BEFORE AND AFTER STUDY OF SAFETY IMPROVEMENT PROJECTS ON STATE HIGHWAYS FUNDED THROUGH THE HIGHWAY SAFETY IMPROVEMENT PROGRAM

Final Report

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by

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16. Abstract

This study develops a transferable framework for the analysis of three low-cost safety improvement projects installed on state highways in Oregon; specifically Rectangular Rapid Flashing Beacon (RRFB), Shoulder Rumble Strips (SRS), and Two-Way to Four-Way Stop Conversion. A before-after EB study was performed for RRFB and SRS. A cross-sectional analysis was conducted for stop control conversion in the absence of installation data. For RRFB, the Crash Modification Factor (CMF) for total pedestrian crashes was found to be 0.481. The total crashes and rear-end crashes were also found to have reduced by 27% and 14%, respectively. The CMF for total crashes and run-off-road crashes in the presence of SRS was found to be 0.72 and 0.73, respectively. The result from the cross-sectional analysis suggested that four-way stops are associated with approximately a 15.7% reduction in crashes compared to two-way stops.

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SI* (Modern Metric) Conversion Factors
Approximate Conversions to SI Units

Physical Quantity	Symbol	When You Know	Multiply By	To Find	Symbol
Length	n	inches	25.4	millimeters	mm
Length	ft	feet	0.305	meters	m
Length	yd	yards	0.914	meters	m
Length	mi	miles	1.61	kilometers	km
Area	in2	square inches	645.2	square millimeters	mm2
Area	ft2	square feet	0.093	square meters	m2
Area	yd2	square yard	0.836	square meters	m2
Area	ac	acres	0.405	hectares	ha
Area	mi2	square miles	2.59	square kilometers	km2
Volume	fl oz	fluid ounces	29.57	milliliters	mL
Volume	gal	gallons	3.785	liters **	L
Volume	ft3	cubic feet	0.028	cubic meters	m3
Volume	yd3	cubic yards	0.765	cubic meters	m3
Mass	oz	ounces	28.35	grams	g
Mass	lb	pounds	0.454	kilograms	kg
Mass	T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
Temperature (exact degrees)	oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	oC
Illumination	fc	foot-candles	10.76	lux	lx
Illumination	fl	foot-Lamberts	3.426	candela/m2	cd/m2
Force and Pressure or Stress	lbf	poundforce	4.45	newtons	N
Force and Pressure or Stress	lbf/in2	poundforce per square inch	6.89	kilopascals	kPa

*SI is the symbol for the International System of Measurement
** Volumes greater than 1000 L shall be shown in m^3

SI* (Modern Metric) Conversion Factors
Approximate Conversions from SI Units

Physical Quantity	Symbol	When You Know	Multiply By	To Find	Symbol
Length	mm	millimeters	0.039	inches	in
Length	m	meters	3.28	feet	ft
Length	m	meters	1.09	yards	yd
Length	km	kilometers	0.621	miles	mi
Area	mm2	square millimeters	0.0016	square inches	in2
Area	m2	square meters	10.764	square feet	ft2
Area	m2	square meters	1.195	square yards	yd2
Area	ha	hectares	2.47	acres	ac
Area	km2	square kilometers	0.386	square miles	mi2
Volume	mL	milliliters	0.034	fluid ounces	fl oz
Volume	L	liters	0.264	gallons	gal
Volume	m3	cubic meters	35.314	cubic feet	ft3
Volume	m3	cubic meters	1.307	cubic yards	yd3
Mass	g	grams	0.035	ounces	oz
Mass	kg	kilograms	2.202	pounds	lb
Mass	Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
Temperature (exact degrees)	oC	Celsius	1.8C+32	Fahrenheit	oF
Illumination	lx	lux	0.0929	foot-candles	fc
Illumination	cd/m2	candela/m2	0.2919	foot-Lamberts	fl
Force and Pressure or Stress	N	newtons	0.225	poundforce	lbf
Force and Pressure or Stress	kPa	kilopascals	0.145	poundforce per square inch	lbf/in2

For More Information see: https://www.fhwa.dot.gov/publications/convtabl.cfm

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DISCLAIMER

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1.0 INTRODUCTION

The Highway Safety Program at the Oregon Department of Transportation (ODOT) focuses on reducing traffic fatalities and injuries through highway safety improvement projects (ODOT, 2021). The program receives significant funding through the Highway Safety Improvement Program (HSIP) for infrastructure improvement projects.

The objective of this study is to develop and document the process by which low-cost safety treatments can be evaluated for safety performance in an Oregon context in the absence of robust calibrated tools like crash modification factors. These processes will be demonstrated through the conduct of comprehensive before-and-after study of safety improvement projects on state highways funded through the ODOT HSIP.

Specifically, this study assesses the safety effectiveness of Rectangular Rapid Flashing Beacon, Shoulder Rumble Strips, and Two-Way to Four-Way Stop Conversion in reducing crashes and improving overall road safety. The impact of these projects and safety treatments on crash frequency and overall safety performance will be assessed. This study develops a transferable framework and analysis approach to determine the safety effectiveness of safety countermeasures as standalone treatments as well as bundles of safety treatments under Oregon conditions.

1.1 RECTANGULAR RAPID FLASHING BEACON (RRFB)

With 7,522 pedestrian deaths in 2022, the number of pedestrian fatalities in the US has been the highest since 1981 (NHTSA, 2024). It was found that pedestrians made up 18% of all traffic fatalities nationwide in 2022. A large proportion of pedestrian deaths occurred in the dark (78%), which suggests that most of these crashes could be because of a lack of visibility, where drivers often fail to see pedestrians crossing. Additionally, 16% of the pedestrian fatalities occurred at intersections; 75% occurred at locations that were not intersections; and 9% occurred at other locations such as sidewalks, roadsides, driveways, and other areas. In Oregon, the percentage of total traffic fatalities who were pedestrians is higher than the national average, with pedestrian fatalities representing 20.5% of total fatalities. The pedestrian fatality rate per 100,000 population is 2.9, one of the highest rates in the country (NHTSA, 2024). These statistics highlight the need to improve pedestrian safety by focusing on safety improvements not just at intersections but also at other high-frequency areas like midblock crossings.

Midblock crossings often provide a shorter and more convenient way for pedestrians to cross. However, on wide arterial streets with high traffic volumes, the risk of crashes can increase, especially at uncontrolled crossings where drivers are not required to stop. Driver yielding rates are generally low at such locations, making it essential to develop effective countermeasures to enhance pedestrian safety. Low-cost treatments can be useful to tackle this issue as they are easy to implement and replicate across multiple sites.

The rectangular rapid flashing beacon (RRFB), as shown in Figure 1-1, is a pedestrian-activated beacon typically installed at unsignalized crossings, in midblock or school zone scenarios. They were introduced as a low-cost safety treatment to improve pedestrian safety by enhancing pedestrian visibility and driver alertness.

Figure 1-1: Rectangular Rapid Flashing Beacon at NW 9th St, Corvallis, OR

RRFBs emit a high-intensity, rapid-flashing light pattern, similar to emergency vehicles, that can alert drivers to the presence of pedestrians in the crosswalk. A study by VanWagner et al. (2011) found that with the activation of the RRFB, the percentage of vehicles going above 41 mph, decreased by 20%. The RRFB was activated when vehicles going above 41 mph were within 200 to 300 ft of the beacon, offering a cost-effective strategy to reduce speeding. It was also found that RRFBs could be effective in increasing the yielding rate of drivers up to 92% for resident pedestrians and up to 66% for staged pedestrians. (Van Houten et al., 2008). Since receiving interim approval by the FHWA in 2008 (FHWA, 2008), RRFBs have been increasing in popularity in recent years.

1.2 SHOULDER RUMBLE STRIPS (SRS)

Roadway departure (RwD) crashes accounted for 51% of all traffic fatalities in the US from 2016 to 2018 (FHWA, 2023). In Oregon, RwD crashes accounted for 50% of all highway fatalities in 2015 (Jones et al., 2017). To reduce fatal and serious injury accidents, ODOT, in coordination with the Federal Highway Administration (FHWA), uses rumble strips as one of the countermeasures against roadway departure crashes.

Rumble strips are defined as grooved patterns on the road that produce audible and haptic feedback to the driver. Rumble strips alert inattentive or drowsy drivers when they have steered off the travel lane. Shoulder rumble strips, installed on the shoulder (rural divided) or edge line (rural undivided), are a low-cost treatment used as a safety measure against run-off-road crashes. Rumble strips also help warn drivers departing their driving lane during low-light conditions. Figure 1-2 shows a series of rumble strips installed on the highway shoulder on Highway 210.

Figure 1-2: Shoulder Rumble Strip on Corvallis-Lebanon Hwy 210, Albany, OR

1.3 TWO-WAY TO FOUR-WAY STOP CONTROL CONVERSION

From 2015-2021, a total of 60,761 crashes occurred at stop-controlled intersections in Oregon, which accounted for 36% of all intersection-related crashes. Of the total fatal and serious injury crashes at all intersection types, 44% of those occurred at stop-controlled intersections. Even though the number of crashes at rural intersections is low, the proportion of fatal or suspected serious injury crashes remains higher than at urban intersections (Oregon Intersection Safety Implementation Plan Update, 2023).

Four-way stop control, displayed in Figure 1-3, offers the potential to be a low-cost and easy-to-implement safety treatment at intersections where crash history or traffic volumes are high. However, the safety benefits of converting a two-way stop control - where the stop control is placed only on the minor approaches- to a four-way stop control - where the stop control is placed on all four approaches are not fully known. There have only been a handful of recent studies documenting the safety effects of converting an intersection to a four-way stop control, with most previous research efforts being nearly forty years old. The purpose of this study is to help fill that gap by quantifying the safety benefits of a two-way to four-way stop control conversion in Oregon.

Figure 1-3: Four-Way Stop at NW Beca Ave and NW 10th St., Corvallis, OR

Figure 1-4 displays a two-way stop control placed at a four-leg intersection.

Figure 1-4: Two-Way Stop at NW 9th St. and NW Beca Ave, Corvallis, OR

2.0 LITERATURE REVIEW

This chapter summarizes the current literature available on before-after studies related to RRFB, SRS, and Two-Way to Four-Way stop control conversions. Journal articles, papers, reports, and publications were extensively reviewed to document past and current practices on conducting before-after studies and their subsequent results on safety improvement. This section primarily focuses on research where crash analysis is the main basis for the study. While there have been countless studies documenting the safety benefits of SRS through a crash analysis lens, most of the current research on RRFB involves surrogate measures of safety analysis. Likewise, only a handful of studies have been conducted on multiway stop control conversions and their safety improvements.

2.1 RECTANGULAR RAPID FLASHING BEACON (RRFB)

Most of the current research on RRFB involves surrogate safety measures of safety analysis. These methods enable assessment of safety through observational measures such as driver behavior and yielding rates without using crash data. However, these surrogate measures may not provide sufficient evidence of safety improvement. This section provides an overview of analysis using both surrogate measures and crash data.

2.1.1 Surrogate Safety Measures of RRFB Effectiveness

Several studies have investigated the driver yielding behavior and rates in response to the presence of RRFBs in a US context. A study by Shurbutt and Houten (2010) in Florida evaluated RRFBs on high-volume, multilane crosswalks. It was found that the average yielding compliance after the installation of RRFBs increased up to 73 to 96% compared to 4% before installation. Brewer & Fitzpatrick (2011) investigated the driver yielding rates at a school zone crosswalk in Garland, Texas and found that the compliance rate increased from less than 1% to an average of 80% before and after the installation of RRFB. Another study in Texas (Fitzpatrick et al., 2014) found that the cities with larger number of RRFBs experienced a higher rate of driver yielding compared to cities that had installations on comparatively fewer crossings. They also found that RRFB had a lower rate of compliance for longer crosswalks, producing the recommendation from the authors that they should be used for crossing distances ranging from 38 to 120 ft.

In a study investigating RRFBs and Pedestrian Hybrid Beacons (PHBs), Brewer et al. (2015) compared the yielding rates of drivers before and after the installation of the treatments at 5 sites (Frisco, San Antonio, Waco, and two in Garland) in Texas. The authors focused their analysis on any change or trend in the pedestrian crossing volume before and after installing treatments. Results suggested that for the treated sites, yielding rates of drivers for pedestrians crossing increased by 35 to 79%. Regarding the change in pedestrian crossing volumes, it was observed that only one of the five sites reflected an increase in crossing rate. To understand the effect of roadway characteristics on driver yielding rate, Fitzpatrick et al. (2014) analyzed 53 sites within Texas. Researchers concluded that driver yielding rates were 94% for one-way traffic and 84% for two-way traffic in the presence of RRFBs.

In a case study of driver behavior and their decision to stop at a crosswalk in the presence of an RRFB, (Fitzpatrick et al., 2017) collected driver yielding data from staged pedestrians with two datasets: a full dataset, which included all pedestrians, and a one-minute dataset which only included the crossings when a one-minute vehicle volume count was available. For the full dataset, the authors observed better yielding behavior for characteristics like the presence of a raised median, shorter crossing distance, one-way traffic, crossings having two legs, and when the waiting pedestrian was located on the far side of crosswalk compared to the near side. For the one-minute dataset, the authors found similar characteristics to be significant as well, except for the presence of refuge and one-way traffic. Surprisingly, they found that the presence of yield or stop lines at the crosswalk corresponded with fewer drivers yielding. More drivers were found to yield at sites where the posted speed limit was 40 mph compared to sites with lower speeds of 35 mph and 30 mph. Better yielding behaviors were observed when an elementary school was within 0.5 mile of the crosswalk, as well as when a transit stop was present within 200 ft of the crosswalk.

There have been four studies on RRFBs in Oregon. One study (Foster et al., 2014) evaluated the driver and pedestrian behavior at two midblock pedestrian crossings in Portland. Consistent with previous studies, this study found that the driver yield rate was approximately 90% with the activation of RRFB. Another study (Ross et al., 2011) in Bend concluded that RRFBs were effective in increasing driver yielding rates and should be used for crossings with 35 mph or higher posted speeds if there is a high volume of pedestrians and bicyclists. Kothuri et al., (2021) analyzed RRFB at crossings with and without median refuge islands to evaluate their combined effect. The study consisted of 23 roadway sites, where 7 sites did not have median refuge; 7 sites had median refuge with RRFB placed outside the roadway, and 9 sites had median refuge with RRFB placed outside the roadway and on the island. The study observed high driver yielding rates of 89.9 to 97%, suggesting that median refuge islands increased driver yielding behavior.

A field study of RRFB installations was conducted in Oregon by Hunter-Zaworski and Mueller (2012). The study compared overhead installations and side-mounted beacons to determine whether overhead installations would increase driver compliance. It was found that the side-beacon crossing at Highway 99W (3rd Avenue) near Mayberry Avenue, Corvallis and Olympic Street near 21st Street, Springfield had 88.1% and 60.8% compliance rates respectively, while the overhead beacon at OR 34 (Main Street) at 17th Street, Philomath had a compliance rate of 77.1%. The study also evaluated the possible increase in effectiveness of RRFB when a raised median is present. At the Astoria site on US 30 at 37th Street (RRFB with no median), the compliance rate was 75.9%, whereas in the Springfield site on OR 126 near 51st Street (RRFB with a median), the compliance rate was 86.4%. The high compliance rate suggests that installation of a median at mid-block crosswalks is effective. Furthermore, the study analyzed driver response by comparing RRFBs to flashing yellow beacons. The compliance rates for the RRFB site (Astoria – 37th Street) and the beacon site (Astoria – Bay Street) were compared and found to be 75.9% and 71.8%, respectively. Comparisons of the Olympic Street, Springfield RRFB installation and Highway 99, Corvallis side-mounted beacon crossing were made, with compliance rates of 86.4% and 88.1% respectively. In summary, most studies on RRFBs to date have focused on behavioral surrogate safety measures like driver yielding rates and vehicular speed. Although these studies report high effectiveness using surrogate safety measures, only a handful of studies have measured crash performance to determine whether safety has truly improved.

2.1.2 Crash Analysis of RRFB

One study (Saari et al., 2024) conducted a before-after and a cross-sectional analysis for RRFB and Pedestrian Hybrid Beacon (PHB) using crash data in Minnesota. The study reported a 67% decrease in fatal crashes for RRFB and a 67% decrease in pedestrian crashes for PHB. Although the study makes use of sufficient crash history, it should be noted that a before-after analysis with a comparison group doesn't fully account for the regression-to-the mean effect, which is a common occurrence for crash data. Treatment sites selected for high crash frequency may yield a biased estimate of safety improvement if the comparison groups aren't matched based on crash history and roadway characteristics- which can be difficult to achieve.

Another study (Monsere et al., 2017) in Oregon explored the safety performance of different pedestrian crossing enhancements like RRFBs, flashing amber, high-visibility, and standard parallel crosswalks. Of the 191 crossings studied, 68 were RRFBs. Most of the RRFBs were installed between 2011 and 2014, leading to fewer crash data being available for the required analyses at the time of the study. The researchers identified 62 pedestrian crashes and 746 rear-end crashes that were attributed to the crosswalks. For the pedestrian crashes, researchers were able to perform a simple before-after analysis with a resulting CMF of 0.64. A comparison group analysis was carried out; however, according to the study authors, the comparison group sites were not particularly similar, and the number of eligible sites was small, so the estimated CMFs were not recommended. A cross-sectional analysis could not be conducted due to the lack of eligible sites where the crossings were only of one category for a given time period. Empirical Bayes (EB) before-after analysis, one of the most reliable methods that accounts for change in crash history due to traffic volume and temporal factors, also could not be estimated due to fewer pedestrian crashes and pedestrian volumes. Conversely, the higher number of rear-end crashes allowed for CMF estimation using all four methods. The recommended CMF for the EB analysis for the rear-end crashes was 0.93.

Arterial streets and streets with four or more lanes have an increased likelihood of pedestrian crashes. Zegeer et al., (2017) developed CMF for uncontrolled pedestrian crossing treatments, including RRFB, by focusing on such sites. Of the 499 treatment sites, only 50 had RRFBs, either alone or in combination with other treatments being studied, such as refuge islands or advance yield marking signs. The study estimated a CMF of 0.526 for RRFB pedestrian crashes by performing a cross-sectional analysis, but since the sample size was small, the CMF should be used prudently.

While research shows a reduction in pedestrian crashes, a study found installation of RRFBs may increase the number of total vehicular crashes. Goswamy & Abdel-Aty, (2023) collected crash data spanning over 8 years for 154 sites to determine the safety effectiveness of RRFBs. The authors estimated a CMF of 0.31 for total pedestrian crashes, which indicated a 69% reduction in such crashes. Interestingly, the CMF for total vehicular crashes and rear-end crashes were 1.14 and 1.11, suggesting an increase in such types of crashes after installation of RRFBs. This may be due to the fact that while pedestrians were able to cross the roads safely, the need for vehicles to reduce their speed or come to a stop could have led to an increase in rear end crashes. While this study calculated CMF estimates with small standard errors, use of pedestrian volumes could have provided a greater reliability of CMF for pedestrian crashes.

To date, there have been no other studies conducting crash analyses of RRFBs. This study will fill that gap by focusing on evaluation of the effectiveness of RRFB as a safety treatment in Oregon through crash frequency analysis along with estimation of CMF.

2.2 SHOULDER RUMBLE STRIPS (SRS)

There have been several studies documenting the effectiveness of shoulder rumble strips (SRS). A study in Montana (Marvin et al., 2003) found that on Interstate highways crash rates were reduced by 14% and the severity of run-off-road (ROR) crashes were reduced by 23.5% when SRS were added. Dadashova et al. (2018) reported a 43% reduction in multiple-vehicle fatal incapacitating crashes through an incidence rate ratio and propensity score matching approach. The study was conducted on SRS installed on freeways of California, Washington and Maine.

A detailed safety evaluation of continuous shoulder rumble strips (CSRS) installed on freeways of California and Illinois was performed by Griffith (1999). He used two before-after approaches to conduct the study: a yoked comparison (one-to-one matching of treated and untreated sites) and a comparison group (a group of untreated sites matched with treated sites). Griffith also investigated any potential adverse effects that might be related to CRS, mainly panic responses by drivers and crash migration. Panic responses describe drivers who may lose control of their vehicles when startled by the haptic and audible feedback from CSRS. The second type of adverse effect, crash migration, refers to the situation where a driver crashes downstream of a highway network with CSRS after being saved from a crash in a treated area. These effects were found to be insignificant. Based on the Illinois data sourced from 55 treatment sites, an 18.3% reduction in total single-vehicle ROR crashes was estimated. The California dataset had 28 treatment sites, which estimated a 7.3% reduction of SVROR crashes (insignificant at the 0.05 level).

In Virginia, Chen et al. (2003) studied CSRS through traditional statistical tests and a yoked comparison. For the traditional method, 12 sites out of 600 were randomly selected after determining the required sample size. Ten sites from the 12 selected showed a statistically significant difference (95% confidence level) of reduction in ROR crash frequency. For the yoked comparison, 9 sites were analyzed and 6 showed a significant reduction in crash frequency before and after the treatment, producing an estimated reduction rate in ROR crash frequency of 51.5%. The methodology used in these earlier studies, however, does not account for time trends or regression-to-the-mean (RTM), as the sites are often chosen for their seemingly high crash counts.

EB before-after analysis is a commonly accepted methodology in road safety analysis. It accounts for characteristics that can change with time such as traffic volume and increases the precision of the estimation (Hauer et al., 2002). Most importantly, it accounts for RTM bias by using reference sites that are untreated but similar to the treatment sites. Numerous studies have used this analysis method to study the safety effectiveness of different safety treatments, including SRS (e.g., Khan et al., 2015; Patel et al., 2007; B. Persaud et al., 2016).

Collision prediction models (CPMs) have also been developed in a study (Sayed et al., 2010) as part of the EB methodology to evaluate the safety of SRS and centerline rumble strips (CRS) in British Columbia, Canada. To develop the CPMs, data from reference groups, i.e., a large number of sites with similar characteristics to the treatment sites, were used. The study consisted of 47 treatment sites and 225 comparison sites. It was found that severe collisions were reduced by 18%, and for SRS sites, off-road collisions to the right were reduced by 22.5%. These results were statistically significant, indicating the effectiveness of rumble strips in reducing the severity of collisions.

SRS have been a highly effective countermeasure on rural, two-lane highways. Patel et al. (2007) performed an EB before-after study estimating the safety benefits of shoulder rumble strips. The authors focused on 24 treatment sites installed on 183 mi of two-lane rural highways in Minnesota. The results estimated a "13% reduction for all single-vehicle, run-off-the-road (SVROR) crashes and an 18% reduction for injury SVROR crashes". However, due to the limited sample size, these results were not statistically significant.

Another study (Khan et al., 2015) was also performed on two-lane rural highways. This study explored the effects of the roadway geometry, (degree of curvature and shoulder width) on the safety effectiveness of shoulder rumble strips in reducing run-off-the-road (ROR) crashes in Idaho. There were 38 treatment sites on a total of 178.63 miles of roadway. The reduction in ROR crashes was estimated to be 13.7%. The analysis showed that SRS were effective in low-volume road sections (i.e., AADT < 1000). In terms of road curvature, the rumble strips were more effective in reducing ROR crashes for roads with no curves (25%) or moderate curvature (22%) as drivers are less likely to be attentive on such roads compared to sharper curves (11%). Shoulder width was found to play a role in reducing ROR crashes if the width was 3 ft or more by providing a larger recovery area. Like the previous study, these results were not statistically significant due to the limited number of treatment sites. Another study (Park et al., 2014) in evaluating RS and their combined treatment with widening shoulder widths also estimated reduction in crash frequencies. For roadway segments with previously shorter shoulder widths (4-6 ft), the safety effect of combined treatment was more effective than single treatment of just SRS or just widening of shoulder width.

A study by Persaud et al. (2016) evaluated the combined treatment of SRS and CRS through a multistate database comprised of Kentucky, Missouri, and Pennsylvania's two-lane rural roads. With an aggregate analysis of all 3 states, it was found that the head-on crash type had the smallest crash modification factor (CMF) of 0.632. With disaggregate analysis, it was found that crash reduction was largest for ROR crashes for high AADT sites. The study also calculated benefit-cost (B:C) ratio of "28.2 for a higher cost/high service life assumption and 67.7 for a lower cost/lower service life assumption." This ratio demonstrates that RS can be a highly beneficial and cost-effective safety treatment.

In a study of safety analysis of SRS in highways of Maine, researchers estimated that dry road ROR crashes were reduced by 43% (Gårder & Davies, 2006). Reduction in sleep-related ROR crashes was estimated to be the most effective, with a 45 to 68% reduction in such crashes. A B:C ratio of 195:1 was estimated on certain sections of the highway.

The safety effectiveness of SRS and CSR on different roadway types and placement locations was analyzed in a study by Torbic et al. (2010). It was found that the highest reduction in crashes was estimated from the installation of SRS on rural two-lane roads with an average reduction in SVROR fatal and injury (FI) crashes of 36%. Installation of SRS on rural freeways had an average 17% reduction in SVROR FI crashes. The safety analysis for the different road types was conducted using data collected in Minnesota, Missouri and Pennsylvania.

Another study (Smith & Ivan, 2005) in Connecticut considered whether SRS were effective in reducing single-vehicle, fixed object crashes. The factors that might influence crash rates and crash migration due to the location of SRS were also evaluated. Results indicated that installation of SRS led to single-vehicle, fixed object crashes being reduced by 33%. Different roadway factors like posted speed limit, number of lanes, artificial illumination and the type of roadway section (i.e., between on and off ramps, interchange area, climbing lanes, and weaving sections) were analyzed to determine that ROR crashes were reduced by up to 48.5% in interchange areas and by 12.8% in sections where the posted speed limit was less than 65 mph. Moreover, upon crash migration analysis, it was found that on certain route directions crash locations had shifted to segments at the end of the routes with lower densities of SRS.

Various state DOTs have conducted studies on SRS. In a study of safety analysis of rumble strips on rural Idaho highways, an average crash reduction factor of up to 74% was estimated on two-lane highways, and up to 67% for rural freeways for most severe ROR crashes, which included Type K-fatal crashes and Type A-serious injury crashes (Abdel-Rahim et al., 2012). Road curvature was also analyzed, and it was found that only relatively straight roads had significantly positive results in crash reduction. For the state of Washington, Olson et al. (2013) found a 40.4% increase for run-off-the-road-to-the-right (ROTRR) crashes and a 100% increase for FI crashes at locations where only SRS and no CRS were installed. However, this was attributed to a small dataset with a low number of miles and low vehicle miles traveled (VMT). The same study also evaluated sites with both CRS and SRS installed at the same time and observed ROTRR crashes had a 61.4% reduction for all injury severity and a 66.6% reduction in FI crashes. The Missouri DOT's study (Spring, 2003) of rumble strips included a benefit-cost analysis on SRS and estimated a B/C ratio of 17.7.

Among the studies involving SRS data from multiple states, there has been a comparable lack of study in Oregon regarding the evaluation of rumble strips through a safety lens. Horne et al. (2021) examined sinusoidal SRS, a modification of traditional SRS, in Oregon as a potential alternative to address the issue of noise concerns associated with rumble strips. Besides this study, analysis of rumble strips has not been publicly documented in Oregon in the peer-reviewed literature, especially as a safety treatment by quantifying their safety effectiveness. This study contributes to closing this research gap by performing a before-after study on the effectiveness of rumble strips in Oregon through a safety perspective.

2.3 TWO-WAY TO FOUR-WAY STOP CONTROL CONVERSION

The safety effects of all-way stop control conversion for different intersection configurations were studied by Deng et al. (2020) through a comparison group analysis. Two comparison sites were selected for each of the 53 treated sites in Washington, DC. Using a negative binomial model, the study found reductions of 43% in total crashes and 54% in injury crashes at four-leg intersections. In contrast, three-leg intersections showed a 10% increase in all crashes and a 65% increase in injury crashes (non-statistically significant). This may be attributed to a small sample size (10) in addition to drivers on the major approach not being compliant with the all-way stop sign at three-leg intersections. Regarding crash types, right angle crashes had the greatest reduction estimated, with a decrease of 83%. It is important to note that while comparison sites were used for control, the crash data was analyzed without accounting for changes in traffic volumes due to data an absence of availability.

To quantify the safety benefits of two-way to all-way stop control, Simpson & Hummer (2010) evaluated 53 locations in North Carolina. The sites were chosen to represent a diverse range of intersections in rural, urban and suburban areas. A naïve before-and-after analysis found rear-end crashes increased by 6%. A separate EB analysis accounting for traffic volume was also conducted. Traffic volumes were assumed to increase linearly. The result for the EB analysis estimated a 68.1% reduction in total crashes. Injury crashes (fatal and non-fatal injury crashes) were found to be reduced by 77%. For the EB analysis, rear-end crashes were not analyzed separately. These results were found to be similar for different intersection volumes, suggesting the conversion to all-way stop is just as effective when the intersection volume is unbalanced between the minor and major approaches.

The relationship between speed limit and the stop signs was also examined, as higher speed sites (45 mph to 55 mph) showed greater reduction in crashes compared to lower speed sites (20 mph to 35 mph). The study revealed that the presence of additional signs and markings such as advance warning signs and “stop ahead” pavement markings at most high-speed intersections likely led to the higher crash reduction compared to the low-speed sites that generally did not have such additional markings to supplement the stop sign.

At low-volume intersections in residential areas of West Virginia, Eck & Biega (1988) performed a field evaluation of two-way vs four-way stop sign control at three intersections. While crash analysis was not performed due to insufficient crash data, researchers were able to evaluate traffic volume, spot speed, delay and compliance at treated intersections. The traffic data was collected by the researchers during a four-week “before” period for two-way stop control and a four-week “after” period following the conversion to four-way stop control. Traffic volumes, degree of compliance and speed characteristics were found to be similar in both periods. The delay on the major approach was increased by an average of about 12 minutes, while the delay on the minor approach was decreased by an average of less than 1 minute. This increase in delay on the major approach produced an increase in the daily road user cost, inferring that the “use of two-way stop control was 3.5 times more efficient economically than the use of four-way stop control.” However, in the absence of a safety analysis it’s difficult to interpret the shift in safety achieved by the conversion.

Several issues regarding analysis of the conversion of intersections to multiway stop control were analyzed by B. N. Persaud (1986). The data used in the analysis was sourced from a thesis (Ebbecke,1976) that analyzed 222 intersections converted from one-way street, one-street-stopped control to multiway stop control in Philadelphia. Issues like safety migration, role of traffic volume, and decrease of effectiveness with more conversion of sites were reexamined for the dataset, which did not originally account for RTM. Persaud found that an unbiased change in unconverted intersections showed an increase of 82 crashes, which called for a more in-depth study into possible explanations for the existence of safety migration. For the effect of traffic volumes, only rear-end crashes showed a decrease in effectiveness as the total entering volume of the intersection increased. Moreover, when analyzed by the volume share of the minor road, rear-end crashes did not show a positive reduction until the minor road volume share exceeded

25 percent. The sites converted in different years were studied to determine if there was any change in effectiveness due to an increase in the number of conversions in an area. This claim was not supported by the data which showed no significant change in the effectiveness of the treatment.

In a similar manner, Lovell & Hauer (1986) reanalyzed data from three studies in San Francisco, Philadelphia, Michigan and an additional new dataset from Toronto to examine the safety effects of conversion of two-way to all-way stops without selection-bias or presence of RTM effects. To remove such bias, the estimated expected number of “after” crashes, if no conversion were to take place, was computed and compared with the number of crashes that actually occurred in the “after’ period. The previous studies had done a simple comparison of the number of crashes in the “after” period to the “before” period. Although some estimates were inflated, most of the corrected comparisons were found to indicate consistent safety effects for all three studies. To estimate percent crash reduction by type, the likelihood function was used. The analysis showed that the conversion to all-way stop control is expected to reduce total crashes by 47 percent. Right-angle and injury crashes were expected to be reduced by 72 % and 71 %, respectively.

3.0 METHODOLOGY

3.1 STUDY DESIGN AND METHODS

EB before–after analyses was used in this study to evaluate the treatment types RRFBs and SRS as widely recognized as a state-of-the-art approach for conducting safety evaluations (Hauer et al., 2002, Khan et al. 2015, Abdel-Rahim et al. 2012, Savolainen et al., 2022). The EB approach involves the development of a Safety Performance Function (SPF) to estimate the predicted number of crashes at treated sites. These SPFs are used to determine the expected number of crashes at a site in the absence of treatment. The expected number of crashes is then compared with the observed number of crashes to estimate CMFs (Gross et al. 2010)

RTM is a statistical phenomenon in which extreme observations tend to move closer to the mean over time. As a result, observed changes in crash frequency may be influenced by RTM, meaning that apparent safety improvements could occur even without any treatment. The EB method helps account for this effect by incorporating information on traffic volumes and roadway characteristics across different time periods through the SPF (Gross, Persaud and Lyon, 2004).

The safety effectiveness of both RRFB and SRS was analyzed using EB analysis. Models were developed for total crashes, rear-end crashes and pedestrian crashes for RRFB. For SRS, total crashes and ROR crashes were modeled.

The observational cross-sectional safety evaluation method was used for the two-way vs. four-way treatment type. This was primarily due to the absence of installation dates for the two-way and four-way stop control. Cross-sectional studies may be comparable to before-and-after studies when treatment installation dates are not available (AASHTO, 2010, Gupta et al., 2022). This method of safety evaluation uses statistical modeling with crash data with and without treatment of interest by including an indicator variable for the presence or absence of treatment at a site.

A generalized linear model (GLM) with a negative binomial distribution was used to model the crash data for the cross-sectional analysis (Savolainen et al., 2022). The safety effect is attributed to the parameter estimate of the indicator variable, which suggests the difference in the number of crashes at the treatment and control sites.

3.1.1 Safety Performance Function (SPF)

An SPF is a crash prediction model used to estimate the number of crashes occurring at a location based on traffic and roadway characteristics like lane width, speed limit, presence of a median, and so on. The "before" period refers to the time prior to the installation of the treatment, while the "after" period refers to the years following its installation. The models were developed using control sites, which are sites with similar traffic and roadway characteristics to the treated sites, but without the treatment installed. This approach is well documented by Hauer et al. (2002), Gross et al. (2010), and (Savolainen et al., 2022). To supplement the analysis, models from the before period of treatment sites were also developed.

A summary of the notation used in the EB analysis is mentioned below:

$N_{predicted,B}$ = The predicted number of crashes estimated by the SPF in the before period

$N_{predicted,A}$ = The predicted number of crashes estimated by the SPF in the after period

$N_{expected,B}$ = The expected number of crashes without treatment in the before period

$N_{expected,A}$ = The expected number of crashes without treatment in the after period

$N_{observed,A}$ = The actual number of crashes in the before period

$N_{observed,A}$ = The actual number of crashes in the after period

w = SPF weight

R = Adjustment factor

The SPF model was developed using a NB model (Hauer et al., 2002). The negative binomial model addresses the overdispersion in the data inconsistent with the Poisson distribution. The predicted number of crashes in the before and after periods was calculated using the SPF for each treatment site.

The overdispersion parameter (k) from the NB model was used to calculate the SPF weight. The SPF weight determines how much influence the predicted and observed crashes will have when calculating the expected before crashes. The weight is calculated as shown in Equation (3-1):

$$\boldsymbol{w = \frac{1}{1 + k * N_{pred,T,B}}} \tag{3-1}$$

Where,
k = overdispersion parameter in the NB model.

The weight was calculated for each individual treatment site. It was then used to estimate the expected number of crashes without treatment in the before period using both the observed and SPF-predicted crashes. The expected number of crashes in the before period is given by Equation (3-2):

$$\boldsymbol{N_{expected,T,B} = w * N_{predicted,T,B} + (1 - w) * N_{observed,T,B}} \tag{3-2}$$

The ratio of the predicted number of crashes in the after period to that in the before period was calculated to estimate the traffic and geometric changes in the before-after period, as shown in Equation (3-3).

$$\boldsymbol{R} = \frac{\boldsymbol{N_{predicted,T,A}}}{\boldsymbol{N_{predicted,T,B}}}$$

(3-3)

The expected number of crashes in the after period without treatment and its variance were calculated using Equations (3-4) and (3-5):

$$\boldsymbol{N_{expected,A}} = \boldsymbol{R} * \boldsymbol{N_{expected,B}}$$

(3-4)

$$\mathbf{Var}\ (\boldsymbol{N_{expected,A}}) = \boldsymbol{N_{expected,A}} * \mathrm{R} * (\mathbf{1} - \mathbf{w})$$

(3-5)

For each treatment site, $N_{expected,T,A}$ and Var ($N_{expected,T,A}$) were calculated and then summed to estimate the CMF. The CMF, its variance (Var) and standard error (SE) were calculated as shown in Equations (3-6), (3-7) and (3-8):

$$\mathbf{CMF} = \frac{\frac{N_{obs,A}}{N_{exp,,A}}}{1 + \frac{Var\left(N_{exp,A}\right)}{\left(N_{exp,A}\right)^2}}$$

(3-6)

$$\mathbf{Var\ (CMF)} = \frac{CMF^2\ (\frac{1}{N_{obs,A}} + \frac{Var\left(N_{exp,A}\right)}{\left(N_{exp,A}\right)^2}}{1 + \frac{Var\ (N_{exp,A})}{\left(N_{exp,A}\right)^2}}$$

(3-7)

$$\mathbf{SE\ (CMF)} = \sqrt{\boldsymbol{Var\ (CMF)}}$$

(3-8)

The standard error provides a measure of the uncertainty associated with the CMF estimate. A smaller standard error indicates greater certainty in the estimate. The standard error was further used to calculate the confidence interval of the CMF; smaller standard errors result in narrower confidence intervals, indicating higher precision.

3.1.2 Cross-sectional Evaluation

A GLM with a negative binomial distribution was used to model the crash data for the stop control treatment. The negative binomial model is a standard approach in crash analysis because it accounts for overdispersion commonly observed in crash data (Savolainen et al., 2022). If λ is the expected number of crashes in segment *i,* the negative binomial model is specified as in Equation (3-9).

$$\boldsymbol{\lambda_i = \exp(\beta_0 + \beta_1 X_i)} \quad \textbf{(3-9)}$$

Where,
$\beta_{0,1}$ = coefficient estimates
X_i = explanatory variables

3.2 DATA COLLECTION

To evaluate the safety performance, the locations of the treated sites were obtained from ODOT. Additional information regarding the funding source and available installation period was also obtained from ODOT. Traffic data (AADT) and roadway geometrics such as number of lanes, lane width, posted speed, and median type were collected from the ODOT TransGIS website and the ODOT Highway Inventory Summary website. A summary of the information collected for each treatment type is given below.

3.2.1 RRFB

A total of 496 sites installed across all five regions of Oregon on state highways were obtained from ODOT. However, installation dates were unavailable for most sites, except for sites in ODOT Region 2. To determine the installation year for the remaining sites, historical imagery from Google Street View and Google Earth Pro was used. If an RRFB was present in a given year but absent in the immediately preceding year, the “present” year was recorded as the installation year, as demonstrated in Figure 3.1 This process was applied to all sites lacking installation data.

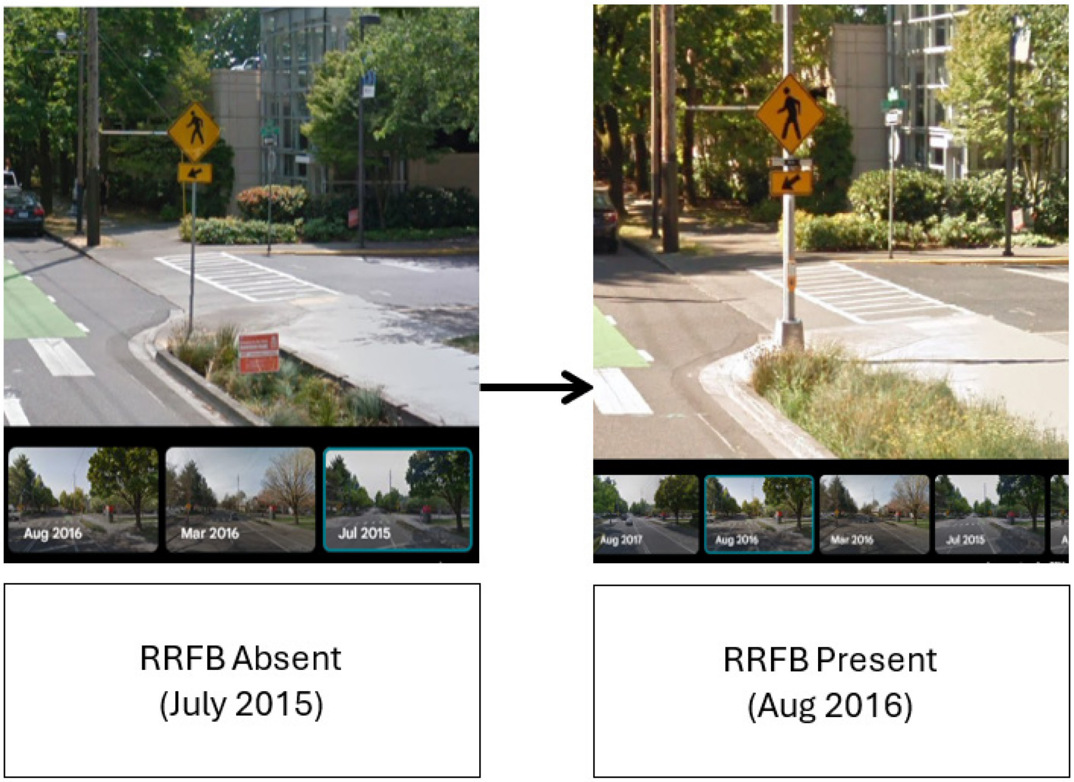

Figure 3-1: Flowchart showing procedure to determine installation year

The installation year for this particular RRFB would be marked as 2016, as the preceding year 2015 does not have an RRFB installed yet.

In many cases, due to the lack of consecutive years of available imagery, it was not possible to determine the installation year with certainty. This limited the number of sites that could be used in the analysis. In total, installation dates were confirmed for 86 sites. The identified installation years ranged from 2010 to 2025. As the analyzed crash data does not include records beyond 2021, only sites installed between 2010 and 2019 were selected for analysis. Ultimately, a total of 46 RRFB sites were used in the final analysis. Table 3-1 shows the final selected RRFB sites installed from 2010 to 2019.

Table 3-1: Number of RRFB sites across various installation years

Installation year	Number of RRFB sites
2010	5
2011	4
2012	6
2013	1
2014	1
2015	7
2016	3
2017	3
2018	11
2019	5
Total	**46**

The number of years in the before and after period was determined based on the installation year and available crash data. Complete crash data was available for 15 years (2007-2021). The before period and after period were set up to 5 years, when possible. Different sites had different before and after periods depending on the installation year. For example, if a site was installed in 2015, the before period was 5 years (2010-2014) and the after period was 5 years (2016-2020). For sites installed in 2018, the before period was 5 years (2013-2017) and the after period was 3 years (2019-2021). The installed year was excluded from the analysis for their respective sites.

Control sites were selected to match the treatment sites as closely as possible in terms of traffic volume and geometric configuration. A total of 77 control sites were identified along similar roadways to the treatment sites. For the selected treatment and control sites, traffic and geometric characteristics were collected. The geometric characteristics, such as lane width, speed limit, and number of lanes were collected from the ODOT TransGIS and ODOT Highway Inventory Detail website. Traffic data were collected from the ODOT Transportation Volume Table for different years in the before-and-after period. Table 3-2 summarizes the traffic and roadway characteristics for the treatment sites.

Table 3-2: Summary of RRFB sites

Variables	Treatment sites mean	Treatment sites min	Treatment sites max
Lane width	37.740	24	58
Number of lanes	3.304	2	4
Median presence	0.720	0	1
Raised median	0.196	0	1
Paved median	0.522	0	1
Speed limit	33.587	25	45
Before AADT	14,945.22	3,425	37,232
After AADT	15,425.72	3,181	36,505

To extract the crashes occurring at RRFB sites, QGIS software was used. A buffer of 250 ft was used to obtain the crashes occurring during the before and after period. Crashes within the buffer that were unrelated to the presence of RRFB, such as parking-related crashes, were removed for the final analysis. The before and after crash data were used for further visualization and descriptive analysis. Table 3-3 summarizes the type of crashes that occurred at the RRFB sites before and after installation.

Table 3-3: Summary of crashes for RRFB sites

Variables	Before	After
Total crashes	502	340
Rear-end crashes	253	172
Total pedestrian crashes	11	6

3.2.2 SRS

SRS installed across segments over 45.67 miles of state highway in Oregon were selected as treatment locations. The road segment data were collected from ODOT. These SRS were installed in 2020 with ODOT All Roads Transportation Safety (ARTS) funding. The segments ranged from 0.73 miles to 6.74 miles long. Table 3-4 summarizes the location of the installed SRS based on the ODOT highway number.

Table 3-4: Location of SRS by Highway Number

Highway Number	Length (miles)
30	13.61
62	2.03
91	14.33
162	15.7
Total	**45.67**

The control sites were selected along the same highway where possible, with consideration given to traffic and geometric characteristics similar to the treatment sites. A total of 34 sections along 47.78 miles of state highway were identified without shoulder rumble strips installed. These sections were used to model the SPF for various crash types.

Since the crash data was only available until 2021, the after period was set as one year (2021). The before period was set as 5 years (2015-2019), similar to the RRFB. Again, traffic data and roadway characteristics were collected for the treated locations. The roadway characteristics collected included number of lanes, lane width, shoulder width, presence and type of median, posted speed, and so on. Based on these roadway characteristics and AADT data, the treated segments were further divided into 58 roadway segments. The length of these segments ranged from 0.1 miles to 2.48 miles. These segments were used for the final analysis and for calculating the predicted crash frequency.

Crashes were extracted using QGIS software in a similar fashion to the RRFB. The crash data obtained were cleaned to remove any unrelated crashes, such as animal-related crashes.

3.2.3 Two-Way and Four-Way Stop Control

ODOT provided locations of all-way stop-controlled intersections in Oregon. The initial dataset included 12 four-way stop sites. Additional stop-control locations were identified near these sites using Google Earth and Google Street View. However, installation timelines were not available for the provided or newly identified locations. It is critical to ascertain the installation data in order to conduct a before-after study, and various attempts were made to determine this information. Unlike the RRFB sites, where installation years could be identified for several locations through Google Street View, the four-way stops predated the historical imagery available. Therefore, a cross-sectional study was adopted as an alternative to the before-after EB approach to evaluate the safety effectiveness.

The cross-sectional safety evaluation requires sites both with and without treatment for the analysis. The four-way stops were considered as treatment sites and two-way stops as control sites. The two-way stops were selected at locations similar to the four-way stop sites. In total, 55 four-way stops and 55 two-way stop locations were identified. The analysis period was defined as 2017-2019. Crash data for both groups were extracted for the selected period using QGIS, with a buffer of 250 ft applied to extract the crashes attributed to the location.

Additional site characteristics, including traffic, speed, and number of lanes were obtained from the ODOT TransGIS database. Google Street View was used to gather information on presence of a left turn lane on the approaches. Satellite images were used for visual inspection to mark whether the intersection was skewed, i.e., intersection angle less than 75 degrees (Brewer & Bedsole, 2015). However, for intersections where one or both approaches were classified as local roads, the traffic volume data was not found to be available. Traffic data were obtained for arterial and collector approaches where available. This limitation primarily affected two-way stop sites, as their minor approaches were more likely to be classified as local roads. Ultimately, 44 four-way stop and 32 two-way stop locations were selected for the cross-sectional analysis based on availability of traffic data. The Highway Safety Manual recommends 10 to 20 treatment and non-treatment sites for cross-sectional safety evaluation (AASHTO, 2010).

4.0 DATA ANALYSIS AND RESULTS

This chapter provides descriptive statistics of the crash data for the three treatments. The estimated parameters of the predictive model developed, and the resulting CMF analyzed from the model are discussed further along in this chapter.

4.1 DESCRIPTIVE STATISTICS

Descriptive analysis of the crashes occurring at the treatment locations before and after installation was conducted. This section presents the changes in crash frequency and the major crash cause at the sites following safety treatment installation.

4.1.1 RRFB

Pedestrian crashes were analyzed to identify the trends before and after installation of RRFBs. Figure 4-1 shows the pedestrian crashes per year for the treatment sites where such crashes occurred. Sites installed during 2011, 2012, 2015 and 2018 were found to have pedestrian crashes. The x-axis represents the installation year, with each having its own before and after timeline due to different installation periods. Pedestrian crashes were observed to decrease for all installation years except for 2015, which had equal crash frequency in the before and after periods.

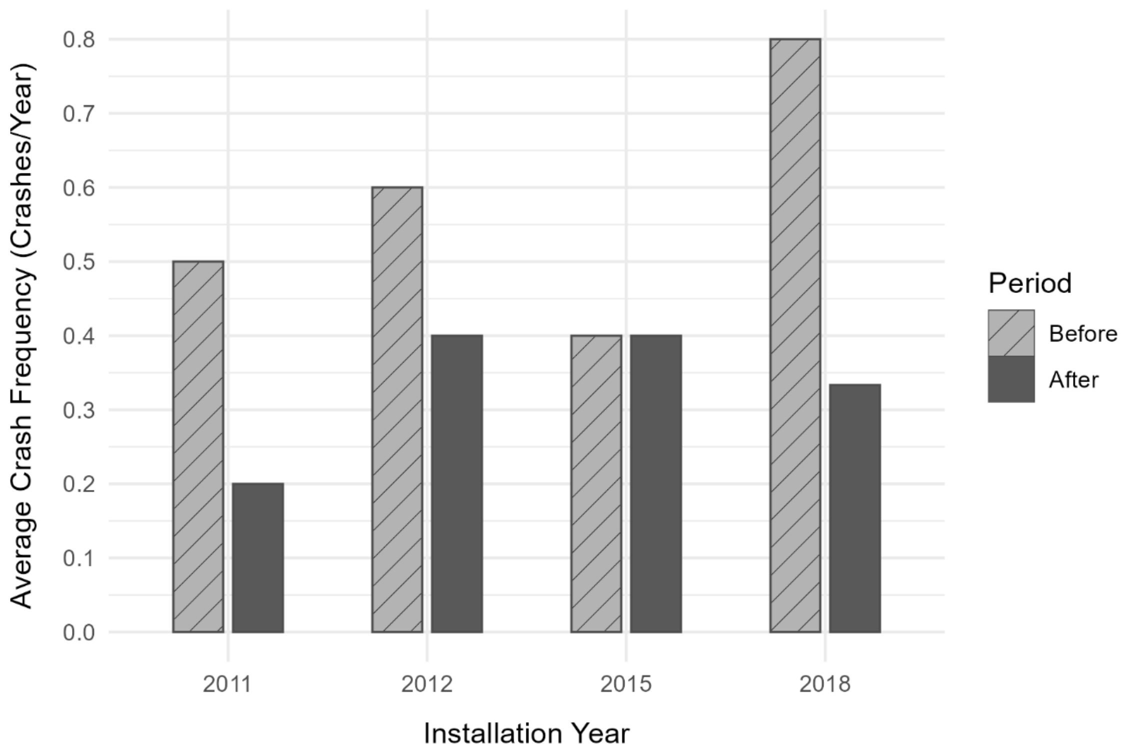

Figure 4-1: Pedestrian Crashes Before and After RRFB Installation

The effect of RRFB installation was also studied for rear-end crashes. Figure 4-2 depicts the rear-end crashes per year during the before and after period selected. The image shows the crash frequency for each installation year. Rear-end crashes were observed to have mixed effects, with an increase in some periods and a decrease in others. The height of the bar for each installation year also accounts for the number of sites installed during the particular year. For example, 11 sites were installed in 2018 vs. 3 sites in 2017, resulting in higher crashes per year for the 2018 installation year compared to the 2017-installed sites.

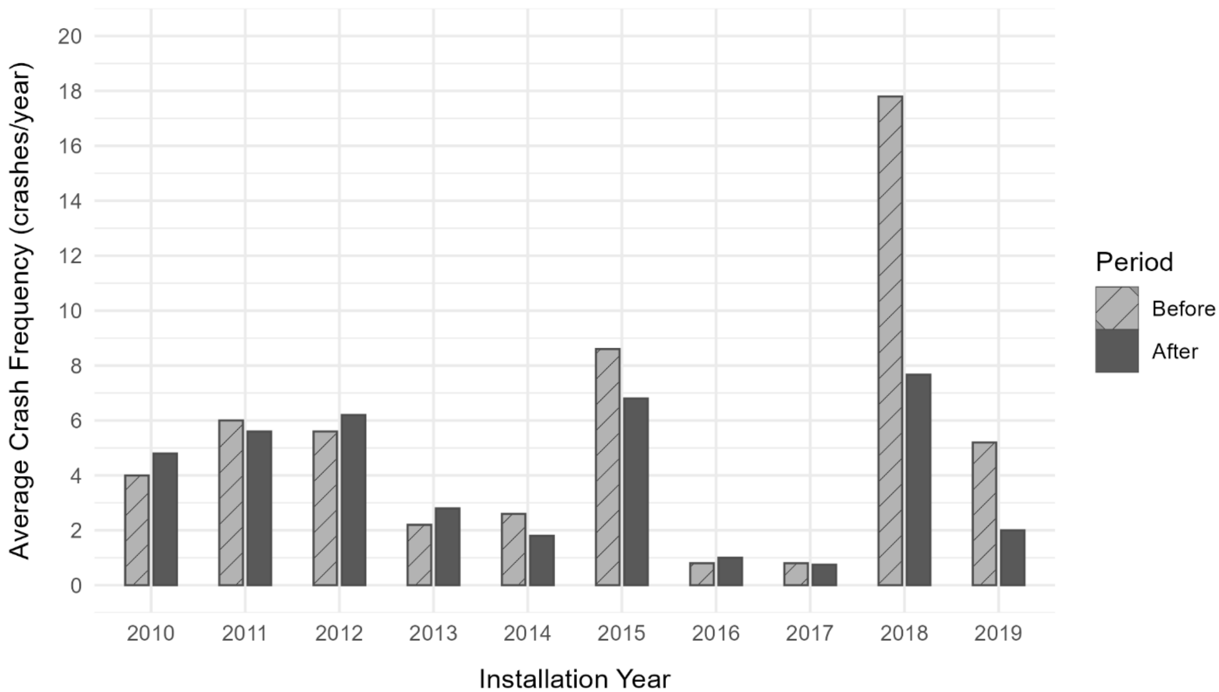

Figure 4-2: Rear-end Crashes Before and After RRFB Installation

Total crashes were also analyzed separately, as shown in Figure 4-3. Overall, the trends indicate that total crash frequency has either decreased or remained similar before and after installation. Failure-to-yield right-of-way (ROW) was found to be a significant cause of crashes at the RRFB treatment sites. Figure 4-4 describes the average crash frequency, before and after installation, for crashes where the cause was listed as failure-to-yield ROW. The figure shows a reduction for all installation years except 2013 and 2014.

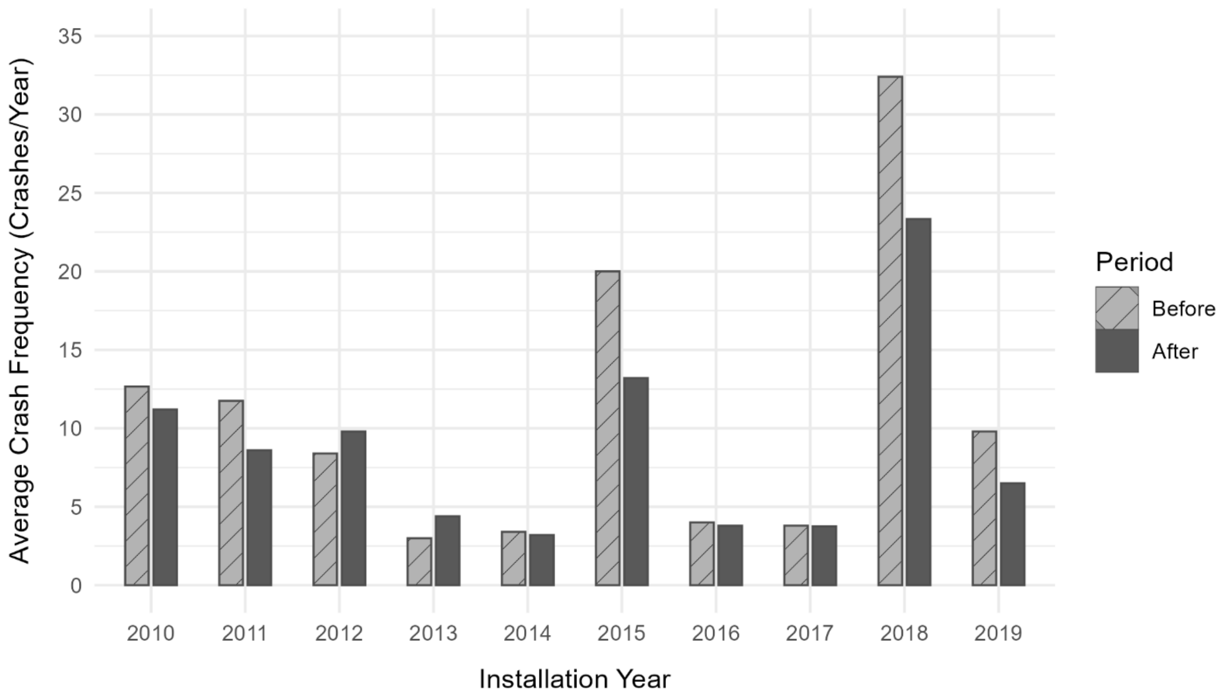

Figure 4-3: Total Crashes Before and After RRFB Installation

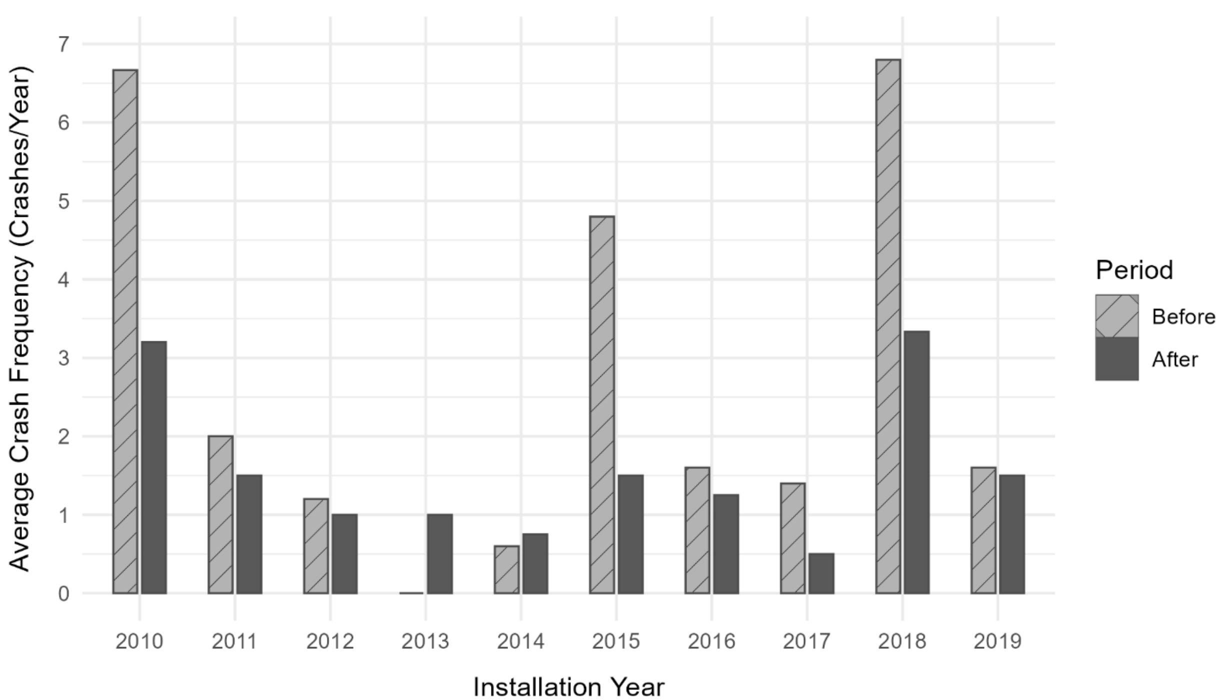

Figure 4-4: Failure-to-Yield Crashes Before and After RRFB Installation

4.1.2 SRS

Crash trends were analyzed for the SRS, with the before period depicting 2015-2019 and the after period depicting 2021. The crash frequency for both the total crash type and the run-off-road (ROR) crash type were found to have reduced after the installation of SRS, as shown in Figure 4-5.

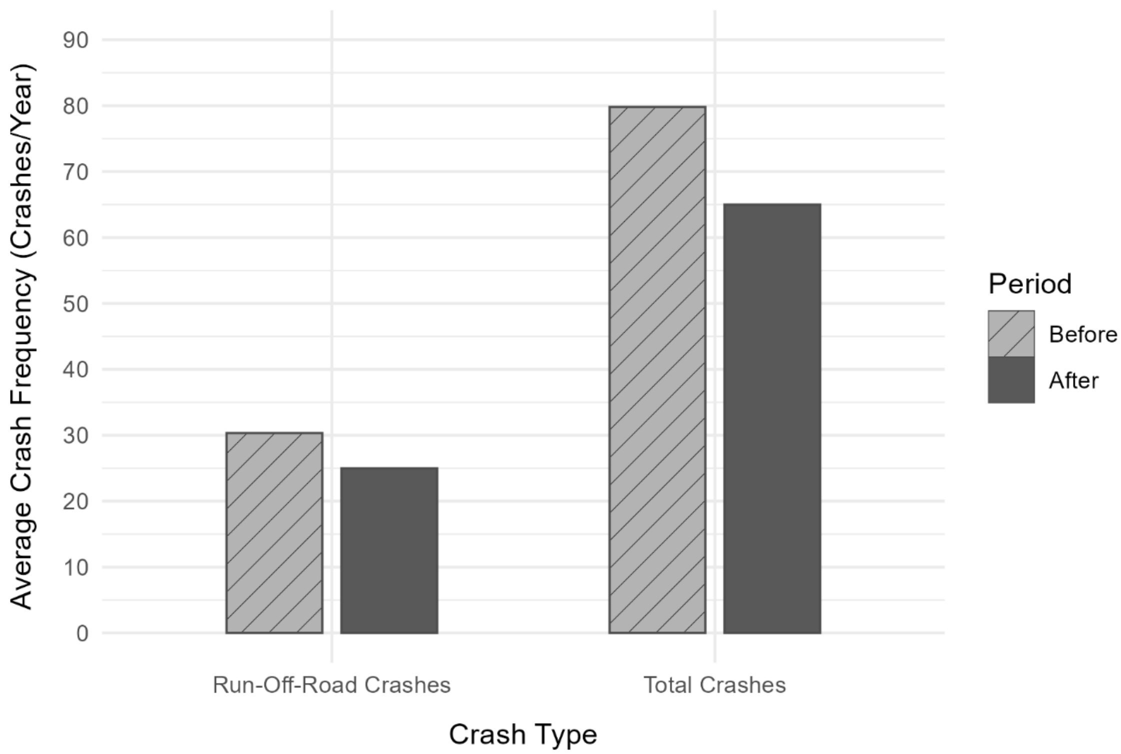

Figure 4-5: Crash Frequency Before and After SRS Installation

Figure 4-6 shows the average crash frequency for the total and ROR crash types that occurred during dark conditions. The light conditions grouped for the analysis were crashes that occurred during darkness with and without streetlights, dusk, and dawn conditions. The figure shows that the average crash frequency during such low-light conditions has decreased after the installation of SRS.

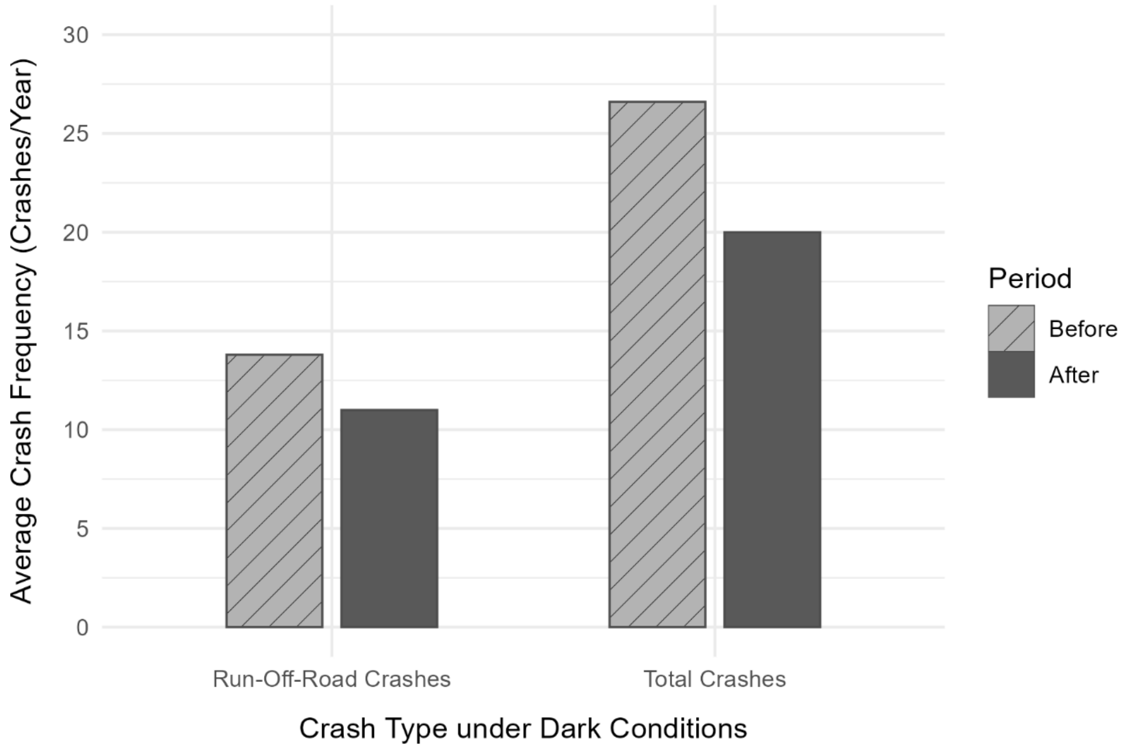

Figure 4-6: Crash Frequency under Dark Conditions Before and After SRS Installation

Figure 4-7 depicts the relevant causes at the SRS treatment sites before and after installation of SRS. The average crash frequency for the two crash types 'Fatigue' and 'Failure to maintain lane' were found to have reduced significantly in the after period.

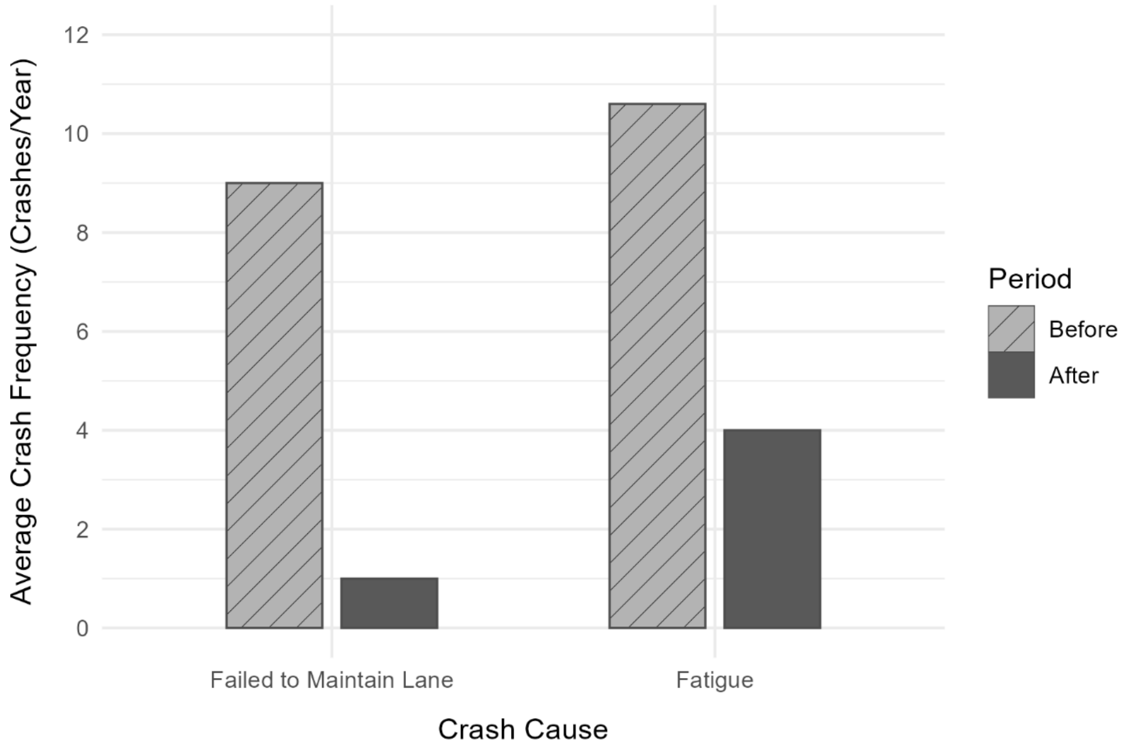

Figure 4-7: Crash Frequency under Different Crash Cause Before and After SRS Installation

4.1.3 Two-Way Vs. Four-Way Stop Control

This treatment type does not have a before/after analysis due to the absence of installation data. Instead, average crashes were compared against 32 two-way stop and 44 four-way stop locations. Figure 4-8 shows the difference between the average crash frequency among the two stop controls, with 4-way stop having fewer average crashes.

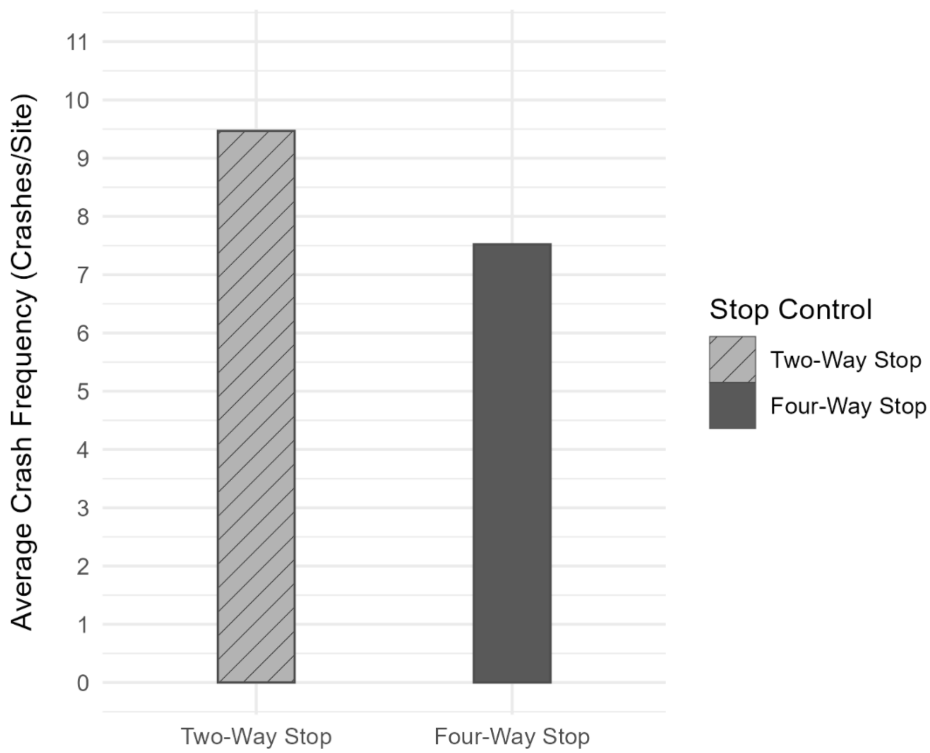

Figure 4-8: Average Crash Frequency under Different Stop Control Types

Figure 4-9 shows the difference between the average number of crashes at the two types of stop-control locations aggregated by posted speed. It was observed that the difference in crashes is higher when the speed limit is greater than 35 mph. At lower speeds, the two stop control types have similar average crashes.

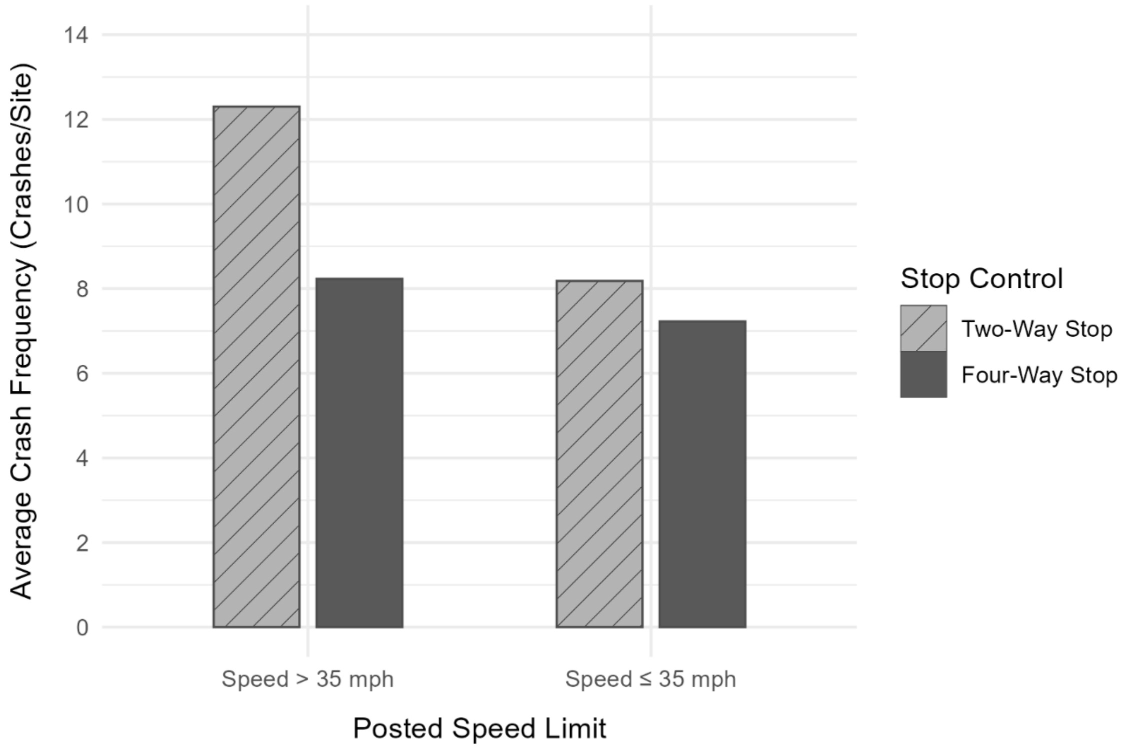

Figure 4-9: Average Crash Frequency under Different Stop Control Types and Speed

Figure 4-10 shows the average crash frequency for the stop control types based on the crash cause. The top two crash causes at the stop-controlled intersection were found to be failure to yield ROW and failure to avoid vehicle ahead. The graph shows that the average crash frequency for four-way stop is lower compared to that of two-way stop when comparing the crash causes.

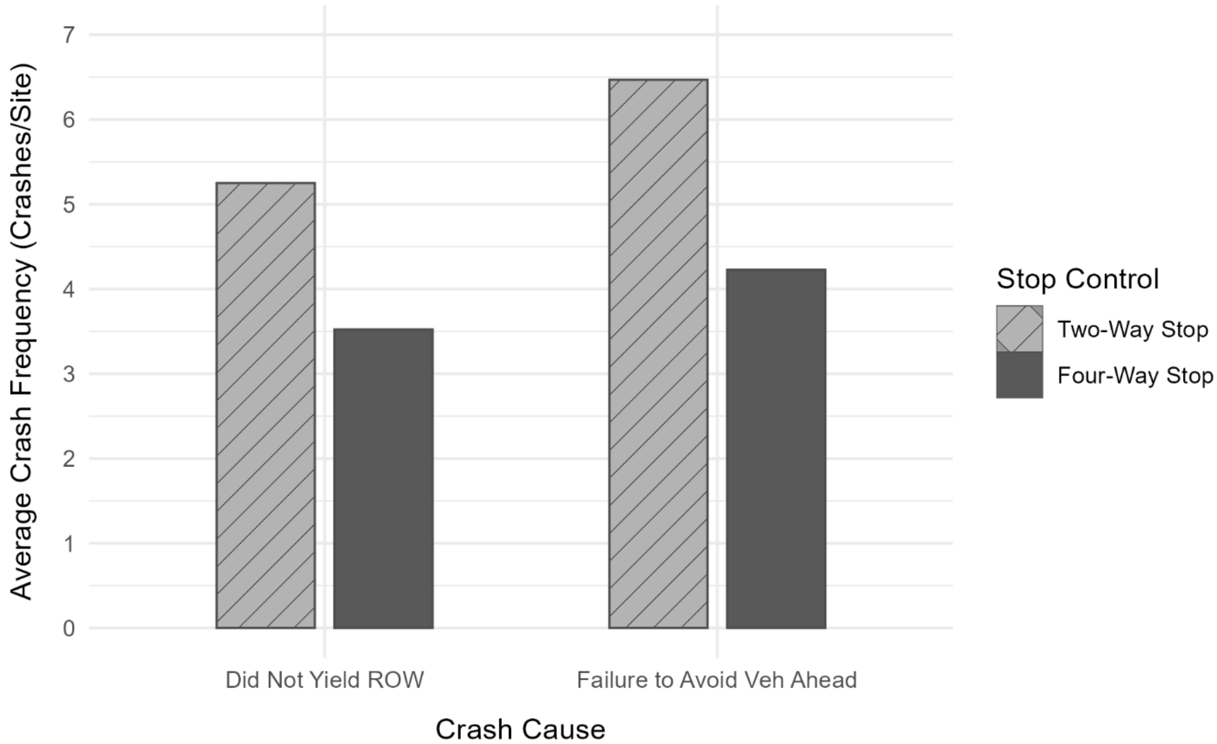

Figure 4-10: Average Crash Frequency under Different Stop Control Types and Crash Cause

4.2 SPF DEVELOPMENT

The SPFs were assumed to follow an NB distribution as mentioned in the methodology section. The development of the SPF model was done using the statistical software R. Models were developed from control sites as well as the 'before' period of treatment sites. The following sections explain the model development as well as the estimate of the coefficients, standard error and *p*-value.

4.2.1 RRFB

Traffic data and roadway parameters of the control sites and treatment sites were explored for development of the model. The log-normalized AADT was used as the base variable. The roadway characteristics used included number of lanes, lane width, presence of median, presence of raised median, presence of paved median, and posted speed limit. The variables were added or removed from the model based on their significance. After extensive testing and iteration, models for total crashes, rear-end crashes and pedestrian crashes were developed.

The SPF models for total and rear-end crashes are shown in Equations 4-9 and 4-10 below.

$$\text{Total crashes/year} = AADT^{a} * e^{raised\ median * b} * e^{c} \tag{4-9}$$

$$\text{Rear-end crashes/year} = AADT^{a} * e^{raised\ median*b} * e^{c} * \text{speed limit}$$

(4-10)

Where,

AADT = average annual daily traffic volume

raised median = 1 if raised median is present; 0 if absent

a,b,c = parameters estimated in the SPF model

speed limit = posted speed limit

The parameters estimated for the model crashes using the 'before' period of treatment sites are given in Table 4-1. The positive sign of the AADT parameter indicates that the probability of crash increases with the increase in AADT.

The raised median variable was found to be significant for both models. It is interesting to note that the sign of the coefficient for the raised median is positive for both total and rear-end crash types. A previous study by Goswamy & Abdel-Aty (2023) on RRFBs installed in Florida also indicated similar findings regarding raised medians. Their results found that raised medians were associated with higher pedestrian and total crashes compared to other types of median. This could be explained by the fact that raised medians are generally installed at crossings that have potentially long or unsafe crossing distances and higher pedestrian volumes. So, the results should not be interpreted as the presence of raised median increasing crash frequency, but rather that pedestrian crashes were fewer at locations with less traffic and pedestrian volume. This may indicate that the installation of RRFB is required at crosswalks with a raised median, as the median alone may not be sufficient to prevent crashes.

Speed limit was introduced as an offset variable, although it did not show significance as a predictor variable, for its effect on pedestrian safety at crossings. RRFBs are generally considered effective for crossings that have a speed limit below 40 mph (FHWA, 2013).

Table 4-1: Parameter estimates and model statistics (RRFB)

Crash Type	Parameter	Estimate	Standard error	*p*-value
Total	Intercept	-6.354	2.169	0.003
	AADT	0.737	0.229	0.001
	Raised median	0.592	0.318	0.062
Rear-end	Intercept	-12.756	2.635	0
	AADT	0.96	0.277	0.001
	Raised median	0.66	0.36	0.066

Models following Equation 4-9 and 4-10 were also developed from the control sites for the total and rear-end crashes. The large number of control sites permitted a robust model for pedestrian crashes as well. Thus, the SPF for pedestrian crashes was also developed and is given in Equation 11 below.

$$\textbf{Pedestrian crashes/year} = AADT^{a} * \ e^{lanes*b} * \ e^{c}$$

(4-11)

Where,
AADT = average annual daily traffic volume
Lanes = number of lanes
a,b,c = parameters estimated in the SPF model

The parameters estimated from the control sites are given in Table 4-2 below. The variables for the total and rear-end models were not found to be as significant compared to the model developed from the 'before' period of treatment sites. The variable 'number of lanes' was found to be positively significant for pedestrian crashes. This makes sense as the increase in number of lanes increases the time spent by pedestrians on the roadway, thereby increasing exposure.

Table 4-2: Parameter estimates and model statistics (RRFB – control sites)

Crash Type	Parameter	Estimate	Standard error	*p*-value
Total	Intercept	-8.798	1.287	0
	AADT	0.967	0.139	0
	Raised median	0..21	0.187	0.27
Rear-end	Intercept	-16.344	1.579	0
	AADT	1.344	0.17	0
	Raised median	-0.013	0.211	0.95
Pedestrian	Intercept	-12.192	3.434	0
	AADT	0.901	0.393	0.022
	Number of lanes	0.309	0.208	0.137

4.2.2 SRS

The traffic data and roadway parameters of the sites were explored for the development of the model. The roadway variables considered included lane width, number of lanes, presence of median, shoulder width and speed limit. Among these, AADT, right shoulder width, and number of lanes were found to be significant.

The models developed for the total crashes and ROR crashes are presented below in Equations 4-12 and 4-13.

$$\textbf{Total crashes/mile/year} = AADT^{a} * e^{b*right\ shoulder\ width} * e^{c*night} * e^{d}$$

(4-12)

$$\text{ROR crashes/mile/year} = AADT^{a} * e^{b*right\ shoulder\ width} * e^{c*night} * e^{d}$$

(4-13)

Where,
AADT = average annual daily traffic volume
right shoulder width = 1 if right shoulder width < 8 feet and 0 if ≥ 8 feet
night = proportion of crashes occurring at dawn/dusk/dark

The parameter estimates from the 'before' period of the model are given in Table 4-3 below.

Table 4-3: Parameter estimates and model statistics (SRS)

Crash Type	Parameter	Estimate	Standard error	*p*-value
Total	Intercept	-9.217	1.27	0
	AADT	1.043	0.137	0
	Right shoulder width <8 ft	0.175	0.113	0.123
	Night	3.295	2.141	0.124
ROR	Intercept	-4.16	-1.831	0.067
	AADT	0.359	1.451	0.147
	Right shoulder width <8 ft	0.515	2.697	0.007
	Night	7.492	2.067	0.039

Table 4-3 presents the estimates of the model using 'before' period of the treatment sites. The positive AADT coefficient suggests an increase in crashes with increase in AADT. This is also in-line with previous studies on SRS (Khan et al., 2015; Patel et al., 2007). The estimate for the variable right shoulder width <8 ft is positive as expected. This indicates that there is an increase in crashes associated with segments having a narrow shoulder width (< 8 ft). This result suggests that the application of SRS may be particularly effective on highways with shoulder width less than 8 ft. Additionally, shoulder width less than 8 ft may serve as an indicator of increased risk of ROR crashes. The coefficient for the variable night is also positive. This suggests that low or no-light conditions are associated with increased crash frequency and that crashes are more likely to occur during nighttime. The installation of rumble strips may help in the reduction of ROR crashes by improving driver alertness.

The models shown in Equation 4-12 and 4-13 were also developed using control sites. The parameter estimates from the control sites are given in Table 4-4 below:

Table 4-4: Parameter estimates and model statistics (SRS - control sites)

Crash Type	Parameter	Estimate	Standard error	*p*-value
Total	Intercept	-4.334	-1.613	0.107
	AADT	0.552	1.894	0.058
	Right shoulder width <8 ft	0.284	1.387	0.166
	Night	5.849	2.103	0.035

ROR	Intercept	-0.944	2.693	0.726
	AADT	0.121	0.295	0.681
	Right shoulder width < 8 ft	0.047	0.202	0.818
	Night	1.313	2.501	0.599

In general, it was found that the variables were not as significant for the model from control sites. However, the CMF was analyzed from both Table 4-3 and 4-4 for a consistent analysis.

4.2.3 Two-Way and Four-Way Stop Control

Crash data from both four-way and two-way stop control along with their traffic and geometric characteristics were assembled. This aggregated data was used for the cross-sectional analysis. An indicator variable representing the presence or absence of the treatment (four-way stop) was included in the model. The following model shown in Equation 14 was developed for the total crashes:

$$\textbf{Total Crashes} = e^{a + \text{treatment}*b + \text{skew}*c + \text{speed}*d + (\text{speed}*\text{skew})*e} * \text{aadt\_major}^{f} \tag{4-14}$$

Where,
treatment = 1 if four-way stop is present; 0 if absent
aadt_major = AADT on major approach
skew = 1 if skewed intersection; 0 if absent
speed = 1 if posted speed on major approach > 35mph; 0 if ≤ 35 mph
a, b, c, d, e, f = regression coefficients

The estimated parameters of the model are given in Table 4-5 below:

Table 4-5: Parameter estimates and model statistics (Stop Control)

Crash Type	Parameter	Estimate	Standard error	*p*-value
Total Crashes	Intercept	2.196	0.044	<0.001
	Treatment	-0.171	0.057	0.003
	Speed > 35mph	0.433	0.073	<0.001
	Skew	-0.442	0.067	<0.001
	Treatment*(Speed > 35)	-0.272	0.099	0.006

The results indicate that the presence of higher posted speeds (> 35 mph) is found to be associated with an increase in crash frequency at all stop control locations. However, the negative coefficient of the interaction term between treatment and posted speed (> 35 mph) indicates that, at higher-speed intersections, crash frequency is more likely to increase at two-way stop-controlled sites than at four-way stop-controlled sites. This suggests that increases in speed limit have a greater impact on crash occurrence at two-way stops compared to four-way stops.

The skewness has a negative coefficient, suggesting that skewed intersections are associated with fewer crashes at four-way stop sites compared to two-way stop sites. This could be explained by the fact that four-way stops force all vehicles to stop, which may mitigate the negative geometric effect of skewness.

The effect of the treatment variable implied that four-way stops are associated with approximately a 15.7% reduction in crashes compared to two-way stops. Previous studies on stop control conversions in other states have reported even higher reductions in crash frequency. A cross-sectional study (Deng et al., 2020) of two-way to all-way stop control conversion in Washington, DC found a 36% reduction in all crashes. An EB before-after study (Simpson & Hummer, 2010) in North Carolina reported a crash reduction of 68% in total crashes on conversion from two-way stops to all-way stops.

Figure 4-10 displays the results of the parameter estimate and statistics for the total crashes.

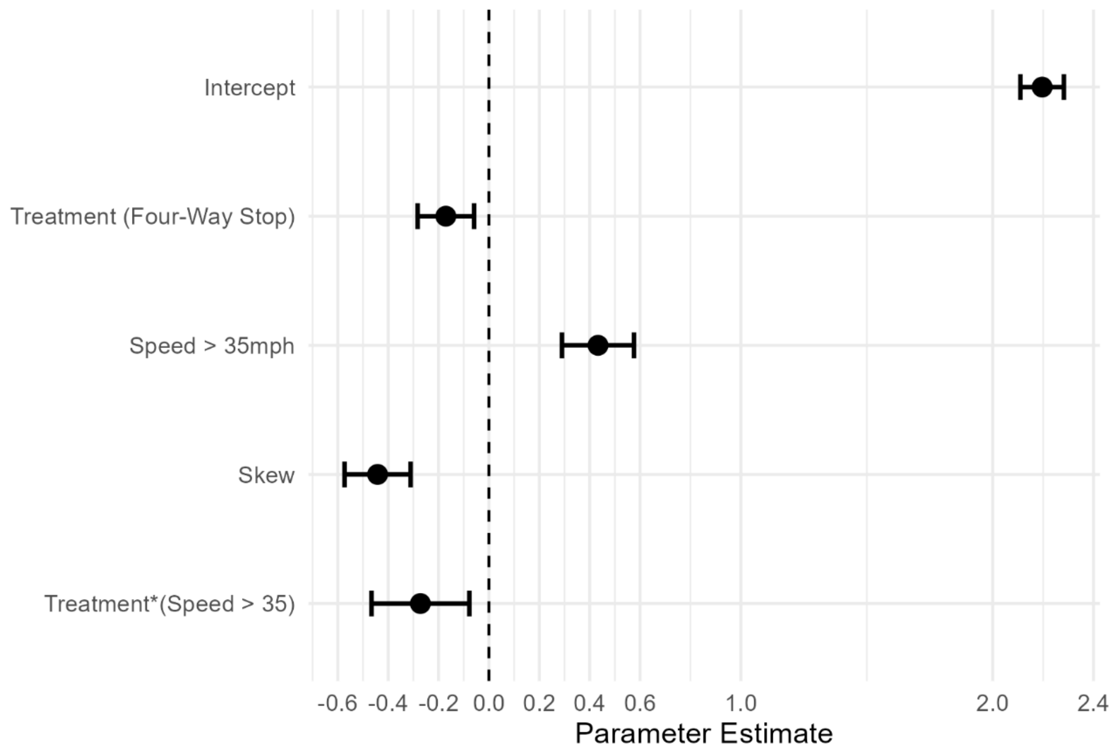

Figure 4-11: Parameter Estimates for Total Crashes for Stop Control Conversion

4.3 CMF CALCULATION

The CMF was calculated for the treatments RRFB and SRS as part of the EB methodology. The EB estimate of expected number of crashes without treatment was calculated for all treatment sites. This EB estimate and the observed number of crashes in the after period was used to determine the CMF. A CMF value of less than 1 indicates a reduction in crashes after installation of the treatment, while a value greater than 1 indicates an expected increase in crashes (Gross, Persaud and Lyon, 2004).

4.3.1 RRFB

The CMFs were calculated for total crashes, rear-end crashes and pedestrian crashes. The rear-end crashes were analyzed to understand the effects of RRFB installation on this crash type. The CMF analyzed for total and rear-end crashes from the 'before' period model is shown in Table 4-6.

Table 4-6: CMF Statistics (RRFB)

Crash Type	Observed crashes during after period	Expected crashes during after period with no treatment	CMF	Standard error	95% confidence interval
Total crashes	340	465.56	0.726	0.052	(0.831, 0.627)
Rear-end crashes	172	199.02	0.86	0.09	(1.037, 0.683)

The CMF for the total crashes was estimated to be 0.726, suggesting that installation of RRFBs has a positive effect in decreasing the total number of crashes in Oregon. The results indicate that there was an approximate 27% reduction in crash frequency. This finding differs from the previous work by Goswamy & Abdel-Aty (2023), whose study on RRFBs installed in Florida found the CMF for total crashes to be 1.14, i.e., an increase in total crashes. This discrepancy could be partly attributed to their study having a larger number of sites (154) compared to this study (46), in addition to the difference in states being analyzed.

For rear-end crashes, the CMF was estimated to be 0.86 (not statistically significant), indicating a decrease in rear-end crashes. However, the relatively higher CMF of rear-end crashes compared to total crashes suggests that the treatment effect is not uniform across crash types. Following the installation of RRFBs, the increased yielding behaviors by drivers could introduce potential rear-end conflict. Left-turning traffic could also influence rear-end crashes and warrant further investigation in terms of rear-end conflict and pedestrian visibility. Previous studies present mixed findings for rear-end crashes. Monsere & Figliozzi's (2016) study in Oregon estimated a CMF of 0.93 (not statistically significant) , indicating a similar CMF but for 2007-2014 years, while Goswamy & Abdel-Aty (2023) found an increase in rear-end crashes with a CMF of 1.11.

Using the models built from the control sites, CMFs were also estimated as presented in Table 4-7 below. The CMF for pedestrian crashes was also estimated for this analysis.

Table 4-7: CMF Statistics (RRFB – control sites)

Crash Type	Observed crashes during after period	Expected crashes during after period with no treatment	CMF	Standard error	95% confidence interval
Total crashes	340	468.930	0.723	0.003	(0.825, 0.621)
Rear-end crashes	172	238.002	0.72	0.072	(0.861, 0.578)
Pedestrian crashes	6	12.001	0.481	0.214	(0.901, 0.062)

The CMFs for the total crashes were found to be comparable between the analysis of control sites and the before period of treatment sites. The CMF for pedestrian crashes, 0.481, was found to be the lowest among the 3 crash types. This result indicates that pedestrian crashes were reduced by up to 52% following the installation of RRFBs. Goswamy & Abdel-Aty's (2023) study reported a CMF of 0.31 for total pedestrian crashes.

Moreover, the installation of RRFBs and median refuge islands encourage pedestrians and bicyclists to use the facility, thereby increasing their activity at the treatment locations. Due to a lack of pedestrian and bicycle volume data, this increase in utilization rate can also influence the observed crash frequencies after installation. This absence of exposure data should be considered when interpreting the safety effectiveness for vulnerable road users.

Figure 4-12 shows the analyzed CMF from the two methods tabulated above. The CMF for the control sites includes those of pedestrian crashes, rear-end crashes and total crashes. Since the ‘before’ period of the treatment sites did not have sufficient pedestrian crashes, the CMFs were only developed for total and rear-end crashes.

The figure indicates that following the installation of RRFBs, pedestrian crashes have the highest reduction among the three crash types. While RRFBs have the potential to bring about an increase in rear-end conflicts, the results should be interpreted in the context of crash severity, as there is an important trade-off between less severe PDO rear-end crashes and comparatively more severe vehicular-pedestrian crashes. From a safety perspective, the overall effect of the treatment can be considered beneficial as the reduction in severe pedestrian crashes outweighs the increase in lower severity rear-end crashes.

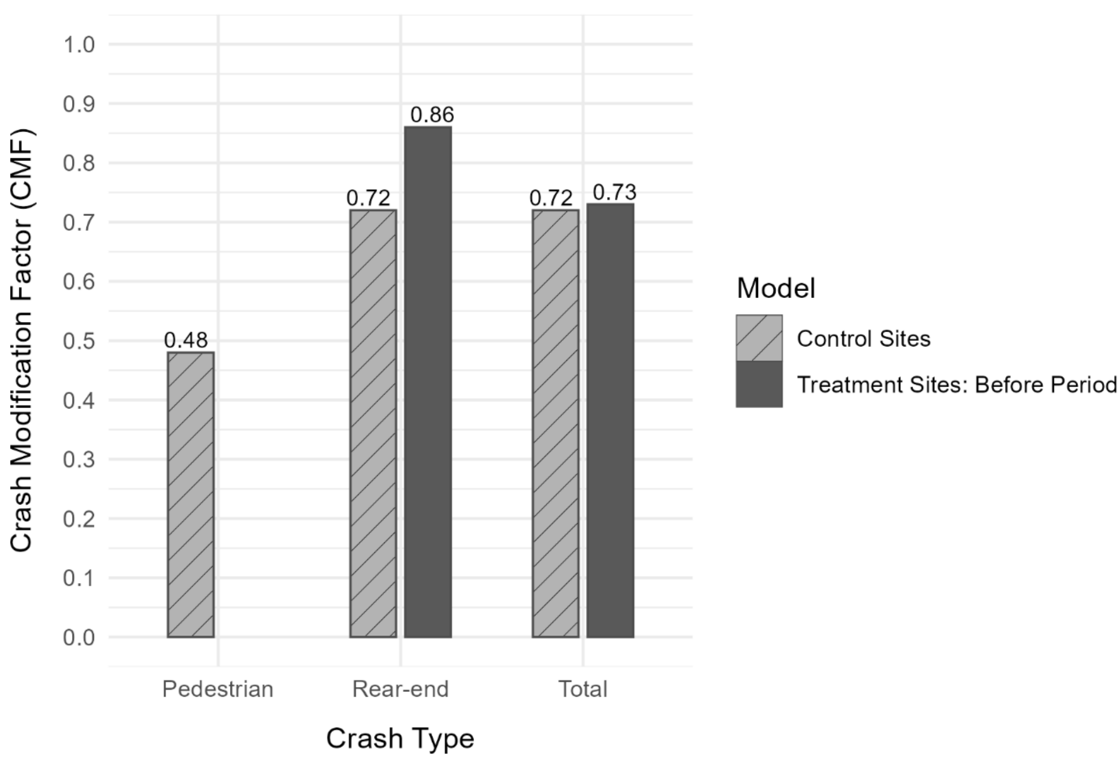

Figure 4-12: CMF Comparison for RRFB under Different Crash Types

4.3.2 SRS

The observed crashes and expected crashes without treatment were calculated for all 58 road segments. The CMF was calculated for total crashes and ROR crashes. The CMF, standard error and confidence interval from the before period are shown in Table 4-8 below.

Table 4-8: CMF Statistics (SRS)

Crash Type	Observed crashes during after period	Expected crashes during after period with no treatment	CMF	Standard error	95% confidence interval
Total crashes	68	94.719	0.716	0.094	(0.9,0.535)
ROR crashes	26	35.557	0.726	0.155	(1.03,0.423)

The CMF for total crashes was estimated to be 0.72, indicating a 28% reduction in all crashes. This is consistent with previous studies which reported similar findings for total crashes (B. Persaud et al., 2016; Zhao et al., 2023). The CMF for ROR crashes was estimated to be 0.73, suggesting a decrease in ROR crashes by approximately 27%. However, this result was not statistically significant. Previous studies have reported CMF for ROR crashes ranging from 0.613 to 0.944 (Khan et al., 2015; Patel et al., 2007; B. Persaud et al., 2016; Zhao et al., 2023)

Because the after period only contained data from one year, the number of observed crashes in the after period for ROR crashes was relatively small. Due to the small sample size and study period, the results may not fully capture the long-term effect of the treatment on relevant crash types. Overall, the CMF for both total and ROR crashes are less than 1, suggesting that SRS are effective in decreasing the crash frequency, although the results for ROR are not statistically significant to be conclusive.

Using the models built from the control sites, the CMF was analyzed as presented in Table 4-10 below. The total crashes were found to have a similar CMF to the results from Table 4-9. The analysis from the control sites showed a greater CMF (0.809 vs. 0.726) for the ROR crashes. Since the model did not have highly significant variables, the results may be deemed less reliable than the results in Table 4-8.

Table 4-9: CMF Statistics (SRS – control sites)

Crash Type	Observed crashes during after period	Expected crashes during after period with no treatment	CMF	Standard error	95% confidence interval
Total crashes	68	95.569	0.710	0.093	(0.89,0.527)
ROR crashes	26	31.941	0.809	0.171	(1.143,0.474)

Figure 4-13 compares the analyzed CMF from the two methods tabulated above. The chart shows that the CMF for the ROR crashes from the two models are similar. The total crashes has a higher CMF using control sites compared to using the ‘before’ period of treatment.

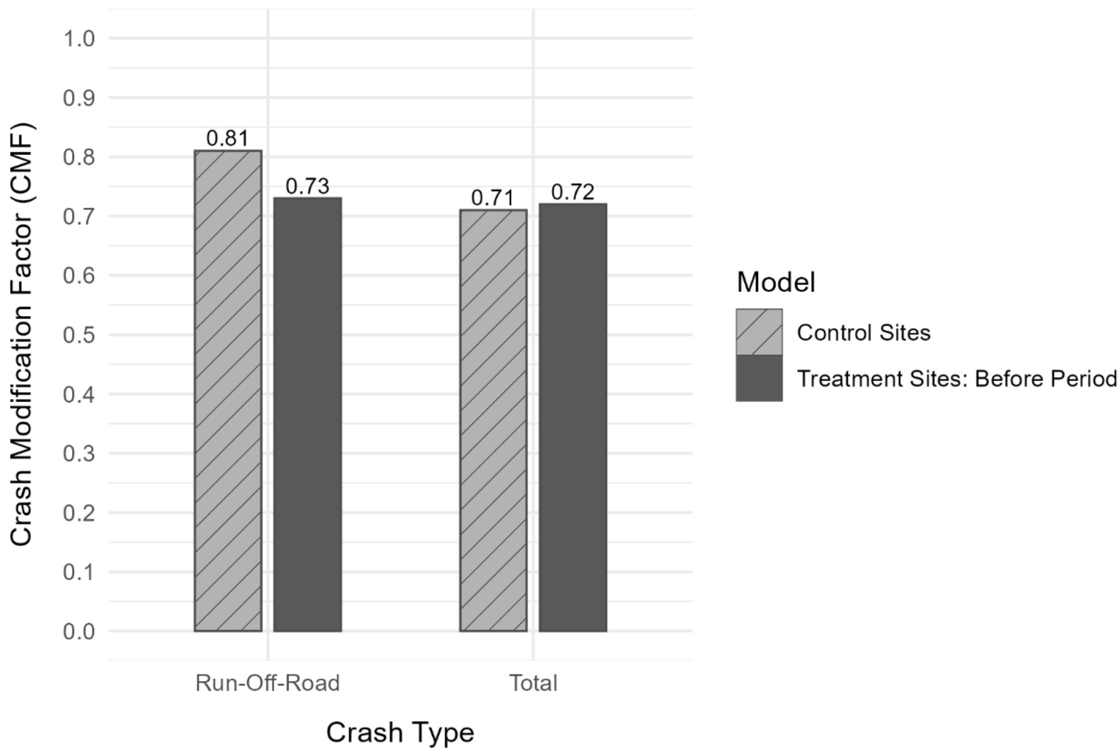

Figure 4-13: CMF Comparison for SRS under Different Models

5.0 CONCLUSION AND RECOMMENDATIONS

This study evaluated the safety effectiveness of three low-cost safety improvement projects in Oregon funded through the Oregon Department of Transportation (ODOT) Highway Safety Improvement Fund (HSIP). Safety effectiveness of Rectangular Rapid Flashing Beacon (RRFB), Shoulder Rumble Strip (SRS) and conversion of Two-Way to Four-Way stop control were evaluated. Empirical Bayes (EB) before-after method was used for the RRFB and SRS while an observational cross-section analysis was adopted for the stop control conversion.

This report also summarizes the available literature on safety analysis of the three treatment types. The methodology was documented along with data collection, analysis approach and results. A transferable framework was developed for both EB study and cross-sectional analysis. The framework also details the reasons that warrant the use of the type of study based on the availability of data.

Most of the available studies on RRFBs relied on surrogate safety measures like yielding rates and vehicle speed for their analysis. Only a handful of studies presented crash analysis and CMF calculation, with only one study (Monsere et al., 2017) in Oregon. This research advanced local knowledge of RRFBs by analyzing sites in Oregon through EB study. Forty-six RRFB sites were selected for the final analysis. The lack of availability of installation data for RRFBs limited the number of sites included in the analysis. Nevertheless, significant results were found for CMFs estimated for total crashes (0.73), rear-end crashes (0.86) and pedestrian crashes (0.48). The results indicated that the installation of RRFB led to a decrease in pedestrian crashes by up to 52%. Based on the analysis, installation of RRFB has positive safety benefits on multilane crossings as well as on crossings with refuge islands to further enhance visibility of crossing pedestrians.

Crash analysis of rumble strips in Oregon was not found to be publicly documented in the peer-reviewed literature. This study contributed to closing this research gap by performing a before-after study on the safety effectiveness of rumble strips in Oregon. SRS installed on 45.67 miles of state highway were analyzed to produce the CMF for total crashes (0.72) and run-off-road (0.73) crashes. Results indicated that installation of SRS is recommended on roadways with shoulder widths less than 8 feet to reduce run-off-road crashes. However, it should be noted that these results are based on only one year of after period data, so caution is warranted when applying the CMFs.

Only three previous studies (Deng et al., 2020; Lovell & Hauer, 1986; Simpson & Hummer, 2010) were found on the crash analysis for the conversion of two-way stop control to four-way stop control. This report contributes to the literature by conducting a cross-sectional analysis of the stop control conversion as an alternative to the before-after study. A total of 32 two-way stops and 44 four-way stops were analyzed to understand the effect on total crash frequency. The results indicated a 15.7% decrease in crashes at four-way stops compared to two-way stops. Based on the analysis, installation of four-way stops may be most effective at high-speed intersections (> 35 mph). It should be noted however that it is difficult to ascertain the cause and effect of treatment from cross-sectional analysis as compared to an EB study.

6.0 FRAMEWORK FOR ANALYSIS

A summary of the methodology has been shown in the flowchart in Figure 6-1 and 6-7. This flowchart outlines the necessary steps required for the approach to determine the safety effectiveness of low-cost safety treatments in Oregon. The framework details the reasons that warrant the use of each study type based on the availability of certain data elements.

Figure 6-1 showcases the comprehensive flow of work when evaluating treatments for a EB before-after study. It ensures that necessary data for the analysis is collected from the various sources listed in the framework. The calculations omitted in the framework can be found in the Methodology chapter of this report.

Figure 6-3 showcases the framework for a safety analysis in the absence of installation data. The methodology for an observational cross-sectional analysis was documented for situations where a before/after evaluation is not feasible due to the unavailability of treatment installation date and crash data prior to installation.

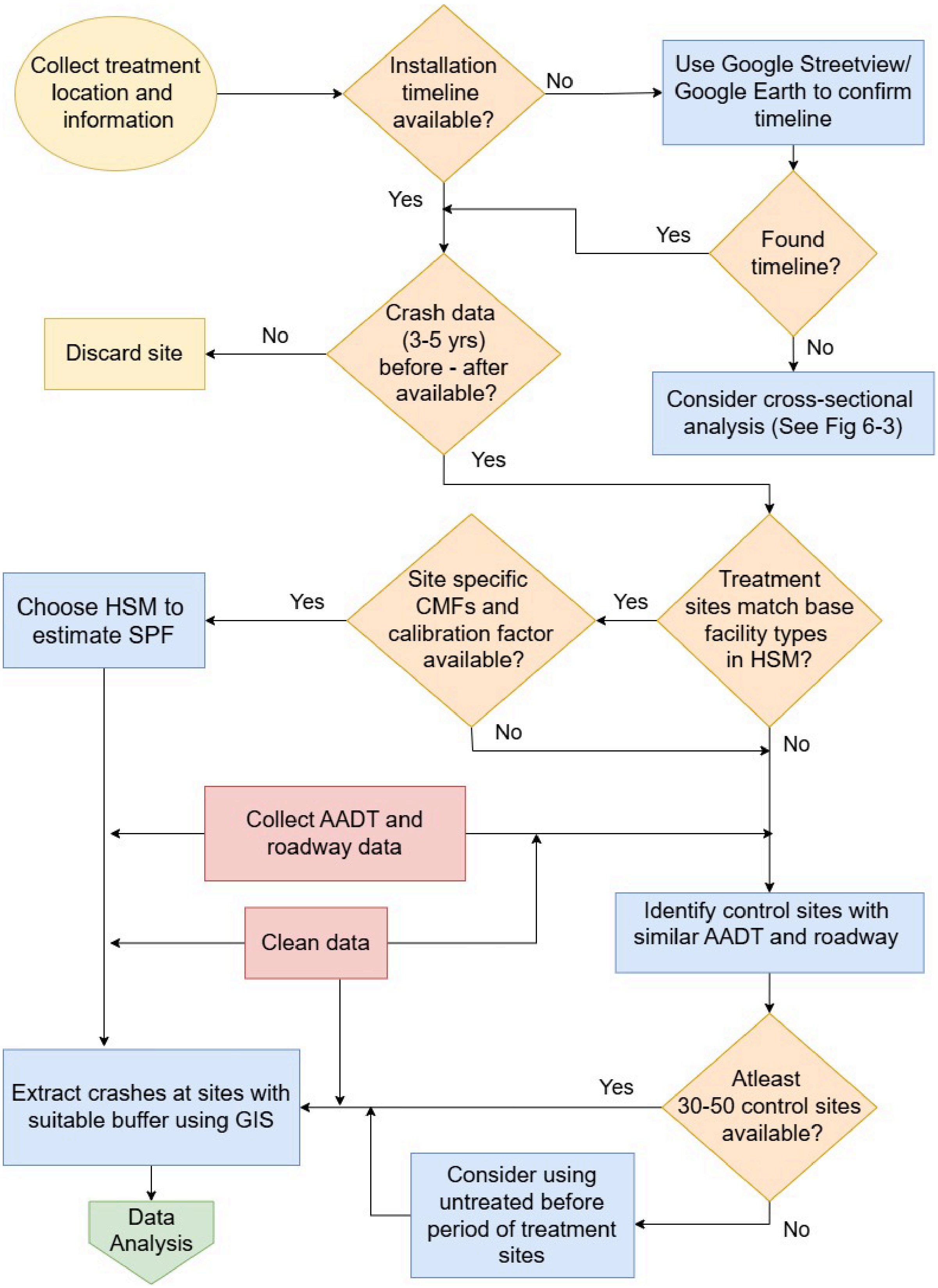

Figure 6-1: EB Before/After Flowchart (Data Collection)

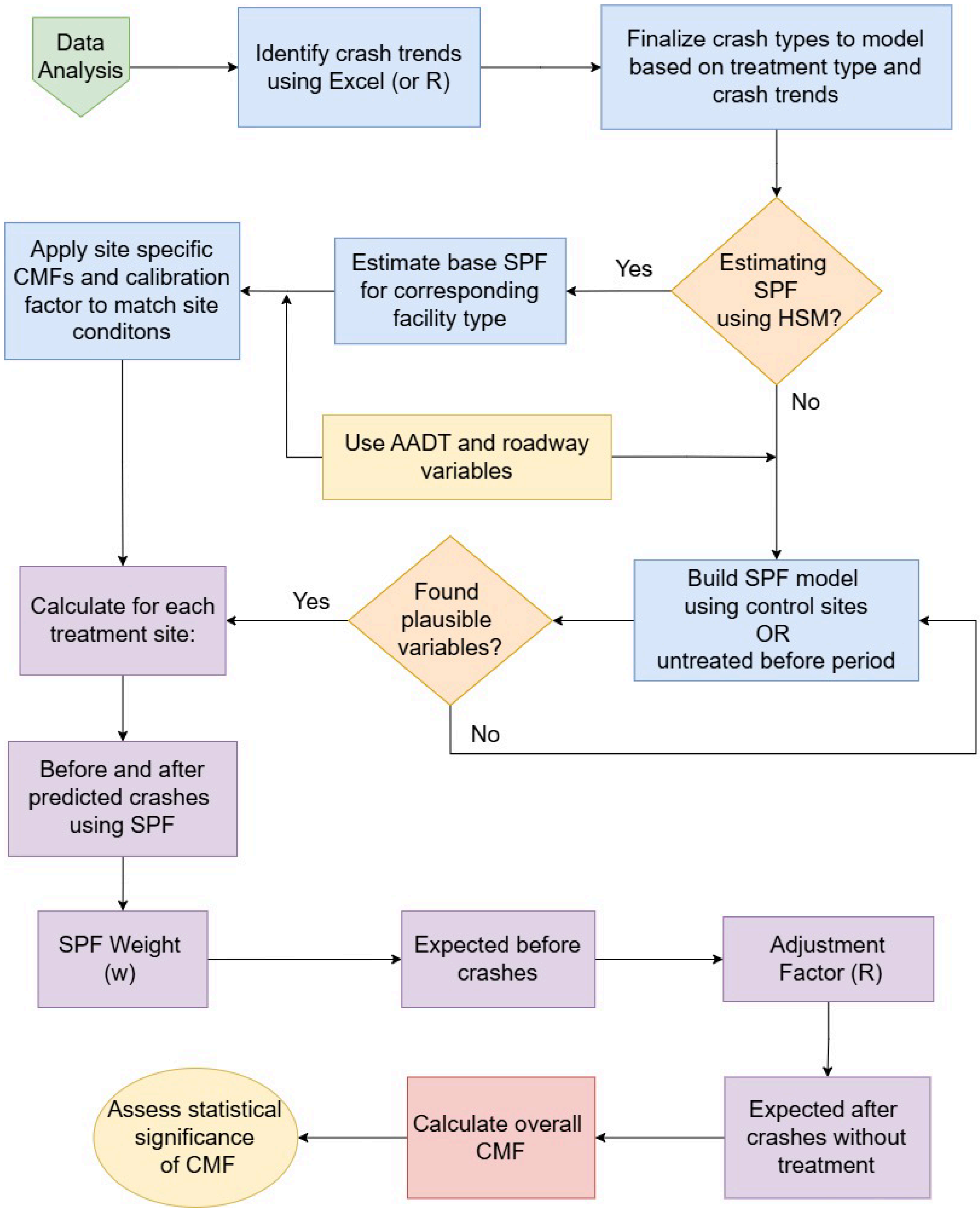

Figure 6-2: EB Before/After Flowchart (Data Analysis)

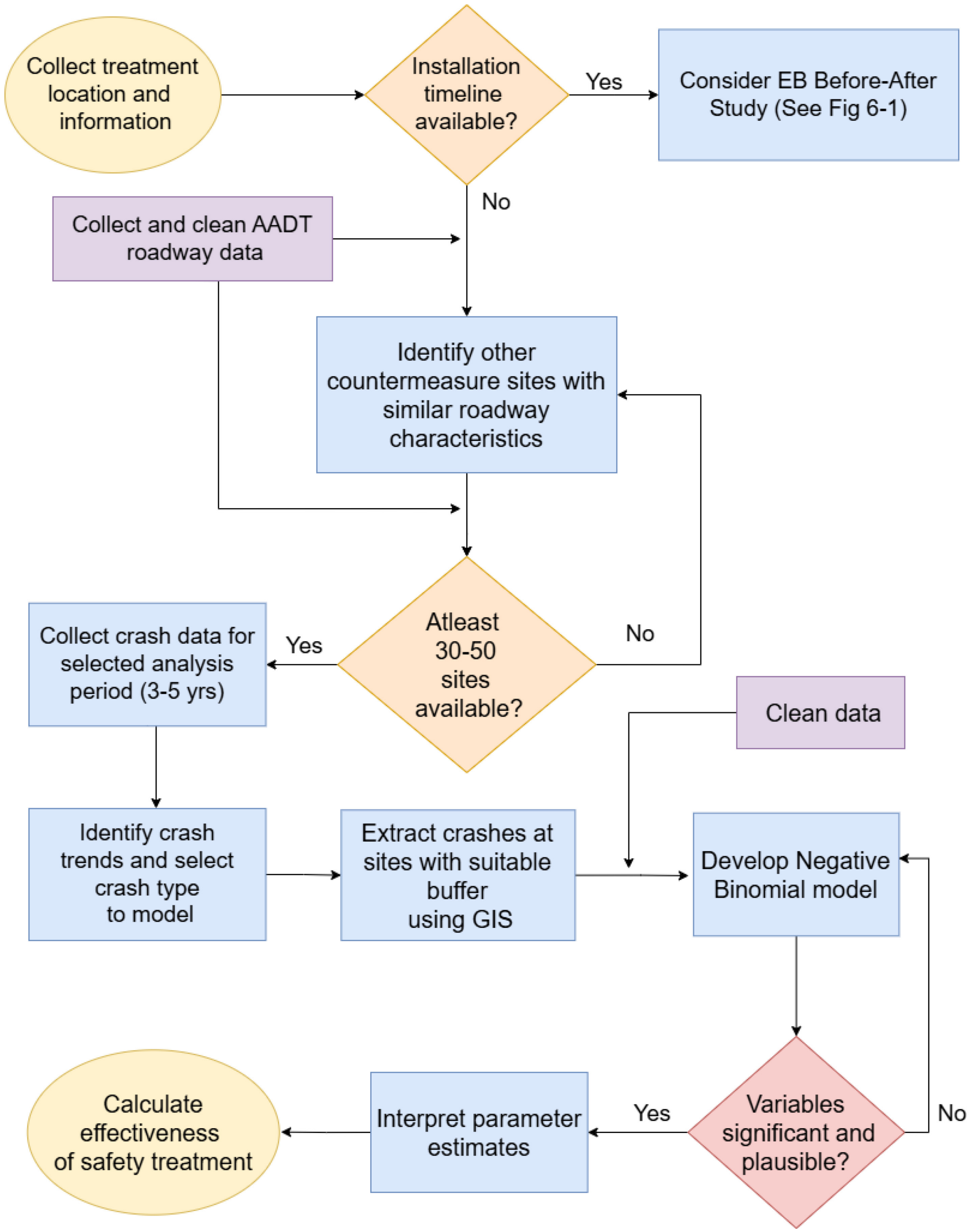

Figure 6-3: Cross-Sectional Analysis

7.0 REFERENCES

AASHTO. 2010. Highway safety manual. Washington, DC: AASHTO.

Abdel-Rahim, A., Khan, M., & National Institute for Advanced Transportation Technology (NIATT) (U.S.). (2012). Potential Crash Reduction Benefits of Safety Improvement Projects - Part A: Shoulder Rumble Strips (No. FHWA-ID-12-191A). /view/dot/25159

Brewer, M. A., & Fitzpatrick, K. (2012). Before-and-after study of the effectiveness of rectangular rapid-flashing beacons used with school sign in Garland, Texas. TexITE Technical Paper Award. Texas District of the Institute of Transportation Engineers.

Brewer, M. A., Fitzpatrick, K., & Avelar, R. (2015). Rectangular Rapid Flashing Beacons and Pedestrian Hybrid Beacons: Pedestrian and Driver Behavior before and after Installation. Transportation Research Record, 2519(1), 1–9. https://doi.org/10.3141/2519-01

Brewer, Marcus A. and Bedsole, Lisa (2015). Desk Reference to the Handbook for Designing Roadways for the Aging Population.

Chen, C., Darko, E. O., & Richardson, T. N. (2003). Optimal continuous shoulder rumble strips and the effects on highway safety and the economy. *Institute of Transportation Engineers. ITE Journal*, *73*(5), 30–41.

Deng, Z., Kyrychenko, S., Lee, T., & Retting, R. (2020). Estimate of the Safety Effect of All-Way Stop Control Conversion in Washington, DC. *Transportation Research Record*, *2674*(7), 77–86. https://doi.org/10.1177/0361198120920871

Dadashova, B., Wu, L., & Dixon, K. (2018). Evaluating the Impact of Rumble Strips on Fatal and Injury Freeway Crashes. *Transportation Research Record*, *2672*(30), 131–141. https://doi.org/10.1177/0361198118793498

Ebbecke, G. M. (1976). An examination of the areawide effects of traffic control device installations in a dense urban area. *Villanova University, Department of Civil Engineering*.

Eck, R., & Biega, J. A. (1988). Field evaluation of two way versus four way stop sign control at low volume intersections in residential areas. *Transportation Research Record*. https://www.semanticscholar.org/paper/Field-evaluation-of-two-way-versus-four-way-stop-at-Eck-Biega/fc5c71186f6a19ebcea72e6aacf5baf3473398d6

Federal Highway Administration. (2013). “Rectangular rapid flash beacon” in PEDSAFE: Pedestrian safety guide and countermeasure selection system. U.S. Department of Transportation. http://www.pedbikesafe.org/PEDSAFE/countermeasures_detail.cfm?CM_NUM=54

Federal Highway Administration (FHWA). (2023). *Roadway departure safety*. Retrieved September 14, 2025, from https://highways.dot.gov/safety/RwD

Fitzpatrick, K., Chrysler, S. T., Van Houten, R., Hunter, W. W., & Turner, S. M. (2011). Evaluation of pedestrian and bicycle engineering countermeasures: Rectangular rapid-flashing beacons, HAWKs, sharrows, crosswalk markings, and the development of an evaluation methods report (Report No. FHWA-HRT-11-039). Federal Highway Administration.

Fitzpatrick, K., Brewer, M. A., & Avelar, R. (2014). Driver Yielding at Traffic Control Signals, Pedestrian Hybrid Beacons, and Rectangular Rapid-Flashing Beacons in Texas. TRANSPORTATION RESEARCH RECORD, 2463, 46–54. https://doi.org/10.3141/2463-06

Fitzpatrick, K., Iragavarapu, V., Brewer, M. A., Lord, D., Hudson, J., Avelar, R., & Robertson, J. (2014). Characteristics of Texas pedestrian crashes and evaluation of driver yielding at pedestrian treatments. Transportation Research Record: Journal of the Transportation Research Board, 2519(1), 1–9. https://doi.org/10.3141/2519-01d

Fitzpatrick, K., Brewer, M. A., Avelar, R., & Lindheimer, T. (2017). Will You Stop for Me? Institute of Transportation Engineers. ITE Journal, 87(3), 36–42.

Foster, N., Monsere, C. M., & Carlos, K. (2014). Evaluating Driver and Pedestrian Behaviors at Enhanced, Multilane, Midblock Pedestrian Crossings Case Study in Portland, Oregon. TRANSPORTATION RESEARCH RECORD, 2464, 59–66. https://doi.org/10.3141/2464-08

Gårder, P., & Davies, M. (2006). Safety Effect of Continuous Shoulder Rumble Strips on Rural Interstates in Maine. *Transportation Research Record*, *1953*(1), 156–162. https://doi.org/10.1177/0361198106195300118

Griffith, M. S. (1999). Safety Evaluation of Rolled-In Continuous Shoulder Rumble Strips Installed on Freeways. *Transportation Research Record*, *1665*(1), 28–34. https://doi.org/10.3141/1665-05

Gross, F., Persaud, B., & Lyon, C. (2010). A guide to developing quality crash modification factors (Report No. FHWA-SA-10-032). Federal Highway Administration, U.S. Department of Transportation.Goswamy, A., & Abdel-Aty, M. (2023). Safety Effectiveness of Rectangular Rapid Flashing Beacons Pedestrian Enhancement. Journal of Transportation Engineering, Part A: Systems, 149(8), 04023070. https://doi.org/10.1061/JTEPBS.TEENG-7507

Gupta, N., Johari, M. U. M., Jashami, H., & Savolainen, P. (2022). How is traffic safety affected by changes in traffic speeds following speed limit increases? An evaluation with probe vehicle data. *Traffic Safety Research*, *3*, 000017-000017.

Hauer, E., Harwood, D. W., Council, F. M., & Griffith, M. S. (2002). Estimating Safety by the Empirical Bayes Method: A Tutorial. *Transportation Research Record: Journal of the Transportation Research Board*, *1784*(1), 126–131. https://doi.org/10.3141/1784-16

Hauer, E. (2004). Statistical road safety modeling. Transportation Research Record, 1897(1), 81-87.

Hauer, E. (2010). Cause, effect and regression in road safety: A case study. *Accident Analysis & Prevention*, *42*(4), 1128–1135. https://doi.org/10.1016/j.aap.2009.12.027

Horne, D., Jashami, H., Monsere, C. M., Kothuri, S., & Hurwitz, D. S. (2021). Evaluating In-Vehicle Sound and Vibration during Incursions on Sinusoidal Rumble Strips. *Transportation Research Record: Journal of the Transportation Research Board*, *2675*(3), 154–166. https://doi.org/10.1177/0361198120967947

Hunter-Zaworski, K. M., & Mueller, J. (2012). Evaluation of alternative pedestrian traffic control devices (Report No. FHWA-OR-RD-12-09). Oregon Department of Transportation.

Jones, J. G., Ercisli, S., Bish, D. W., & Burks, T. W. (2017). *Oregon Roadway Departure Implementation Plan Update, 2009-2015: Final report*. Oregon Department of Transportation. Retrieved September 14, 2025, from https://www.oregon.gov/odot/Engineering/Docs_TrafficEng/Departure-Implementation-Plan.pdf

Khan, M., Abdel-Rahim, A., & Williams, C. J. (2015). Potential crash reduction benefits of shoulder rumble strips in two-lane rural highways. *Accident Analysis & Prevention*, *75*, 35–42. https://doi.org/10.1016/j.aap.2014.11.007

Kothuri, S., Appiah, F. B., & Monsere, C. (2021). Driver Yielding and Pedestrian Performance at Midblock Crossings on Three-Lane Roadways with Rectangular Rapid Flashing Beacons. TRANSPORTATION RESEARCH RECORD, 2675(9), 910–923. https://doi.org/10.1177/03611981211004962

Lovell, J., & Hauer, E. (1986). The safety effect of conversion to all-way stop control. *Transportation Research Record*, *1068*, 103-107.

Marvin, R. R., Clark, D. J., & Marvin & Associates. (2003). *An Evaluation of Shoulder Rumble Strips in Montana* (No. FHWA/MT-03-008/8157). https://doi.org/10.21949/1518187

Monsere, C., Figliozzi, M., Kothuri, S., Razmpa, A., & Hazel, D. (2017). Safety effectiveness of pedestrian crossing enhancements (Final Report SPR 778). Oregon Department of Transportation.

National Highway Traffic Safety Administration. (2024). Traffic safety fact: 2022 data – Pedestrians (NHTSA Traffic Safety Facts Report). U.S. Department of Transportation, National Highway Traffic Safety Administration.

Oregon Department of Transportation. (2021). ODOT Highway Safety Improvement Program (HSIP) Guide: A Guide to Developing Highway Safety Projects. https://www.oregon.gov/odot/engineering/docs_trafficeng/safety_hsip-guide.pdf

Oregon Intersection Safety Implementation Plan Update. (n.d.). Retrieved December 19, 2025, from https://www.oregon.gov/ODOT/Engineering/TRSDocs/Intersection_Safety_Implementation_Plan.pdf

Olson, D., Sujka, M., Manchas, B., & Washington (State). Dept. of Transportation. Design Policy Research. (2013). *Performance analysis of centerline and shoulder rumble strips installed in combination in Washington State.* (No. WA-RD 799.1). https://rosap.ntl.bts.gov/view/dot/25848

Park, J., Abdel-Aty, M., & Lee, C. (2014). Exploration and comparison of crash modification factors for multiple treatments on rural multilane roadways. *Accident Analysis & Prevention*, *70*, 167–177. https://doi.org/10.1016/j.aap.2014.03.016

Patel, R. B., Council, F. M., & Griffith, M. S. (2007). Estimating Safety Benefits of Shoulder Rumble Strips on Two-Lane Rural Highways in Minnesota: Empirical Bayes Observational Before-and-After Study. *Transportation Research Record*, *2019*(1), 205–211. https://doi.org/10.3141/2019-24

Persaud, B. N. (1986). Safety migration, the influence of traffic volumes, and other issues in evaluating safety effectiveness: some findings on conversion of intersections to multiway stop control. Injury, 73, 81.

Persaud, B., & Lyon, C. (2007). Empirical Bayes before–after safety studies: Lessons learned from two decades of experience and future directions. *Accident Analysis & Prevention*, *39*(3), 546-555.

Persaud, B., Lyon, C., Eccles, K., & Soika, J. (2016). Safety Effectiveness of Centerline Plus Shoulder Rumble Strips on Two-Lane Rural Roads. *Journal of Transportation Engineering*, *142*(5), 04016012. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000821

Ross, J., Serpico, D., & Lewis, R. (2011). Assessment of driver yielding rates pre- and post-RRFB installation (FHWA-OR-RD-12-05). Oregon Department of Transportation.

Saari, I., Wagner, M., & Minnesota Department of Transportation. Office of Traffic Engineering. (2024). Traffic Safety Evaluation of Pedestrians and Bicyclists at Rectangular Rapid Flashing Beacons and Pedestrian Hybrid Beacons in Minnesota (No. MN 2024-11). https://rosap.ntl.bts.gov/view/dot/75585

Sayed, T., deLeur, P., & Pump, J. (2010). Impact of Rumble Strips on Collision Reduction on Highways in British Columbia, Canada: Comprehensive Before-and-After Safety Study. *Transportation Research Record*, *2148*(1), 9–15. https://doi.org/10.3141/2148-02

Savolainen, P. T., Gates, T. J., Kassens-Noor, E., Gupta, N., Mahmud, M. S., Kay, J., Megat-Johari, M.-U., Hisham, J., Lord, D., & Srinivas, G. (2022). Evaluating the impacts of the 2017 legislative mandated speed limit increases. *Michigan Department of Transportation, Report No. SPR-1714.*

Simpson, C. L., & Hummer, J. E. (2010). Evaluation of the Conversion from Two-Way Stop Sign Control to All-Way Stop Sign Control at 53 Locations in North Carolina. *Journal of Transportation Safety & Security*, *2*(3), 239–260. https://doi.org/10.1080/19439962.2010.506355

Smith, E. B., & Ivan, J. N. (2005). Evaluation of Safety Benefits and Potential Crash Migration Due to Shoulder Rumble Strip Installation on Connecticut Freeways. *Transportation Research Record*, *1908*(1), 104–113. https://doi.org/10.1177/0361198105190800113

Spring, G. S. (2003). Shoulder Rumble Strips in Missouri (No. RDT 03-007). https://rosap.ntl.bts.gov/view/dot/37983

Torbic, D. J., Hutton, J. M., Bokenkroger, C. D., Bauer, K. M., Donnell, E. T., Lyon, C., & Persaud, B. (2010). Guidance on Design and Application of Rumble Strips. *Transportation Research Record*, *2149*(1), 59–69. https://doi.org/10.3141/2149-07

Van Houten, R., Ellis, R., & Marmolejo, E. (2008). Stutter-Flash Light-Emitting-Diode Beacons to Increase Yielding to Pedestrians at Crosswalks. Transportation Research Record, 2073(1), 69–78. https://doi.org/10.3141/2073-08

VanWagner, M., Van Houten, R., & Betts, B. (2011). The Effects of a Rectangular Rapid-Flashing Beacon on Vehicle Speed. JOURNAL OF APPLIED BEHAVIOR ANALYSIS, 44(3), 629–633. https://doi.org/10.1901/jaba.2011.44-629

Zegeer, C., Lyon, C., Srinivasan, R., Persaud, B., Lan, B., Smith, S., Carter, D., Thirsk, N. J., Zegeer, J., Ferguson, E., Van Houten, R., & Sundstrom, C. (2017). Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments. Transportation Research Record, 2636(1), 1–8. https://doi.org/10.3141/263

APPENDIX A

Table A-1: Statistics of RRFB sites

Site	Installation Year	Before Years	After Years	Before AADT	After AADT	Before Total Crashes	After Total Crashes	Before Rear-end crashes	After Rear-end crashes	Before Pedestrian Crashes	After Pedestrian Crashes
1	2018	5	3	18,214	23,239	31	7	17	3	3	0
2	2015	5	5	7,762	9,332	2	2	2	1	0	0
3	2019	5	2	8,614	8,275	3	1	0	0	0	0
4	2018	5	3	37,232	36,505	0	1	0	0	0	0
5	2019	5	2	17,620	15,418	30	5	17	0	0	0
6	2016	5	5	4,406	4,500	4	3	2	2	0	0
7	2010	3	5	9,921	10,798	3	1	0	1	0	0
8	2010	3	5	13,075	14,367	6	6	2	1	0	0
9	2018	5	3	15,483	15,402	9	7	4	1	0	0
10	2018	5	3	13,013	11,931	3	5	1	0	0	0
11	2010	3	5	12,880	13,225	9	17	5	5	0	0
12	2010	3	5	7,340	8,762	5	5	3	1	0	0
13	2012	5	5	4,852	6,838	6	6	2	3	1	0
14	2012	5	5	8,677	9,519	0	1	0	1	0	0
15	2013	5	5	15,657	18,756	15	18	11	14	0	0
16	2019	5	2	20,849	20,642	10	4	5	2	0	0
17	2015	5	5	16,284	17,497	12	14	10	12	1	0
18	2015	5	5	6,045	6,860	0	1	0	1	0	0
19	2018	5	3	25,940	23,997	33	7	17	2	0	0
20	2018	5	3	25,940	23,997	15	11	9	4	0	0
21	2018	5	3	23,496	25,520	31	16	17	8	0	0
22	2015	5	5	18,367	18,481	15	6	6	2	0	0
23	2018	5	3	17,239	18,803	13	5	10	2	0	0
24	2018	5	3	16,614	21,028	20	6	11	2	1	1
25	2018	5	3	8,798	9,027	1	3	0	0	0	0

Site	Installation Year	Before Years	After Years	Before AADT	After AADT	Before Total Crashes	After Total Crashes	Before Rear-end crashes	After Rear-end crashes	Before Pedestrian Crashes	After Pedestrian Crashes
26	2019	5	2	10,327	9,622	6	2	4	1	0	0
27	2018	5	3	6,186	6,227	6	0	3	0	0	0
28	2015	5	5	21,624	20,443	16	6	5	4	0	0
29	2015	5	5	23,219	20,931	21	13	3	3	1	2
30	2012	5	5	27,125	23,881	2	6	1	5	0	0
31	2017	5	4	17,390	15,633	5	6	2	2	0	0
32	2011	4	5	18,656	17,390	14	16	4	7	1	1
33	2017	5	4	17,390	15,633	11	6	2	1	0	0
34	2019	5	2	4,527	4,981	0	1	0	1	0	0
35	2012	5	5	3,425	3,181	2	1	1	1	0	0
36	2010	3	5	12,547	13,299	13	23	1	14	0	0
37	2017	5	4	4,990	4,614	3	2	0	0	0	0
38	2012	5	5	17,350	18,546	23	24	17	16	2	2
39	2011	4	5	24,175	24,580	1	11	0	10	0	0
40	2011	4	5	17,208	19,791	11	9	9	7	1	0
41	2011	4	5	26,642	27,974	19	7	11	4	0	0
42	2015	5	5	11,422	16,656	31	14	17	11	0	0
43	2012	5	5	11,254	16,498	9	8	7	5	0	0
44	2016	5	5	24,373	21,849	1	8	1	3	0	0
45	2014	5	5	8,322	9,484	17	14	13	9	0	0
46	2016	5	5	5,010	5,651	15	5	1	0	0	0

APPENDIX B

Table B-1: Statistics for SRS sites

Site	Length (mi)	Before AADT	After AADT	No. of Lanes	Lane width	Median	Shoulder width	Total Crashes Before	Total Crashes After	ROR Crashes Before	ROR Crashes After
1	0.97	8,633	10,996	2	24	0	8	7	3	0	3
2	0.76	8,633	10,996	2	25	0	5	5	0	2	0
3	0.98	8,633	10,996	3	36	0	6	6	1	3	0
4	0.99	8,633	10,996	2	24	0	8	5	2	1	2
5	0.4	8,633	10,996	2	24	0	5	3	0	2	0
6	0.78	8,200	11,461	3	36	0	5	11	2	6	1
7	0.65	10,033	12,842	2	24	0	5	8	2	1	1
8	0.25	10,033	12,842	3	36	0	8	1	0	0	0
9	0.57	10,033	13,198	2	24	0	8	3	1	1	0
10	0.39	9,967	13,198	2	24	0	4	0	2	0	0
11	0.13	9,967	13,198	2	24	0	8	0	0	0	0
12	0.29	9,967	13,198	2	24	0	8	4	0	0	0
13	1.66	9,867	12,070	2	24	0	8	11	0	4	0
14	0.84	10,600	14,199	2	24	0	8	3	1	2	0
15	0.71	10,600	14,199	2	25	0	9	4	1	3	0
16	0.13	10,333	12,650	2	25	1	9	5	1	2	0
17	0.8	9,867	12,650	2	24	0	6	11	1	7	1
18	2.31	10,633	13,461	2	24	0	6	24	1	7	0
19	1.25	4,900	5,254	2	24	0	7	4	1	3	1
20	0.78	4,900	5,254	2	24	0	5	5	3	5	2
21	0.46	25,533	18,220	2	24	1	7	7	0	1	0
22	0.34	25,533	18,220	1	20	1	12	11	0	0	0
23	0.21	25,533	18,220	3	36	1	7	9	1	1	0
24	0.18	21,200	14,998	2	24	0	7	5	1	1	0
25	1.04	21,200	14,998	3	16	1	5	30	6	15	3
26	0.61	23,767	24,277	2	27	0	7	14	1	8	1
27	0.58	25,867	27,830	2	24	1	5	7	2	0	1

Site	Length (mi)	Before AADT	After AADT	No. of Lanes	Lane width	Median	Shoulder width	Total Crashes Before	Total Crashes After	ROR Crashes Before	ROR Crashes After
28	0.5	25,867	27,830	2	24	1	8	11	2	4	0
29	0.73	14,300	11,132	2	26	0	6	15	4	2	0
30	1.25	8,700	8,470	2	24	0	8	13	1	4	0
31	0.64	10,500	10,451	2	24	0	4	9	2	4	0
32	1.72	9,467	9,622	2	24	0	8	6	1	1	0
33	0.49	9,333	9,654	2	24	0	8	5	1	0	1
34	0.79	9,333	9,654	2	24	0	8	5	1	3	1
35	0.44	7,900	8,009	2	24	0	8	4	1	2	0
36	0.44	7,933	7,128	2	24	0	9	2	0	2	0
37	1.31	8,900	8,754	2	24	0	6	10	1	5	0
38	0.31	10,933	10,605	2	24	0	10	2	1	1	0
39	0.71	10,933	10,605	2	24	0	8	10	1	1	0
40	0.96	13,167	12,982	2	24	1	8	10	0	2	0
41	0.62	15,200	15,000	2	24	0	8	8	1	3	0
42	1.37	10,600	13,808	3	36	0	10	12	4	3	2
43	1.26	11,200	14,389	3	38	0	10	12	2	5	0
44	0.35	11,200	14,389	2	24	0	10	1	1	0	0
45	1.89	11,200	14,389	2	24	1	10	6	1	5	0
46	0.2	11,200	14,389	4	48	0	8	4	0	2	0
47	0.24	11,200	14,389	2	24	1	8	3	0	2	0
48	2.48	11,200	14,389	2	24	0	8	23	5	3	4
49	0.39	8,600	10,169	2	24	0	8	2	0	1	0
50	0.34	7,133	8,362	2	24	0	11	7	1	2	0
51	0.52	7,133	8,362	3	36	1	7	1	1	0	1
52	2.44	7,133	8,362	3	36	0	6	12	1	9	0
53	0.58	7,133	8,362	3	36	1	7	6	1	5	0
54	1.47	7,133	8,362	3	36	0	6	9	0	6	0
55	0.97	7,133	8,362	2	24	0	7	6	1	4	1

Site	Length (mi)	Before AADT	After AADT	No. of Lanes	Lane width	Median	Shoulder width	Total Crashes Before	Total Crashes After	ROR Crashes Before	ROR Crashes After
56	0.41	6,133	5,981	2	24	0	6	2	0	0	0
57	0.69	6,133	5,981	3	36	0	6	3	0	0	0
58	0.1	6,133	5,981	2	24	0	6	0	0	0	0

APPENDIX C

Table C-1: Statistics of Four-Way Stops

Site	AADT Major	AADT Minor	Posted Speed Major	Posted Speed Minor	Skew	Left-turn lane major	Left-turn lane major	Number of lanes (major)	Number of lanes (minor)
1	2208	701	25	25	0	0	0	2	2
2	5005	5005	35	35	0	1	1	3	3
3	4452	1866	25	25	0	0	0	2	2
4	4538	2327	45	35	0	0	0	2	2
5	12,071	5013	30	20	0	1	0	3	2
6	3972	3808	45	35	0	0	0	2	2
7	4361	2108	25	25	0	0	0	2	2
8	6344	4582	25	25	0	1	0	4	2
9	10250	3469	25	25	0	0	0	2	2
10	6939	3469	35	25	0	0	0	2	2
11	13,794	10,911	35	25	0	1	1	3	3
12	5245	2217	25	25	0	0	0	2	2
13	4153	1950	55	40	0	0	0	2	2
14	4339	2782	25	25	0	0	0	2	2
15	7402	6742	55	50	1	0	0	2	2
16	9153	4575	55	55	0	0	0	2	2
17	3202	1098	55	40	0	0	0	2	2
18	5815	4336	25	25	0	0	0	2	2
19	4344	2740	25	25	0	0	0	2	2
20	6067	3834	55	40	0	0	0	2	2
21	8726	1783	35	25	0	0	0	2	2
22	7831	2554	35	25	1	1	1	3	3
23	8485	2619	35	35	1	0	0	2	2
24	7193	4062	25	25	1	0	0	2	2

Site	AADT Major	AADT Minor	Posted Speed Major	Posted Speed Minor	Skew	Left-turn lane major	Left-turn lane major	Number of lanes (major)	Number of lanes (minor)
25	4609	1516	25	25	0	1	0	3	2
26	4306	3389	25	25	0	0	0	2	2
27	4894	4221	35	25	0	0	0	3	2
28	8948	3600	35	20	0	0	0	2	2
29	6465	2736	20	20	0	0	0	2	2
30	1743	1284	25	25	0	0	0	2	2
31	2015	1158	35	35	0	1	0	3	3
32	4272	2457	25	25	0	0	0	2	2
33	8498	4352	25	25	0	0	0	4	2
34	9153	4575	55	55	0	0	0	2	2
35	12,982	2624	55	45	0	0	0	2	2
36	13059	6428	35	25	0	1	0	4	2
37	4938	3249	55	40	0	0	0	2	2
38	4255	3807	25	25	0	0	0	2	2
39	8723	7213	40	35	0	0	0	2	2
40	9468	6960	32	25	0	1	0	3	2
41	5496	2316	55	45	0	0	0	2	2
42	5824	5247	25	20	0	0	0	2	2
43	3823	2567	55	55	1	0	0	2	2
44	4689	1795	30	25	0	0	0	3	2

APPENDIX D

Table D-1: Statistics of Two-Way Stops

Site	AADT Major	AADT Minor	Posted Speed Major	Posted Speed Minor	Skew	Left-turn lane major	Left-turn lane major	Number of lanes (major)	Number of lanes (minor)
1	6590	1239	30	25	0	1	1	3	3
2	16,495	2482	35	25	0	1	0	3	2
3	27,263	1549	40	25	0	1	0	5	2
4	21,339	1260	30	25	0	0	0	4	2
5	15,540	1849	35	25	0	1	0	5	2
6	23,607	3291	45	20	0	1	0	5	2
7	10,810	2652	45	45	0	1	0	3	2
8	12,211	1829	50	45	1	1	0	3	2
9	7069	1296	25	25	1	1	0	3	2
10	12,703	1158	35	35	1	1	0	3	2
11	12689	347	25	25	0	0	0	4	2
12	7881	1176	25	25	0	0	0	2	2
13	11,637	2527	25	25	0	0	0	2	2
14	23,638	894	25	25	0	0	0	4	2
15	6682	1082	25	25	1	0	0	2	2
16	12,889	2177	25	25	0	0	0	2	2
17	14,164	648	55	30	1	1	1	3	2
18	6587	3157	35	35	0	1	1	5	3
19	5695	1365	25	25	0	0	0	2	2
20	2030	1192	25	25	0	0	0	2	2
21	9690	1179	25	25	0	1	1	3	2
22	1444	718	30	25	1	0	0	4	2
23	2967	1664	55	55	1	0	0	2	2
24	8822	1252	55	45	0	0	0	3	2

Site	AADT Major	AADT Minor	Posted Speed Major	Posted Speed Minor	Skew	Left-turn lane major	Left-turn lane major	Number of lanes (major)	Number of lanes (minor)
25	10,810	1855	55	35	0	1	1	3	3
26	9344	4523	35	25	0	1	1	3	3
27	16,774	2802	35	25	0	1	0	5	2
28	4830	811	55	40	0	0	0	2	2
29	3146	3112	25	25	0	0	0	2	2
30	3043	1275	25	20	0	0	0	2	2
31	13,433	6161	25	20	0	1	0	2	2
32	16,844	3385	55	40	0	1	0	3	2