BENEFITS OF ADVANCED TRAFFIC MANAGEMENT SOLUTIONS: BEFORE AND AFTER CRASH ANALYSIS FOR DEPLOYMENT OF A VARIABLE ADVISORY SPEED LIMIT SYSTEM

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TITLE: Benefits of Advanced Traffic Management Solutions: Before and After Crash Analysis for Deployment of a Variable Advisory Speed Limit System

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ABSTRACT

Benefits of Advanced Traffic Management Solutions: Before and After Crash Analysis for Deployment of a Variable Advisory Speed Limit System

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Variable speed limit (VSL) systems are important active traffic management tools that are being deployed across the U.S. and indeed around the world for relieving congestion and improving safety. Oregon’s first variable advisory speed limit signs were activated along Oregon Highway 217 in the summer of 2014. The variable advisory speed system is responsive to both congestion and weather conditions. This seven-mile corridor stretches around Western Portland and has suffered from high crash rates and peak period congestion in the past. VSL systems are often deployed to address safety, mobility and sustainability related performance. This research seeks to determine whether the newly implemented variable advisory speed limit system has had measurable impacts on traffic safety and what the scale of the impact has been. The research utilizes a before-after crash analysis with three years of data prior to implementation and around 16 months after. Statistical analysis using an Empirical Bayes (EB) approach will aim to separate the direct impacts of the variable advisory speed limit signs from the long term trends on the highway. In addition, the analysis corrects for the changes in traffic volumes over the study period. Three data sources will be utilized including Washington County 911 call data, Oregon incident reports, and official Oregon Department of Transportation crash data reports. The analysis results are compared between data sources to determine the reliability of 911 call data as a proxy for crash statistics. The conclusions should be able to provide an indication of whether variable advisory speed limits can provide increased safety along high crash corridors.

Keywords: Variable Advisory Speed Limit, Empirical Bayes, Naïve Before After, ITS

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1.0 Introduction

Roadway safety is an ever present and increasingly visible problem in the United States. Despite significant declines in fatalities over the past few decades, in 2014 traffic crashes caused a total of 32,675 fatalities and over 2.3 million injuries (NHTSA). Recent initiatives such as Vision Zero address the fact that these deaths are far too high a cost as “life and health can never be exchanged for other benefits within the society,” eschewing traditional cost benefit models. (Monash 1999). The goal of reducing traffic deaths to zero has been adopted by many US cities in the past few years including Portland, Oregon, which aims for no fatalities in the city in 10 years.

A complementary issue to roadway safety in urban environments is congestion. Congestion compounds safety issues as crash “frequency on both freeways and arterials tends to increase with an increase in the congestion level” (Chang 2003). This is in addition to other issues congestion brings such as the cost of excess travel time, fuel consumption and emissions. The Texas A&M Transportation Institute (TTI) estimates that congestion costs Americans $121 billion per year, equating to a rate of $818 per commuter (Schrank et al., 2012). As urbanization increases in the US the congestion problems, and associated safety issues, are expected to increase significantly.

To support the lofty safety goals of Vision Zero new strategies for managing traffic are needed. In congested urban areas, building out of the problem with more lanes or freeways is not possible from a right of way standpoint and cost prohibitive. The goal now is to achieve more with existing assets through proactive management strategies. One of the most promising recent strategies is Active Traffic Management (ATM) systems. Transportation Research Board's (TRB) Glossary of Regional Transportation Systems Management and Operations (RTSMO) terms defines ATM as "the ability to dynamically manage recurrent and non-recurrent congestion on the mainline based on prevailing traffic congestion" through the use of new technologies (Neudorff, Mason, & Bauer, 2012). ATM systems come in many forms, including (either individually or in combination) surveillance, incident management, ramp metering, queue warning, traveler information, lane management and variable speed limits, with the latter serving as the focus of this study. They have been implemented in both congestion and weather-responsive applications and have produced some promising results to be discussed later.

1.1 Variable Speed Limits

Variable speed limit (VSL) systems are a form of ATM that assign an appropriate speed limit to the roadway depending on information from traffic detectors, weather sensors, and other road surface condition data. Through driver compliance, the speed limits are intended to improve safety or the operation of the roadway through speed and flow harmonization across lanes, and longitudinal speed dampening upstream of a queue/bottleneck. The systems can be used for several different purposes, with speed management in congested conditions, adverse roadways conditions, or work zones the most common applications. Figure 1 shows an example of the overhead signage for the new focus VSL system on OR 217. Each travel lane has its own display, and the difference from standard speed limit signs is immediately apparent by the location, coloring, and electronic display. The two primary objectives of most VSL systems are improving safety and capacity. They aim to enhance safety through reducing the likelihood of rear-end crashes and enhance capacity by harmonizing the flow of traffic. This can also result in improved travel time reliability (Downey, 2015). VSL systems generally consist of detector stations, weather detectors, CCTV surveillance, VSL signs, a control center and a communications system.

Figure 1: Sample VSL Configuration
Source: The Oregonian

A VSL system is typically controlled manually by traffic management personnel and patrol officers or automatically using predetermined algorithms (Vukanovic, 2007). In both cases, the jurisdiction in charge typically has threshold values set for measures such as rainfall intensity or lane occupancy, and activates the system when these values are surpassed. Therefore, the signs may be blank and off for large periods of time before activating, showing reduced speeds when conditions dictate. They will then adjust to the conditions until deactivating when conditions improve and no longer exceed any thresholds. VSL systems can gradually step down speeds upstream of congestion, to help drivers avoid being caught off guard when they come upon more congested conditions.

A key distinguishing feature of any VSL system is whether the speeds displayed are regulatory or advisory. Regulatory systems are subject to local enforcement, while variable advisory speed (VAS) systems are generally not but speeds may be enforced under the principle of Oregon’s basic speed rule (ORS 811.100). In this study the term VSL will be used for both systems with the terms regulatory or advisory attached as needed. The Federal Highway Administration (FHWA) recommends that VSL systems be regulatory rather than advisory because they generally result in higher levels of compliance. Most international applications include automated enforcement (spot or section) as part of each VSL implementation. However, the OR 217 system was installed as an advisory system at the behest of the Oregon State Police, the enforcement agency for this freeway. The Oregon Statewide Variable Speed System Concept of Operations, created before installation of the OR 217 system, determined that the benefits of greater flexibility in setting speeds and greater public acceptance, as well as the basic speed rule enforcement, made an advisory system workable for OR 217 (DKS Associates, 2013).

Several general guidelines regarding the display and placement of VSL signs have been established when setting up any VSL system, despite the unique characteristics of each VSL installation. The FHWA summarized such guidelines in a 2012 report (Katz et al., 2012) as follows:

- Using speed limits in five mph increments
- Displaying speed limit changes for at least one minute
- Not allowing speed differentials of more than 15 mph between consecutive signs without advance warning
- Using variable message signs to explain reason for speed reductions

Additionally, the state of Oregon has a number of rules dictating the establishment of VSL systems. OAR 734-020-0018 is the most important of these, mandating a comprehensive engineering study with crash patterns, traffic characteristics, and the adverse road conditions, including the type and frequency, prior to the establishment of VSL (ODOT, 2012). Furthermore, the engineering study shall provide specific recommendations regarding system boundaries, algorithms, sign placement, and the procedures for changing posted speeds.

1.2 OR 217 VSL System Background

The VSL system on OR 217 was under construction during early 2014 and activated on July 22, 2014. This study seeks to evaluate the effectiveness of this advisory VSL system on the safety of drivers in the corridor. OR 217 is shown in the middle of Figure 2, and is a 7.5 mile highway southwest of downtown Portland travelling between two large suburban communities of Beaverton and Tigard. It has developed a well established reputation for heavy congestion with traffic dynamics being quite sudden. In 2010, the Oregon Department of Transportation published the OR 217 Interchange Management Study in an attempt to identify strategies to enhance the safety and operations of this corridor. Initially geometric improvements of widening to six lanes with braided on and off ramps was considered, however, the cost of $1 billion was too high and an advisory VSL system was ultimately chosen as the most promising and cost-effective solution.

Figure 2: Portland Area Freeway Map
Source: AARoads

The justification for choosing VSL revolved around the speed harmonizing effects of VSL, which had the potential to address all of the crash and congestion issues experienced on OR 217. Bottlenecks and stop-and-go traffic often arise from un-expecting drivers coming upon heavy traffic and suddenly hitting the brakes to decelerate creating a shockwave that propagates upstream as other drivers also use their brakes. By gradually dampening the speed of all drivers in a harmonious fashion, preventing them from slamming on their brakes and scaring following drivers into doing the same, such situations could be eliminated or minimized. Travel times would also become more reliable, as vehicles travel at a uniform predictable rate. Harmonizing traffic speeds and flows can also be linked with heightened safety, particularly on OR 217 where a substantial proportion of crashes are typically rear-ends. These crashes are closely linked to stop and go traffic and a reduction in this traffic would lead to a corresponding decline in crashes. In giving their final endorsement of the VSL system, ODOT estimated it would bring about a 20% reduction in rear-end crashes and a 5% reduction in delay, with a total benefit of $6.6 million in improved mobility and safety (DKS Associates, 2010).

Portland area freeway on-ramps all include ramp meters. Although not considered in this study, the System-Wide Adaptive Ramp Metering (SWARM) system which was present both before and after the deployment of the VSL, was reprogrammed in the entire Portland region (including on OR 217) in an attempt to improve operations. Implementation of this system began in May 2005 and a similar “before and after” evaluation of the SWARM system was carried out in 2008. That study found that with SWARM implemented along OR 217, average delay increased and reliability decreased, contrary to the system’s intent (Monsere, Eshel, & Bertini, 2009). The fact that OR 217 is relatively short and bounded by freeway interchanges on both ends along with, the corridor’s relatively short ramp spacing and high mainline flows were highlighted as possible reasons for why the results did not align with expectations and changes to SWARM parameters were recommended. Many of the demand and geometric issues that limited the SWARM system’s effectiveness will likely apply to the VSL system and limit its impact. In addition, the SWARM system occasionally switches back and forth between fixed-rate and optimized metering, making it difficult to definitively separate any operational benefits associated with the VSL system from the variable SWARM system conditions. Notably the SWARM system was offline and functioning as a fixed-time system for several months (September – December 2014) immediately following the VSL system activation.

Another aspect of the ATM system implemented on OR 217 in July 2014 was the curve warning detectors and traveler information system that provides travel time information on variable message signs. An example of each is shown in Figure 3. These were activated at the same time as the VSL signs and are placed at four ramps along OR 217. Three are active curve warning displays on loop ramps at the northern terminus with US 26 and one at the southern interchange with I-5. These activate when poor weather is detected and road conditions as measured by the “grip factor” decline. As a caveat, the difficulty in attributing crashes to specific locations on OR 217 could cause any impacts from these curve warning detectors to be mixed in with the VSL results.

Figure 3: Curve Warning Sign and Travel Time Advisory Sign on OR 217

1.3 Motivation & Objectives

The OR 217 advisory VSL system was activated for the first time on July 22, 2014 and has been in continuous operation since. This study seeks to determine how effective the system has been in improving safety on OR 217. This study will serve as a valuable addition to the large, but by no means conclusive, body of literature regarding field evaluations of variable speed limit systems. They are still a relatively new addition to the worlds of transportation engineering and traffic management in the United States, and the results of many past studies contradict one another, leaving the question of their effectiveness still unanswered.

1.4 Organization

The remainder of this document is structured as follows. Section 2 reviews previous literature relating to VSL systems. Specifically, the literature review includes a discussion of various types of VSL systems in place, how they have been evaluated, and what the results of past studies have indicated. Section 3 details the corridor and the motivations for installing a VSL system on OR 217. The following section discusses the sources of data for this study and their merits. Section 5 analyzes the corridor using a Naïve Before After study with the methodology and results discussed. Section 6 completes the same safety analysis using the more powerful Empirical Bayes analysis, complete with methodology and results. The following section discusses the results from both analysis methods, develops conclusions, and provides future research recommendations.

2.0 Literature Review

VSL systems are perhaps the most visible and novel aspects of ATM systems, consequently becoming a well-studied component. As ATM has become a more common solution to congestion and other roadway performance issues, interest in the performance of such systems has grown. This section reviews and discusses previous research related to VSL systems. Their history, adoption, wide variety of system types, various evaluation methods, and the evaluation results are all reviewed.

2.1 History

In the past decade, interest in VSL systems has increased significantly but the systems have a much longer history with some of the first dating to the 1950's. New Jersey police officer occasionally put up temporary wooden signs during adverse weather to try to reduce vehicle speeds (Goodwin, 2003). These changes were not based on algorithms but rather the police officers' feel for the appropriate speeds. Following this early experimental tradition New Jersey was one of the first two domestic location to try VSL systems, along with Michigan (Robinson, 2000). On the John C. Lodge Freeway near Detroit and the New Jersey Turnpike, systems utilized traffic officials to manually change posted speed limits based on personal observations of traffic conditions. Both of these precursor systems aimed to improve safety and operation during congestion. However officials in Michigan did not feel results were apparent or significant enough and elected to dismantle and remove the system around 1967 after 5 years of running (Robinson, 2000). The New Jersey Turnpike system still operates, however it has had substantial upgrades to make it an automated and weather responsive system (Robinson, 2000). Internationally, Germany installed its first VSL system with automated enforcement in the 1970s to stabilize traffic flow during congestion, and the Netherlands first implemented a system in the early 1980s, also an automated enforcement system (Han, Luk, Pyta, & Cairney, 2009).

Since the first experimental systems, the number of VSL systems has grown tremendously, especially since 1990. As of 2012, 20 U.S. states had either implemented VSL systems or were planning future installations (Katz et al., 2012). Table 1, created with information from a 2012 report by the FHWA's Safety Program (Katz et al., 2012), summarizes the VSL systems that, as of 2012, have been built or planned in the United States. Most systems are regulatory and require manual activation, with speed and weather being the typical targets. In the United States many systems have been taken down after failing to meet expectations. Abroad, installations have also been implemented in Australia, France, Finland, Sweden and the United Kingdom, with the early systems in Germany and the Netherlands updated and expanded (Al-Kaisy, Ewan, & Veneziano, 2012). The sizes, purposes and characteristics of these systems vary widely, and the results match this with large variations in effectiveness. Each system can be distinguished with manual or automatic activation, congestion or weather-responsive, urban or rural, and regulatory or advisory. Details on the performance of a few of these systems will help to illustrate the variation among their performance and how no one system is perfect for every application.

Table 1: VSL Systems in the United States
Source: FHWA Safety Program

State	Location	Activation Type	Enforcement Type	Sensor Type	Status
AL	I-10	Manual	Regulatory	Visibility, CCTV	Active
CO	I-70	Manual	Regulatory	Loops, Radar, Temperature, Precipitation, Wind speed	Active
DE	Bridges	Manual	Regulatory	Speed, Volume, Occupancy, Weather	Active
FL	I-4	Hybrid	Regulatory	Loops, Radar, CCTV	Active
ME	I-95	Manual	Advisory	Cameras, Radar	Active
ME	I-295	Manual	Advisory	Cameras, Radar	Active
MN	I-35W	Automated	Advisory	Loops	Active
MO	I-270	Hybrid	Advisory	Speed, Occupancy	Removed
NJ	Turnpike	Manual	Regulatory	Speed	Active
PA	Turnpike	Manual	Regulatory	Speed, Weather, CCTV	Active
VA	Bridges & Tunnels	Manual	Regulatory	CCTV	Active
TN	I-75	Manual	Regulatory	Speed, Weather (Fog)	Active
WA	I-90	Manual	Regulatory	Speed, Weather	Active
WA	US 2	Manual	Regulatory	Speed, Weather	Active
WA	I-5, I-90, SR 520	Automated	Regulatory	Speed, Weather	Active
WY	I-80	Manual	Regulatory	Speed, Weather	Active
ID	I-84	Manual	Advisory	Vehicle, Weather	Test Site
MN	I-94	Automated	Advisory	Loops	Under construction
VA	I-77	Hybrid	Regulatory	TBD	Planned
FL	Turnpike /I-595	Automated	Advisory	Moisture	Removed
LA	I-10/I-310	Manual	Advisory	Speed, Visibility	Removed
MD	I-695	Automated	Regulatory	Speed, Queue	Removed
MI	I-96	Automated	Regulatory	Speed	Removed
MN	I-494	Automated	Advisory	Speed	Removed
NV	I-80	Manual	Regulatory	Visibility	Removed
NM	I-40	Automated	Regulatory	Speed, Weather	Removed
SC	I-526	Manual	No speed change	Fog	Removed
UT	I-80	Manual	Regulatory	Day/Night automatic	Removed
UT	I-215	Manual	Regulatory	Speed, Weather	Removed
VA	I-95	Hybrid	Regulatory	Speed, Queue length	Removed

2.2 System Types & Purposes

2.2.1 Weather-Responsive

The first VSL systems primarily focused on coping with inclement weather, so the majority of systems worldwide are still weather-oriented. In 1994, Finland built its first experimental VSL system on a 15 mile rural segment of E18 in the southeastern portion of the country (Al-Kaisy et al., 2012; Robinson, 2000). This regulatory system is purely weather-responsive. A series of 67 VSL signs are connected to 2 automated weather stations capable of measuring precipitation, temperature, and road surface conditions, and posted speeds range from 49 to 74 miles per hour (mph) depending on measured conditions. Both drivers and officials support the system with an astounding 95% of drivers in favor.

In the United States, the state of Wyoming installed its first variable speed limit corridor along a remote section of Interstate 80 in 2009, adding four other sections in the following years. The remoteness of the system encourages the use of overhead boards to inform drivers of conditions during Wyoming’s notoriously difficult winters faster than they might be informed otherwise. Each VSL corridor has LED VSL signs, road weather information systems (RWIS) capable of monitoring temperature, humidity, and wind speed, and Wavetronix radar based speed sensors capable of monitoring volume, individual vehicle speed, occupancy, and vehicle classification. These systems are currently manually operated by highway patrol officers and the Traffic Management Center. They observe the recorded weather data and adjust speed limits accordingly. Perhaps unsurprisingly for such a remote area, the manual activation was shown to be inefficient by a University of Wyoming research project, so an automated protocol based on real-time speed and weather data was developed, and simulations showed it would be more effective and efficient (Buddemeyer, Young, Sabawat, & Layton, 2010; Young, Sabawat, Saha, & Sui, 2012).

2.2.2 Congestion-Responsive

In urban scenarios heavy congestion and high incident frequency is often a focus of VSL implementations. One example is the advisory VSL system activated in Minnesota in 2010. This system was deployed in a heavily urbanized corridor of I-35W near downtown Minneapolis. This particular system is not regulatory but rather an advisory system and primarily responds to the congestion, however it is capable of weather warnings as Minnesota can experience heavy winter weather. It is one of the few active VSL deployments in the United States that focuses improving highway operations during congestion, however this is an area of increasing interest (Edara, Sun, & Hou, 2013). A total of 174 VSL signs are linked with the highway’s system of single loop detectors (Katz et al., 2012). Detector readings of speed and density are collected every 30 seconds, as an algorithm determines if using a reduced speed limit is appropriate according to several set thresholds. The algorithm utilized is designed to mitigate shockwave formation on the highway (Kwon, Park, Lau, & Kary, 2011).

In 2008, the Missouri Department of Transportation installed a VSL system along parts of Interstate 270 and Interstate 255 near St. Louis. Like the Minneapolis system, the St. Louis system is primarily aimed at dealing with recurring congestion in an urban area. During the first three years the system used regulatory speed limits however on I-270 this was changed to advisory speed limits in 2011. The corridor is split into zones composed of a few loop detector stations, and 30-second average speed, flow and occupancy readings for each zone are fed into a VSL algorithm. If average occupancy is found to be greater than 7%, flow greater than 10 vehicles in 30 seconds (equivalent to 1200 vehicles per hour), and average speed less than 55 mph, an enforceable reduced speed limit equal to the average speed rounded up to the nearest multiple of 5 will be recommended by the system. A degree of manual control is built in as well, as TMC operators verify conditions through camera feeds before posting reduced speed limits (Kianfar, Edara, & Sun, 2013). However, this system was unsuccessful and was ultimately removed in 2013. Operators cited that it did not produce the results that they aimed for (Lippmann 2013).

2.2.3 Work Zone Systems

In addition to permanent corridor-wide applications VSL systems have been used around temporary work zones in the past few years to improve both operations and safety during construction. Before implementation, simulation studies by Lin et al. and others demonstrated the potential benefits of VSL control around work zones (Lin, Kang, & Chang, 2004), and the results of those studies have since led to real applications. In 2006, a two-state VAS system was developed and implemented for a work zone on I-494 near Minneapolis in order to bring upstream speeds down to the level of downstream traffic (Kwon, Brannan, Shouman, Isackson, & Arseneau, 2007). Both regulatory and advisory VSL systems have also been utilized around work zones in Washington, Missouri, Ohio, Virginia and New Hampshire (Edara et al., 2013).

2.3 Evaluation Methods & Results

Given the unique characteristics of each VSL/VAS system, it is difficult to single out a specific set of evaluation methods and performance measures that can be applied to each of them. In an FHWA report documenting lessons learned from ATM installations throughout the United States, travel time, travel speeds, travel time reliability and variability, spatial and temporal extent of congestion, throughput, and user perceptions are identified as key measures of effectiveness for ATM evaluations (Kuhn, Gopalakrishna, & Schreffler, 2013). Another potentially important performance measure is compliance with the VSL systems. Using a Paramics simulation model, Hellinga and Mandelzys found that a very high compliance scenario resulted in a 39% improvement in safety relative to no VSL, while a low compliance scenario resulted in only a 10% improvement (Hellinga & Mandelzys, 2011). With loop detector data, compliance rates are fairly straightforward to calculate. The University of Wyoming summarized speed compliance for Wyoming’s VSL system by computing the percentage of vehicles traveling above and below the posted speed limit. Speed variance was also captured by computing the percentage of vehicles traveling three and five mph above and below the posted speed limit (Young et al., 2012).

Given the nature of this study and its emphasis on safety, crash records from before and after are the primary performance measure, using analysis methodologies that have been utilized in prior studies, the Naïve Before After Study and an Empirical Bayes study. A work zone safety VSL system in place on I-495 in Virginia was also removed two years after installation. This project was studied by Fudala and Fontaine, finding that simulations produced a reduction in safety surrogates such as lane changes and speed harmonization. The authors recommend continued study of VSL systems as a potential solution but that scenarios be carefully screened for potential effectiveness. (Fudula & Fontaine, 2010)

2.3.1 Naïve Before and After Evaluation Methods

Naïve Before and after studies of VSL systems similar to the one studied here have been conducted several times before. In Missouri a hybrid automated system installed in 2008 was shown by Bham et al. to result in a reduction in crashes of around 6.5% with a Naïve Before After study and 8.4% with an Empirical Bayes study (Bham et al., 2010). This system changed from a regulatory to advisory system after three years of use. Despite these reductions, other factors caused the system to be removed a few years later in 2013. The agency chose to focus on changeable message signs as the main method of communicating slowdowns to drivers.

Rama and Schirokoff found that a weather-responsive VSL system in Finland reduced crashes by 13% during the winter and 2% during the summer and reduced the overall injury crash risk by 10% (Rama & Schirokoff, 2004). Model estimation using field data showed that Wyoming's VSL system was expected to reduce crash frequency by 0.67 crashes per week per 100 miles of corridor length, or about 50 crashes per year. In monetary terms, this was equated to an annual safety benefit of about $4.7 million (Young et al., 2012). In a summary of VSL applications throughout the world, Robinson noted that VSL on several rural Autobahn stretches in Germany has reduced crash rates by 20 to 30% and a system on the M-25 highway near London contributed to a 10 to 15% reduction in crashes (Robinson, 2000).

Related to the reduction in crashes associated with VSL systems, they have also been effective at reducing speeds and speed variability during poor weather in several locations. A system on A16 in the Netherlands aimed at creating safer driving conditions during fog led to an 8 to 10 kilometer per hour (kph) drop in mean speeds during foggy conditions (Robinson, 2000). Another VSL system primarily aimed at addressing foggy conditions in Utah led to a reduction in the average standard deviation of vehicle speeds by 22% (Perrin, Martin, & Coleman, 2002). The previously mentioned Wyoming system also helped to reduce speed variation during winter storms because it provided drivers guidance as to an appropriate reduced speed (Young et al., 2012).

2.3.2 Empirical Bayes Analysis

The Empirical Bayes methodology has been applied less often in safety studies but is often noted as producing more accurate results. An 18% reduction in crashes was observed in Belgium on freeways with a regulatory, automated VSL system. This analysis by De Pauw et al., found that the decrease was largely due to a significant reduction in rear end crashes of 20%. The authors conducted an Empirical Bayes analysis with up to 12 years of crash data for 5 separate freeway segments (De Pauw at al., 2015). The Missouri study by Bham et al. was shown to have a higher 8.4% reduction when an Empirical Bayes study was conducted (Bham et al., 2010).

Despite the numerous studies linking VSL systems to lower crash rates, in an evaluation of the same VSL system near Antwerp, Belgium, Corthout et al. claimed that the homogenizing effects of VSL actually have little to do with observed reductions in crashes. Rather, they argued that crashes dropped mostly because of accompanying warning signs that heighten driver awareness, since secondary crashes tend to be reduced more than crashes as a whole (Corthout, Tampere, & Deknudt, 2010). Their conclusions suggest that even the safety benefits of VSL, which have been studied in much more depth than the operational benefits, are still a matter of contention and lacking overarching consensus.

The Empirical Bayes methodology is noted for combating regression to the mean bias and creating more accurate estimates of the actual treatment effect. Ezra Hauer is a key figure in the development of this methodology and his book “Observational Before-After Studies in Road Safety” forms the backbone of both the Naïve Before After Study and the Empirical Bayes Analysis utilized in this work (Hauer 1997). Similarly, the Highway Safety Manual (HSM) makes extensive use of Empirical Bayes studies in the methodology and the draft freeway section helped to guide the Empirical Bayes portion of this study (HSM 2012).

2.4 OR 217 Evaluations

OR 217 has been studied multiple times before after the implementation of the VSL system. One study by Riggins, et al. focused on the compliance of drivers along OR 217 as compared to those on German Autobahns. The results showed that compliance was fairly poor with speeds typically 5 to 15 mph above the displayed speed limit (Riggins et al. 2015). Compliance was also lower on OR 217 than the one the German roadways. Another study by Downey, et al. studied safety, travel time reliability, lane flows, and bottleneck flow characteristics. This crash analysis in that report used one data source and found that the crash distribution had shifted away from the VSL sign locations. However, the analysis did not show any significant safety benefits with crash increases, based on a small sample of data from a 5 month period after VSL activation (Downey, et al. 2015). A more recent study summary of safety on the corridor was conducted by ODOT using multiple data sources in a simple comparison of crash numbers before and after the VSL implementation showing a 13% decline with 911 call data and 20% decline with official crash data (ODOT, 2016).

2.5 Summary

A large body of previous research into various aspects of VSL systems exists. This section has shown that there is a substantial amount of diversity among VSL applications, evaluation methods, and results. Regarding the actual effects of VSL systems, studies seem to indicate that crashes decrease however the effect is quite varied and the reasoning disputed.

Several potential reasons exist for why so many VSL studies seem to contradict one another, but a major one is the inherent differences in the characteristics of each system. A system designed to address winter weather in Finland is going to be very different in purpose and have a different impact than a system aimed at mitigating congestion problems near downtown Seattle. Similarly, a system in rural Wyoming and systems in urban Germany have little in common. Even similar congestion-responsive systems in St. Louis, Minneapolis, and Portland will vary quite a bit from one another because the cities have unique highway alignments, driver characteristics, and traffic flows.

Studies should be carried out before the implementation of a system to ensure that the corridor being looked at has potential for a benefit rather than applying past results haphazardly. Goals for the corridor must be firmly set and used as part of the analysis of any intended system.

The system in place on OR 217 is unique from many of those reviewed as since it is both congestion and weather-responsive with safety as the primarily goal. In addition, it has not been installed for a long period of time requiring more careful analysis to determine the results. Because of this, the study will be conducted with multiple data sources and both standard crash analysis methods. OR 217 has been studied before and this research intends to build upon and clarify results for this particular corridor using more detailed safety analysis methods. Furthermore, the analysis will add to the body of research for VSL systems in general and develop a better understanding of them.

3.0 Motivations for VSL on OR 217

The issues associated with OR 217 pre-VSL are numerous and wide-ranging, relating to both safety and operations. In this section, a brief almanac of the corridor and its general performance trends is presented and the major problems with the corridor that prompted to ODOT to explore and ultimately implement VSL are discussed.

3.1 Corridor Almanac

OR 217 is a 7.52-mile highway stretching between Interstate 5 at the southern terminus and US Highway 26 at the northern terminus (refer to Figure 2). It primarily serves as a connector between downtown Portland and southwestern suburbs including Beaverton and Tigard. The highway has a

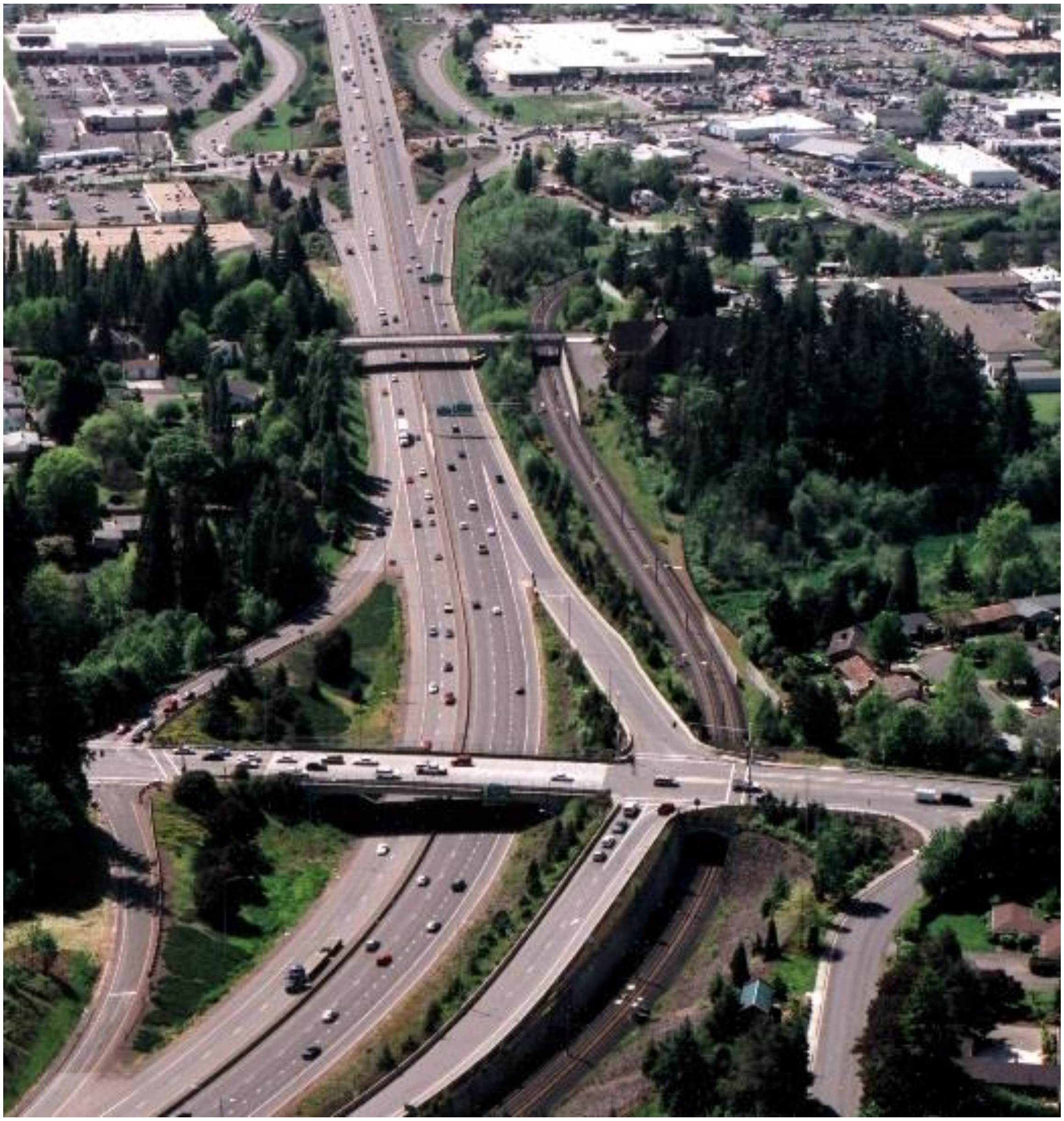


Figure 4: OR 217 at Allen Blvd
Source: DKS Associates

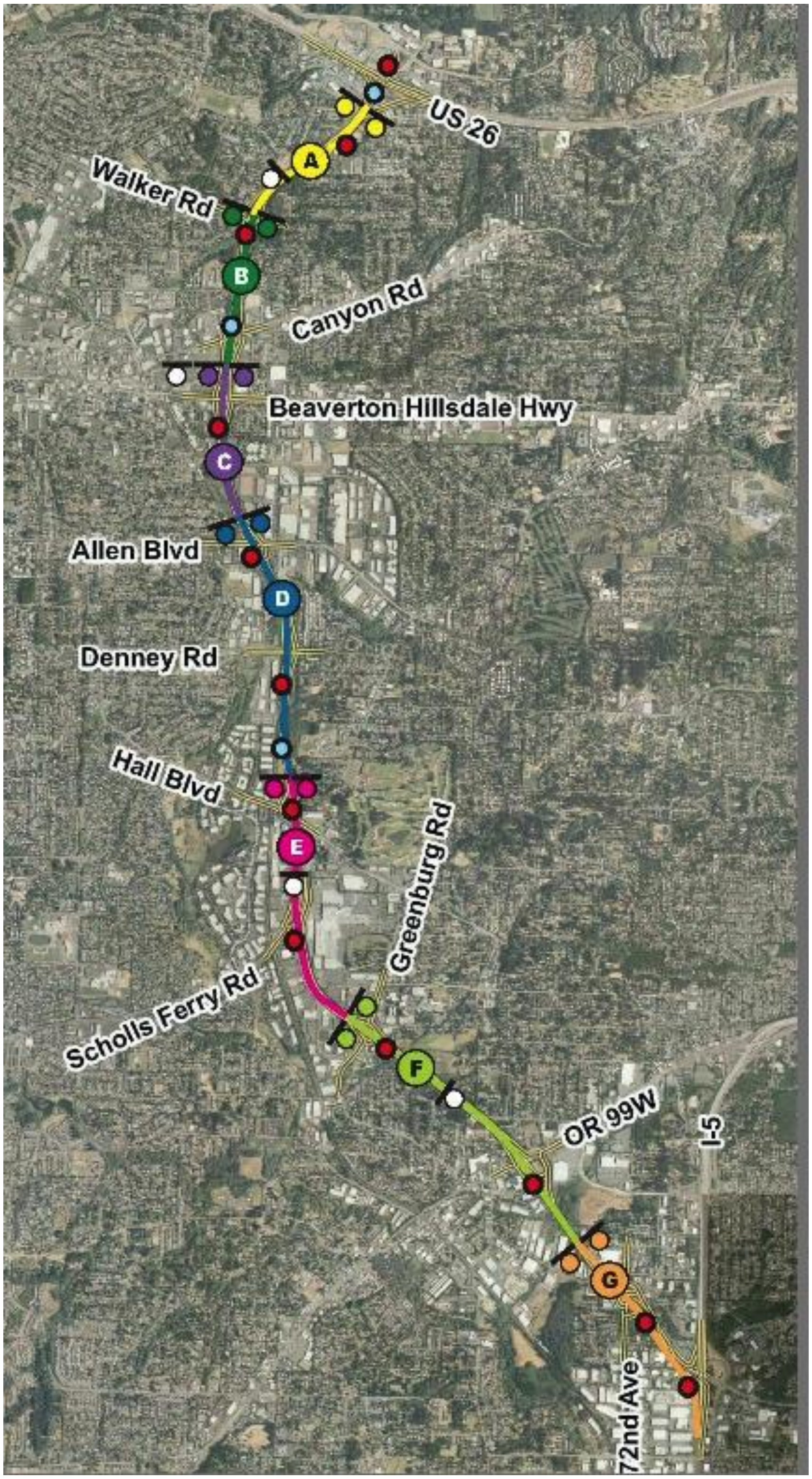


Figure 5: OR 217 Corridor Map
Source: DKS Associates

posted speed limit of 55 miles per hour and fully divided with typically 2 lanes of traffic in each direction. The corridor developed from an older highway with at-grade intersections and as it developed formed a large number of connections with local streets. After full grade separation it has eleven sets of on- and off-ramps in each direction. Most interchanges are typical diamonds but several have loop or hook ramps. The close spacing of the ramps has led to most being connected by short auxiliary lanes, creating many weaving zones along the highway. Its location relative to downtown Portland makes OR 217 a popular route for commuters. All on-ramps include ramp meters. Figure 5 provided, courtesy of DKS, presents a map of the study area, with the labels indicating the locations of interchanges, and Figure 4 and Figure 6 are current aerial photographs of two of these interchanges.

According to official Oregon Department of Transportation’s officially published traffic volumes, in the most recent year before the VSL system was deployed, OR 217 had an average annual daily traffic (AADT) of approximately 110,000 vehicles across both directions, equivalent to an average daily vehicle-miles traveled (VMT) value of about 830,000 vehicle-miles. In the immediate full year before the system activation, 2013, there were 322 crashes reported along the corridor in 2013, a rate of 1.06 crashes per million VMT (2013 Crash Book).

Figure 6: OR 217 at Scholls Ferry Rd
Source: DKS Associates

3.2 Crash Trends

In addition to the capacity and mobility challenges facing OR 217, it also exhibits safety issues. In 2013 (the last full calendar year prior to the VSL system deployment) OR 217 had 322 reported crashes according to the ODOT 2013 State Highway Crash Rate Tables (these are the official statewide crash data, later referred to as TDS). This equates to a crash rate of 1.06 crashes per million vehicle miles, higher than the statewide average of 0.92 for urban non-interstate freeways. All but one of the eight segments into which the corridor is split in the report experienced increased from the previous year crash rates.

OR 217 is particularly prone to rear-end crashes, likely due to the regular congestion. As shown in Figure 7, more than two-thirds of the 1,118 crashes reported on OR 217 in the three full years immediately prior to VSL activation (July 23, 2011 to July 22, 2014) were rear-end type crashes. Three years of crash data were analyzed to help account for any annual fluctuations in crash numbers unrepresentative of long-term trends. The relative proportion of rear-end crashes on OR 217 is slightly higher than statewide average of 65.6% for urban freeways according to the State Highway Crash Rate Tables.

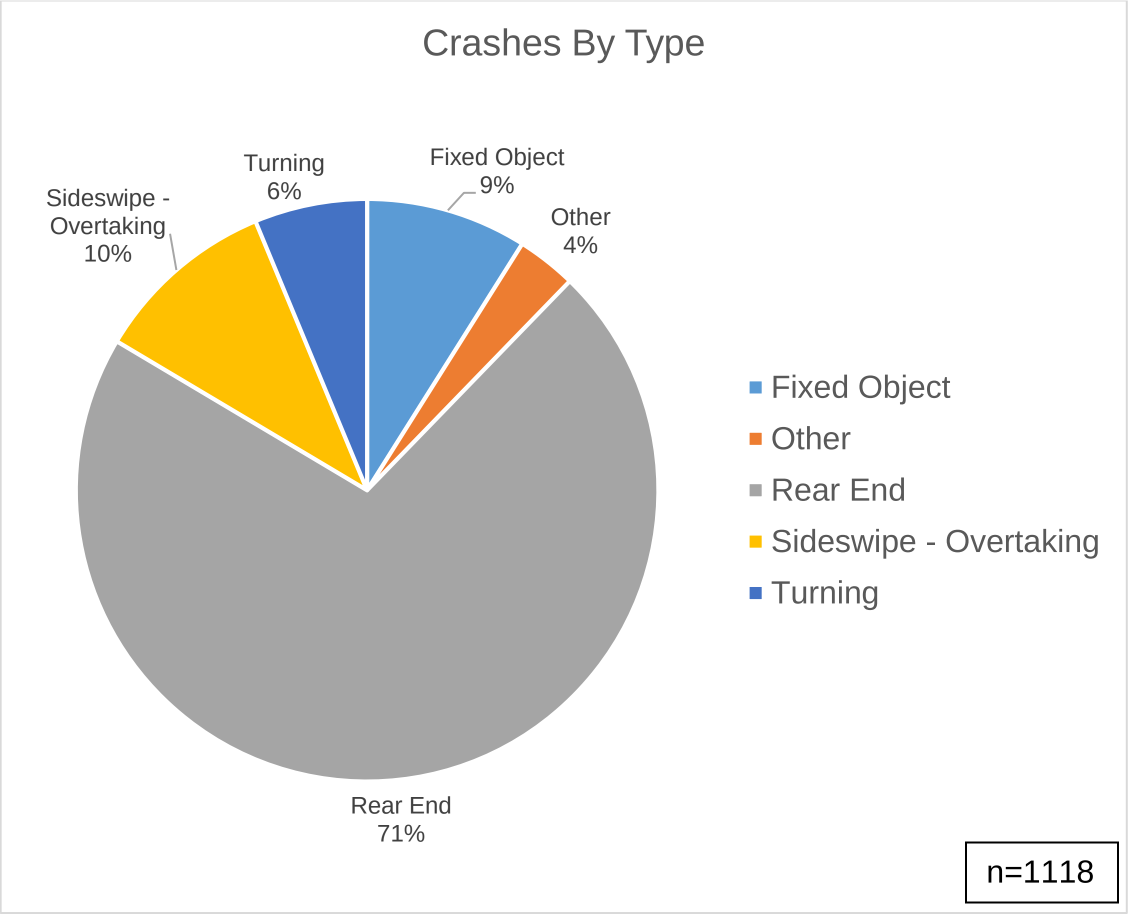


Figure 7: OR 217 Crashes by Crash Type
2011 - 2014

Just under half of the 1,118 total crashes on OR 217 between 2011 and 2014 involved at least one injury. As shown in Figure 8, the majority of these injuries were Class C and came from rear-end crashes. In Oregon, Class C injury crashes are those resulting in “possible injuries”, which are generally complaints of pain or relatively minor visible injuries. Figure 8 and Figure 9 demonstrates that the common notion that rear-end crashes tend to be minor “fender benders” is a misconception, as more than near half of the rear-end crashes on OR 217 between July 23, 2011 and July 22, 2014 resulted in at least one injury. In addition to the safety-related consequences, each one of these frequent rear-end crashes typically leads to the formation of a new bottleneck, restricting flow through the entire corridor for an extended period of time.

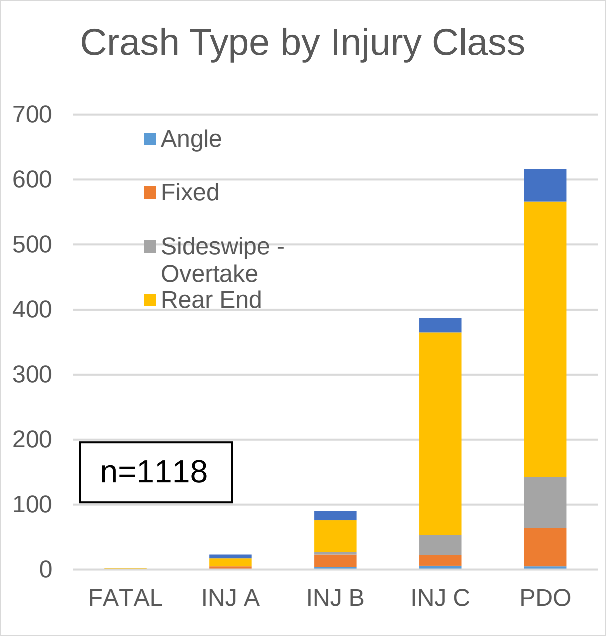


Figure 8: OR 217 Injuries by Crash Type & Severity 2011-2014

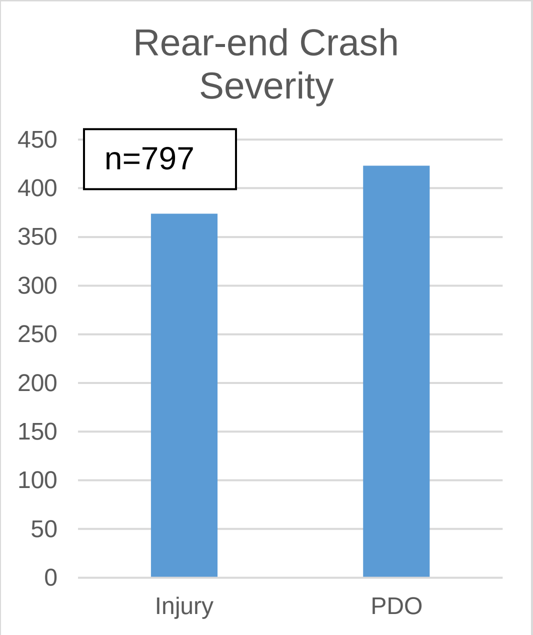


Figure 9: OR 217 Rear-end Crash Severity 2011-2014

3.3 Effects of Adverse Weather

OR 217 has a weather-responsive component in addition to the congestion-responsive component because the corridor has a history of diminished safety and efficiency during adverse weather. With adverse weather, particularly precipitation, present, OR 217 has a tendency to experience more crashes and significantly higher and even less reliable travel times.

Figure 10 shows the percentage of the 1,118 crashes on OR 217 from 2011 through 2014 that occurred in various road surface conditions. Forms of winter precipitation such as snow were factors in a very small portion of crashes, which can be attributed to the relatively rare occurrence of frozen precipitation in

Portland. Rain, however, was falling during more than one quarter of the reported crashes and roads were wet during more than one third. Precipitation was only reported by the National Weather Service during about 10% of all the hours during these three years, indicating that wet weather conditions are significantly overrepresented in the crash data and that crashes become much more likely on OR 217 during precipitation events.

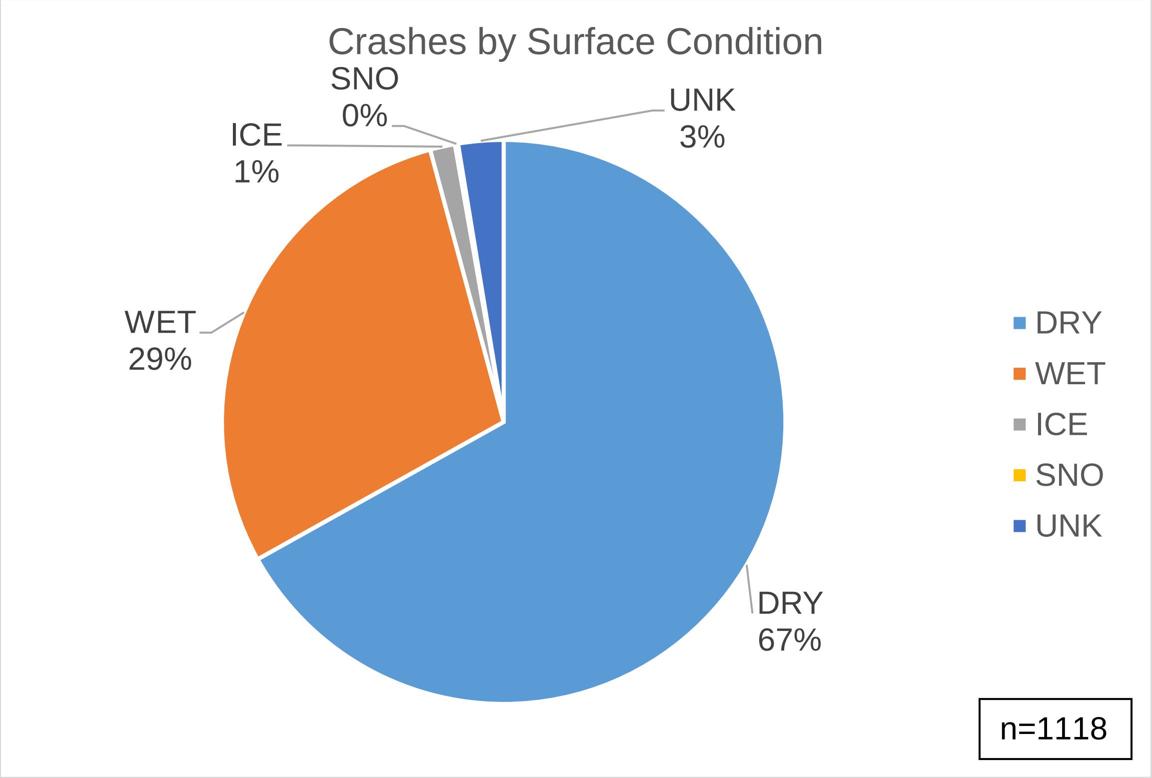


Figure 10: Crashes by Surface Condition on OR 217 Between July 23, 2011 and July 22, 2014

3.4 Summary

Analysis of the conditions on OR 217 prior to the VSL system's implementation clearly demonstrates that the corridor has some significant problems and has the potential to benefit from an effective VSL system. OR 217 is prone to severe congestion and recurrent bottlenecks on a regular basis during weekdays, with average speed declines of 50% not uncommon during peak demand hours. Recurrent bottlenecks in both directions create queues several miles long that last for several hours. Additionally, the corridor’s performance varies a great deal between different hours and days, contributing to highly unreliable travel times. OR 217 is particularly prone to rear-end crashes, with an average of more than one every day, and these crashes can have major consequences in terms of both safety and throughput. Finally, during adverse weather, OR 217 is even more susceptible to crashes and travel times are higher and more unreliable.

Historical trends suggest OR 217’s problems are not going to solve themselves. Between 1985 and 2005, traffic volumes doubled, and they are expected to grow another 30% by 2025. The growth in demand is expected to increase the extent of daily congestion from 3 hours to 8 hours by 2025. The crash rate has increased 89% just since 2009. These trends, combined with the previously discussed mobility and safety issues, clearly indicate that something needed to be done to improve OR 217, and ODOT ultimately settled on an advisory VSL system.

4.0 Data Sources

The previous section demonstrated that prior the VSL system, OR 217 was suffering from a number of issues. In order to assess the effectiveness of the VSL system in addressing these issues, data from several different sources was obtained and analyzed using an array of analysis techniques. Each of these analyses was carried out in the form of a “before and after” comparison in order to gain an understanding of how safety on OR 217 has changed since the VSL system’s implementation. In this chapter, available instrumentation along OR 217 and the various types of data used are detailed as well as any addendums made.

4.1 Corridor Instrumentation

The primary means of traffic data collection along OR 217 is a series of dual-loop detector stations placed upstream of each entrance ramp. These stations record and store vehicle count, occupancy, and speed measurements every 20 seconds. At each detector station, there are one set of dual-loop detectors in each traffic lane. Single loops are also located on each accompanying ramp, but these loops only capable of recording vehicle counts. Since 2014 OR 217 is also instrumented with a series of radar traffic sensors, manufactured by Wavetronix, which collect the same data as the loop detectors. As with the loop detectors, the radar detectors are grouped into stations, with one sensor for each traffic lane. The Wavetronix sensors were strategically located along OR 217 to minimize any large gaps between loop detector stations, thus improving the resolution of traffic measurements. Figure 13 and Figure 14 show the lane configurations and layout of available instrumentation on OR 217 southbound and northbound, respectively.

The VAS system being evaluated in this study was constructed on OR 217 over the past several years as one component of the OR 217 Active Traffic Management project and consists of a series of large electronic message signs. There are ten locations along OR 217 with these variable speed signs for both the northbound and southbound directions. Figure 15 and Figure16 show the two primary configurations of these signs, either on bridges or metal structures. As shown, each travel lane has its own sign, and adjacent signs do not necessarily display the same speed.

The congestion-responsive component of the system works by collecting data from the corridor’s traffic detectors. Each VAS sign is assigned a segment reaching to the next sign downstream, and any sensor data within that segment is relayed to that sign. Each detector station is assigned a certain volume and occupancy threshold, one of which must be met for its speed readings to influence the VAS sign. If one of these thresholds is met, the 85th percentile speed at that station is computed and rounded to the nearest 5 mph. Finally, these 85th percentile station speeds for each station within a VAS sign’s segments meeting either the volume or occupancy threshold are compiled, and the lowest one is displayed on the sign until the controlling station’s 85th percentile speed has risen to the next highest 5 mph increment. If the lowest 85th percentile station speed is below 25 mph, the sign display will read “SLOW” instead of an actual speed. Speeds displayed at VAS signs upstream of the most congested segments are stepped down based on how far upstream they are to encourage drivers to gradually decelerate before they reach the heaviest congestion.

The weather-responsive component of OR 217's VAS sign continuously collects real-time data from new RWIS sensors installed along the corridor, represented as diamonds in Figure 17. The VAS systems then uses a lookup table to determine an appropriate reduced speed to display based on the sensor measurements of visibility and grip factor, which indicates the level of grip of the roadway surface. If both congestion and adverse weather are occurring, the component which computes the lowest appropriate speed for each sign takes priority. The Oregon Statewide Variable Speed System Concept of Operations explains the two different components in greater detail (DKS Associates, 2013).

In addition to these signs, new radar detectors, variable message signs, weather responsive curve warning signs, and roadway weather sensors were installed along OR 217 as part of the project. Figure 17, courtesy of DKS Associates, details the locations of components of the ATM project, with VAS signs labeled in orange.

Figure 11: Variable Message Sign on OR 217

Figure 12: Travel Time Indication on OR 217

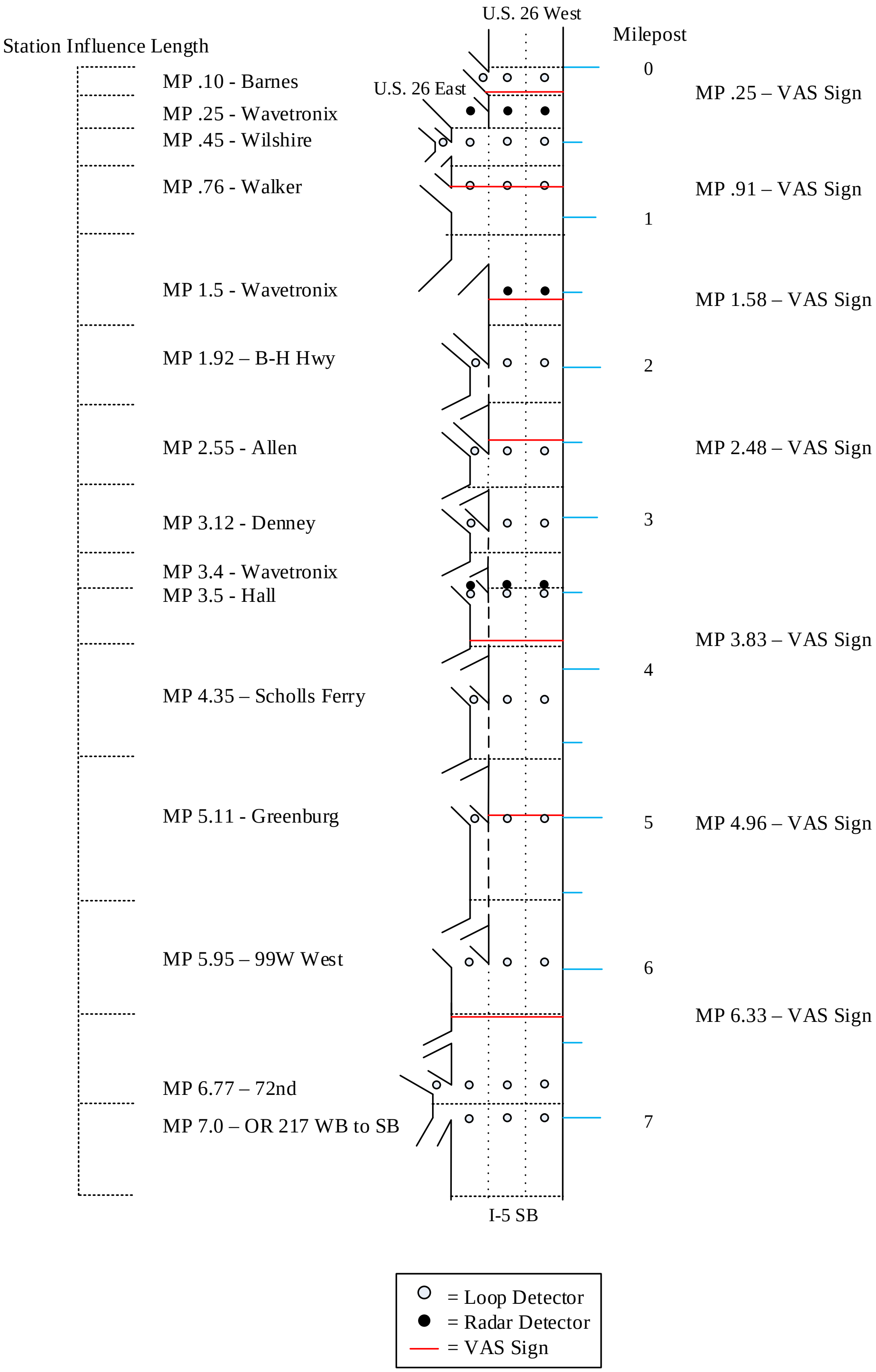


Figure 13: OR 217 Southbound VSL & Detector Layout

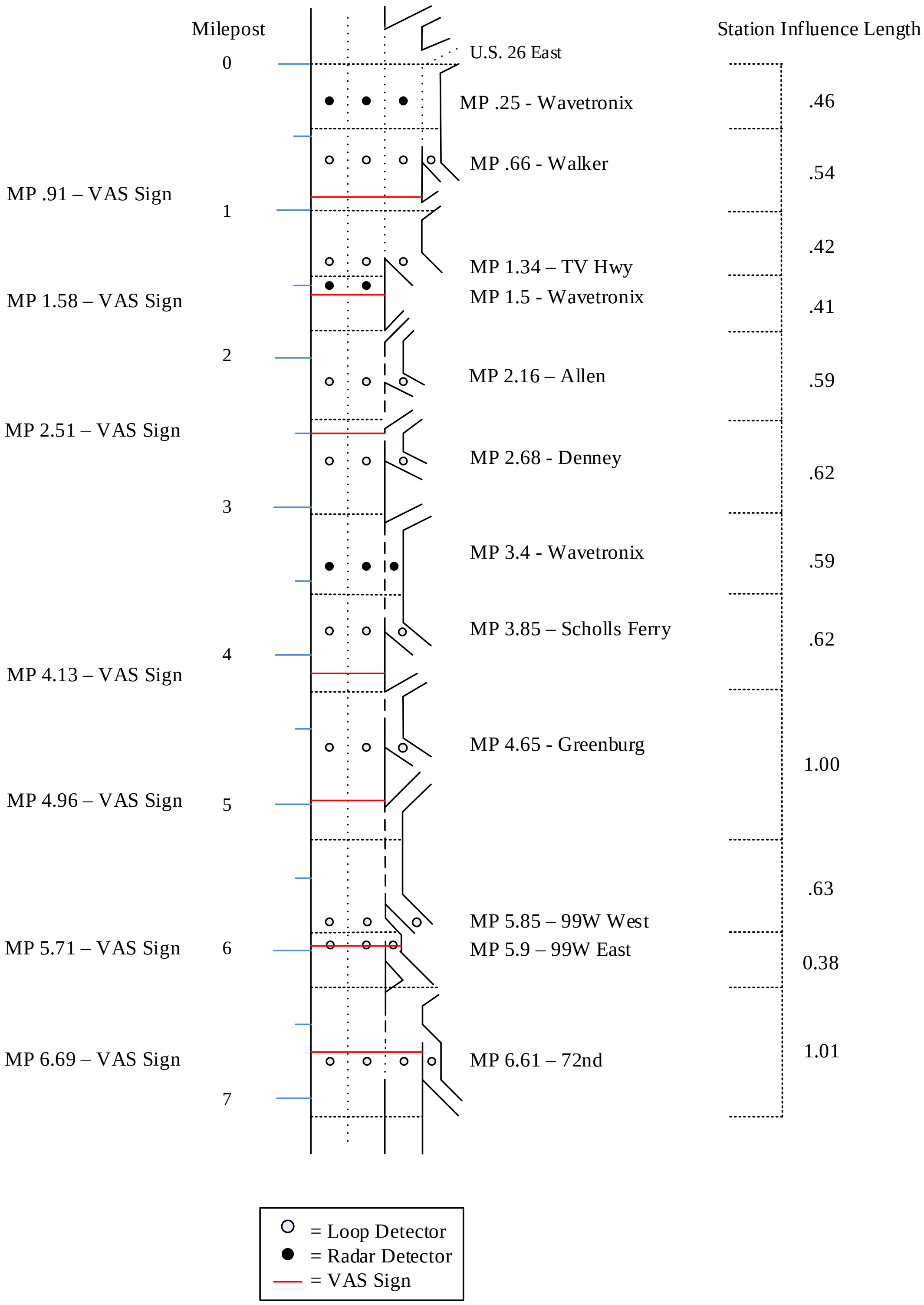


Figure 14: OR 217 Northbound VSL & Detector Layout

Figure 15: OR 217 VSL Signs on Bridges
Source: The Oregonian

Figure 16: OR 217 VSL Signs on Sign Gantry

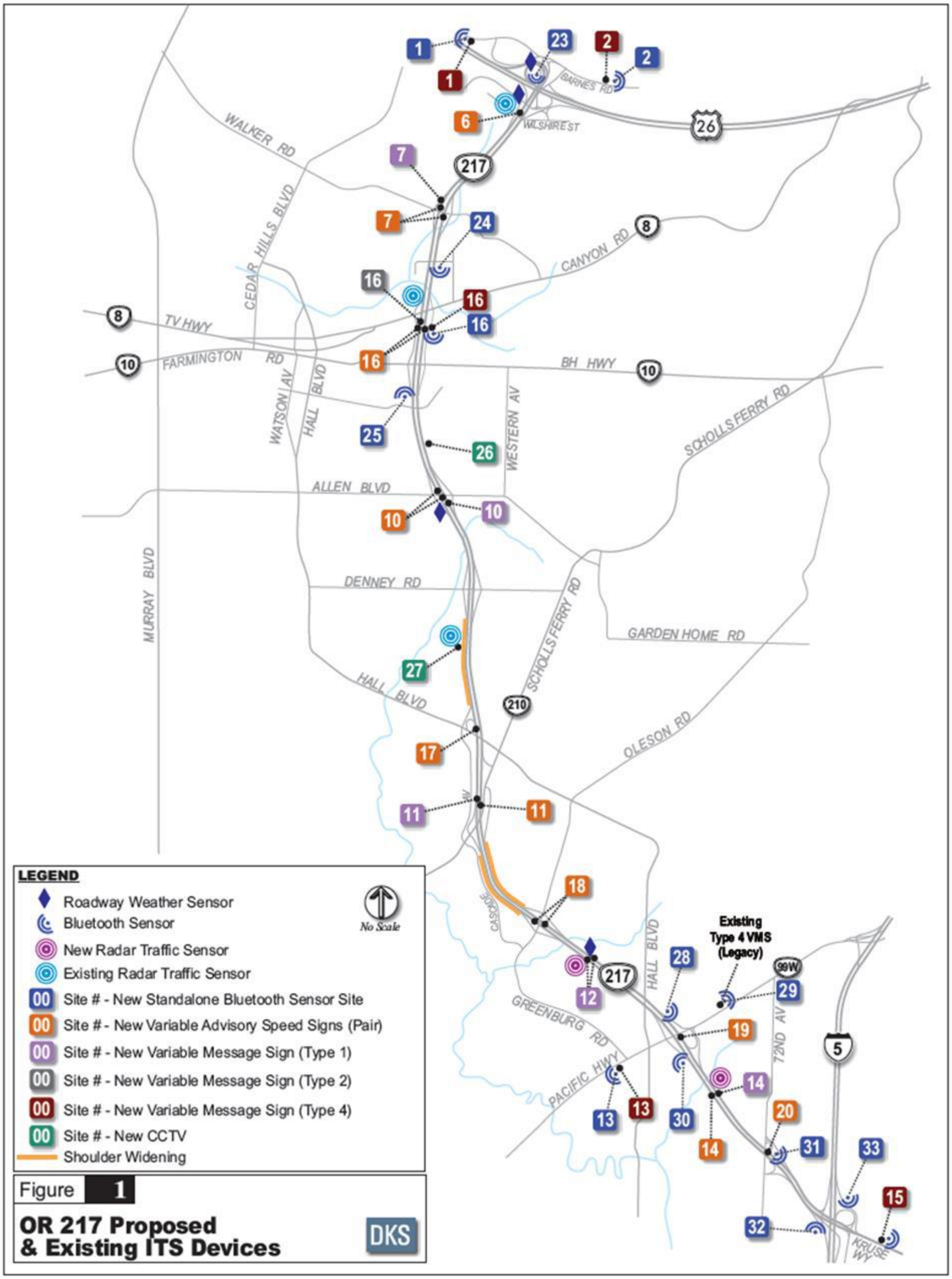


Figure 17: OR 217 ATM Installations
Source: DKS Associates

4.2 Data Description

4.2.1 Traffic Flow Data

This study uses multiple sources of traffic data for the differing analysis methods. ODOT provides official traffic volumes for the corridor at several different mileposts. However due to construction occurring on OR 217 and the deactivation of most traffic detectors, the officially published statewide traffic volumes for the year 2014 are understandably problematic, indicating a decrease of 50% in a single year. These values are not used in this study. In addition, no official volume data for the corridor has been published yet for 2015. The ODOT report on the OR 217 VSL systems (ODOT, 2016) provided traffic data for both before and after the VSL system by determining peak hour vehicle per hour per lane volumes from functioning in road loop detectors before and after implementation. This traffic information was not utilized as the crash databases do not provide enough resolution to attribute crashes by time of day.

The main traffic flow data utilized comes from Portal (portal.its.pdx.edu), a comprehensive transportation data archive for Portland’s transportation network, collecting and storing data relating to a number of different performance measures. The Portal user interface offers a number of useful and interesting features in addition to raw data, such as various charts and plots, but all Portal data used in this evaluation was raw counts downloaded directly from the database.

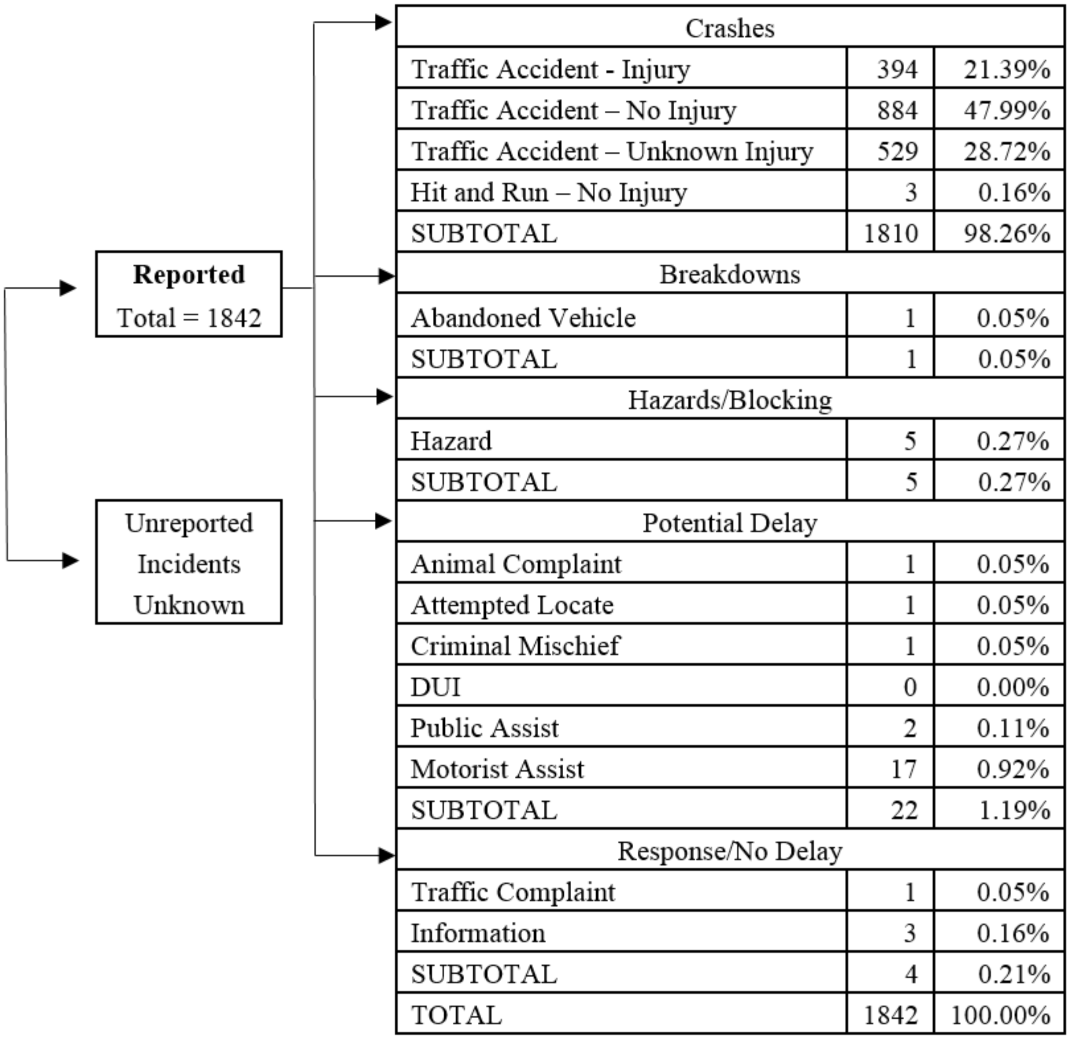
Of particular interest was Portal’s historical traffic data for OR 217. The previously mentioned loop detectors and radar detectors installed on OR 217 are connected to this archive, so that all 20-second volume, occupancy and speed readings from the corridor’s detector stations are easily obtainable. The tables of detector readings contain five columns for time, volume, speed, occupancy, and detector ID, and were merged with a separate table containing more detailed information for each detector, such as lane number and milepost. Data from detectors placed in the mainline lanes in each directions was considered for this study. Ramp detector data was omitted because the ramp detectors often experienced system errors making ramp data unavailable for a large portions of time. Ramp detectors are also only present on on-ramps making it unsuitable for portions of the analysis.

Ramp data was instead obtained from another official ODOT resource, the published ramp volumes for OR 217. These are published annually and were available online through 2014. Correspondence with ODOT officials provided the preliminary volumes for 2015 as well. These volumes were utilized as they included volumes for off-ramps as well.

Since this was a “before and after” evaluation, it was necessary to select appropriate time periods to act as sources for the “before” and “after” data sets. The OR 217 VSL system was activated on July 22, 2014, so the chosen “after” period for most data types was July 22, 2014 through April 30, 2016. This time period matches the most up to date crash resources available and maximizes the length of the after period, increasing statistical reliability. For the “before” traffic data, a standard 3 years of information, July 22, 2011 through July 21, 2014 was used to match the crash information. Using data from before the study period was considered to develop a more complete three years of traffic volume information but decides against due to the rapid growth in traffic volumes making older data less relevant. Some of the loop detectors were installed as part of the project, and so some detectors lacked information from before the VSL system and were eliminated from the analysis. In addition, this data does have flaws, as detectors go down and come back up sporadically. The period immediately prior to activation of the VSL system is notably problematic with no detectors functioning for several months due to construction operations that deactivated the detectors. Others will generate erroneous values requiring data clean up as will be explained in Section 5.1.1. Once the data has been cleaned up to remove any erroneous volumes, the most consistent detectors can be used to determine a representative before and after traffic volumes, forming a key basis of the study analysis.

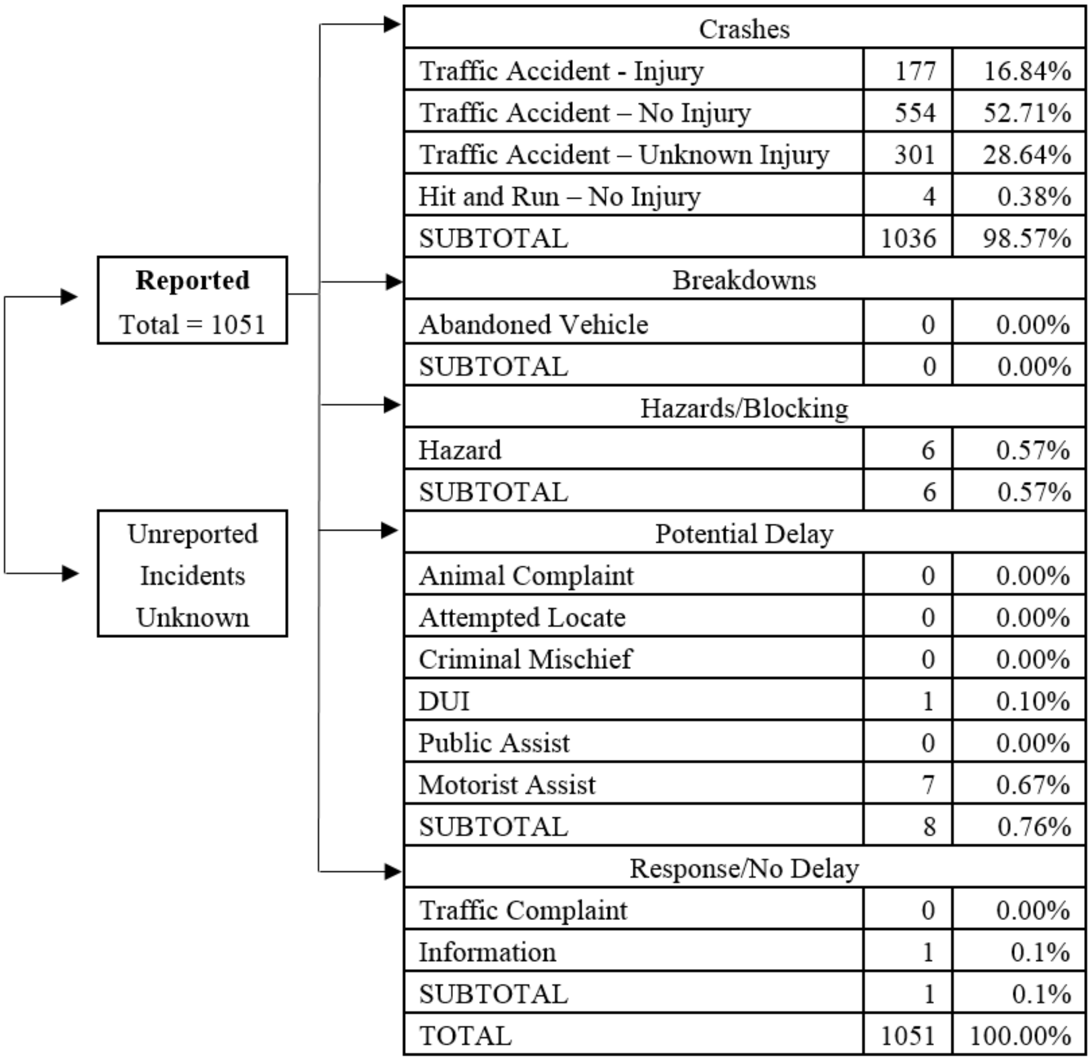
4.2.2 Washington County 911 Call Data

Washington County retains detailed dispatch records of all 911 calls received by jurisdiction, location, and type of emergency in database referred to as WCCCA in this study. It serves as the primary database for the study to determine its usefulness in transportation safety studies. The 911 call records for any reported crashes occurring on OR 217 that led to an emergency response for 3 years prior to the implementation of the VSL system in July 2014 and since have been utilized for this study. The database is extremely up to date with records becoming available almost immediately. This makes it especially valuable for studying the OR 217 VSL system due to the limited time frame of after data. Information contained within the database for each record includes the record number, date, responding agency, crash classification acronym, crash description (typically the crash acronym written out), and a description of the location. Newer additions to the database may include GPS coordinates for the approximate location of the crash. The data used for this study has been screened to ensure that only crashes on Highway 217 have been utilized and that duplicate records, resulting when multiple citizens contact emergency services about the same crash, are resolved. With the crash location description, the direction of travel can be ascertained. Also using the location text description and OR 217 inventory documents, the milepost for each crash can be found. Weather information obtained from another data source detailed below can be combined to determine approximate weather conditions for the dates on which crashes occur. Some of the crashes logged in this database do not directly pertain to traffic crashes and have been removed from the analysis in this study. The incident trees below show the relative frequency of each reported crash type before and after the system’s activation.



Crashes		
Traffic Accident - Injury	394	21.39%
Traffic Accident – No Injury	884	47.99%
Traffic Accident – Unknown Injury	529	28.72%
Hit and Run – No Injury	3	0.16%
SUBTOTAL	1810	98.26%
Breakdowns		
Abandoned Vehicle	1	0.05%
SUBTOTAL	1	0.05%
Hazards/Blocking		
Hazard	5	0.27%
SUBTOTAL	5	0.27%
Potential Delay		
Animal Complaint	1	0.05%
Attempted Locate	1	0.05%
Criminal Mischief	1	0.05%
DUI	0	0.00%
Public Assist	2	0.11%
Motorist Assist	17	0.92%
SUBTOTAL	22	1.19%
Response/No Delay		
Traffic Complaint	1	0.05%
Information	3	0.16%
SUBTOTAL	4	0.21%
TOTAL	1842	100.00%

Figure 18: WCCCA Before VSL Incident Tree



Crashes		
Traffic Accident - Injury	177	16.84%
Traffic Accident – No Injury	554	52.71%
Traffic Accident – Unknown Injury	301	28.64%
Hit and Run – No Injury	4	0.38%
SUBTOTAL	1036	98.57%
Breakdowns		
Abandoned Vehicle	0	0.00%
SUBTOTAL	0	0.00%
Hazards/Blocking		
Hazard	6	0.57%
SUBTOTAL	6	0.57%
Potential Delay		
Animal Complaint	0	0.00%
Attempted Locate	0	0.00%
Criminal Mischief	0	0.00%
DUI	1	0.10%
Public Assist	0	0.00%
Motorist Assist	7	0.67%
SUBTOTAL	8	0.76%
Response/No Delay		
Traffic Complaint	0	0.00%
Information	1	0.1%
SUBTOTAL	1	0.1%
TOTAL	1051	100.00%

Figure 19: WCCCA After VSL Incident Tree

The WCCCA data is comprised of 2894 recorded incidents making it the largest database used in this study. As the incident trees show the large majority are crashes with over 98% both before and after the VSL system activation. As indicated in the incident tree, crashes are divided into four categories. Minor, non-life threatening crashes are not included in this database (such as breakdowns or other random events), though they may appear in the TOCS database described in section 4.2.3. For the purposes of this study all of the data not in the crash category was eliminated.

4.2.3 Transportation Operation Center Data

Data from all reported incidents along OR 217 that initiate a response from ODOT are available from the agency's Transportation Operation Center System (TOCS) database. These incidents include, but are not limited to, crashes, breakdowns, stalls, maintenance, and construction. This database contains data regarding the type, time, duration and location of each incident. It should be noted that the TOCS database does not include all OR 217 incidents, as some are responded to by other agencies, some are not reported, and some occur while the traffic management center is not staffed. The data provided for this study was limited to only include crashes and portions of the data do not include all of the associated information, such as time of day. With only 829 crashes in the database, 510 from before, the data is limited and statistical conclusions harder to extract. However, this data source is also extremely up to date allowing for a longer after period in the analysis.

4.2.4 Transportation Data Section Data

The Transportation Data Section (TDS) database is the official statewide crash reporting system. ODOT's statewide reported crash database stores information pertaining to any reported crash involving a fatality, injury and/or damages in excess of $1,500. This database contains extensive amounts of data for each crash, including time, location, type and severity. ODOT's annual state highway crash rate tables combine this reported crash data with vehicle miles traveled (VMT) data to compute crash rates for each highway covered by the agency. Because the database is so extensive and detailed it has a long lag time while details of each crash are reported, evaluated, and compiled. For this study, the complete database with finalized data is available from July 2011 to December 2014. This provides a full three years of before data but only 5 months of after VSL implementation data. This data contains a total of 1301 crashes with over 1100 being from before the VSL system was implemented.

Preliminary data for the year of 2015 is available but cannot be fully utilized due to incompleteness, as more crashes could be reported to the DOT, and it does not contain Property Damage Only (PDO) crashes. Nevertheless the additional 149 crashes in the preliminary 2015 data can still be used, provided analysis does not include PDO crashes and understands the likelihood of the newer data underreporting crashes. This data source provides the best information regarding the overall crash rate of rear end crashes, a particular focus of the OR 217 VSL system. Future research should be done in the future that can incorporate TDS crash data through July 2017 for the full three year after period.

4.2.5 Summary of Crash Databases

The WCCCA and TOCS databases both provide up to date crash information and potentially offer the ability to more quickly determine safety impacts from the system. However, the low data resolution does not allow for detailed analysis of crash types, time of day, or even fine-tuned locations. The TDS data by contrast offers extremely high resolution but does a long lag time making a thorough determination of the VSL impacts difficult at present. The incomplete analysis for 2015 increases the TDS value significantly but limits its application to only injury crashes. WCCCA is treated as the principal data source in this study, with TOCS as a supplementary source, and TDS serving to illuminate more targeted information such as rear end crashes.

All three data sources offer different data period lengths, through WCCCA and TOCS are virtually identical. All of the data sources have full and complete before data for three years. TDS only provides complete data for 5 months after the installation, with another twelve available in a more limited function. WCCCA and TOCS both have around twenty-one months of after data, over half of the traditional thirty six months. The relative timelines are indicated in Figure 20. The raw crashes are shown by month and datasource for both before and after the VSL implementation in Figure 21.

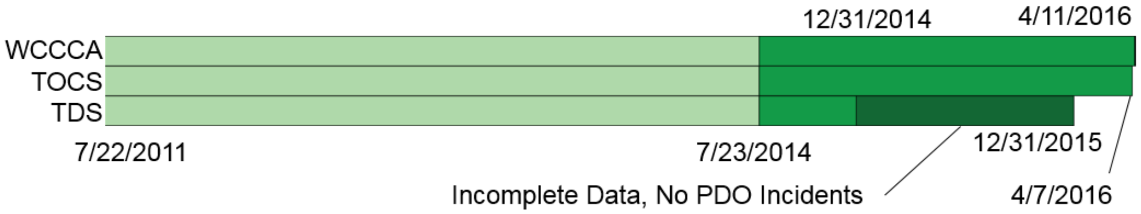


Figure 20: Timeline of Data Availability

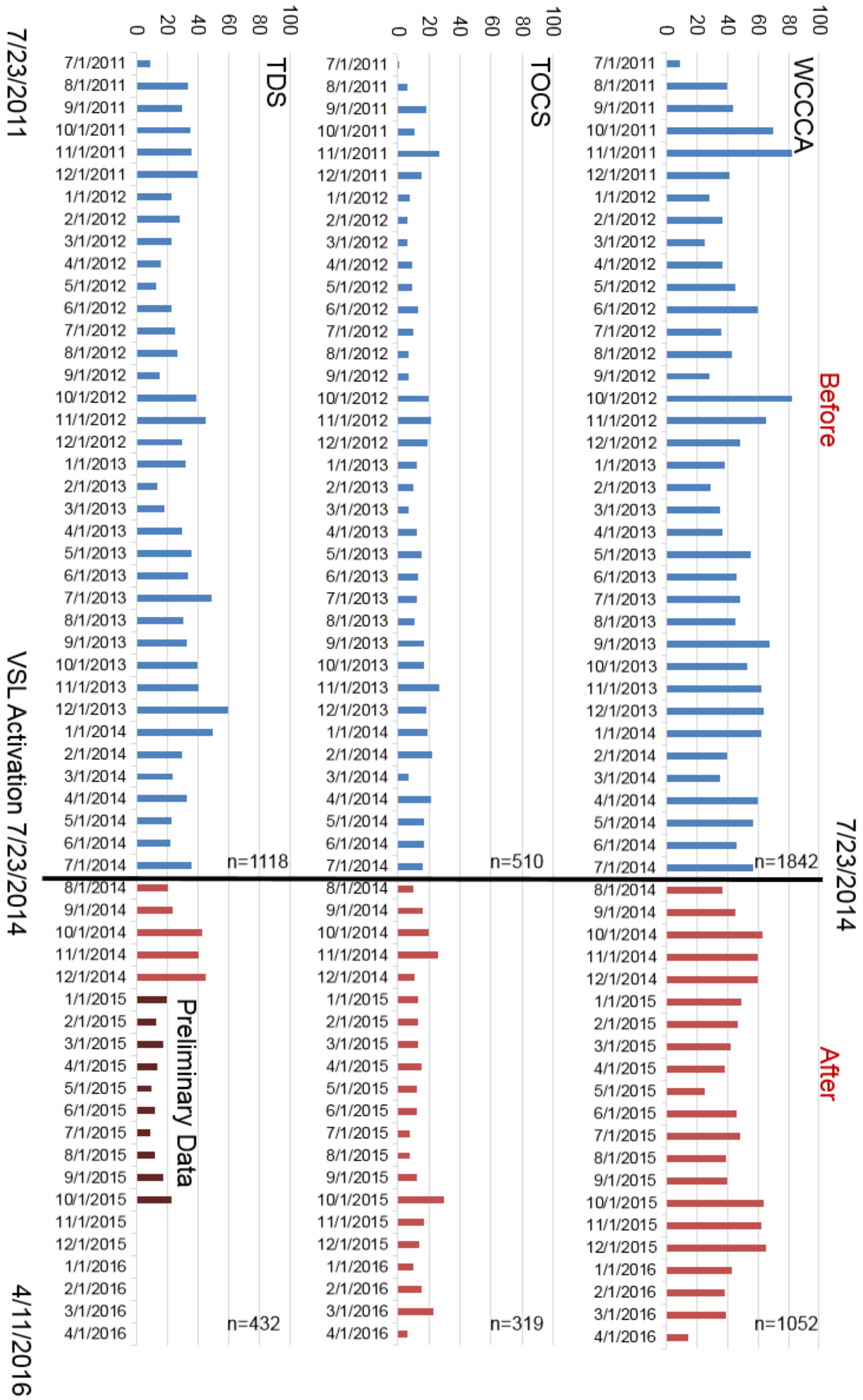


Figure 21: Crashes by Month by Data Source

4.2.6 Weather Data

As the OR 217 VSL system is weather responsive it was important to incorporate weather data into the analysis. The new RWIS sensors embedded in the system to be used for VSL operations do not have data available for prior to implementation. Instead daily weather data from the nearby Hillsboro Airport provided by the National Oceanic and Atmospheric Administration (NOAA) is utilized. The airport is located approximately 10 miles to the Northwest of OR 217. This data is combined with the WCCCA and TOCS crash databases to help determine weather conditions for each crash on a daily basis. Given that the WCCCA data, the primary resource, only records crashes and other crashes on a daily basis the weather information is restricted to merely if there was rain, snow, or thunderstorms recorded that day. This may not reflect conditions on the road at the time of the crashes but is the best possible resolution. The low resolution limits the usefulness but still allows for some insight.

In order to verify that weather did not have a significant impact on the analysis the proportion of before and after days characterized as having rain or snow was compared. The percentage of days experiencing each condition is shown in Table 3. The before and after periods had similar amounts of days with rain at around 45% while the snow portion declines from 3% before to 0.6% after. This decline is noticeable and large but ultimately snow is an uncommon occurrence and affected a small portion of time. Overall the weather is similar before and after, not requiring any special compensation in the analysis.

Table 2: Percentage of All Days by Weather Type

Conditions	Before		After	
	No. of Days	Percent	No. of Days	Percent
Clear	575	52.4%	345	54.9%
Rain	489	44.5%	280	44.5%
Snow	34	3.1%	4	0.6%
Total	1098	100%	629	100%

4.3 Evaluation Framework

The data sources outlined above are all utilized as inputs to the two studies made. This information regarding crashes, traffic volumes, and weather is used in evaluating OR 217 in both a Naïve Before-After study and Empirical Bayes study. The specific use of each data source in Naïve Before-After and Empirical Bayes Analysis is explained in methodology sections.

5.0 Naïve Before-After Study

The first portion of analysis for OR 217 used in this study is a Naïve Before-After analysis. This utilizes crash data for prior to and after the installation of the system. It uses simple statistical procedures to make predict crash rates for comparison with recorded ones. Because of its ease of use it is a good measure for quick updates, suiting some of the data sources. The methodology behind the analysis is explained in Section 5.1.

5.1 Methodology

The Naïve Before After analysis relies on using crash data prior to the system implementation to predict the number of crashes expected in the after period should the VSL system have not been activated. The ideal situation is to use the same amount of data for both before and after, with three years being the established typical value. Because of the recent installation of the system a full three years of data is not available for the after period. The methodology can accommodate this time disparity through use of a correction factor, correlating the length of before and after time and their respective crash counts.

A known issue with this methodology is that it holds all other factors as constant, notably traffic volumes. The correction factor for the traffic functions similarly to the study time period function by relating the number of crashes prior to the crash with the traffic volumes prior and essentially creating a crash rate. The correction does the same with after crashes and forms a ratio between the rates to be applied to the before crash counts to create the after crash predictions. This single traffic rate has an outsize impact on the overall after crash prediction, and thus overall reduction, making it essential that traffic volumes for both before and after are as accurate and representative of the corridor as possible. Traffic volumes for the before and after periods do not require a standard format, only that they be the same measurement for a fair comparison.

As this method requires prediction of how many crashes would have occurred the estimate is only the center part of a possible range of values. The data also requires a large amount of before data to make accurate predictions that are able to observe small impacts. All of the predictions made are shown with error bars representing the possible range of prediction, though changes are estimated from the center. The statistical viability of predictions is addressed in Section 5.5.

5.1.1 Traffic Volumes

Multiple sources of traffic data provide competing information about number of vehicles utilizing OR 217 before and after implementation. ODOT produces an annual report with traffic volumes for all highways in the state, and this document is considered to be the official traffic information. Because the traffic data is produced in an annual January to December format it doesn’t allow for easy comparison given the July system activation. In addition, the data collectors along OR 217 were not recording data during the construction phase of the project. The official figures are shown below in Figure 22. The official data is an unusable source of information about the corridor as traffic volumes did not decrease by 50% in 2014. In addition, 2014 volumes are the latest available, severely limiting the representation of traffic after VSL activation.

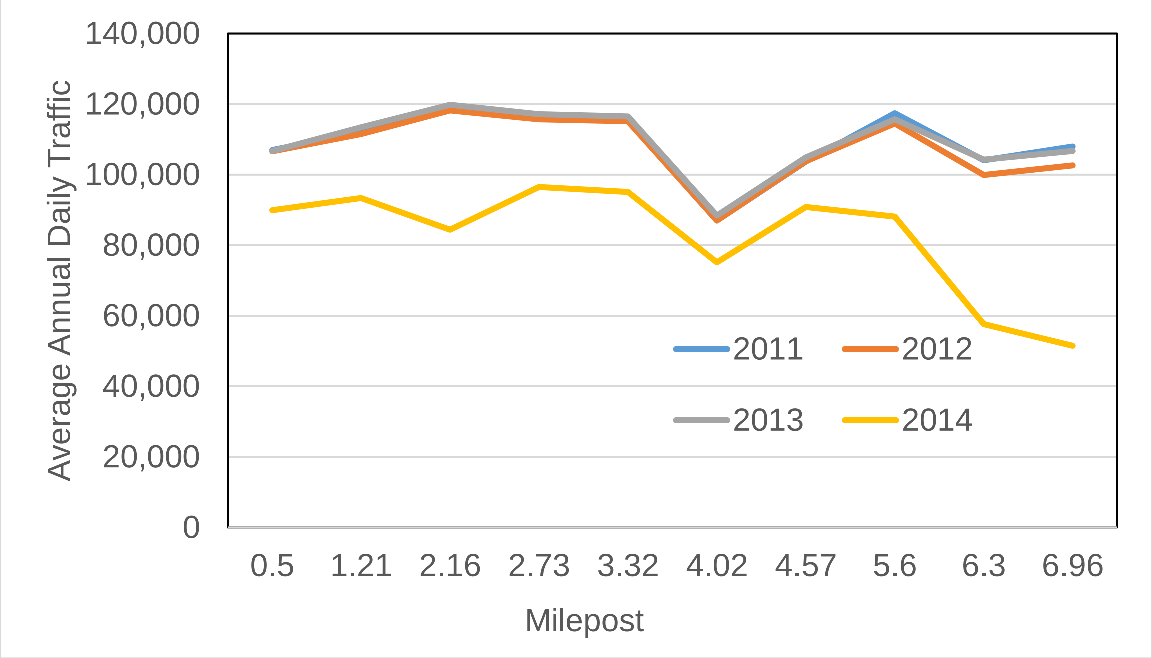


Figure 22: Official OR 217 Traffic Volumes

Instead monthly traffic volumes were downloaded from Portal for both northbound and southbound OR 217. The volumes are counted by the embedded loop detectors located along the corridor just upstream of on-ramp merges. Data was collected from July 2011 to March 2016, matching the crash data source timeframes. Although data is available in a higher resolution, such as daily or hourly volumes (down to 20-sec resolution), the long study period negates any advantages of increased accuracy with large increases in processing time. As noted previously detectors were offline during construction and often had faults at other points in the study period. In order to make the data acceptable it is sanitized, removing any extraneous data points. Values that vary significantly from the long term trends, typically by a factor of 2 or more, are eliminated from the data. To ensure that traffic volumes were consistent in capturing the same traffic before and after installation, detectors that existed only before or after the systems implementation were eliminated. The northbound and southbound mainline traffic volumes are shown in Figure 23 and 24.

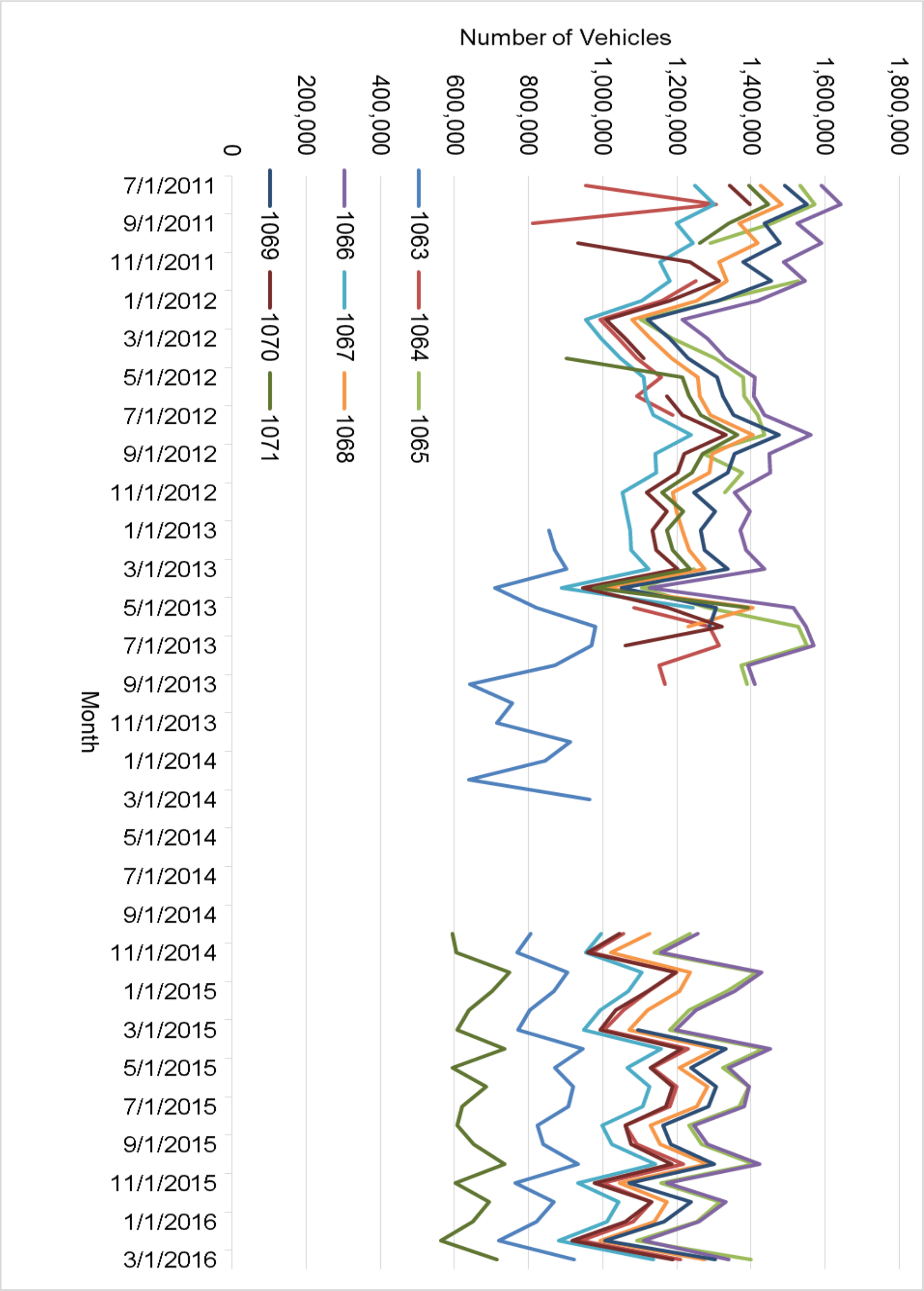


Figure 23: Traffic Volumes NB Sanitized by Station

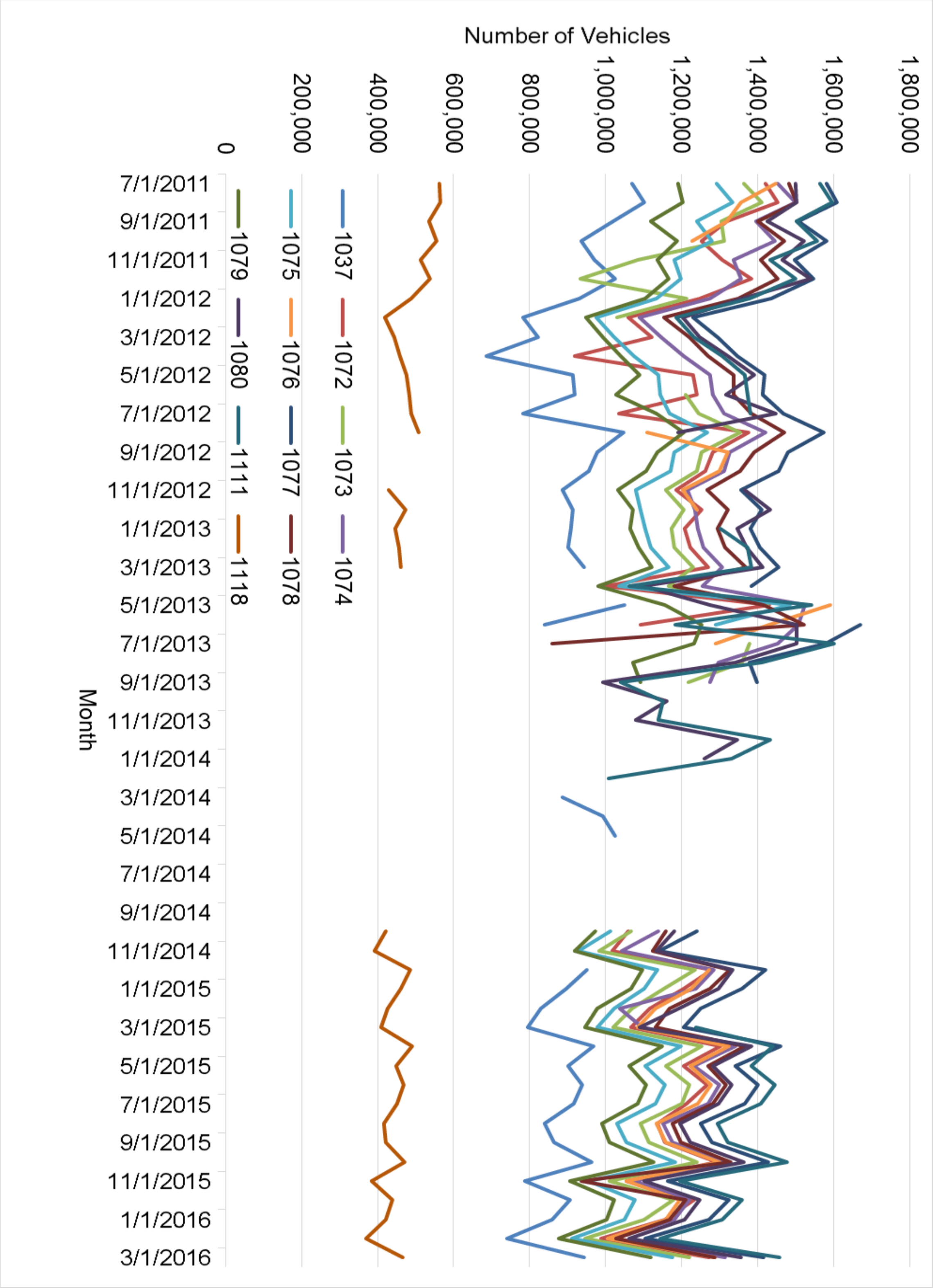


Figure 24: Traffic Volumes SB Sanitized by Station

The detectors experienced a significant amount of variation among the detector stations prior to the VSL system implementation, even after cleaning the data. After implementation the detector stations are more consistent from month to month, relative to other detector stations. The change in the mean volume for before and after the VSL implementation by each detector is detailed in Table 3.

Table 3: Monthly Traffic Volumes Before and After VSL Implementation by Station

Northbound				**Southbound**			
Station	**2011-2014 Mean**	**2014-2016 Mean**	**Traffic Volume Change**	**Station**	**2011-2014 Mean**	**2014-2016 Mean**	**Traffic Volume Change**
1063	830719	848185	+2.10%	1037	928366	881531	-5.04%
1064	1108456	1105351	-0.28%	1072	1232390	1168461	-5.19%
1065	1352899	1288993	-4.72%	1073	1237558	1126062	-9.01%
1066	1439729	1299793	-9.72%	1074	1322649	1191867	-9.89%
1067	1124182	1039036	-7.57%	1075	1174287	1067609	-9.08%
1068	1273096	1168570	-8.21%	1076	1310312	1192512	-8.99%
1069	1328014	1203734	-9.36%	1077	1456601	1301948	-10.62%
1070	1170702	1092182	-6.71%	1078	1341374	1208817	-9.88%
1071	1238064	6533897	-47.22%	1079	1109688	1024555	-7.67%
				1080	1346803	1238564	-8.04%
				1111	1346581	1344728	-0.14%
				1118	490114	436528	-10.93%

All detectors, with the exception of one, experience a decrease in average monthly traffic volumes after the implementation of the system, with the decline typically 8-10% from the prior to implementation volumes. This seems counterintuitive with the previous growth rate shown by traffic on the corridor, however the data shows the trend clearly. For the purposes of this portion of the study, the data is used and analysis results are compared to if traffic volumes had no changed.

To develop reliable before and after traffic volumes several of the detector stations are excluded from the analysis. The northbound end detectors both are missing data for one of the lanes, giving a heavily reduced volume. The southbound data includes two sets of detectors at the northern end of the corridor that only capture on ramp volumes but do not include the traffic coming from eastbound OR 26. After exclusion, the monthly traffic volumes for all of the detectors is averaged for northbound and southbound. The average northbound and southbound values are shown in Figure 25 and Figure 26.

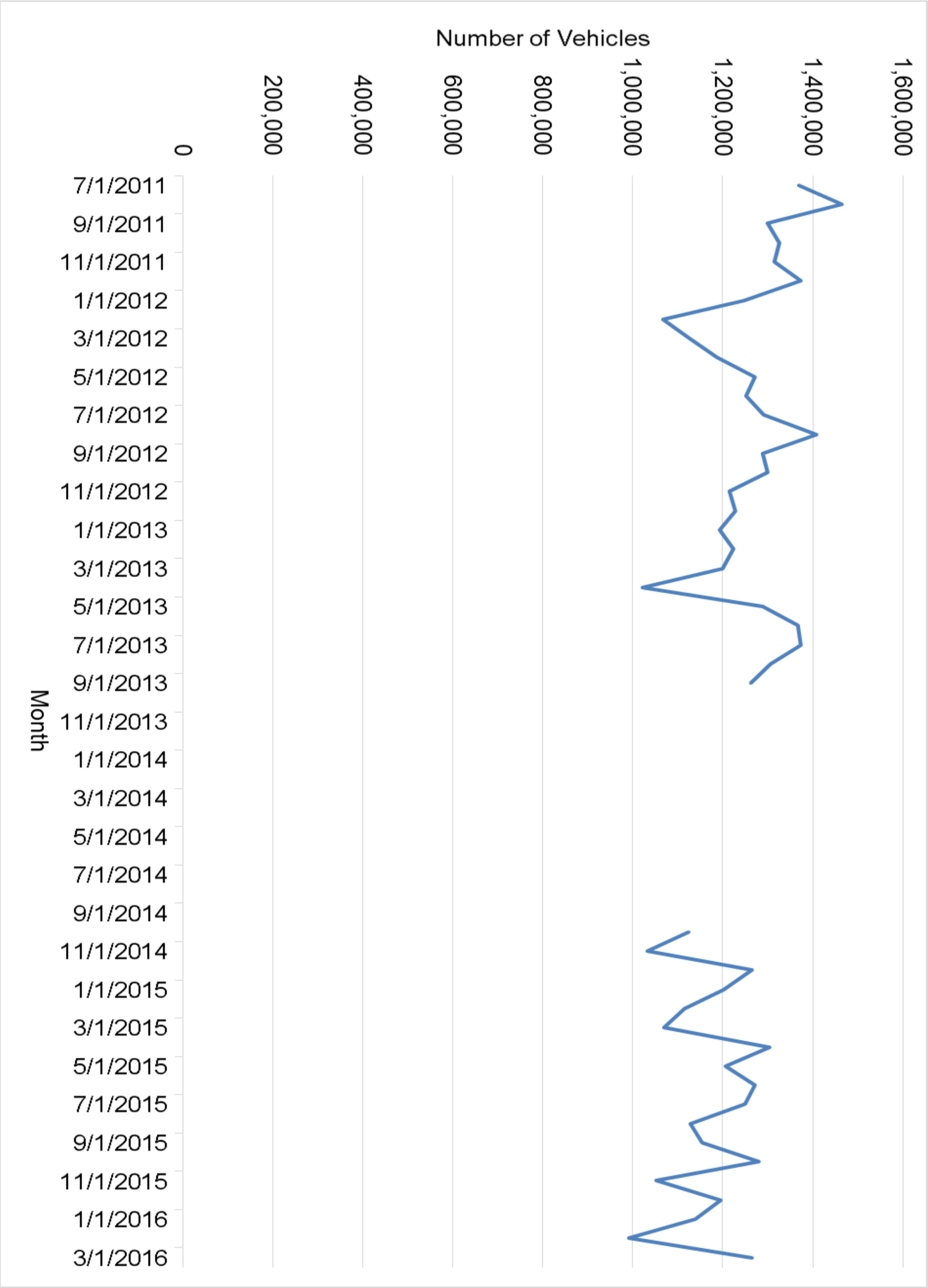


Figure 25: SB Average Monthly Traffic Volumes

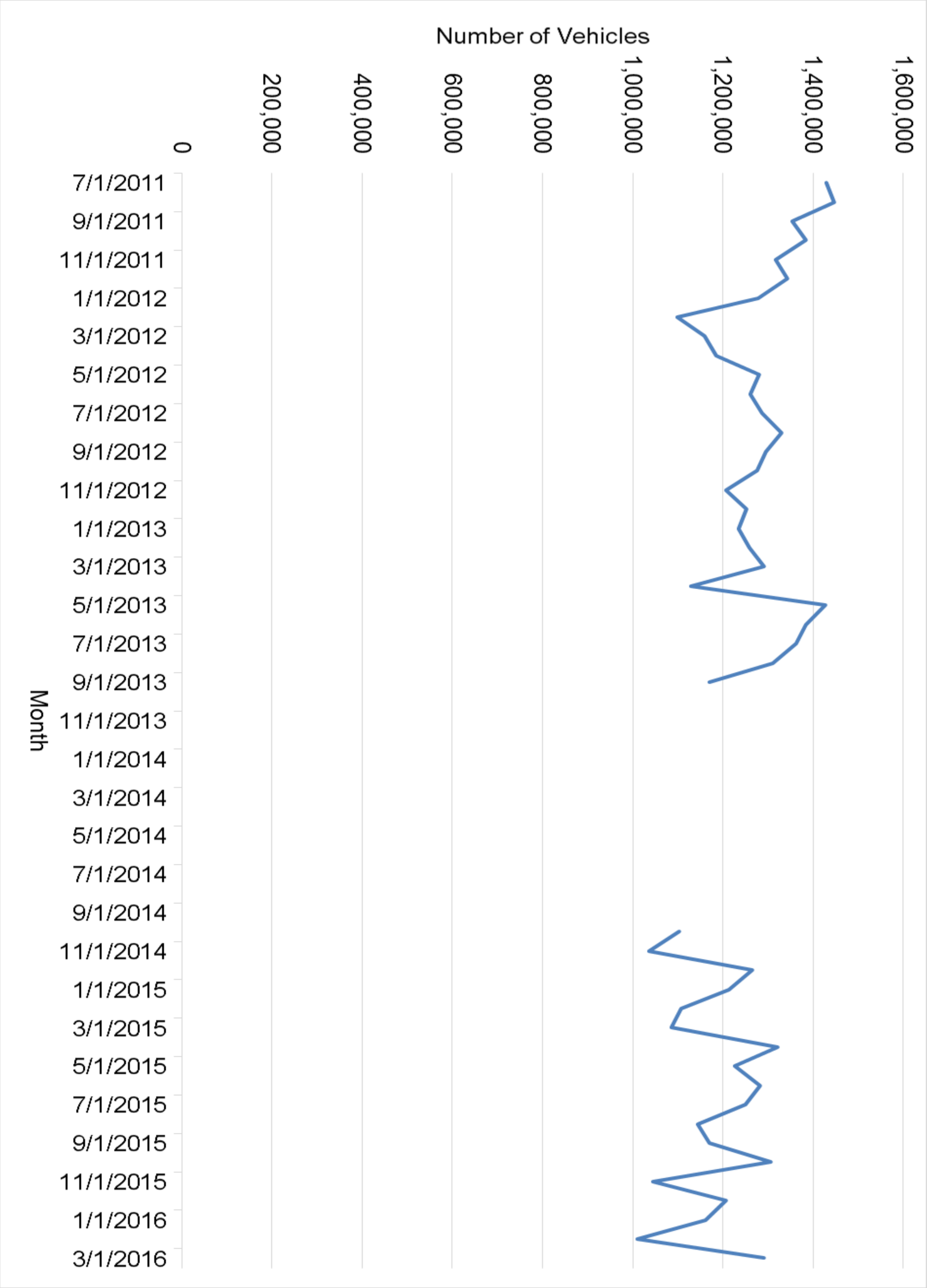


Figure 26: SB Average Monthly Traffic Volumes

Both sets of data follow similar trends from month to month and exhibit consistent seasonal variations. The southbound direction experiences a small amount more traffic with volumes typically 1-2% higher. Using this information, the average monthly traffic volumes for before and after VSL implementation were determined for each direction, as well as the corridor in total. Both directions showed traffic volume declines consistent with those measured by individual loop detector stations. Verification that the monthly traffic volumes are reliable was done by dividing the volume by 30 and comparing against the official ODOT Average Annual Daily Traffic (AADT) volumes.

5.1.2 Crash Data

All of the crash databases required being divided into before and after periods. The raw data was filtered into crashes by years starting on July 22, and ending on July 21 in line with the VSL activation date. This data was further processed into a variety of categories such as by type of crash, crash milepost, or weather conditions. This allows for analysis of the VSL impact on more specific elements of crashes. For example, filtering the TDS data allows for understanding the VSL impacts on rear end crashes, a target of the VSL system. Naïve Before-After analysis was then conducted on each data sources and the subsets of data within them.

5.2 WCCCA Data

The WCCCA data serves as the primary database for this project and the main analysis target. As the data contains a limited amount of information, analysis cannot be extremely targeted, such as for rear end crashes. The main categorization that was possible is by injury level, location, and direction of travel. For the purposes of this analysis with a focus crashes, the only crash types used are the “Traffic Accident – Injury”, “Traffic Accident – No Injury”, and “Traffic Accident – Unknown Injury”. These three categories are referred to as TAI, TAN, and TAU respectively. In total before and after there were 2,839 reported crashes, of which 571 were TAI (20%), 1,438 TAN (51%), and 830 TAU (29%) There were two known fatal crashes. In the before period (36 months), there were 1842 reported crashes, of which 394 were TAI (21%), 884 TAN (48%), and 529 TAU (29%) There were 2 known fatal crashes in the before period. In the after period (21 months) there were 1051 reported crashes, of which x177 were TAI (17%) , 554 TAN (53%), and 301 TAU (29%) There were 0 known fatal crashes in the after period. A graph illustrating the raw number of crashes by month and type before and after the VSL system is shown in Figure 27.

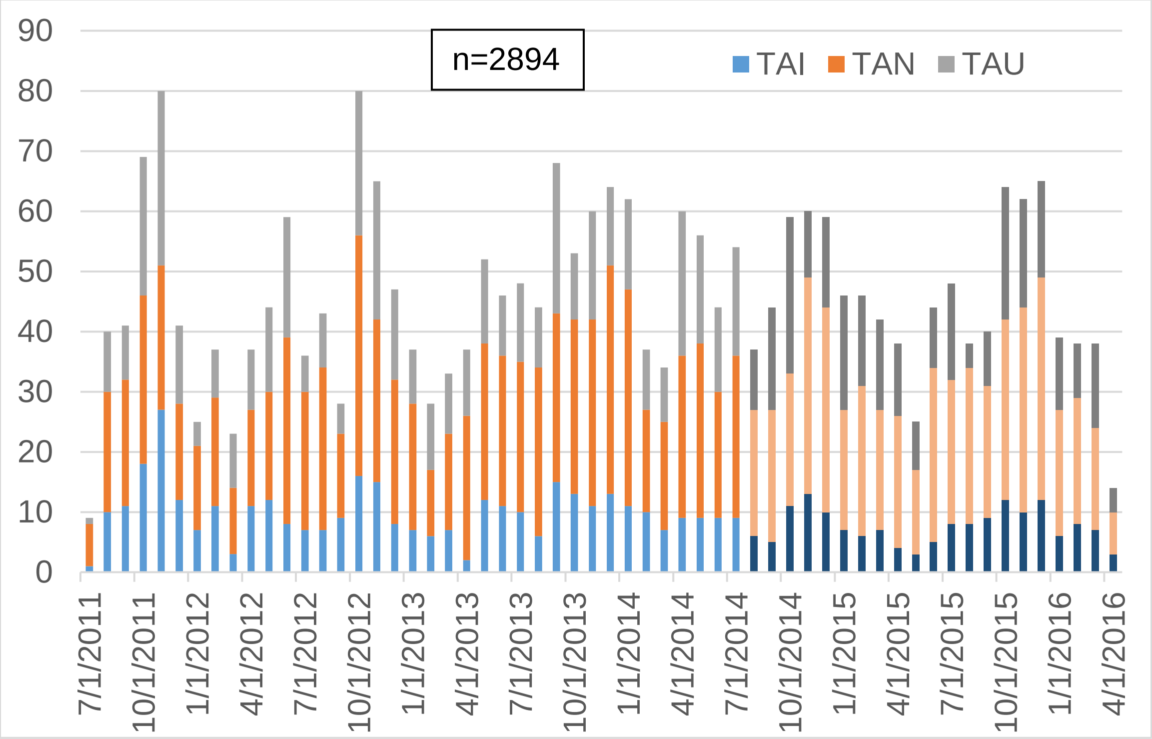


Figure 27: Crashes By Type and Month

5.2.1 Crash Frequency

To search for large changes in conditions the first analysis simply compared the location of crashes in the before and after conditions. This may show whether the corridor has experienced a shift that could point to improvements or degradations. This analysis also shows the impact of VSL signs on local crashes. Using the raw count information, Figures 28 and 29 show the crash frequency before (36 months) and after (21 months) in both northbound and southbound directions.

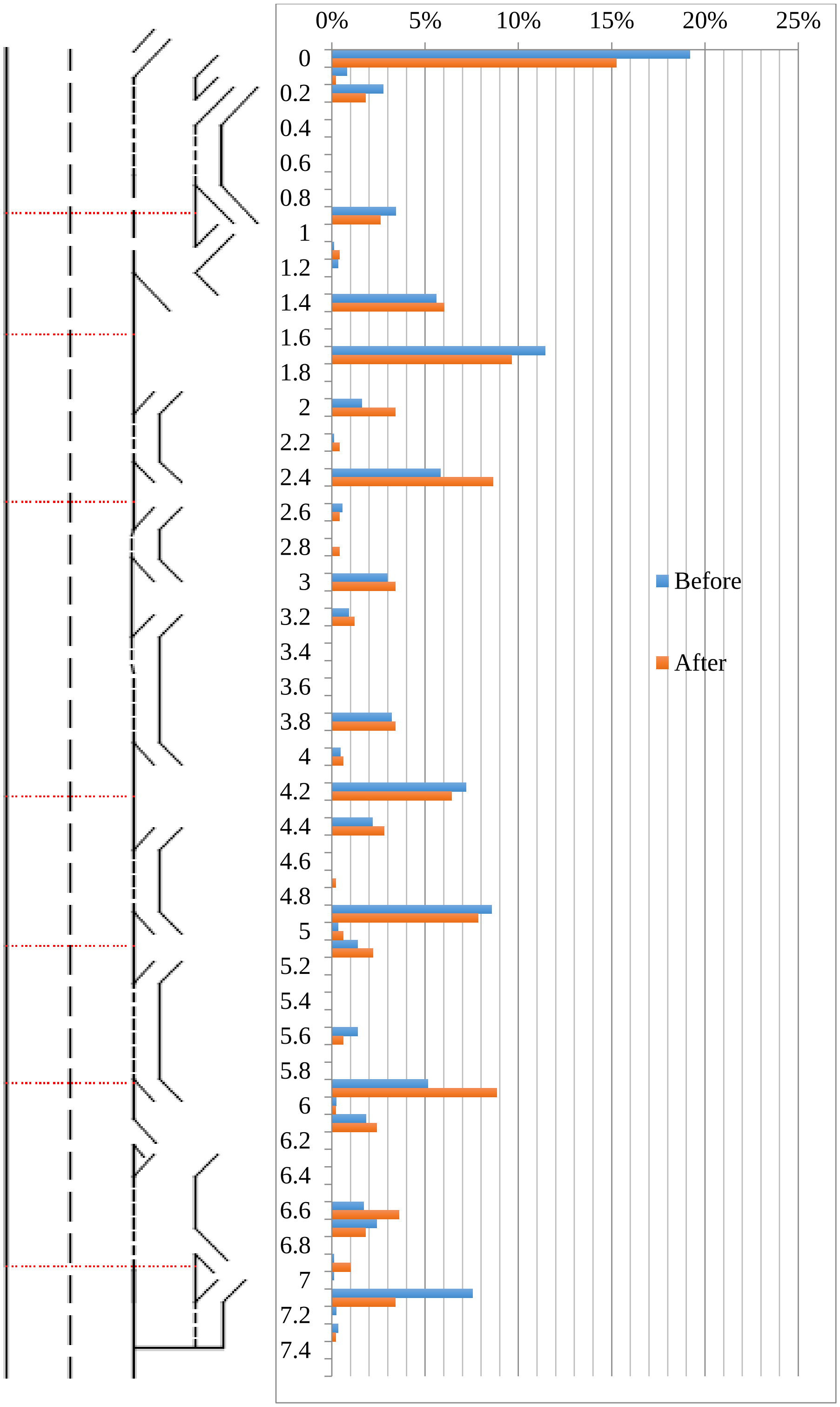


Figure 28: NB Before and After Crash Frequency

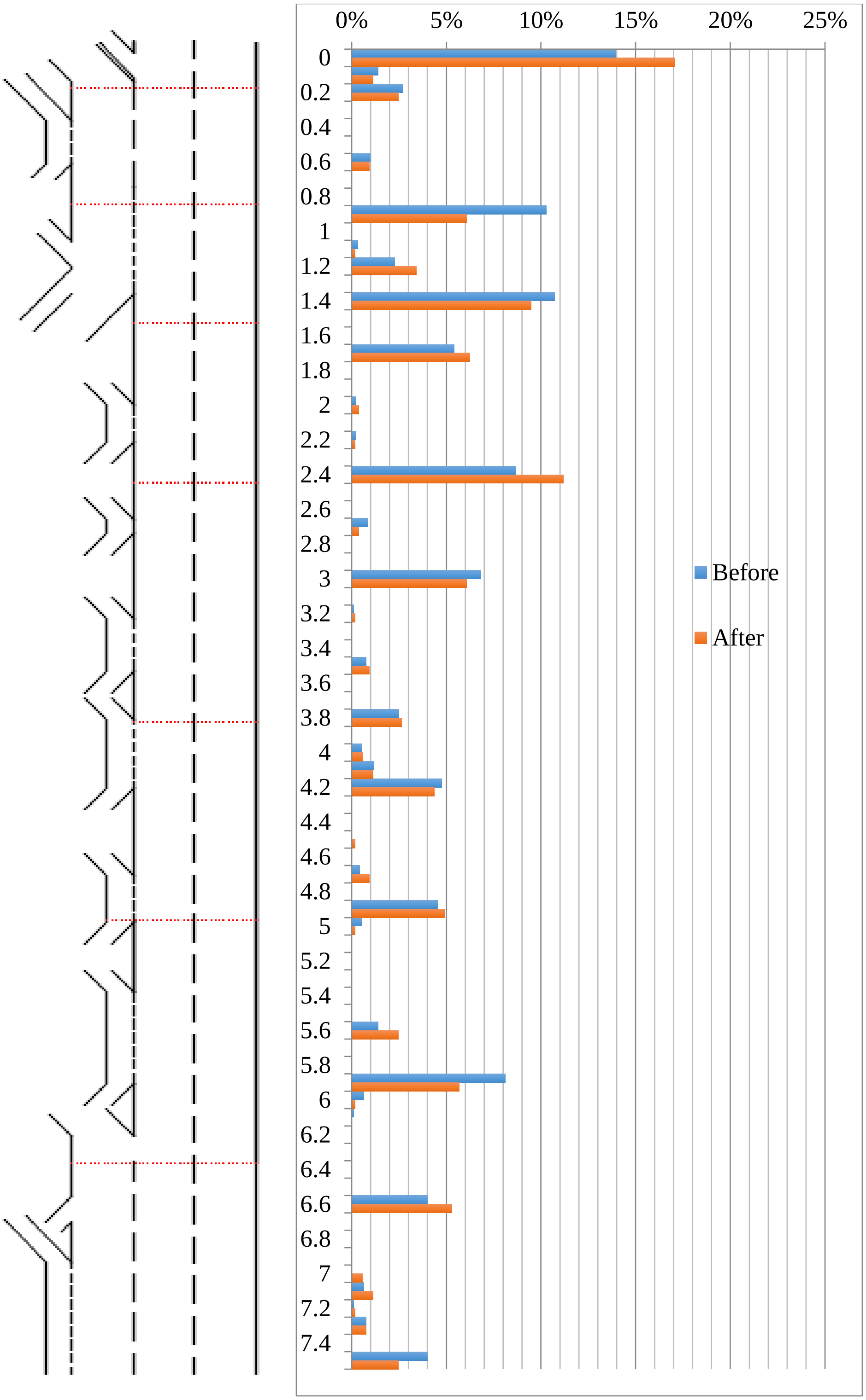


Figure 29: SB Before and After Crash Frequency

Based on a visual inspection, the overall crash distribution along the corridor did not appear to experience any significant shifts due to the VSL implementation. A significant portion of around 15% of crashes are clustered at the northern end of the corridor at the interchange with US 26. The overall distribution of crashes appears heavily clustered due to milepost information being taken from approximate location descriptions. For the northbound direction this cluster of crashes had a relative decrease, while the southbound had the opposite impact with an increase. Three curve warning detectors were installed at this northern terminus with two on the SB ramps. The decrease in crashes northbound could potentially be attributed to this curve warning device however it does not explain the southbound relative increase in crashes.

The red lines indicate the VSL sign locations for each direction, with crash frequency around them having mixed results. In the northbound direction the crashes near the sign at milepost 1.8 and 7.0 both saw declines in crashes, while the rest had little change. For the southbound direction, the sign at milepost 1.4 had a decreased crash frequency while signs at 2.4 and 6.4 had increased crash frequency.

5.2.2 By Crash Category

The previous section only showed the distribution of crashes along the corridor but did not indicate the crash volumes. The least granular analysis of the WCCCA data is the analysis by crash category. This provides the overall rate of reduction for crashes by crash type. Figure 30 shows the overall before/after crash percent change by crash type as well as for the corridor overall (left hand y-axis). The whisker bars show plus/minus one standard deviation in each direction. The values indicate the difference between the recorded number of crashes and what would be expected given the before conditions. Adjustments to the length of study period and the traffic volumes were made, as explained in the Methodology Section 5.1. The numbers of before and after crashes are also shown (right hand y-axis).

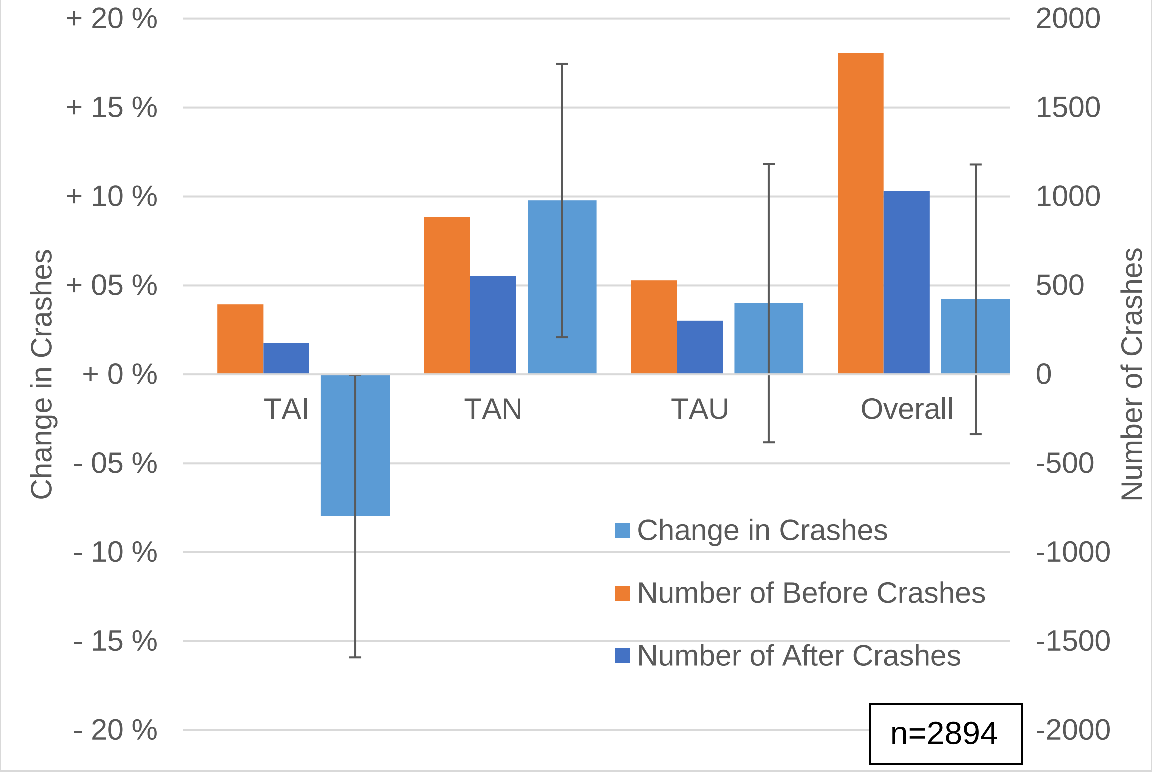


Figure 30: Overall Naïve Before After Analysis Percent Change by Crash Type

According to the Naïve Before After analysis, the Injury crashes showed a decrease of 8% after the VSL implementation. The overall corridor saw an increase of 4% in crashes after the VSL system was activated. As the figure shows the increase was heavily focused in the No Injury and Unknown Injury categories, with a 9% and 4% increases respectively against the predicted. The increase in No Injury and Unknown crashes could be due to smaller speed disparities between drivers reducing the severity of crashes, while they do occur more often.

If the traffic volume changes are ignored, the overall crashes experience an adjusted decrease of 0.5%, indicating the scale of the traffic volume declines shown by the traffic.

5.2.3 By Milepost

To better understand this rise in overall crashes the Naïve Before After analysis was also conducted by milepost for the corridor. Similar to the Crash Frequency section, this analysis relies on approximate locations from text descriptions, leading to small amounts of clustering on the corridor.

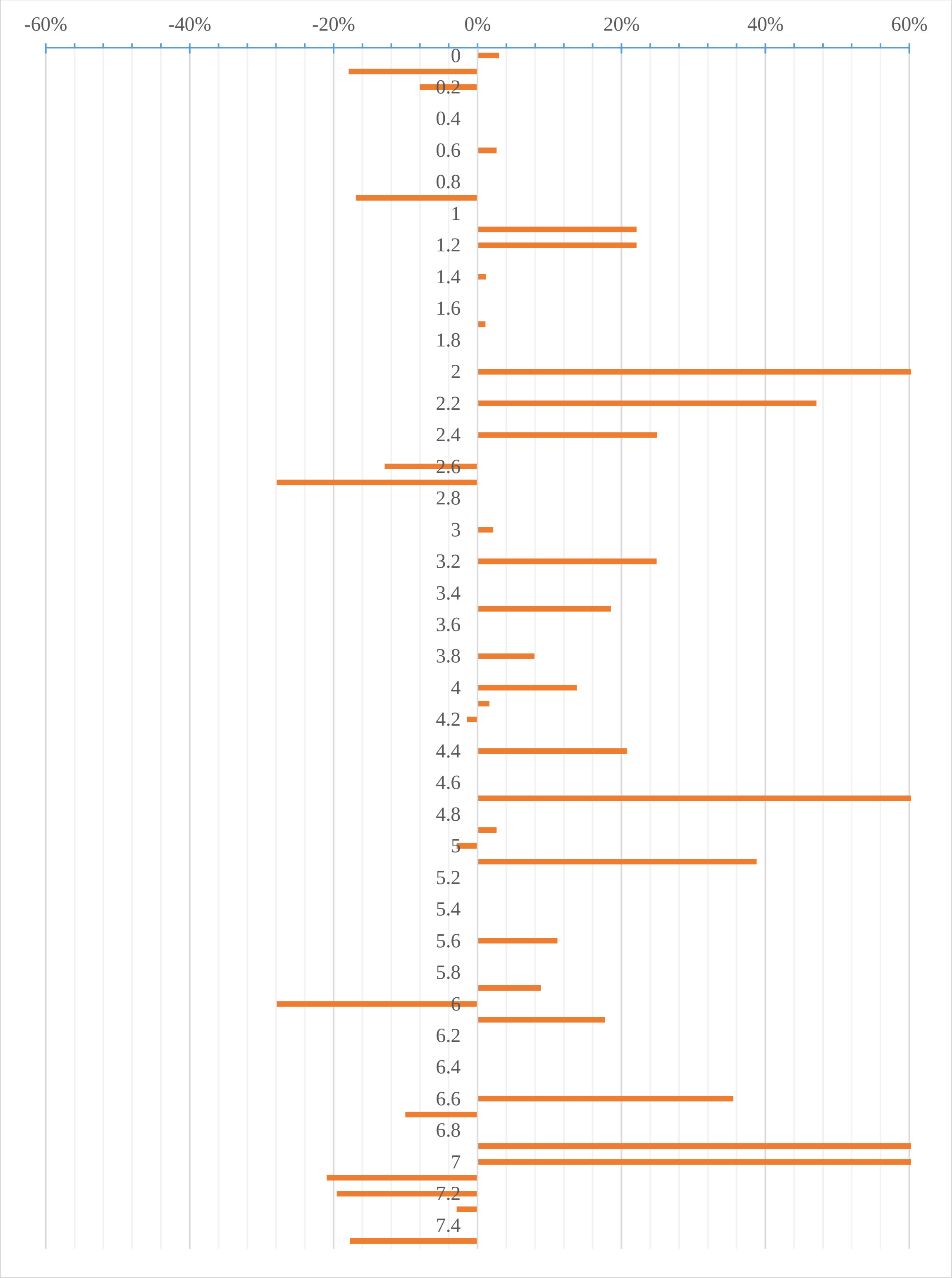


Figure 31: Crash Change by Milepost

The overall corridor shows a few bright spots with reductions up to 16% at two locations. Overall the large majority of the corridor shows increases of 10% to 30%. Three particular sections had large increases of over 100% in crashes but these were due to an extremely small sample size of before and after data exaggerating trends.

5.2.4 By Direction by Crash Category

To further understand the impact of the VSL system and understanding whether crash trends were propagating heavily depending on direction of travel the data was split by direction. Figure 32 shows the reductions for northbound travel by crash type and Figure 33 shows the southbound reductions.

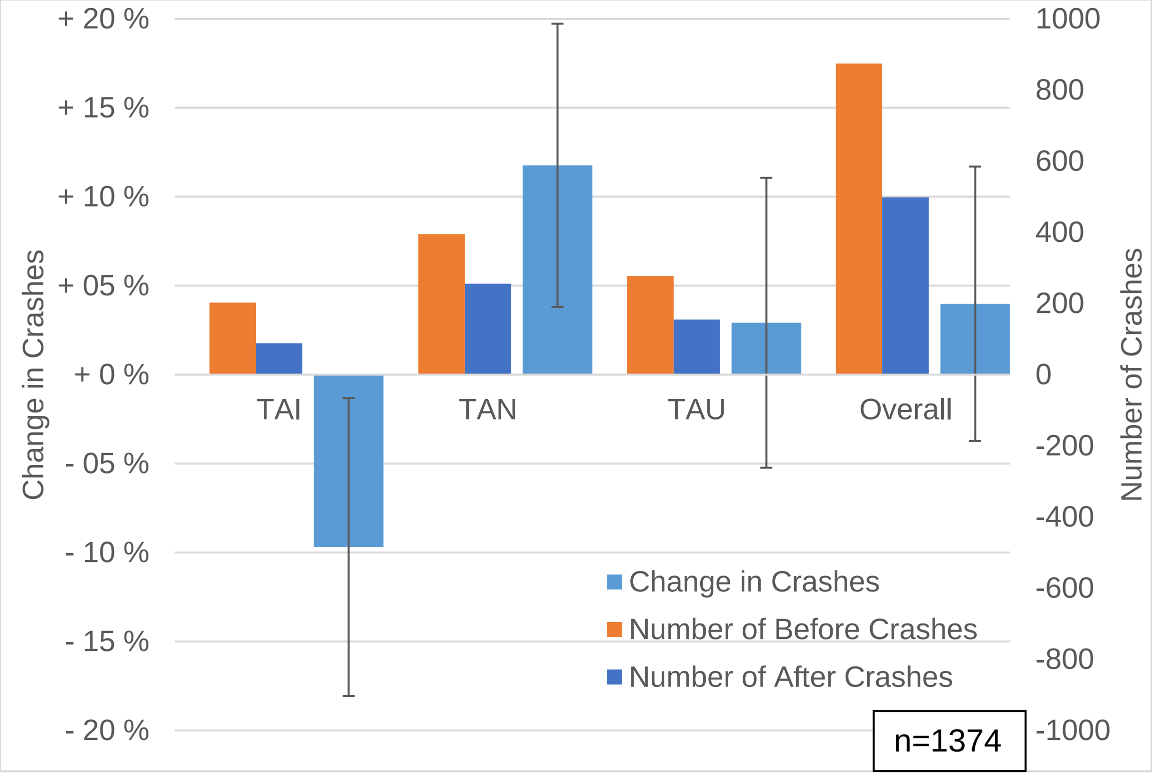


Figure 32: Naïve Before After Analysis NB Crash Change by Crash Type

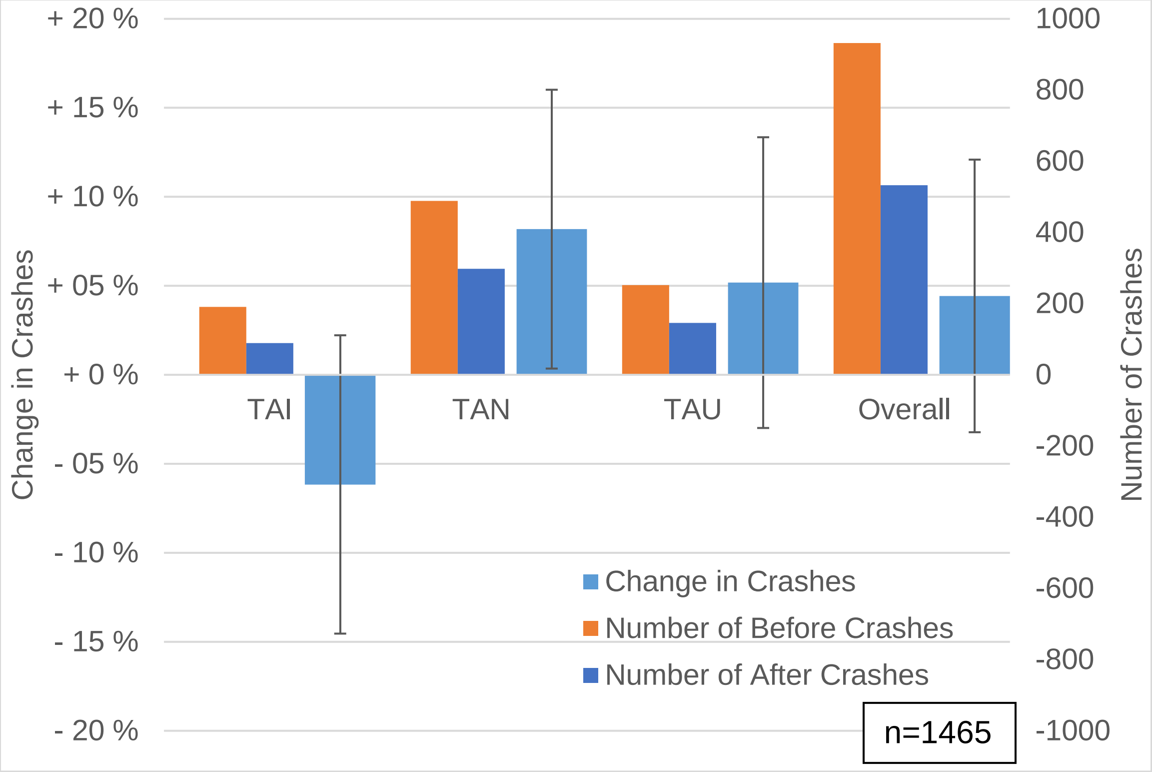


Figure 33: Naïve Before Analysis SB Crash Change by Crash Type

The by direction information shows that the increase in Injury crashes has been almost entirely due to the southbound traffic. The northbound direction has experienced an increase of only 1% for injury crashes. However the other crash type's crashes increase more notably in the northbound direction, rising by 22% for No Injury and 14% for Unknown Injury crashes. This disparity could be due to better harmonization in traffic volumes resulting in lower speed differentials reducing the number of crashes. It could also be related to the larger number of VSL signs in the southbound direction causing distractions.

5.2.5 By Direction by Milepost

To identify the problem spots in each direction the crashes were also divided by mile post and direction of travel. Figure 34 shows the change in crashes for northbound traffic and Figure 35 shows the same for southbound.

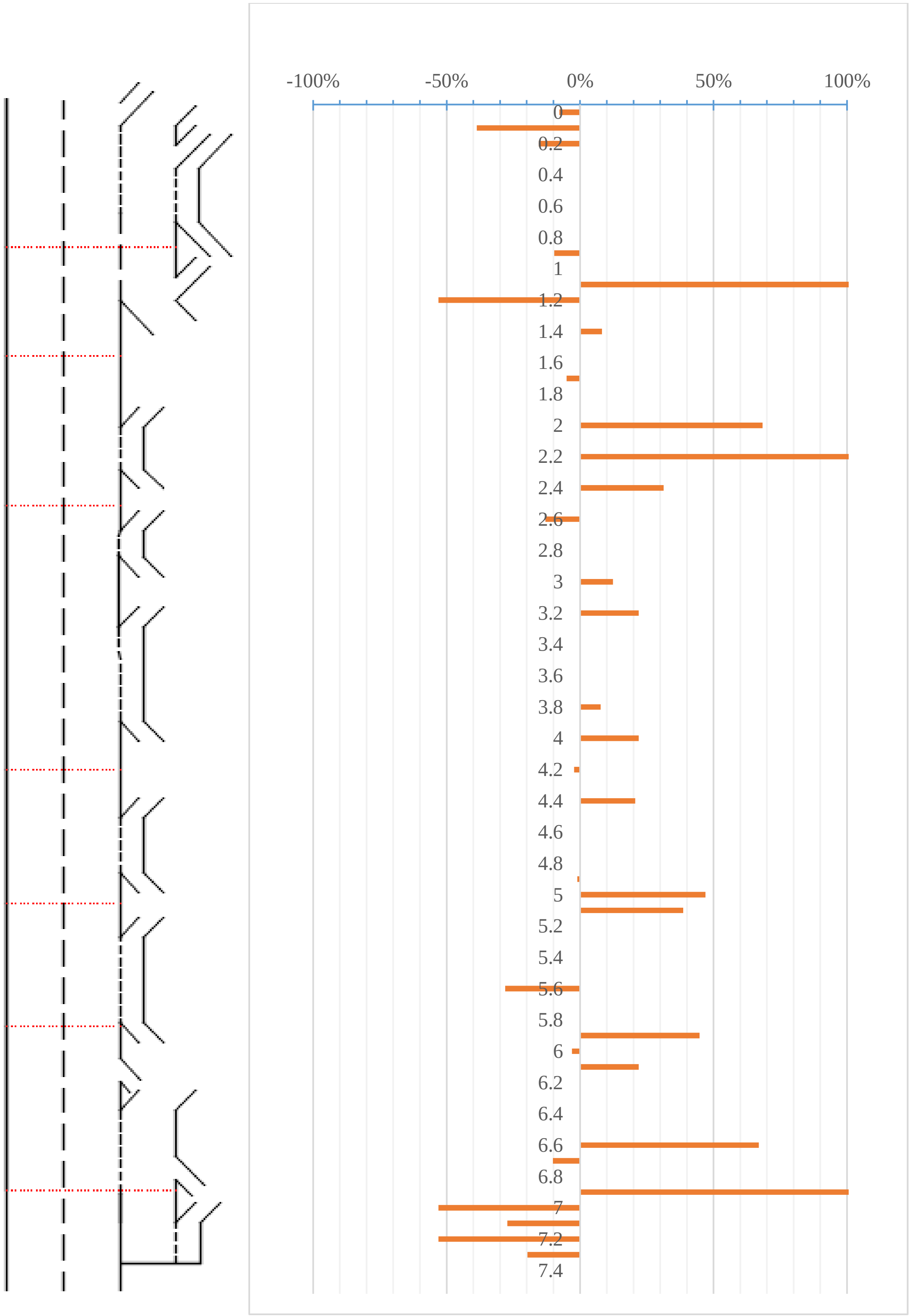


Figure 34: NB Crash Change by Milepost

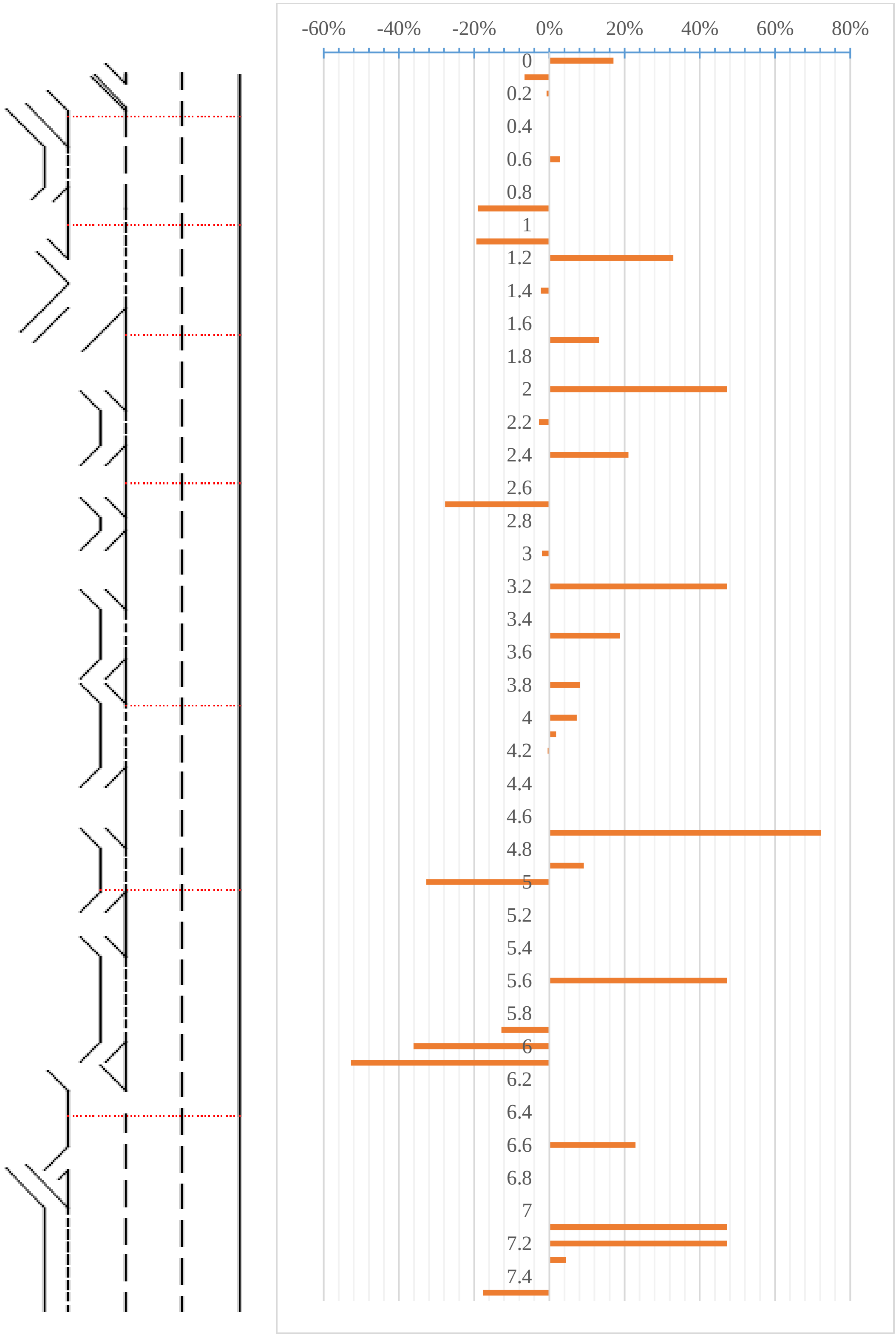


Figure 35: SB Crash Change by Milepost

The by milepost analysis shows that the large increases in crashes at a few locations shown in Section 5.2.3 are due to the northbound traffic. The southbound traffic has a more consistent amount of smaller crash increases along the corridor, typically around 15%.

5.2.6 Analysis by Weather

To determine the impact that weather conditions have had on the corridor, the Naïve Before After analysis was completed using the recorded weather for each day on which a crash occurred and was logged in the WCCCA database. The weather information is simplistic and only notes if a weather event did occur that day as crashes cannot be attributed to certain times of day to determine more accurate roadway conditions. The relative frequencies of the weather for the before and after periods are shown in Section 4.2.6.

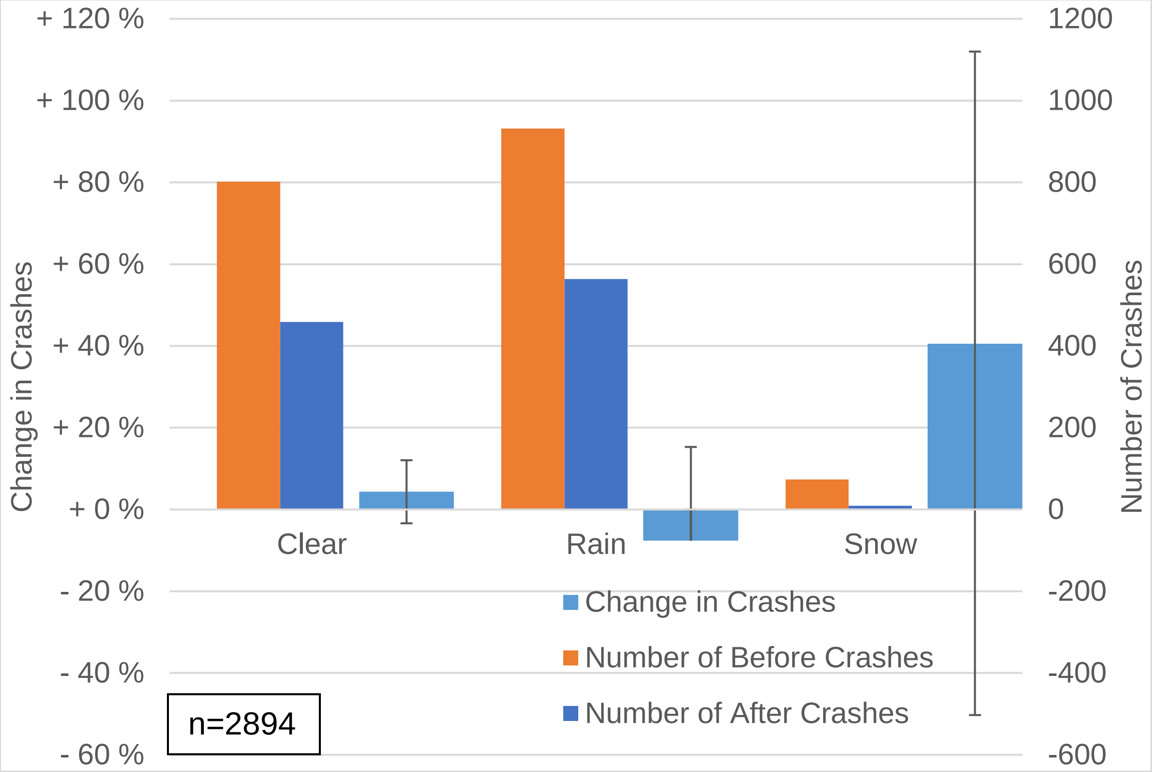


Figure 36: Naive Before After Analysis Percent Change by Weather Condition

The results indicate that the crashes occurring on days with wet weather experienced a decline of 8%. The snow conditions in the after period were less often but more crashes occurring creating the appearance of a large increase. The extremely large variability is indicative of the low frequency of this type of crash both before and after the VSL system. Clear days showed a 4% increase in crashes with the Naïve Before After analysis, showing that the system may be performing best during adverse weather conditions.

5.2.7 Summary

The WCCCA data shows a large increase in crashes occurring around the VSL installation. The overall Naïve Before After adjusted crash rate increased by roughly 4% with No Injury crashes having a dramatic increase of 20%. The smaller increase of only 2.7% for crashes resulting in an injury shows that the more severe crashes are increasing a lower rate. The northbound traffic experiences higher increases in crashes at peak places and a larger increase in No Injury crashes but has almost no increase in Injury crashes. These results contrast with the reported 13% decrease that the ODOT determined from the WCCCA data. The ODOT research used the numbers for just one year before and after, whereas this study used a much larger study period. In addition the ODOT report utilized a simple comparison of the raw numbers not accounting for the changes in traffic volumes, as this analysis does. If this Naïve Before After Analysis ignores the traffic volume changes, the WCCCA data shows a .5% decrease in crashes using the full study period data.

5.3 TOCS Data

The TOCS data provides an account of traffic crashes from a different perspective. Whereas the WCCCA data is crowdsourced through public 911 calls and subsequently verified by emergency responders, the TOCS data comes from the highway operating agency’s traffic management center responding in real time and notifying incident responders and the public of possible issues. This database is also used in real time to manage incident response. The crash data logged in this database is then more focused on incidents that the agency believes impacts operations. As a result it likely does not capture the same crashes as the 911 call data, but rather the more operationally important crashes.

In the TOCS database there were 510 crashes before, and 319 crashes after. Figure 37 shows the change in crashes by month for before and after the VSL system was activated. The overall crash distribution for the corridor from the raw TOCS data is shown in Figure 38.

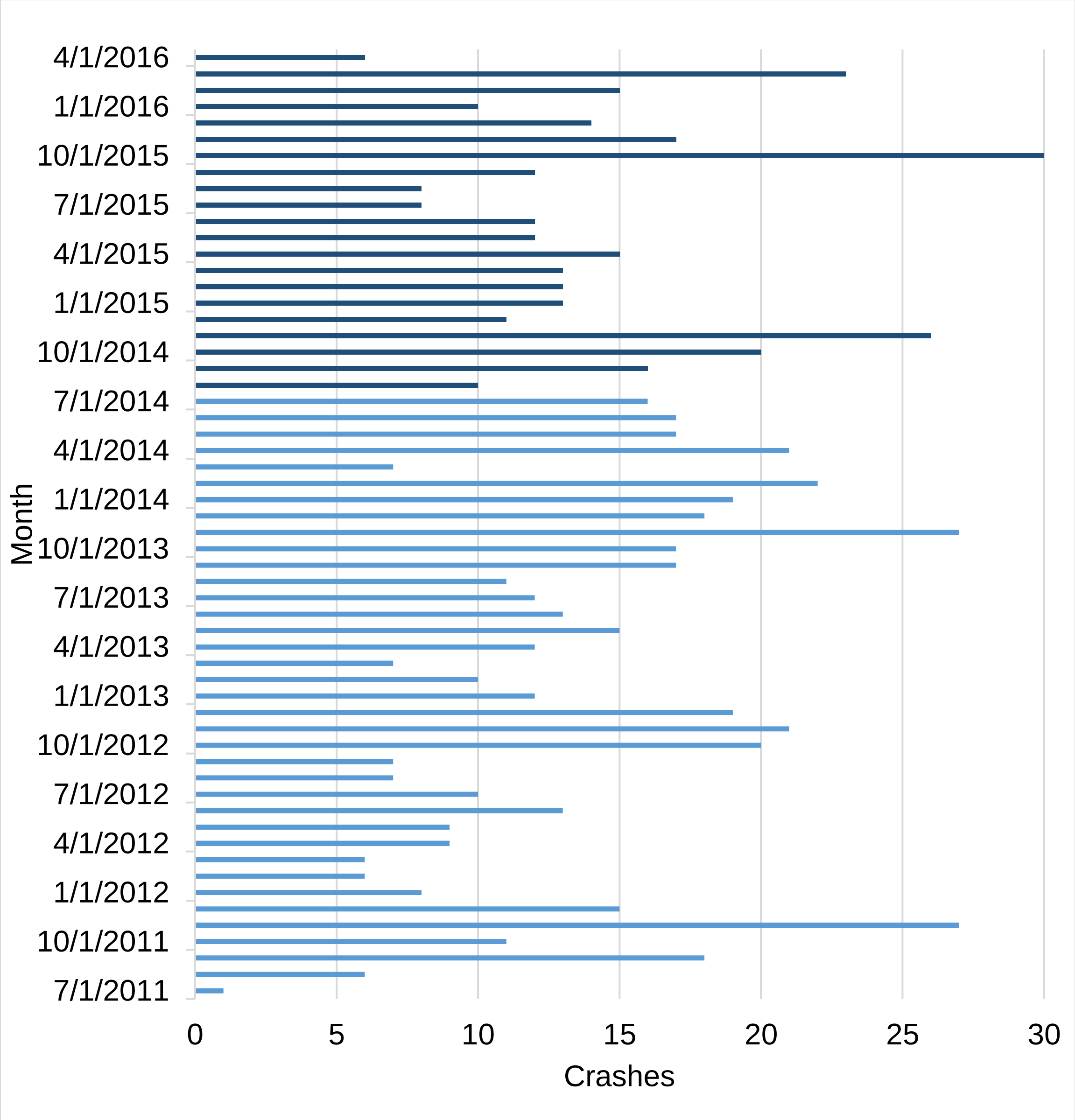


Figure 37: TOCS Recorded Crashes by Month

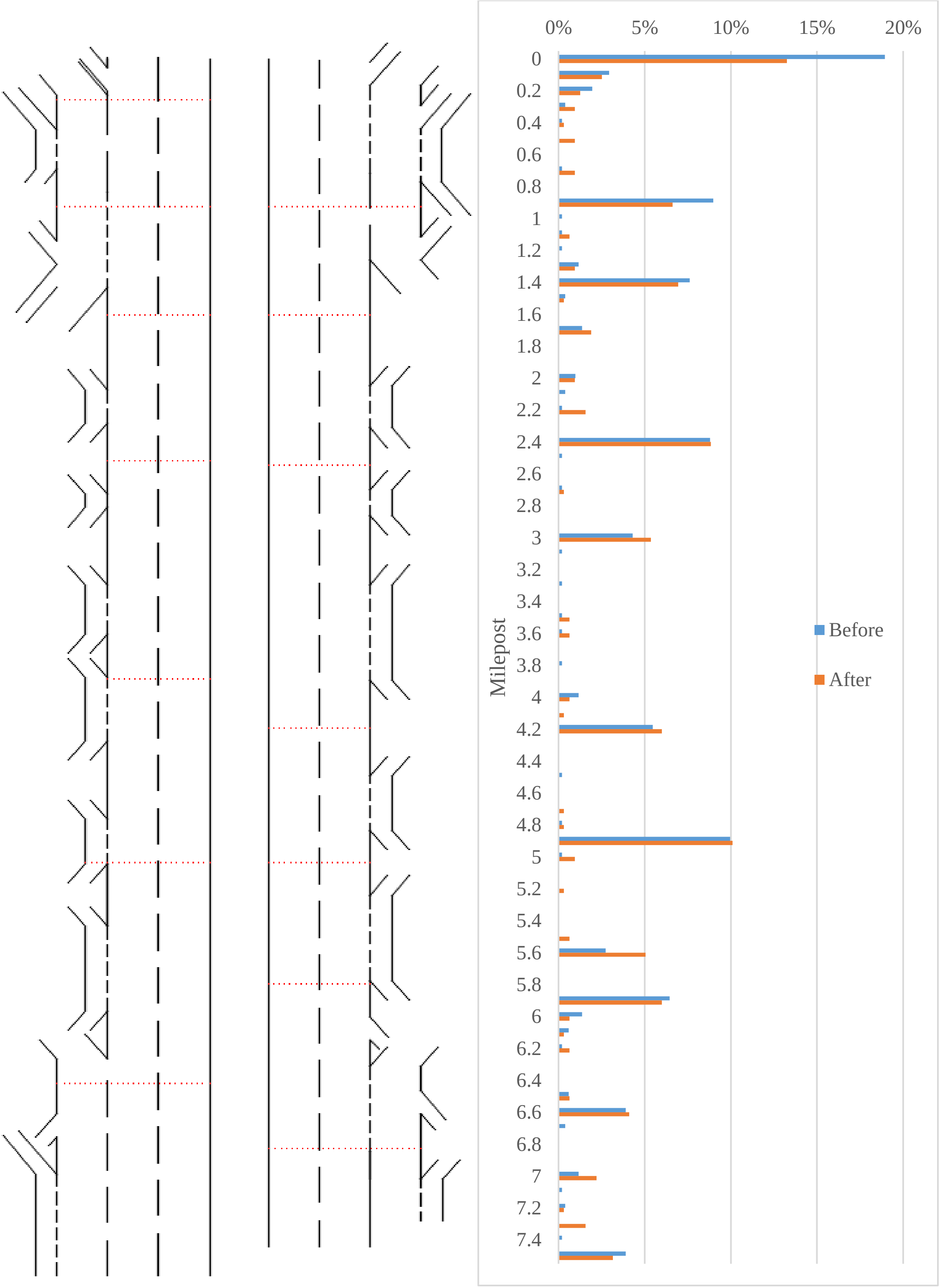


Figure 38: TOCS Crash Frequency

The corridor shows similar clustering to that of the WCCCA data indicating similar underlying crash trends. The crash frequency declined at the northern terminus of the corridor at the interchange with US 26. This may be attributable to the curve warning detectors installed at the large loop ramps. A similar marked decline in frequency occurs at the 1 mile post, between two VSL signs. Another location at milepost 5.6 saw a significant increase in crashes as a percent of the total. This location is not near a VSL sign and the increase is likely unassociated with the system.

5.3.1 Crashes Over Time

Figure 37 showed the raw crash distribution by month over the before and after period. The crashes showed a higher frequency in the year before the VSL implementation with almost all months showing high crash counts. These crashes could potentially be due to the construction associated with the VSL system. After the system activation the crashes regained the more seasonal nature of the previous years, but with higher counts per month. Immediately after the system activations crashes spiked, however these month coincided with the historically more crash prone fall months. This seasonal increase was repeated the following year October of 2015 the most crash heavy month in the database.

5.3.2 Summary

When the Naïve Before After Analysis is applied to the TOCS data the end results is an overall increase in crashes of 10%. This is higher than the WCCCA data indicates. The data in the TOCS records is not for all hours of the day and many crashes could be missed by this database. It is possible that with the activation of the VSL system the TOCS database started recording crashes for more hours than previously. Another possibility is that the enhanced ATM measures as part of the overall project provided more information about crashes, and thus more were recorded. This could explain the higher increase in crashes when the Before After Analysis is applied to the TOCS database compared with WCCCA. If the traffic volume change is ignored the database shows a more moderate crash increase of around 5%.

5.4 TDS Data

The TDS database provides the most information of any utilized in this study but has a long lag time as an expense. This database is also self-reporting as Oregon law requires all crashes with over $1,500 of damage or injuries to be reported. Compared to both WCCCA and TOCS it may capture smaller amounts of crashes as drivers choose to not report. Past wisdom and experience indicates that roughly 50% of crashes go unreported for this database, particularly in the PDO category. There were 1118 crashes before and 183 crashes after without the preliminary 2015 data. A total of 71% percent of crashes before were rear end crashes, while 80% percent of crashes were rear end crashes after.

5.4.1 Crashes Over Time

To take advantage of the more detailed data available in the TDS database, the raw crashes were examined for trends. Figure 39 shows the raw crash volumes on a monthly basis by crash category. Other factors such as the weather and lighting will be examined individually in subsequent sections.

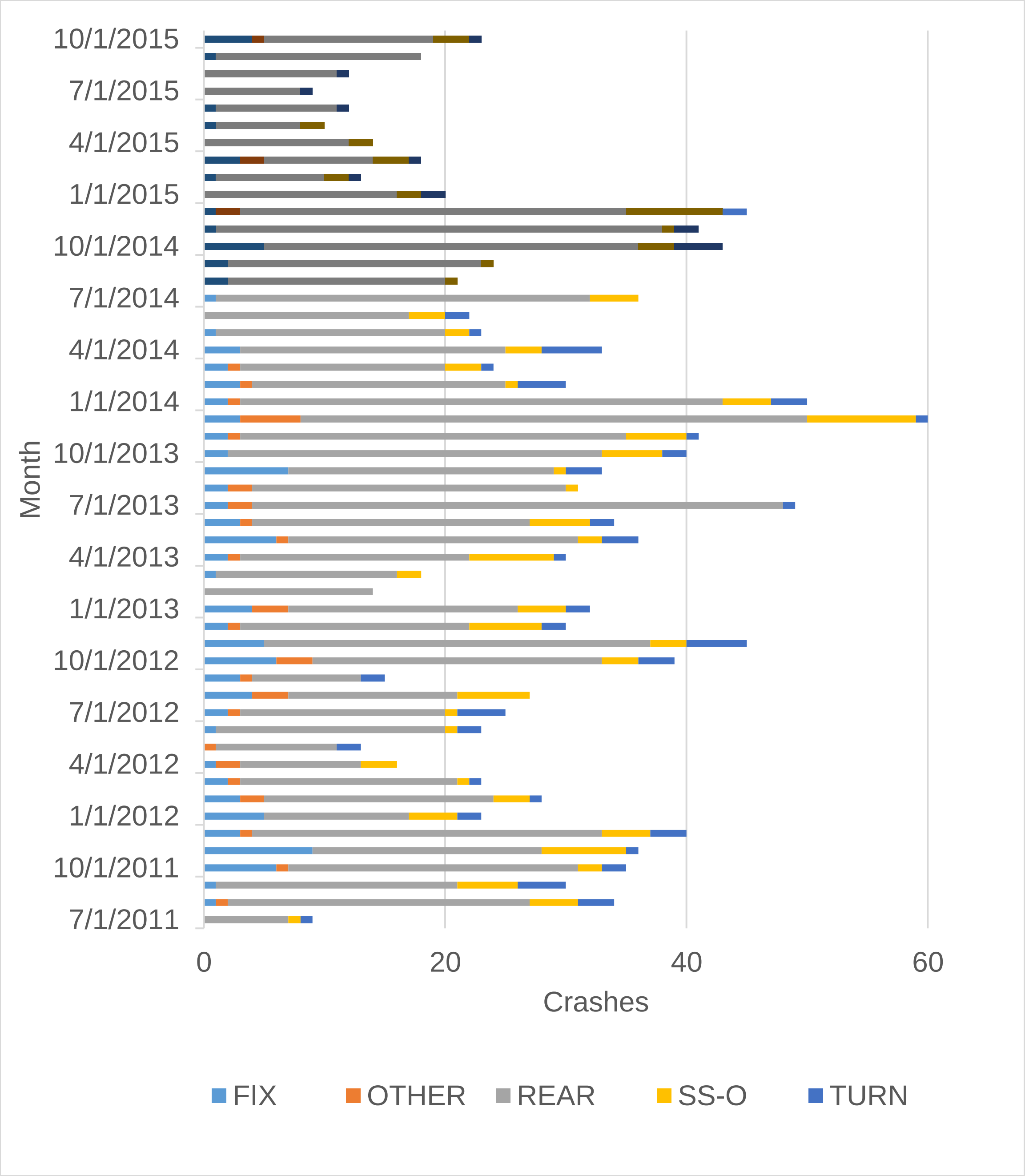


Figure 39: Crashes in the TDS Database By Month and Type

Similar to the crash trends for the other data sources, the corridor showed an apparent spike in crashes shortly after the VSL system was activated. This time period is associated with higher crash rates historically although the trend is more pronounced in the TDS data. The “Other” crash category largely disappears in the later data shortly before the VSL activation and is infrequent afterward, similar to “Sideswipe – Overtake” crashes. However the target crash type, rear end crashes, seem to comprise a higher proportion of the after crashes. The number of crashes in the before period is 1,118 and 432 total in the after period. The small number of after crashes includes a very short 5 month complete after data section, and another year of partial data.

5.4.2 By Weather Condition

As discussed in Section 4.2.6 the weather conditions were relatively consistent in the after period compared to the before period; about 44% of the days included precipitation and 52-54% of the days were clear, as shown in Table 2. The TDS database provides crashes sorted by weather conditions allowing testing of the weather conditions. Figure 40 shows the percent reduction estimated by the Naive Before After Analysis for each weather condition.

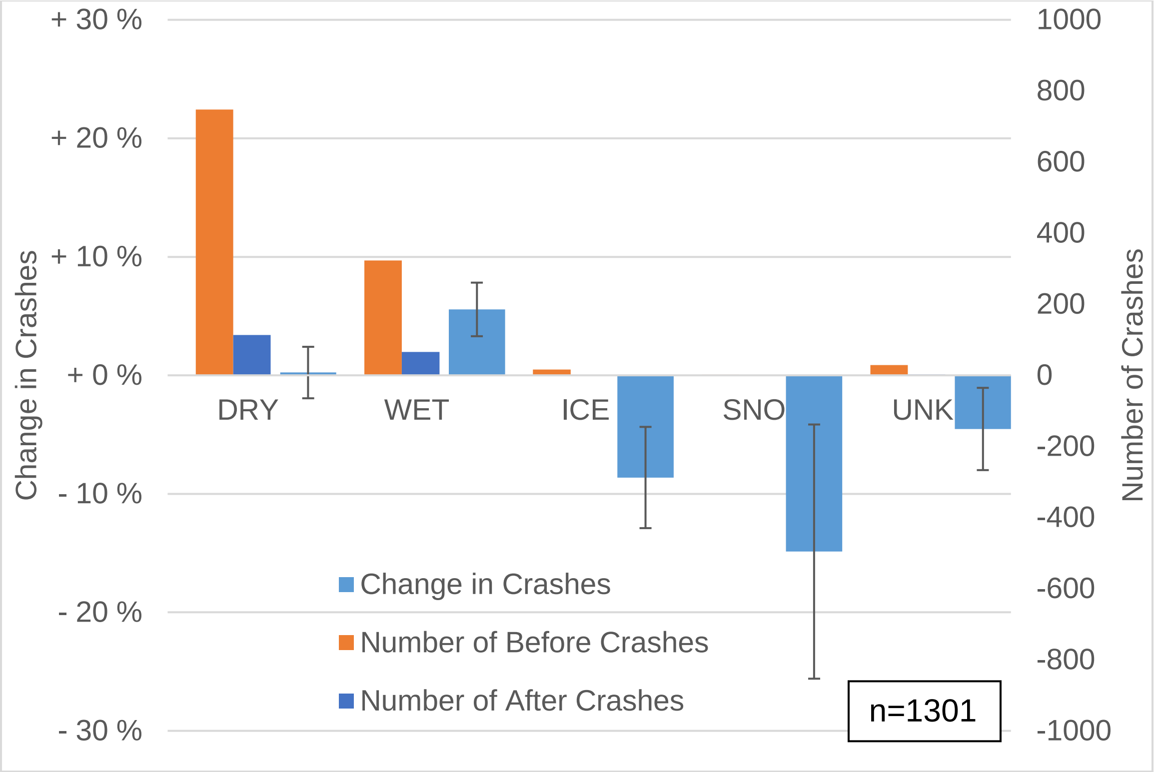


Figure 40: Naïve Before After Analysis Percent Change by Weather Condition

During wet surface conditions crashes were noted as increasing by approximately 5%. Other surface conditions improved, through dry surface conditions only improved by 0.54%. Less snow was recorded in the after condition potentially explaining the reduction in crashes. The "Unknown" condition also declined, however this could be due to better records of weather or crashes. Given that Section 3.3 showed dry and wet surface conditions are associated with over 95% of all crashes, the increase for wet conditions and small reduction in dry conditions is concerning.

5.4.3 By Lighting Condition

The other data sources provide limited information about time of day that crashes occur making the TDS lighting condition information valuable. To illustrate the lighting conditions commonly occurring with the crashes see Figure 41 and Figure 42. The figure shows that the percentage of crashes occurring during dusk increased while the percentage during the day decreased markedly.

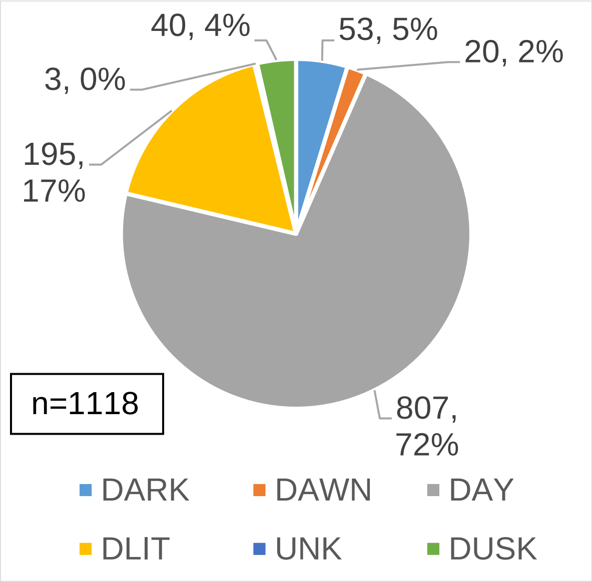


Figure 41: Crashes by Lighting Condition Before VSL Implementation

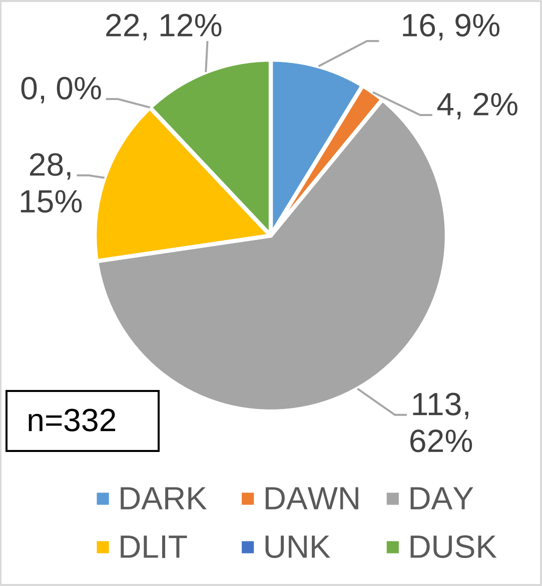


Figure 42: Crashes by Lighting Condition After VSL Implementation

To test the casual observations the Naïve Before After methodology was applied by lighting condition and results are shown below in Figure 43. Note that the DLIT category means Dark, Lighted and that most of OR 217 is well lit.

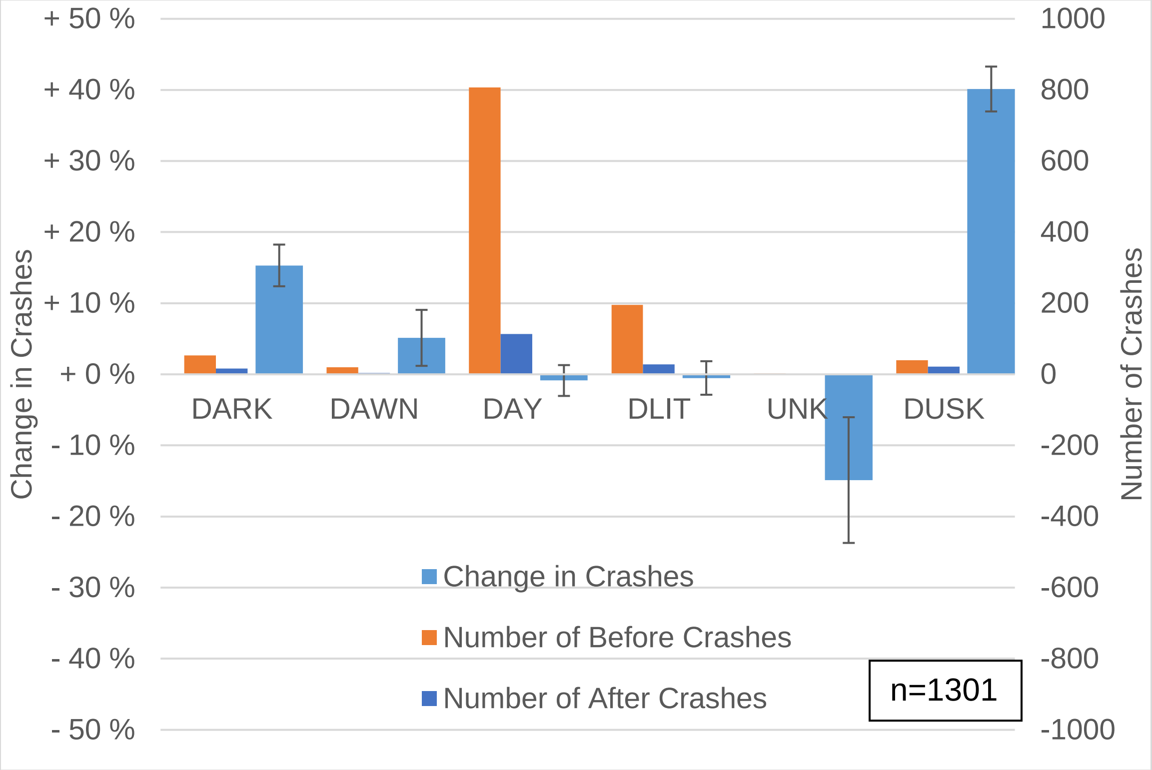


Figure 43: Naïve Before After Analysis Percent Change By Lighting Condition

During darkness and dusk crashes showed a marked increase in the after period. Both lighting conditions make up a very small percentage of overall crashes making the increase appear more marked than it may be. Due to the small number of crashes, a small perception change in what is considered dusk hours may be causing the outsize increase. Furthermore, the VSL system is least likely to be active during either of these time periods limiting its potential impact. The crashes which comprise the majority occur during the day, and saw a decrease of 1.7%. Similarly the second largest crash lighting condition, dark with lighting, had a 1.3% decline with the before after analysis. The unknown lighting condition reduction was entirely due to better reporting, with none reported in the after period.

5.4.4 By Crash Type

A focus of the VSL system was to reduce the number of rear end crashes occurring on OR 217. The TDS database categorizes each crash by its type allowing for comparison using the Naïve Before After methodology. In both before and after conditions, rear end is the largest category with fixed object, sideswipe – overtake, and turning crashes contributing the bulk of the remainder. The reduction in crashes can be seen in Figure 44.

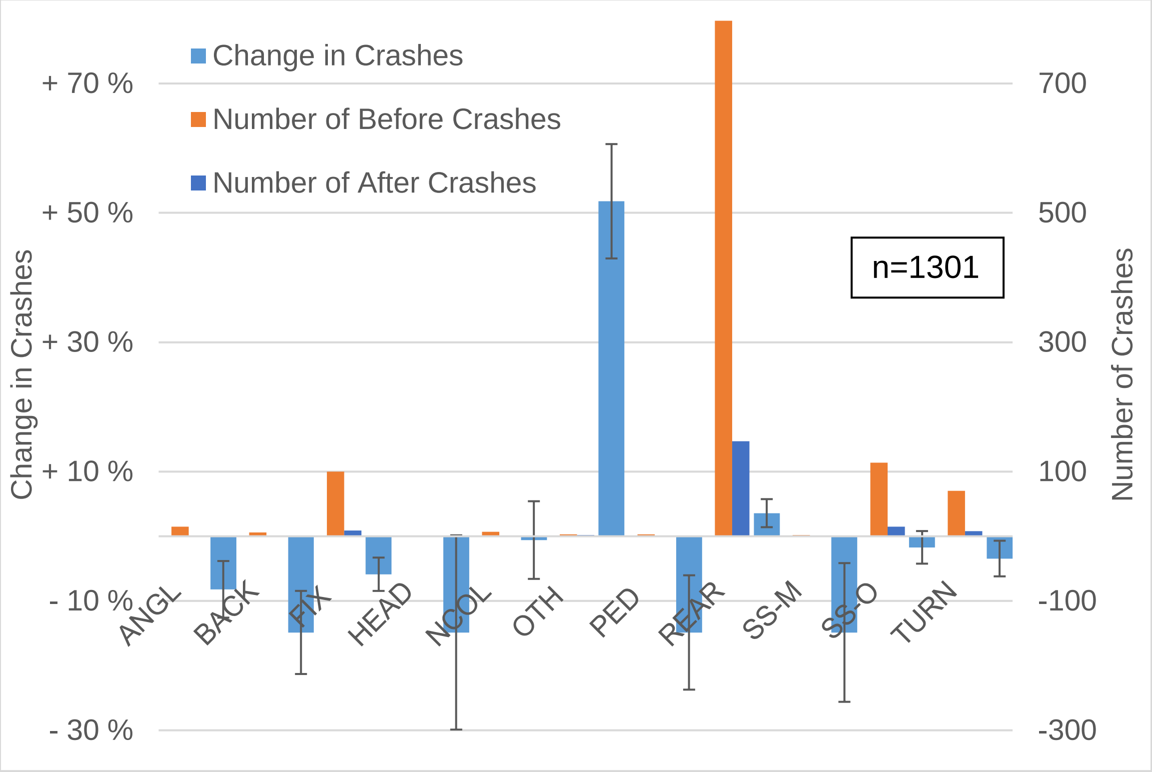


Figure 44: Naïve Before After Analysis Percent Change by Crash Type

The target crashes, rear end, have increased in the after condition according to the Naïve Before After analysis. The other main crash type categories all experience reductions with the new VSL system. The “Other” crash type experiences a dramatic increase however this is due to an extremely small sample size. Similarly, the crash types showing a 15% reduction are all due to having no recorded crashes of that type in the after condition making the Naïve Before After Analysis not applicable.

5.4.5 By Injury Class

The TDS data provides information on the class of injury recorded. Oregon follows a standard five class system with Fatal, Injury A (incapacitating injury), Injury B (visible injury), Injury C (complaint of pain or minor), or Property Damage Only. The most severe category, fatal, has a small sample size and is combined with Injury A to increase the statistical reliability. Figure 45 shows the percent reduction by injury class.

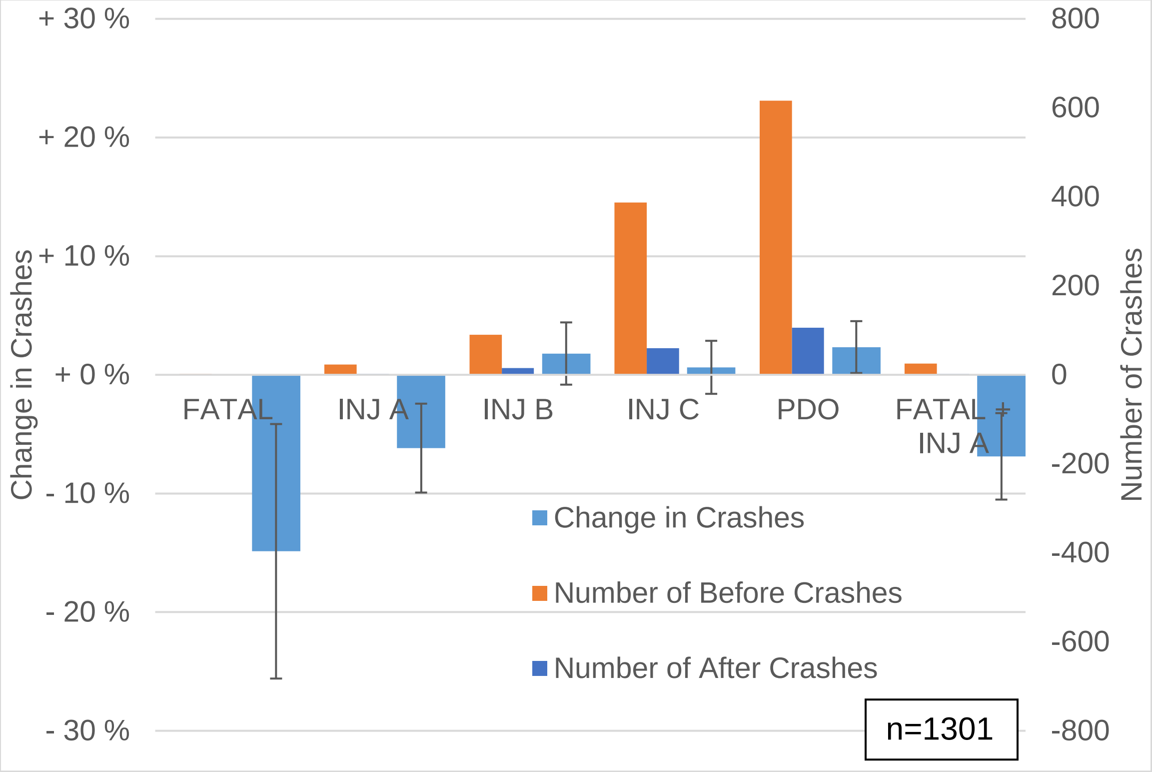


Figure 45: Naïve Before After Analysis Percent Change By Injury Class

The most severe injury categories experienced a reduction in crashes compared with the prediction. The low sample size makes the fatal category unreliable but when combined with Injury A crashes it still shows a reduction of 7.5%. If the change in traffic volumes shown by the Portal data is ignored, the severe crashes experience a decline of 7%. Crashes with minor injuries or complaints of pain also declined by very small margins. Crashes with either visible injuries or property damage only both increased by around 1.5%. If constant traffic volumes are assumed this increase is a more muted 1%. The VSL system activation appears to be associated with a reduction in the number of severe crashes but with small increases in less severe ones.

5.4.6 Summary

The Naïve Before After Analysis of the TDS data shows an overall 3% increase in crashes on the corridor. When conditions of the crashes are looked at in more detail, analysis shows that crashes are reduced during daylight hours, and when it is dry. However, an increase in crashes occurs during wet conditions, already a significant contributor to the crashes on OR 217. One of the targets of the VSL system, rear end crashes, increased by 2% during the after condition. Severe crashes decline significantly while less severe crashes increase by a more modest amount. The results show a mixture of good and bad for the corridor. The short after period for this analysis of only 5 months causes some reliability problems. The after data does not capture all seasons but covers the notably tricky fall conditions, potentially skewing the results. If the traffic volumes are not adjusted and assumed identical, the crash rate increases by a more modest 1.5% according to the Naïve Before After methodology.

5.4.7 Updated Incomplete Data

To try to compensate for the small quantity of after data from the TDS data source, additional analysis was conducted on some preliminary, incomplete data from the year 2015. This new data does not include any property damage only crashes, and may not include all of the other crashes as well. The state of Oregon has a long reporting period and some crashes may have not yet been processed into the database at the time it was received. Analysis was then conducted without any of the property damage only crashes. The results by injury class are shown in Figure 46.

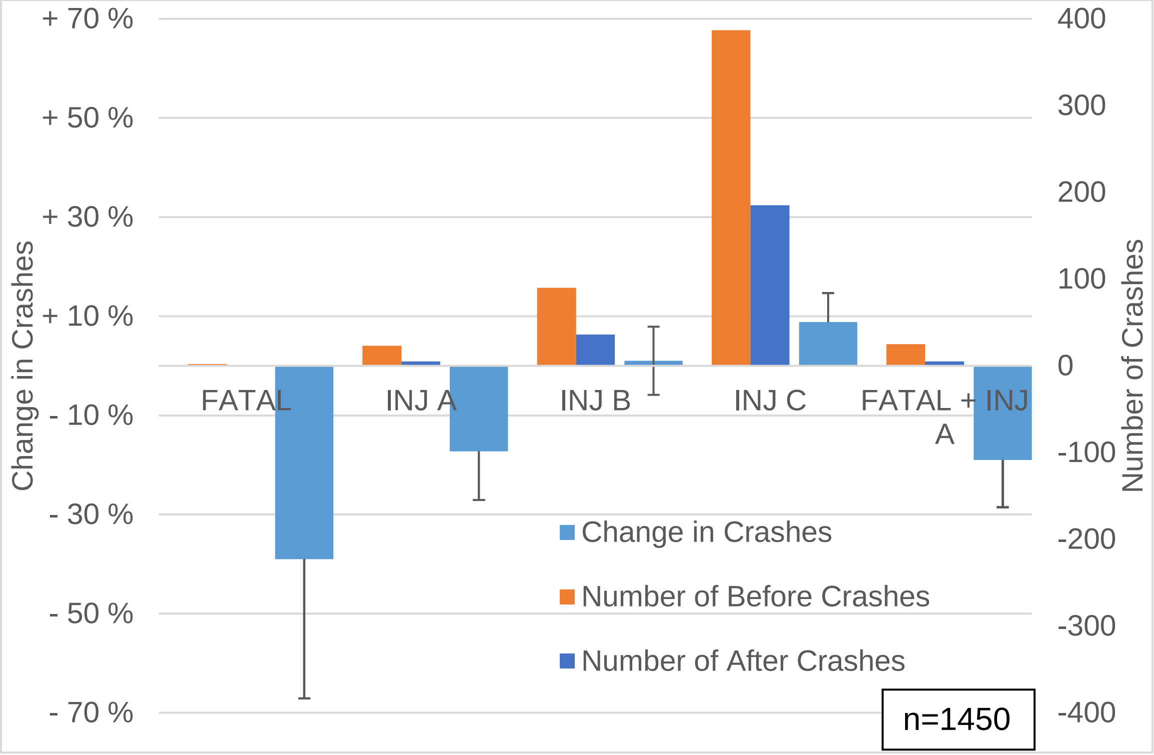


Figure 46: Naïve Before After Analysis Percent Change by Injury Class

With almost a full year of new data more than doubling the after period, all of the injury crashes showed changes in the Before After methodology. The continued absence of fatal crashes and severe injuries caused the reduction to increase as a percentage. However, Injury B maintained the same 1% increase in crashes. Injury C, the most frequent type, no longer showed a small reduction in crashes but instead increased by 8%. Due to the incomplete nature of the data these reductions are likely to be overstated and will decline after more crashes are added to the database. Because the less severe crashes are more numerous the Naïve Before After Analysis of the new data indicates a 6% increase in crashes overall. Regardless the declines in the most severe crashes may indicate a positive impact from the VSL system.

With the new data including only injury crashes, further analysis of rear end crashes was needed. Rear end crashes are the highest contributor to injury crashes and are a target of the VSL system. Figure 47 shows the change in rear end crashes by crash severity.

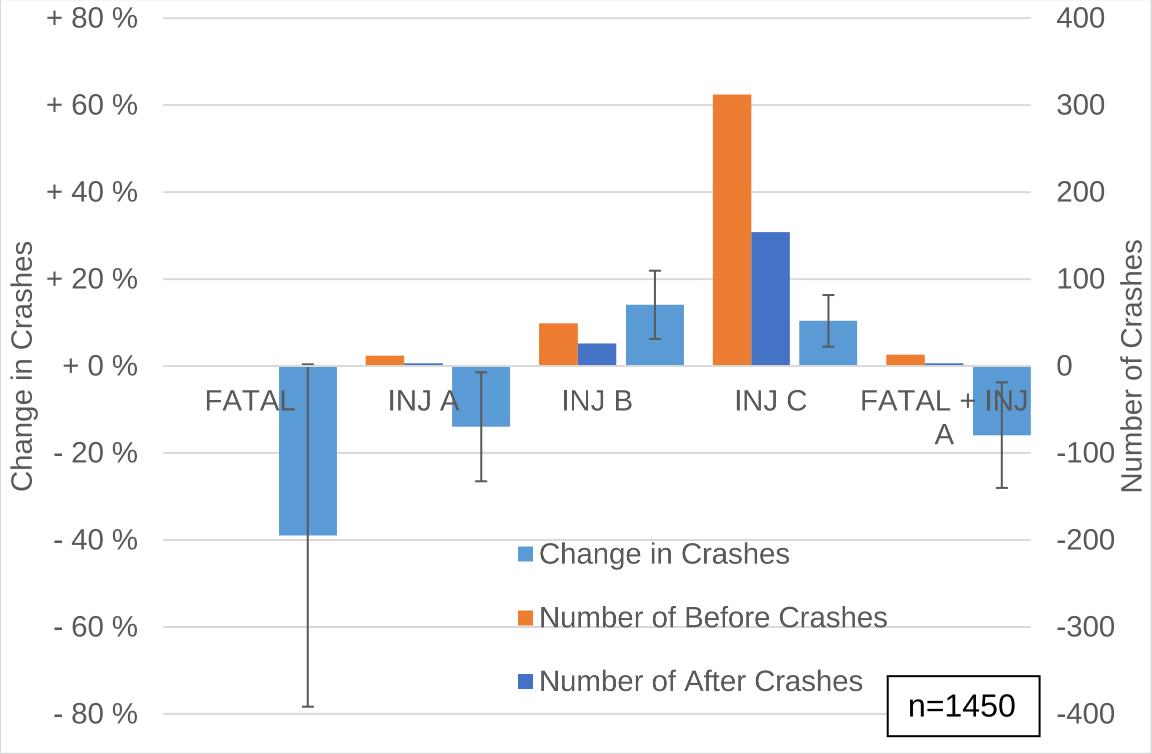


Figure 47: Naïve Before After Analysis Percent Change of Rear End Crashes by Crash Severity

The more severe crashes saw sharp declines for rear end crashes, dropping by around 15%. However, the less severe crashes of visible injuries and minor injuries, both had increases in the number of crashes according to the Before After methodology. This suggests that rear end crashes are becoming less severe but may be occurring more often. Conducting this analysis again at the end of 2018 would yield more reliable results and capture the longer term trends.

5.5 Statistical Analysis

To test whether results are statistically significant the methodology established by Hauer provides a method of determining how many data points are needed to reliably detect changes of specified percentages. Given that in this case the data was all complete and could not be added to, the process was reversed in this analysis, determining the change that could be detected from each data source. The number of crashes in the before period is compared with the index of effectiveness and ratio of before and after study time periods to determine the change observable by a formula. The index of effectiveness is a measure of the predicted crashes and the actual crashes to determine the reduction or increase that occurred. For example, an index of effectiveness of 0.9 represents 9 crashes occurring for every 10 predicted.

For the overall WCCCA data source with 1842 crashes before the VSL activation, the change that can be reliably detected is around 8%. The TOCS data source only has 510 crashes in the before data set and cannot reliably detect changes of 15%. The TDS data source had 1,118 crashes in the before data set and can detect changes of around 10%. Any division of the data into smaller categories prior to analysis makes the detectable change larger and the estimates more statistically unreliable. All of the data sources are unable to reliable detect changes as small as those determined from the naïve analysis making the results potentially unreliable. However, they do provide an idea of the change that may be occurring.

The simplest way to decrease the number of before crashes required is to lengthen the after study period, making the R_d factor larger. In this particular study the R_d factor is 0.6 as the after period is shorter than the before period, requiring more before crashes to detect changes. A study in the future when the R_d factor is 1.0 or greater would be far better for analyzing the corridor and developing reliable estimates for the safety capable of determining smaller impacts.

5.6 Summary

With all three data sources analyzed using the Naïve Before After Analysis, the results generally show an increase in crashes after the VSL system was activated. Figure 48 summarizes the key results from all three data sources.

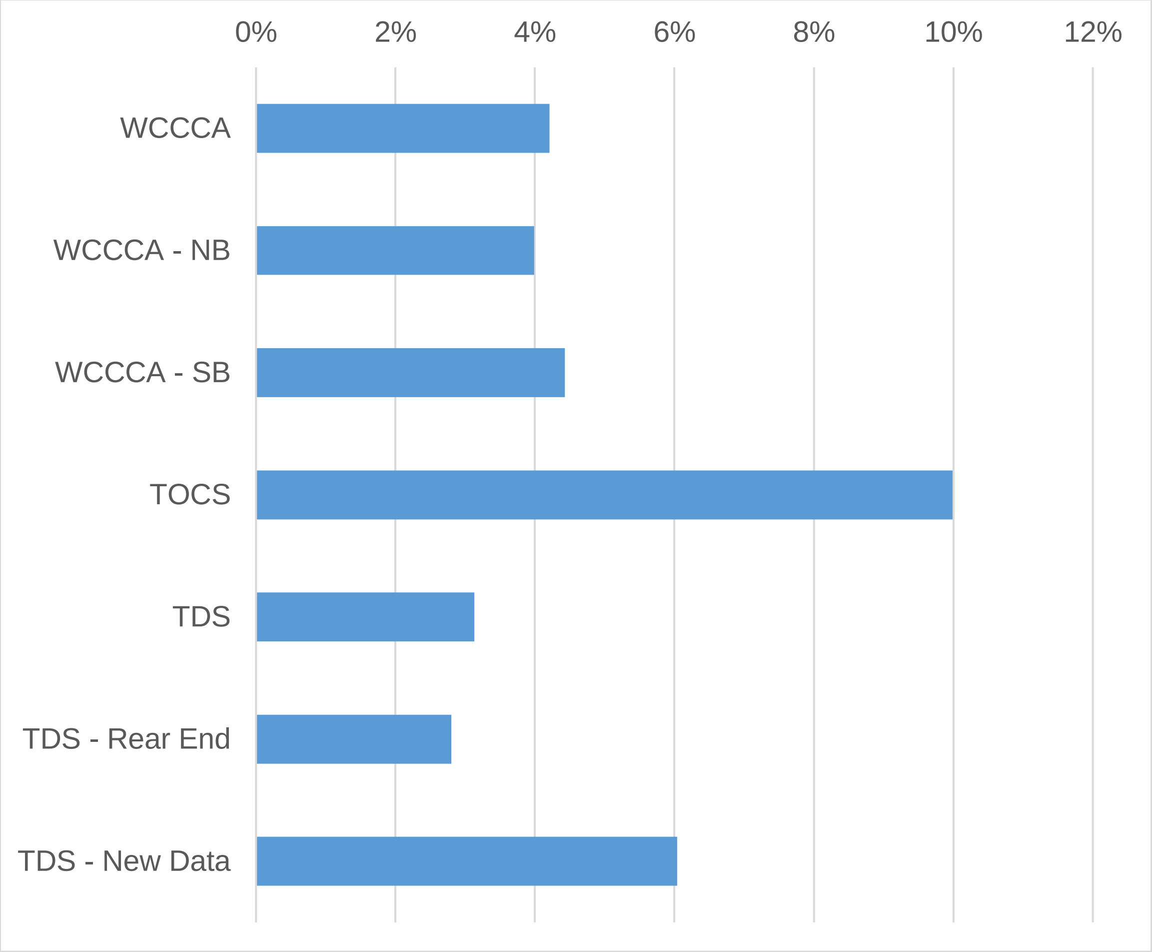


Figure 48: Before After Methodology Percent Change By Data Source

The complete databases range from estimating a 3% to 10% increase in crashes. The 10% value from the TOCS analysis is out of line with the other data sources. It may be due to enhanced ATM capabilities on the corridor making it easier to identify and track crashes during the after period. WCCCA and TDS both show similar crash increases of around 4%. Splitting the crashes by direction of travel did not indicate that either experienced a major change. The TDS database was studied to determine the impact to the targeted crash type, rear end crashes, which experienced a 3% increase as well. All of the crash data sources do not have enough data to reliably detect the change that the Before After analysis is showing.

6.0 Empirical Bayesian Analysis

The Naïve Before After Study forms a solid base understanding of the impact the VSL system has had but has some flaws. This research aims to address those flaws by using Empirical Bayes analysis, a more complex method that accounts for regression to the mean. The Empirical Bayes Analysis is well established as the best analysis method for roadway safety studies. It seeks to use the crash records for the study site as well as comparative sites to determine the impact of a treatment. Section 6.1 explains the methodology behind the analysis.

6.1 Methodology

The flaw with Naive Before After studies is assuming that crashes before the implementation of the system are representative of conditions occurring afterward. Adjusting for the study period length and the traffic volumes helps to correct this but better estimates are possible through the Empirical Bayes method. The methodology allows for adapting expected crash counts from similar sites to the study site. This method reduces the likelihood of regression to the mean as a cause for an apparent decline in crashes. Sites selected for treatment, such as OR 217, are often outliers with higher than typical crash rates. These higher rates could merely reflect the roadway experiencing a time period of above the mean crashes, or could reflect a fundamental issue with the roadway causing the increased crashes. Treatments showing a decrease in crashes could be the roadway reverting closer the mean, something that would have happened anyway, or an actual improvement at the site. The Empirical Bayes methodology accounts for the regression to the mean and gives a clearer picture of improvements resulting from the treatment. Figure 49 shows an example scenario where standard methods may overestimate the treatment effectiveness.

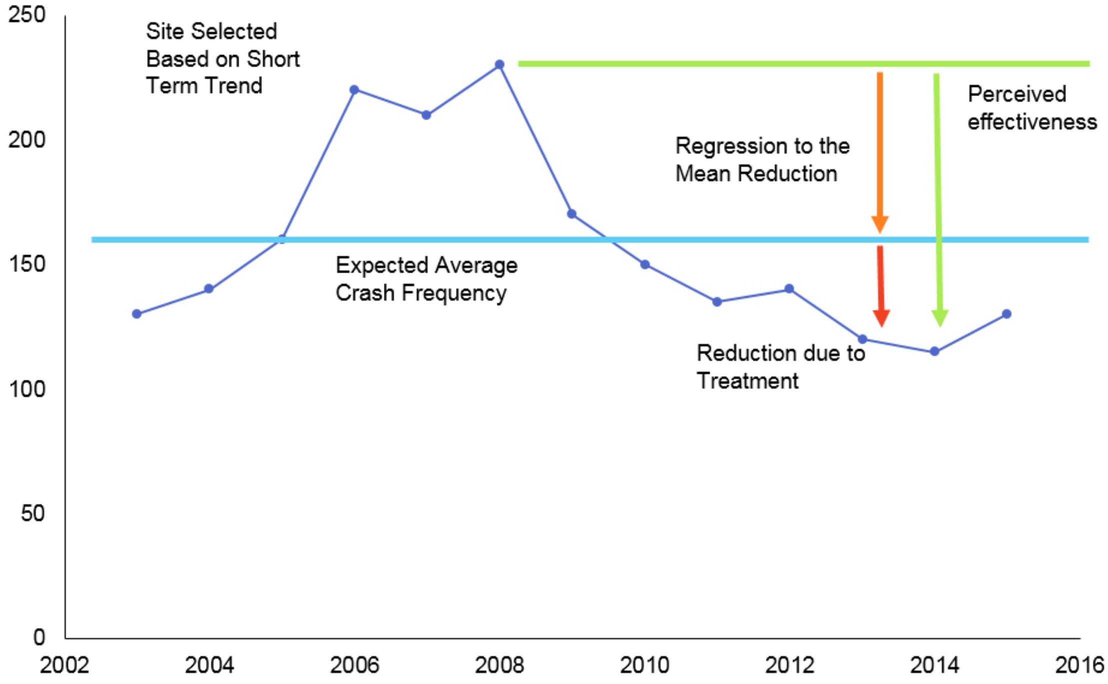


Figure 49: Illustration of Regression to the Mean

In order to utilize this analysis method a baseline estimate of crashes for the site is required. The estimate is a result of the Safety Performance Function (SPF), which is a basic relationship from a few site characteristics that predicts the number of crashes typically occurring on the site. The estimate is further clarified by application of Crash Modification Factors (CMFs). These account for various other site conditions and modify the SPF result. A simple application would the traffic volume or the width of the lanes at the site. The Highway Safety

Manual (HSM) provides a method for creating SPFs for three main site types and the associated CMFs (Bonneson 2010). Currently the First Edition does not contain any methodology on urban freeway segments, however a draft chapter for freeways is available online (Bonneson 2012). This methodology was applied to OR 217 to develop the crash estimates.

The first step in applying the SPF is dividing the facility, OR 217, into smaller “sites” which are either homogeneous freeway segments or speed change lanes. Figure 50 shows a simplified version of the segmentation process for speed change lanes and freeway segments.

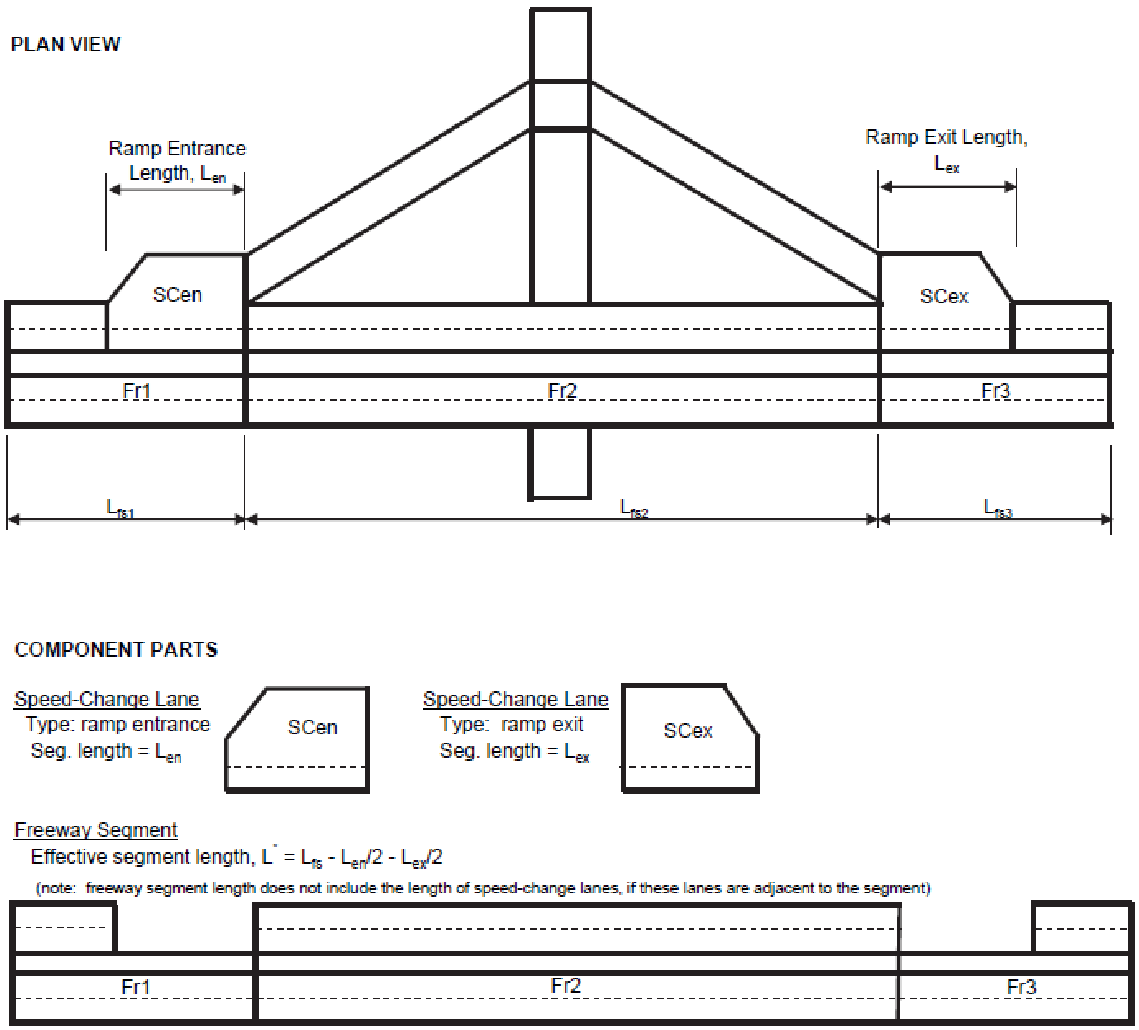


Figure 50: Example Segmentation of the Corridor
Source: Highway Safety Manual

Figure 51 shows an example of how one portion of OR 217 was segmented into sites. The green section represents a speed change lane next to a freeway segment in red. These segments begin and end at every ramp gore point. OR 217 was divided into a total of 23 segments for this analysis with the ends of the corridor excluded. These ends were excluded as the VSL signs are not located at the very ends of the corridor and the geometry of the freeway begins to lose conformity with the methodology at these points. Furthermore the crash data sources WCCCA and TOCS do not give enough detail to determine whether crashes occurred on the ramps ending the freeway or near to the ramps while still on the freeway.

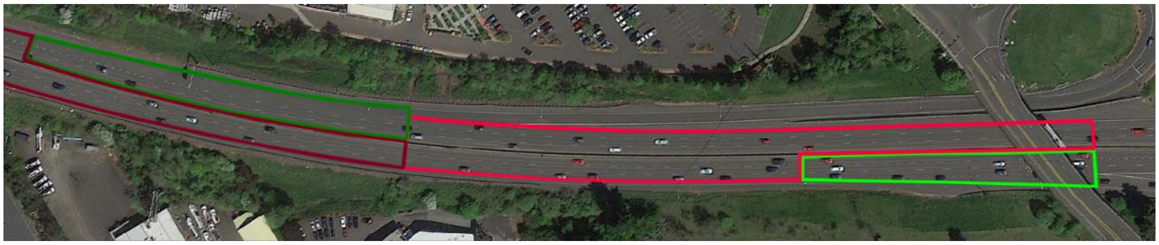


Figure 51: Illustration of Segmentation of OR 217

An SPF is developed for each of these sites, and appropriate CMFs are applied to give a predicted number of crashes. To calibrate the predicted number of crashes to local conditions the prediction and recorded crashes volumes are combined using a weight determined by the overdispersion parameter. This new value is the expected number of crashes for each site. The sites are summed and adjusted to local conditions through a calibration factor to give the expected number of crashes on the corridor. In this case the local calibration was not made as the methodology is largely based on highways in neighboring Washington State.

For OR 217 the information needed to develop the SPF was mostly provided through official ODOT documentation. The Highway Inventory Report provides all of the lane, shoulder, and median width as well as barrier types and other important information. Supplementary measurements verify the accuracy of the information provided. The horizontal alignment with all curve information is provided in a separate report and converted for use with the curve CMF. The traffic data is needed at a granular ramp level and obtained from official ODOT ramp volumes. Data for the ramps is available from 2011 to 2015 and was used to compute mainline volumes as well. This data source is different than that used in the Naïve Before After Analysis. It is notable that the traffic volumes are integral to the analysis and if traffic was to not change the expected values would be identical per year and the analysis would degrade to a simple comparison.

This methodology provides crashes volumes for both fatal and injury crashes, as well as property damage only crashes. Because the SPF takes account of many roadway factors, including traffic volumes, it is evaluated for each year of the study period. The calibration occurs during the before years to establish a baseline understanding of the corridor and how it relates to the predicted crash frequency. A ratio of the predicted and expected crashes for the before years is multiplied against the after predictions to give the after expected crashes. This result accounts for both the changing geometry or traffic volumes on the corridor, and the roadways natural difference from SPF predictions.

6.2 WCCCA

The WCCCA data was used to calibrate the SPF predictions. Because this data does not include much information about crash severity assumptions were made. The records that had “Traffic Accidents – Unknown Injury” were assumed to all have no injuries. It seems likely that crashes involving an injury are more noticeable and will be reported to 911 when called in. Table 4 below compares the predictions and actual crashes by year.

Table 4: Expected and Actual Crash Volumes

Crash Type	Source	Before			After	
		2011-2012	2012-2013	2013-2014	2014-2015	2015-2016
Fatal And Injury	Predicted	83.42	82.37	80.94	67.57	60.69
	Actual	**87**	**92**	**103**	**68**	**63**
PDO	Predicted	216.15	213.01	210.85	170.50	156.42
	Actual	**312**	**361**	**445**	**404**	**285**

After the predictions for the three before years are weighted and converted to estimated crashes per year, they are forecast out to 2014-2015 and 2015-2016. The expected number of crashes and the recorded number for 2014-2015 is shown in Figure 52. The error bars on the figures represent the maximum range of possible expected crash values from the Bayesian Analysis.

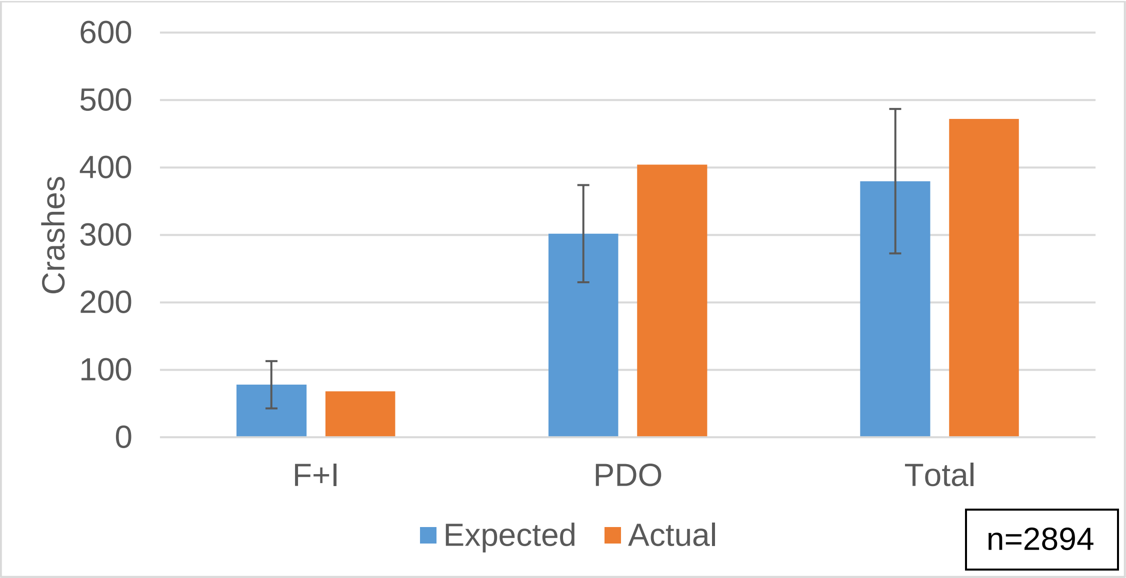


Figure 52: WCCCA 2014-2015 Expected and Actual Crashes

Figure 53 shows that fatal and injury crashes are lower in the year immediately following the system activation. However, as the figure also shows, these crashes are much fewer in number than non-injury crashes and the overall freeway saw a large increase in overall crashes. If the trend is carried out to the most recent data from 2015-2016 the same pattern emerges as Figure 54 shows.

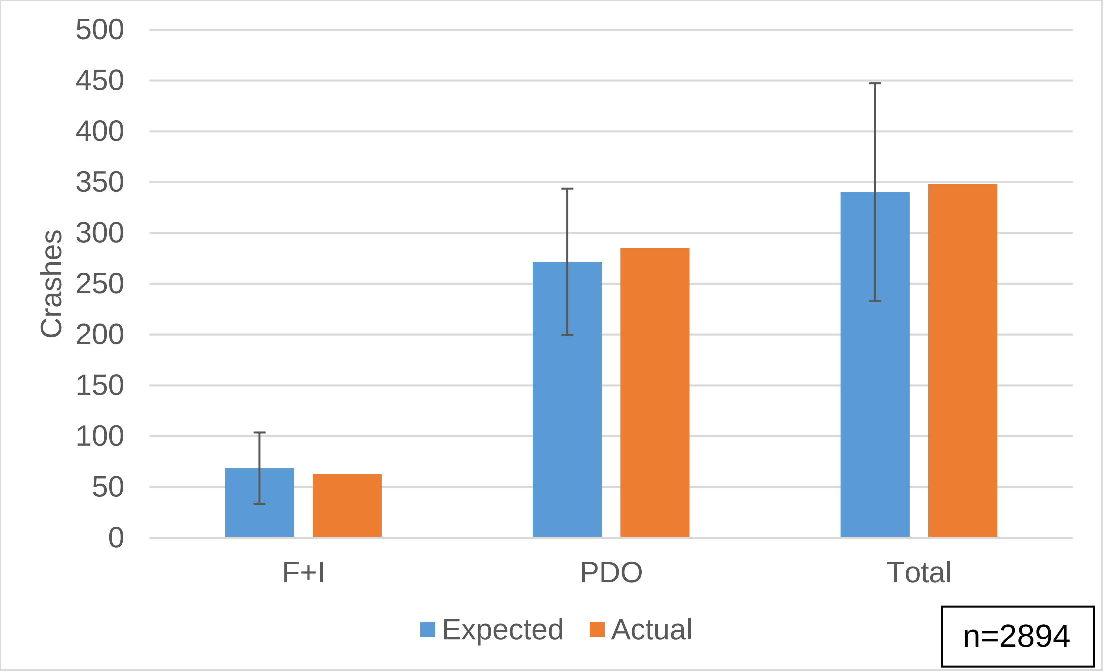


Figure 53: WCCCA 2015-2016 Expected and Actual Crashes

The newer data shows an even larger decline in the small numbers of crashes with injuries, while also have a reduced increase in the number of property damage only crashes. This may indicate that the system is performing and improving but needs more time for drivers to become accustomed to it. The overall after period estimate and actual crash counts are in Figure 54.

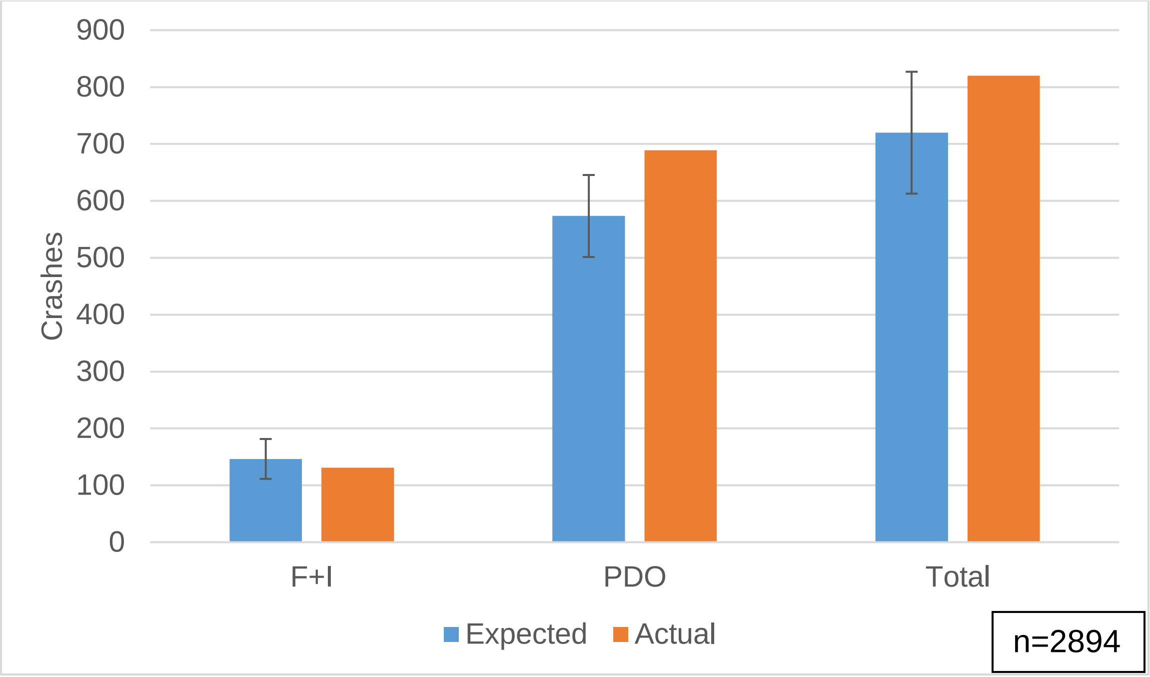


Figure 54: WCCCA After Expected and Actual Crashes

When the data for both after years is used the result appears much the same with the fatal and injury crashes declining slightly and property damage only crashes increases by several percent. However based on the result shown from each year the trends may improve as the system remains in place and the next year could show a drop in the number of property damage only crashes if trends continued. In addition the error bars for the ranges of expected values indicate that the system could potentially be experiencing a small decline in crashes and still fall within the margin of error.

6.3 TOCS

After analysis with the WCCCA data the TOCS data was also compared to determine if trends were consistent between data sources. Because the TOCS database has no information on the severity level of any crashes, all of the crashes for the corridor had to be summed and compared. This results in no information about smaller trends and Figure 55.

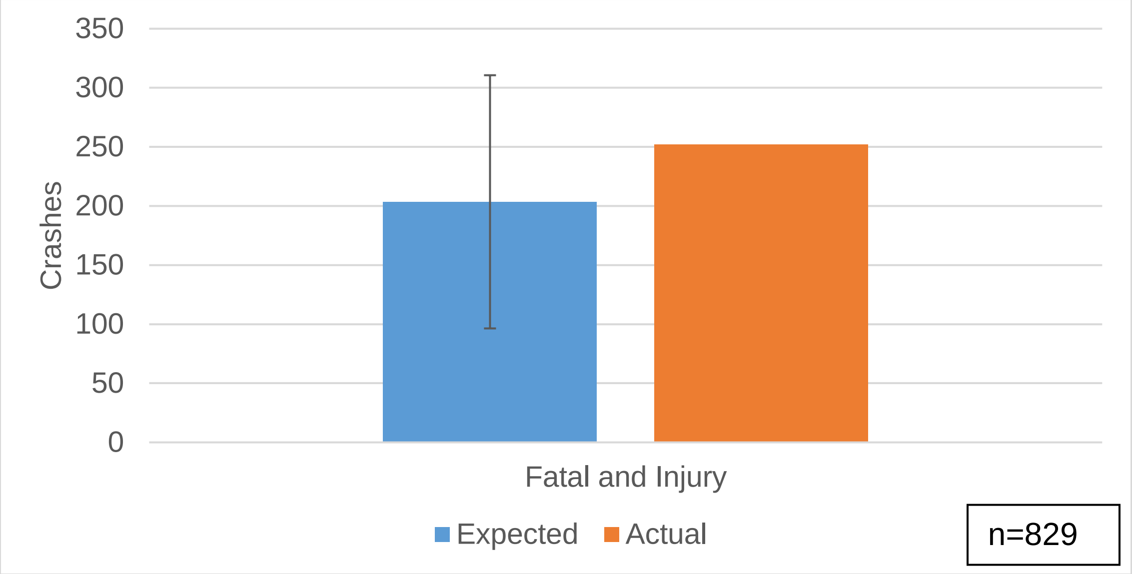


Figure 55: TOCS Empirical Bayes Prediction

The TOCS data shows an increase in the number of recorded crashes with the jump being approximately 20%. This is steeper than even the Naïve Before After Analysis showed. Despite the smaller number of crashes, the estimate shown from the Empirical Bayes may still be more accurate due to the stricter methodology accurately making due with less data. The error bars indicate the lack of confidence with an extremely large potential range for the number of expected crashes. This large margin of error makes it possible that the system could have been improved by the VSL system. As with the Naïve Before After Study it is very possible that the project has added capabilities to detect more crashes in the after period than in the before period and that this is causing the large uptick in crashes.

6.4 TDS

The final data source comparison used the official statewide crash data with the unofficial, incomplete data mixed in. Without including the preliminary data from 2015 the after period was too short to make any reasonable predictions. Instead the data simply had to be looked at for fatal and injury crashes only as the 2015 property damage only crashes are not yet available. Figure 57 shows the expected number of crashes and the actual fatal and injury crashes.

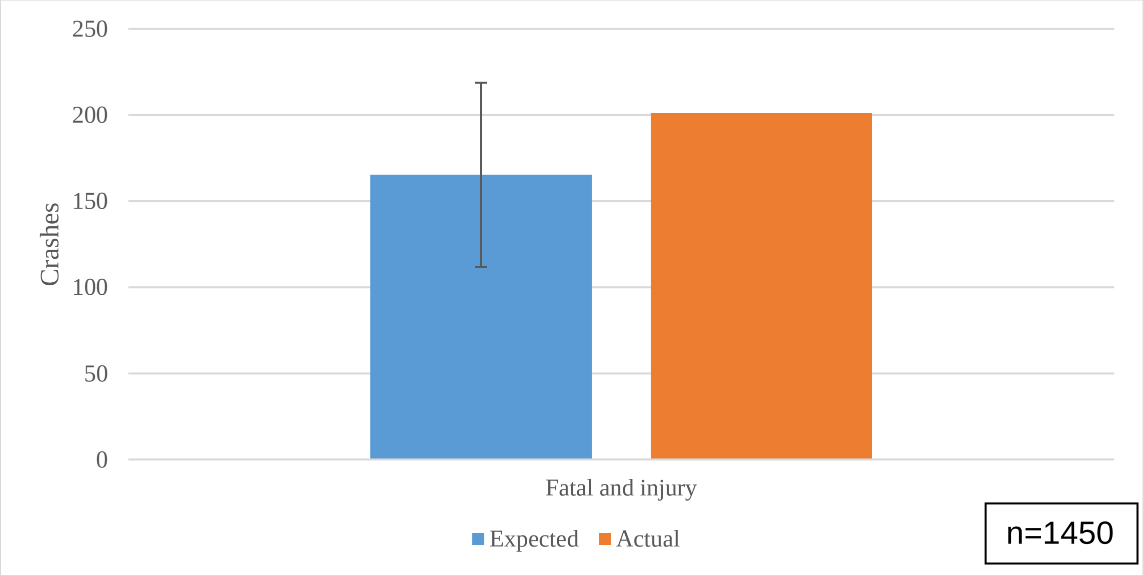


Figure 56: TDS Empirical Bayes Prediction

The TDS data mimics the TOCS data with a 20% increase in the number of crashes recorded against expectations. This difference is surprising given that WCCCA showed a small decrease in fatal and injury crashes using the Empirical Bayes analysis. It could be tied to the shorter study period that the TDS data had as WCCCA started to show real improvements the further from the VSL activation date. The error bars show that the range of expected crashes is quite large and the system could be potentially experiencing a small decline at one extreme.

7.0 Conclusions

When the analysis methods of both a Naïve Before After study and Empirical Bayes study are considered, the results for OR 217 are not clear regarding safety. Most measures show the corridor as have a marked decline in safety with crashes going up by between 4% and 20%. However, the same sample sizes render some of these estimates null while others may be inflated by unequal data reporting in the before and after period. The Naïve study results generally conform, despite having statistical difficulty proving their validity, while the Bayesian results vary more substantially.

The main data source for this study, WCCCA, shows a decrease in more severe crashes through the Bayesian Analysis while the other data sources show large jumps. This could be due to better data collection for TOCS and the limited time period for the TDS data as the results generally appear to improve as time goes on, shown even in the WCCCA data for 2014-2015 and 2015-2016.

The increase in crashes generally appears to be more noticeable for the lower severity crashes, a potential positive. This could be due to drivers having closer speed matches after the system was activated and thus reducing the crash severity. The past research on OR 217 showed that speed lane differentials changed little before and after with different sites experiencing either an increase or decrease of less than 5%. The possible rise is crashes may similarly be due to the lower compliance of drivers on the roadway as recent research found (Riggins, 2015).

The increase in crashes could also be the result of information overload as drivers are suddenly faced with additional information on an already busy corridor. Drivers have new VSL signs, variable message signs, curve warning signs, and all of the other signage associated with 11 sets of ramps in one 7-mile freeway. In the literature review about the removed system in Missouri, too much information for drivers was cited as a common complaint and heavily influenced the decision to remove those boards.

7.1 Contributions

This study shed more light on the complex subject of roadway safety and how it is impacted by VSL systems. Its results add to the knowledge of systems evaluated using both a Naïve Before After Analysis and Empirical Bayes Analysis.

7.2 Limitations

This analysis does have limitations about the implications of its results. The limited data available in all of the data sources prevented small changes in crash volumes from being reliably detected. In addition, the short after period made seeing trends more difficult and may not be capturing the full impact after drivers have settled into the new system and gotten used to all of the information available.

7.3 Future Research

Conducting this study again in two years when the full three years of after data is available would allow for better determinations of the actual impact. The safety effects are currently generally negative and to follow up with additional data could show an improvement that starts slowly as the WCCCA data may indicate. In addition, this research would likely be more accurate due to the reduced volume of before crashes required.

Research into drivers' perceptions of the system would also help to answer a crucial part of the analysis, how safe drivers feel. Improvements in safety may occur but if drivers do not feel safer then it may not have been worth it. Determining this would go a long way towards deciding if the OR 217 VSL system is a success in the eyes of its most important people, the users.

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