449	OUT OF CONTROL	11/22/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 E	4.115	PASSING	11/23/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 E	3.477	OUT OF CONTROL	11/27/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	RAIN
IS 170 E	3.515	OUT OF CONTROL	11/27/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	WET	RAIN
IS 170 E	4.871	REAR-END	12/3/2015	PROPERTY DAMAGE ONLY	DARK - UNKNOWN	DRY	CLEAR
IS 170 E	4.375	REAR-END	12/3/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 E	5.255	REAR-END	12/10/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS OFF	DRY	CLEAR
IS 170 E	5.255	REAR-END	12/14/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS OFF	WET	RAIN
IS 170 E	4.047	CHANGING LANE	2/1/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	3.477	OUT OF CONTROL	2/10/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	SNOW	SNOW
IS 170 E	4.831	REAR-END	2/25/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 E	3.449	REAR-END	3/15/2016	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 E	5.255	REAR-END	3/16/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.796	OUT OF CONTROL	3/19/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS OFF	WET	CLOUDY
IS 170 E	4.253	REAR-END	4/16/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.186	PASSING	5/14/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.167	REAR-END	5/18/2016	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.167	REAR-END	6/2/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR

Travelway	Log	Crash Class	Date	Severity Rating	Light Cond	Road Surf Cond	Weather Cond
IS 170 E	4.086	REAR-END	6/26/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 E	3.592	PASSING	6/28/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.08	PASSING	8/5/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.088	REAR-END	8/12/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS OFF	WET	RAIN
IS 170 E	5.255	REAR-END	8/30/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 E	4.092	PASSING	9/2/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	UNKN	UNKNOWN
IS 170 E	4.594	PASSING	9/10/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 E	5.024	PASSING	9/28/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS OFF	DRY	CLOUDY
IS 170 E	4.108	REAR-END	10/18/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 E	5.153	DEER	11/9/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.508	PASSING	11/27/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 E	4.985	REAR-END	11/28/2016	MINOR INJURY	DARK W/ STREET LIGHTS OFF	WET	RAIN
IS 170 E	4.985	REAR-END	11/28/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	WET	RAIN
IS 170 E	4.015	PASSING	12/1/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	4.614	PASSING	12/8/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	3.695	PASSING	12/19/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 E	3.558	REAR-END	12/21/2016	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 E	3.862	PASSING	12/23/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 E	3.583	OUT OF CONTROL	12/27/2016	MINOR INJURY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 W	6.989	OUT OF CONTROL	1/4/2015	MINOR INJURY	DAYLIGHT	WET	CLOUDY
IS 170 W	7.623	REAR-END	1/15/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.511	REAR-END	1/20/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 W	6.396	REAR-END	1/27/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.865	REAR-END	1/31/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.621	REAR-END	2/4/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	SNOW	FREEZING
IS 170 W	6.979	OUT OF CONTROL	2/4/2015	PROPERTY DAMAGE ONLY	DARK - UNKNOWN	SNOW	SNOW

Travelway	Log	Crash Class	Date	Severity Rating	Light Cond	Road Surf Cond	Weather Cond
IS 170 W	7.616	OUT OF CONTROL	2/4/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	SNOW	SNOW
IS 170 W	7.616	PASSING	2/4/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	ICE	SNOW
IS 170 W	6.984	REAR-END	2/11/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.663	REAR-END	2/15/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	SNOW	CLOUDY
IS 170 W	7.631	OUT OF CONTROL	2/15/2015	MINOR INJURY	DARK W/ STREET LIGHTS ON	SNOW	SNOW
IS 170 W	7.044	OUT OF CONTROL	2/16/2015	MINOR INJURY	DAYLIGHT	SNOW	CLOUDY
IS 170 W	7.53	REAR-END	2/18/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	SNOW	FREEZING
IS 170 W	6.634	CROSS MEDIAN	2/20/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.436	REAR-END	2/22/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.96	OUT OF CONTROL	2/25/2015	DISABLING INJURY	DARK W/ STREET LIGHTS OFF	DRY	CLEAR
IS 170 W	5.893	PASSING	3/3/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	WET	RAIN
IS 170 W	7.634	PASSING	3/16/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.008	REAR-END	3/28/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.027	REAR-END	3/30/2015	MINOR INJURY	DAYLIGHT	DRY	CLOUDY
IS 170 W	7.587	REAR-END	3/31/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	6.628	PASSING	4/1/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 W	7.606	REAR-END	4/3/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.606	OUT OF CONTROL	4/5/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 W	7.606	REAR-END	4/8/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.856	CHANGING LANE	4/10/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	CLEAR
IS 170 W	5.865	REAR-END	4/12/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.865	REAR-END	4/12/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.017	REAR-END	4/13/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	CLOUDY
IS 170 W	7.62	PASSING	4/15/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.621	REAR-END	4/18/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.621	REAR-END	4/21/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.846	REAR-END	4/23/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR

Travelway	Log	Crash Class	Date	Severity Rating	Light Cond	Road Surf Cond	Weather Cond
IS 170 W	7.616	REAR-END	5/4/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.008	REAR-END	5/8/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.64	OUT OF CONTROL	5/17/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	CLOUDY
IS 170 W	7.53	PASSING	5/26/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.903	REAR-END	5/28/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	6.941	PASSING	5/28/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLOUDY
IS 170 W	6.373	REAR-END	5/30/2015	MINOR INJURY	DAYLIGHT	WET	CLOUDY
IS 170 W	7.026	OTHER	5/31/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS OFF	WET	CLOUDY
IS 170 W	7.634	OUT OF CONTROL	6/7/2015	MINOR INJURY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 W	6.552	REAR-END	6/17/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 W	6.593	OUT OF CONTROL	6/21/2015	DISABLING INJURY	DARK W/ STREET LIGHTS ON	DRY	CLOUDY
IS 170 W	7.012	REAR-END	6/30/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 W	7.016	OUT OF CONTROL	7/7/2015	MINOR INJURY	DAYLIGHT	WET	RAIN
IS 170 W	7.581	OUT OF CONTROL	7/8/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	WET	CLOUDY
IS 170 W	7.606	REAR-END	7/9/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.606	REAR-END	7/13/2015	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.865	REAR-END	7/23/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.511	REAR-END	7/29/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.036	AVOIDING	7/31/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.873	CHANGING LANE	8/5/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	WET	RAIN
IS 170 W	6.487	FIXED OBJECT	8/6/2015	MINOR INJURY	DAYLIGHT	DRY	CLOUDY
IS 170 W	7.63	PASSING	8/7/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 W	6.98	PASSING	8/11/2015	PROPERTY DAMAGE ONLY	DARK - UNKNOWN	DRY	CLEAR
IS 170 W	5.865	PASSING	9/1/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.865	REAR-END	9/2/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.008	REAR-END	9/3/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR

Travelway	Log	Crash Class	Date	Severity Rating	Light Cond	Road Surf Cond	Weather Cond
IS 170 W	5.865	REAR-END	9/9/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 W	7.452	REAR-END	9/11/2015	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.968	OUT OF CONTROL	9/14/2015	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.865	REAR-END	9/15/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	6.657	PASSING	9/17/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.628	REAR-END	9/18/2015	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 W	6.513	PASSING	9/19/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.606	PASSING	9/22/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.865	PASSING	9/24/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.644	REAR-END	9/29/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	CLOUDY
IS 170 W	5.835	REAR-END	9/30/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.027	OUT OF CONTROL	10/6/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLOUDY
IS 170 W	5.903	PASSING	10/6/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	6.547	PASSING	10/8/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	6.723	PASSING	10/8/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 W	7.411	REAR-END	10/13/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.396	PASSING	10/18/2015	MINOR INJURY	DARK W/ STREET LIGHTS OFF	DRY	CLEAR
IS 170 W	5.865	REAR-END	10/24/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 W	7.031	OTHER	11/2/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.865	REAR-END	11/3/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.865	REAR-END	11/5/2015	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.865	RIGHT TURN RIGHT ANGLE COLLISION	11/6/2015	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.125	PASSING	11/10/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 W	6.998	PASSING	11/11/2015	MINOR INJURY	DARK W/ STREET LIGHTS ON	DRY	CLOUDY
IS 170 W	7.208	PASSING	11/13/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.431	REAR-END	11/17/2015	MINOR INJURY	DARK W/ STREET LIGHTS ON	WET	RAIN

Travelway	Log	Crash Class	Date	Severity Rating	Light Cond	Road Surf Cond	Weather Cond
IS 170 W	6.524	PASSING	11/18/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.095	REAR-END	11/19/2015	DISABLING INJURY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.26	REAR-END	11/20/2015	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.53	REAR-END	11/21/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 W	6.175	CHANGING LANE	11/21/2015	MINOR INJURY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 W	7.616	PASSING	11/23/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS OFF	DRY	CLEAR
IS 170 W	5.865	REAR-END	11/24/2015	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.644	OUT OF CONTROL	11/30/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS OFF	WET	RAIN
IS 170 W	7.634	OUT OF CONTROL	11/30/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	RAIN
IS 170 W	7.49	REAR-END	12/3/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 W	5.865	REAR-END	12/16/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 W	7.027	REAR-END	12/22/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.864	REAR-END	12/31/2015	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 W	7.036	OUT OF CONTROL	1/7/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 W	7.359	REAR-END	1/19/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	SNOW	SNOW
IS 170 W	7.015	RIGHT TURN	1/19/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	SNOW	SNOW
IS 170 W	7.106	PASSING	1/20/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	CLOUDY
IS 170 W	7.036	PASSING	1/23/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS OFF	DRY	CLEAR
IS 170 W	7.616	REAR-END	1/25/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS OFF	WET	CLOUDY
IS 170 W	7.297	REAR-END	1/27/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.865	REAR-END	2/1/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 W	7.396	REAR-END	2/1/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS OFF	DRY	CLEAR
IS 170 W	7.606	OUT OF CONTROL	2/3/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 W	7.552	PASSING	2/7/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.865	OUT OF CONTROL	2/10/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	SNOW	FREEZING

Travelway	Log	Crash Class	Date	Severity Rating	Light Cond	Road Surf Cond	Weather Cond
IS 170 W	7.171	OUT OF CONTROL	2/11/2016	MINOR INJURY	DAYLIGHT	WET	CLOUDY
IS 170 W	5.865	REAR-END	2/11/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	CLEAR
IS 170 W	7.086	OUT OF CONTROL	2/14/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	ICE	SNOW
IS 170 W	7.065	HEAD ON	2/14/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	SNOW	SNOW
IS 170 W	6.75	CHANGING LANE	2/25/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 W	7.616	REAR-END	3/1/2016	MINOR INJURY	DAYLIGHT	DRY	CLOUDY
IS 170 W	5.865	REAR-END	3/8/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 W	7.017	REAR-END	3/9/2016	MINOR INJURY	DAYLIGHT	WET	CLOUDY
IS 170 W	7.644	REAR-END	3/10/2016	MINOR INJURY	DAYLIGHT	DRY	CLOUDY
IS 170 W	6.333	OTHER	3/18/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	6.333	OUT OF CONTROL	3/20/2016	PROPERTY DAMAGE ONLY	NOT STATED/UNKNOWN	UNKN	UNKNOWN
IS 170 W	6.632	RIGHT ANGLE	3/30/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	RAIN
IS 170 W	5.912	REAR-END	4/7/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.116	REAR-END	4/13/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.172	PASSING	4/15/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 W	6.371	OUT OF CONTROL	4/17/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 W	7.626	PASSING	5/11/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	RAIN
IS 170 W	7.252	REAR-END	5/12/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.664	OUT OF CONTROL	5/17/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	RAIN
IS 170 W	7.045	REAR-END	5/23/2016	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.008	REAR-END	5/24/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.865	REAR-END	6/3/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	6.789	REAR-END	6/3/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	6.379	REAR-END	6/26/2016	MINOR INJURY	DARK W/ STREET LIGHTS OFF	DRY	CLEAR
IS 170 W	7.565	PASSING	6/29/2016	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.197	OTHER	7/1/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.657	OUT OF CONTROL	7/25/2016	MINOR INJURY	DAYLIGHT	WET	RAIN
IS 170 W	6.53	OUT OF CONTROL	7/26/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 W	6.37	PASSING	7/27/2016	DISABLING INJURY	DAYLIGHT	DRY	CLEAR

Travelway	Log	Crash Class	Date	Severity Rating	Light Cond	Road Surf Cond	Weather Cond
IS 170 W	5.865	REAR-END	7/30/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.02	REAR-END	8/3/2016	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.525	REAR-END	8/3/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.598	REAR-END	8/8/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.359	PASSING	8/12/2016	MINOR INJURY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.865	REAR-END	8/23/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.865	REAR-END	8/26/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	6.911	REAR-END	8/31/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLOUDY
IS 170 W	7.117	PASSING	9/1/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	6.468	OUT OF CONTROL	9/6/2016	DISABLING INJURY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.282	REAR-END	9/29/2016	DISABLING INJURY	DAYLIGHT	DRY	CLOUDY
IS 170 W	6.502	OUT OF CONTROL	10/5/2016	MINOR INJURY	DAYLIGHT	DRY	CLOUDY
IS 170 W	6.19	OUT OF CONTROL	10/19/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	RAIN
IS 170 W	6.932	REAR-END	10/19/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	RAIN
IS 170 W	6.272	OUT OF CONTROL	10/21/2016	MINOR INJURY	DARK W/ STREET LIGHTS OFF	DRY	CLEAR
IS 170 W	7.157	OUT OF CONTROL	10/22/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 W	7.229	REAR-END	10/28/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.525	REAR-END	11/14/2016	MINOR INJURY	DARK W/ STREET LIGHTS OFF	DRY	CLEAR
IS 170 W	7.05	PASSING	11/20/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	7.656	AVOIDING	11/27/2016	MINOR INJURY	DAYLIGHT	DRY	CLOUDY
IS 170 W	7.548	REAR-END	11/30/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLOUDY
IS 170 W	7.124	REAR-END	11/30/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
IS 170 W	7.473	REAR-END	11/30/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	DRY	CLOUDY
IS 170 W	7.049	REAR-END	12/12/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	DRY	CLEAR
IS 170 W	5.869	PASSING	12/16/2016	INJURY	DARK W/ STREET LIGHTS ON	ICE	FREEZING
IS 170 W	6.943	CHANGING LANE	12/19/2016	MINOR INJURY	DAYLIGHT	DRY	CLEAR

Travelway	Log	Crash Class	Date	Severity Rating	Light Cond	Road Surf Cond	Weather Cond
IS 170 W	6.558	REAR-END	12/20/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS OFF	DRY	CLOUDY
RP IS170W TO IS70E E	0.019	OUT OF CONTROL	1/31/2016	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	WET	CLEAR
RP IS170W TO IS70E E	0.018	REAR-END	11/1/2016	MINOR INJURY	DARK W/ STREET LIGHTS ON	DRY	CLEAR
RP IS70E TO IS170E E	0.389	OUT OF CONTROL	12/16/2015	PROPERTY DAMAGE ONLY	DARK W/ STREET LIGHTS ON	WET	CLOUDY
RP IS70W TO IS170E E	0.362	OUT OF CONTROL	7/4/2016	PROPERTY DAMAGE ONLY	DAYLIGHT	WET	CLOUDY

IS=Interstate and RP=Ramp

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