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Evaluation of Wrong-Way Driving Countermeasures at Kansas Urban and Rural Interstate Ramps

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16 Abstract

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This study evaluated low-cost countermeasures at partial cloverleaf interchanges in Kansas. Six ramps were selected in the metropolitan area of Topeka, including four study sites and two control sites. Three sets of WWD incident data were gathered over a 10-day to a 14-day period, including one before study and two after studies, using two sets of pneumatic road tubes on the ramps at each site. Three cases were established to grade the severity of wrong-way incidents based on wrong entry, self-correction, and error; the results converted to a rate of incidents per 100,000 entering vehicles (ev). In the before study, incident rates ranged from 3.7 to 92 incidents per 100,000 ev. The evaluated countermeasures were red retroreflective delineators, oversized and lowered wrong-way signs, and a flashing LED wrong-way sign. The first set of after data, which were collected immediately after the countermeasures were installed, showed improvements at all but one of the study sites, with incident rates ranging from 3 to 103 incidents per 100,000 ev. The second set of after data were collected months after installation, and they showed improvement at all the study sites, with incident rates ranging from 0 to 40 incidents per 100,000 ev. Although the results for the flashing LED sign were inconclusive, the study found that red retroreflective delineators and oversized and lowered signs effectively reduced the number and type of WWD incidents.

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PREFACE

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

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Abstract

Wrong-way driving (WWD) incidents and crashes are a serious concern for communities throughout the United States. WWD events typically occur at high travel speeds during low light conditions on roadways with limited horizontal maneuverability. These variables reduce driver reaction times and, in conjunction with other human factor variables that cannot be quantified, they significantly contribute to the increased rates of fatalities and serious injuries for wrong-way crashes. Previous WWD research has included statistical analyses of crash data, multiple countermeasure comparisons, investigations of driver characteristics, and proposed rewording of the *Manual on Uniform Traffic Control Devices* (MUTCD).

This study evaluated low-cost countermeasures at partial cloverleaf interchanges in Kansas. Six ramps were selected in the metropolitan area of Topeka, including four study sites and two control sites. Three sets of WWD incident data were gathered over a 10-day to a 14-day period, including one before study and two after studies, using two sets of pneumatic road tubes on the ramps at each site. Three cases were established to grade the severity of wrong-way incidents based on wrong entry, self-correction, and error; the results converted to a rate of incidents per 100,000 entering vehicles (ev). In the before study, incident rates ranged from 3.7 to 92 incidents per 100,000 ev. The evaluated countermeasures were red retroreflective delineators, oversized and lowered wrong-way signs, and a flashing LED wrong-way sign. The first set of after data, which were collected immediately after the countermeasures were installed, showed improvements at all but one of the study sites, with incident rates ranging from 3 to 103 incidents per 100,000 ev. The second set of after data were collected months after installation, and they showed improvement at all the study sites, with incident rates ranging from 0 to 40 incidents per 100,000 ev. Although the results for the flashing LED sign were inconclusive, the study found that red retroreflective delineators and oversized and lowered signs effectively reduced the number and type of WWD incidents.

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Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
DNE	Do Not Enter
DOT	Department of Transportation
FARS	Fatality Analysis Reporting System
KDOT	Kansas Department of Transportation
MUTCD	Manual on Uniform Traffic Control Devices
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
TxDOT	Texas Department of Transportation
WWD	Wrong-Way Driving
WW	Wrong Way

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Chapter 1: Introduction

Wrong-way driving (WWD) incidents and crashes are an ongoing concern for communities worldwide, especially for developed nations with high-speed roadway facilities. Transportation officials, state highway agencies, and researchers in the United States are committed to preventing these incidents. According to the National Transportation Safety Board (NTSB), WWD occurs when a vehicle accidentally or intentionally travels in a direction opposite of the legal direction (NTSB, 2012; Tamburri, 1965). WWD vehicles traveling at high speeds pose a serious safety risk to other drivers. On average, approximately 300–400 people are involved in a fatal crash due to a WWD incident in the United States each year (FHWA, 2020). The Fatality Analysis Reporting System (FARS) database reported that an average of 269 fatal crashes resulted in an average of 359 fatalities each year from 2004 to 2011 (Baratian-Ghorghi et al., 2014). The 2011 FARS database also showed an average fatality rate of 1.24 per WWD crash compared to 1.09 fatalities for all other roadway crashes in the United States (NTSB, 2012). Similarly, the NTSB analyzed the FARS database and found that one-half to three-quarters of WWD crashes in the United States are caused by an intoxicated driver, with 60% of those crashes resulting in a fatality. An overwhelming majority of those fatal crashes occur at night (NTSB, 2012).

Although WWD crashes occur less frequently than other crashes, they are more likely to result in fatalities (Baratian-Ghorghi et al., 2015; Cooner et al., 2004b). Furthermore, WWD crashes frequently result in head-on crashes, which are often fatal (Baratian-Ghorghi et al., 2015). Although WWD crashes in Kansas account for only approximately 0.05% of all vehicle crashes, they result in approximately 2% of all fatalities in Kansas (KDOT, 2016). WWD crashes also have been shown to have a much higher rate (2.0 to 1.4) of fatalities and serious injuries per fatal/serious injury crash than all other types of fatal/serious injury crashes (KDOT, 2016). High vehicle speed was a factor in more than half of all WWD crashes that resulted in at least one fatality or serious injury. Additionally, research has found that approximately 35% of WWD crashes in Kansas involve alcohol or drugs (KDOT, 2016). In addition to the loss of life, each fatal crash in the state results in an economic loss of approximately $4 million. Therefore, reducing the number of WWD incidents would significantly benefit the state of Kansas.

Chapter 2: Literature Review

This study focused on WWD incidents on high-speed, divided interstates with interchanges. Coding in the crash report by the Kansas Department of Transportation (2016) defines a wrong-way crash as any crash that involves a vehicle traveling on the wrong side of the road. For non-divided highways, these incidents may include crashes that are not a typical wrong-way crash, such as when a vehicle drifts over the centerline. Although WWD crashes are difficult to alleviate via countermeasures other than rumble strips, divided highways typically divide the opposing directions of travel by a barrier or a wide median to prevent traffic from easily crossing over into opposing lanes, thereby restricting traffic to one side of the roadway. Because access to divided highways and interstates is limited to interstate ramps and intersections, WWD countermeasures can specifically target drivers at multiple points going in the wrong direction of travel.

Previous WWD research has primarily focused on driver factors and countermeasures. Driver factors can be driver related, geometric, environmental, and locality factors that influence driving performance. Prevalent countermeasure research has investigated every countermeasure in a wide variety of conditions. However, minimal research has focused on summarizing previous WWD research that specifically pertains to partial cloverleaf (ParClo) interchanges, turning movements, and data collection methods. The following sections summarize significant previous WWD research that helped guide the methodology for this study.

2.1 Wrong-Way Driving Factors

Factors of WWD incidents can be driver related (i.e., variables that affect driving performance), environmental (i.e., factors that affect the vehicle on the roadway), geometric (i.e., guidance of the driver), or locality factors (i.e., specific signs, businesses, or other objects unique to the area). Although several state transportation agencies have found common factors for WWD incidents, many other studies have identified unique WWD factors, thereby adding to the complexity of WWD research.

2.1.1 Driver-Related Factors

Many studies have researched ways to develop and implement WWD countermeasures and policies. Results have shown that driver-related factors such as driver age, sex, or level of impairment significantly contribute to WWD incidents. For example, an analysis of previous studies concluded that men are typically more likely to be involved in a WWD crash (Cooner et al., 2004b; Saidi et al., 2014; Ponnaluri, 2015) due in part because, as determined by Bener (2013), men are more likely to drive at excessive speeds and consequently disregard traffic control (signs and traffic signal) indications. Similarly, a driver's level of impairment was found to be statistically significant in determining the likelihood of a WWD crash (Ponnaluri, 2016), and previous studies showed that typically 60% of WWD crashes involve an impaired driver under the influence of alcohol and/or drugs (Cooner et al., 2004b; Morena & Leix, 2012).

Previous studies have also concluded that elderly drivers (over the age of 65) are typically overrepresented compared to the rest of the driving population (Cooner et al., 2004b; Braam, 2006; Morena & Leix, 2012; Ponnaluri, 2016; Langford & Koppel, 2006). Additionally, a study from Pour-Rouholamin et al. (2016) found that elderly drivers are nine times more likely to be involved in a WWD crash. Ponnaluri (2016) determined that these results were most likely due to the age-related losses of physical, sensory, and cognitive abilities. A strong correlation was also observed between drivers older than 65 and WWD crashes occurring in the morning or afternoon with no impairment (Jalayer et al., 2017; Bergman et al., 2000; Hamilton, 2008; Rudisill et al., 2014), as well as a strong correlation between young drivers and WWD crashes occurring at night on the weekends (Jalayer et al., 2017; Ponnaluri, 2016; Rogers et al., 2015; Ruer et al., 2014; Simpson & Bruggeman, 2015; Zhou et al., 2015; Howard, 1980; Fisher & Garcia, 2016). These studies concluded that young (under the age of 24) and elderly (over the age of 65) driving populations are most at risk for involvement in a WWD crash.

Fortunately, potential countermeasures have been shown to mitigate the negative effects of driver-related factors associated with WWD crashes. Educational countermeasures include safety and awareness programs for older drivers and drivers convicted of impairment violations. Development of a safety program geared towards elderly drivers highlighted alternative transportation modes for the elderly population, which reduced the number of WWD crashes involving those drivers (NHTSA, 2014; Jalayer et al., 2017). Similarly, efforts to prevent DUI (driving under the influence) incidents have helped educate potential DUI drivers, and strong enforcement initiatives have helped mitigate WWD incidents related to driver impairment (Jalayer et al., 2017; Ponnaluri, 2016). Ignition interlock devices were also found to reduce the occurrence of driver impaired WWD crashes (Jalayer et al., 2017).

2.1.2 Environmental Factors

Environmental factors such as the time of day and the day of the week have also been shown to strongly affect the likelihood of a WWD crash. Previous studies found that WWD crashes are more prevalent in the nighttime hours, from 11:00 p.m. to 6:00 a.m., and typically represent approximately 80% of the total number of crashes (Pour-Rouholamin et al., 2016; Morena & Leix, 2012; Clay, 2011). Additionally, Morena & Leix (2012) found that 71% of fatal and incapacitating crashes occur in the nighttime hours. WWD crashes were found to be more prevalent in locations with no roadway lighting (Das et al., 2017) and were likely to occur on weekend days (Howard, 1980; Fisher & Garcia, 2016; Ponnaluri, 2016), suggesting a possible correlation between WWD crashes and drivers under the influence.

2.1.3 Geometric Factors

Researchers have also determined that geometric factors, such as interchange ramps, increase the likelihood of a WWD crash. Interchanges most susceptible to WWD incidents included ParClo interchanges, half-diamond interchanges, full-diamond interchanges, and diverging diamond interchanges (Garber & Fontaine, 1999; Monsere et al., 2017; Howard, 1980; Copelan, 1989; Zhou et al., 2014a; Moler, 2002; Baratian-Ghorghi et al., 2015). Based on research results, attention should be given to WWD entry points at an interchange, specifically at exit ramps and crossroad intersections. Left-side exit ramps have also been shown to be prime locations for WWD entry points with increased crash severity compared to other ramps (Monsere et al., 2017; Cooner et al., 2004a; Cooner et al., 2004b; Howard, 1980; Chen et al., 2011). Roadways that are not physically separated and have no traffic control devices also typically have a higher frequency of WWD crashes (Das et al., 2017).

Studies have also shown that full cloverleaf interchanges have the lowest numbers of WWD entries and crash rates (Zhou et al., 2014a; Howard, 1980), while other studies have shown that ParClo interchanges have the highest occurrences of WWD crashes (Garber & Fontaine, 1999; Copelan, 1989; Howard, 1980; Morena & Leix, 2012; Morena & Ault, 2014; Baratian-Ghorghi et al., 2015; Moler, 2002). According to these studies, parallel and closely spaced exit and entrance ramps make these interchanges prone to wrong-way maneuvers. However, raised channelization and narrow median openings for a crossroad are effective, low-cost geometric modifications for ParClo and other interchange locations (Morena & Ault, 2014; AASHTO, 2011).

Potential geometric countermeasures include raised medians, channelized islands, adjusted turning radii, additional/improved signage and pavement markings, adaptive traffic signals, and additional lighting if lighting conditions are insufficient (Jalayer et al., 2017; Morena & Leix, 2012; Pour-Rouholamin et al., 2016; Zhou & Pour-Rouholamin, 2014). Closing the median opening at the crossroad between a two-way street and an exit ramp was also shown to be an effective countermeasure to eliminate wrong-way left-turn movements (Ouyang, 2014). The use of roundabouts at the intersections of an exit ramp and a crossroad was also found to be an effective countermeasure because the roundabouts enhance directional movement (Pour-Rouholamin et al., 2016). For locations with no traffic control, the addition of Stop, Yield, or Do Not Enter signs was recommended (Das et al., 2017), and the use of raised medians or median barriers between two abutting exit and entrance ramps (i.e., trumpet interchange) was shown to mitigate wrong-way movement (Moler, 2002).

2.1.4 Locality Factors

Although the *Manual on Uniform Traffic Control Devices* (MUTCD) (2009) does not distinguish between rural and urban locations or high-speed and low-speed facilities for WWD crashes, previous studies have shown that locality directly impacts WWD incidents and crash risks. For example, WWD crashes are more likely to occur on divided, rural roadways with no nighttime lighting and with full access control, highlighting the need for unique WWD guidelines according to location (Das et al., 2017; Ponnaluri, 2018).

2.2 Countermeasures for Wrong-Way Driving

The MUTCD, a handbook issued by the Federal Highway Administration (FHWA) pertaining to transportation design standards, includes policies for WWD and countermeasures that state departments of transportation (DOTs) and local communities may implement. However, these policies are a minimum, and some state DOTs have added policies and countermeasures due to safety concerns. Although more than 30 state DOTs have supplemented their state MUTCD, a survey from Baratian-Ghorghi & Zhou (2017) showed that some of the added WWD traffic control devices do not meet MUTCD guidance and standards.

Studies have shown that repairing deficient signs and enhancing the visibility of pavement markings (as described in the MUTCD) are effective, low-cost countermeasures that help deter WWD (Cooner & Ranft, 2008; Jalayer et al., 2017; Zhou & Pour-Rouholamin, 2014; Khalilikhah & Heaslip, 2016; Pour-Rouholamin et al., 2016). Conversely, faded pavement markings and/or deficient signs can lead to driver confusion, which increases the risk of WWD incidents. The implementation of pilot projects to determine the effectiveness of technology alternatives with advanced signage would be beneficial for areas at risk for WWD incidents (Das et al., 2017).

2.2.1 Lowered and Oversized Signs

Lowering the Do Not Enter and Wrong Way signs (mounted together on one post) has proven to be an effective countermeasure to mitigate WWD movements (Baratian-Ghorghi & Zhou, 2017; Das et al., 2017; Staplin et al., 2001; Cooner et al., 2004b; Kaminski Leduc, 2008). California, for example, has placed the Do Not Enter and Wrong Way signs 2 ft above the pavement (Cooner et al., 2004b), with results showing a decrease in WWD incidents from 50–60 entries per month to 2–6 entries per month (Baratian-Ghorghi & Zhou, 2017). This countermeasure was particularly beneficial during nighttime hours because low-beam vehicle headlights shone directly onto the lowered signs (Staplin et al., 2001; Cooner et al., 2004b). This countermeasure also benefitted impaired and elderly drivers because the lowered signs readily attracted their attention (Finley et al., 2014; Baisyet & Stevens, 2015; Kaminski Leduc, 2008). Cooner & Ranft (2008) surveyed 29 state DOTs and 12 Texas DOT (TxDOT) districts and found no existing crash tests to justify the safety of lowering signs. Oversized signs and additional signs are also effective countermeasures that increase sign visibility and give drivers repetitive cues (Zhou et al., 2012; Baisyet & Stevens, 2015; Staplin et al., 2001; Jalayer et al., 2017; Zhou et al., 2014b).

2.2.2 Flashing LED Signs

Studies by Ponnaluri (2015) and Clay (2011) found that Wrong Way signs with LED lights that flash upon detection of WWD effectively attract attention and alert drivers. In fact, these signs reduced WWD incidents in Texas by 30% (Clay, 2011). They are particularly beneficial for WWD locations with a high frequency of nighttime crashes.

2.2.3 Sign Supplements

Sign supplements such as fluorescent red sheeting and retroreflective sheeting have been shown to effectively increase sign visibility, especially during dawn and dusk hours (Staplin et al., 2001; Pour-Rouholamin et al., 2016; NTTA, 2009). Figure 2.1 shows a red retroreflective beacon (RRFB) to supplement a Wrong Way warning sign. An RRFB is a set of red lights attached above and below a sign that flashes when a vehicle is detected going the wrong way. RRFBs were found to effectively attract drivers' attention due to the beacon's high intensity and flashing light (Ozkul & Lin, 2017; Ponnaluri, 2015). They are a more effective countermeasure for deterring WWD than a red flashing beacon with a single flashing light (Ozkul & Lin, 2017). Public surveys have shown that drivers prefer RRFBs over other countermeasures such as LED Wrong Way signs, especially if the Wrong Way signs are placed on the left and right sides of a roadway, with RRFBs on the top and bottom sections of the signs, similar to Figure 2.1 (Sandt et al., 2015; Ozkul & Lin, 2017).

Figure 2.1: Red RRFBs on Wrong-Way Sign
Source: Ozkul & Lin (2017)

2.2.4 Pavement Marking Arrows

The use of lane direction pavement marking arrows downstream from an exit ramp and on a two-way frontage road (Figure 2.2) was found to be an effective safety countermeasure to help mitigate WWD incidents (Schrock et al., 2005; Zhou et al., 2014b). Similarly, installing reflectorized wrong-way pavement arrows has proven to be an effective countermeasure if the arrows are placed upstream on the exit ramp and downstream near the crossroad (Cooner & Ranft, 2008; Das et al., 2017; Schrock et al., 2005; Monsere et al., 2017). Pavement arrows are most effective when they are placed on the left-side exit ramps, locations known to be susceptible to WWD crashes (Cooner et al., 2004a; Cooner et al., 2004b). In general, pavement marking arrows are an effective low-cost countermeasure because they are easily recognizable by drivers.

Figure 2.2: Lane Direction Pavement Arrows on Two-Way Frontage Road
Source: Schrock et al. (2005)

2.2.5 Directional Rumble Strips

Directional rumble strips, which are variations of transverse rumble strips, are used to catch the attention of wrong-way drivers. Zhou et al. (2018) compared various rumble strips to determine the most effective strips. Figure 2.3 shows the directional rumble strip configurations that produced effective sound and vibration effects and increased visual alertness. These configurations produce an adequate sound increase for drivers traveling in the wrong direction compared to vehicles traveling in the correct direction.

Figure 2.3: Effective Directional Rumble Strips
Source: Zhou et al. (2018)

2.2.6 Pavement Marking Supplements

Arrow markings may also be supplemented by red reflective pavement markers (RRPMs) and Wrong Way signs placed along the exit ramp, as shown in Figure 2.4 (Caltrans, 2014; Vaswani, 1977; Cooner et al., 2004b; Zhou & Pour-Rouholamin, 2014). RRPMs are small, raised markers on the pavement that appear red to a driver traveling in the wrong direction and white to drivers traveling in the correct direction. These markers are typically placed in such a way as to form an arrow pointing in the correct direction of movement. A study by Ponnaluri (2015) showed rapid driver recognition of RRPMs because their placements are within the driver's cone of vision.

RRPMs (Figure 2.5) are typically used on undivided highways to indicate that a driver is traveling in the wrong direction. The state of Hawaii uses these markings to remind tourists to drive on the right side of the road (Miles et al., 2008). Although these markings are most effective at night, concerns have been raised about whether drivers understand the markings. A study by Miles et al. (2008) determined that pavement marking arrows increase drivers' understanding of the correct direction of travel more than RRPMs.

Figure 2.4: Wrong-Way Arrow with RRPMs and Supplemental Wrong-Way Signs
Source: Zhou & Pour-Rouholamin (2014)

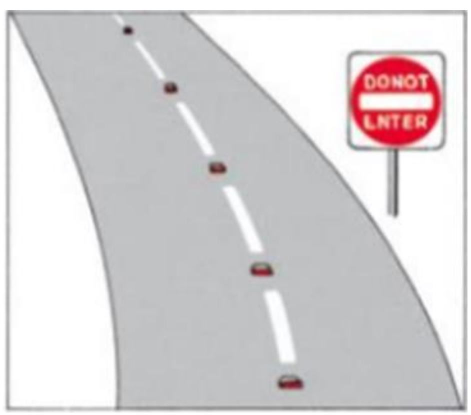


Figure 2.5: Red Retroreflective Pavement Markings
Source: Monsere et al. (2017)

MUTCD Section 3B.13 states that RRPMs should not be used to supplement edge lines because drivers traveling in the correct direction on undivided highways can see the red RRPMs from the opposite side of the roadway, which can lead to driver confusion. However, Section 3B.14 states that the side of the RRPM that is visible to wrong-way drivers may be red (FHWA, 2009).

2.2.7 Delineators

The use of delineators along exit ramp barriers has been shown to effectively catch drivers' attention, especially at night. Yellow delineators are utilized on the left side for vehicles traveling in the correct direction, and red delineators are used on the right side for vehicles traveling in the wrong direction (Zhou & Pour-Rouholamin, 2014).

2.2.8 Summary

Overall, a significant amount of previous research has been conducted to understand WWD, including studies that have focused on quantifiable factors relating to drivers, the environment, and countermeasures to reduce WWD incidents and crashes. This literature review focused on wrong-way incidents and roadway geometry, such as interchange ramps, turning movement at intersections, and interchange types. However, a review of literature showed that limited studies have investigated WWD incidents at ParClo interchanges, a common type of interchange used in the Midwest. Additionally, previous studies have used a variety of data collection methods to collect WWD incidents (and crashes), ranging from video, road tubes, or a combination of data collection methods – many have provided strengths and weaknesses of each method depending on the location of the study.

Chapter 3: Research Objectives

As described in Chapter 2, previous research has utilized various data collection techniques to investigate many aspects of WWD, especially driver characteristics, crash causation, countermeasure effectiveness, and roadway geometric characteristics. However, a gap in knowledge exists when considering WWD incidents and roadway geometry. This study focused on ParClo interchanges with on- and off-ramps that are in close proximity to each other, specifically in areas where a traditional diamond, full cloverleaf, or other interchange type may not be conducive.

The primary objective of this study was to evaluate the effectiveness of low-cost WWD countermeasures at ParClo interchanges to reduce WWD incidents. Effectiveness was based on a before-after analysis and long-term after-analysis. A low-cost countermeasure was defined as an intervention device that could easily be acquired by a community or state highway agency with minimal technology and communication capabilities. The secondary objective of this study was to use pneumatic road tubes to collect wrong-way incident data at ParClo interchanges to determine location and understand traffic operations at interchanges while data are collected to determine effectiveness.

Chapter 4: State Department of Transportation Survey

Many state transportation agencies have conducted research or implemented guidelines for installing countermeasures to reduce or prevent WWD incidents throughout the United States. However, each state has unique priorities and budgets for various levels of treatments with varying levels of effectiveness. To determine which countermeasures may be effective in the Midwest, this study conducted a survey of Midwest states and other states with prior major research. Colorado and Oklahoma were included in the survey because they neighbor Kansas. The first stage of the survey involved searching each state's DOT website for WWD-specific policies, while the second stage involved searching for specific research, guidelines, or countermeasures specific to each state. Researched states included Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin, Colorado, Florida, Texas, and Oklahoma. Only Illinois, North Dakota, Ohio, and Wisconsin have WWD policies that extend beyond the MUTCD, and only Indiana, Minnesota, South Dakota, and Oklahoma have no additional countermeasure guidelines.

A table was constructed using the data gathered from each state, as presented in Appendix A. The first column of the table lists the state and the DOT abbreviation, the second column shows the reference document for the countermeasure guidelines, and the year(s) of research is shown in the third column. The fourth column describes the countermeasures, research, or guidelines that have been conducted or implemented by the state agency, and the fifth column indicates whether the state has additional policies for WWD beyond the MUTCD, with a description of those policies. State countermeasures or policies were found in either the referenced documents or obtained from a DOT employee.

Although the policies of the four states with additional WWD polices had some similarities, they were also unique to each state. Two states specifically address possible interchanges and interchange arrangements, including signage, additions to signage based on interchange type, and ramp geometry based on interchange type, but their solutions are not identical. Although the other two states use every available countermeasure on the ramp, one state addresses only divided highways with median crossings, which is not the type of interchange this report examined, and the fourth state focuses exclusively on interchange area geometry and the types of connections used between the interstate and connector roads, not the signage.

Almost all Midwest states utilize some sort of WWD countermeasure, but the countermeasures vary, including flashing LED signs, additional or doubled Wrong Way signs, lowered signs, red retroreflective delineators (RRFDs), and setups that alert a traffic management center (TMC). Some of the countermeasures are specified for certain interchange types, such as diamond or ParClos, and other countermeasures are activated only when WWD incidents occur at a particular interchange. A few states only offer possible alternatives and countermeasures for local officials if they want to use them.

Overall, state transportation agencies (even regionally), have no consensus on ramp geometry or signage beyond the MUTCD. DOTs typically use all the countermeasures, only what is needed, or almost no countermeasures. This variety could be due to a lack of research or lack of funds to make changes. However, areas of disagreement exist even in states in which extensive research has been conducted due to varying degrees of effectiveness of each countermeasure within the regions and within each state. Although one general solution does not work for every state, a general selection of countermeasures can be used as a starting point.

Chapter 5: Methodology

This project focused on thoroughly evaluating countermeasures at one interchange type rather than studying all interchanges, which potentially leads to limited data and unreliable conclusions. Since previous research identified ParClo interchanges as particularly susceptible to WWD incidents, ParClo interchanges were chosen for evaluation in this study.

5.1 Partial Cloverleafs

Ever since Henry Ford first mass-produced cars, drivers have strived to go further and faster. As roads evolved from dirt paths to gravel and then pavement, safe interchanges to enter and exit these roads became essential. The cloverleaf interchange was the first interchange to be patented in 1912, but the first cloverleaf was not constructed until 1928 (Leisch & Morrall, 2014). The initial straight-line construction of highways perfectly accommodated the cloverleaf interchange, but as interstate and interchange designs improved beginning in the 1960s, the objective became to decrease the footprint of the interchange and increase traffic flow (Leisch & Morrall, 2014).

Figure 5.1 shows the typical layout of a cloverleaf interchange, which resembles a four-leaf clover. Cloverleaf interchanges have a total of eight ramps: four loop ramps and four directional ramps. Each directional ramp is paired with a looping ramp, with one for exiting and the other for traffic entering from one direction of the interstate and one side of the crossroad. The interchange also has two ramps in each quadrant. The loop ramps are located closest to the crossroad with a very short weaving area in which entering and exiting traffic cross each other onto and off the interstate. The directional ramps have a long weaving lane for merging and exiting traffic. Each directional ramp of a cloverleaf interchange is typically located before or after the intersection of the crossroad and the interstate, and the ramps intersect the crossroad so that they can only be entered by traffic traveling in the correct direction. The loop ramps are situated close to the intersection of the crossroad and the interstate, with two ramps located on each side of the interstate, one after the other, so that the entering ramp enters the interstate, and the exiting ramp exits the interstate. Both loop ramps share the same acceleration and deceleration lanes, forcing entering and exiting traffic to merge with the through traffic.

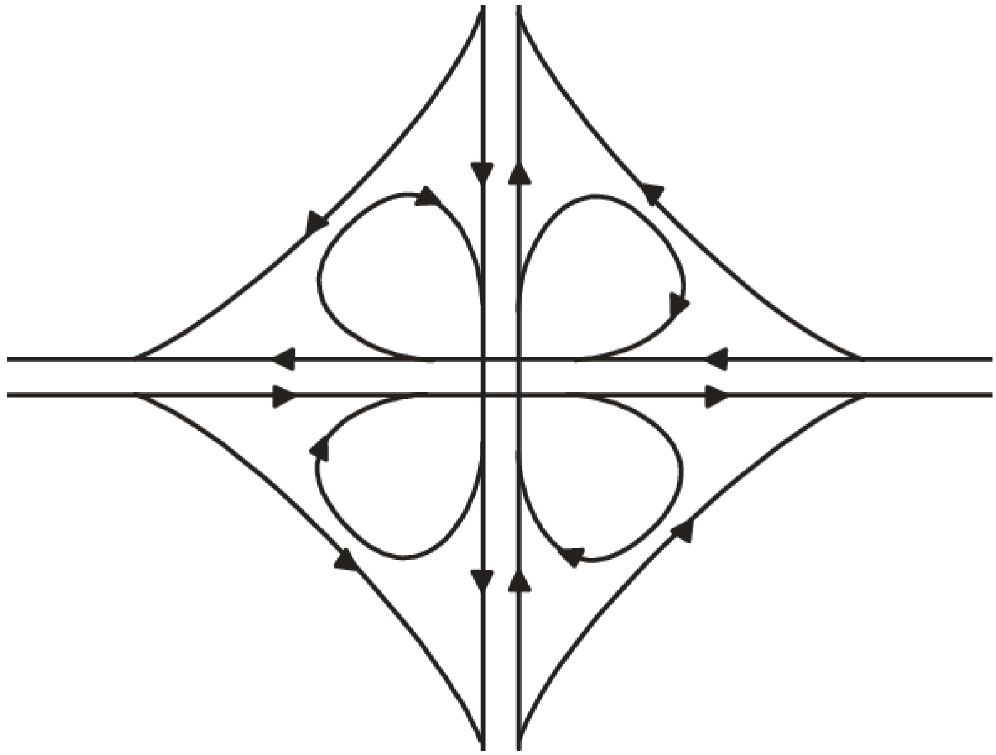


Figure 5.1: Typical Cloverleaf Interchange

Safety records regarding WWD incidents reveal cloverleaf interchanges to be one of the safest interchanges due to their eight-ramp design, with one ramp per direction entering or leaving the interstate. The ramp layout and design prevent incorrect ramp usage. However, the extensive space requirement for this design feature is a drawback. Therefore, the ParClo, as shown in Figure 5.2, was created as a versatile interchange with a reduced footprint. Where a cloverleaf requires ramps in all four quadrants, a ParClo requires only two quadrants if they are on opposite sides of the interstate.

ParClo interchanges are identified by their interstate exit and entrance ramps and their location to the crossroad with respect to the direction of travel. If the ramps begin before the crossroad, the interchange is a ParClo A; if the ramps are located after the crossroad, the interchange is a ParClo B. If the interchange has both ParClos, it is a ParClo AB. A ParClo interchange can be a ParClo A or B with a half diamond, collapsed diamond, or partial diamond, depending on the space available for construction or, in most cases, the type of previous interchange.

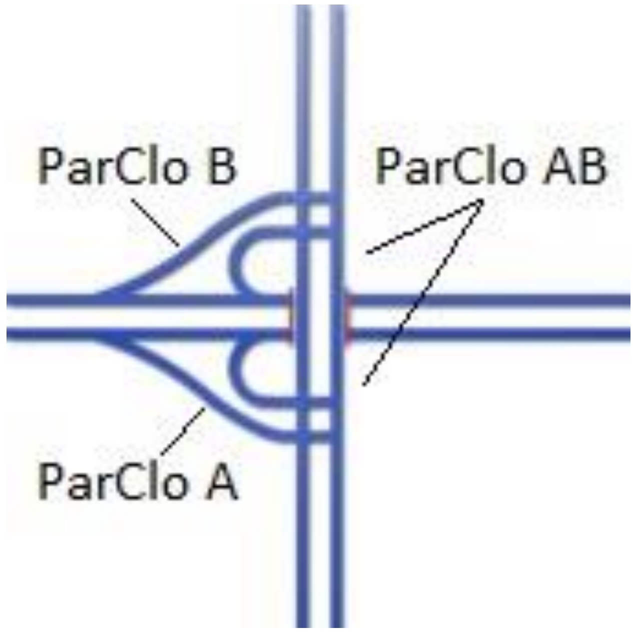


Figure 5.2: Partial Cloverleaf Interchange

ParClo interchange research has primarily focused on vehicle capacity; the only exception found is a paper on the history of interchange design (Leisch & Morrall, 2014). When examining the capacity research, ParClos are one of the top three interchanges in capacity based on area. Although advances in ParClo design have been continuous, WWD research on ramps with wrong-way crash histories has shown that ParClo interchanges pose risks under certain circumstances (Howard, 1980; Campbell & Middlebrooks, 1988). Previous studies utilized a single set of pneumatic road tubes, one with cameras, to study ramps and evaluate countermeasures. One study found that WWD incidents increased immediately after the wrong-way driving and directional signs were installed and adjusted and then decreased after users became familiar with the new signs (Campbell & Middlebrooks, 1988), while the other study noted an immediate reduction in WWD incidents (Howard, 1980). However, other studies have found that ParClos are more susceptible to WWD incidents (Garber & Fontaine, 1999; Copelan, 1989; Morena & Leix, 2012; Morena & Ault, 2014; Baratian-Ghorghi et al., 2015; Moler, 2002).

5.2 Site Selection

This study decided to focus on ParClos after a review of previous research and a discussion with the project manager at KDOT. Several criteria were established to determine the study sites. The sites needed to be close enough to Manhattan, Kansas, to monitor regularly and be on a divided interstate in an area with a high volume of traffic. The sites also had to contain several proximate ramps, ramps on both sides of the interstate, and both ParClo A and B interchanges.

The study initially focused on Interstate 70 (I-70), which runs east and west through Kansas City and has traffic volumes that exceed 10,000 vehicles per day. The interstate is located approximately eight miles south of Manhattan, Kansas. The highest traffic volumes occur on the section of I-70 that runs through the north side of Topeka, the capital of Kansas and the state’s third largest city, approximately 58 miles east of Manhattan. The team found six ParClo interchange ramps throughout the Topeka area, as shown in Figure 5.3. Sites 1–4 in the figure are test sites, and sites 5–6 are control sites. The control sites included one ParClo A and one ParClo B interchange on opposite sides of the interstate, and the treatment sites contained three interchanges on the westbound side and one interchange on the eastbound side. The four interchanges consist of one ParClo A, one ParClo B, and one ParClo AB.

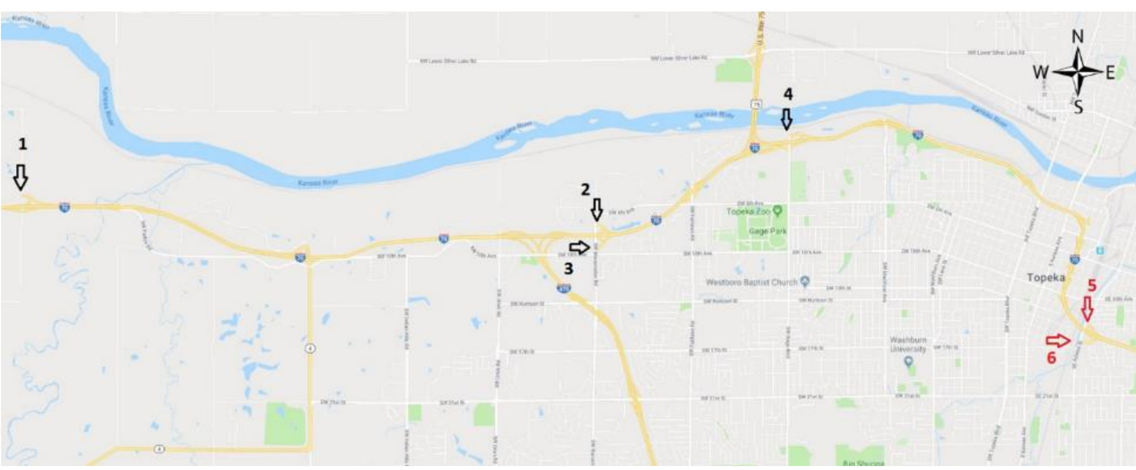


Figure 5.3: WWD Study Sites in Topeka, Kansas

The test ramps chosen on the westbound side of I-70 were exit 353, Auburn Rd; exit 356, Wanamaker Rd; and exit 358, Gage Blvd. The control ramp was exit 363, Adams St. The test site on the eastbound side was exit 356, Wanamaker Rd, and the control site was exit 363, Adams St.

5.3 Westbound Ramps

5.3.1 Auburn Rd

The Auburn Rd exit, shown in Figure 5.4, is the last Topeka exit when heading west on I-70. This exit is a ParClo B that crosses underneath I-70, and the interchange covers three quadrants. The other side of the interchange is a diamond intersection. The exit and entrance ramps are divided by a low, curb-height median with 3-ft plastic delineators that mark the centerline of the median. Prior to the study, a Do Not Enter sign was located on the left side of the entrance, a Keep Right sign was located on the median between the entrance and exit ramps, a Wrong Way sign was located on the left side of the ramp approximately 300 ft from the crossroad, and another Wrong Way sign was located on the right side of the ramp 200 ft from the first sign.

To the north of the exit, Auburn Rd is a private drive with a material dump just prior to drive. The West Lawn Memorial Gardens cemetery is located in the northeast quadrant, and several businesses, including a sports bar, are visible from the interstate south of the exit. A frontage road, 10th St, runs parallel to the interstate and leads to Wanamaker Rd, a major thoroughfare in Topeka. Most traffic that enters I-70 westbound at Auburn Rd makes a left-hand turn from the crossroad.

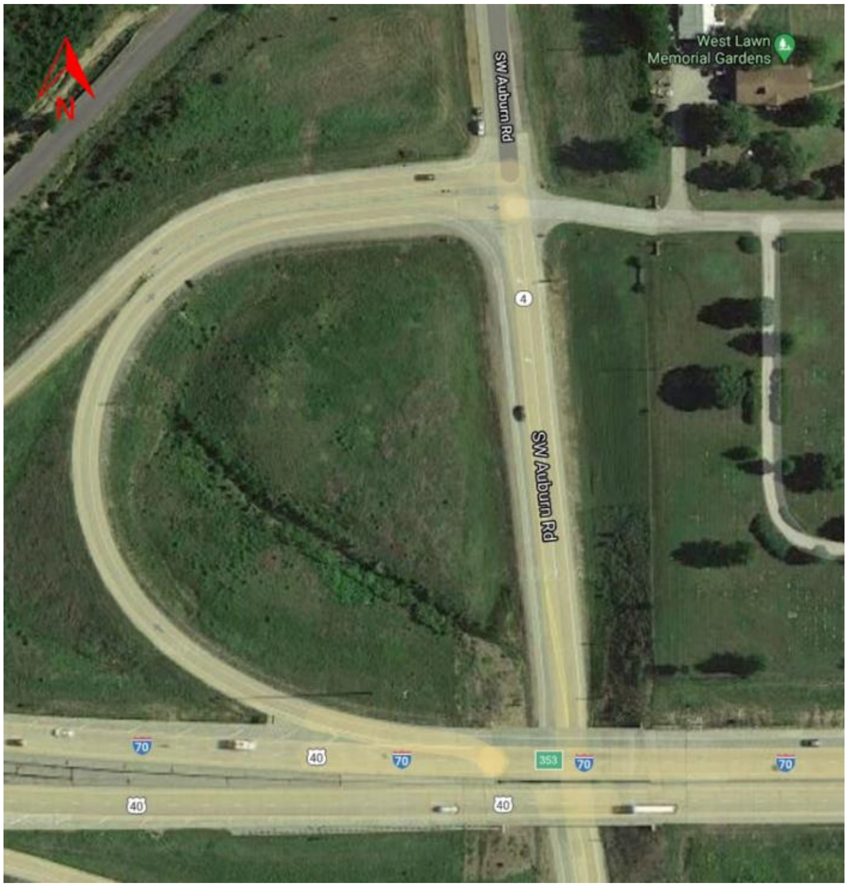


Figure 5.4: Aerial View of Exit 353, Auburn Rd
Source: Google (n.d.)

5.3.2 Wanamaker Rd North Exit

The Wanamaker Rd North exit, shown in Figure 5.5, is the westbound exit from I-70 to Wanamaker Rd. Wanamaker Rd North is a ParClo A interchange, and the crossroad crosses over I-70. The other side of the interchange is a ParClo B interchange and is another treatment site. The Wanamaker Rd interchange covers two quadrants. The exit ends with two lanes, one left-turn-only and one left- and right-turn lane. The exit also contains a traffic signal where the exit ramp intersects the crossroad, and the exit and entrance ramps are divided by a continuous barrier until the entrance ramp bears right away from the exit ramp. Prior to the study, a Do Not Enter sign was located on the left side of the exit ramp, as well as a Keep Right sign on the right, a Wrong Way sign on the left approximately 350 ft from the crossroad, and a second Wrong Way sign on the right side approximately 160 ft past the first sign.

Figure 5.5: Aerial View of Exit 356, Wanamaker Rd North
Source: Google (n.d.)

Wanamaker Rd is surrounded by numerous restaurants/bars, gas stations, hotels, and strip malls. The main shopping district in Topeka, which includes an indoor shopping mall, is located directly south of I-70 along Wanamaker Rd and is a popular spot for travelers to stop for gas and food. Most traffic that enters I-70 at this exit makes a right turn onto the entrance ramp; the ramp has a traffic signal to control movement through the intersection.

5.3.3 Gage Blvd

The Gage Blvd exit, shown in Figure 5.6, is the westbound exit from I-70. Gage Blvd is a ParClo A interchange that crosses underneath I-70. The exit to Gage Blvd on the eastbound side is also the exit to US-75 North and includes a weaving area for traffic to merge onto US-75 North and traffic exiting from US-75 South to merge with I-70 or exit to Gage Blvd. The treatment exit ramp is divided by a curb-height raised median that becomes a barrier dividing the exit and entrance ramp. Prior to the study, a Do Not Enter sign was located on the left side of the exit, a Keep Right sign was located on the median on the right side of the exit, a Wrong Way sign was located approximately 300 ft from the crossroad on the left side, and another Wrong Way sign was located approximately 350 ft from the first sign on the right side.

Figure 5.6: Aerial View of Exit 358, Gage Blvd
Source: Google (n.d.)

The Topeka Water Division, which handles water treatment and sewage treatment, is located north of the exit ramp, and the Metro Area Maintenance office is located directly to the west of the exit ramp. Large residential neighborhoods, various businesses and restaurants, and the local Veterans Affairs Hospital are located south of the ramp. Almost all traffic entering westbound I-70 from Gage Blvd makes a right turn.

5.3.4 Adams St North Exit

The Adams St North ramp, shown in Figure 5.7, is located on the east side of Topeka on the westbound side of I-70. The exit is approximately three miles west of where I-470 ties into I-70 and the turnpike begins. The exit is a ParClo A interchange, and the crossroad crosses underneath I-70. The other side of the interchange is a ParClo B interchange that was included in this study. Because this exit ramp was a control ramp, no changes were made to the sign configurations. The exit contains a Do Not Enter sign on the left approximately 10 ft in front of the stop line on the right side and angled slightly to face traffic coming from the north. In addition, a Keep Right sign is located on the median on the right side of the exit ramp, a Wrong Way sign is on the left about 325 ft from the crossroad, and another Wrong Way sign is on the right side approximately 225 ft further up the exit ramp. The entrance and exit ramps are divided by a curb-height median for approximately 50 ft, which rises to a barrier that divides the two ramps.

Figure 5.7: Aerial View of Exit 363, Adams St North
Source: Google (n.d.)

The Adams St North exit is surrounded by residential neighborhoods and small businesses. Only the eastbound exit is controlled by a traffic signal. A gas station convenience store is located south of the eastbound exit, but no other major shopping outlets are in the nearby area.

5.4 Eastbound Exits

5.4.1 Adams St South Exit

The Adams St South exit (Figure 5.8) is located on the east side of Topeka and is one of the last eastbound exits on I-70 within Topeka city limits. This exit is a ParClo B interchange, and the crossroad passes underneath I-70. The exit ramp is the other control ramp in this study, so no changes were made to this ramp. The Adams St interchange covers two quadrants, both on the east side, and the exit and entrance ramps are separated by a flush median with double yellow lines. The curb-height median rises to a barrier to further divide the two ramps. The exit contains a Do Not Enter sign on the left side of the exit ramp, a Keep Right sign on the median on the right side of the exit ramp, a Wrong Way sign on the left side approximately 300 ft from the crossroad, and another Wrong Way sign on the right approximately 350 ft further up the exit ramp. Similar to the north exit, this exit is surrounded by residential neighborhoods and small businesses. The exit is controlled by a traffic signal near a gas station convenience store south of the exit. No other major shopping outlets are in the nearby area.

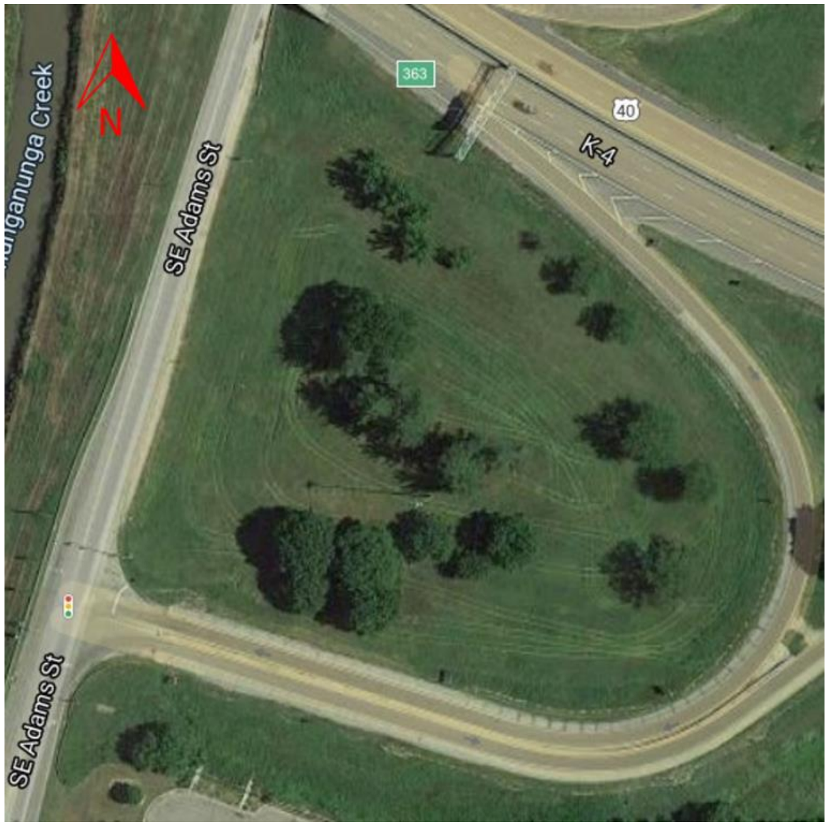


Figure 5.8: Aerial View of Exit 363, Adams St South
Source Google (n.d.)

5.4.2 Wanamaker Rd South

The Wanamaker Rd South exit (Figure 5.9) is the eastbound exit from I-70 to Wanamaker Road. This exit is comprised of a ParClo B interchange with a crossroad that crosses over the interstate, a ParClo A interchange, and another treatment site. The Wanamaker Rd interchange covers two quadrants. The Wanamaker Rd South exit ends as a one-lane road that allows either left or right turns, with an unsignalized interchange controlled by a stop sign for the exiting lane. A continuous concrete barrier begins as a slightly raised median and rises to a full-sized barrier to divide the exit and entrance ramps until the ramps separate. Prior to the study, a Do Not Enter sign was located on the left side of the exit ramp at the entrance and a Keep Right sign was on the concrete divider. One Wrong Way sign was located on the left side approximately 450 ft from the crossroad, and another Wrong Way sign was located on the right side 100 ft further down the exit ramp.

Figure 5.9: Aerial View of Exit 356, Wanamaker Rd South
Source: Google (n.d.)

Wanamaker Rd is surrounded by numerous restaurants/bars, gas stations, hotels, and strip malls. The main shopping district in Topeka, which includes an indoor shopping mall, is located directly south of I-70 along Wanamaker Rd and is a popular spot for travelers to stop for gas and food. Most traffic that enters I-70 at this entrance makes a right turn onto the ramp; a signal is located just south of the ramps, but it does not control traffic at the ramp.

5.5 Wrong-Way Driving Working Group

As a part of this study, a WWD working group was convened to gather information about potential countermeasures. Working with KDOT, a Wrong-Way Driving Working Group was scheduled at the KDOT 2019 Transportation Safety Conference in Wichita, Kansas. The group was comprised of 27 participants, including KDOT personnel, private engineers, emergency medical services (EMS) workers, vendors, and researchers. The workshop began with an overview of WWD research, including MUTCD guidance. The presentation then highlighted a previous statistical study of WWD crashes on Kansas interstates, followed by a description of the current study. Results of the before study were covered, as well as the chosen countermeasures. Each group was given a packet (Appendix B) containing aerial color pictures of each ramp with counter placement; three street-level views from the exit, the midpoint, and the I-70 entrance; color photos of the three chosen countermeasures; summaries of WWD incidents for both counters on each ramp and ramp volume data for counter 1; and MUTCD excerpts regarding wrong-way signage.

The working group was divided into nine small groups to discuss the countermeasures on the Auburn Rd ramp and the two Wanamaker Rd ramps. The groups then shared their selected countermeasures for each ramp, as summarized in Table 5.1. Due to time constraints, only three ramps were discussed, and some groups did not offer recommendations on the last ramp, Wanamaker Rd South.

Table 5.1: Summary of WWD Working Group Discussion

	Auburn Rd	Wanamaker Rd North	Wanamaker Rd South
Flashing LED Sign	5	0	1
RRFDs	6	4	1
Oversized & Lowered Wrong Way Sign	5	3	3

5.5.1 Auburn Rd

Most groups determined that flashing LED signs, oversized and lowered signs, and RRFDs would be the most effective countermeasures for the Auburn Rd ramp, although cost-effective options such as dashed pavement markings and pavement arrows for correct turning movements were also considered. Other options involved realigning the exit with the cemetery road, squaring up the exit to make it more prominent, and separating the entrance and exit ramps. The latter options are expensive, however, and require an impractical, invasive approach.

5.5.2 Wanamaker Rd North

Since most WWD incidents at the Wanamaker Rd North exit occur during the day, the most popular countermeasures were oversized and lowered signs and RRFDs. Adding dashed lines and pavement arrows to mark turning movements and adding red reflectors to the median barrier were also suggested. The most expensive ramp-improvement options included realigning the exit to reconfigure the lanes and raising the median.

5.5.3 Wanamaker Rd South

Although several groups did not have time to discuss the Wanamaker Rd South exit, the most popular suggested countermeasure was oversized and lowered signs. Additional suggestions included a video traffic-detection system and improved drivers' training to reduce WWD incidents at this location.

5.6 Data Collection Methodology

The use of video and pneumatic road tubes were the two methods considered for the collection of WWD incident data. Video recording is beneficial because a vehicle can be observed making an incorrect movement and then followed to see if the driver self-corrects or wrongly enters the interstate. When logging a WWD incident with video, the observer can note the date, time, and vehicle type from the video and determine total ramp volume by counting the vehicles. However, video recording requires someone to observe the video for the same amount of time it was set out, meaning a significant amount of time is often required for observation. Video systems may also have a restricted field of vision that prevents the observation of vehicles at certain times, potentially resulting in missing information. Video recording also has limited storage capacity, which limits the time the system can be in place. Typical studies using video systems occur over a two- or three-day period.

In contrast, pneumatic road tubes can be emplaced and left for an extended period of time, and they have a large storage capacity that is unrestricted by video feedback. Pneumatic road tube counters have multiple setup options that can collect valuable information, such as volume, speed, gap, vehicle class, date, time, and direction of each vehicle. Pneumatic road tubes are also less expensive than video systems, meaning multiple ramps can be monitored simultaneously. The primary disadvantage to pneumatic road tubes, however, is their inability to determine a vehicle's circumstances before and after the tube registers the WWD incident. Another disadvantage is that pneumatic road tubes require dry, sunny weather to emplace, and severe adverse weather can cause the mastic tape to come loose. Certain weather temperature limitations render the use of pneumatic road tubes impractical. After considering the advantages and disadvantages of both methods, pneumatic roads tubes were chosen for data collection in this study.

Specific methodologies were investigated to obtain the most accurate account of ramp incidents. Previous research used only one set of road tubes to track WWD incidents (Howard, 1980; Campbell & Middlebrooks, 1988). Therefore, this study utilized two sets of road tubes spaced out on the ramp to collect additional information about vehicles. Figure 5.10 shows the general layout for the pneumatic road tubes. The first counter was placed near the crossroad but far enough back so vehicles in the queue would not rest on the tubes. The second set of road tubes was placed near the exit from the interstate. Road tubes were placed in the same spots for all studies, and data were collected before and after countermeasure installation for data analysis. Since previous research results disagreed on when the best time to conduct the after study was (Howard, 1980; Campbell & Middlebrooks, 1988), this study collected the after data immediately after installation and then again at least 90 days later.

A JAMAR pneumatic road tube counter was used to collect vehicle directional data. The L6 setting on the counter along with two rubber tubes allow for vehicles to be collected traveling in both directions, which are indicated by direction/lane one or two. Setting L6 on the JAMAR counter was used to collect the data, which includes traffic information in two directions from lane one and lane two. Data from the counters were extracted using JAMAR software and then exported to Excel to facilitate processing. The data were then sorted by lane, with lane 1 as the correct direction and lane 2 as the wrong-way movement. Initial examination of the data showed error rates between 1% and 3.6%, which were significantly less than the 20% error rate threshold for the recollection of vehicle data. The 20% threshold allows for natural data processing errors, false positives, and incidents where the pneumatic may not have been able to classify the vehicle, direction, or number of axles. Data errors may have resulted from false positives, issues determining vehicle class, or because vehicles stopped on the road tube at intersections. Data flagged as an error were given a vehicle class of 14 and then filtered out. Besides a vehicle class of 14 indicating a data processing error, the JAMAR pneumatic tube counter provided 13 vehicle classes based on the number of axles, which corresponds to the FHWA vehicle classification scheme. Data were further filtered by lane and then sorted to determine wrong-way movements. Once WW movements were identified for both counters for each ramp, the movements were compared to determine which case applied to each incident.

Figure 5.10: Road Tube Layout Used for Data Collection
Source: Google (n.d.)

5.7 Wrong-Way Driving Incident Classification

Each ramp contained two counters placed in the same locations for both the before and after studies. Each counter used two road tubes set 2 ft apart, as shown in Figure 5.11a, and the date and time of the counters were synced. The counters were set to use layout L6 to capture data, which captures volume, speed, gap, vehicle class, and direction. Because this layout was designed to gather data on a two lane, two-way street and this study gathered data on ramps with one-way traffic, any movement in the other direction was considered a possible WWD incident. The first counter was placed near the crossroad, approximately 50–100 ft back, depending on the ramp and determined by signalization of the intersection, number of exit ramp lanes at the intersection, and the traffic levels. The first counter was placed at a point before the exit ramp divided into more than one lane, and the second counter was placed on the ramp near the interstate.

Figure 5.11: Tube Placement for Each Counter

The WWD incident data were collected and processed into Excel spreadsheets, sorted by direction, and then the hits that registered in the wrong direction were separated for analysis. Typical analysis of WWD data would count every hit as an entry to the interstate. Three scenarios were expected from the use of two sets of road tubes on the ramp, and each scenario was classified as a case. Case 1 incidents registered on counter 1 and then on counter 2 within a time frame that was appropriate for the distance between the road tubes. Each hit was examined to verify that it could be from the same vehicle, meaning the vehicle entered the ramp going the wrong way at counter 1 and continued until it reached the interstate, or the entrance to the exit ramp, at counter 2. Case 1 was assumed to indicate a wrong-way entry onto the interstate, as shown in Figure 5.12. However, the vehicle could have passed counter 2 and then performed a U-turn and proceeded in the correct direction down the interstate.

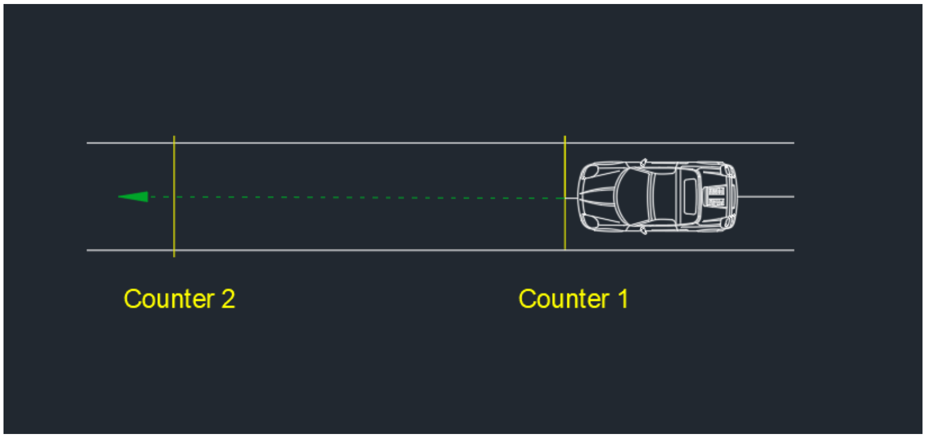


Figure 5.12: Case 1 Wrong-Way Incident

Case 2 incidents registered on counter 1, but no corresponding hit occurred on counter 2, indicating that the vehicle entered the exit ramp in the wrong direction but did not leave the exit ramp and enter the interstate. Figure 5.13 shows an example of this movement in which the vehicle was assumed to self-correct the wrong-way movement between counter 1 and counter 2 by turning around on the ramp and going the correct direction or, if the ramp design allows, maneuvering from the exit ramp to the entrance ramp. The Auburn Rd ramp allows for this maneuver, and such WWD incidents may actually be intentional. In addition to self-correction, hits registering as WWD movements may also be rollbacks due to traffic stopping near the counter or vehicles maneuvering into two lanes when the design is intended for one lane. Therefore, prior observation of the interchange intersection is helpful to determine the best location for counter 1 to ensure the queue does not affect the results. Although errors are possible due to drivers who likely self-corrected, case 2 incidents were included in the incident rate calculations.

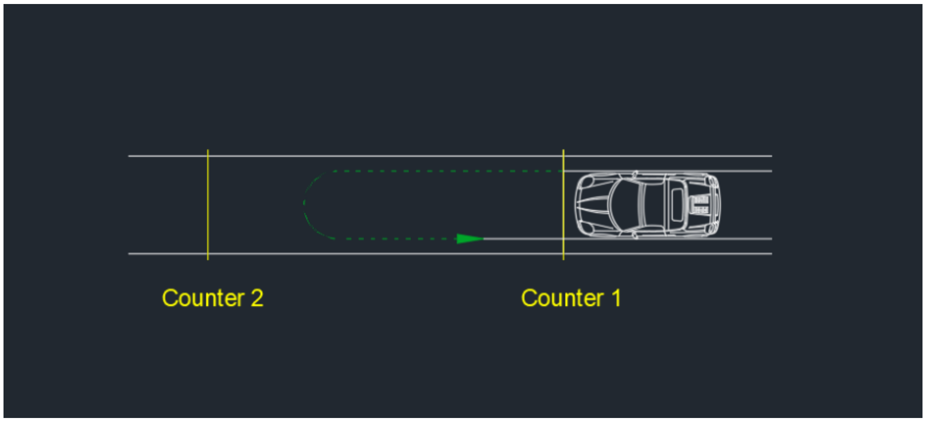


Figure 5.13: Case 2 Wrong-Way Incident

Case 3 incidents registered hits on counter 2 without a corresponding hit on counter 1, as shown in Figure 5.14. Examination of the ramp layouts showed that each ramp had barriers or concrete near counter 1 and open areas and grass around counter 2. Mowing and other maintenance occurs on the ramp, so the mowers and related vehicles may have registered WWD hits on the counter. No definitive explanation was offered for how a vehicle got to counter 2 without hitting counter 1 first. Examination of the before data showed almost all (85%) of case 3 incidents were class one vehicles with a wheelbase shorter than typical motorcycles, indicative of a mower or bicycle, neither of which are potential WWD vehicles. Additionally, almost all WWD incidents occurred during typical working hours.

North Wanamaker Rd had 57 of 59 (97%) of the case 3 incidents on a single day from just before 9:00 a.m. to 11:00 a.m. The other ramps also showed indications of clustered case 3 incidents during daylight hours. Five case 3 incidents occurred with vehicle speeds exceeding 70 mph, with a maximum of 119 mph, during times when traffic was entering the entrance ramp to the interstate. One incident occurred during morning peak hour, three occurred around noon, and one incident was recorded during the evening peak hour. Given the volume of traffic during the evening peak hour, these hits were assumed to be inaccurate and likely due to equipment errors. Case 3 incidents were speculated to be due to ramp maintenance vehicles and possible equipment misreads, and these were further investigated throughout the calculation process. Therefore, since case 3 incidents could not be verified without video or on-site visual inspection of the incident, these events were recorded but not included in either the initial scan or data analysis. The second counter confirmed WWD incidents that entered the interstate.

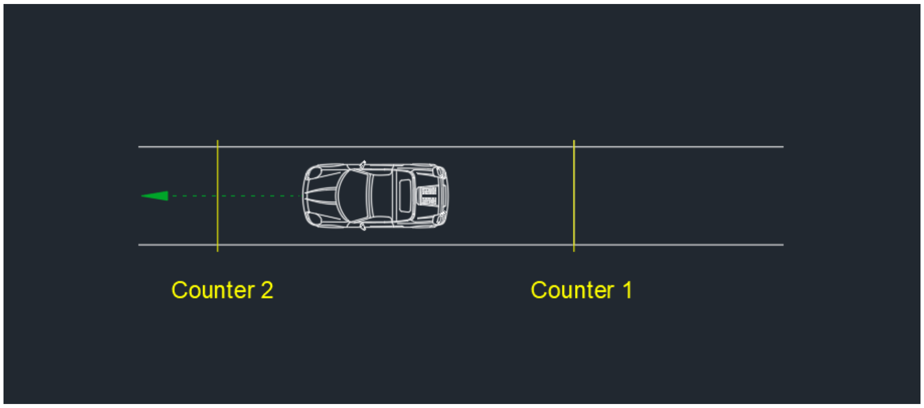


Figure 5.14: Case 3 Wrong-Way Incident

5.8 Selection of Low-Cost Countermeasure for Each Site

An initial examination of available countermeasures revealed a wide range of options, including pavement markings and signs to full-range countermeasures such as cameras, detection notification, and flashing LED signs. These countermeasures range in price from $200 to more than $60,000. An initial list of some of the low-cost countermeasures was developed, and each sign was studied to determine effectiveness, ease of installation, and maintenance requirements.

Results showed that countermeasure effectiveness varies depending on geographic region. Countermeasures that were effective in southern states may not be as effective in eastern or western states. In addition, each ramp was investigated to determine what countermeasures were already in use and to evaluate the surrounding area. The collected information was combined with results from the before study to develop a working list of countermeasures that included RRFDs on posts with Do Not Enter and Wrong Way signs, Wrong Way signs with red flashing LEDs, and oversized and lowered Wrong Way signs, as shown in Figures 5.15 and 5.16. These signs were chosen because the before data highlighted three ramps for countermeasure evaluation that had several daytime incidents.

The RRFDs (Figure 5.15a) are red delineators, or small reflective signs, that are typically used on signposts or median barriers. They were chosen by the research team for their low light and nighttime effectiveness. Research conducted on nighttime driving has shown that RRFDs effectively draw the eye to the post and cause drivers to notice the signs (Finley et al., 2014). Research has also shown that drunk drivers shift their focus to the lower right area of the road where RRFDs draw attention to the Wrong Way signs and that flashing LED signs (Figure 5.15b) effectively attract the attention of intoxicated and sober drivers (Finley et al., 2014). The use of oversized, lowered signs (Figure 5.16) has also proven to effectively reduce WWD incidents, particularly in the daytime (Baratian-Ghorghi & Zhou, 2017; Cooner & Ranft, 2008; Das et al., 2017; Staplin et al., 2001; Cooner et al., 2004b; Kaminski Leduc, 2008). The MUTCD allows signs along interstates and ramps to be lowered to 3 ft, the height used in this study, which places the sign at the driver's height, thereby increasing sign prominence.

(a) (b)

Figure 5.15: Preliminary Countermeasures: (a) RRFD; (b) Flashing LED Wrong Way Sign

Figure 5.16: Preliminary Countermeasures: Oversized and Lowered Wrong Way Sign

After considering previous research, the WWD Working Group results, and discussions with the KDOT project manager, RRFDs were selected as a countermeasure to be used on the Auburn Rd and Gage Blvd ramps. The RRFDs were installed on the Do Not Enter sign at the entrance of the ramp and on the first Wrong Way sign. Because WWD incidents at Auburn Rd occur primarily at night and incidents at Gage Blvd occur in the early morning and late afternoon, RRFDs were determined to be most effective during low light and dark conditions. This data can be found in Appendix B.

The second countermeasure, oversized Wrong Way signs, were installed lower than normal (3 ft above the pavement), meaning the signs were at approximately the same height as a driver sitting in a car. The oversized signs were placed at Wanamaker Rd North, Wanamaker Rd South, and Gage Blvd. At the two Wanamaker Rd ramps, two existing Wrong Way signs were replaced by the oversized signs and lowered to 3 ft. One existing Wrong Way sign was replaced with a larger sign and lowered on Gage Blvd. Fortunately, the geometry of the Wanamaker Rd South ramp allowed the first lowered sign to be eye level to the driver on the left, while the second sign, when lowered, was directly in front of the vehicle as it entered the curve. The other two locations allowed for similar placement of the lowered signs, although they were not quite as prominent as the Wanamaker Rd South ramp. Because WWD incidents at both Wanamaker ramps primarily occur during daylight hours and most incidents at Gage Blvd occur early in the morning or late afternoon in lighted conditions, enlarging and lowering the Wrong Way sign was expected to increase sign visibility. This data can be found in Appendix B.

The third selected countermeasure was a Wrong Way sign surrounded with red flashing LEDs. Although this countermeasure was more expensive than the other selections, it was chosen for the Auburn Rd site due to the minimal traffic on this ramp and the minimal lighting in the surrounding area. A private drive and a cemetery are located to the north of I-70 at this location, and the primary business to the south is a sports bar. In addition, the before data showed two case 1 incidents, both close to the bar closing times. This data can be found in Appendix B. Since research conducted in Texas has shown that flashing LED signs and RRFDs are very effective at night, especially with inebriated drivers (Finley et al., 2014), this targeted approach was chosen for this site.

Each sign was evaluated for initial cost and ease of installation. The RRFDs for each pole consisted of a total of twenty-one 4 in. x 4 in. delineators placed flush together from the sign down to the ground. The cost per delineator was $5.95, totaling approximately $125 per pole, or $250 per interchange. However, during the installation process, the head of the maintenance crew for the area suggested using a roll of thin aluminum with red reflective material on one side to reduce cost and increase ease of installation. The oversized signs were approximately $85 per sign, and the most expensive countermeasure was the flashing LED sign, which cost $1,500 per sign. The LED sign included a solar panel, a battery, and a control box that could be used to customize the sign's flashing time. The RRFDs were installed on poles already in use, so only screws or other mounting materials were required. The oversized signs replaced existing signs, and the poles already had holes at the appropriate heights and intervals. The flashing LED sign also replaced an existing sign, using the same pole and existing holes and hardware.

Chapter 6: Results

Before and after studies were designed to evaluate the effectiveness of the selected countermeasures. The before study was planned after ramp selection was finalized. Pneumatic road tubes were placed on the ramps on October 28, 2018. The initial plan was to leave the road tubes in place for 14 days, but inclement weather forced the tubes to be removed after 10 days. Table 6.1 presents the results from the before study. This data can be found in Appendix B.

Table 6.1: Results from the Before Study

		Before Study (10 Days of Data)						
Study Site	Wrong-Way Countermeasure(s)	Wrong-Way Incidents	Case 1	Case 2	Case 3	ADT	Wrong-Way Incident Rate per 100,000 Entering Vehicles	
							With Case 3	Without Case 3
Auburn Rd	Retro-Reflective Strips and LED Sign	8	2	4	2	760	105.26	78.95
Wanamaker Rd North	Oversized and Lowered Sign	77	0	18	59	1,950	394.87	92.31
Wanamaker Rd South	Oversized and Lowered Sign	10	2	8	0	2,090	47.85	47.85
Gage Blvd	Oversized and Lowered Sign and Retro-Reflective Strips	27	0	0	27	4,740	56.96	0.00
Adams St North	Control Site	3	0	2	1	2,175	13.79	9.20
Adams St South	Control Site	1	0	1	0	2,705	3.70	3.70

In Table 6.1, each study site is identified either by the ramp and the proposed WWD countermeasure or as a control site. The results are presented as total WWD incidents and then categorized as case 1, case 2, or case 3 incidents. However, comparisons of all the ramps and studies were difficult due to various ramp and daily volumes. Large volumes may result in more total incidents, but the high volume may not increase the rate of incidence. Therefore, the raw total number of WWD incidents was converted to an incident rate per 100,000 entering vehicles. Previous WWD studies reported WWD incidents as a rate of incidents per 30 days (Parsonson & Marks, 1979; Howard, 1980; Campbell & Middlebrooks, 1988). Although this previous rate allows ramps with WWD incidents to be easily identified, it does not account for ramp volume; high-volume ramps may have more WWD incidents than a low-volume ramp, but high-volume ramps may have a lower incident rate. Recently, WWD studies have begun to use incident rates based on ramp volumes.

This study utilized two average daily traffic (ADT) values to set up an equation to determine the WWD incident rate. The first ADT was the volume of vehicles that exited the interstate and were counted by the road tubes. An actual count of vehicles on the ramp was obtained, but those vehicles never had the opportunity to make an incorrect movement at the interchange. Discussions at the Transportation Research Board (TRB) meeting in 2020 with Dr. Huaguo Zhou, a leading WWD researcher from Auburn University, revealed that the number of vehicles using the ramp to enter the interstate is the "pool" of vehicles that could potentially enter the ramp going the wrong way, resulting in an accurate count that leads to a true incident rate based on the number of possible drivers who could make a wrong-way movement. KDOT provided ramp data from 2019, and ramp counts were compared to the ADT for vehicles entering the ramp at the interchange. Results were inconclusive as to whether the exiting or entering ramp had a higher volume of traffic, with differences as high as 4000 vpd. Given the disparity of results and the discussion at TRB, the ADT for the interstate entrance ramp was used in the ADT column for all the studies, and an incident rate per 100,000 entering vehicles was calculated using the following formula:

$$\frac{\# \, incidents * 100{,}000}{ADT * \# \, of \, Days} = Incident \, Rate \qquad \textbf{Equation 6.1}$$

The incident rates for the ramps varied from 3.70 to 394.87. Results by case revealed four total case 1 entries, two each at the Auburn Rd and Wanamaker Rd South ramps. Overall, although 152 hits occurred across all three cases, more than 75% of those hits were case 3 incidents, 98% of which came from the Wanamaker Rd North, Gage Blvd, and Adams St North ramps.

The first after study was conducted immediately after the countermeasures were installed on September 26, 2019. Initially the road tubes were intended to stay out for the same length of time as the before study, but the time was extended to 14 days due to issues with the flashing LED sign. Technical support was able to fix the sign on October 4, 2019, seven days after the road tubes were emplaced. The tubes were left out another seven days to have the same amount of time with a working sign. Both control sites also had one set of road tubes that experienced issues during the first after study. At the Adams St South ramp, one road tube was damaged near counter 1, resulting in inaccurate data, and a tube became damaged at counter 2 at the Adams St North ramp, resulting in unreliable data. Data from the other two counters at the control sites also showed WWD incidents similar to the before study, but all the data were excluded due to missing data from damaged tubes. Results from the first after study are presented in Table 6.2.

Table 6.2: Results from After Study #1

		After Study #1 (14 Days of Data)						
Study Site	Wrong-Way Countermeasure(s)	Wrong-Way Incidents	Case 1	Case 2	Case 3	ADT	Wrong-Way Incident Rate per 100,000 Entering Vehicles	
							With Case 3	Without Case 3
Auburn Rd**	Retro-Reflective Strips and LED Sign	12	0	11	1	760	112.78	103.38
Wanamaker Rd North	Oversized and Lowered Sign	26	0	20	6	1,950	95.24	73.26
Wanamaker Rd South	Oversized and Lowered Sign	9	0	4	5	2,090	30.76	13.67
Gage Blvd	Oversized and Lowered Sign and Retro-Reflective Strips	2	0	2	0	4,740	3.01	3.01
Adams St North	Control Site	Equipment Error						
Adams St South	Control Site							

**Results for Auburn Rd are cumulative.

Results from the first after study showed that case 1 incidents decreased to zero, and three of the ramps showed marked improvement compared to the before study. One ramp, Auburn Rd, had a similar incident rate as the before study. One countermeasure used at Auburn Rd was the flashing LED Wrong Way sign. Although sign installation was successful and the sign was activated per vendor instructions to blink from 9:00 p.m. to 4:00 a.m. each night, the sign did not blink as intended. Tech support discovered an issue with the sign operating through midnight into the next day, so a work around was developed where the sign successfully operated from 9:00 p.m. to 11:55 p.m. and then from 12:01 a.m. to 4:00 a.m. However, the issue caused a seven-day span in which the sign did not work properly, and a seven-day span with data in which the sign did work properly. An incident rate was determined for each time period with their countermeasures, as shown in Table 6.3. The observed difference was an incident rate of 93.98 before the sign was operational compared to an incident rate of 112.78 after the sign was operational.

Table 6.3: Results from Auburn Rd—Before and After Flashing LED Sign

		Before the Flashing sign was working						
Study Site	**Wrong-Way Countermeasure(s)**	**Wrong-Way Incidents**	**Case 1**	**Case 2**	**Case 3**	**ADT**	**Wrong-Way Incident Rate per 100,000 Entering Vehicles**	
							With Case 3	**Without Case 3**
Auburn Rd	**Retro-Reflective Strips and LED Sign**	5	0	5	0	760	93.98	93.98

		After the Flashing sign was working						
Study Site	**Wrong-Way Countermeasure(s)**	**Wrong-Way Incidents**	**Case 1**	**Case 2**	**Case 3**	**ADT**	**Wrong-Way Incident Rate per 100,000 Entering Vehicles**	
							With Case 3	**Without Case 3**
Auburn Rd	**Retro-Reflective Strips and LED Sign**	7	0	6	1	760	131.58	112.78

Data for the long-after study were scheduled to be gathered in mid-March 2020, approximately five months after the first after study, but unfortunately, the state of Kansas was placed under travel restrictions and lockdown due to the coronavirus pandemic, and traffic volumes dropped dramatically. Therefore, the second after study was delayed because reduced traffic volumes could have skewed the data, inflating the effectiveness of the countermeasures. Once travel and lockdown restrictions were lifted and traffic volumes returned to normal, road tubes were set out for the long-after study. The road tubes were emplaced on June 7, 2020, and left in place for 14 days to match the first after study. Data showed that overall traffic volumes for the ramps were within 10%–15% of the first after study. One of the road tubes for counter 2 on Gage Blvd was damaged, but the data did not show any errors, so the data were used. Table 6.4 presents results from the second after study.

Table 6.4: Results from After Study #2

		After Study #2 (14 Days of Data)						
Study Site	**Wrong-Way Countermeasure(s)**	**Wrong-Way Incidents**	**Case 1**	**Case 2**	**Case 3**	**ADT**	**Wrong-Way Incident Rate per 100,000 Entering Vehicles**	
							With Case 3	**Without Case 3**
Auburn Rd	**Retro-Reflective Strips and LED Sign**	4	0	3	1	760	37.59	28.20
Wanamaker Rd North	**Oversized and Lowered Sign**	24	0	11	13	1,950	87.91	40.29
Wanamaker Rd South	**Oversized and Lowered Sign**	4	0	4	0	2,090	13.67	13.67
Gage Blvd	**Oversized and Lowered Sign and Retro-Reflective Strips**	12	0	9	3	4,740	18.08	13.56
Adams St North	**Control Site**	4	0	4	0	2,175	13.14	13.14
Adams St South	**Control Site**	0	0	0	0	2,705	0.00	0.00

Data from WWD incident rates for ramps from the second study showed zero case 1 incidents and a decrease in the number of case 2 incidents, including the two control ramps. Case 3 incidents showed a slight increase, but none of the case 3 incidents occurred on the control ramps. Overall, incident rates decreased from the first after study for three of the four treatment ramps. The fourth ramp, Gage Blvd, increased from an incident rate of zero to 13.14. Table 6.5 summarizes all incident rates for all the studies in this research.

Table 6.5: Summary of All Incident Rates

		Before Study		After Study #1		After Study #2	
Study Site	Wrong-Way Countermeasure(s)	Incident Rate w/ Case 3	Incident Rate w/out Case 3	Incident Rate w/ Case 3	Incident Rate w/out Case 3	Incident Rate w/ Case 3	Incident Rate w/out Case 3
Auburn Rd	Retro-Reflective Strips and LED Sign	105.26	78.95	112.78	103.38	37.59	28.20
Wanamaker Rd North	Oversized and Lowered Sign	394.87	92.31	95.24	73.26	87.91	40.29
Wanamaker Rd South	Oversized and Lowered Sign	47.85	47.85	30.76	13.67	13.67	13.67
Gage Blvd	Oversized and Lowered Sign and Retro-Reflective Strips	56.96	0.00	3.01	3.01	18.08	13.56
Adams St North	Control Site	13.79	9.20	Equipment Error			13.14
Adams St South	Control Site	3.70	3.70	Equipment Error			0.00

When evaluating WWD countermeasures using before and after studies, a determination of success previously has been based on a reduction in WWD incidents. For this study, a statistical two-proportion z-test was run to identify a significant reduction in WWD incidents. This test considers the various volumes of traffic on each ramp as well as the numbers of days between studies. The actual counts of case 1 and case 2 incidents were used for each ramp. Results are shown in Table 6.6.

Table 6.6: Ramp *z*-Values

		z-values	
Ramp	Countermeasure	Before - After	Before - Long After
Auburn Rd	Retro-Reflective Strips and LED Sign	-0.53320	1.52165
Wanamaker N	Oversized and Lowered Sign	-0.63093	0.69076
Wanamaker S	Oversized and Lowered Sign	2.25909	2.25909
Gage	Oversized and Lowered Sign and Retro-Reflective Strips	1.19524	0.56346

The first and second columns of Table 6.6 list each ramp with a deployed countermeasure and the specific countermeasures used, respectively. The listed z-values compare the proportion of WWD incidents to the total number of vehicles that entered the ramp. The last two columns in the table show the z-values when comparing the before study to the after study and to the long-after study. As shown in the table, Wanamaker Rd South has a z-value of 2.26 for both comparisons, which indicates a significant reduction in WWD incidents to the 98th percentile. Similarly, Auburn Rd has a z-value of 1.52 for the before and long-after comparison, indicating that the reduction in WWD incidents is significant to the 90th percentile. The Wanamaker Rd North ramp did not show any significance in either of the studies, and the Gage Blvd ramp had a z-value that was closer to significant for the before and after study than the before and long-after study.

Chapter 7: Summary of Findings

Wrong-way driving (WWD) incidents are a serious safety concern throughout the United States, with many incidents resulting in serious crashes involving at least one fatality. The focus of this research centered around wrong-way driving (WWD) incidents at partial cloverleaf (ParClo) interchanges. ParClo interchanges, which are common in the Midwest, are often located in areas with constrained right-of-way on one or both sides of the interchange. The primary objective of this study was to determine the effectiveness of low-cost WWD countermeasures at ParClo interchanges to reduce the number of WWD incidents. Interchanges were selected in the metropolitan area of Topeka, Kansas, based on input from KDOT and available ParClo interchanges. Proposed low-cost countermeasures were selected after a state-of-practice survey was completed (Chapter 4 and Appendix A). An expert workshop was also conducted to validate low-cost countermeasure selection and possible placement. WWD incident data were collected using pneumatic road tubes at treatment and control interchanges, and countermeasure effectiveness was determined using a before-after short-term and long-term analysis. WWD rates were expressed at a rate of 100,000 ev, and the results of each interchange are explained in the following sections.

7.1 Countermeasures by Ramp

7.1.1 Auburn Rd

The Auburn Rd ramp demonstrated consistent results from the before study to the first after study, but a comparison of the data indicated that the time when the sign was not working (incident rate of 93.98) performed slightly better than the time when the sign was working (incident rate of 112.78). However, the case 1 entries at Auburn Rd were eliminated, which is a substantial improvement from the before study even if the case 2 incidents increased, thereby indicating that the countermeasures were effective. The increase in case 2 incidents could be due to drivers noticing the signs and then self-correcting. Results from the Auburn Rd exit showed significant improvement from after study 1 to after study 2, with the incident rate decreasing from 103.38 to 28.20 incidents per 100,000 ev. An examination of case 3 incident rates revealed a decline from 105.26 incidents in the before study to 37.59 incidents per 100,000 ev in the second after study. Examination of the incident rates from all three studies showed that the incident rate increased from 78.95 to 103.38 and then dropped to 28.20 incidents per 100,000 ev. A statistical comparison of the proportion of WWD incidents between the before study and the long-after study showed a significant reduction to the 90th percentile. The results showed that the RRFDs and the oversized sign were effective but results for the flashing LED sign were inconclusive. The WWD sign itself is oversized, potentially contributing to the RRFD effectiveness, but no evidence proved the effectiveness of the flashing LEDs.

7.1.2 Wanamaker Rd North

Results from the Wanamaker Rd North exit showed a reduction from the before study (92.31 incidents) to the first after study (73.26 incidents) per 100,000 ev. The incident rate for the before study decreased from 394.87 to 95.24 incidents per 100,000 ev, even with case 3 incidents. Data from the after studies showed that the incident rate of the ramp also improved, dropping to 73.26 incidents for the first after study and then to 40.29 incidents for the second after study. This steady improvement in the change in incident rate indicates that the combination of oversized and lowered Wrong Way signs effectively reduced WWD incidents throughout the study period.

7.1.3 Wanamaker Rd South

Results from the Wanamaker Rd South exit showed a significant reduction in incident rate from the before study to the after study. This ramp also had two case 1 incidents during the before study and no case 1 incidents during the after studies, demonstrating a marked improvement for the ramp. The incident rate stayed the same during the long-after study: the before study incident rate was 47.85 and then dropped to 13.67 during the first after study and stayed at 13.67 incident per 100,000 ev for the long-after study. Statistically, the proportion of WWD incidents from the before to both after studies was significant to the 98th percentile. In addition to eliminating case 1 incidents, the improvement in incident rates indicates that the combination of oversized and lowered Wrong Way signs was effective.

7.1.4 Gage Blvd

The Gage Blvd ramp had an incident rate of 0 in the before study and 3.01 for the first after study, with the incident rate rising slightly to 13.56 incident per 100,000 ev. Two WWD incidents occurred on this ramp during the first after study, but the rate was very close to zero when considering the traffic volume on this ramp. The decrease and then rise of incident rates during the study rendered the results at Gage Blvd inconclusive, and the decrease of WWD incident proportions was not statistically significant. The oversized and lowered Wrong-Way sign and the RRFDs were used at the Gage Blvd ramp.

7.1.5 Control Sites

The control sites were expected to maintain the same incident rates across all three studies, but equipment error during the first after study left only the before and second after study for examination. The incident rates for both control sites were very similar from the before study to the second after study. The incident rates for the Adams St South ramp were 3.70 for the before study and zero for the second after study, and the incident rates for the Adams St North exit for the before study and second after study were 9.20 and 13.14 incidents per 100,000 ev, respectively. Since both control sites showed very similar incident rates during the before study and the second after study, the changes at the treatment ramps were assumed to be a result of the countermeasures.

7.2 Contributions to Highway Safety

WWD is a complicated highway safety concern that often leads to very serious crashes. Although the interstate system in the United States has been operational for over 50 years, understanding of the sequence of events leading to WWD incidents is still not complete. This study focused on a gap in previous literature that sought to explain WWD, test the effectiveness of countermeasures, and implement a variety of intervention and geometric improvement strategies to prevent WWD crashes.

ParClos are a unique type of interchange commonly used in midwestern states. However, ParClo on- and off-ramps are very close to each other, causing many drivers to turn onto the wrong ramp when proper lighting, pavement markings, or signage are lacking. This study focused on reducing WWD incidents at ParClos by investigating countermeasure effectiveness and identifying more robust WWD data collection methods using pneumatic road tubes. Although quantifying the effectiveness of the deployed countermeasures may be difficult, the prevention of just one WWD incident could have a significant economic benefit to the state of Kansas by at least one life potentially saved. This research can also prompt communities and state DOTs to implement low-cost WWD countermeasures.

7.3 Limitations

Several limitations were identified while conducting this study. Some of these limitations could not be fully addressed due to the input of the sponsor of this research, but other limitations were recognized and accounted for if possible. First, as the sponsor of this research project, KDOT recognized the importance of the research, but limitations were placed on how the countermeasures were installed and which countermeasures could be used based on past experiences with long-term countermeasure maintenance. Additionally, some WWD countermeasures (e.g., raised pavement markings) could not be utilized due to environmental factors in Kansas, such as snow and ice. Accurate evaluation of the effectiveness of some of the countermeasures was also difficult because sites often utilized multiple countermeasures, which prevented the isolation of countermeasures to measure effectiveness. The use of multiple types of countermeasures may have influenced driver behavior.

7.4 Future Research

Future research of WWD incidents in Kansas should vary the types of ramps investigated, including ramps that are known to be susceptible to WWD movements and those that are not susceptible to WWD movements. Varying the ramp types will increase the data variation to help explain WWD incidents and reveal why drivers enter ramps incorrectly. Further studies of individual countermeasures on a single ramp should be conducted to evaluate each countermeasure separately, thereby providing further quantifiable evidence to determine how each countermeasure reduces WWD incidents under control conditions. Each countermeasure should also be evaluated for its effectiveness on various driver characteristics of known WWD crashes, such as age or physical impairments. This data could assist local agencies with initial countermeasure selection. Finally, further study of data collection methods for WWD incidents at signalized and unsignalized interchange ramps and at high-volume ramps is still needed to help evaluate countermeasures at interchanges.

References

AASHTO. (2011). *A policy on geometric design of highways and streets.* Washington, D.C.: America Association of State Highway and Transportation Officials.

Arizona Department of Transportation (2015). *ADOT traffic engineering guidelines and processes*. https://azdot.gov/sites/default/files/2019/05/tgp0314-2015-12.pdf

Alluri, P., Wu, W., Nafis, S., & Hagen, L. (2018) *A data-driven approach to implementing wrong-way driving countermeasures* [Final report]. Florida Department of Transportation.

Arkansas Department of Transportation. (2017). *Arkansas 2017 strategic highway safety plan*. Little Rock, AR.

Arkansas Department of Transportation. (2020). *Wrong-way crash study: Interstate and freeways, Calendar Year 2018*. Little Rock, AR.

Arkansas Department of Transportation. (2017). *Arkansas motor vehicle and traffic laws and state highway commission regulations.* LexisNexis.

Baisyet, R., & Stevens, A. (2015). Combating wrong way drivers on divided carriageways [Paper Presentation]. Christchurch, New Zealand: *Institution of Professional Engineers New Zealand (IPENZ) World Class Transport Conference*.

Baratian-Ghorghi, F. & Zhou, H. (2017). Traffic control devices for deterring wrong-way driving: Historical evolution and current practice. *Journal of Traffic and Transportation Engineering* (English Edition), *4*(3), 280–289.

Baratian-Ghorghi, F., Zhou, H., & Shaw, J. (2014a). Overview of wrong-way driving fatal crashes in the United States. *ITE Journal, 84*(8), 41–47.

Baratian-Ghorghi, F., Zhou, H., Jalayer, M., & Pour-Rouholamin, M. (2015). Prediction of potential wrong-way entries and exit ramps of signalized partial cloverleaf interchanges. *Traffic Injury Prevention*, *16*(6). 599–604. https://doi.org/10.1080/15389588.2014.981651.

Bener, A. (2013). The psychological distress and aggressive driving: Age and gender differences in voluntary risk-taking behavior in road traffic crashes. *European Psychiatry*, *28*(1), 1. doi:10.1016/S0924-9338(13)75901-7

Bergman, H., Hubicka, B., Laurell, H., & Schlyter, F. (2000). *BAC level and alcohol problems among drivers suspected of DUI*. Paper presented at 15th International Conference on Alcohol, Drugs and Traffic Safety.

Braam, A. C. (2006). *Wrong way crashes statewide study of wrong way crashes on freeways in North Carolina.* North Carolina Division of Highways.

Caltrans. (2014). *California manual on uniform traffic control devices.* California: California State Transportation Agency, Department of Transportation.

Caltrans. (2016). *Prevention and detection of wrong-way collisions on freeways* [Final report]. Sacramento, CA.

Campbell, B. E., & Middlebrooks, P. B. (1988). *Wrong-way movements on partial cloverleaf ramps* [Report FHWA-GA-88-8203]. Atlanta, GA: Georgia Department of Transportation.

Chen, H., Zhou, H., Zhao, J., & Hsu, P. (2011). Safety performance evaluation of left-side off-ramps at freeway diverge areas. *Accident Analysis & Prevention*, *43*(3), 605–612.

Clay, R. S. (2011). *The San Antonio wrong way driver initiative US 281 pilot project*. Texas Department of Transportation, Austin.

Colorado Department of Transportation. (2013). *Work zone safety guidelines for municipalities, utilities and contractors.*

Colorado Department of Transportation. (2022). *I-25 wrong way preventive signage updates.* https://www.codot.gov/projects/i-25-wrong-way-sign-installation

Cooner, S. A., & Ranft, S. E. (2008). *Wrong-way driving on freeways: Problems, issues, and countermeasures* [Proceedings]. Transportation Research Board 87th Annual Meeting, Washington, D.C.

Cooner, S. A., Cothron, A., & Ranft, S. E. (2004). *Countermeasures for wrong-way movement on freeways: Overview of project activities and findings* (Report No. FHWA/TX-04/4128-1). Texas Transportation Institute: Texas A&M University.

Cooner, S. A., Cothron, S. A., & Ranft, S. E. (2004). *Countermeasures for wrong-way movement on freeways: Guidelines and recommended practices* (Report No. FHWA/TX-04/4128-2). Texas Transportation Institute: Texas A&M University.

Copelan, J. E. (1989). *Prevention of wrong way accidents on freeways* [Report No. FHWA/CA-TE-89-2]. California Department of Transportation.

Das, S., Avelar, R., & Sun, X. (2017). Investigation on the wrong way driving crash patterns using multiple correspondence analysis. *Accident Analysis & Prevention*, *111*, 43–55.

FHWA. (2009). *Manual on Uniform Traffic Control Devices*. Washington, D.C.: Federal Highway Administration.

FHWA. (2009). *Manual on Uniform Traffic Control Devices*. Washington, D.C.: Federal Highway Administration.

FHWA. (2020). Wrong-way driving. Federal Highway Administration. https://safety.fhwa.dot.gov/intersection/other_topics/wwd/

Finley, M. D., Venglar, S. P., Iragavarapu, V., Miles, J. D., Park, E. S., Cooner, S. A., & Ranft, S. E. (2014). *Assessment of the effectiveness of wrong way driving countermeasures and mitigation methods.* Texas Transportation Institute: Texas A&M University.

Fisher, M. P., & Garcia, C. (2016). *Compendium of student papers: 2016 undergraduate scholars program.* Southwest Region University Transportation Center: Texas A&M Transportation Institute.

Garber, N. J., & Fontaine, M. D. (1999). *Guidelines for preliminary selection of the optimum interchange type for a specific location.* Charlottesville, Virginia: Virginia Transportation Research Council.

Google. (n.d.). [Google Map for overhead satellite views]. Retrieved June 15, 2020, from https://www.google.com/maps/@39.0537307,-95.7368463,12085m/data=!3m1!1e3?hl=en&authuser=0

Hamilton, S. L. (2008). *Evaluation of risk factors for repeat DUI offenses* [No. FHWA-AK-RD-09-02]. Alaska Department of Transportation and Public Facilities.

Howard, C. (1980). *Wrong-way driving at selected interstate off-ramps*. Charlottesville, VA: Virginia Highway & Transportation Research Council.

IDOT. (2020). *Bureau of design and environment manual.* Springfield, IL: Illinois Department of Transportation.

Jalayer, M., Pour-Rouholamin, M., & Zhou, H. (2017). *Multiple correspondence approach to identifying contributing factors regarding wrong-way driving crashes* [Proceedings]. Transportation Research Board 96th Annual Meeting, Washington, D.C.

Kaminski Leduc, J. L. (2008). *Wrong-way driving countermeasures*. Retrieved July 28, 2020, from https://www.cga.ct.gov/2008/rpt/2008-r-0491.htm

Kansas Department of Transportation. *Crash statistics 2005-2015*. (2016). https://www.ksdot.org/burtransplan/prodinfo/accista.asp

Khalilikhah, M., & Heaslip, K. (2016). *Important environmental factors contributing to the temporary obstruction of the sign messages* [Proceedings, No. 16-3785]. Transportation Research Board 95th Annual Meeting, Washington, D.C.

Langford, J., & Koppel, S. (2006). Epidemiology of older driver crashes - Identifying older driver risk factors and exposure patterns. *Transportation Research Part F: Traffic Psychology and Behavior, 9*(5), 309–321.

Leisch, J. P., & Morrall, J. P. (2014). *Evolution of interchange design in North America* [Paper presentation]. Transportation Association of Canada (TAC) Conference, Montreal, Quebec.

Miles, J. D., Carlson, P. J., Ullman, B., & Trout, N. (2008). Red retroreflective raised pavement markings: Driver understanding of their purpose. In *Transportation Research Record, 2056*(1), 34 – 42. https://doi.org/10.3141/2056-05.

Moler, S. (2002). Stop. You're going the wrong way! United States Department of Transportation: Federal Highway Administration: *Public Roads, 66*(2). https://www.fhwa.dot.gov/publications/publicroads/02sep/06.cfm

Monsere, C., Kothuri, S., & Razmpa, A. (2017). *Wrong way driving analysis and recommendations* [Final report], Oregon Department of Transportation.

Morena, D. A., & Ault, K. (2014). "Michigan wrong-way freeway crashes" [Proceedings]. *2013 National Wrong-Way Driving Summit*, 126-153.

Morena, D. A., & Leix, T. J. (2012). Where these drivers went wrong. *Public Roads*, *75*(6), 33–41.

North Dakota Department of Transportation. (2011). *Installation of Do Not Enter and Wrong Way signs at stop controlled divided highway intersections* [Policy memorandum].

National Highway Traffic Safety Administration. (2014). “Older driver safety”. *Uniform Guidelines for State Highway Safety Programs* [No. DOT-HS-812-007D].

National Transportation Safety Board. (2012). *Wrong-way driving* [Highway special investigation report, NTSB/SIR-12/01, PB2012-917003, Notation 8453]. Washington, D.C.

North Texas Tollway Authority. (2009, September 23). *Keeping NTTA roadways safe: Wrong-way driver task force staff analysis.* North Texas Tollway Authority. https://www.ntta.org/newsresources/safeinfo/wrongway/Documents/WWDAnalysisAUG2011.pdf

Ohio Department of Transportation. (2020). *Location and Design Manual*, Vol. 1.

Ouyang, Y. (2014). “North Texas tollway authority’s wrong way driving program: From a traffic engineer’s perspective”. In *Proceedings of the 2013 National Wrong-Way Driving Summit,* (81-105).

Ozkul, A., & Lin, P. (2017). Evaluation of red RRFB implementation at freeway off-ramps and its effectiveness on alleviating wrong-way driving. *Transportation Research Procedia*, *22*, 570–579. https://doi.org/10.1016/j.trpro.2017.03.046

Parsonson, P. S., & Marks, J. R. (1979). *Wrong-way traffic movements on freeway ramps* [Project E-20-624]. Atlanta, GA: Georgia Department of Transportation. https://smartech.gatech.edu/bitstream/handle/1853/34601/e-20-624_149297.pdf

Ponnaluri, R. V. (2015). Addressing wrong-way driving as a matter of policy: The Florida experience. *Transportation Policy*, *46*, 92–100.

Ponnaluri, R. V. (2016). The odds of wrong-way crashes and resulting fatalities: A comprehensive analysis. *Accident Analysis & Prevention*, *88*, 105–116.

Ponnaluri, R. V. (2018). Modeling wrong-way crashes and fatalities on arterials and freeways. *IATSS Research*, *42*(1). https://doi.org/10.1016/j.iatssr.2017.04.001

Pour-Rouholamin, M., Zhou, H., Zhang, B., & Turochy, R. E. (2016). Comprehensive analysis of wrong-way driving crashes on Alabama interstates. *Transportation Research Record*, *2601*(1), 50-58. https://doi.org/10.3141/2601-07.

Rogers, J. H., Jr., Sandt, A., Al-Deek, H., Alomari, A. H., Uddin, N., Gordin, E., Dos Santos, C., Renfrow, J., Carrick, G. (2015). Wrong-way driving multifactor risk-based model for Florida interstates and toll facilities. *Transportation Research Record*, *2484*(1), 119–128.

Rudisill, T. M., Zhao, S., Abate, M. A., Coben, J. H., & Zhu, M. (2014). Trends in drug use among drivers killed in U.S. traffic crashes. *Accident Analysis & Prevention, 70*, 178–187.

Ruer, P., Cabon, P., & Vienne, F. (2014). Prevention of wrong way accidents on highways: A human factors approach [Paper presentation]. *Transport Research Arena 2014 Proceedings*.

Saetern, L. (2015). *Wrong-way driving prevention methods*. Caltrans Division of Research, Innovation and System Information.

Saidi, H., Mutiso, B. K., & Ogengo, J. (2014). Mortality after road traffic crashes in a system with limited trauma data capability. *Journal of Trauma Management & Outcomes, 8*(4), 1–6.

Sandt, A., Al-Deek, H., Rogers, J. H., Jr., & Alomari, A. H. (2015). Wrong-way driving prevention incident survey results and planned countermeasure implementation in Florida. *Transportation Research Record, 2484*(1), 99–109.

Schrock, S. D., Hawkins, H. G., & Chrysler, S. T. (2005). Effectiveness of lane direction arrows as pavement markings in reducing wrong-way movements on two-way frontage roads. *Transportation Research Record, 1918*(1), 63-67. https://doi.org/10.1177/0361198105191800108.

Simpson, S., Bruggeman, D. (2015). *Detection and warning systems for wrong-way driving* [No. FHWA-AZ-15-741]. Phoenix, AZ: Arizona Department of Transportation.

Sorenson, W. (2016). Countermeasures for wrong-way driving on freeways [Study TPF-5 (231)], Michigan Department of Transportation.

Staplin, L., Lococo, K., Byington, S., & Harkey, D. (2001). *Highway design handbook for older drivers And pedestrians.* Federal Highway Administration.

Tamburri, T. (1965). *Report on wrong-way automatic sign, light and horn device.* Traffic Department, Division of Highways, Department of Public Works, State of California.

Vaswani, N. K. (1977). *Further reduction in incidents of wrong-way driving* (Report No. VHTRC 77-R45). Virginia Highway & Transportation Research Council.

Zhou, H., & Pour-Rouholamin, M. (2014). *Guidelines for reducing wrong-way crashes on freeways*. Illinois Department of Transportation.

Zhou, H., Zhao, J., Fries, R., Gahrooei, M. R., Wang, L., Vaughn, B., Bahaaldin, K., Ayyalasomayajula, B. (2012). *Investigation of contributing factors regarding wrong-way driving on freeways* (Report No. FHWA-ICT-12-010). Illinois Center for Transportation.

Zhou, H., Zhao, J., Fries, R., & Pour Rouholamin, M. (2014a). Statistical characteristics of wrong-way driving crashes on Illinois freeways. In *Transportation Research Board 93rd Annual Meeting Compendium of Papers*.

Zhou, H., Pour-Rouholamin, M., & Jalayer, M. (2014b). *Emerging safety countermeasures for wrong-way driving*. Fredericksburg, VA: American Traffic Safety Services Association.

Zhou, H., Zhao, J., Pour-Rouholamin, M., & Tobias, P. A. (2015). Statistical characteristics of wrong-way driving crashes on Illinois freeways. *Traffic Injury Prevention*, *16*(8), 760–767.

Zhou, H., Xue, C., Yang, L., & Luo, A. (2018). *Directional rumble strips for reducing wrong-way driving on freeway entries* [Final report]. Roadway Safety Institute.

Appendix A: DOT Survey Table

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Arizona (ADOT)	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016. Arizona Department of Transportation, Traffic Guidelines and Processes (TGP), Accessed 2025, available at: https://azdot.gov/business/engineering-and-construction/traffic/guidelines-and-processes	2016, 2015	1. Improvements to static signs and pavement markings *a. Larger signs: WRONG WAY 48” x 36” and DO NOT ENTER 48” x 48”* *b. WRONG WAY and DO NOT ENTER signs mounted on the same post* *c. Low mounted signs: 3’ minimum height* *d. Optional red reflective strips on posts* *e. Wrong-way arrows with raised reflective markers surrounding the arrow art the exit ramps* *f. Left-turn pavement marking guides to assist drivers entering on entrance ramps* *g. If an overhead sign structure is present, overhead WRONG WAY signs and post-mounted WRONG WAY signs are installed* 2. Detection at entrance ramps with alerts to drivers and Transportation Management Center (TMC) *a. High-definition radar* *b. Vehicle-activated flashing LED WRONG WAY signs*	1. Wrong way signs should be used as a supplement to the DO NOT ENTER sign where experience indicates the need for such a sign on the basis of wrong-way movements, or where an engineering evaluation indicates that it is desirable to install such signs because geometrics are conductive to wrong-way entry. Locations where WRONG WAY signs may be warranted include: *a. Where an exit ramp intersects a two-way crossroad or frontage road* *b. Where a one-way, right turning roadway joins a two-way, undivided roadway* *c. At a divided roadway intersection where traffic from the crossroad may tend to enter the wrong side of the divided road* *d. Where direct access from abutting property to an exit ramp is permitted* *e. Where a one-way roadway becomes two-way*

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Arizona (ADOT), continued	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016. Arizona Department of Transportation, Traffic Guidelines and Processes (TGP), Accessed 2025, available at: https://azdot.gov/business/engineering-and-construction/traffic/guidelines-and-processes	2016, 2015		2. WRONG WAY signs shall not be installed in lieu of the standard regulatory and guide signs at freeway interchanges 3. Approval for use of WRONG WAY signs is not required for use on freeway exit ramps or similarly design traffic intersections a. The use of wrong-way signs at other locations shall be approved by the Regional Traffic Engineer before they are installed 4. At interchange exit ramps terminals where an exit ramp departing a freeway or highway intersects a crossroad in such a manner that wrong-way entry could inadvertently be made, DO NOT ENTER and WRONG WAY signs are installed to inform road users and discourage wrong-way travel. 5. Diamond interchange or one-way exit ramp terminal *a. DO NOT ENTER and WRONG WAY assemblies should be installed adjacent to the left and right hand sides of the exit ramp at or*

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Arizona (ADOT), continued	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016. Arizona Department of Transportation, Traffic Guidelines and Processes (TGP), Accessed 2025, available at: https://azdot.gov/business/engineering-and-construction/traffic/guidelines-and-processes	2016, 2015		*near the intersection of the crossroad* *b. Additional WRONG WAY signs should be installed to the left and right-hand sides of the exit ramp upstream of the intersections* 6. Single-point diamond interchange (with no through frontage road) *a. DO NOT ENTER / WRONG WAY assemblies should be installed to the left and right-hand sides of each exit ramp at or near the intersection of the crossroad* *b. Additional WRONG WAY signs should be installed to the left and right-hand sides of the ramp upstream of the intersection. If overhead sign structure is present, overhead WRONG WAY signs should be installed.* 7. Single-point diamond interchange (with through frontage road) *a. DO NOT ENTER / WRONG WAY assemblies should be installed to the left and right-hand sides of each exit ramp at or near the intersection of the crossroad* *b. Additional WRONG WAY signs should be installed to the left and right-hand sides*

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Arizona (ADOT), continued	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016. Arizona Department of Transportation, Traffic Guidelines and Processes (TGP), Accessed 2025, available at: https://azdot.gov/business/engineering-and-construction/traffic/guidelines-and-processes	2016, 2015		*of the ramp upstream of the intersection. If overhead sign structure is present, overhead WRONG WAY signs should be installed.* 8. Partial Cloverleaf of Loop Ramp interchange (without and right-turn island) *a. DO NOT ENTER / WRONG WAY should be installed adjacent to the left and right-hand sides of the exit ramp* *b. Additional WRONG WAY signs should be installed to the left and right-hand sides of the ramp upstream of the intersections. If an overhead sign structure is present, overhead WRONG WAY signs should be installed.* 9. Partial Cloverleaf or Loop Ramp interchange (with right turn island) a. *DO NOT ENTER / WRONG WAY should be installed adjacent to the left and right-hand sides of the exit ramp* b. *Additional WRONG WAY signs should be installed to the left and right-hand sides of the ramp upstream of the intersections. If an overhead sign structure is present, overhead WRONG WAY signs should be installed.*

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Arkansas (ArDOT)	Arkansas 2017 Strategic Highway Safety Plan, Arkansas Department of Transportation, Access 2025, available at: https://ardot.gov/wp-content/uploads/VRU_SHSP_AppendedFINAL.pdf Arkansas Motor Vehicle and Traffic Laws and State Highway Commission Regulations, Access 2025, available at: https://www.ardot.gov/wp-content/uploads/2022/03/ACT-300-Book-2021.pdf Arkansas Annual Wrong-Way Crash Studies, Accessed 2025, available at:https://ardot.gov/divisions/planning/traffic-safety/annual-wrong-way-crash-studies/	2017, 2017, 2020	1. Emphasis are action plan: Older Drivers *a. Install WRONG WAY pavement markings to help warn older drivers* *b. Lower WRONG WAY sign heights to help alert older drivers and prevent wrong-way crashes* 2. The ArDOT will analyze all reported wrong-way crashes on interstate highways and other freeways that are part of the state highway system to determine whether the installation of Additional traffic control devices are warranted and feasible in order to reduce the possibility of future wrong-way crashes 3. in 2018, the ArDOT implemented a low-cost countermeasure deployment based off of MUTCD guidance including the operational and oversize signs	There are no additional policies beyond what is included in the 2009 MUTCD
Colorado (CDOT)	Work Zone Safety Guidelines for Municipalities, Utilities, and Contractors Accessed 2025, available at: https://www.coloradocontractors.org/htdocs/TCS_Online_Documents/2013_Work_Zone_Safety_Guidelines.pdf	2019, 2013	1. Crews are in charge of replacing WRONG WAY signs, and updating highway markings for on-ramps and off-ramps	There are no additional policies beyond what is included in the 2009 MUTCD

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Colorado (CDOT), continued	I-25 Wrong Way Preventive Signage Update, Access 2025, available at: https://www.codot.gov/news/2019/july/cdot-continues-wrong-way-preventive-project-on-interstate-25-dates-updated		2. On-ramp closure from cross street a. Type 3 barricades are placed continuously across the on-ramp to prevent entrance	
Florida (FDOT)	Alluri, P., W. Wu, S. Nafis, L. Hagen. A Data-Driven Approach to Implementing Wrong-Way Driving Countermeasures, Accessed 2025, Available at: https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/research/reports/fdot-bdv29-977-36-rpt.pdf		1. FDOT has installed the required DO NOT ENTER and WRONG WAY signs and pavement markings per the Manual on Uniform Traffic Control Devices (MUTCD), as well as higher Signing and Pavement Marking Standards *a. Static signing and pavement marking (S&PM) standards* *b. Red flush-mount internally illuminated raised pavement markers* *c. Red rectangular rapids flashing beacons* *d. LED highlighted WRONG WAY signs, which send alerts to RTMC / TMC* *e. Detection-triggered blank-out signs that slash WRONG WAY* *f. Delineators along off-ramps* *g. Wigwag flashing beacons*	There are no additional policies beyond what is included in the 2009 MUTCD
Illinois (IDOT)		2014, 2015	1. Enhanced DOT NOT ENTER and WRONG WAY signing	1. Operations / safety considerations for wrong-way incidents

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Illinois (IDOT), continued	Zhou, H., M. Pour-Rouholamin. Investigation of Contributing Factors Regarding Wrong-Way Driving on Freeways, Phase II. Report ICT-R27-090, Illinois Center for Transportation, 2015. Access February 2025, Available at: https://idot.illinois.gov/content/dam/soi/en/web/idot/documents/transportation-system/specialty-lists/safety/fhwa-ict-15-016.pdf Zhou, H. M. Pour-Rouholamin. Guidelines for Reducing Wrong-way Crashes on Freeways. Report ICT-R27-090, Illinois Center for Transportation, 2014. Access February 2025, Available at: https://idot.illinois.gov/content/dam/soi/en/web/idot/documents/transportation-system/specialty-lists/safety/fhwa-ict-14-010.pdf	2014, 2015	2. Enhanced pavement marking and improved lane use arrows 3. Guidelines *a. Red retroreflective tape on mounting poles and signs can improve visibility* *b. Signs with LED lights are more visible, but more expensive* *c. Barrier delineators that would be visible when traveling the wrong-way can help against WWD incidents* *d. Acute angles between the interchanges and access roads can help guard against WWD incidents* *e. Two-way frontage roads are more susceptible to WWD incidents* *f. Diamond interchanges have more incidents of WWD than full cloverleaf interchanges* *g. Detection of wrong-way drivers could include inductive loops, magnetic sensors, video image processing, microwave radar* *h. Use changeable message signs to alert drivers that a wrong-way driver is on the highway* *i. Pavement embedded warning lights can deter wrong-way drivers*	*a. Provide channelized medians, islands, and adequate signing* 2. Diamond Interchange *a. Raised-curve channelization is used on the crossroad* 3. Two-quadrant partial cloverleaf interchanges *a. To discourage wrong-way movements into an exit ramp, use a maximum left-turn control radius of 80' from the crossroad into the entrance ramp and a 100' left-turn control radius from the exit ramp onto the crossroad* *b. Type A: Both exit and entrance terminals are located in advance of the structure and two channelized "T" intersections are formed on the crossroads. However, all turning movements from the crossroads must undergo a "reverse" operations; i.e. drivers traveling to the right must turn left and those traveling to the left must turn right* *c. Type B: Because "T" intersections allow normal operations for turning movements from the crossroads, the probability of wrong-way movements from*

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Illinois (IDOT), continued	Zhou, H., M. Pour-Rouholamin. Investigation of Contributing Factors Regarding Wrong-Way Driving on Freeways, Phase II. Report ICT-R27-090, Illinois Center for Transportation, 2015. Access February 2025, Available at: https://idot.illinois.gov/content/dam/soi/en/web/idot/documents/transportation-system/specialty-lists/safety/fhwa-ict-15-016.pdf Zhou, H. M. Pour-Rouholamin. Guidelines for Reducing Wrong-way Crashes on Freeways. Report ICT-R27-090, Illinois Center for Transportation, 2014. Access February 2025, Available at: https://idot.illinois.gov/content/dam/soi/en/web/idot/documents/transportation-system/specialty-lists/safety/fhwa-ict-14-010.pdf	2014-2015	4. Partial Cloverleaf interchange *a. Install KEEP RIGHT sign if median width is greater than 8'* *b. Install DO NOT ENTER sign if median width is greater than 12;* *c. Interchange with island – additional DOT NOT ENTER and WRONG WAY signs can be placed on the island* *d. At Exits, a paringed island combined with a left-turn marking extension is recommended* 5. Diamond interchange with continuous frontage road *a. If there is an existing cross-street or driveway near the exit gore area, a ONE WAY sign should be installed* *b. a pair of ONE WAY signs at the beginning of the entrance ramp is recommended if the intersection is unsignalized* 5. Diamond interchange *a. No LEFT TURN sign near the entrance ramp can also be placed in the median* 6. Hal-diamond interchange *a. Trailblazing signs should be provided to direct drivers to the closest entrance for*	*the crossroad are greatly reduced. the exit terminals are located beyond the structure and, due to the lower design speed on the loop ramp, drivers tend to decelerate more on the mainline through lanes in advance of the exit.* *d. Type C: No uniform pattern of operation is realized because traffic on the freeway exists in advance of the structure in one direction and beyond the structure in the other. Movements to the right or left from the crossroad are made by turning left for the opposing direction.* 4. Four-quadrant partial cloverleaf interchange *a. The left-turning path from the controlled ramp terminal of the four-quadrant partial cloverleaf Type A must intersect the crossroad downstream from the fore of the exit terminal. The minimum distance of 200' discourages wrong-way movements.*

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Illinois (IDOT), continued	Zhou, H., M. Pour-Rouholamin. Investigation of Contributing Factors Regarding Wrong-Way Driving on Freeways, Phase II. Report ICT-R27-090, Illinois Center for Transportation, 2015. Access February 2025, Available at: https://idot.illinois.gov/content/dam/soi/en/web/idot/documents/transportation-system/specialty-lists/safety/fhwa-ict-15-016.pdf Zhou, H. M. Pour-Rouholamin. Guidelines for Reducing Wrong-way Crashes on Freeways. Report ICT-R27-090, Illinois Center for Transportation, 2014. Access February 2025, Available at: https://idot.illinois.gov/content/dam/soi/en/web/idot/documents/transportation-system/specialty-lists/safety/fhwa-ict-14-010.pdf	2014-2015	*ramp movement not provided at this interchange*	5. Interchange Intersections *a. The preferred range for intersection angle is 30 to 45 degrees. Lower/shallower angles may increase the risk of wrong-way movements* *b. Wrong-way movement may originate at the ramp/crossroad intersections onto an exit ramp. To minimize the probability of these movements, provide a raised-curb median on the crossroad and sign the ramp according to the MUTCD* 6. One-way/two-way rural and urban freeways *a. Off-ramps joining two-way frontage roads should not be used because of the potential for wrong-way entries.*
Iowa (IowaDOT)	Savolainen, P., N. Hawkins. Investigation of Wrong-Way Driving. Report 17-623, Institute for Transportation, Iowa State University, 2017. Access February 2025, Available at: https://www.intrans.iastate.edu/research/completed/investigation-of-wrong-way-driving/	2016	1. High-definition radar detection at various mainline locations, with alers to DOT personnel for post-processing 2. Video analytics software detection with alerts to DOT personnel 3. Improvements to static signing and pavement markings *a. Targeted improvements – red conspicuity tape, larger signs, two signs mounted on*	There are no additional policies beyond what is included in the 2009 MUTCD

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Iowa (IowaDOT), continued	Savolainen, P., N. Hawkins. Investigation of Wrong-Way Driving. Report 17-623, Institute for Transportation, Iowa State University, 2017. Access February 2025, Available at: https://www.intrans.iastate.edu/research/completed/investigation-of-wrong-way-driving/		*the same post, DO NOT ENTER signs installed on both sides, wrong-way pavement marking arrows* *b. spot treatments – red conspicuity tape on all DO NOT ENTER and WRONG WAY signs, NO RIGHT TURN or NO LEFT TURN signs at selected locations, adding "RE-CHECK CROSS TRAFFIC BEOFRE ENTERING signs at selected locations*	
Michigan (MDOT), continued		2014, 2016	*1. Signing and pavement marking improvements* *a. Low-mounted WRONG WAY and DO NOT ENTER signs (4')* *b. Red reflective sheeting on WRONG WAY and DO NOT ENTER signs* *c. Stop bars at exit ramps* *d. Wrong-way pavement marking arrows on exit ramps* *e. Pavement marking extensions that guide drivers onto entrance ramps* *f. Paint island between exit and entrance ramps* *g. Red delineators along exit ramp (on guardrail or on posts)* *h. Land assignment arrows at top of exit ramp (selected locations; not mandatory)*	There are no additional policies beyond what is included in the 2009 MUTCD

State Agency	**Source Document**	**Date**	**WWD Countermeasures, Research, and Guidance**	**WWD Policy**
Michigan (MDOT), continued	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016.	2014, 2016	2. All statewide ramps: *a. Low mounted signs and red reflective sheeting on signposts at all exit ramps, regardless of the interchange type* *b. Revised signing standard to require low height WRONG WAY and DO NOT ENTER signs (4') and red reflective sheeting on signposts at exit ramps* 3. Geometric modification: *a. MDOT implemented a lane separator system that prevents drivers from making left turns onto the exit ramps* 4. Partial cloverleaf (ParClo) interchanges: *a. Developed enhanced signing and markings treatment to be deployed at these interchanges across the state*	
Missouri (MoDOT)	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016.	2016	1. Increased quantity of priority 1 signing *a. Doubled up priority signing (ONE WAY, DO NOT ENTER, and WRONG WAY signs); now one sign on each side of ramps* *b. Deployed at exit ramps and divided highways including turn-arounds and at-grade crossings*	There are no additional policies beyond what is included in the 2009 MUTCD

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Missouri (MoDOT), continued	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016.	2016	2. Blinking LED WRONG WAY sign system with alert to TMC *a. No alert to oncoming right-way traffic* *b. ONE WAY signs and DO NOT ENTER signs are placed at the intersection. Static and blinking WRONG WAY signs are placed along the ramp* 3. Blinking LED WRONG WAY sign system without alert to TMC *a. No alert to TMC or right-way traffic*	
Nebraska (NDOT)	Email from a member of the Nebraska Department of Roads Technical Advisory Committee	2020	1. There are no additional countermeasures beyond what is included in MUTCD 2. Optional: *a. Retroreflective red sheeting that can be used on signposts for WRONG WAY an DO NOT ENTER signs*	There are no additional policies beyond what is included in the 2009 MUTCD
New Mexico (NMDOT)	Email from DOT State Traffic Engineer	2020	1. Cloverleaf interchanges: The state has not implemented wrong way detection on cloverleafs 2. Diamond interchanges: The state has started implementing the TAPCO system for four-ramps	There are no additional policies beyond what is included in the 2009 MUTCD
North Dakota (NDDOT)		2011	No countermeasures were found	1.This policy outlines how and where DO NOT ENTER and WRONG WAY signs should be installed at stop controlled divided highway intersections.

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
North Dakota (NDDOT), continued	Traffic Control Requirements for NDDOT Operations on Highways and Streets, 2011. Access February 2025, Available at: https://www.dot.nd.gov/sites/www/files/documents/construction-and-planning/Traffic-Control-Requirements.pdf	2011		This is not intended to take the place of engineering judgment. The signs shall conform with respect to size, color, legend, and placement to the latest standards in the MUTCD. *a. DO NOT ENTER and WRONG WAY signs shall be installed at all intersections of State/US Highways and Divided Highways with median widths of 30' or greater. The signs will be installed on both sides of the road* *b. DO NOT ENTER signs may be installed at intersections of Local Roads and Divided Highways with median widths of 30' or greater, if the AADT on the Local Road exceeds 250. The signs will be installed on both sides of the road.* *c. WRONG WAY signs may be installed to supplement the DO NOT ENTER signs at intersections of Local Roads and Divided Highways with median widths greater of 30' or greater. The signs will be installed on both sides of the road.* *d. DO NOT ENTER signs may be installed at intersections of Local Roads and Divided Highways if there have been two or more crashes in three years related to a vehicle turning the wrong way onto a*

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
North Dakota (NDDOT), continued	Traffic Control Requirements for NDDOT Operations on Highways and Streets, 2011. Access February 2025, Available at: https://www.dot.nd.gov/sites/www/files/documents/construction-and-planning/Traffic-Control-Requirements.pdf	2011		*Divided Highway. The signs will be installed on both sides of the road. If the crash problem persists, WRONG WAY signs may be installed to supplement the DO NOT ENTER signs at the intersection.*
Ohio (ODOT)	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016. Location & Design Manual, Volume 1 – Roadway Design, Ohio Department of Transportation, 2020. Access February 2025, Available at: https://www.transportation.ohio.gov/working/engineering/roadway/manuals-standards/location-design-vol-1/search Enhanced Wrong-Way Traffic Control for Ramps, Ohio Department of Transportation, TC-73.20., 2020.	2016, 2020, 2020	1. Static signing and pavement marking improvements *a. Two WRONG WAY signs on the same post, lower sign mounted at 3'* *b. Pavement marking extension lines to guide drivers onto entrance ramp* *c. Red reflective tape on signposts: WRONG WAY and DO NOT ENTER signs* *d. Additional signs beyond MUTCD minimums (both sides of ramp)* *e. Yellow painted island between entrance and exit ramps* *f. Wrong-Way arrows on exit ramps (At some locations, this is not standard)* *g. At all ramps: Increased the number of DO NOT ENTER and WRONG WAY signs, now one signs on each side of ramp* *h. At side-by side partial cloverleaf ramps: Implemented the entire*	1. Diverging diamond interchange (DDI): *a. Large channelized islands* *b. The greater the crossover angle, the more the crossover will appear like a "normal" intersection of two different cross routes* *c. Provide left turn lanes on exit ramps with enough curvature to ensure drivers turn into the inside through lanes and not make a wrong way turn* *2. Wrong-way arrow markings are placed on the ramps as follows:* *a. On ramps where lane-use arrows are not used, place the first wrong-way arrow 10 to 30 feet in advance of stop line. Place the second wrong-way arrow according to engineering judgment* *b. On ramps where lane-use arrows are used, place the wrong-way arrow in advance of the first lane-use arrow at a spacing equal to or greater*

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Ohio (ODOT)	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016. Location & Design Manual, Volume 1 – Roadway Design, Ohio Department of Transportation, 2020. Access February 2025, Available at: https://www.transportation.ohio.gov/working/engineering/roadway/manuals-standards/location-design-vol-1/search Enhanced Wrong-Way Traffic Control for Ramps, Ohio Department of Transportation, TC-73.20., 2020.	2016, 2020, 2020	*improved design configuration* 2. Wrong-Way traffic control for partial cloverleaf interchanges (single-lane exit) 3. Wrong-Way traffic control for diamond interchanges (single-lane exit) 4. Flashing LEDs around Wrong-Way signs and alerts *a. Alert to TMC and law enforcement* *b. Two sets of detection plus a camera for verification*	*than the spacing between the lane-use arrows* *c. On multi-lane ramps, a wrong-way arrow should be placed in each lane, side by side* 2. Traffic control signs are placed as follows: *a. Place the WRONG WAY sign in advance of the stop line. The height of the 2nd wrong-way sign should be 3' above the nearest edge of the pavement* *i. On ParClo interchanges, the WRONG WAY sign between the on and off ramps should be angled 45 degrees toward the off ramp* *ii. A second set of WRONG WAY signs may be placed on the ramp according to engineering judgement* *iii. On ParClo interchanges, the optional entrance ramp directional sign assembly should be angled 45 degrees toward the left turning traffic* *b. The red signpost reflectors shall be added to the STOP sign, DO NOT ENTER sign, and wrong-way sign assembly* *c. The DO NOT ENTER sign may be angled up to 45 degrees toward left and right turning traffic*

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Ohio (ODOT)	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016. Location & Design Manual, Volume 1 – Roadway Design, Ohio Department of Transportation, 2020. Access February 2025, Available at: https://www.transportation.ohio.gov/working/engineering/roadway/manuals-standards/location-design-vol-1/search Enhanced Wrong-Way Traffic Control for Ramps, Ohio Department of Transportation, TC-73.20., 2020.	2016, 2020, 2020		3. Raised pavement markers are placed as follows: *a. Raised pavement markers on the edge line- shall be two-way white/red on white edge line, two ways yellow/red on yellow edge line, and eleven raised pavement markings shall be spaced 40' apart in advance of the stop line; the rest shall be installed per SCD TC-65.11.* *b. Raised pavement markings on the channelizing line/lane line- shall be two-way white/red, spaced 40' apart and eleven raised pavement markings shall be spaced 40' apart in advance of the stop line; the rest shall be installed per SCD TC-65.11.*
Oklahoma (OKDOT)	Email correspondence with state traffic engineer	2020	No studies or reports found online	There are no additional policies beyond what is included in the 2009 MUTCD
South Dakota (SDDOT)	Email correspondence with state traffic engineer	2020	No studies or reports found online	There are no additional policies beyond what is included in the 2009 MUTCD
Texas (HCTRA & TxDOT)	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016.	2016	1. Detection at ramps and mainline with alert to Incident Management Center (IMC) *a. Initial installation included radar detection and in-pavement loop detectors along the mainline and at exit ramps* 2. Alert to oncoming right-way traffic	There are no additional policies beyond what is included in the 2009 MUTCD

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Texas (HCTRA & TxDOT), continued	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016.	2016	*a. A message is displayed on dynamic message signs to warn oncoming right-way traffic* 3. In-pavement LED lighting 4. LED-enhanced WRONG WAY signs 5. Enhanced signing at exit ramps, including LED-Enhanced WRONG WAY signs *a. Additional static DO NOT ENTER and WRONG WAY signs beyond MUTCD minimums- one on each side of ramp* *b. Red reflective tape on signposts* *c. Two additional flashing LED WRONG WAY signs- one on each side of ramp* *d. If there is not enough room to implement all signs at a ramp, then install flashing WRONG WAY signs in lieu of 2 standard WRONG WAY signs* 6. Detection at exit ramps with alert to TMC 7. Main lane detection with alerts (high-definition radar detection devices are installed on overhead sign bridges) *a. Main line radar detection triggers the following:*	

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Texas (HCTRA & TxDOT), continued	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016.	2016	*i. Blank-out dynamic message sign displays WRONG WAY ii. Flashing LED signs downstream attempt to catch driver's attention* *iii. An alert is sent to the TransGuide TMC, to begin response efforts*	
Wisconsin (WisDOT)	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016.	2016	1. Static signing and pavement marking improvements *a. Additional signs- placed on both sides of ramp rather than one side as required* *b. WRONG WAY and DO NOT ENTER signs on same post, with lower WRONG WAY sign at 3' mounting height* *c. Added NO LEFT TURN and NO RIGHT TURN signs* *d. Added freeway entrance signs at side-by-side ramps* *e. Red reflective tape in a few locations, especially side by side ramps* *f. Skip line pavement markings to guide drivers onto the entrance ramp* 2. Detection with alert to TOC and Milwaukee County Sherriff's Office *a. Radar detection devices* *b. Extensive CCTV camera system on freeways*	1. Divided highway with wide median intersection with two-way cross street *a. Allow the installation of DO NOT ENTER and WRONG WAY signs. Where the median width is 30 feet or greater, the signs should be installed on the median side* 2. Divided Highway with narrow median intersection with two-way cross street *a. Allow for the single installation of DO NOT ENTER and WRONG WAY signs where he median which is less than 30 feet, the signs should be installed on the outer side* 3. Divided highway with the wide median intersection with interchange ramps *a. The typical signing plans according to MUTCD except that the Turn Prohibition signs are designated optional*

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Wisconsin (WisDOT)	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016.	2016	3. LED-Enhanced WRONG WAY signs (blink continuously at night) *a. The blinking LED WRONG WAY signs are typically placed halfway down the ramp with one sign on each side of the ramp. However, placement depends on each individual ramp configuration; need to position signs so they can't be seen by right-way drivers on freeway*	4. Divided highway with narrow median intersection with interchange ramps *a. The typical signing plans according to MUTCD except that the Turn Prohibition signs are designated optional* 5. Two-way undivided highway intersection with interchange ramps *a. The typical signing plans according to MUTCD except that the Turn Prohibition signs are designated optional* 6. Transition from two-way undivided highway to divided highway *a. The typical signing plan according to MUTCD except that the Turn Prohibition signs are designated optional* 7. Divided highway with intersecting sideroad *a. The typical signing plans according to MUTCD should be sufficient for most side roads of these types. Additional needs may be met by installing additional signs* *b. Allow for the single installation of the DO NOT ENTER and WRONG WAY signs. Where the median width is less than 30 feet, the signs*

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Wisconsin (WisDOT)	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016.	2016		*should be installed on the outer side* 8. Divided highway with narrow or wide median driveway *a. The typical signing plans according to MUTCD should be sufficient for most driveways of these types. Additional needs may be met by installing additional signs* *b. Allow for the single installation of the DO NOT ENTER and WRONG WAY signs. Where the median width is less than 30 feet, the signs should be installed on the outer side* 9. Roundabouts *a. The typical signing plans according to the MUTCD should be sufficient for the prevention of wrong way movements on roundabouts with single and multiple approach lanes and interchange off-ramps* 10. Divided highway with signalized wide median intersection *a. The typical signing plans according to the MUTCD should be sufficient for most intersections of this type*

State Agency	Source Document	Date	WWD Countermeasures, Research, and Guidance	WWD Policy
Wisconsin (WisDOT)	Athey Creek Consulting. Countermeasures for Wrong-Way Driving on Freeways. Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency, Transportation Pooled Fund Study TPF-5 (231), 2016.	2016		*b. Allow for the single installation of the DO NOT ENTER and WRONG WAY signs. Where the median width is 30 feet or greater, the signs should be installed on the median side* 11. Divided highway with signalized narrow median intersection *a. The typical signing plans according to the MUTCD should be sufficient for most intersections of this type* *b. Allow for the single installation of the DO NOT ENTER and WRONG WAY signs. Where the median with is less than 30 feet, the signs should be installed on the outer side*

Appendix B: Safety Conference Materials

Group:	
____________________ Ramp	Recommendations for countermeasures
Which countermeasures? Where? Why?	

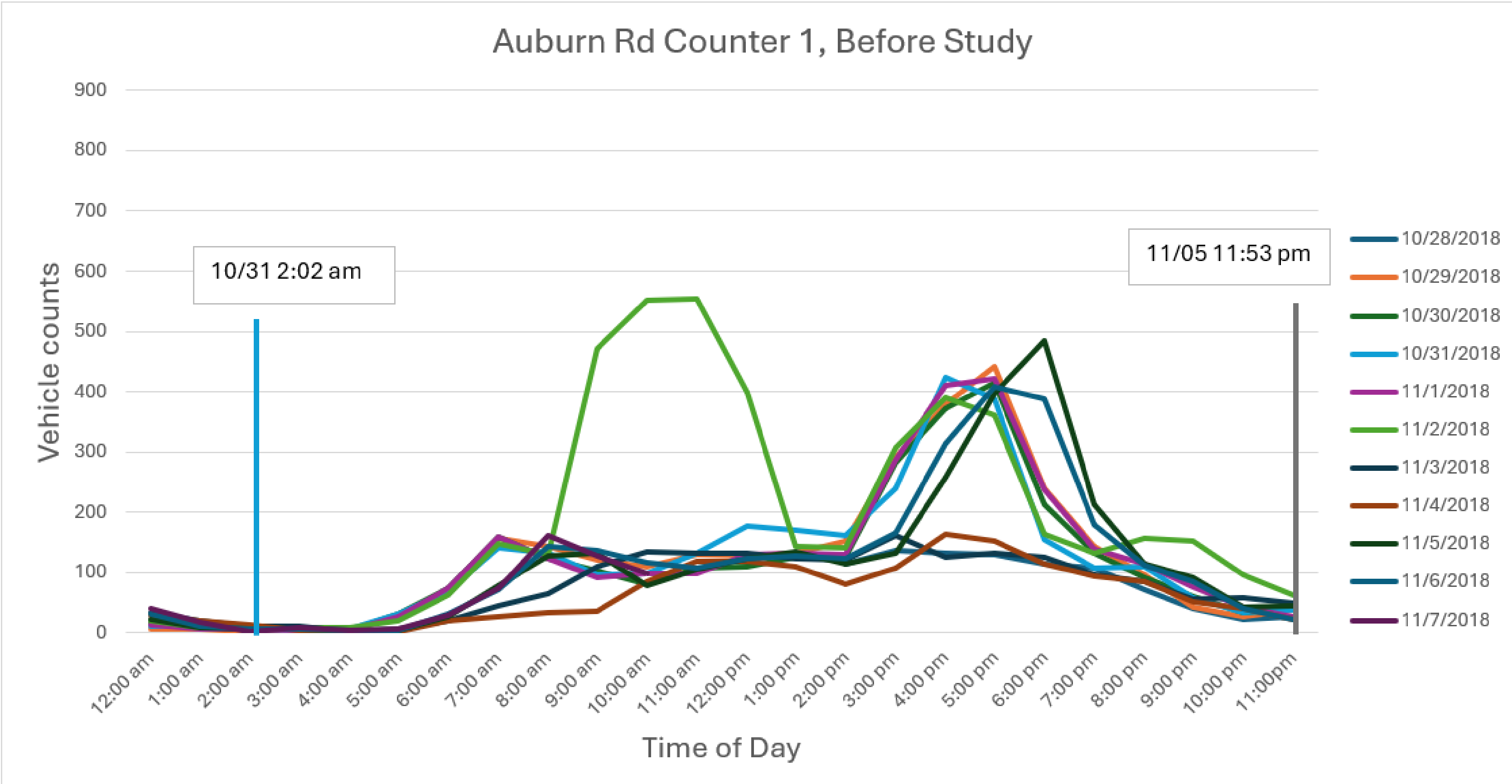


Figure B.1: Auburn Road Counter 1, Before Study

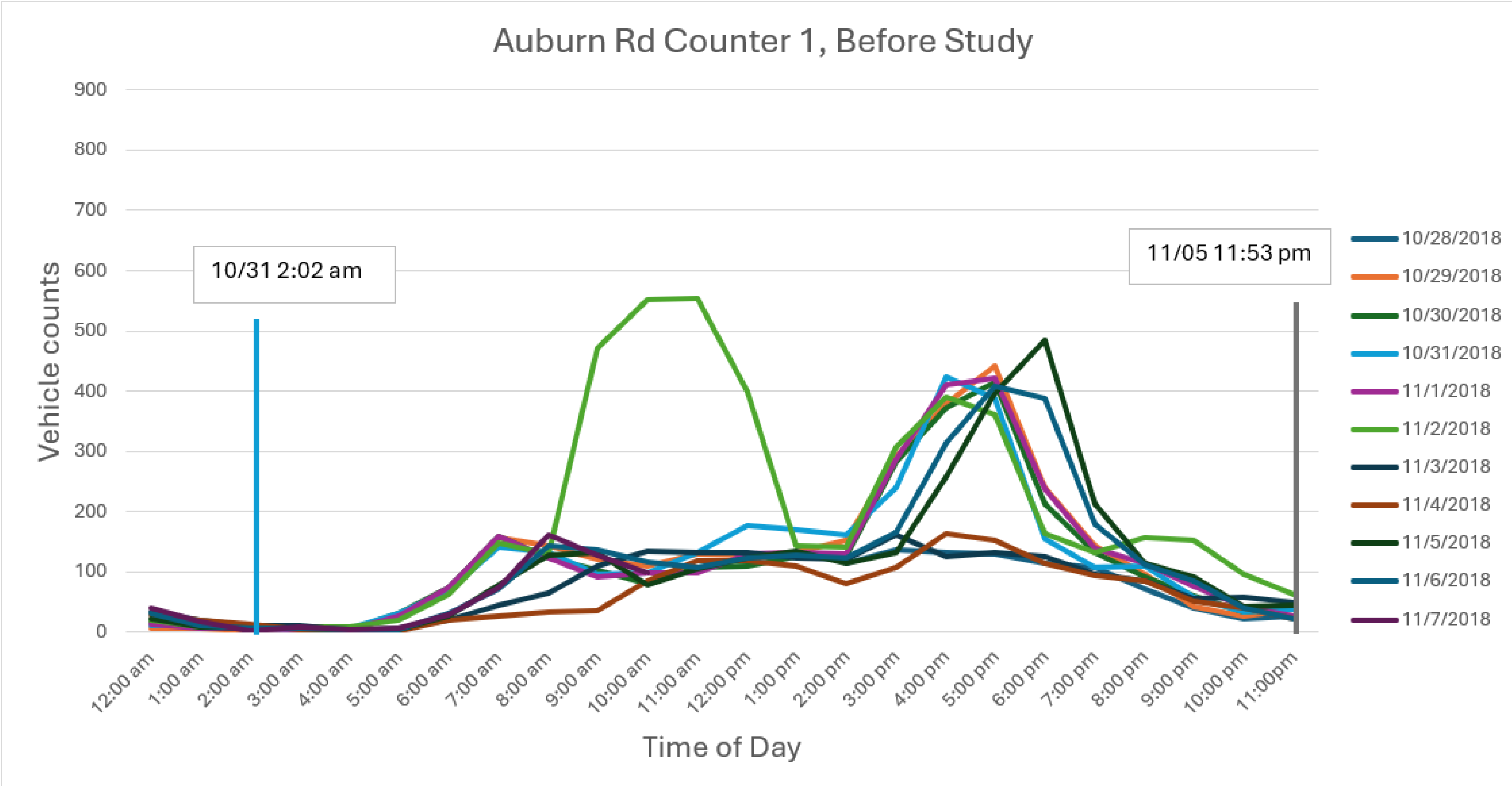


Figure B.2: Auburn Road Counter 2, Before Study

Table B.1: Auburn Avenue Before Counter 1 and Counter 2

Auburn Ave Before Counter 1					Auburn Ave Before Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
10/28/2018	7:39:13 PM	2	32		10/31/2018	2:02:50 AM	2	34
10/29/2018	1:21:28 PM	1	17		11/5/2018	11:53:56 PM	2	31
10/31/2018	2:02:35 AM	2	34					
11/2/2018	12:31:31 PM	1	21					
11/5/2018	11:53:35 PM	2	35					
11/6/2018	8:10:23 PM	2	26					

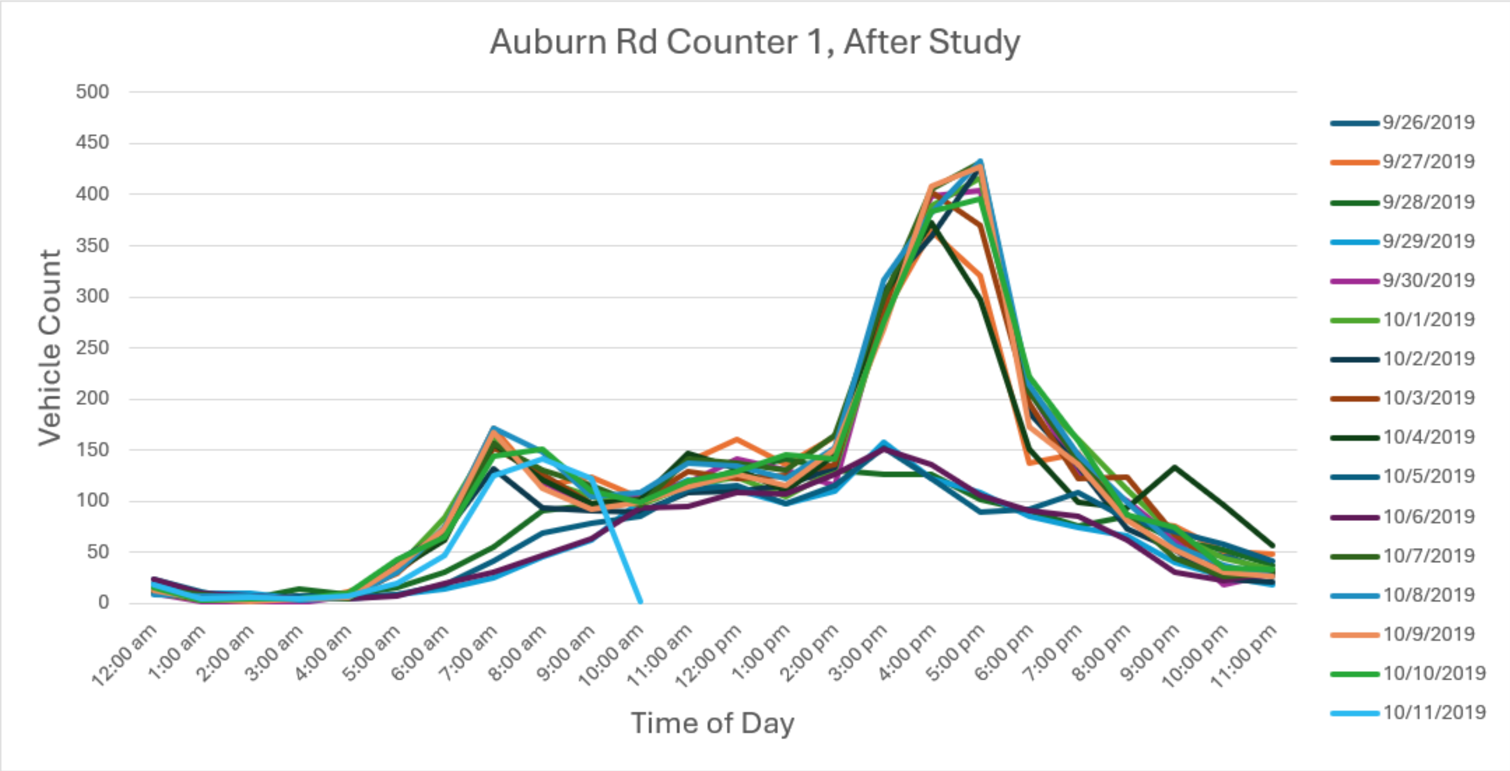


Figure B.3: Auburn Road Counter 1, After Study

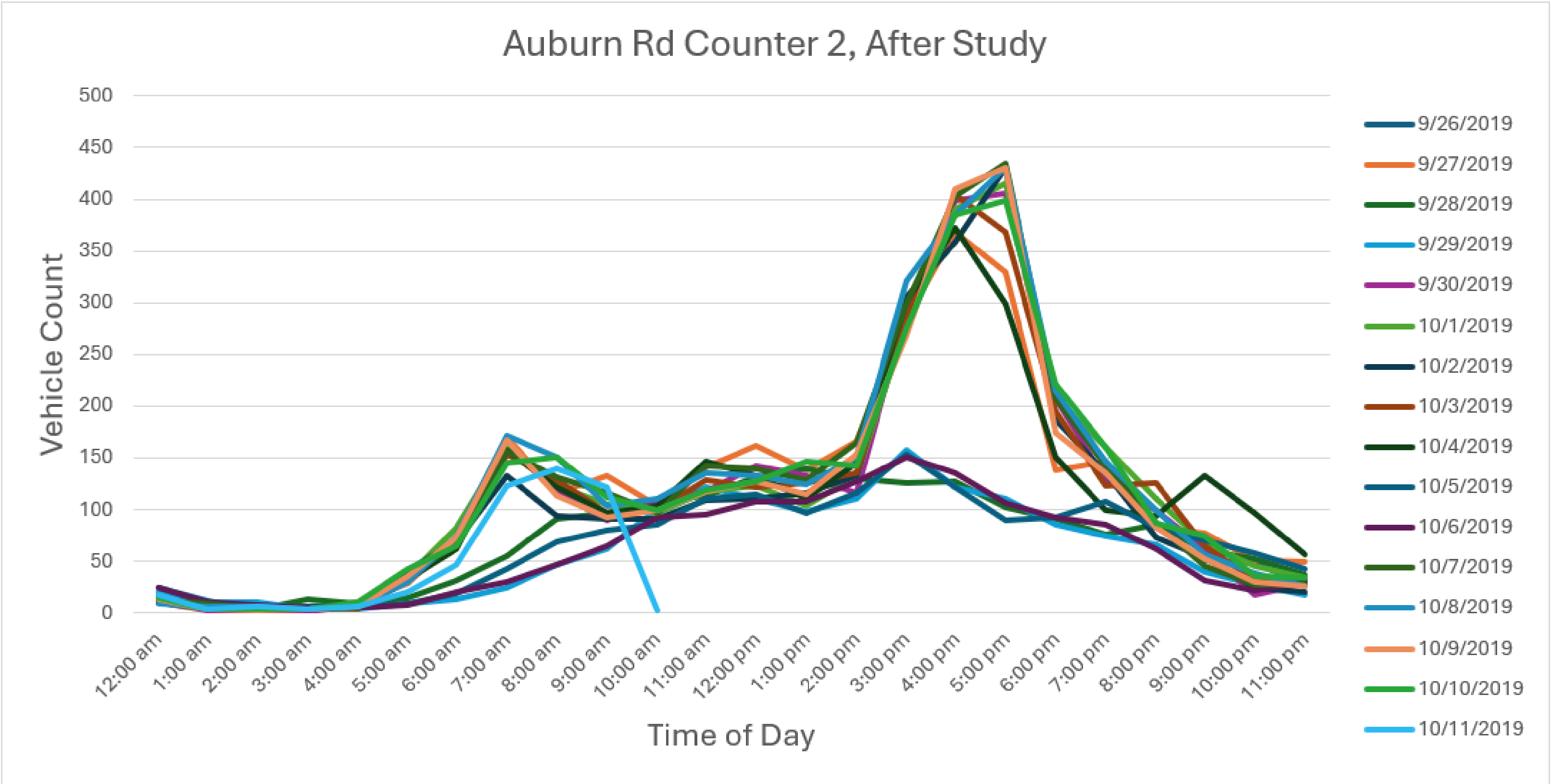


Figure B.4: Auburn Road Counter 2, After Study

Table B.2: Auburn Avenue After Counter 1 and Counter 2

Auburn Ave After Counter 1					Auburn Ave After Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
10/1/2019	7:12:41 AM	1	20		10/8/2019	8:48:33 AM	1	10
10/1/2019	12:40:50 PM	1	22					
10/8/2019	11:47:35 AM	1	20					
10/8/2019	12:53:54 PM	1	22					
10/8/2019	1:28:20 PM	1	24					
10/8/2019	4:20:39 PM	1	10					
10/10/2019	11:32:45 AM	1	8					
10/10/2019	12:14:39 PM	1	21					
9/28/2019	9:05:35 PM	2	32					
9/30/2019	9:04:04 PM	2	23					
9/30/2019	9:04:07 PM	2	21					

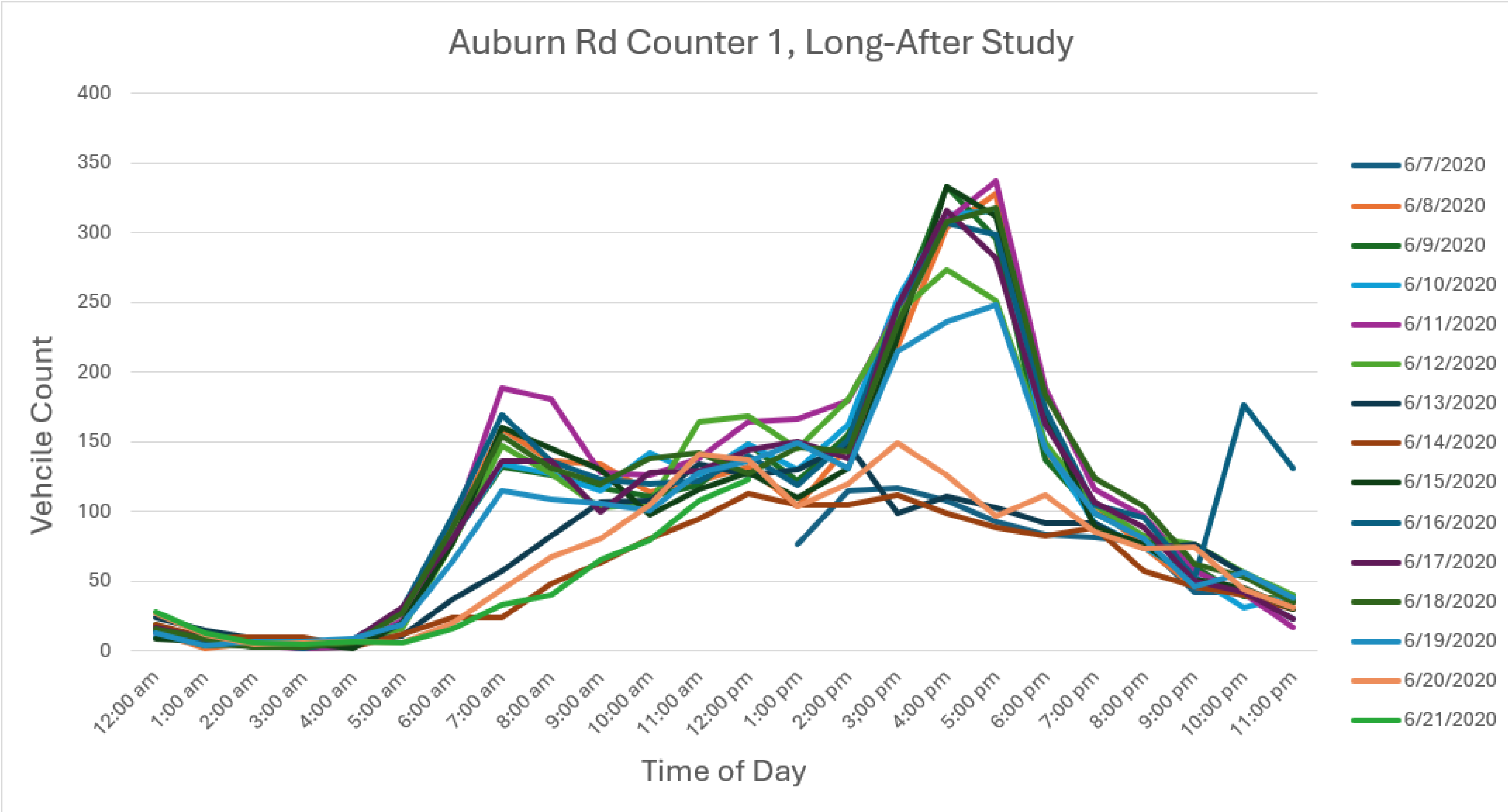


Figure B.5: Auburn Road Counter 1, Long-After Study

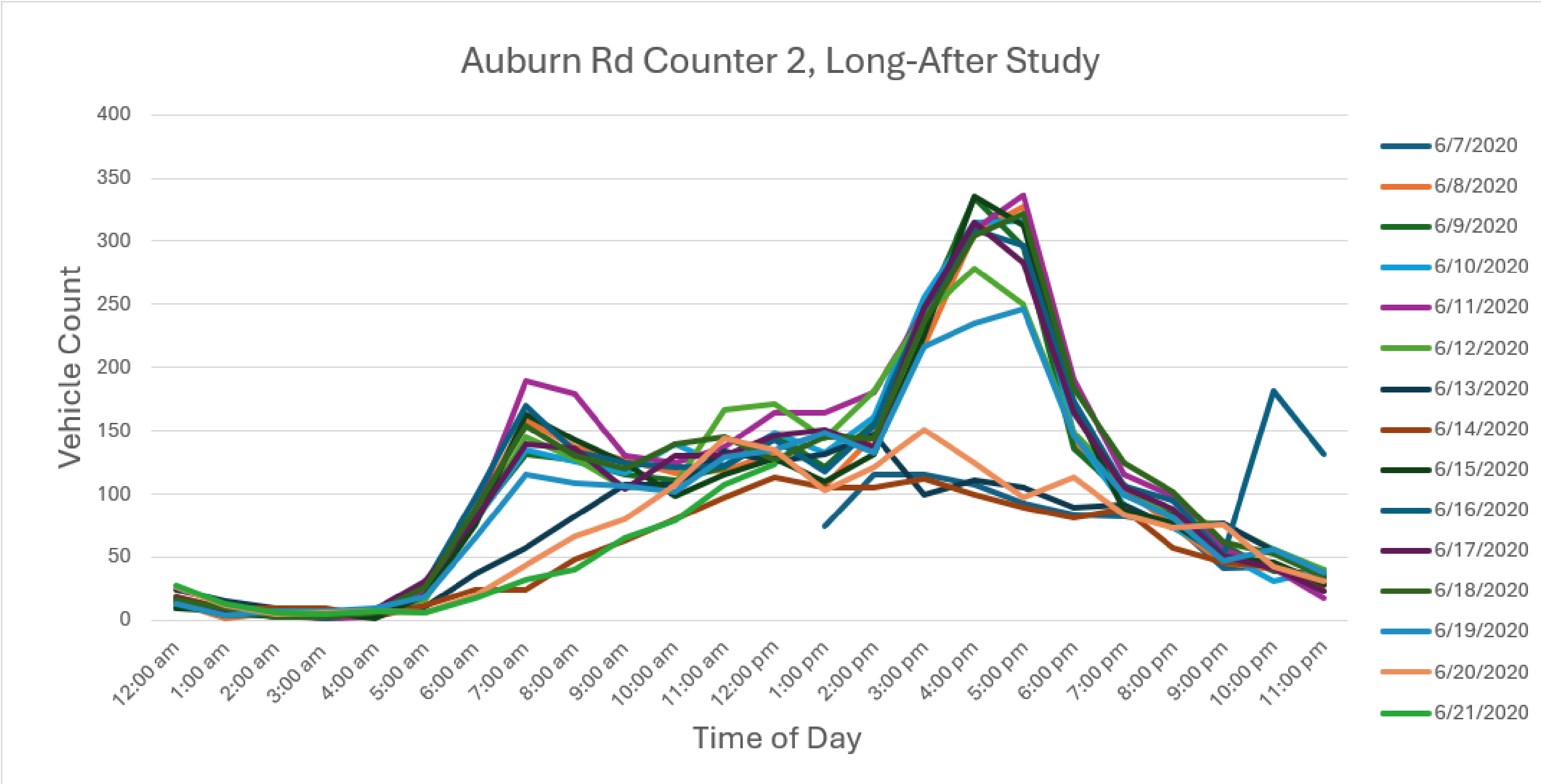


Figure B.6: Auburn Road Counter 2, Long-After Study

Table B.3: Auburn Avenue Long-After Counter 1 and Counter 2

Auburn Ave Long-After Counter 1					Auburn Ave Long-After Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
6/10/2020	2:04:11 PM	1	25		6/9/2020	8:25:28 PM	1	5
6/16/2020	7:28:20 AM	1	16					

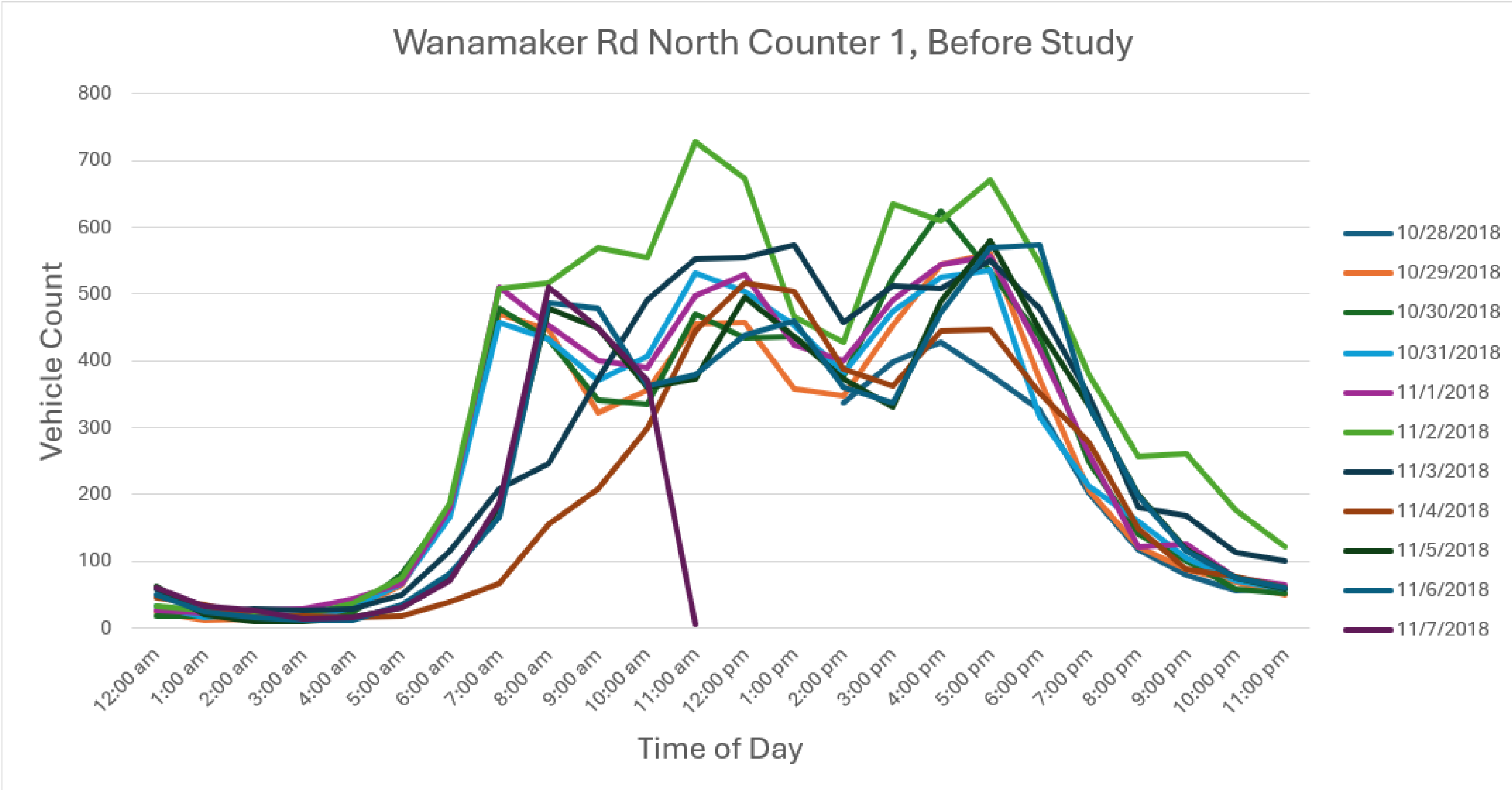


Figure B.7: Wanamaker Road North Counter 1, Before Study

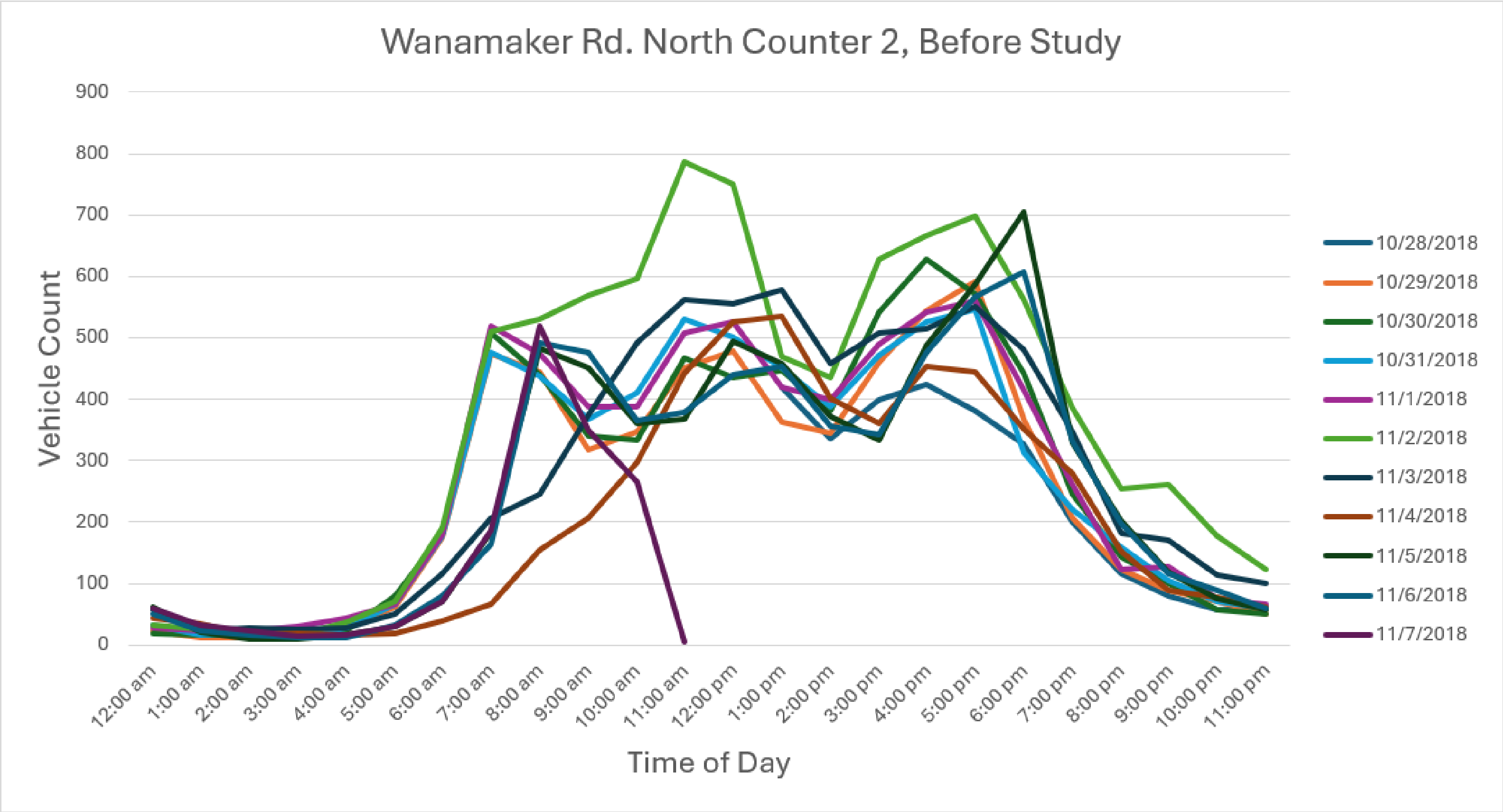


Figure B.8: Wanamaker Road North Counter 2, Before Study

Table B.4: North Wanamaker Counter 1 and Counter 2

N Wanamaker Counter 1					N Wanamaker Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
11/6/2018	12:36:58 PM	1	29		11/1/2018	7:29:45 PM	1	82
11/6/2018	8:26:31 AM	2	145		11/7/2018	9:48:39 AM	1	35
					11/7/2018	9:55:56 AM	1	21
					11/7/2018	9:57:41 AM	1	20
					11/7/2018	10:01:37 AM	1	119
					11/7/2018	10:05:46 AM	1	24
					11/7/2018	10:25:57 AM	1	24

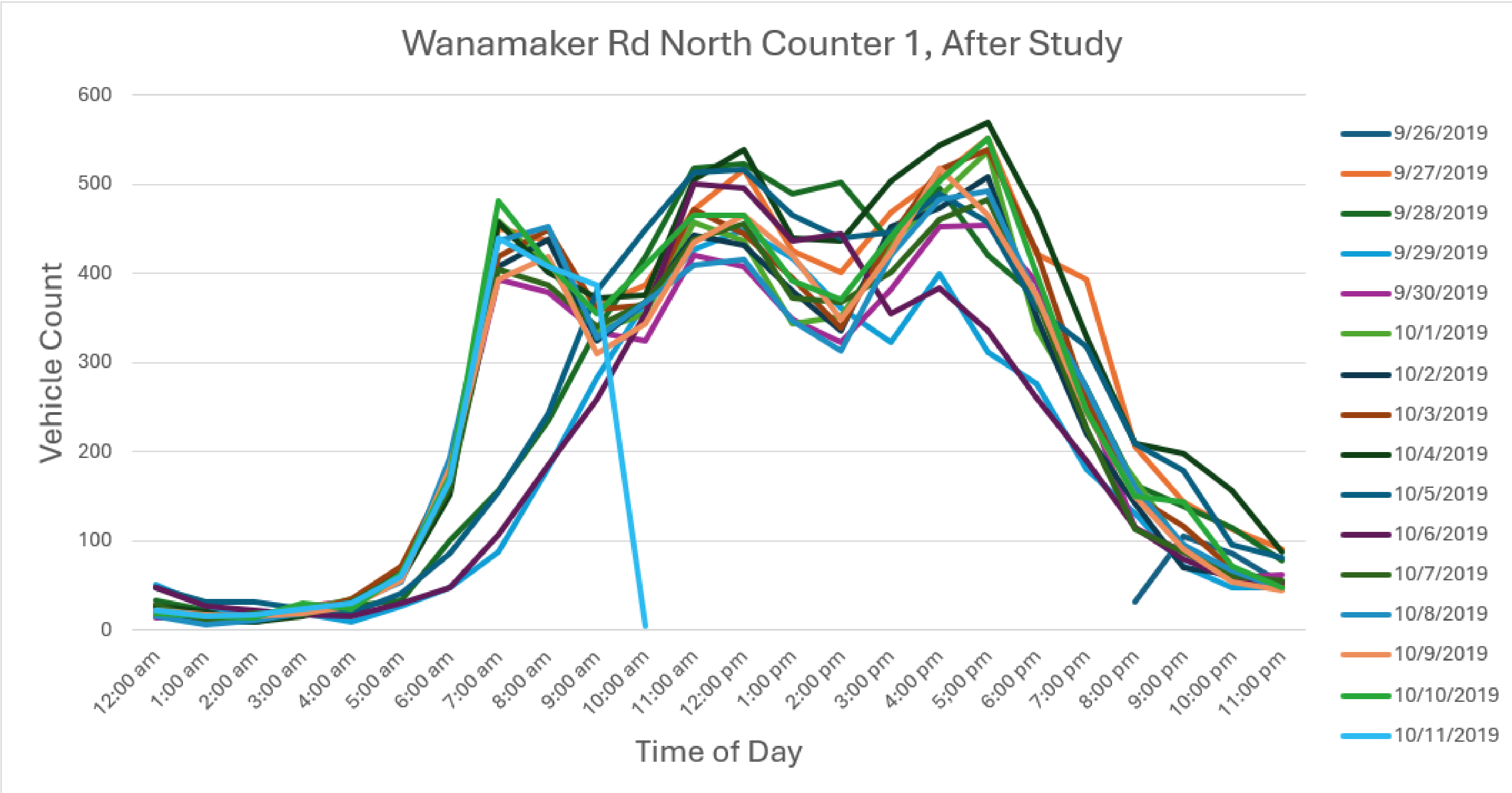


Figure B.9: Wanamaker Road North Counter 1, After Study

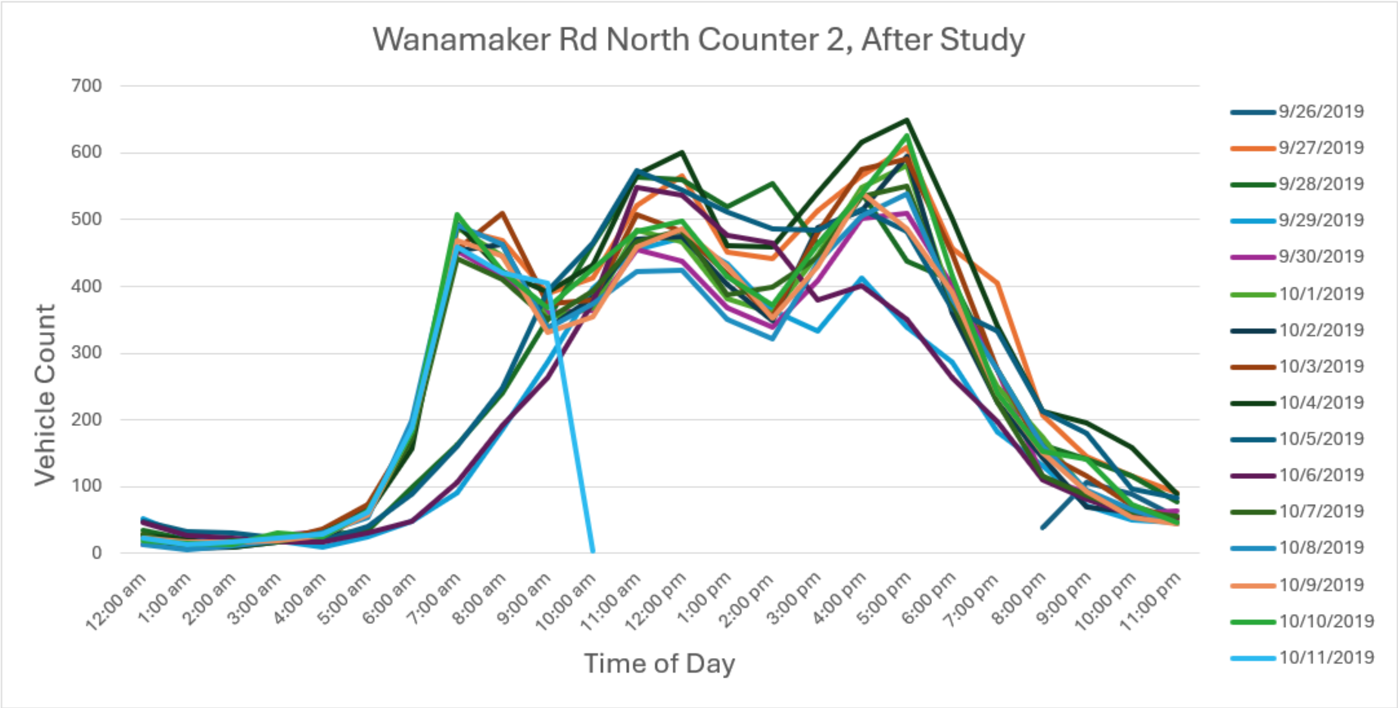


Figure B.10: Wanamaker Road North Counter 2, After Study

Table B.5: Wanamaker North After Counter 1 and Counter 2

Wanamaker North After Counter 1					Wanamaker North After Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
9/27/2019	12:53:50 PM	1	22		9/27/2019	4:18:11 PM	4	51
9/27/2019	2:52:42 PM	3	41		10/4/2019	7:12:10 AM	6	48
9/28/2019	3:44:54 PM	5	49		10/6/2019	3:05:03 PM	4	57
9/28/2019	4:56:22 PM	3	34		10/7/2019	5:57:40 PM	4	42
9/29/2019	10:55:33 AM	1	19		10/8/2019	7:32:29 AM	2	59
9/30/2019	7:49:38 AM	1	8		10/10/2019	7:15:50 AM	7	51
9/30/2019	11:58:32 AM	2	25					
9/30/2019	1:17:05 PM	2	25					
10/1/2019	7:43:01 AM	2	28					
10/1/2019	8:22:57 AM	1	8					
10/3/2019	12:45:25 PM	3	33					
10/4/2019	6:01:56 PM	5	38					
10/5/2019	12:48:34 PM	2	22					
10/5/2019	5:16:47 PM	1	10					
10/6/2019	4:34:07 PM	1	12					
10/7/2019	7:41:59 AM	1	31					
10/7/2019	9:20:23 AM	2	48					
10/7/2019	12:43:54 PM	6	24					
10/7/2019	4:23:04 PM	5	45					
10/8/2019	9:19:38 AM	3	40					

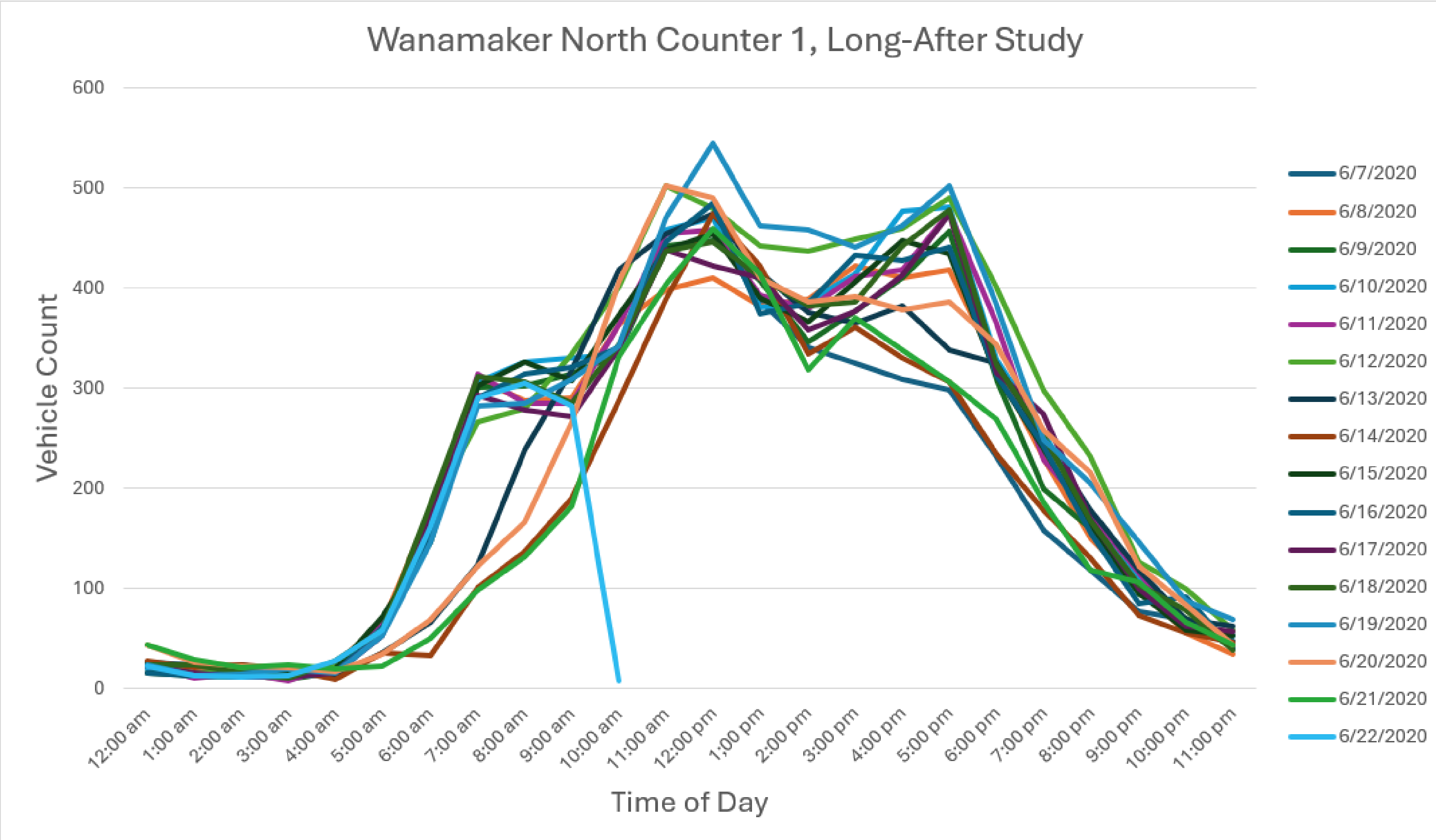


Figure B.11: Wanamaker North Counter 1, Long-After Study

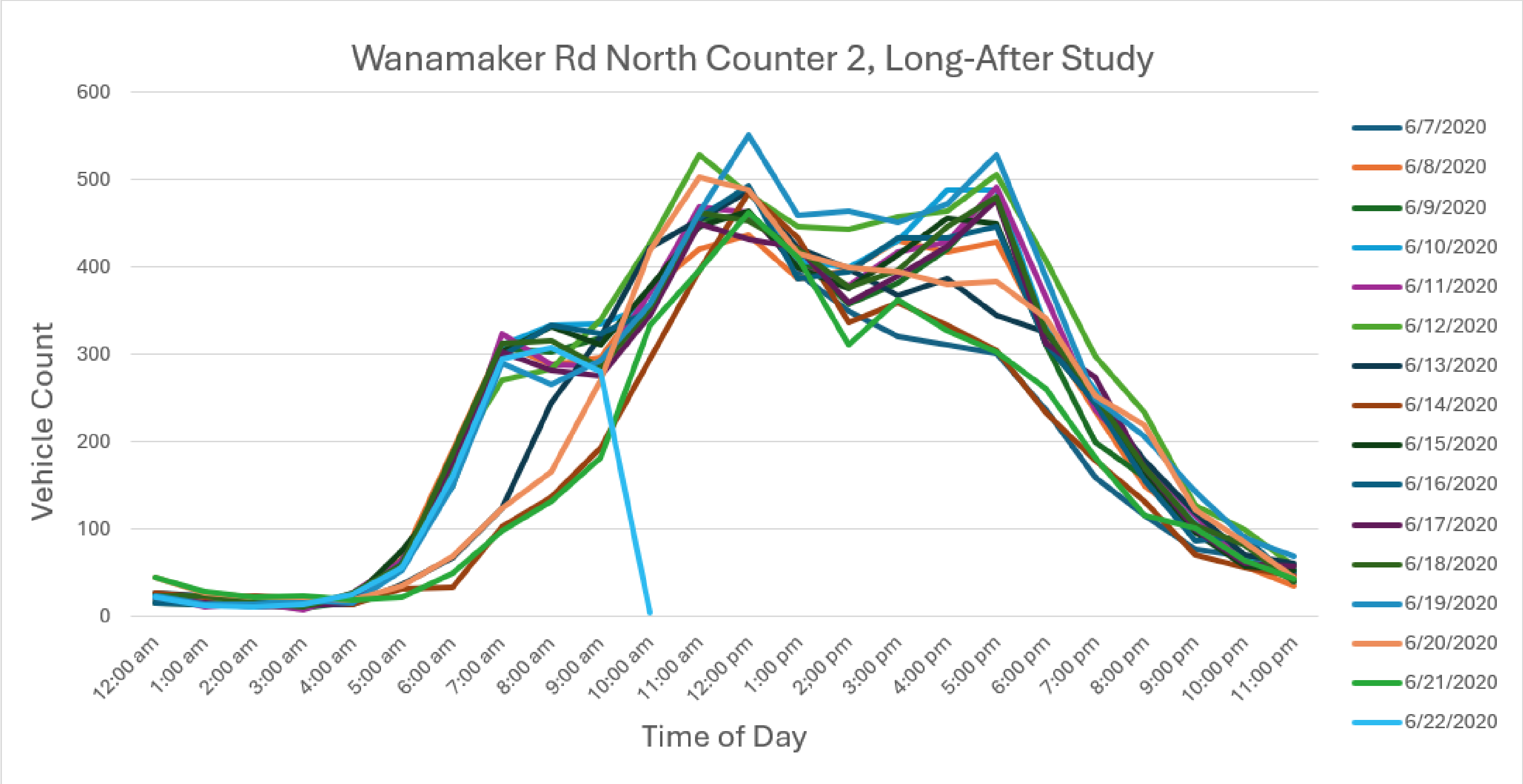


Figure B.12: Wanamaker Road North Counter 2, Long-After Study

Table B.6: Wanamaker North Long-After Counter 1 and Counter 2

Wanamaker North Long-After Counter 1					Wanamaker North Long-After Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
6/7/2020	12:25:48 PM	3	49		6/9/2020	6:15:18 AM	5	41
6/10/2020	6:21:34 AM	1	24		6/9/2020	9:00:42 AM	5	46
6/12/2020	12:25:32 PM	5	44		6/10/2020	9:09:25 AM	5	36
6/12/2020	2:58:35 PM	1	13		6/11/2020	7:45:30 AM	4	41
6/12/2020	4:42:35 PM	2	26		6/12/2020	5:57:44 AM	4	45
6/15/2020	1:08:20 PM	5	47		6/12/2020	10:43:59 AM	1	56
6/15/2020	4:39:02 PM	6	8		6/15/2020	5:42:34 AM	5	46
6/16/2020	3:25:09 PM	1	7		6/15/2020	5:51:58 AM	5	42
6/17/2020	7:01:46 PM	1	16		6/15/2020	7:44:01 PM	1	58
6/18/2020	11:07:38 AM	4	22		6/16/2020	8:11:35 AM	4	49
6/22/2020	8:48:18 AM	1	11		6/16/2020	2:33:15 PM	4	40
					6/19/2020	4:55:55 PM	4	38
					6/22/2020	5:43:25 AM	4	36

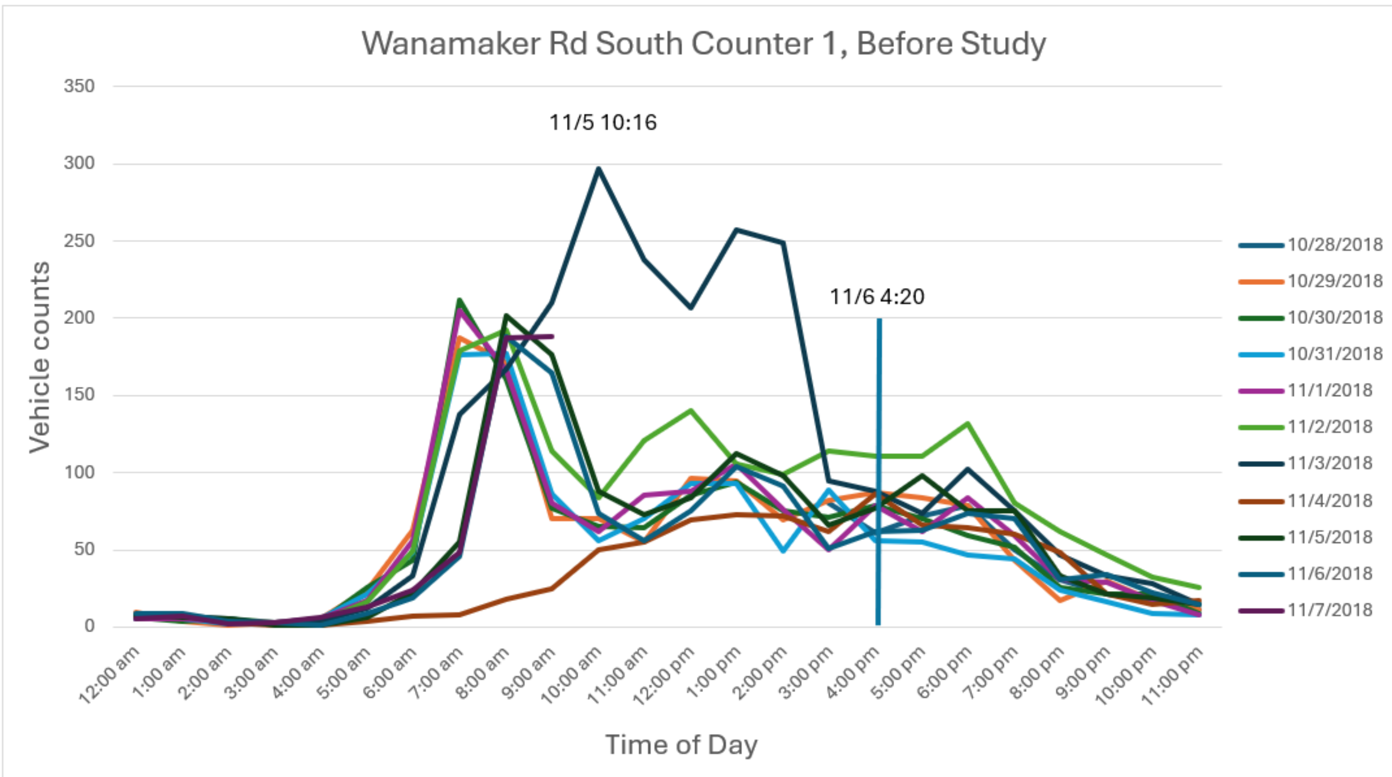


Figure B.13: Wanamaker Road South Counter 1, Before Study

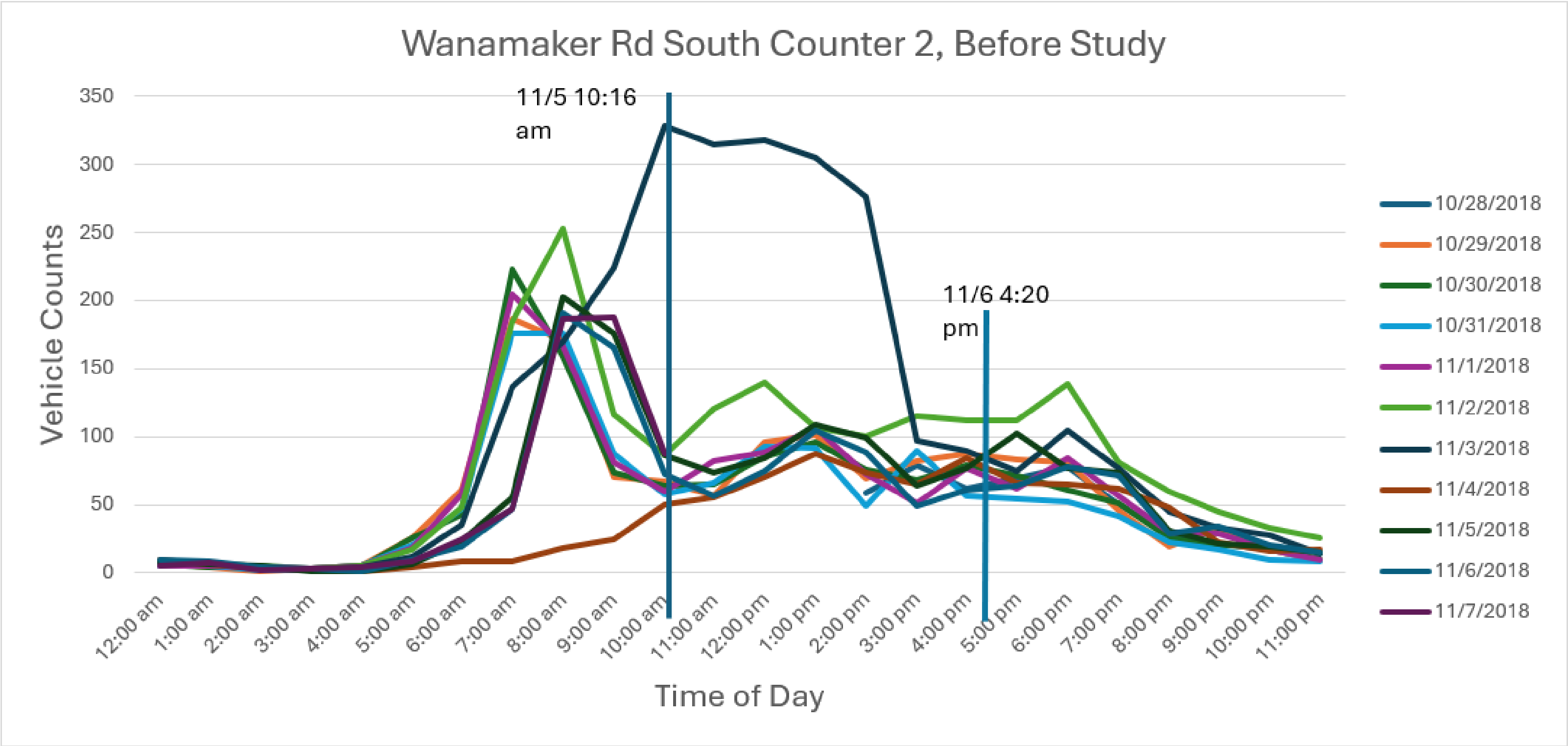


Figure B.14: Wanamaker Road South Counter 2, Before Study

Table B.7: South Wanamaker Road Counter 1 and Counter 2

S Wanamaker Rd Counter 1					S Wanamaker Rd Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
11/5/2018	10:16:50 AM	2	29		11/5/2018	10:17:02 AM	2	35
11/6/2018	4:20:28 PM	3	26		11/6/2018	4:20:40 PM	3	32
11/5/2018	1:58:51 PM	5	24					

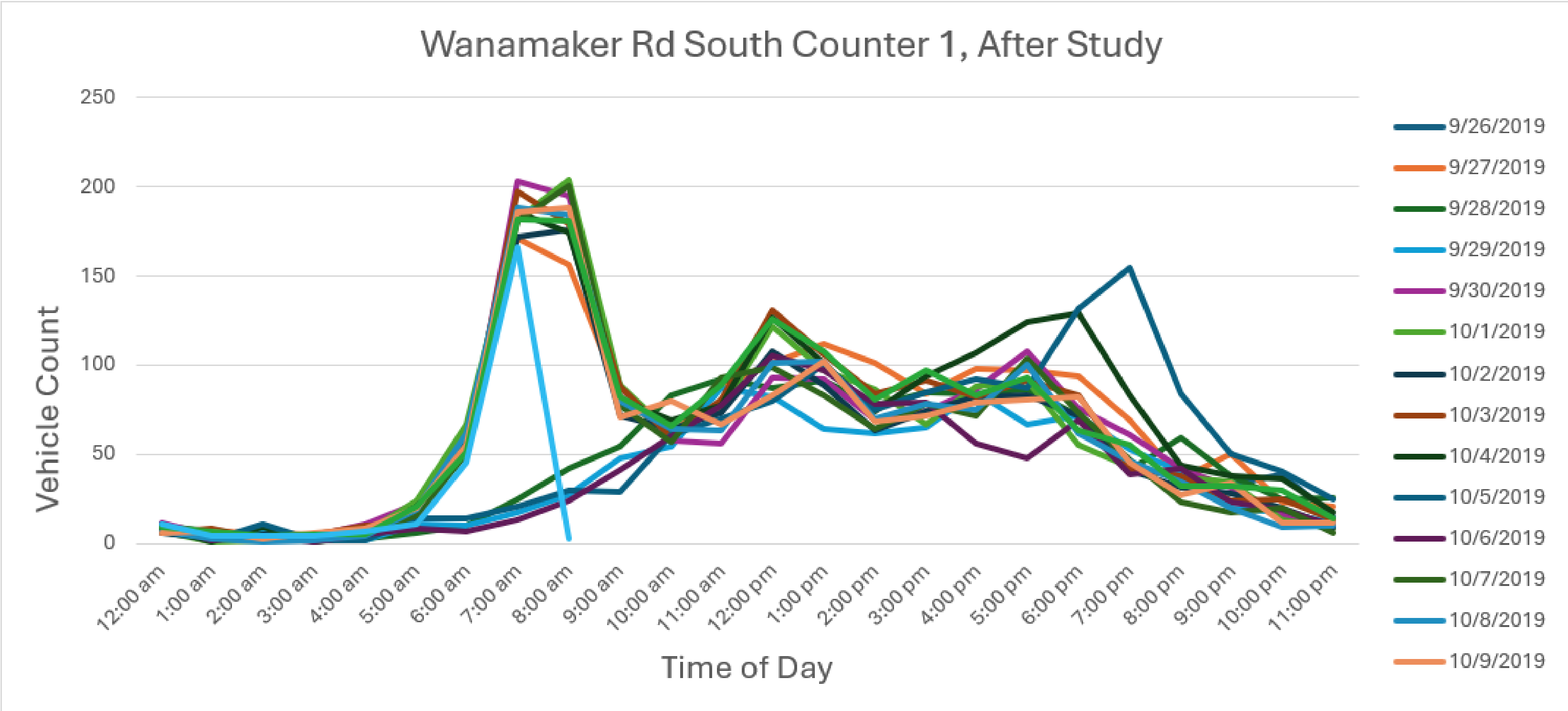


Figure B.15: Wanamaker Road South Counter 1, After Study

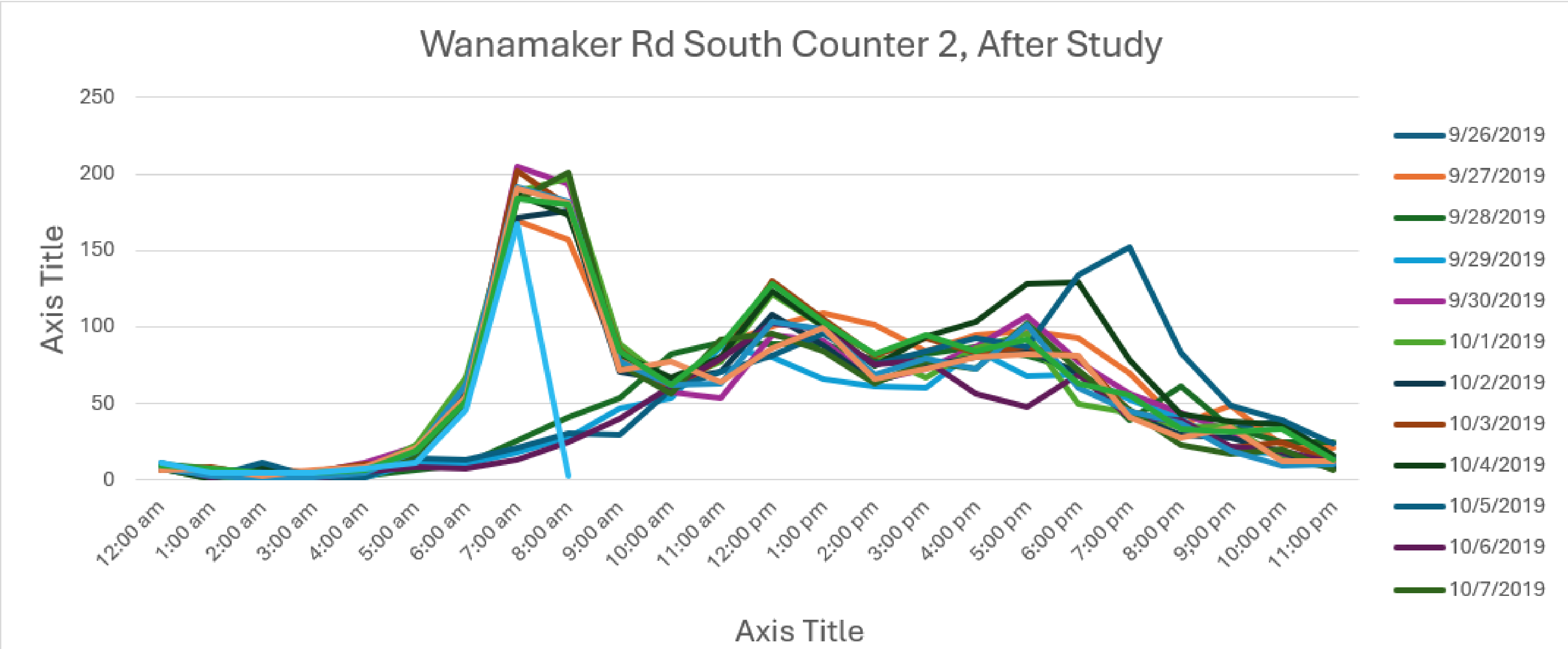


Figure B.16: Wanamaker Road South Counter 2, After Study

Table B.8: Wanamaker South After Counter 1 and Counter 2

Wanamaker South After Counter 1					Wanamaker South After Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
9/28/2019	3:17:28 PM	2	24		9/26/2019	9:10:06 PM	1	10
10/3/2019	11:50:13 AM	2	19		10/9/2019	7:08:47 AM	2	76
10/4/2019	3:14:44 PM	1	1		10/9/2019	8:58:45 AM	2	4
10/9/2019	8:03:37 AM	2	48		10/9/2019	8:58:45 AM	2	7
					10/10/2019	10:48:00 PM	6	1

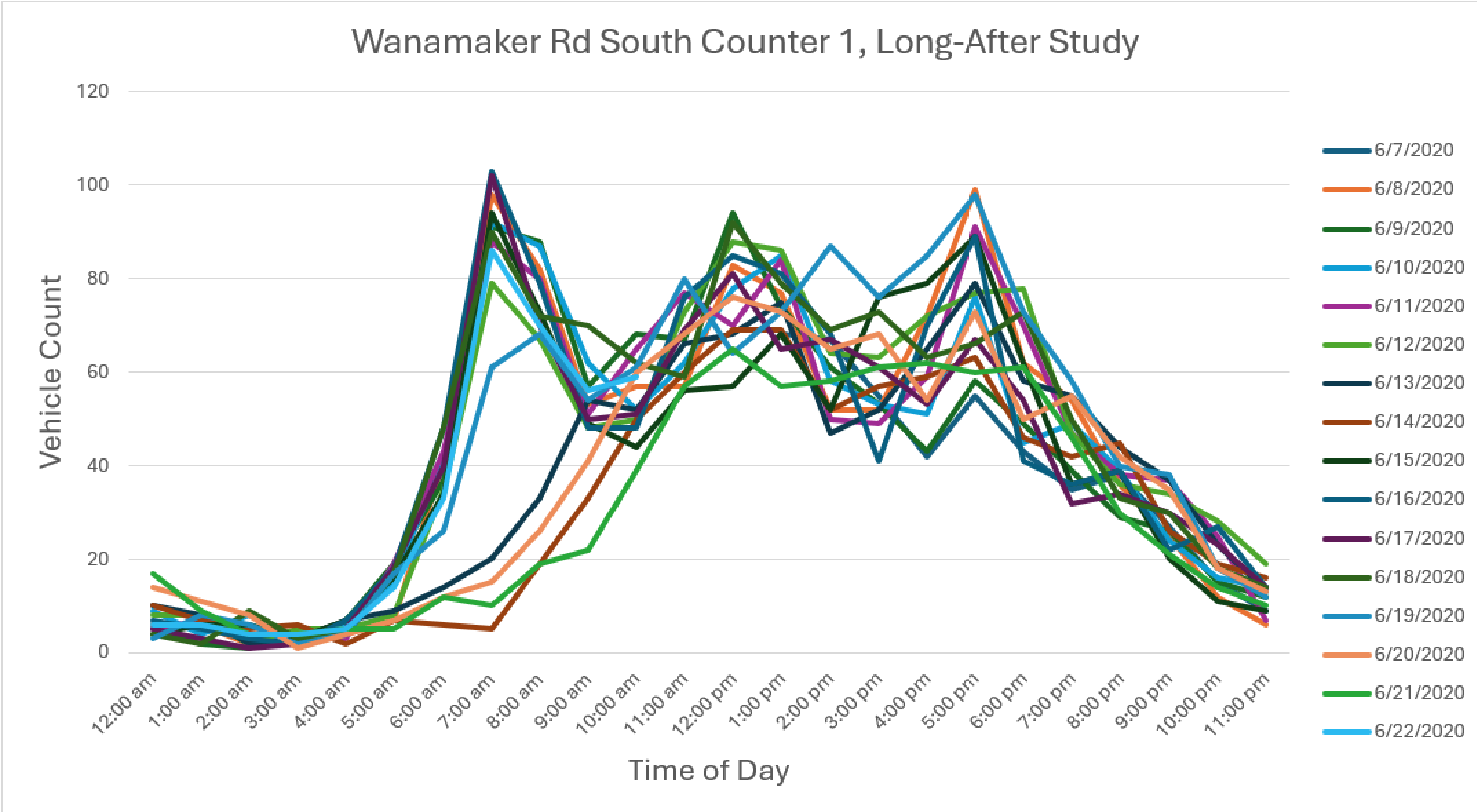


Figure B.17: Wanamaker Road South Counter 1, Long-After Study

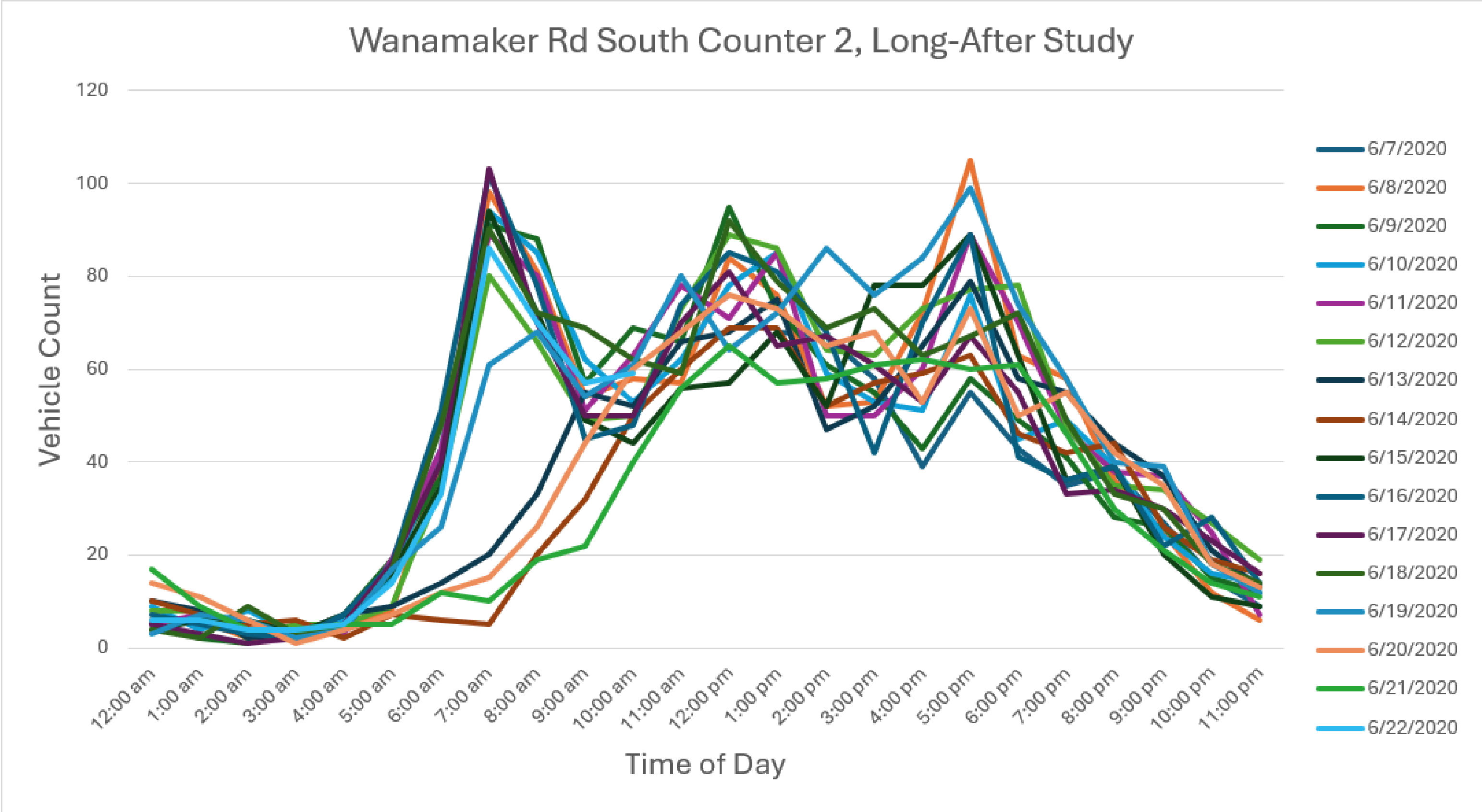


Figure B.18: Wanamaker Road South Counter 2, Long-After Study

Table B.8: Wanamaker South Long-After Counter 1 and Counter 2

Wanamaker South Long-After Counter 1					Wanamaker South Long-After Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
6/19/2020	2:53:10 PM	1	9		No WW movements			
6/20/2020	9:38:53 AM	1	11					
6/16/2020	9:15:42 AM	2	26					
6/16/2020	11:56:56 AM	2	22					

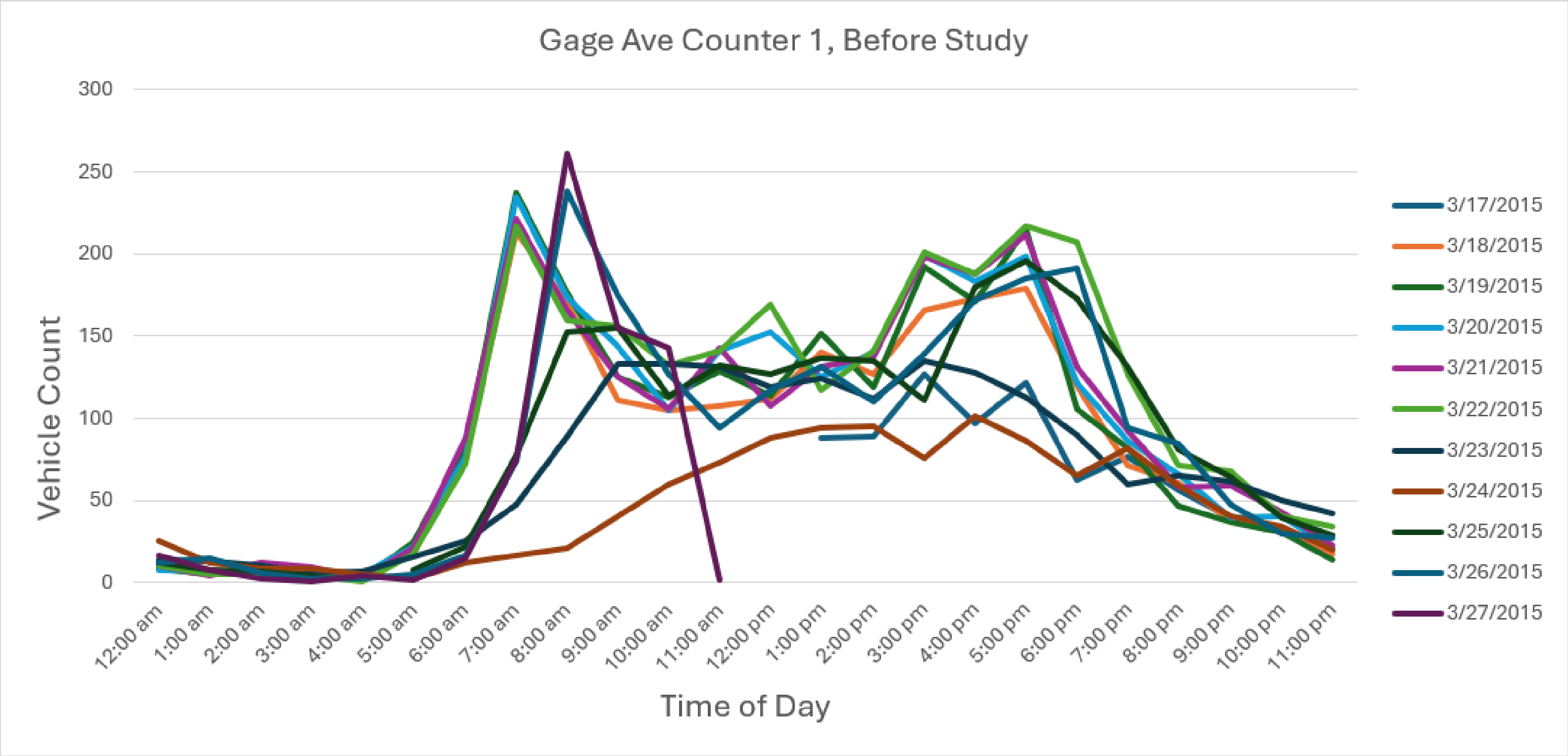


Figure B.19: Gage Avenue Counter 1, Before Study

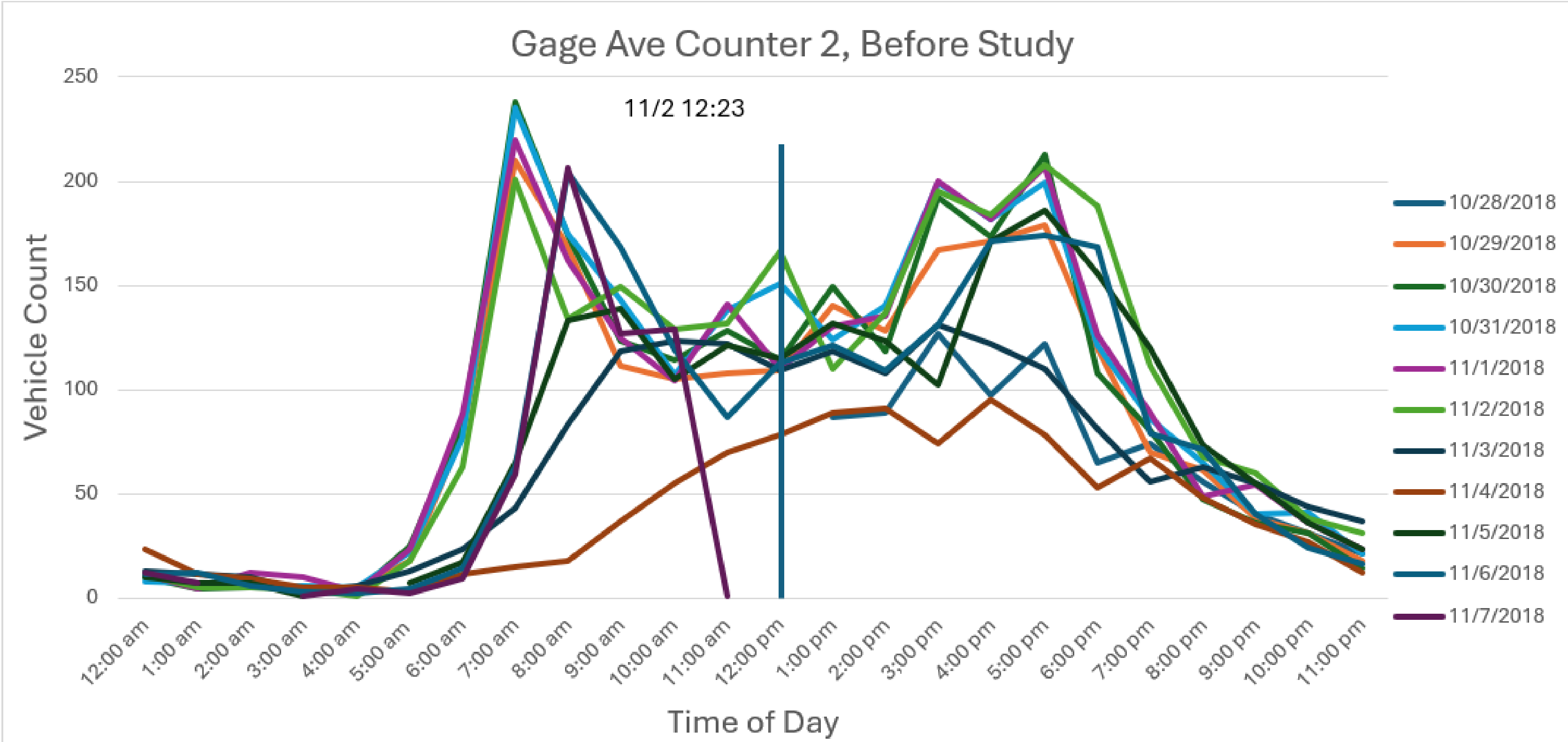


Figure B.20: Gage Avenue Counter 2, Before Study

Table B.9: Gage Counter 1 and Counter 2

Gage Counter 1					Gage Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
No WW movements					11/2/2018	12:23:59 PM	1	73
					11/3/2018	7:18:21 AM	2	82
					11/5/2018	1:06:03 PM	1	34
					11/6/2018	12:18:04 PM	1	74

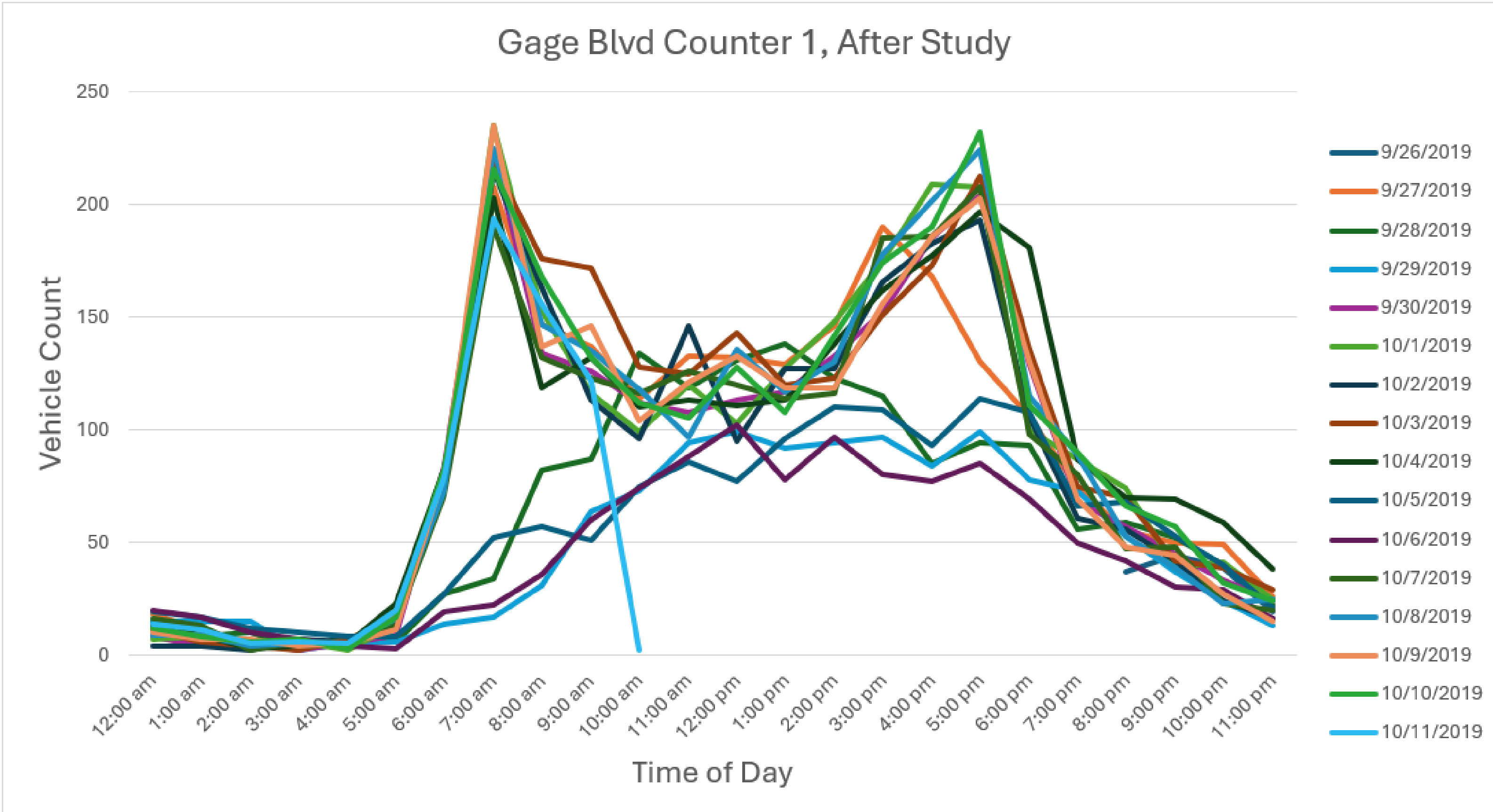


Figure B.21: Gage Boulevard Counter 1, After Study

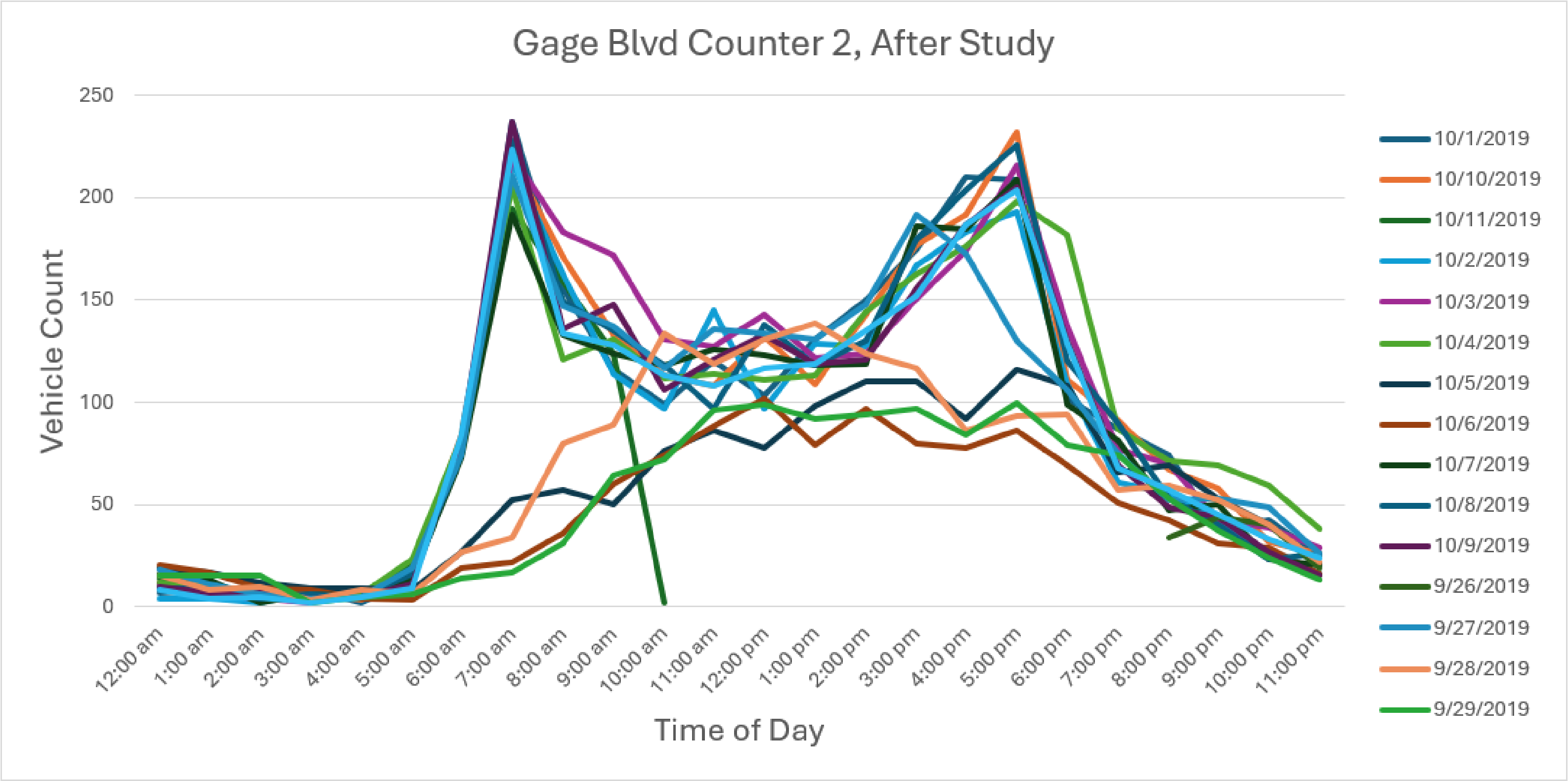


Figure B.22: Gage Boulevard Counter 2, After Study

Table B.10: Gage After Counter 1 and Counter 2

Gage After Counter 1					Gage After Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
10/9/2019	11:28:27 AM	3	32		No WW movements			
10/10/2019	7:43:46 AM	1	41					

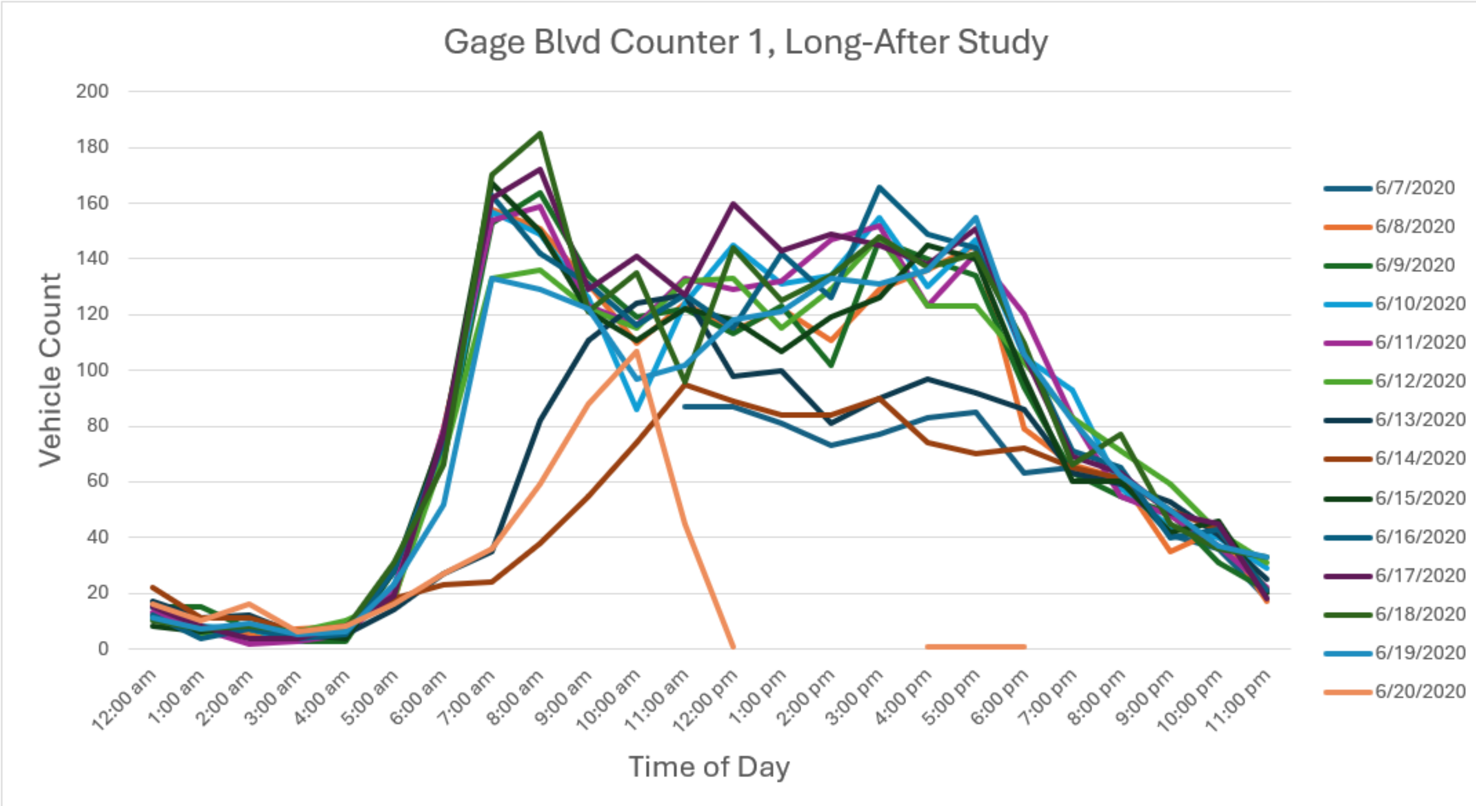


Figure B.23: Gage Boulevard Counter 1, Long-After Study

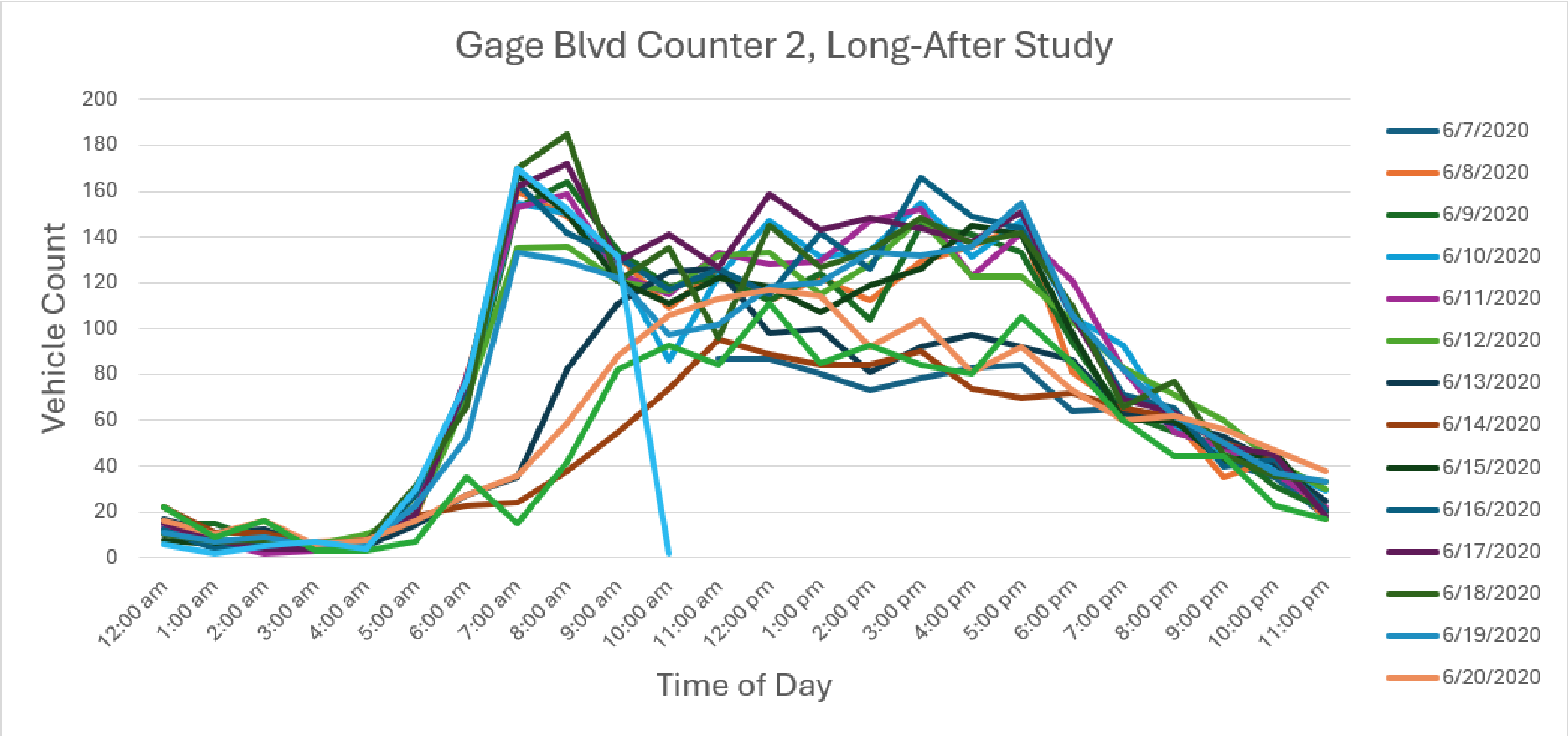


Figure B.24: Gage Boulevard Counter 2, Long-After Study

Table B.11: Gage Long-After Counter 1 and Counter 2

Gage Long-After Counter 1					Gage Long-After Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
6/10/2020	7:51:29 AM	1	24		6/9/2020	1:19:06 PM	6	41
6/12/2020	2:36:25 PM	4	29		6/18/2020	1:04:08 PM	1	26
6/20/2020	12:55:04 PM	5	52		6/20/2020	1:09:20 PM	4	36
6/20/2020	2:55:36 PM	1	18					
6/20/2020	4:54:59 PM	1	25					
6/20/2020	5:32:54 PM	1	16					
6/20/2020	6:09:12 PM	2	18					
6/22/2020	7:47:10 AM	5	68					
6/22/2020	9:52:00 AM	1	18					

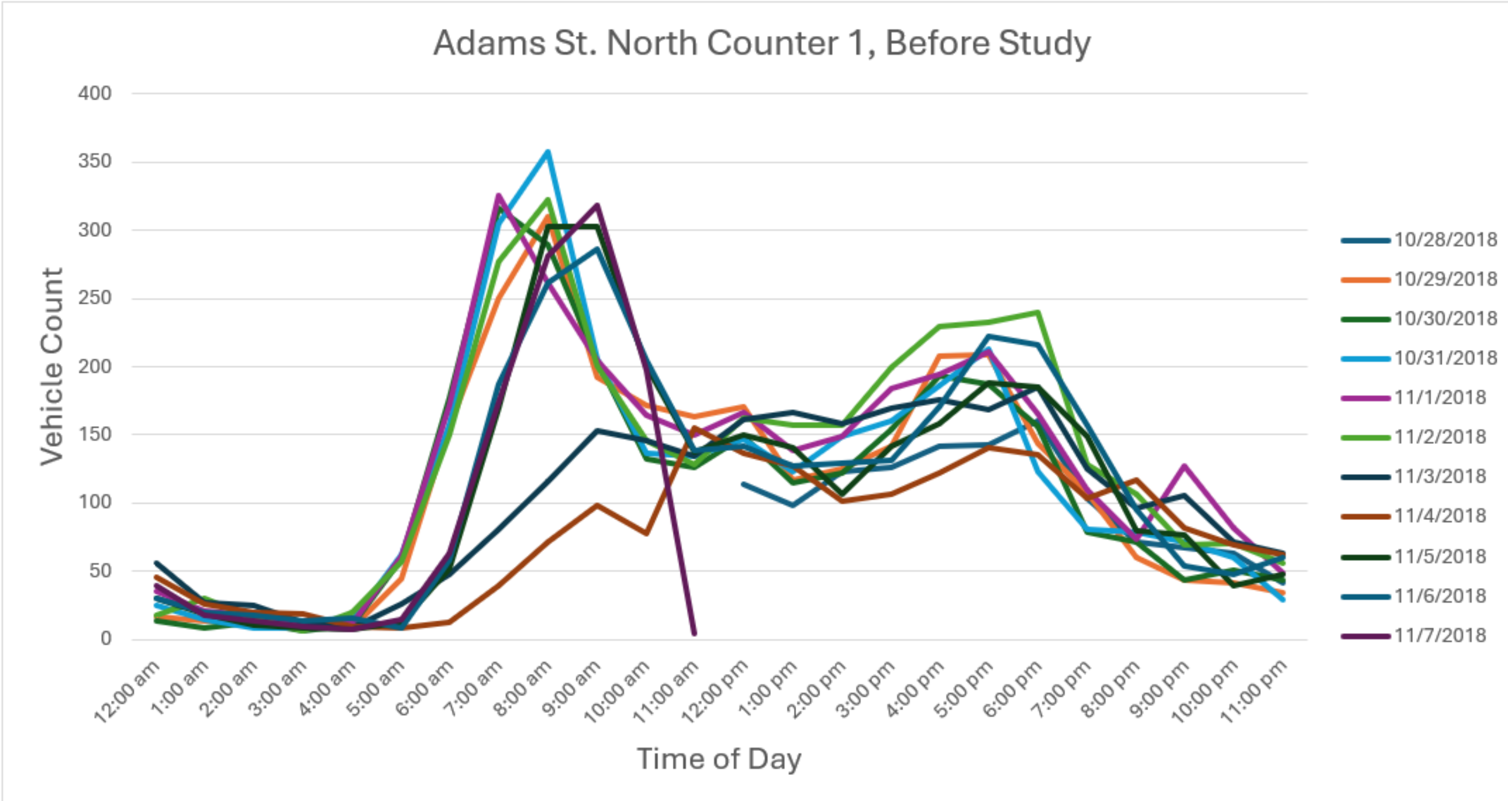


Figure B.25: Adams Street North Counter 1, Before Study

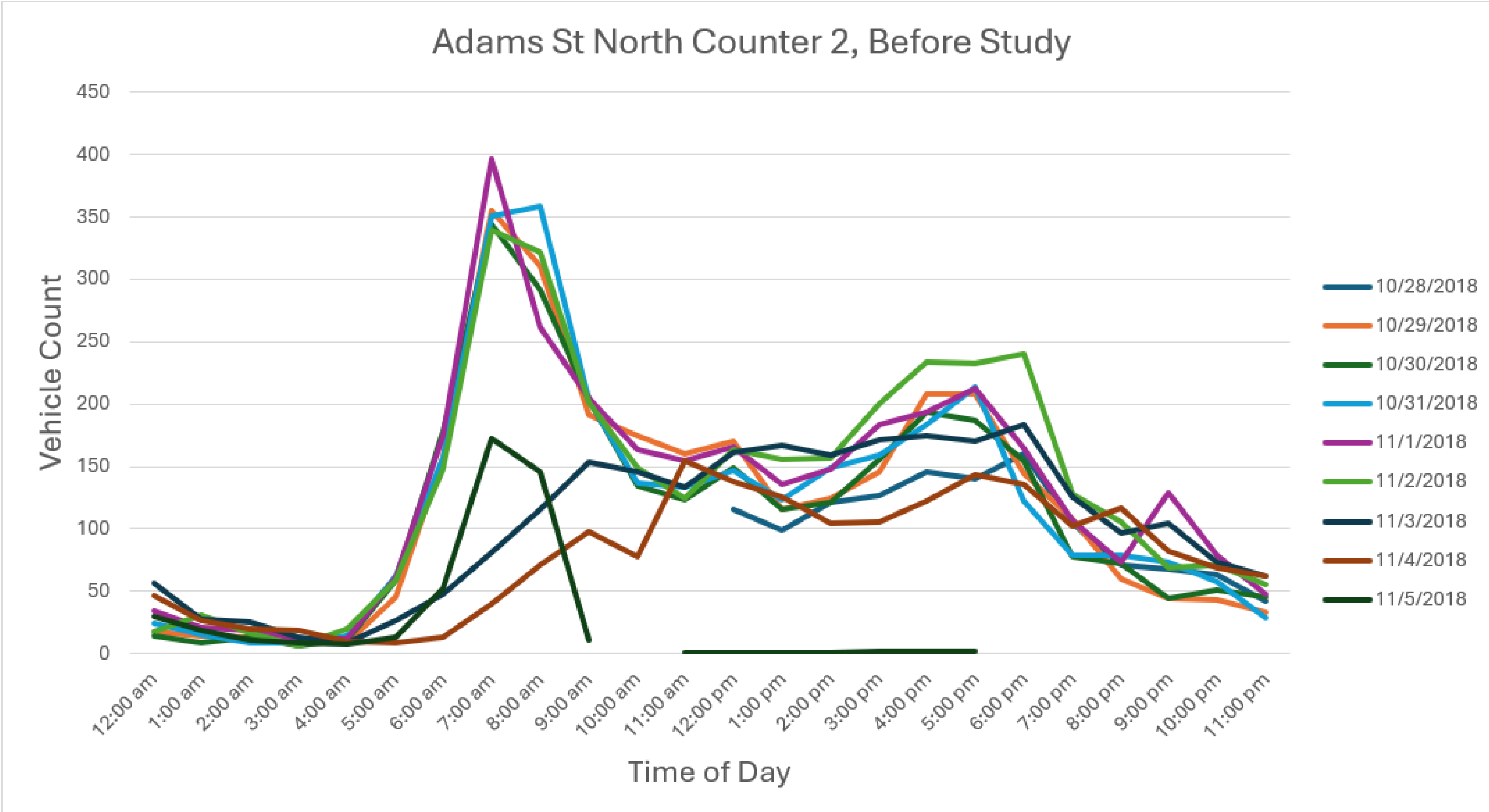


Figure B.26: Adams Street North Counter 2, Before Study

Table B.12: Southeast Adams North Before Counter 1 and Counter 2

SE Adams North Before Counter 1					SE Adams North Before Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
11/1/2018	12:03:56 AM	1	32		11/5/2018	8:12:09 AM	1	10
11/6/2018	8:42:45 AM	2	2					

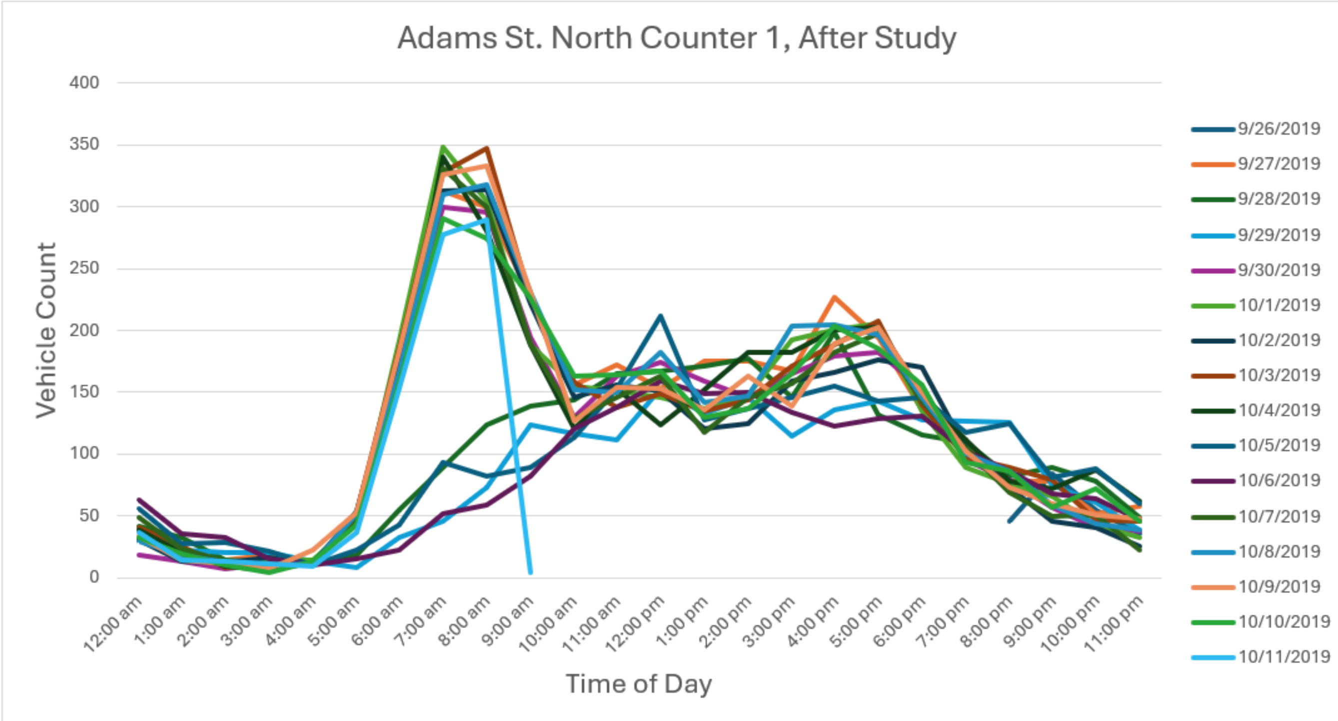


Figure B.27: Adams Street North Counter 1, After Study

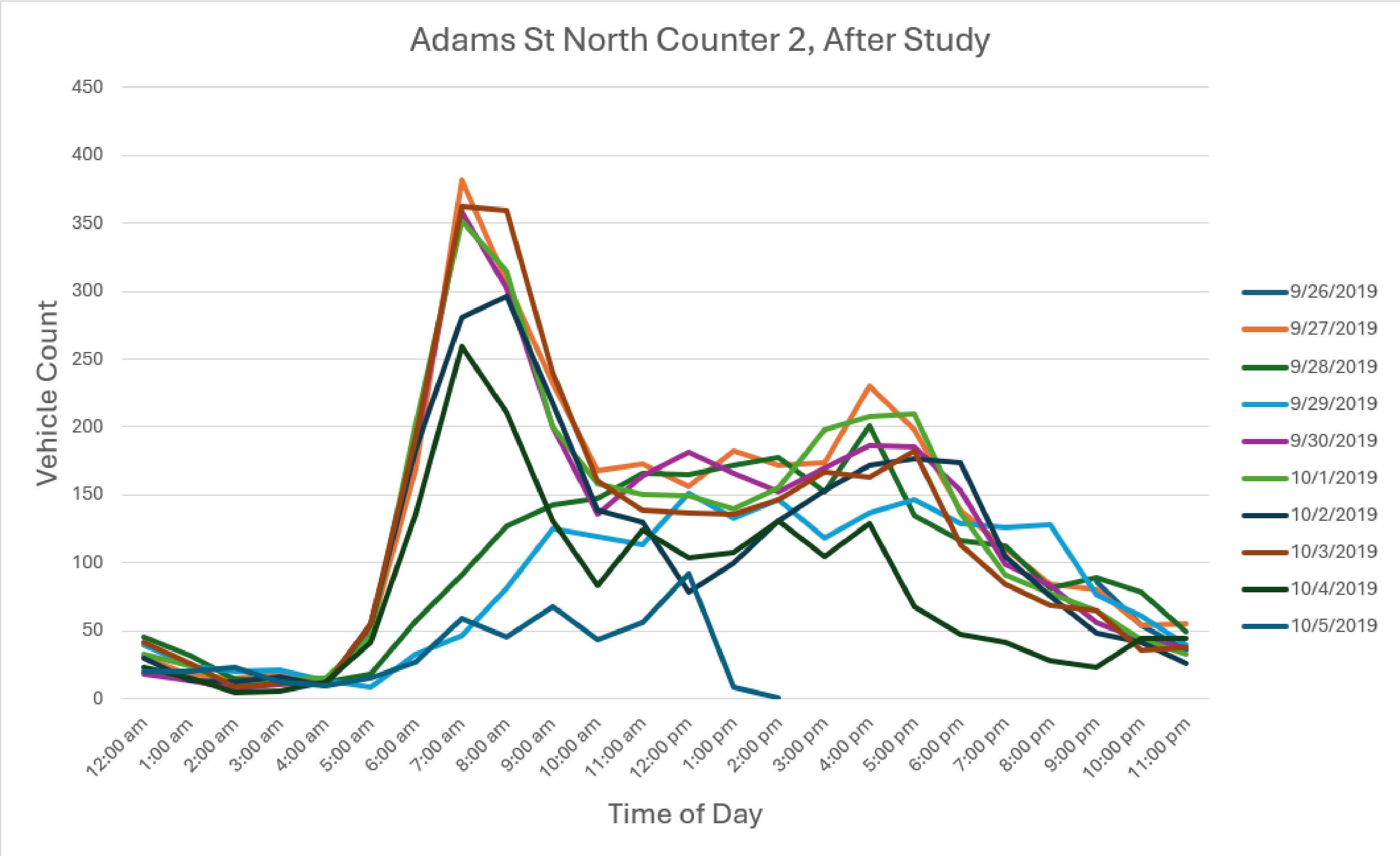


Figure B.28: Adams Street North Counter 2, After Study

Table B.13: Southeast Adams North After Counter 1 and Counter 2

SE Adams North After Counter 1					SE Adams North After Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
9/30/2019	7:52:22 AM	2	23		10/3/2019	12:54:46 PM	4	12
10/10/2019	7:43:48 AM	4	6		10/3/2019	3:37:59 PM	4	14
					10/3/2019	4:11:26 PM	4	13
					10/3/2019	4:36:58 PM	1	8
					10/3/2019	8:17:39 PM	1	4
					10/3/2019	9:21:15 PM	5	12
					10/3/2019	9:22:16 PM	4	12
					10/3/2019	9:31:52 PM	4	14
					10/4/2019	12:52:25 AM	1	4
					10/4/2019	2:43:20 AM	5	11
					10/4/2019	2:48:51 AM	1	11
					10/4/2019	6:57:58 AM	4	13
					10/4/2019	6:58:50 AM	1	3
					10/4/2019	7:08:27 AM	1	4
					10/4/2019	7:27:06 AM	4	14
					10/4/2019	7:27:51 AM	4	13
					10/4/2019	7:49:08 AM	4	14
					10/4/2019	8:24:32 AM	1	5
					10/4/2019	8:37:11 AM	5	12
					10/4/2019	8:58:49 AM	4	14
					10/4/2019	9:34:56 AM	1	7
					10/4/2019	9:37:25 AM	4	13
					10/4/2019	9:40:43 AM	1	4
					10/4/2019	10:30:08 AM	1	6
					10/4/2019	10:30:09 AM	1	32
					10/4/2019	11:52:47 AM	4	15
					10/4/2019	12:02:58 PM	1	3
					10/4/2019	12:09:41 PM	4	14
					10/4/2019	12:22:14 PM	1	69
					10/4/2019	2:01:50 PM	4	12
					10/4/2019	2:15:00 PM	4	13
					10/4/2019	2:16:49 PM	4	12
					10/4/2019	2:29:07 PM	1	6
					10/4/2019	3:02:28 PM	1	7
					10/4/2019	3:37:24 PM	1	3
					10/4/2019	3:39:51 PM	4	14
					10/4/2019	3:44:57 PM	4	13
					10/4/2019	3:46:11 PM	4	13
					10/4/2019	4:55:58 PM	5	10
					10/4/2019	6:31:29 PM	4	14

					10/4/2019	8:59:38 PM	1	7
					10/5/2019	1:23:16 AM	1	5
					10/5/2019	1:33:57 AM	1	11
					10/5/2019	5:25:19 AM	1	12
					10/5/2019	5:35:11 AM	5	12
					10/5/2019	5:38:52 AM	1	10
					10/5/2019	5:45:40 AM	1	12
					10/5/2019	5:49:41 AM	1	12
					10/5/2019	5:50:19 AM	1	11
					10/5/2019	6:00:01 AM	1	12
					10/5/2019	6:08:01 AM	1	11
					10/5/2019	7:17:00 AM	1	4
					10/5/2019	7:43:01 AM	4	14
					10/5/2019	9:37:55 AM	4	13
					10/5/2019	11:16:11 AM	1	4
					10/5/2019	11:32:35 AM	4	12
					10/5/2019	12:32:33 PM	5	8
					10/5/2019	12:37:43 PM	5	11
					10/5/2019	12:38:52 PM	1	5
					10/5/2019	12:38:53 PM	1	30

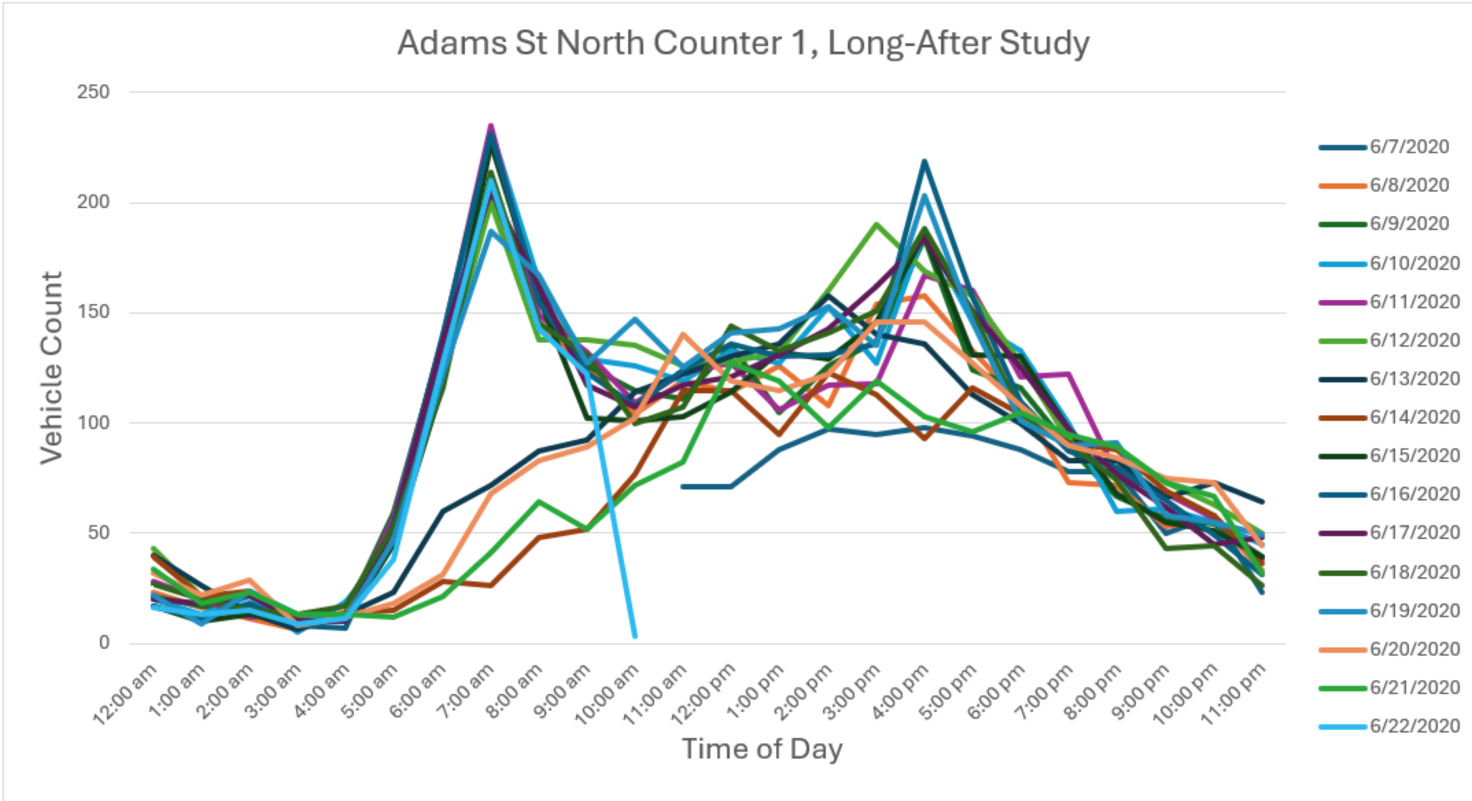


Figure B.29: Adams Street North Counter 1, Long-After Study

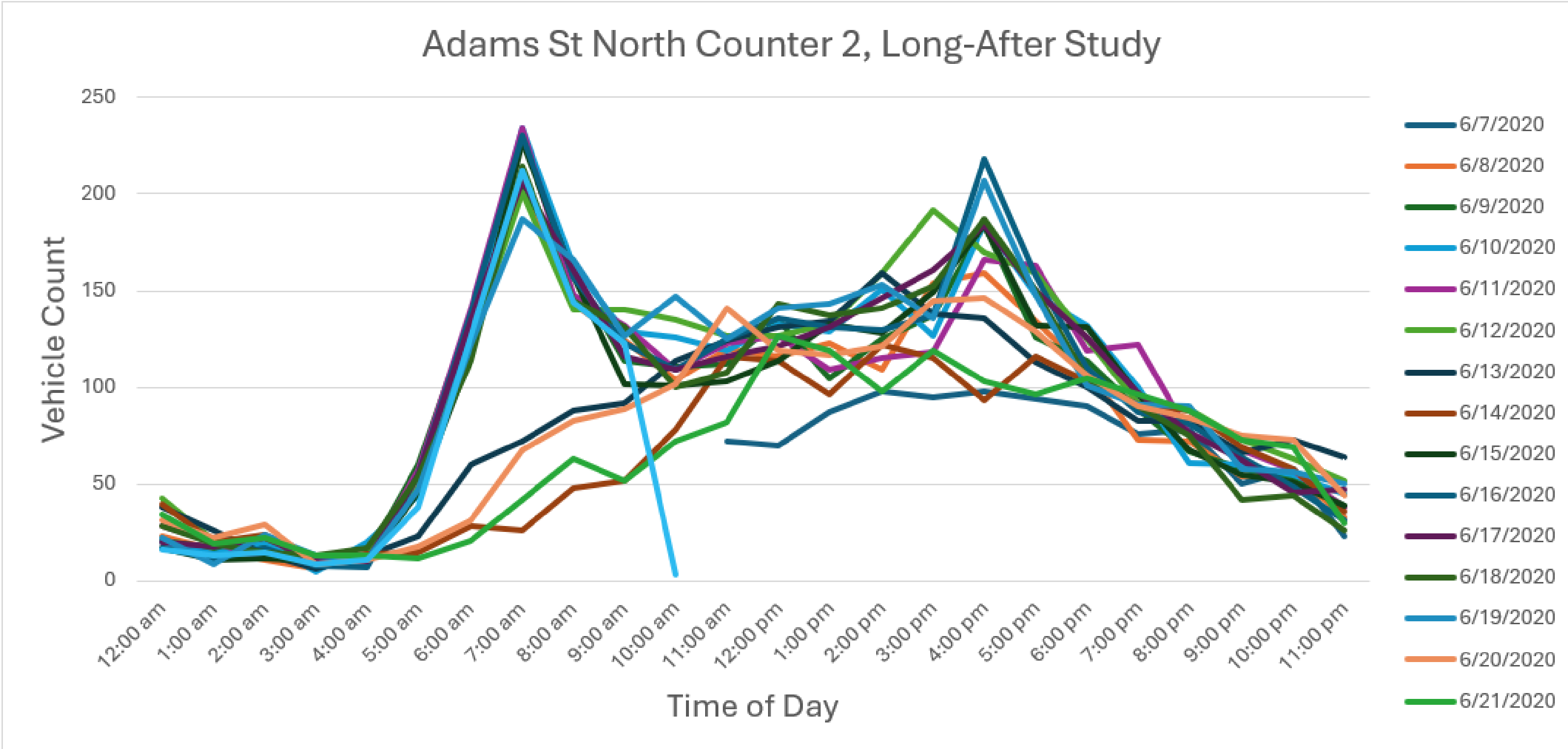


Figure B.30: Adams Street North Counter 2, Long-After Study

Table B.14: Southeast Adams North Long-After Counter 1 and Counter 2

SE Adams North Long-After Counter 1					SE Adams North Long-After Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
6/8/2020	1:52:50 PM	5	22		No WW movements			
6/11/2020	4:11:04 PM	6	18					
6/14/2020	5:42:19 PM	4	21					
6/19/2020	8:42:28 AM	4	21					

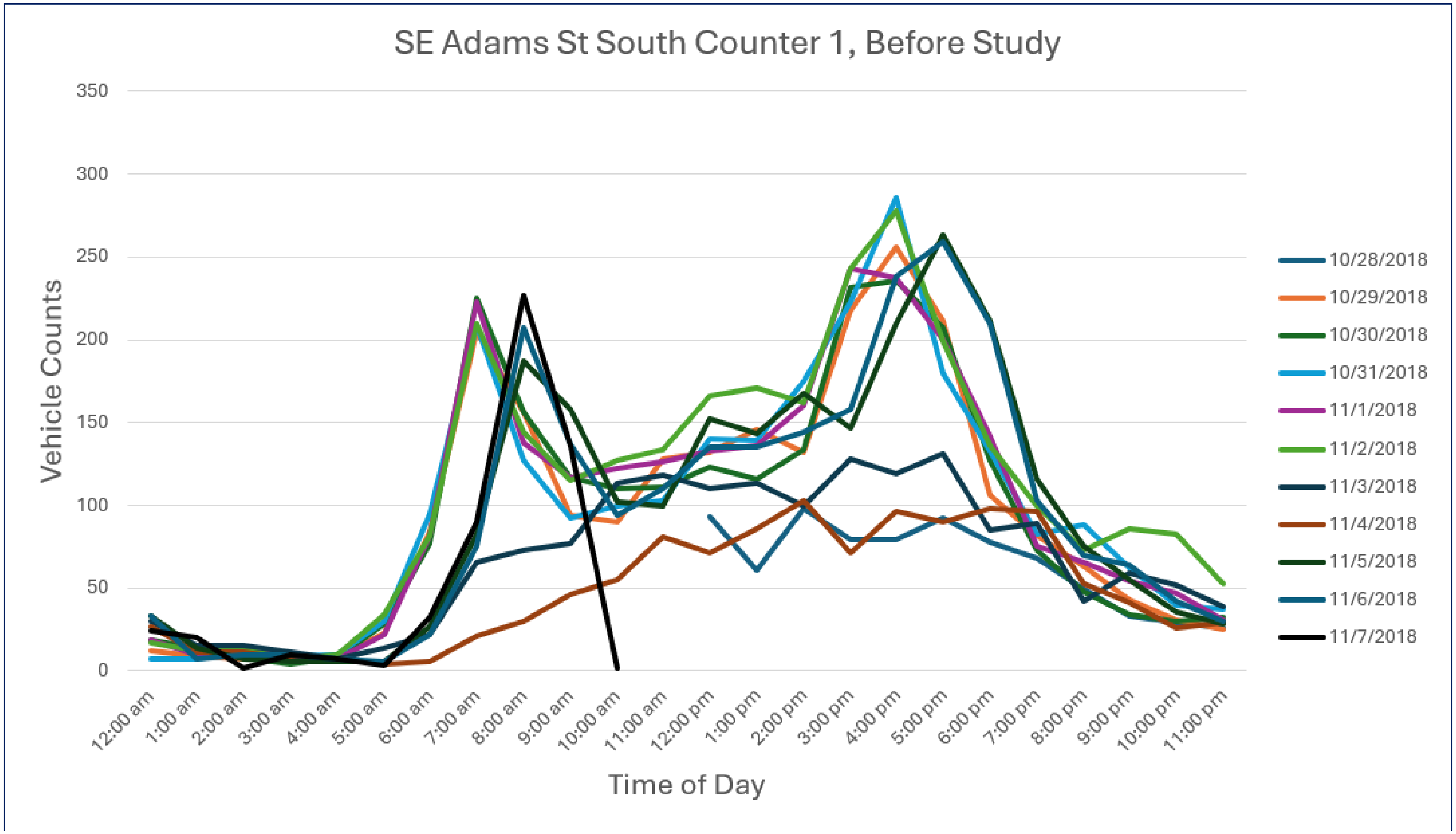


Figure B.31: Southeast Adams Street South Counter 1, Before Study

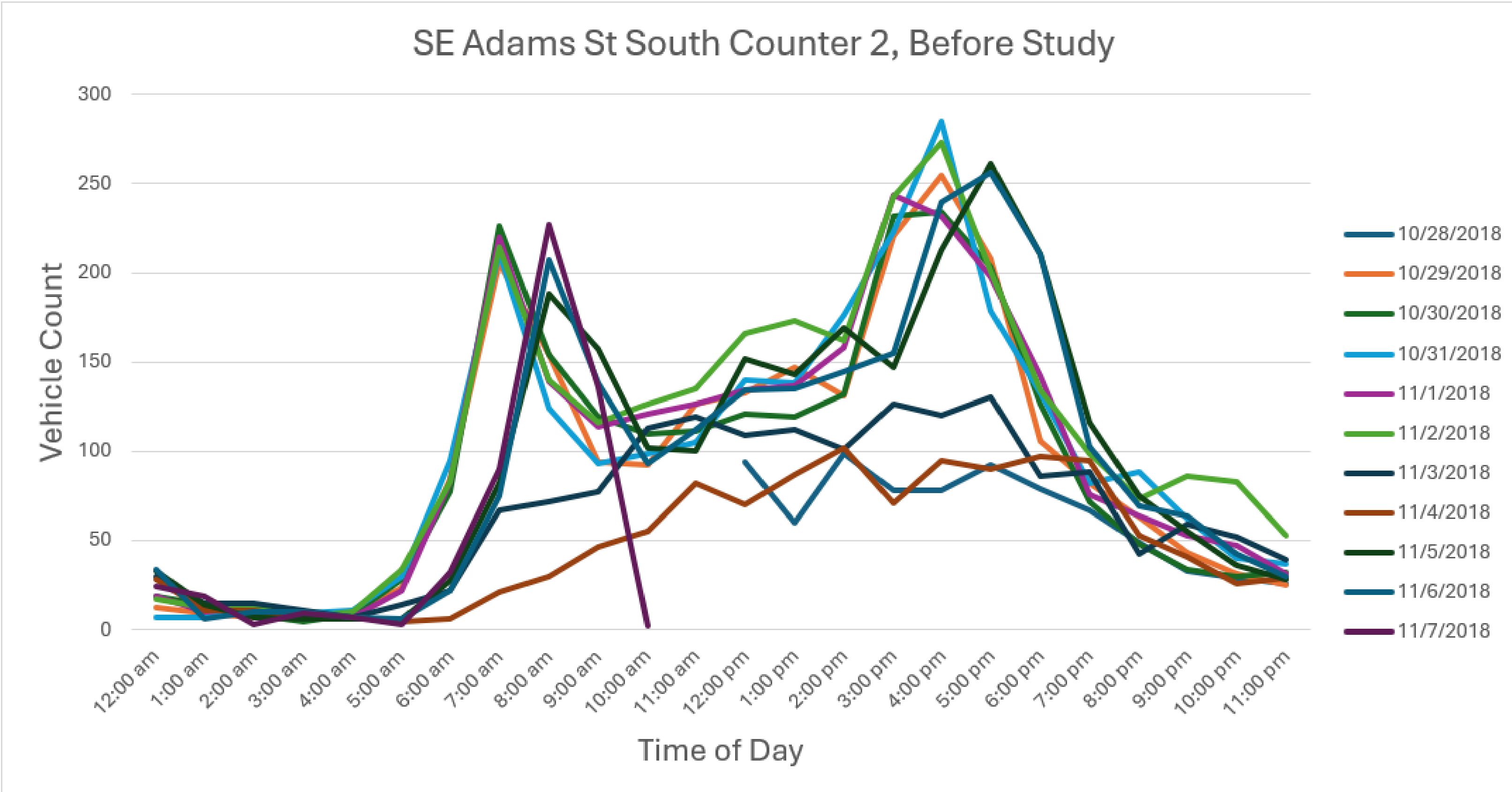


Figure B.32: Southeast Adams Street South Counter 2, Before Study

Table B.15: Southeast Adams South Before Counter 1 and Counter 2

SE Adams South Before Counter 1					SE Adams North Long-After Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
11/4/2018	3:43:57 PM	3	28		No WW movements			

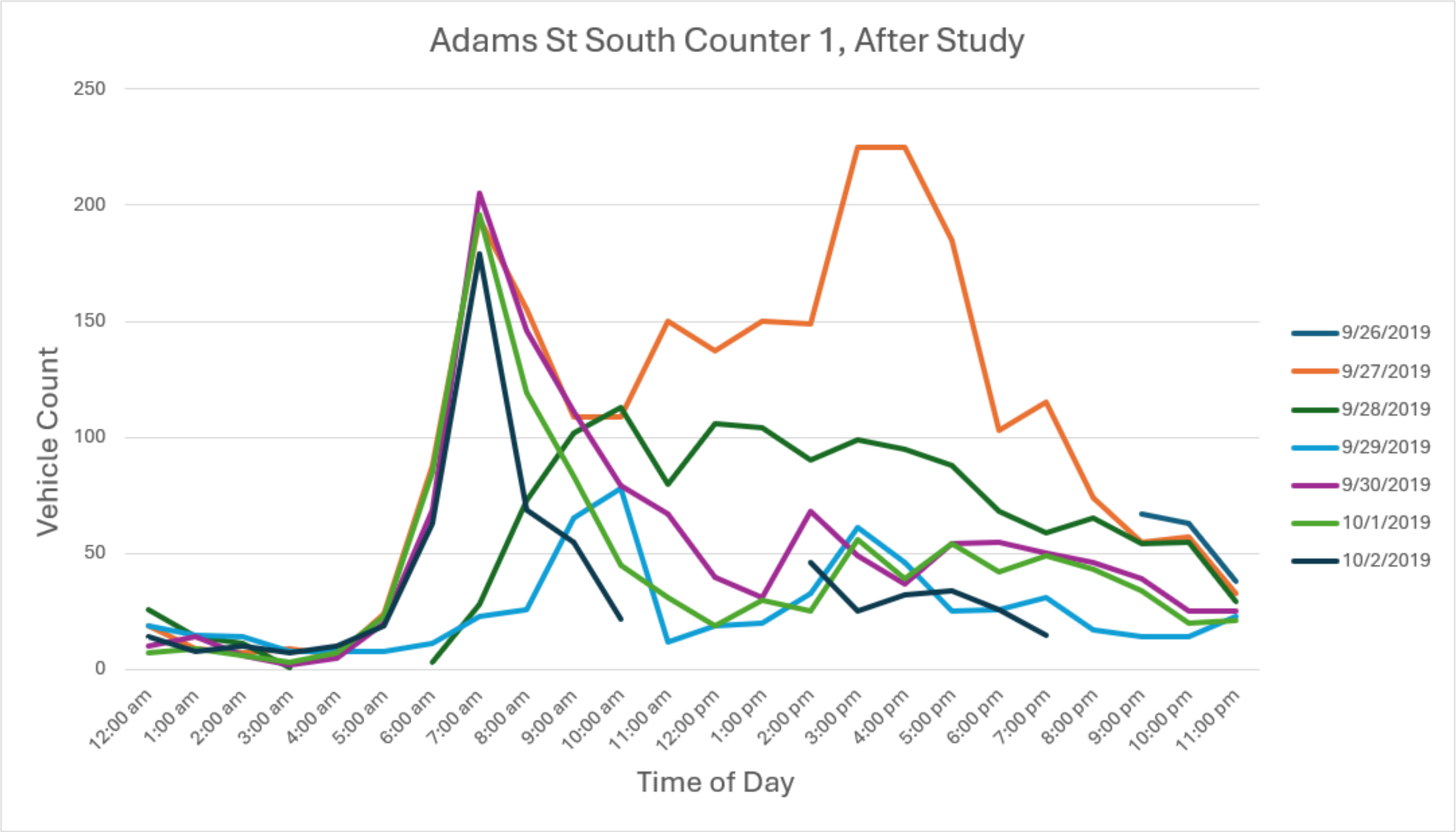


Figure B.33: Adams Street South Counter 1, After Study

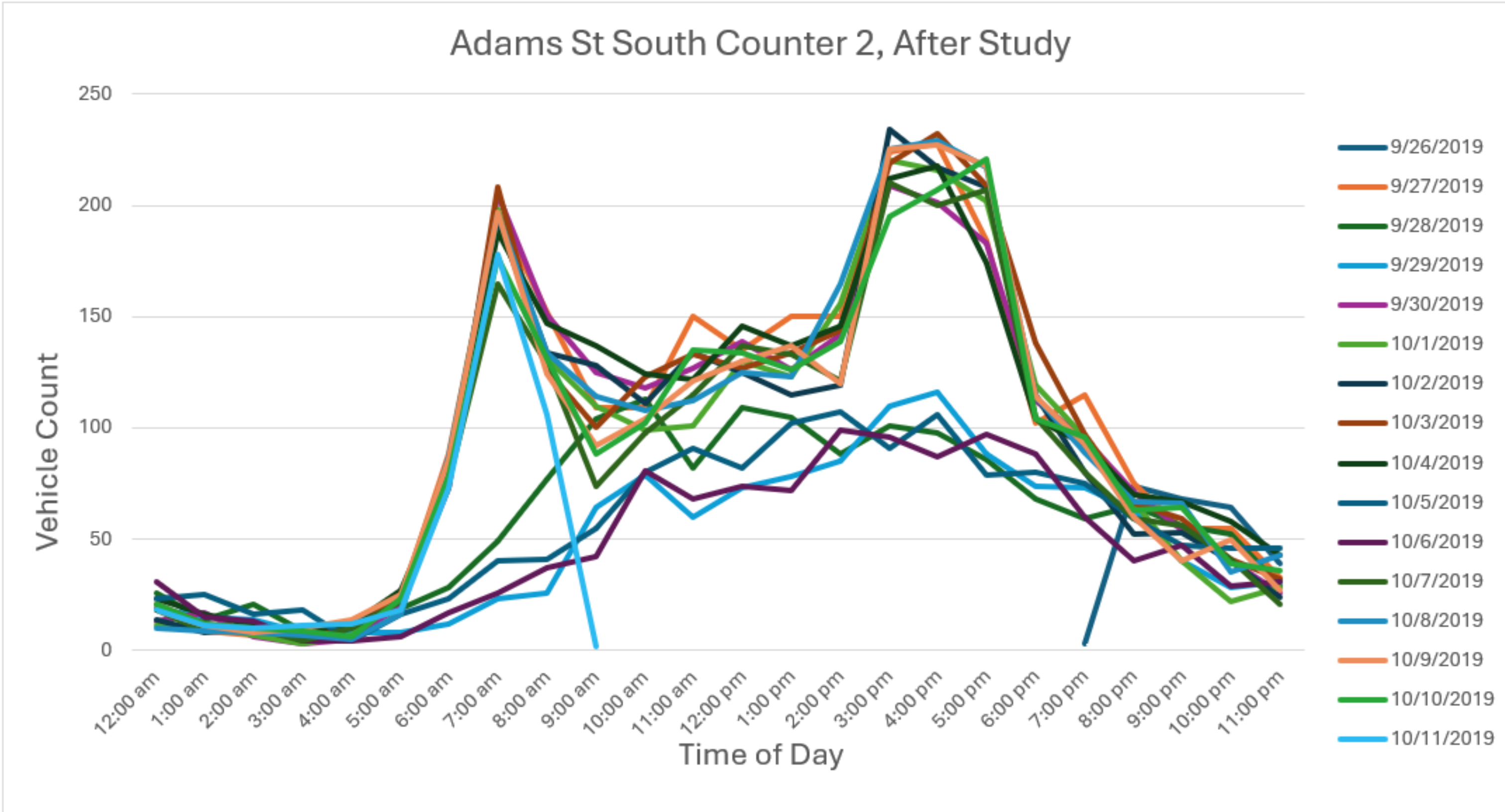


Figure B.34: Adams Street South Counter 2, After Study

Table B.16: Southeast Adams South After Counter 1 and Counter 2

SE Adams South After Counter 1					SE Adams South After Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
10/2/2019	4:30:51 PM	1	6		9/26/2019	7:57:42 PM	1	7
					10/2/2019	4:30:42 PM	1	5
					10/6/2019	9:15:54 PM	2	19

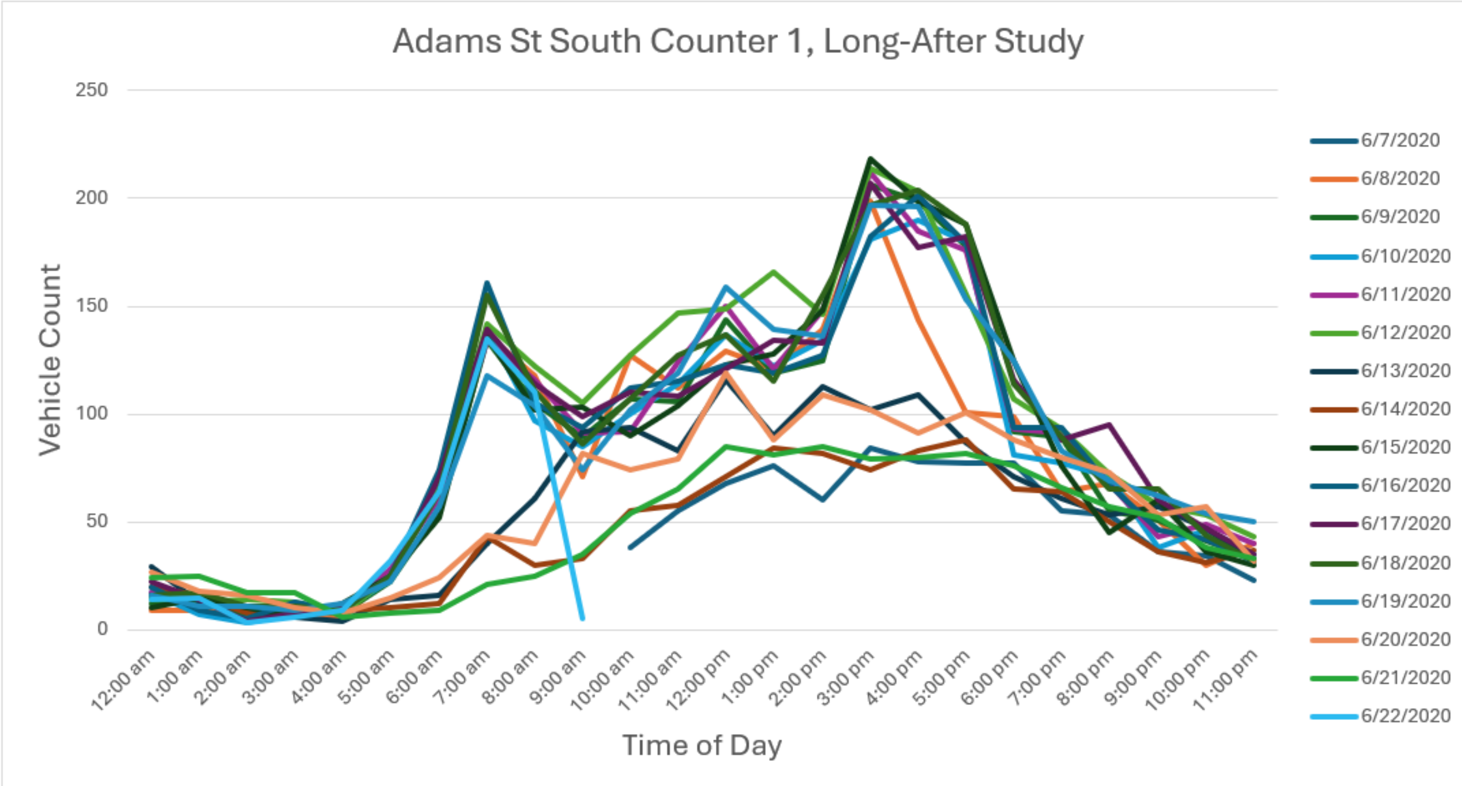


Figure B.35: Adams Street South Counter 1, Long-After Study

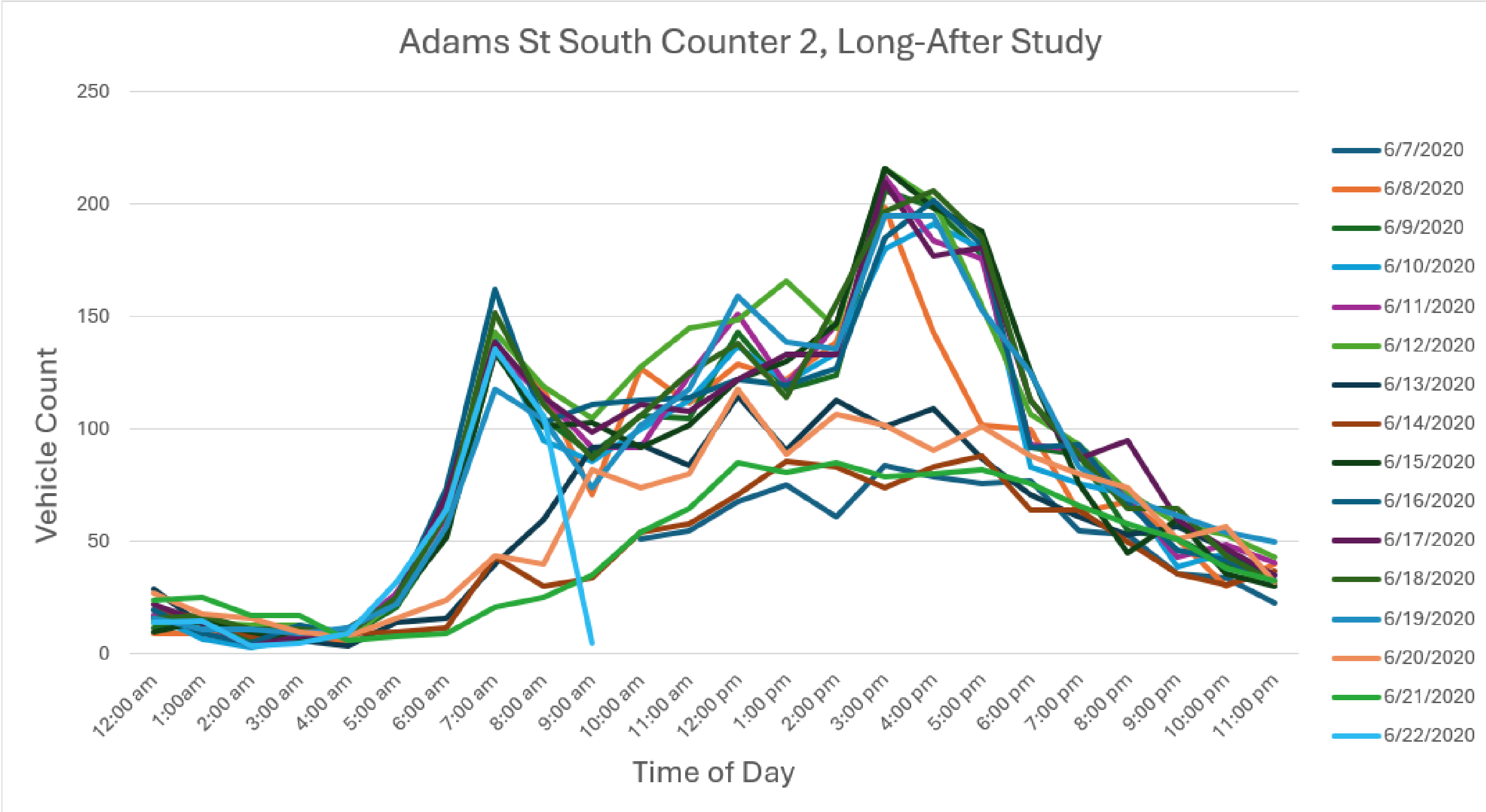


Figure B.36: Adams Street South Counter 2, Long-After Study

Table B.17: Southeast Adams South Long-After Counter 1 and Counter 2

SE Adams South Long-After Counter 1					SE Adams South Long-After Counter 2			
Date	Time	Class	Speed (In MPH)		Date	Time	Class	Speed (In MPH)
No WW movements					No WW movements			

Figure B.37: Location of Counter #1 (#32124) and Counter #2 (#32125)

Figure B.38: View of the Auburn Road Ramp from the Midpoint

Figure B.39: View from the Auburn Road Ramp to the I-70 Entrance

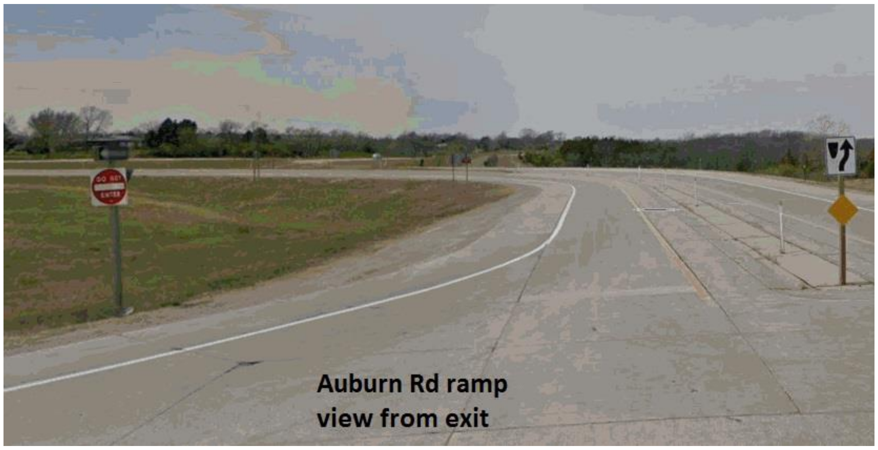


Figure B.40: View of the Auburn Road Ramp from the Exit

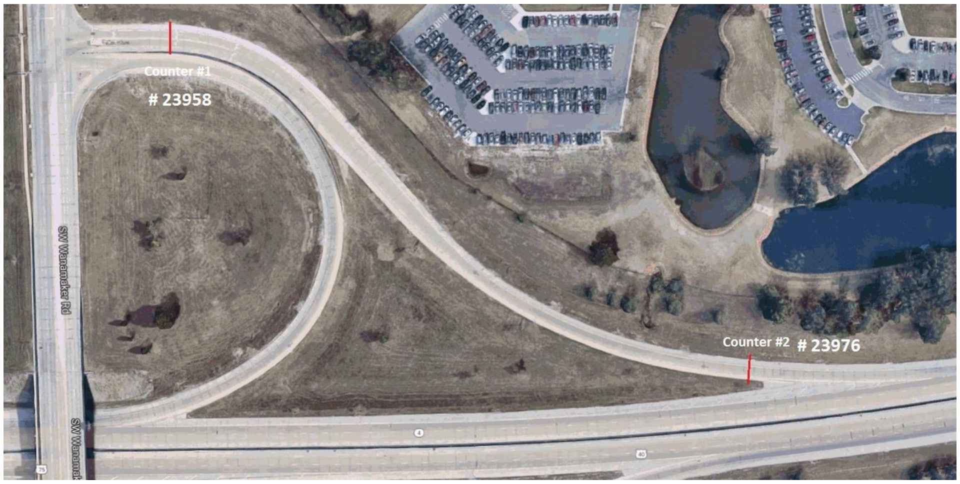


Figure B.41: Location of Counter #1 (#23958) and Counter #2 (#23976)

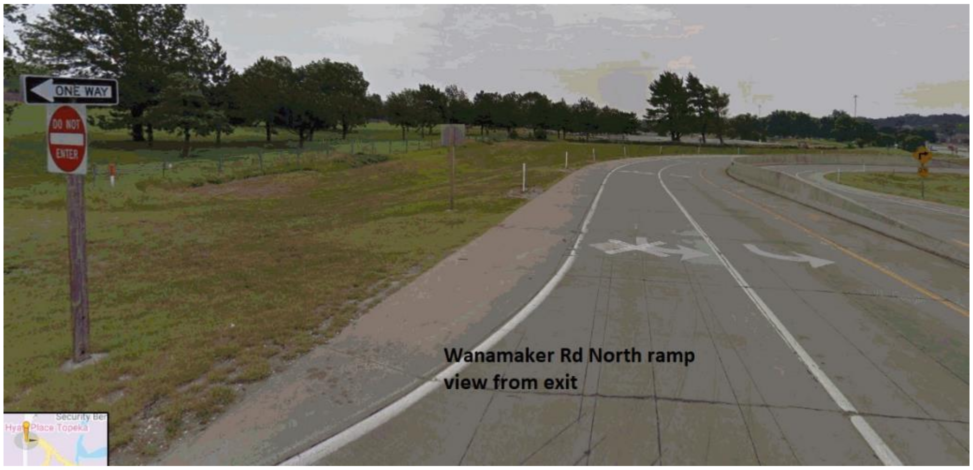


Figure B.42: View of the Wanamaker Road North Ramp from the Exit

Figure B.43: View of Wanamaker Road North Ramp from the Midpoint

Figure B.44: View from the Wanamaker Road North Ramp to the I-70 Entrance

Figure B.45: Location of Counter #1 (#31113) and Counter #2 (#23471)

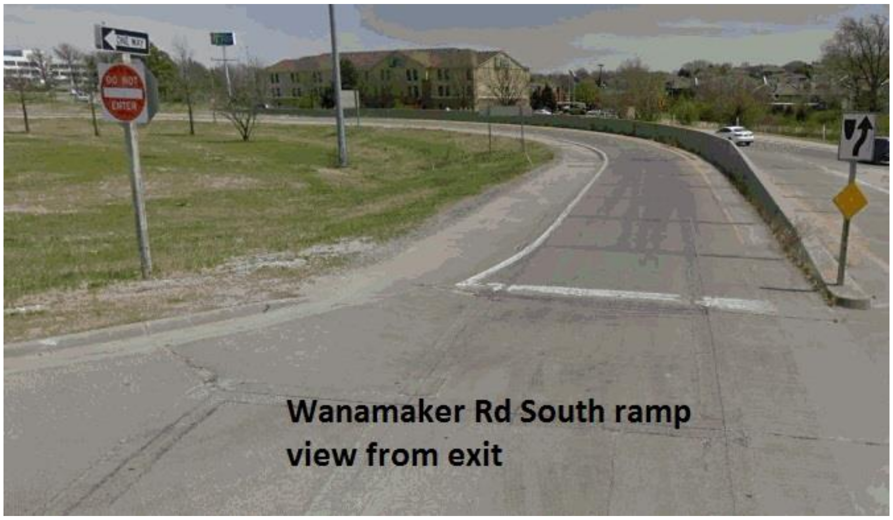


Figure B.46: View of the Wanamaker Road South Ramp from the Exit

Figure B.47: View of the Wanamaker Road South Ramp from the Midpoint

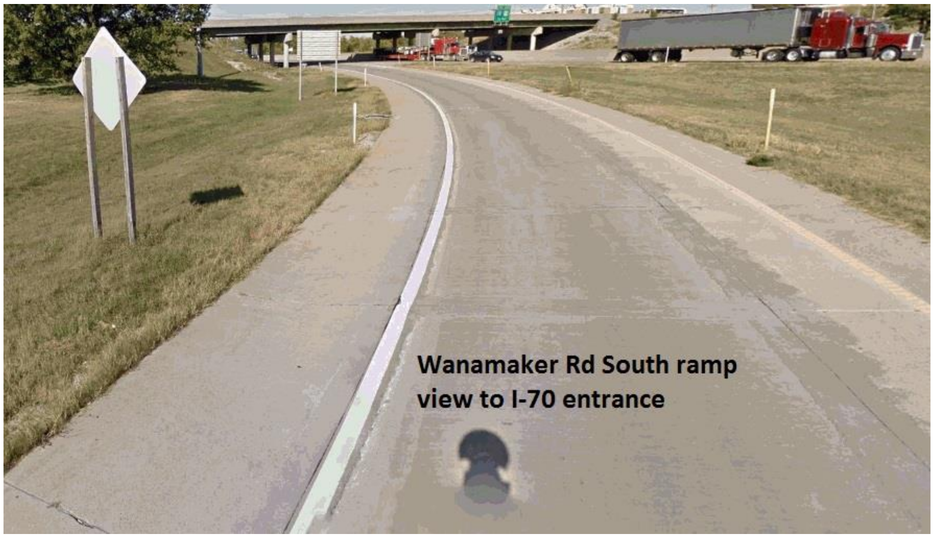


Figure B.48: View of the Wanamaker Road South Ramp to the I-70 Entrance

Figure B.49: Wrong Way Sign with Red LED Lights

Figure B.50: Time Actuated Flashing LED Wrong Way Sign

Figure B.51: Oversized Wrong Way Sign (42 X 30)

Caltrans

Figure B.52: Oversized and Lowered Signs

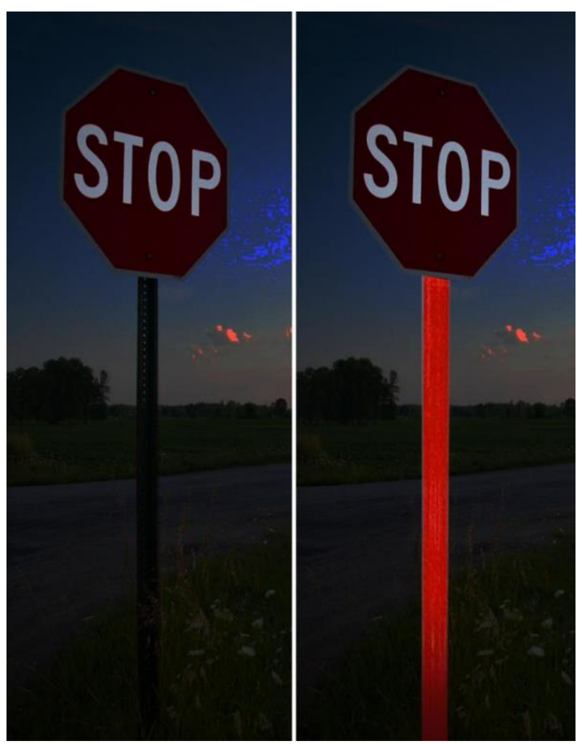


Figure B.53: Red Retroreflective Tape/Delineators

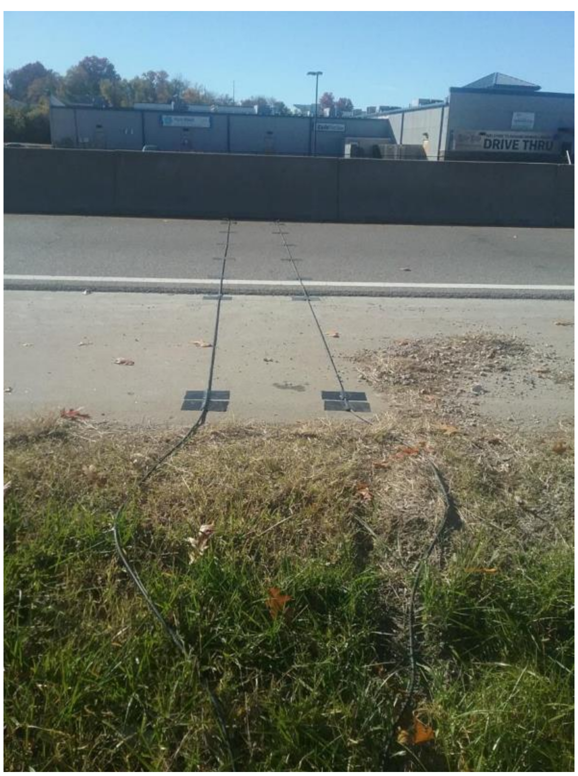
Appendix C: Additional Photos

C.1 Before Study

(a) 

(b) 

Figure C.1: Adams South Counter 2 View 1 (a) and View 2 (b)

(a) 

(b) 

Figure C.2: Adams South Counter 1 View 1 (a) and View 2 (b)

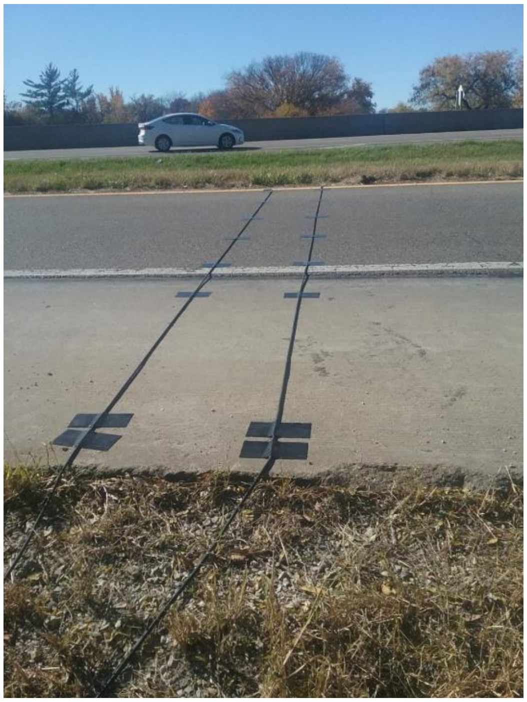
(a)  (b) 

Figure C.3: Adams North Counter 2 View 1 (a) and View 2 (b)

(a)  (b) 

Figure C.4: Adams North Counter 1 View 1 (a) and View 2 (b)

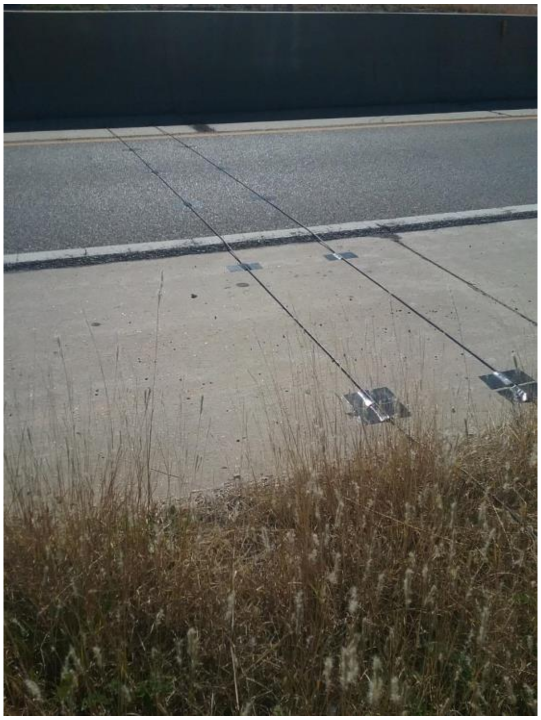
(a)  (b) 

Figure C.5: Gage Blvd Counter 2 View 1 (a) and View 2 (b)

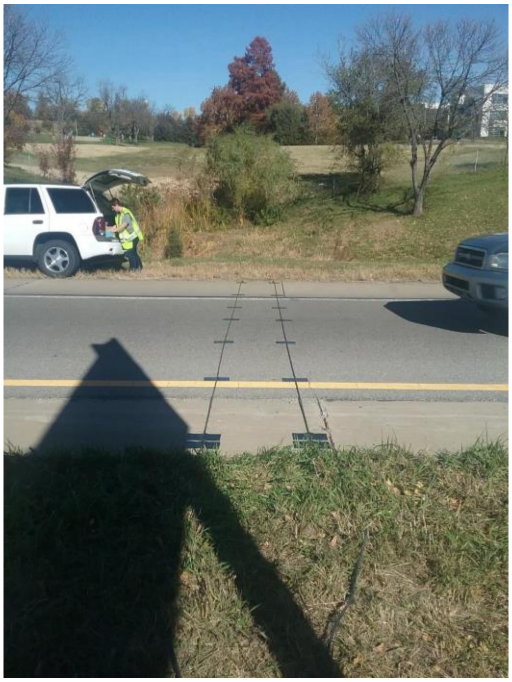
(a)  (b) 

Figure C.6: Wanamaker North Counter 2 View 1 (a) and View 2 (b)

(a) (b) (c)

Figure C.7: Wanamaker North Counter 1 View 1 (a), View 2 (b), and View 3 (c)

(a) 
(b) 

(c) 

Figure C.8: Auburn Rd Counter 2 View 1 (a), View 2 (b), and View 3 (c)

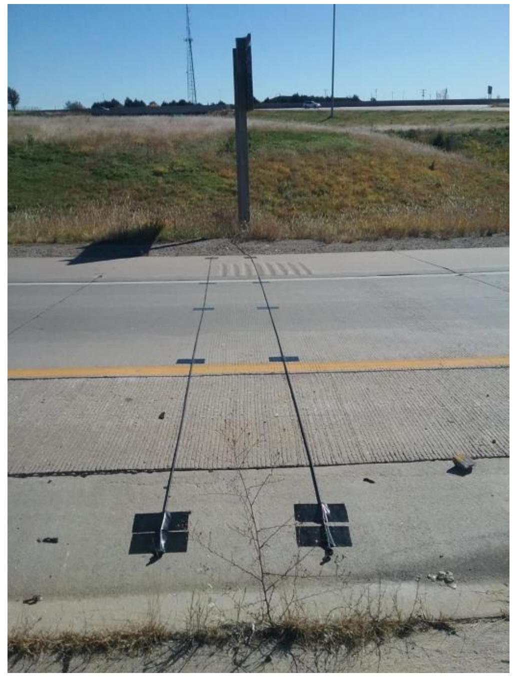
(a)  (b) 

Figure C.9: Auburn Rd Counter 1 View 1 (a) and View 2 (b)

(a) 

(b) 

(c) 

Figure C.10: Wanamaker South Counter 2 View 1 (a), View 2 (b), and View 3 (c)

(a) (b)

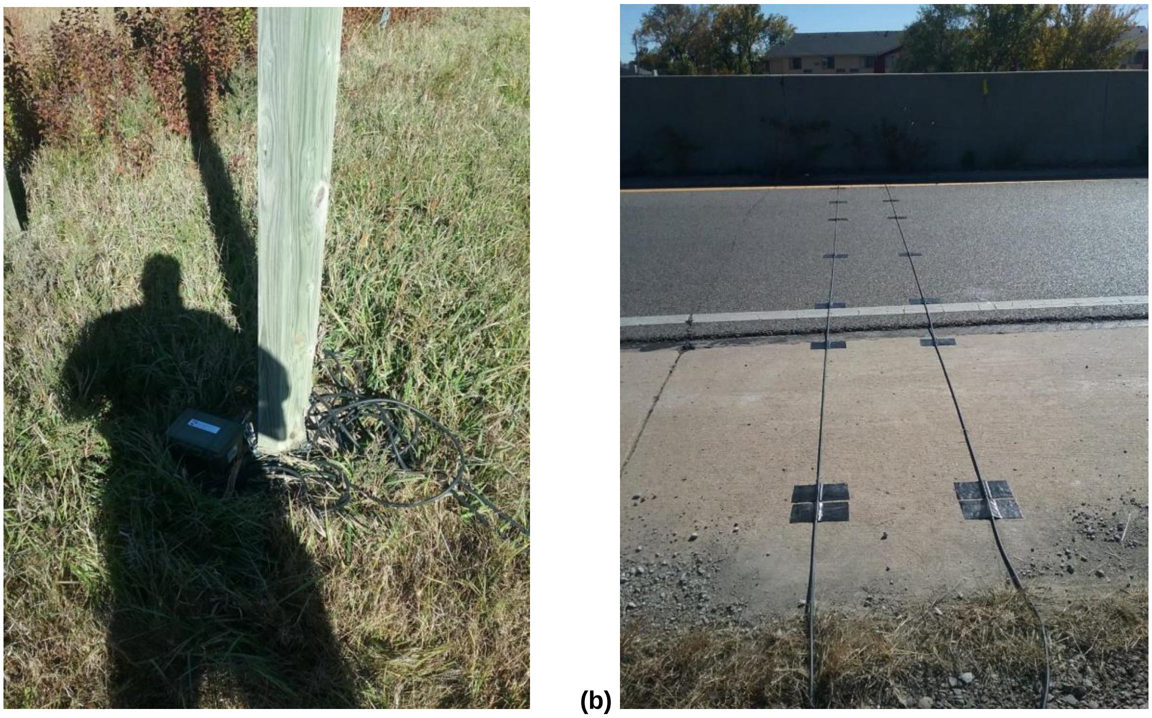


Figure C.11: Wanamaker South Counter 1 View 1 (a) and View 2 (b)

C.2 First After Study

Figure C.12: Adams Street South, Later Discovered Road Tube Damaged

Figure C.13: Adams St North Counter 2, Broken Road Tube

C.3 Countermeasure Installation

Figure C.14: Installation of Oversized and Lowered Wrong Way Sign at Gage Blvd Ramp

Figure C.15: Installation of RRFDs on Gage Blvd

Figure C.16: Installation of 2nd Oversized and Lowered Wrong Way Sign on Wanamaker Rd North

Figure C.17: Installation of 1st Oversized and Lowered Wrong Way Signs on Wanamaker Rd North Ramp

Figure C.18: Installation of 1st Oversized and Lowered Sign at Wanamaker Rd South Ramp

Figure C.19: Installation of 2nd Oversized and Lowered Wrong Way Sign on Wanamaker South Ramp

Figure C.20: Installation of Flashing LED Wrong Way Sign at Auburn Rd Ramp

Figure C.21: Installation of Flashing LED Wrong Way Sign at Auburn Rd Ramp

C.4 Data Collection Method

Figure C.22: Counter 1 Location on Auburn Rd Ramp

Figure C.23: Counter 2 Location on Auburn Rd Ramp

Figure C.24: Counter 3 Location on Northbound Auburn Rd

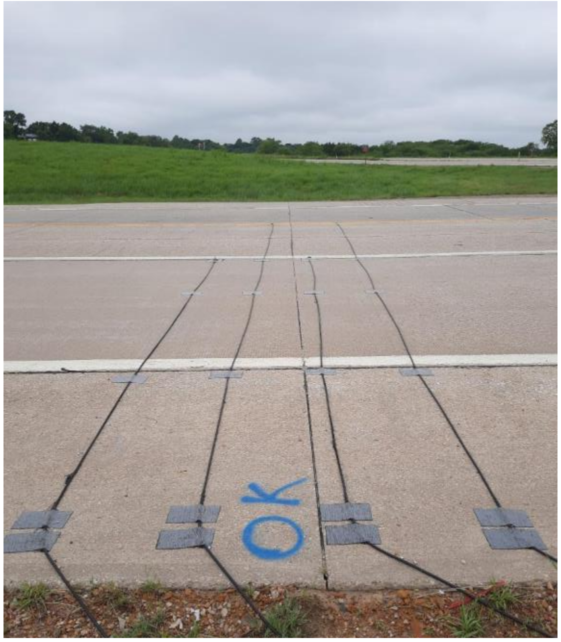


Figure C.25: Counter 3 Layout on northbound Auburn Rd

Figure C.26: Counter 4 Location on Southbound Auburn Rd

Figure C.27: Counter 4 Location on Southbound Auburn Rd

Figure C.28: Counter 5 Location on I-70 Entrance Ramp

Figure C.29: Counter 5 Location on I-70 Entrance Ramp

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