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# Safety evaluation of roadway segments provided with Safety Edge in Iowa

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**Safety evaluation of roadway segments provided with Safety Edge in Iowa**

by

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# DEDICATION

This thesis is dedicated to my parents Chinmoy Goswamy and Subrota Goswamy, my maternal uncle Dr. Swarup Ray, and my husband Animesh Biswas.

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# ABSTRACT

Pavement edge drop-off is the vertical difference in elevation between the paved roadway and the adjacent ground. It is a serious safety concern for vehicles that goes off the track and encounters a drop-off. The errant vehicles, in order to restore their position back on the paved road, exert a greater amount of force which may result in loss of control for the driver. This may indicate an increase in the possibility of lane departure crashes, rollovers or head on collisions. According to an estimation by the Federal Highway Administration about 11,000 people suffers from injuries and about 160 people lose their lives each year in crashes related to unsafe pavement edges in the United States. Safety Edge, on the other hand, is a design feature that creates a fillet along the edge of the pavement of the roadway that allows drivers, who drift off roadways, to return safely to the roads. This study intended to conduct a safety evaluation of road segments provided with Safety Edge in Iowa. Thus a before and after crash analysis was conducted to estimate any reduction in crashes in the after period of installation. This research also looked into the road and traffic characteristics that significantly affected the crashes on road segments provided with Safety Edge.

A total length of 483 miles of roadway segments installed with Safety Edge was identified all over Iowa. Roadway, traffic, lane characteristics and crashes on the treatment segments for the study period of eleven years from 2004 to 2011 was obtained from Iowa Department of Transportation. A Preliminary before and after crash analysis for all types of crashes showed a 50% reduction in all types of fatal crashes, 18.5% reduction in all types of property damage only (PDO) crashes and an overall decrease of 19% for all types of total crashes. A preliminary before and after crash analysis for target crashes showed a 75% reduction in Target fatal crashes, 1% increase in target PDO crashes and overall 17% reduction in total target crashes.

The crash data which is a form of count data was analyzed using negative binomial regression. Positive safety impact of installation of Safety Edges was observed for almost all the statistical models (except for property damage only target crashes), as the crashes in the after period was observed to be less than that of the before period. Both scenarios of all types of crashes and target crashes were considered separately in the study. The variables that significantly affected the different crash models were average annual daily traffic (AADT), shoulder width, Rural/Urban indicator, and surface width. Negative Binomial Models for All types of KABCO crashes (all crash severity levels taken together) showed 21% reduction in crashes in the after period. The percentage reduction of all types of injury (KABC) crashes was 20%. For all types of PDO crashes the reduction was seen to be again 20%. Negative Binomial Models for target crashes showed 16.3% reduction in target KABCO crashes and 2.4% increase in target PDO crashes, along with 21% reduction in all types of KABCO crashes, and 20 % reduction in all types of PDO crashes. The results indicated that Safety Edge installation may also be able to reduce the severity of a crash.

# CHAPTER 1

# INTRODUCTION

## 1.1 Problem Statement

Pavement edge drop-off proves to be a serious concern when vehicles drift off the pavement and encounter a difference in height between the pavement and the adjacent ground. The errant vehicles, in order to restore their position back on the paved road, exert a greater amount of force which may result in loss of control for the driver. This may indicate an increase in the possibility of lane departure crashes, rollovers or head on collisions. Lane departure crashes account for over half of all the fatal crashes in the United States. Some of these crashes can be avoided by taking care of the edge drop-offs. According to the Federal Highway Administration (FHWA) the pavement edge drop-off on highways has been linked to numerous serious crashes including fatal collisions. According to statistics by the Iowa Department of Transportation (DOT) that 52% of roadway-related fatal crashes are lane departures and that 39% of Iowa's fatal crashes are single vehicle run off roads (Hallmark et al., 2009).

According to an estimation by the Federal Highway Administration (FHWA, 2010), about 11,000 people suffers from injuries and about 160 people lose their lives each year in crashes related to unsafe pavement edges in the United States. A study by Georgia Tech estimated 150 fatal crashes on rural two-lane roads in Georgia (2004) suggested that 55% of the crashes included edge drop off issue. Pavement edge drop offs contribute to about 18% of rural ROR crashes with paved roadways and unpaved shoulders and it is two times more likely that a fatal crash may occur due to pavement drop off than any other factor (Hallmark et. al., 2006).

Hallmark et al. (2006) evaluated the crash forms to access the frequency and severity of edge drop off crashes in rural roadways. Determining edge drop-off as the cause of crash included evaluation of the scene of crash. The team examined drop-off related crashes in Iowa and Missouri. The summary of crashes from 2002-2004 showed that 17.7 percent of crashes on rural two-lane roadways in Iowa and 24.7 percent in Missouri were probably or possibly related to edge drop offs. They also stated that the edge drop-off related crashes were usually run-off road crashes.

## 1.2 Research Motivation

The motivation of the current research was derived looking into the number and severity of crashes occurred due to pavement edge drop-offs. According to literatures like Humphreys and Parham (1994), the probable types of crashes due to the loss of control experienced by encountering a pavement edge drop-off include:

- head-on collisions;
- sideswipe with an oncoming vehicle in the opposite lane or sideswipe with a vehicle in the adjacent lane;
- collision with any physical object or the nearby ditch on the opposite side; or
- collision with an object on the right side of the roadway

All of the above mentioned crashes pose severe consequences for the driver. Moreover, the vehicle experiencing a pavement drop-off may also skid and overturn causing both life and property damage. Many studies have been conducted on the hazardous effects of pavement edge drop-offs. One of these studies by Moler (2007) have pointed out that according to highway safety experts a drop-off more than 5 inches, especially if it is at a 90 degree angle to the shoulder surface are unsafe. The United States Department of Transportation (DOT) suggests that a drop-off with a vertical differential of 3 inches or more should be considered unsafe. The American Association of State Highway and Transportation suggests that vertical difference greater than 2 inches should not occur between lanes. Pavement edge drop off crashes tend to be more severe than other types of crashes on similar roadways. Drop-off related crashes result in serious injuries and are more likely to be fatal because the vehicle often leaves the roadway, rolls over, hits a roadside object, or is involved in a head-on collision. In contrast to several studies conducted on ill effects of pavement edge drop off, a very few studies have been conducted on the safety effectiveness of the countermeasure for reducing edge drop-off related crashes, that is the Safety Edge. Thus there existed an utter need for fulfilling this gap. The FHWA advocates for Safety Edge which is a 30 degree fillet along the outside edge of the pavement edge, as a simple, cutting edge and cost effective technology to mitigate these crashes. Among the few studies conducted on safety evaluation of Safety Edge, mention may be made of Graham et al. (2011) who conducted an observational before and after evaluation of sites treated with Safety Edge using two safety evaluation methods, the Empirical Bayes (EB) method and the cross-sectional comparison of the safety effect between the treatment and the comparison sites. The results of the study showed that the treatment had a small positive crash reduction effect. The best effectiveness measure for the safety edge treatment was a 5.7% reduction in total crashes (not statistically significant though) on rural two-lane roadways. The same report also examined the costs, and benefits of the treatment for two-lane as well as multilane rural highways. The economic analysis reinforced that the treatment was inexpensive and that its application can be highly cost-effective keeping several conditions in mind. But there were very less crash data for the after period. Thus to obtain more accurate results for safety evaluation, research must be conducted on safety edge installations with enough before and after period data.

### 1.3 Research Objectives

The objective of this research was to assess the safety effectiveness of Safety Edge installations in the state of Iowa. This was accomplished by the following steps:

- A total of 82 undivided roadway segments of total length of 483 miles were identified all over Iowa having Safety Edge installed in them. These segments were digitized using ArcGIS Software and are the treatment segments. Segments similar to the treatment segments with respect to location, geometric and traffic characteristics having no Safety Edge were chosen. These segments represent the control segments. Crashes on all of the study segments were obtained for the years 2004-2014.
- Datasets were created compiling 11 years (2004-2014) of roadway, traffic and lane characteristics and corresponding crashes for the treatment segments. A preliminary before and after crash analysis was performed to look into changes in crashes in the after period.
- As crash data is in the form of count data, thus the statistical method that was used in analyzing the crash data models was negative binomial regression.
- Due to inconsistency in the length of some segments over the eleven years of study period and due to presence of some very small segments less than 0.1 mile, some adjacent segments were aggregated. Different ways were used to aggregate the segments manually. Aggregated dataset was used to build before and after Safety Edge SPFs. Crash reduction factors and percentages were also calculated.

- Positive safety impacts of Safety Edge were observed as the crashes in the after period went down from the before period. Both scenarios of all crashes and target crashes on the treatment segments showed comparable reduction in crashes in the after period.
- Positive safety impacts of Safety Edge were observed as the crashes in the control segments were less compared to the treatment segments. Both scenarios of all crashes and target crashes on the treatment segments showed comparable reduction in crashes compared to control segments.

## 1.4 Thesis Organization

The thesis is organized into eight chapters. Chapter 1 that is this chapter provides the problem statement, the research motivation and the research objectives.

Chapter 2 provides a thorough review of previous literatures on pavement edge drop-offs and Safety Edge.

Chapter 3 describes the various data sources, data description and data processing steps used to perform a simple before and after analysis and also built up models to specify the most significant factors affecting Safety Edge related crashes.

Chapter 4 provides a simple comparison of before and after crashes for the road segments having Safety Edge on them.

Chapter 5 provides the Statistical method used for the analysis.

Chapter 6 provides the data cleaning and aggregation process, summary statistics, data analysis, model results and interpretation.

and last but not the least the final chapter that is chapter-7 highlighted the conclusions, limitations and future research ideas.

# CHAPTER 2

# LITERATURE REVIEW

This chapter provides a thorough review of previous literatures on pavement edge drop-offs and Safety Edge. The chapter also contains brief overview of advantages of Safety Edge, different types of Safety Edge construction equipment, crash modification factors (CMF) and crash reduction factors (CRF) and different types of before and after crash analysis methods.

## 2.1 Pavement Edge Drop-Off: A Concern

Pavement edge drop-off is the vertical difference in elevation between the paved roadway and the adjacent ground. This has been a serious safety concern for vehicles. When a vehicle leaves the edge of the traveled roadway and attempts to return immediately to the roadway surface, it tries to return by applying greater speed and angle which may lead to overcorrection and influences the driver to lose control over the vehicle. This may indicate an increase in the possibility of lane departure crashes, rollover or head-on collisions. Figure 2. 1 shows a typical example of pavement edge drop-off.

Figure 2. 1 Typical Example of Pavement Edge Drop-Off. Source: Hallmark et al. (2006)

Scrubbing occurs when the sidewalls of the tires are forced against a vertical pavement edge, resulting in friction between the tire and pavement as shown in Figure 2. 2. Thus when the driver remounts the tires back to the pavement with greater force and angle this friction suddenly diminishes to a great extent which results in loss of control.

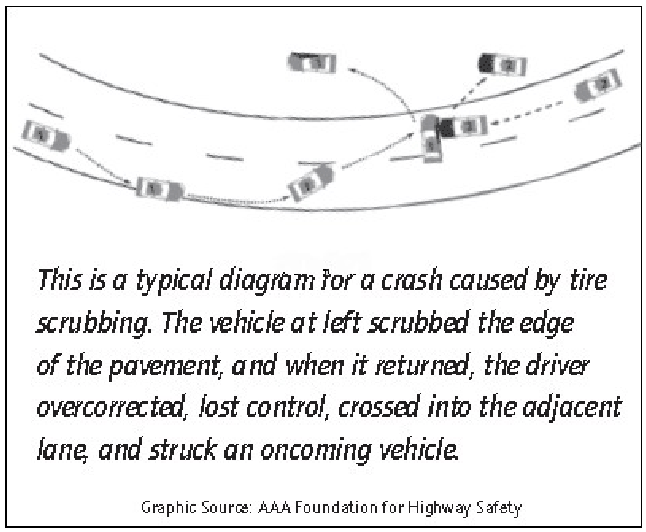


Figure 2. 2 Tire Scrubbing Condition. Source: Hallmark et al. (2006)

The edge drop-off can be located in horizontal curves, near mailboxes, turnouts, shaded areas, eroded areas, asphalt pavement overlay, etc. The most hazardous location for a pavement edge drop-off crashes should be the horizontal curves. Three times as many crashes occur in curves than in tangents. The turnouts can be explained as, where one vehicle is turning and another vehicle passes on the shoulder and a tire may get onto the unpaved shoulder. Again, mail delivery vehicles generally leave the paved surface causing edge rutting. And most importantly the addition of hot mix asphalt overlay increases the drop off height. Lawson et al. (2004) opined that the key factors causing edge drop-off were narrow road width or absence of shoulders, traffic volume or type, and adverse environmental conditions. The study stressed on the fact that good edge maintenance strategy was highly important in achieving good roads. They divided the edge maintenance practices and procedures into three broad categories: awareness, preventive maintenance, and edge repair techniques

The American Association of State Highway and Transportation commented that the causes of formation of the pavement edge drop off can be due to either resurfacing or settling between the pavement surfaces; or due to untimely maintenance of unpaved shoulders as excessive wear and erosion can also result in the migration of shoulder material away from the pavement edge; or when roadways are resurfaced without providing a proper transition to the shoulder that may result in a vertical elevation difference.

The pavement drop-off proves to be more dangerous for vehicles like motorcycles, subcompact vehicles and semi-tractor trailers as these drivers are more susceptible to lose control on uneven surfaces. Similarly for large trucks the drop-off proves to be quite fatal. Possessing a high center of gravity can lead to rollovers for the large trucks. If this drop off is sloped then the driver would easily traverse it to pull up the vehicle on track again.

Humphreys and Parham (1994) lists the probable types of crashes due to the loss of control due to drop-off. Head on collision or sideswipe with an oncoming vehicle in the opposite lane, or collision with any physical object or the nearby ditch on the opposite side or even to the right side of the roadway can be the probable types of accidents. The vehicle experiencing a pavement drop-off may also skid and overturn.

It has been pointed out by Moler (2007) that according to highway safety experts a drop-off more than 5 inches, especially if it is at a 90 degree angle to the shoulder surface is unsafe. The United States Department of Transportation suggests that a drop-off with a vertical differential of 3 inches or more should be considered unsafe (USDOT, 2004). The American Association of State

Highway and Transportation (AASHTO, 1996) suggests that vertical difference greater than 2 inches should not occur between lanes. Pavement edge drop off crashes tend to be more severe than other types of crashes on similar roadways. Drop-off related crashes result in serious injuries and are more likely to be fatal because the vehicle often leaves the roadway, rolls over, hits a roadside object, or is involved in a head-on collision.

Hallmark et al. (2006) examined sections of rural two-lane paved highways with unpaved shoulders in two Midwestern States (Iowa and Missouri) to understand the magnitude of edge drop-off. The study found that 12% of the 150 drop off segments sampled in Iowa were 2 inches or more, 1% were 3 inches or more, and less than 1% were 4 inches or more. In Missouri, the situation was worse than Iowa, as almost 19% of the 71 drop off segments sampled were 2 inches or more, 3% were 3 inches or more, 1% were 4 inches or more, and less than 1% were 5 inches or more. The researchers also provided guiding information on design, construction, maintenance and reconstruction of edge drop-offs for different states in the same study.

Dixon et al. (2004) put forward some relationship between fatal crashes and pavement edge drop-off. Fatal crashes for the state of Georgia were evaluated in 1997. A total of 150 fatal crashes occurring on rural two-lane state and non-state-system roads were selected randomly. Roadway characteristics of the crash locations were also recorded. The researchers estimated that in 38 of the 69 non-state-system fatal crashes (55%) edge rutting or edge drop-off was present. In 21 of the 38 sites where drop-off was present, drop-off appeared to be one of the crash causal factors. The drop-off present at the locations ranged from 2.5–5 inches. Edge drop-off was more likely to have been present on non-state-system roads than on state-system roads.

Klein et al. (1977) conducted a study to evaluate driver's ability to recover from a pavement edge drop-off. Both field and simulation tests were carried out. The field test included testing a 4.5

inch drop-off with a vertical face using 3 different passenger cars with 22 non-professional drivers at constant speeds of 44, 30, and 32 miles per hour. Scrubbing did not occur in 34 of the total trials, and drivers were able to recover within their 12-ft lane after they returned to the roadway. Scrubbing occurred in 39 of the test runs and in 22 of those runs, the drivers exceeded the lane boundary while returning to the travel lane. It was also seen that the likelihood that the lane boundary would be exceeded when scrubbing occurred, was strongly related to vehicle speed. It was also indicated that each vehicle had a unique speed when this occurred. It was also determined that the maximum drop-off height that could be climbed in the scrubbing condition was 5 inches.

Stoughton et al. (1979) investigated the effect of pavement edge drop-off on vehicle stability. Professional drivers in different sized automobiles and pick-up trucks were involved in the study. The authors tested 1.5, 3.5, and 4.5 inches drop-offs at 60 mph. Drivers were able to recover safely within the12-ft lane under all situations. The limitations of the study included absence of information about edge shape, no element of surprise was present, and no indication of whether scrubbing had occurred was present.

In a study by Ivey and Sicking (1986) the relationship between drop-off height and a driver’s ability to recover it were evaluated. The technique of simulation and analytical relationships were used in the study to determine the steer angle necessary to remount a drop-off with different heights and edge shapes at 50 mph. They evaluated 2, 4, and 6 inch drop-offs with a 45 degree wedge and found that even with drop-offs of 6 inches, recovery within a 12 foot lane was possible. Their results also reinforced earlier findings that edge shape influences the driver’s ability to recover. A 4 inches vertical edge resulted in loss of vehicle control. As the edge shape became flatter, less effect was noted.

## 2.2 Crashes Due To Edge Drop Offs

According to an estimation by the Federal Highway Administration (FHWA, 2010), about 11,000 people are injured and about 160 people lose their lives each year in crashes related to unsafe pavement edges in the United States. FHWA also indicates that the true extent of problem created by edge drop offs is difficult to access due to improper and inadequate documentation of hazardous pavement edges leading to crashes.

National Highway Traffic Safety Administration (NHTSA) statistics from 2009 showed that of all the fatal accidents, approximately 53% can be attributed to vehicles leaving the roadway (NHTSA, 2009).

Crashes on two-lane undivided highways result in nearly 60% of the total fatalities in the United States. One major concern for driver safety on highways is the interface of the paved surface and the unpaved shoulder. Studies have also shown that crashes due to edge drop offs can be 2 to 4 times more fatal than other crashes.

A study by Georgia Tech estimated 150 fatal crashes on rural two-lane roads in Georgia (2004) suggested that 55% of the crashes included edge drop off issue. Pavement edge drop offs contribute to about 18% of rural ROR crashes with paved roadways and unpaved shoulders and it is two times more likely that a fatal crash may occur due to pavement drop off than any other factor (Hallmark et. al., 2006). The drop off greater than equal to 2.5 inches are of concern and should be provided with Safety Edge (Hallmark et.al, 2006).

Hallmark et al. (2006) evaluated the crash forms to access the frequency and severity of edge drop off crashes in rural roadways. Determining edge drop-off as the cause of crash included evaluation of the scene of crash. The team examined drop-off related crashes in Iowa and Missouri.

The summary of crashes from 2002-2004 showed that 17.7 percent of crashes on rural two-lane roadways in Iowa and 24.7 percent in Missouri were probably or possibly related to edge drop offs. They also stated that the edge drop-off related crashes were usually run-off road crashes.

## 2.3 Safety Edge: A Solution

The Federal Highway Administration suggested several treatments for mitigating pavement edge drop-off hazards which included resurfacing of the shoulders while roadways are getting resurfaced. Safety Edge is a treatment that allows drivers who drift off roadways to return safely to the roads. Safety Edge are nothing but a design feature that creates a fillet along the edge of the pavement of the roadway. Figure 2. 3 shows a typical Safety Edge installed road segment.

Previous research in the early 1980s found that a 45 degree Safety Edge on pavements were effective in alleviating severity of crashes. But it was found that a 30 degree angle was easier to construct. Thus a 30 degree Safety Edge was recommended by the FHWA. It has been pointed out by Hallmark et al. (2011) that a demonstration project of Safety Edge by FHWA showed a sloped pavement edge surface is easier to traverse than a vertical drop-off by a vehicle that attempts to remount back to the lane after going off the track.

Graham and Richard et al. (2011) defined the Safety Edge as a treatment to make the edge of the pavement to be sloped at an angle of 30 degrees which has the capability to reduce the resistance of the tires. Neuman et al. (2003) also suggested construction of a 45 degree wedge during pavement resurfacing in a National Cooperative Highway Research Program report. Moler (2007) also indicated Safety Edge to be a relatively easy and an inexpensive countermeasure that also have the capability to reduce crashes on rural two-lane highways.

Figure 2. 3 FHWA. A Typical Safety Edge

Factors that influence the effectiveness of the Safety Edge are the edge drop-off height, the type of highway, the number of lanes, the width of the shoulder, the design speed, the curve, the presence of rumble strips and the guard rail at the edge.

The Safety Edge are mostly appropriate for rural two-lane roadways without paved shoulders, but it is also appropriate on all primary highways unless the paved shoulder width is 4 feet or greater and the roadway or shoulder is curbed. The Iowa DOT design guidance puts forward that the Safety Edge is required unless if the roadway is an interchange ramp or loop, or the roadway or shoulder has curbs, or paved shoulder width is 4 or more feet. The Iowa Safety Edge design guidance does not explicitly address traffic volume thresholds or crash history values as indicators for its placement, however they suggest that locations with high crash history should also be considered as potential candidate locations.

## 2.4 Safety and Cost Effectiveness of Safety Edge

### *2.4.1 Studies in Iowa*

Earlier use of Safety Edge in Iowa was highlighted in a study by Hallmark et al. (2010). It was stated that in 2010 the Iowa DOT adopted the Safety Edge as a standard practice for construction and rehabilitation projects based on guiding information from the FHWA and some other states where the Safety Edge was already popularly used. The Safety Edge was constructed for both hot-mix asphalt (HMA) and Portland cement concrete (PCC) pavement and overlays. The initial use of the Safety Edge in Iowa was said to be in September of 2008 on a HMA resurfacing project on County Road (CR) Z36 in Clinton County. (Hallmark et al., 2010).

Hallmark et al. (2010) thoroughly investigated the initial safety and performance evaluation of the Safety Edge projects in Iowa. The study was also conducted to develop educational materials like design standards and specification for Safety Edge and for estimating material and equipment needed for the construction of Safety Edge. The study was also done for marketing and outreach to state and local agencies in Iowa. The project team acquired Safety Edge equipment and made them available for loan to contractors who were assigned to construct the Safety Edge in different counties of Iowa. An advisory committee was also set up to obtain guidance and advice on the project. It was recommended by the team that 30 (+/- 10) degrees was an appropriate target for the Safety Edge slopes to be constructed. Measurements after the construction of all Safety Edge projects were seen to have an average slope measurement as 33 degrees. A paired t-test between the mean pavement edge drop-off for the side with and without the Safety Edge indicated no statistically significant difference. Due to unavailability of sufficient crash data of the period after the construction a statistically valid conclusion was not made.

Hallmark et al. (2012) conducted a second phase of the previous Safety Edge study in Iowa. Field conditions of previously installed Safety Edge in the hot-mix asphalt (HMA) projects were evaluated to access any increased deterioration of the sloped edges. Field conditions like changes in shoulder settlement or erosion were observed. Some new and modified designs for the Safety Edge equipment were also evaluated. These new designs were found to have the potential to add consistency and overall improvement in the Safety Edge. Safety Edge slope measurement was done for 25 additional projects. Though not all Safety Edge slopes were measured to be 30 degree but all the Safety Edge slopes included in the project resulted in the construction of more traversable slopes. It was also pointed out that the addition of paved shoulders was capable to reduce edge maintenance and some lane departure incidents.

*2.4.2 Other Studies*

Graham et al. (2011) conducted an observational before and after evaluation of sites treated with Safety Edge using two safety evaluation methods, the Empirical Bayes (EB) method and the cross-sectional comparison of the safety effect between the treatment and the comparison sites. The project scope included two road types, the rural two-lane highway with a paved shoulder no wider than four feet and the second road type was the multilane highway with a paved shoulder no wider than four feet. All sites were divided into three types: treatment, comparison, and reference sites. Crash records for 2-5 years before and 3 years after the installation of Safety Edge were analyzed for Colorado, Georgia, Indiana and New York. The results indicated that 70% of the EB comparisons were associated with a positive effect of the Safety Edge on safety improvements. 56 of the 81 comparisons demonstrated a positive safety effect as a result of the Safety Edge installation. Only 11 of these comparisons were statistically significant. The results of the study showed that treatment had a small positive crash reduction effect. The best effectiveness measure for the Safety Edge treatment was a 5.7% reduction in total crashes (not statistically significant though) on rural two-lane roadways. This report also examined the costs, and benefits of the treatment for two-lane as well as multilane rural highways. The economic analysis reinforced that the treatment was inexpensive and that its application can be highly cost-effective keeping several conditions in mind. The computed minimum values for benefit-cost ratios ranged from 4 to 44 for two-lane highways with paved shoulders and from 4 to 63 for two-lane highways with unpaved shoulders.

The year 1 interim report of the previous project "Safety Evaluation of the Safety Edge Treatment" by FHWA included an EB and a cross-sectional analysis with the one year data. It was observed that proportion of fatal and injury crashes decreased significantly after resurfacing. Although no apparent shift in crash severity distributions between resurfacing with and without Safety Edge treatment was noticed. The result stated that the overall resurfacing with the Safety Edge treatment was slightly more effective than without Safety Edge as the Safety Edge were successful in reducing the drop-off heights that otherwise would exceed 2 inches. Comparisons of cost of resurfacing with and without Safety Edge was not seen to differ much (FHWA, 2008).

Ivey et al. (2009) used relative degree of safety to show the expected safety influence for different types of pavement edge. The researchers used Figure 2. 4 to show the relative degree of safety for pavement edge configurations. Shape A represented a sharp vertical edge drop-off. For this shape. Shape B includes a rounded pavement edge with a vertical face. Shape A and B had safety concerns for larger values of longitudinal edge elevation change. Shapes C and D showed increase in the relative safety by getting shifted from "Unsafe" or "Questionable Safety" conditions to "Reasonably Safe" or "Safe" conditions. Figure 2. 5 shows the safety improvement of using the Safety Edge compared with Shape A (90-degree) pavement edge. The Y-axis represents the relative degree of safety for a scale ranging from 0 to 10. When the Safety Edge treatments are constructed, especially the 30-degree fillet, there is an improvement in safety for all speed thresholds. Shape D represents the 30-degree Safety Edge that is recommended by the FHWA. The figure clearly showed the safety improvement of using the Safety Edge compared with Shape A (90-degree) pavement edge.

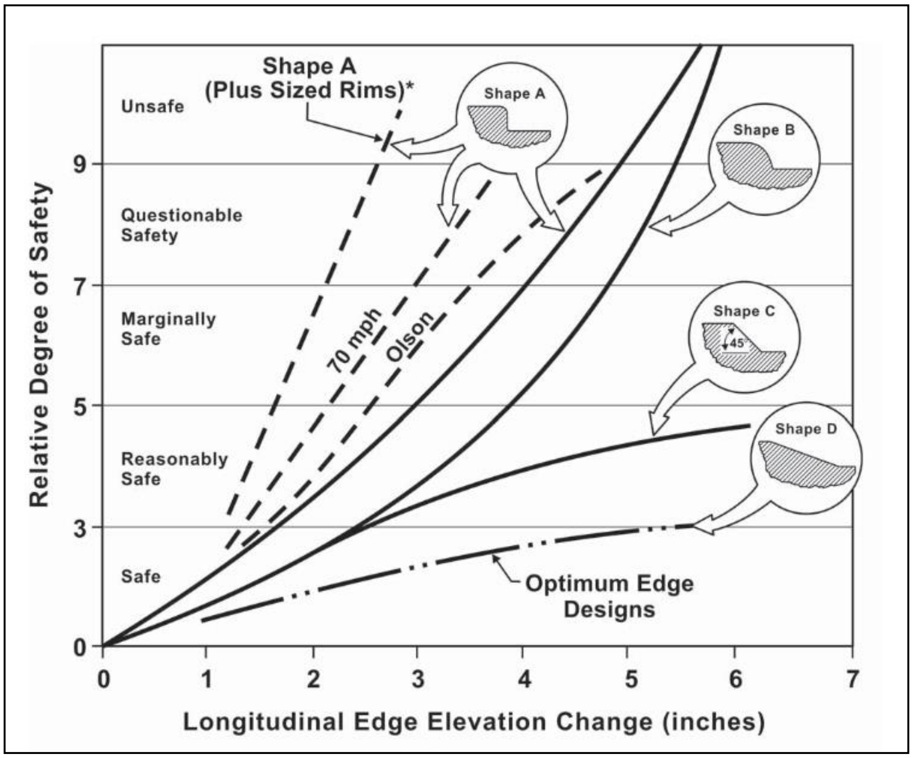


Figure 2. 4 Relative Degree of Safety for Pavement Edge Configurations. Source: Ivey Et Al. (2009)

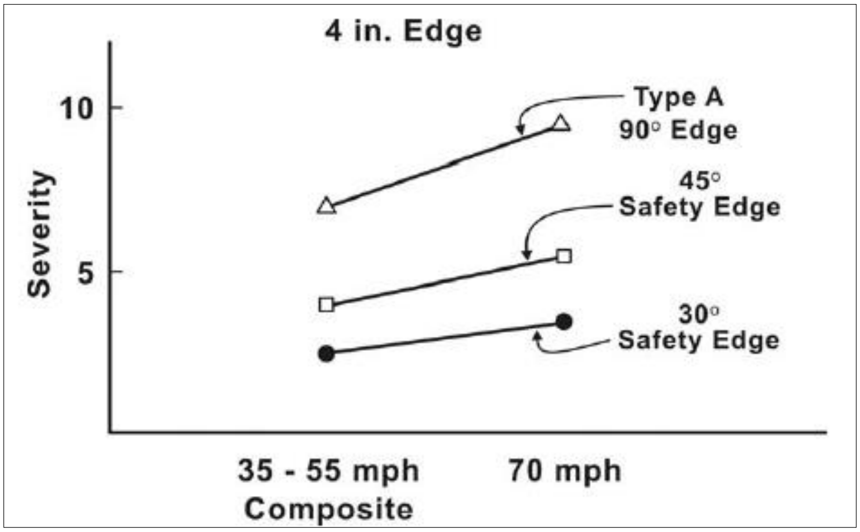


Figure 2. 5 Safety Improvement of Using the Safety Edge Compared with Shape A (90-Degree) Pavement Edge. Source: Ivey et al. (2009)

Humphreys and Parham (1994) studied the methods of mitigation of hazards associated with pavement edge drop-offs during roadway resurfacing. The study suggested a 45 degree angle of asphalt fillet can act as a simple and cost-effective method to mitigate the drop-off related crashes. It was also pointed out that other benefits of the fillet included increased safety during construction as well as increased future safety for drivers after being dropped to the adjacent ground due to the presence of edge drop-off. The Safety Edge also provided added protection for roadway drainage for base and sub-base material.

Olson et al. (1986) conducted a study on driver's performance in negotiating edge drop-offs from scrubbing condition. 3.0inches and 4.5 inches vertical and 45 degree Safety Edge were used in the study. It was found that a drop-off of more than 4.5 inches was not safely negotiated by the drivers for speeds as low as 20 mph. The 3.0-inch drop-off was safely negotiated at speeds of 30 mph. With the use of the 45-degree bevel edge the participants were seen to consistently remount back on street successfully at speeds of up to 55 mph. Thus it was seen that with construction of a sloped angle, it was easy for the drivers to recover from a drop-off.

Wagner et al. (2004) documented the construction of Safety Edge using two different device on a two lane undivided highway in rural Georgia. The Safety Edge was produced successfully by a 9.5 mm Marshall HMA design and a 12.5 mm Superpave HMA, which are the typical HMA designs for the type of roadway. The findings of this research indicate that the Safety Edge can be constructed at less than 1% additional material costs and based on the field observations conducted one year after construction the Safety Edge was seen to have no visible signs of deterioration.

## 2.5 Types of Safety Edge Construction Equipment

Hallmark et al. (2010) listed the different types of Safety Edge equipment available. The TransTech Systems Device, by, Inc. from Schenectady, New York.  TransTech Systems worked with the FHWA Resource Center and the Georgia DOT (GDOT) to develop the first device to create the Safety Edge. The device has a mounting plate that can be easily attached to the screed face of all varieties of asphalt paving machines. The device has a self-adjusting spring that helps to follow the roadside surface. Figure 2. 7 Shows a TransTech Systems Device.

Figure 2. 6 Hallmark et al. (2010), Notched Wedge Joint

Figure 2. 7 Hallmark et al. (2010), TransTech Systems Device

Figure 2. 8 Hallmark et al. (2010), Advant Edger

A curved runner along with the spring helps the device to adapt to any obstacles that it encounter. There is the angled surface that pre-compacts the asphaltic material as it enters the device and continues on to the wedge forming surface. The Trans Tech Safety Edge Shoes are side specific like left- and right-side shoes. The final angle is created after the compaction of the roadway. The Advant-Edger device was said to be manufactured by Advant-Edge Paving Equipment, LLC, of Loudonville, New York. The Advant-Edger Universal model can be used on both the right and left side of the paving machine which facilitate creating the lane edge wedge fillet whether paving in the direction against the direction of traffic. Thus only one unit is required for both functions. The bottom edge of the device prevents asphalt leakage under the wedge, producing a well-defined wedge fillet. Figure 2. 8 shows a typical advent edger. The Notched Wedge Joint Maker was created to build a denser joint between two lanes of asphalt paving. The equipment was created to adjust to any angle and leaves a notch on the top surface of the asphalt. Figure 2. 6 shows a typical Notched Wedge Joint Maker.

## 2.6 Studies on Design and Construction of Safety Edge

The Iowa DOT Design Manual (2010) chapter 3- Cross Sections provides information about Safety Edge design for Iowa. Iowa is one of the few states that has fully developed and incorporated the Safety Edge in their standard specifications as well as their Iowa DOT Design Manual. Iowa currently requires the installation of the Safety Edge on all primary highways unless the roadway is an interchange ramp or loop, the roadway or shoulder is curbed, or the paved shoulder width is at least four feet wide (Iowa DOT, 2010). Currently the Iowa DOT uses the 30-degree Safety Edge recommended by the FHWA. The installation of the Safety Edge can occur during new construction or in conjunction with resurfacing projects. In addition, the Safety Edge can be applied to both PCC and HMA pavement.

Anderson et al. (2013) constructed four projects using four Safety Edge devices in Wisconsin. It was seen that all of the pavement edge devices were capable of producing a finished pavement that met the FHWA's goal of 30 degrees. The slope angles of the Safety Edge constructed for the four WSDOT projects ranged from 20 to 30 degrees and was generally lower and in the case of the Avant-EdgeTM and TransTech, it was significantly lower than those reported on the FHWA demonstration projects.

Delaigue et al. (2005) used a Human Vehicle Simulation Tool (HVE) to build a safety design criterion for pavement edge wedges. A large sample of wedge dimensions was investigated and tractor semi-trailers were seen to experience the most severe instabilities. A geometric criterion was introduced to help design safer roadside edge wedges. The design criterion was defined as the weighted ratio of wedge height and inclination. Based on simulated vehicle driving outcomes, it was estimated that if the design criterion does not exceed 3 inches/rad3, the wedge geometry is safe for all types of vehicles and under all kinds of driving conditions. Roads in which heavy commercial vehicles do not ply, can have wedge geometries with design criterion values up to 10 in/rad3 without being detrimental to the user safety. The criterion defined is valid for both wedges of limited dimensions and wider wedges. This factor could be used to provide simple and effective guidelines for safer highway edge design.

Lau et al. (2014) documented a project dealing with resurfacing along with installation of Safety Edge on a rural two-lane moderately travelled roadway with S-curves and linear sections. This project was planned for construction in the summer of 2014, which will be closely monitored and documented. After the completion of the project it was said that it will be reviewed and annually monitored to determine if the use of the Safety Edge meets design expectations. The design criteria for the project warranted increased structural strength but the viable solution of widening of the platform or grade increases was ruled out due to regulated lands and drainage concerns. It was also stated that if the use of the Safety Edge met with the design criteria, the application of this low cost enhancement would begin to be considered for other roadway rehabilitation projects within the Regional Municipality of Halton.

A report about the Safety Edge of Kansas by Harris (Harris, 2012) included an investigation of effectiveness of Safety Edge construction shoes used in different counties. The Safety Edge showed mostly positive results for all the counties. The safety shoe was also easy to install on the pavers. It was stated in the report that the width of the paver in relation to the road is something to consider when deciding whether to use the shoe.

## 2.7 Advantages of Safety Edge

Safety Edge are best known for the smooth gradual rather than abrupt transition between the ground and the track. The vehicles are aided with a technique that reduces the chances of getting imbalanced. The potential benefits of pavement edge drop-offs are summarized below.

- Reduces crashes and saves lives by mitigating pavement edge drop-off.
- It is a low cost systematic improvement applied during paving of roads.
- Improves durability by reducing edge raveling.
- Temporary safety benefit during construction
- Permanent Solution for future drop-off re-emergence.
- Reduce tort liability – Providing “Due Care”.
- Minimal hardware, labor, or material costs.

The common problem associated with work zones is the presence of uneven lanes. The Iowa DOT recommends using the Safety Edge to provide a smooth transition between the lanes whenever uneven lanes with greater than a 2-inch difference in height are present on highways. Figure 2. 9 depicts the installation of the Safety Edge on uneven lanes.

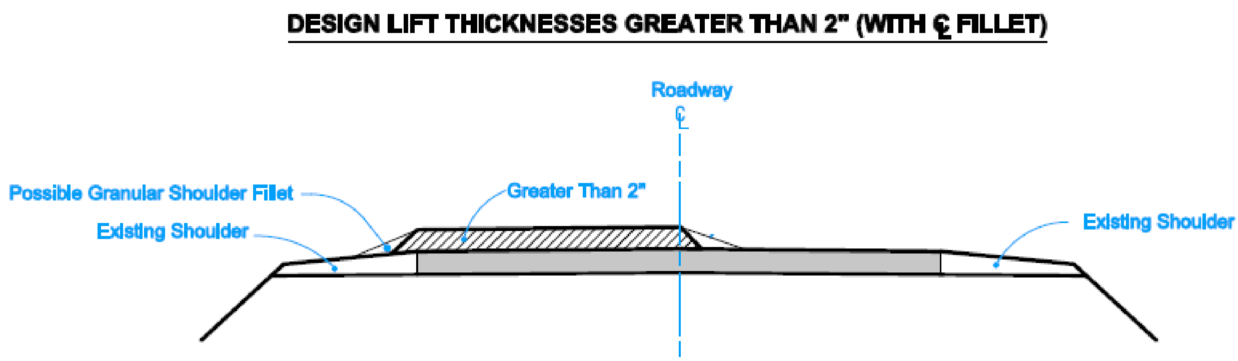


Figure 2. 9 Source: Iowa DOT.

## 2.8 Crash Modification Factors and Crash reduction Factors

The crash modification factor or CMF have been defined by the Highway Safety Manual (HSM) (Bonneson, 2010) as an index that describes how much the crash experience would be expected to change following a modification in design or traffic control, the HSM thus defined it as the ratio between the number of crashes per unit of time expected after the implementation of a modification or measure and the number of crashes per unit of time estimated if the change was not implemented. In other words, a CMF is a multiplicative factor to compute the expected number of crashes after implementing a given countermeasure. A CMF of 0.80 indicates that the expected number of crashes after the treatment would decrease by 20 percent.  CMFs are usually developed using statistical analyses which study the number of crashes before and after implementation of a particular countermeasures.  Ideally CMFs are developed using a large number of test sites so that the results are statistically significant.

The Crash Reduction Factor (CRF) have been defined by the HSM as the percentage of crash reduction that might be expected after the implementation of a modification in design or traffic control. The CRF is equivalent to the CMF subtracted from unity.

Several countermeasures are frequently applied to address lane departure crashes by transportation agencies rather than considering major reconstruction. Since agencies have limited resources, they rely on studies that demonstrate the effectiveness of a particular countermeasure in order to make decisions about which countermeasures to be selected. Most agencies prefer calculation of Crash Modification factors or CMFs to get an idea of the effectiveness of a particular countermeasure as CMFs are easily understood and commonly used nowadays. The objective of this research was to develop CMFs for Safety Edge as a type of lane departure countermeasure that have been used in Iowa.

CMFs have not been developed for a number of lane departure countermeasures. As a result, the Iowa DOT is interested in developing CMFs for several countermeasures of interest. CMFs are used by highway safety engineers, traffic engineers, highway designers, transportation planners, transportation researchers, and managers and administrators to estimate the safety effects of various countermeasures, to compare safety benefits among various alternatives and locations, to identify cost-effective strategies and locations in terms of crash effects, to check reasonableness of evaluations (i.e., compare new analyses with existing CMFs), to check validity of assumptions in cost-benefit analyses. A CMF should be selected based on crash severity, crash type, and site condition (Gross et al., 2010).

Gross et al. (2010) in a report on developing quality crash modification factors indicated that CMFs derived from before and after crash data are based on the change in safety performance due to the implementation of some treatment. The issues with deriving quality CMFs from before-after designs are the sample size and potential bias caused due to changes in traffic volumes, changes in reported crash experiences and regression to the mean.

## 2.9 Different Approaches of Before and After Crash Analysis

### *2.9.1 Simple Before and After Analysis*

Before and after study methods are generally used for calculation of crash modification factors or crash reduction factors. According to Shen et al. (2003) State DOTs use the simple before and after crash analysis to develop CMFs. The study assumes no changes in the before and after periods, and that the crashes before improvement to be good estimate of probable crashes during the after period without the installation of the countermeasure. The formula for CRF developments given by this method is given by difference of before and after crashes divided by the crashes in the before period. Positive value indicates there has been a considerable improvement due the countermeasure (Shen et al., 2003).

### *2.9.2 Before and After Analysis with Comparison Group Studies*

Gross et al. (2010) provided overview on before and after study with comparison groups. The comparison groups are the group of sites that are similar to the sites treated with a countermeasure with respect to geometric and operational characteristics. The comparison group is referred to as control segments in the report. The comparison group is used to calculate the ratio of observed crash frequency in the after period to that in the before period. The observed crash frequency in the before period at a treatment site group is then multiplied by this comparison ratio. This provides an estimate for the number of expected crashes at the treatment group had there no treatment been applied. This is then compared to the observed crashes in the after period at the treatment site group to estimate the changes in crashes to evaluate the safety effects of the treatment.

The treatment and comparison sites should also be matched on the basis of the observed crash frequency in the before period. In other words, a control site would need to be matched to each treated site based on the annual crashes in the before period. A suitable comparison group is one where the ratios of expected crash counts in the after period to that in the before period are equal for the comparison group and the treatment group, had there been no treatment applied. A test of comparability for the treatment group and potential comparison groups can be performed to test the suitability of the comparison group (Hauer et al. 1997). The test compares a time series of target crashes for a treatment group and the comparison group during a period before the implementation of the treatment. A good comparison site will show a trend similar to that of the treatment group (in the absence of treatment) (Gross et al., 2010).

*2.9.3 Empirical Bayes Before and After Crash Analysis*

The objective of the empirical Bayes methodology is to more precisely estimate the number of crashes accounting for observed changes in crash frequencies before and after a treatment that may be due to regression-to-the-mean. The method involves calculation of safety performance function (SPF) which is a mathematical equation that is used to predict the mean crash frequency for similar locations with the same traffic and geometric characteristics (Gross et al., 2010). The method assumes that the number of crashes follows a Poisson distribution, the means for a population of systems can be approximated by a gamma distribution and the changes from year to year from different factors are similar for all reference sites (Shen et al., 2003).

## 2.10 Summary

This chapter provided a comprehensive review of the literatures on pavement edge drop-offs to reveal the hazards and danger related to it. Past studies also provided percentages of crashes due to the drop-offs which was detailed in the chapter. The chapter also reviewed literatures on the effectiveness of Safety Edge as a unique and cost effective countermeasure for reducing edge drop-off related crashes.  There were very few studies found on safety evaluation and effectiveness of Safety Edge. Thus there is a need for such studies to establish the improvement in crashes if any due to the installation Safety Edge. The chapter briefly described the types of equipment used to construct a Safety Edge and studies on design and construction of Safety Edge and briefly listed out the advantages of installing Safety Edge.

This chapter also provided some overview of the crash modification factors (CMF) and crash reduction factors (CRF) along with techniques of before and after analysis of crash data.

# CHAPTER 3

# DATA

This chapter describes the various data sources, data description and data processing steps used to perform a simple before and after as well as a cross sectional analysis to develop the crash modification factor for Safety Edge. The data period used in the study was from the year 2004-2014. Information of primary source of locations of the Safety Edge were obtained from previous studies conducted in Iowa by the Institute of Transportation, Iowa State University and secondary source of locations or road segments with Safety Edge were obtained from Iowa Department of Transportation. Crash data, roadway information and traffic data were collected using a variety of data sources.

## 3.1 Data Sources

The types of data used in this project includes location, roadway information and traffic data, and crash data. These data were obtained from different sources and were integrated together to create suitable datasets for further analysis to accomplish research objectives.

## 3.2 Location Details

The primary source of data for obtaining the locations for this project was a list of roadway segments where the Safety Edge had been installed in the state of Iowa and recorded as part of an outreach project which assisted agencies in using the Safety Edge in construction and rehabilitation in 2010 (Hallmark et al., 2011). Prior to 2010, use of the Safety Edge was rare in Iowa so the Center for Transportation Research and Education at Iowa State University provided guidance and technical assistance to contractors during the 2010 construction season who wanted to install the Safety Edge in Iowa. The team acquired different types of Safety Edge equipment to make it available for loan to the contractors. The team had had built up an advisory committee of experienced and knowledgeable professionals that included staff from both asphalt and plain cement concrete (PCC) paving associations, industry, the FHWA, the Iowa DOT, academia, and interested county engineers in Iowa. The research team along with the advisory team had listed potential projects for implementation of Safety Edge concept. A survey was conducted on counties having upcoming planned projects to encourage them to use the Safety Edge with both Portland Cement Concrete and Hot-mix Asphalt (HMA) Projects. Several counties participated and included the Safety Edge construction with their existing project plans. The CTRE team had developed and administered as well as hosted several open house demonstrations of the technique of Safety Edge construction around Iowa to promote the concept. During this process the CTRE team recorded the extents of known projects where the Safety Edge was used. Additionally they made site visits to some locations and recorded other information such as Safety Edge slopes, surface material, lengths, start and end dates. These locations are enlisted in Table 3. 1. It can be observed from Table 3. 1 that this study includes Safety Edge segments from over fourteen counties of Iowa and the year of installations was either 2009 or 2010. There were mostly HMA projects than PCC projects. The table also provides information on length of the road segments subjected to any kind of roadwork (which varies from I mile to 8.6 miles), lane width (varying from 22 feet to 32 feet), average slopes of Safety Edge after construction varying from 18 degrees to 51 degrees, and also information about shoulder type and width.

Locations of some additional Safety Edge segments were obtained in a follow-up study (Hallmark et al., 2012). The Phase II study was conducted to inspect, observe and document field conditions on previously installed Safety Edge projects and the study also looked into advances in design and utilization of Safety Edge equipment. The research team also sampled, tested, and assessed consolidation of the Safety Edge, evaluated changes in shoulder settlement/erosion, and assessed any deterioration of sloped HMA pavement edges. The location details of the additional Safety Edge obtained from the above mention study are as provided in Table 3. 2 (Hallmark et al., 2012). It can be seen from Table 3. 2 that the Safety Edge segments from this study were scattered over eleven counties of Iowa and the year of construction was either 2011 or 2012. The average slopes of the Safety Edge after construction varied from 21 degrees to 46 degrees. The lengths of the segments falls between 1 mile and 8.8 miles.

The secondary source of locations of road segments provided with Safety Edge was a database of files provided by the Iowa Department of Transportation. The files contained various information, the most important information among which was a series of construction plans that was used in the study. These construction plans included road segments subjected to some construction and/or repair work like resurfacing or other pavement improvement projects in Iowa that included installation of Safety Edge provided letting dates. Important information obtained from these construction plans were letting dates which were later used to confirm the date of construction, extents of the installation of Safety Edge in respective counties in Iowa. Table 3. 3 provides the road segments with Safety Edge from the secondary source.  It can be seen from Table 3. 3 that the Safety Edge segments are situated over 32 counties of Iowa and the primary type of work with which Safety Edge would also be installed were HMS resurfacing, HMA overlay, cold in place recycling, etc.

Table 3. 1 Location and Information of PCC and HMA Projects with Safety Edge Installation (Hallmark et al., 2011)

| Locations | Information Collected |
|---|---|
| Interstate 29 Woodbury County | PCC pavement- 9 inches<br>Paved Shoulders: 7 inches<br>Year of construction: 2009 |
| County Road E34 in Jones/Linn Counties<br>Contractor: Horsfield Construction, Inc. of Epworth, Iowa. | Surface Material: 6 inch PCC overlay over 6 inch PCC pavement<br>26 feet paved width<br>Length: 2.5 miles<br>Construction start/end: May1-July 20, 2010. |
| County Road V63 in Keokuk County<br>Contractor: Wicks Construction and Gomaco Corporation of Ida Grove, Iowa. | PCC surface<br>24 feet paved width<br>1 mile in length<br>Construction start/end: May17-Nov, 2010 |
| University, Winslow, and Beaver Valley/Skyline in Blackhawk County<br>Contractor: Aspro, Inc. of Waterloo, Iowa. | HMA overlay<br>24 feet paved width<br>8.6 miles in length<br>Construction start/end: May-June11, 2010<br>TransTech Notch Wedge Joint Maker equipment used to construct the Safety Edge.<br>Average Slope: 26 degrees |
| County Road F62 in Jasper County<br>Contractor: Manatt's, Inc. of Brooklyn, Iowa | HMA<br>24 feet paved width<br>4.5 miles in length<br>Construction start: July, 2010.<br>Average Slope: 37 degrees |
| County Roads A21, P20, and B20 in Kossuth County<br>Contractor: Manatt's, Inc. | HMA<br>26 feet total paved width with 11 foot lanes and approximate 2 foot wide shoulders<br>7 miles, 6 miles, and 1 mile<br>Construction start/end: August 10 – August 31, 2010.<br>Average Slope: 36 and 35 degrees for A21 and P20. |
| | |

| | |
|---|---|
| County Roads H24, P27, and 130th in Union County<br>Contractor: Henningsen Construction, Inc. of Atlantic, Iowa. | 6 inch HMA Grade<br>22 feet paved width<br>6.5 miles combined<br>Construction start/end: October 25-November 18, 2010.<br>Average Slope: 18 degrees |
| County Roads D14, D46, and P59 in Webster County<br>Contractor: Ft. Dodge Asphalt Company of Ft. Dodge, Iowa. | HMA<br>32, 22, 22 feet paved width respectively<br>2.4 miles, 4 miles, and 2 miles, respectively<br>Construction start/end: July 5 – August 2010.<br>Average Slope: 30 and 31 degrees for D46 and P59. |
| County Road Y26 in Cedar County<br>Contractor: IlIowa Investments, Inc. of Blue Grass, Iowa. | HMA<br>24 feet paved width<br>4.1 miles in length<br>Construction start/end: June 21 – mid-August 2010.<br>Average Slope: 40 degrees |
| County Road D34 in Delaware County<br>Contractor: Mathy Construction Co. of Onalaska, Wisconsin. | HMA<br>22.5 feet paved width<br>5 miles in length<br>Construction start/end: June 1 – June 30, 2010.<br>Average Slope: 51 degrees |
| US Highway 20 in Sac and Ida Counties<br>Contractor: Oldcastle® Materials (OMG) Midwest/Tri-State Paving, of Estherville, Iowa. | HMA<br>28 feet paved width<br>6 miles in length<br>Construction start/end: August – September 2010.<br>Average Slope: 30 degrees |
| County Road Z30 in Clinton County<br>Contractor: Flynn Company, Inc. of Dubuque, Iowa. | Part HMA part PCC<br>22 feet with 4 foot granular shoulders<br>4.2 miles with 0.9 miles HMA<br>Construction start/end: July 12 – September 15, 2010.<br>Average Slope: 39 degrees |

Table 3. 2 Locations of Some Additional Safety Edge Segments from Phase II Study of Safety Edge in Iowa (Hallmark et al., 2012).

| County | Site | Year of Construction | Average slope left | Average Slope right | Length (Miles) |
|---|---|---|---|---|---|
| 1. Lee | J40 | 2011 | 44 | 42 | 8 |
| 2. Carroll | E26 | 2012 | 36 | 33 | 2.97 |
| 3. Story | Arrasmith Trl | 2011 | 27 | 21 | 1 |
| 4. Story | E15 | 2011 | 31 | 31 | 4 |
| 5. Guthrie | N70 | 2011 | 26 | 22 | 8.5 |
| 6. IA DOT | IA 175-Webster | 2011 | 36 | 38 | 4.5 |
| 7. Montgomery | H54 | 2011 | 29 | 30 | 8.8 |
| 8. Webster | D20 | 2011 | 41 | 37 | 3.5 |
| 9. Webster | D26 | 2011 | 41 | 38 | 6 |
| 10. Webster | P29 | 2011 | 46 | 48 | 5 |
| 11. Kossuth | P60 | 2011 | 34 | 34 | 5 |
| 12. Kossuth | P66 | 2011 | 33 | 29 | 3 |
| 13. IA DOT | IA 38 – Jones | 2011 | 29 | 28 | 4.2 |
| 14. Black Hawk | Union Road | 2011 | 23 | 23 | 5 |
| 15. Black Hawk | V51 | 2011 | 21 | 28 | 7 |
| 16. Dickinson | A43-M54-A48 | 2012 | 37 | 40 | 11 |
| 17. Dickinson | A31 | 2012 | 35 | 34 | 3 |
| 18. Kossuth | A38 | 2012 | 24 | 24 | 4.4 |
| 19. Kossuth | P30 | 2012 | 25 | 23 | 8 |
| 20. Kossuth | P20 | 2012 | 25 | 23 | 7 |
| 21. IA DOT | IA 146 | 2012 | 31 | 32 | N.A. |
| 22. Carroll | E63 | 2012 | 42 | 38 | 2.1 |
| 23. Carroll | E37-East | 2012 | 35 | 37 | 1.86 |
| 24. Carroll | E37-West-71 | 2012 | 40 | 37 | 1.28 |
| 25. Carroll | US30 S to Airport | 2012 | 42 | 43 | 1.24 |

## 3.3 Installation Periods

Installation year was necessary so that a before and after analysis could be conducted. When segments were available from the primary source that is the previous CTRE studies, the construction date for each segment was known. When segments were obtained from secondary sources, the actual construction dates where not known since this information was not recorded within construction plans.

When the construction date was not available from previous studies, construction plans were used to extract the letting dates. These construction plans were obtained from Iowa DOT. Construction dates were considered to be within 6 months of letting dates and the year of construction of the projects were determined accordingly. The deduced date of construction using the letting dates can be seen from Table 3. 3. The construction period of all the treatment segments ranged from 2009 to 2012. So, while analyzing eleven years of crashes on the treatment segments some segments had greater span of before period than that of the after period.

Table 3. 3 Locations of Safety Edge Segments from Secondary Source (IADOT)

| County/counties | Description of location | Type of work | Letting date | Deduced date of construction |
|---|---|---|---|---|
| Ringgold | On US 169 From IA 2 North 13 Miles To The Union County Line (MP 17.46 – MP 30.38) | Cold in place recycling (C.I.R) and HMA overlay | 06-16-2009 | 2010 |
| Union | On US 169 From Ringgold County Line To South Corporate Limits Of The City Of Afton (MP 30.38 – MP 39.13) | Cold in place recycling and HMA overlay | 06-16-2009 | 2010 |
| Johnson/Muscatine | US 6 from ECL Iowa City southeasterly to WCL West library | HMA resurfacing with milling | 3-16-2010 | 2010 |
| Ida/Sac | US 20 from E. Jct. US 59 E. to IA 110 | HMA widening / HMA resurfacing | 2-16-2010 | 2010 |
| Harrison/ Crawford | US 30 from Dunlop East to Dow City | HMA resurfacing with milling | 1-20-2010 | 2010 |
| Emmet | IA 9 from approx. 0.15 miles east of the ECL of Estherville to Kossuth County | HMA resurfacing with cold in place recycling | 12-15-2009 | 2010 |
| Sioux/O'Brien | IA 10 from Jct. IA 450 South and East to 500 feet East of Maple St. in Paulina | HMA widening and resurfacing | 7-21-2009 | 2010 |
| Page/Taylor | From Clarinda to East of New Market (MP 51.87-MP 59.84) | Widen, HMA resurface | 12-15-2009 | 2010 |
| Davis/Van Buren | IA 2 from East Jct. US 63 E. to near Co. Rd. V-64 near Cantril | HMA pavement widening/ HMA resurfacing | 11-17-2009 | 2010 |
| Cherokee/ Buena Vista | IA 3 From 0.27 Mile W. Of IA 7 E.<br>To 0.25 Mile W. Of Co. Rd. M-31. | HMA pavement widening / HMA resurfacing | 10-20-2009 | 2010 |
| Kossuth/Winnebago | On IA 9 from the east Jct. of US 169 in Kossuth county to Co. Rd. R20 in Winnebago County and from Co. Rd. R50 east to the north jct. of US 69 in Winnebago County | HMA pavement widening with HMA resurfacing | 02-16-2010 | 2010 |

| | | | | |
|---|---|---|---|---|
| Guthrie | On IA 25 from Guthrie Center to Junction IA 141 (MP 85.83 – MP 97.35) | Cold in place recycling and HMA overlay | 12-15-2009 | 2010 |
| Woodbury | IA 31 From IA 141 In Smithland N. To S. Jct. Co. Rd. D54 | HMA widening / HMA resurfacing | 11-17-2009 | 2010 |
| Clinton/Jones | On IA 136 from Lost Nation northwesterly to the west junction IA 64 | HMA pavement widening with HMA resurfacing | 02-16-2010 | 2010 |
| Taylor | On IA 148 from Missouri State Line to City of Bedford (MP 0.00 - MP 7.52) | Cold in place recycling and HMA overlay | 03-16-10 | 2010 |
| Ringgold/Decatur | IA 2 from NCL of Kellerton E. to I-35 | HMA resurfacing with milling | 10-19-2010 | 2011 |
| Iowa/Johnson | On US 6 from the East Junction with US 151 easterly to Tiffin | HMA resurfacing | 02-15-11 | 2011 |
| Ringgold | IA 2 from IA 25 through Mt. Ayr to the E. Int. of US 169 | Cold in place recycling, widening and HMA resurfacing | 6-21-2011 | 2012 |
| Linn | On Iowa 13 from 0.7 mile north of County Home Road northerly to 0.5 mile north of Central City | HMA pavement widening with HMA resurfacing | 01-19-2011 | 2011 |
| Butler | IA 14 from Beaver Creek in Parkersburg north to the east junction with IA 3 in Allison | HMA pavement widening with HMA resurfacing | 01-19-2011 | 2011 |
| Guthrie/Greene | IA 25 from the west Jct. of IA 141 North to Co. Rd. E-63 | HMA resurfacing | 4-19-2011 | 2012 |
| Jones | On Iowa 38 from Olin northerly to Iowa 64 | HMA resurfacing with milling | 05-17-2011 | 2012 |
| Jones | On Iowa 64 from the east junction with Iowa 38 | HMA Resurfacing With Cold-In-Place Recycling | 05-17-2011 | 2012 |
| Clinton | On Iowa 136 from 16th St. NW in Clinton northwesterly to just west of Charlotte | HMA Resurfacing With Milling | 04-19-2011 | 2012 |
| Woodbury | From Just W. Co. Rd. K-67 E. To ECL Of Smithland | HMA Pavement Widening/HMA Resurfacing | 1-19-2011 | 2011 |

| | | | | |
|---|---|---|---|---|
| Guthrie | On IA 141 from the South Corp. Limit of Coon Rapids east to just west of the north Jct. of IA 4 | HMA Resurfacing With C.I.R | 4-19-2011 | 2012 |
| Webster | On IA 175 from just east of the east junction of US 169 east to 1.7 miles west of the Des Moines river. | HMA Resurfacing With Cold-In-Place Recycling | 12-21-2010 | 2011 |
| Tama | On IA 8 from the Corp. Line of Traer east 7.5 miles | HMA Resurfacing With Cold-In-Place Recycling | 10-19-2010 | 2011 |

### 3.4 Extents of Safety Edge Segments

In the previous projects by Hallmark et al., 2011 and Hallmark et al., 2012, the start and end points of the Safety Edge were determined by the CTRE team along with the help of Iowa DOT by conducting site visit or by looking into construction plans. The locations and extents of the Safety Edge projects were documented by highlighting the road segments manually over Geo-referenced tagged image file format (TIFF) or raster images of highway and transportation maps of the different counties of Iowa which were downloaded from Iowa DOT Geographic Information Systems downloads website. For example, a raster image containing the highlighted Safety Edge segments of Lee County is shown in Figure 3. 1.

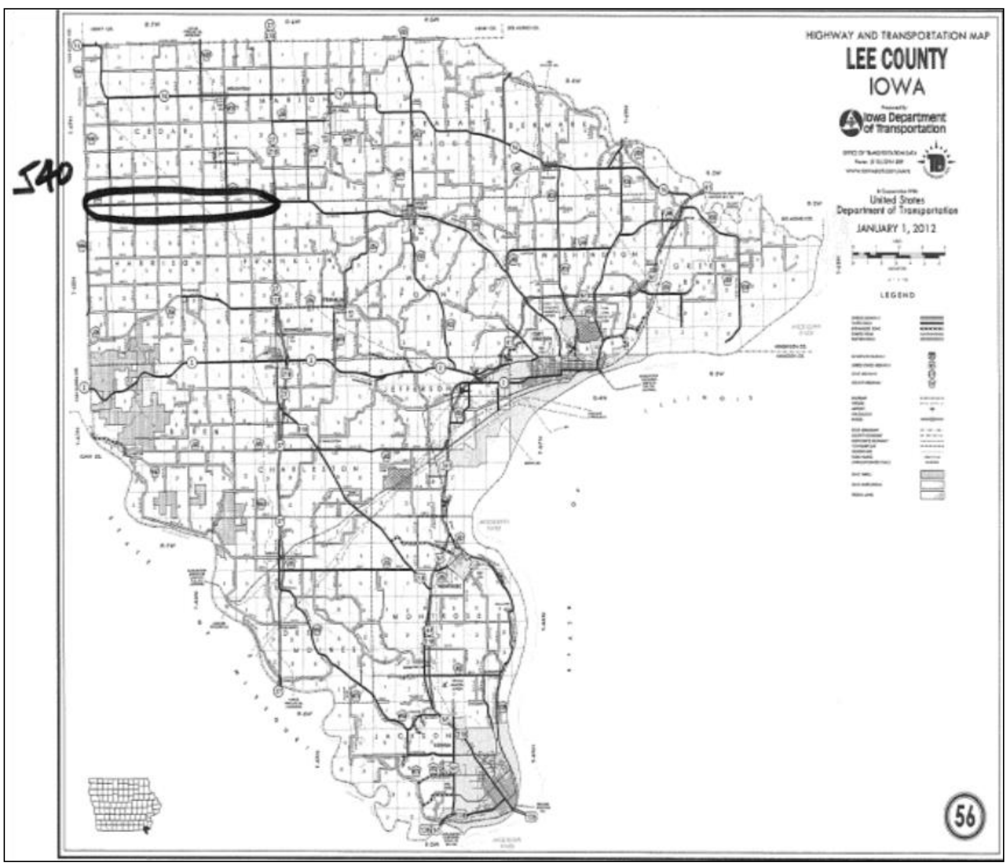


Figure 3. 1 Raster Image Containing the Highlighted Safety Edge Segments of Lee County

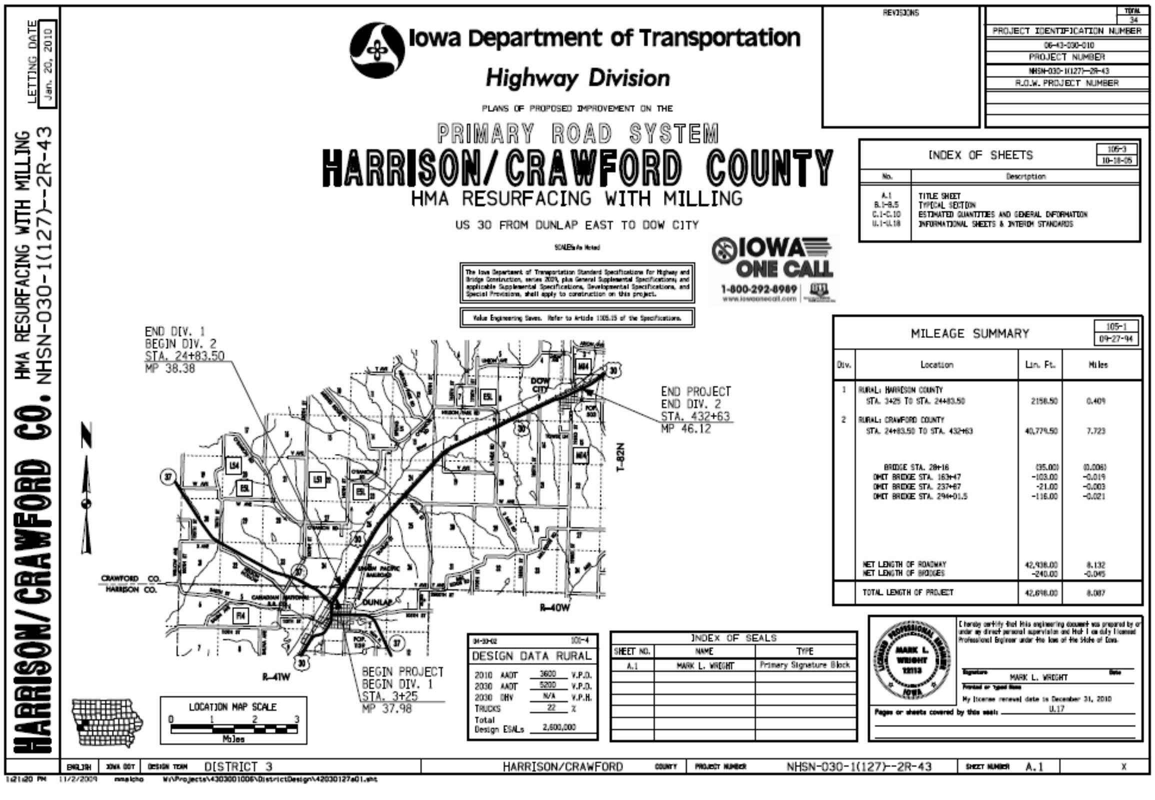


Figure 3. 2 Construction Plan for Road Resurfacing Project Including Construction of Safety Edge in Harrison/Crawford County.

Construction plans (shown in Figure-3.2) obtained from Iowa DOT were also used to determine the start and end points of the resurfacing projects that included installation of Safety Edge. At the end of the process of gathering all available information about locations of road segments having Safety Edge from primary and secondary sources, a total of 84 road segments having Safety Edge installed were obtained all over Iowa. These 84 segments (a total of about 490 miles) became the treatment segments for the study. The treatment segments comprised of both rural/urban, divided/undivided two-lane/multi-lane roadways with paved/unpaved shoulders. The total lengths and year of construction of the final treatment segments that were used in the study are provided in Table 3. 4.

Table 3. 4 Total Lengths and Year of Construction Final Treatment Segments Used For the Project

| Treatment Segment Identities | County ID | Route/Street | Length in miles | Year of Construction |
|---|---|---|---|---|
| 1 | 84 & 71 | 460TH ST | 15.98 | 2009 |
| 2 | 97 | HWY 31 | 4.59 | 2010 |
| 3 | 39 | IOWA 141 | 9.57 | 2011 |
| 4 | 97 | IOWA 141 | 5.83 | 2011 |
| 5 | 18 & 11 | 530TH ST and IOWA 3 | 8.01 | 2010 |
| 6 | 81 & 47 | US 20 | 11.39 | 2010 |
| 7 | 24 | US 30 | 7.64 | 2010 |
| 8 | 30 | 260TH ST | 4.91 | 2012 |
| 9 | 30 | 270TH AVE | 2.01 | 2012 |
| 10 | 30 | 240TH ST | 4 | 2012 |
| 11 | 30 | 200TH ST | 2.99 | 2012 |
| 12 | 81 | MACE AVE | 7.65 | 2010 |
| 13 | 69 | 270 ST | 8.43 | 2011 |
| 14 | 32 | IOWA 9 | 18.08 | 2010 |
| 15 | 55 | 20 AVE | 3.12 | 2010 |
| 16 | 55 | 405 ST | 0.97 | 2012 |
| 17 | 55 | 40 AVE | 13.1 | 2012 |
| 18 | 55 | 80 AVE | 7.96 | 2012 |
| 19 | 55 | 390 ST | 4.49 | 2012 |
| 20 | 95 & 55 | IOWA 9 | 7.28 | 2010 |
| 21 | 95 | 420TH ST | 2.94 | 2010 |
| 22 | 55 | 220 AVE | 2.94 | 2011 |
| 23 | 55 | 190 AVE | 4.97 | 2011 |
| 24 | 55 | 270 ST | 1 | 2010 |
| 25 | 94 | FAIRBANKS AVE | 5.03 | 2011 |
| 26 | 94 | 170TH ST | 2.53 | 2010 |

| | | | | |
|---|---|---|---|---|
| 27 | 94 | 230TH ST | 6.29 | 2011 |
| 28 | 94 | 310TH ST | 3.99 | 2010 |
| 29 | 94 | CO RTE D43 and Iowa 2 | 3.9 | 2011 |
| 30 | 94 | PARAGON AVE | 6.96 | 2011 |
| 31 | 94 | 360TH ST | 1.51 | 2011 |
| 32 | 94 | IOWA 175 | 2.76 | 2011 |
| 34 | 94 | OLD HWY 20 | 2.94 | 2011 |
| 35 | 81 | XAVIER AVE | 1.26 | 2010 |
| 36 | 14 | 160TH ST | 2.98 | 2012 |
| 37 | 14 | 210TH ST | 1.88 | 2012 |
| 38 | 14 | Iowa 136 | 1.39 | 2012 |
| 39 | 14 | QUAIL AVE | 1.3 | 2012 |
| 40 | 85 | 110TH ST and 460th Ave | 4 | 2011 |
| 42 | 14 | 330TH ST | 2.23 | 2012 |
| 43 | 39 & 37 | E AVE | 2.94 | 2011 |
| 44 | 39 | JUSTICE RD | 8.45 | 2011 |
| 45 | 39 | IOWA 25 | 11.19 | 2010 |
| 46 | 39 | IOWA 141 | 6.37 | 2011 |
| 47 | 87 & 73 | IOWA 2 | 7.99 | 2010 |
| 48 | 87 | IOWA 148 | 7.72 | 2010 |
| 49 | 80 | IOWA 2 | 12.39 | 2011 |
| 50 | 88 & 80 | US 169 | 21.64 | 2009 |
| 51 | 88 | 140TH ST | 2.27 | 2010 |
| 52 | 88 | GREEN VALLEY RD | 0.35 | 2010 |
| 53 | 88 | GREEN VALLEY RD | 2.49 | 2010 |
| 54 | 80 & 27 | IOWA 2 | 11.05 | 2011 |
| 55 | 12 | IOWA 14 | 11.24 | 2011 |
| 56 | 50 | HWY 225 E and CO RD F62 E | 4.32 | 2010 |
| 57 | 79 & 62 | IOWA 146 | 6.75 | 2012 |
| 58 | 79 | IOWA 146 | 6.56 | 2012 |

| | | | | |
|---|---|---|---|---|
| 59 | 79 | IOWA 146 | 4.28 | 2012 |
| 60 | 89 & 26 | IOWA 2 | 20.15 | 2010 |
| 61 | 54 | 270TH AVE | 1.01 | 2010 |
| 62 | 56 | 160 ST | 7.82 | 2011 |
| 63 | 7 | WINSLOW RD | 3.39 | 2011 |
| 64 | 7 | TAYLOR RD | 0.66 | 2011 |
| 65 | 7 | N UNION RD | 5.02 | 2011 |
| 66 | 7 | BEAVER VALLEY RD | 2.4 | 2011 |
| 67 | 53 | IOWA 136 | 3.25 | 2010 |
| 68 | 7 | UNIVERSITY AVE | 2.53 | 2010 |
| 69 | 86 | 2ND ST | 0.71 | 2011 |
| 70 | 6 | IOWA 21 | 3.99 | 2010 |
| 71 | 7 | S CANFIELD RD | 6.18 | 2011 |
| 72 | 28 | 255TH ST | 5.02 | 2010 |
| 73 | 57 | IOWA 13 | 1.03 | 2011 |
| 74 | 53 | CO RD E-34 and FAIRVIEW RD | 4.64 | 2010 |
| 75 | 52 & 48 | US 6 | 11.13 | 2011 |
| 76 | 70 & 52 | US 6 | 12.14 | 2010 |
| 77 | 16 | YANKEE AVE | 4.27 | 2010 |
| 78 | 23 | 350 AVE | 0.99 | 2010 |
| 79 | 23 | IOWA 136 | 16.22 | 2011 |
| 80 | 23 | IOWA 136 | 0.17 | 2011 |
| 81 | 53 & 23 | IOWA 136 | 7.32 | 2010 |
| 82 | 53 | IOWA 136 | 3.27 | 2010 |
| 83 | 53 | IOWA 38 | 4.61 | 2011 |
| 84 | 53 | IOWA 38 and IOWA 64 | 6.38 | 2011 |

It can be observed from Table 3. 4 that all the treatment segments having Safety Edge were located over 42 counties among 99 counties of Iowa. The lengths of the treatment segments ranged from 0.17 miles to 21.64 miles and the date of construction of the Safety Edge was either 2009, or 2010, or 2011 or 2012. Table 3. 5 shows summarized total length of all treatment segments considered in the study by type of area, number of lanes, and type of shoulder.

Table 3. 5 Total Lengths of Treatment Segments by Type of Area, Number of Lanes and Type of Shoulder.

| Area Type | Number of Lanes | Shoulder Type | Length in Miles | Percentages of Total length |
|---|---|---|---|---|
| Rural | Two-Lane | Paved shoulder | 266.42 | 56.31 |
| | | Unpaved shoulder | 193.15 | 40.83 |
| | Multilane | Paved shoulder | 6.85 | 1.45 |
| | | Unpaved shoulder | 0.26 | 0.05 |
| Urban | Two-Lane | Paved shoulder | 5.05 | 1.07 |
| | | Unpaved shoulder | 1.26 | 0.27 |
| | Multilane | Paved shoulder | 0.11 | 0.02 |
| | | Unpaved shoulder | 0 | 0.00 |
| | | | 473.1 | |

It can be observed from Table 3. 5 that the maximum portion of the treatment segments having Safety Edge are comprised of rural two-lane roads having paved shoulders representing 56.3% of the total length of treatment segments , followed by rural two lane roads with unpaved shoulders that takes up 40.83% of the total length of the treatment segments. Rural multilane roadways with paved shoulders contribute about 1.45% of the total treatment segment length.

### 3.5 ArcGIS 10.2.2 Software

Road segments having Safety Edge on them were digitized using ArcGIS 10.2.2 software. Location details and extents obtained as discussed earlier were used to select the GIMS road segments with the help of raster images in the background using ArcGIS10.2.2. Software. The raster images were available for download from the Iowa DOT GIS downloads website. After all the treatment segments were selected, the selected segments of the Iowa roadways were exported as a new layer in the map which represented exclusively the Safety Edge. Slope measurements, year of construction and other information accumulated from previous studies were included in the attribute table of the Safety Edge in the map along with GIMS attributes. Figure-3.3 shows all the roadway segments having Safety Edge that were located in Iowa using the ArcGIS 10.2.2 software.

### 3.6 Information about Road, Traffic, Lane, Surface, etc.

In order to analyze the safety effectiveness of Safety Edge installations, several roadway, and traffic and lane characteristics were needed to be obtained for each treatment roadway segment. The Iowa Department of Transportation (Iowa DOT) Geographic Information Management System (GIMS) data was used to obtain this information. Roadway geometry data and traffic volume data and pavement and shoulder related data for each road segment were obtained from the GIMS database which is updated annually. Three types of GIMS datasets, TRAFFIC, ROAD INFO and DIRECT LANE were used in this study. The location of each of the 82 treatment segments was mapped against links within GIMS. In many cases, a treatment segment was made up of smaller GIMS segments. Each of the smaller GIMS roadway segment had unique identities designated as MSLINKs. The corresponding MSLINKs were identified and roadway and crash data for eleven years (2004-2014) was extracted for each treatment link.

Several roadway geometry related attributes such as surface width, lane width, number of lanes, shoulder width, shoulder type and others are reported in the GIMS database along with the Annual Average Daily Traffic (AADT) for specific segment of roadways. The descriptions and definition and transformed names of the attributes that were used from the GIMS data for the project are provided in Table 3. 6. Attributes in the TRAFFIC and ROAD INFO datasets provided data that correspond to both the direction of travel for divided road segments. Whereas the attributes in DIRECT LANE apply to the individual directions of travel. DIRECT LANE attributes of divided roadways in Iowa were thus critical to the analysis if taken with ROAD INFO AND TRAFFIC datasets. Only eight miles of divided roadway segments among 490 miles of roadway segments having Safety Edge were present in the data. This was only about 1.6% of the treatment segments. Thus it was decided to remove the divided segments from the data used in the study. The divided roadways were also excluded due to the reason that they were inherently different in nature than undivided roadways. So divided and undivided segments should be analyzed separately. Because of the reason that there were very small percentage of divided roads that was seen to have Safety Edge on them a separate analysis for divided roads was not feasible.

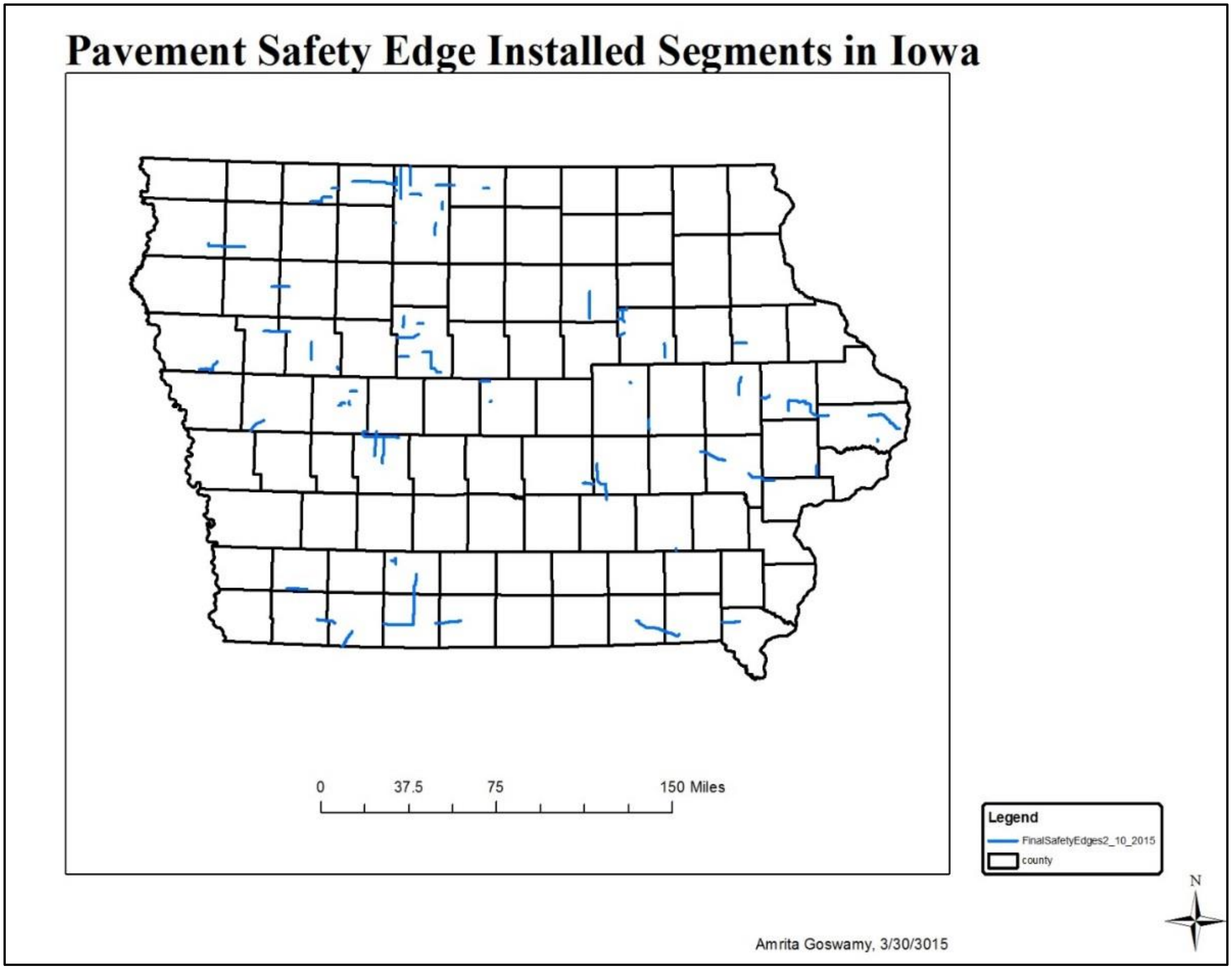


Figure 3. 3 Roadway Segments in Iowa having Safety Edge

Table 3. 6 GIMS DATA Attributes. Source: GIMS Manual, IDOT.

| GIMS Attribute | Changed Field Name | Description |
|---|---|---|
| COUNTYNO | County No | Number of each county |
| MSLINK | Mslink | link between the data in all the road tables |
| NINEONEONE | Street Name | The name used by the 911 system to identify that road. |
| URBANAREA | Rural/Urban | This field identifies if the road segment is within an urban area or rural. |
| NUMLANES | Number of Lanes | This field indicates the number of lanes for all road systems. This is the total number of lanes on both sides of the highway including those with a median.<br>Code Description<br>1 1 Lane<br>4 4 Lanes |
| SURFWIDTH | Lane Width | This field indicates the width of a road to the nearest foot for all road systems. |
| SURFTYPE | Surface Type | 60 Generic asphalt |
| SHDTYPER | Right Shoulder Type | This field indicates the right side or outside shoulder type for all road systems using the following criteria.<br>Code Description<br>0 No shoulder<br>1 Earth<br>2 Gravel<br>6 Paved<br>7 Combination shoulder – paved and earth<br>8 Combination shoulder – paved and gravel<br>9 Combination shoulder – paved and paved |
| SHDWIDTHR | Right Shoulder Width | This field indicates the width of the right side or outside shoulder to the nearest foot |
| SHDTYPEL | Left Shoulder Type | This field indicates the left side or inside shoulder type. |
| SHDWIDTHL | Left Shoulder Width | This field indicates the width of the left side or inside shoulder to the nearest foot. |
| LIMITMPH | Speed Limit | This code indicates the lowest posted MPH excluding MPH for curves for a road segment |
| AADT | AADT | This field indicates the average annual daily traffic on this road segment. This is applicable for primary, secondary, and municipal roads. |

## 3.7 Control Segments

In order to compare the performance of roadway segments control segments were identified Control segments are segments that do not have the Safety Edge in place but are similar to the treatment segments in several aspects like: geometry, location, geographic characteristics, road characteristics like Average Annual Daily Traffic (AADT), Shoulder type and width, pavement type and width, percentage of trucks, number of intersections, and number of lanes. Queries were built in ArcGIS 10.2.2 using the fields AADT, number of lanes, pavement width, etc. to select and choose segments of similar characteristics could be chosen by manual inspection on the map. Two control segments were selected for each of the treatment segments. Some of the control segments were not of same length as of the treatment segments. However, length is accounted for in the statistical model. The control segments were very carefully chosen for linear and curved treatment segments so that they are mostly similar to each other. Control segments were provided with unique identities according to their corresponding treatment segments. A total length of 825 miles of control segments were obtained which is almost the double amount of length of treatment segments. The final control segments selected for the study is shown in Figure-3.4.

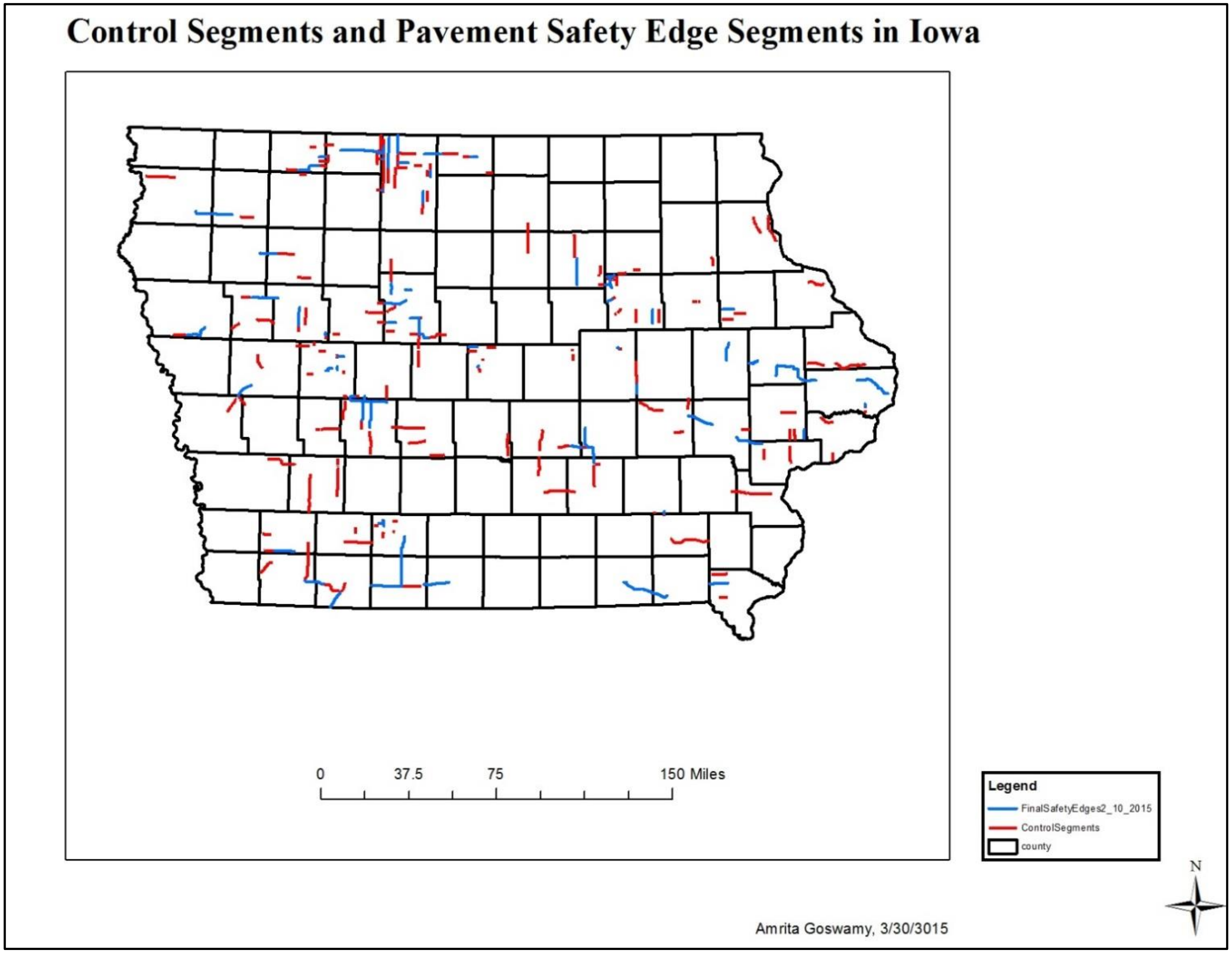


Figure 3. 4 Control Segments and Safety Edge Segments in Iowa

The roadway, traffic, lane and surface characteristics of each of the control segments were obtained in the same way from Iowa DOT GIMS data as was done for the treatment segments for the same eleven years interval from 2004 till 2014. Due to anomalies of taking undivided and divided roadways together, the undivided roadways among the control segments were excluded out from the study. There was only 6 miles of control segments among 825 total miles which was divided. Thus excluding these divided roads meant only loosing less than one percent of control segment data. Table 3. 7 summarized total length of all control segments considered in the study by type of area, number of lanes, and type of shoulder.

Table 3. 7 Total length of Control Segments by Type of Area, Number of Lanes, and Type of Shoulder

| Area Type | Number of Lanes | Shoulder Type | Length | Percentage |
|---|---|---|---|---|
| Rural | Two-Lane | Paved shoulder | 427.2 | 51.80 |
| | | Unpaved shoulder | 353.6 | 42.88 |
| | Multilane | Paved shoulder | 24.4 | 2.96 |
| | | Unpaved shoulder | 3.7 | 0.45 |
| Urban | Two-Lane | Paved shoulder | 6.9 | 0.84 |
| | | Unpaved shoulder | 6.8 | 0.82 |
| | Multilane | Paved shoulder | 2.09 | 0.25 |
| | | Unpaved shoulder | 0 | 0.00 |
| | | | 824.69 | |

It can be observed from Table 3. 7 that the maximum portion of the control segments are comprised of rural two-lane roads having paved shoulders representing 51.8% of the total length of control segments, followed by rural two lane roads with unpaved shoulders that takes up 42.88% of the total length of the treatment segments. Rural multilane roadways with paved shoulders contribute about 2.96% of the total length of control segments. Graphs were generated to assess if the chosen control segments for corresponding treatment segments were similar to each other with respect to annual average daily traffic. The similarity between the AADT/ Segment Length of the treatment and control segments can be shown by Figure-3.5. It can be seen from the figure that the AADT per unit length of the control segments were seen to be more or less similar to that of the treatment segments.

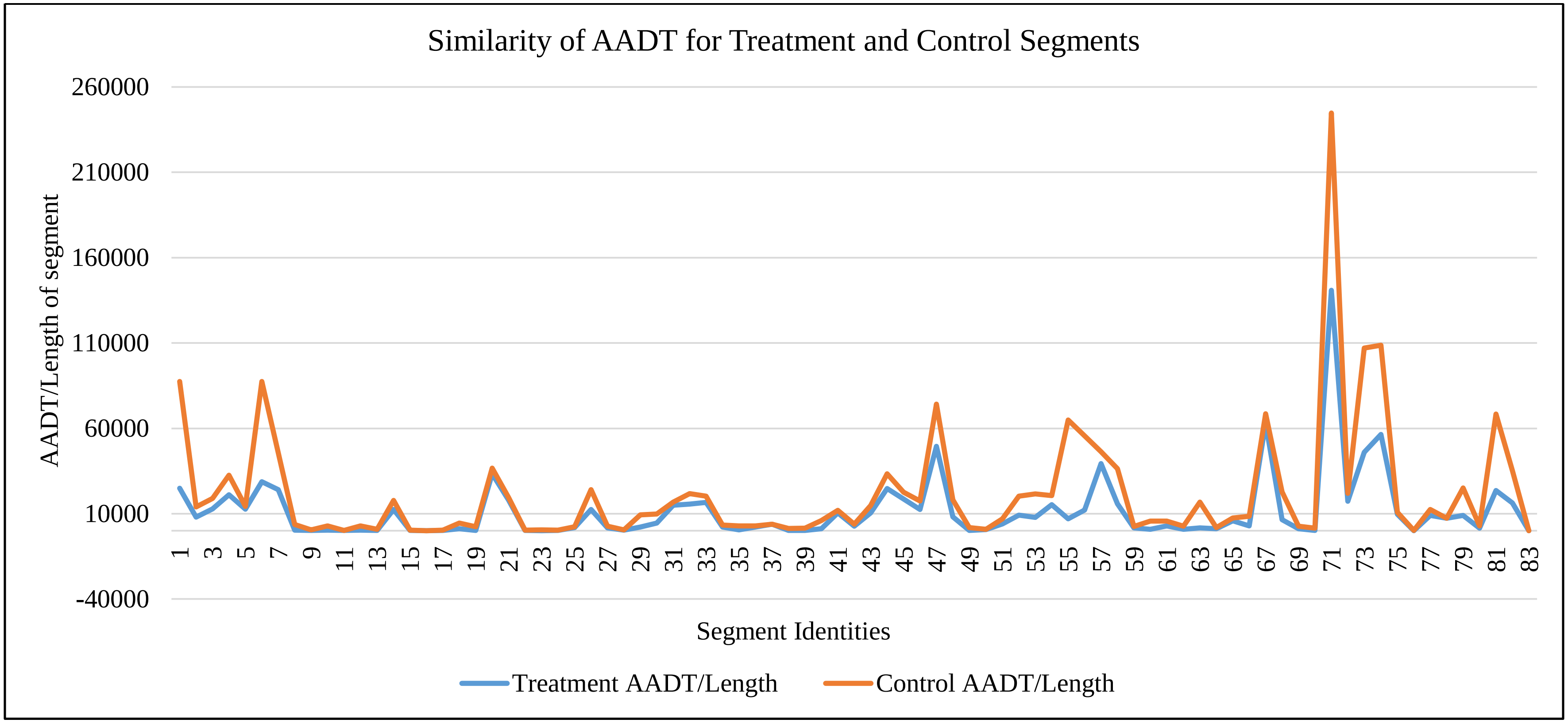


Figure 3. 5 Similarity of AADT for Treatment and Control Segments

## 3.8 Using GOOGLE Earth

GIS layers of treatment and control segments were pulled up in Google earth and inspected carefully. Though presence of Safety Edge could not be ascertained from google earth but other road characteristics such as paved shoulders, presence of rumble strips, presence of curbs, speed limit etc. could be easily verified from google earth. Since Safety Edge could not be present in localities where curbs were present, those particular parts of the treatment segments were excluded from the study.

## 3.9 Crash Data

The primary objective of the project was to evaluate the safety effectiveness of constructing Safety Edge to pavement edges and ultimately calculation of Crash Modification factors to gauge if there has been any reduction in crashes after the installation. Once all the treatment and control segments were geographically referenced in the map, all crashes occurring within 100 meters on those segments were obtained for years 2004 through 2014. The Institute of Transportation at Iowa State University maintains a copy of the Iowa DOT crash database which was queried to select crashes along treatment and control segments.

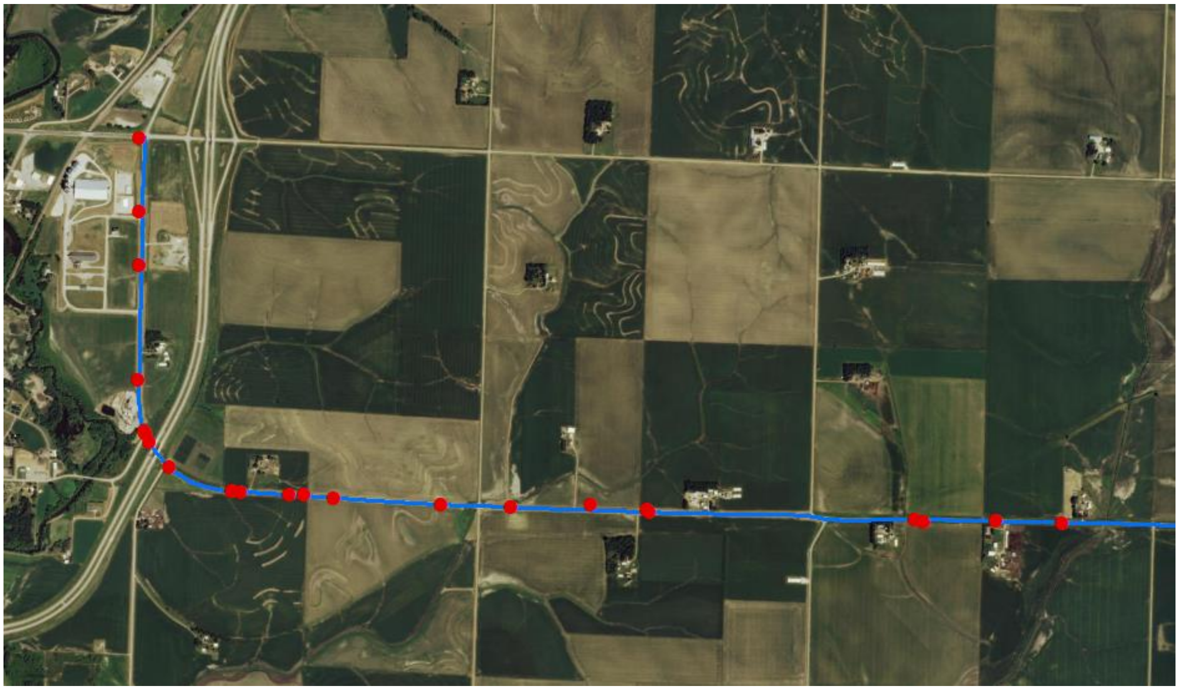

Figure 3. 6. 2004-2014 Crashes Occurring within 100 Meters on a Typical Road Segment.

Crashes at intersection within the study sections were excluded from the study as the crashes occurring at intersection have a high chance of not experiencing any pavement edge drop-off. A typical section of a road segment (that was used in the study) with eleven years of crashes from 2004 to 2014 is shown in Figure-3.6.

A dataset was created by joining all the eleven years of crash data on the treatment segments to the previously created GIMS dataset having all the road, traffic, lane, etc. information. A total of 2112 crashes were obtained in the eleven years of crash data on the treatment segments. A similar dataset was obtained for the control segments also. Since the primary purpose of the study was to analyze the safety effectiveness of Safety Edge installation, target crashes which can be defined as crashes that could be affected by the installation of the Safety Edge were needed to be identified. The crash data obtained contained both crash level and vehicle level information. The vehicle level data for the crashes included information about sequence of events that took place during the crash. Installation of Safety Edge is more likely to have a greater effect on run-off-road crashes than other crashes. So by limiting the analysis to include only the target crashes the likelihood of finding statistically significant effect may be improved. Target crashes were chosen by looking into these sequence of events for each vehicles involved in a crash. If the first event experienced by the vehicle involved in a crashes in the sequence of events included ran off road in either right or left or straight direction from the road were considered to be the crash due to pavement edge drop-off. Again if the first event experienced by the vehicle was an evasive action like swerve or panic braking was also considered as a candidate pavement edge drop-off related crash. Crashes that did not experience these first event were not considered as target crash and were excluded. Thus the types of crashes that was considered as target crashes can be tabulated as:

1. Ran off road, right.
2. Ran off road, straight.
3. Ran off road, left.
4. Evasive action (swerve, panic braking, etc.)

The records of interest were selected from the vehicle-level table based on the appropriate sequence using ArcGIS. Then, based on this selection, the corresponding crash-level records were selected which represented the target crashes. After choosing the target crashes for both the treatment and control segments a dataset was created by joining the eleven years of target crashes on the treatment segments to the previously created GIMS dataset having all the road, traffic, lane, etc. information to get the roadway, traffic and lane characteristics and corresponding crashes for the treatment segments. A similar dataset was created for the control segments also. A total of 674 target crashes were obtained in the eleven years of crash data for the treatment segments.

The crash data for the study contained following types and combinations of crashes according to crash severity levels. The crash severity levels according to the highway safety improvement program manual (HSIPM, 2010) are categorized as:

- Fatal Injury Crashes (K)
- Disabling Injury Crashes (A)
- Visible Injury Crashes (B)
- Possible Injury Crashes (C)
- Property-Damage-Only (PDO) Crashes (PDO)
- Total Crashes (KABCO)

The abbreviations of each of the severity levels are provided in the brackets respectively. The combinations of the above mentioned crash severity levels that was considered for safety analysis were as follows:

- Fatal, injury, and PDO crashes ( KABCO that is all crashes taken together)
- Fatal and injury crashes (KABC)
- Property-Damage-Only crashes (PDO)

The summary statistics of all crashes and target crashes on the treatment segments for eleven years are shown in Table 3. 8 and Table 3. 9.

Table 3. 8 Summary of All Types of Crashes on All Treatment Segments:

| | Mean | Standard Deviation | Sum |
|---|---|---|---|
| Fatal Injury Crashes | 0.365854 | 0.890494452 | 30 |
| Disabling Injury Crashes | 1.158537 | 2.109615109 | 95 |
| Visible Injury Crashes | 2.621951 | 4.723166166 | 215 |
| Possible Injury Crashes | 3.365854 | 5.090671035 | 276 |
| Property Damage Only Crashes | 18.2439 | 28.57833094 | 1496 |
| Total Crashes | 25.7561 | 38.81022023 | 2112 |

Table 3. 9 Summary of Target Crashes on all Treatment Segments:

| | Mean | Standard Deviation | Sum |
|---|---|---|---|
| Fatal Injury Crashes | 0.122 | 0.36 | 10 |
| Disabling Injury Crashes | 0.707 | 1.44 | 58 |
| Visible Injury Crashes | 1.476 | 2.94 | 121 |
| Possible Injury Crashes | 1.878 | 3.33 | 154 |
| Property Damage Only Crashes | 4.037 | 7.23 | 331 |
| Total Crashes | 8.220 | 13.87 | 674 |

It can be observed from Table 3. 8 and Table 3. 9 that the total target crashes comprised of about 32% of the total of all types of crashes. The fatal injury crashes, disabling injury crashes, visible injury crashes, possible injury crashes, property damage only crashes comprised of 33.3%, 61.1%, 56.3%, 55.8%, 22.1% of the total of crashes respectively . Table 3. 10 and Table 3. 11 summarized the non-intersection all types of crashes and target crashes for the treatment segments for the before and after periods combined respectively.

Table 3. 10 Summary of Total Non-Intersection All Types of Crash Data for Treatment Segments

| Treatment | | | | | Total number of all types of crashes during before and after study periods combined | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Length | Percentage | Fatal Injury | Disabling Injury | Visible Injury | Possible Injury | Property Damage Only | Total |
| Rural | Two-Lane | Paved | 266.42 | 56.3 | 19 | 68 | 158 | 197 | 1057 | 1499 |
| | | Unpaved | 193.15 | 40.8 | 9 | 22 | 49 | 67 | 304 | 451 |
| | Multilane | Paved | 6.85 | 1.4 | 1 | 3 | 1 | 2 | 58 | 65 |
| | | Unpaved | 0.26 | 0.1 | 0 | 0 | 1 | 1 | 4 | 6 |
| Urban | Two-Lane | Paved | 5.05 | 1.1 | 0 | 2 | 6 | 9 | 65 | 82 |
| | | Unpaved | 1.26 | 0.3 | 1 | 0 | 0 | 0 | 6 | 7 |
| | Multilane | Paved | 0.11 | 0.0 | 0 | 0 | 0 | 0 | 2 | 2 |
| | | Unpaved | 0 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | | | 473.1 | | 30 | 95 | 215 | 276 | 1496 | 2112 |

Table 3. 11 Summary of Total Non-Intersection Target Crash Data for Treatment Segments

| Treatment | | | | | Total number of target crashes during before and after study periods combined | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Length | Percent age | Fatal Injury | Disabling Injury | Visible Injury | Possible Injury | Property Damage Only | Total |
| Rural | Two-Lane | Paved | 266.42 | 56.3 | 6 | 41 | 92 | 112 | 244 | 495 |
| | | Unpaved | 193.15 | 40.8 | 4 | 15 | 25 | 34 | 68 | 146 |
| | Multi lane | Paved | 6.85 | 1.4 | 0 | 2 | 1 | 1 | 6 | 10 |
| | | Unpaved | 0.26 | 0.1 | 0 | 0 | 0 | 1 | 0 | 1 |
| Urban | Two-Lane | Paved | 5.05 | 1.1 | 0 | 0 | 3 | 6 | 11 | 20 |
| | | Unpaved | 1.26 | 0.3 | 0 | 0 | 0 | 0 | 2 | 2 |
| | Multi lane | Paved | 0.11 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Unpaved | 0 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | | | 473.1 | | 10 | 58 | 121 | 154 | 331 | 674 |

# CHAPTER 4

# A SIMPLE BEFORE AND AFTER CRASH ANALYSIS OF SAFETY EDGE INSTALLATION

As described previously, the primary purpose of the study was to evaluate the effectiveness of Safety Edge in reducing the frequency of pavement edge drop-off related crashes and resultant injuries on undivided roadways of Iowa. This chapter provides a comparison of before and after crashes for the road segments having Safety Edge on them.

## 4.1 Comparison of All Types of Crashes for Before and After Periods for Treatment Segments.

This section deals with the safety analysis in which all types of crashes evaluated together. For the purpose of the before-after evaluation of Safety Edge in Iowa, the year of construction for each installation was excluded from the analysis. Crash data for 2004 through 2014 were analyzed for this study, and, as such, each Safety Edge installation had between 5 and 8 years of before data and between 2 and 5 years of after data, depending on the year of construction. As mentioned earlier, the injury level for each crash is reported on the KACBO injury scale which classifies injuries into one of five discrete categories (Pawlovich, 2007):

- K-Level - Fatality (results in the death of a crash-involved person)
- A-Level– Major injury or incapacitating injury (any injury, other than a fatal injury, that prevents an injured crash-involved person from walking, driving, or normally continuing the activities the person was capable of performing before the injury occurred.)
- B-Level – Minor injury or non-incapacitating injury (any injury not incapacitating but evident to observers at the scene of the crash in which the injury occurred.)

- C-Level – Possible or unknown injury (any injury reported or claimed that is not a fatal injury, incapacitating injury or non-incapacitating injury.)

- O-Level – Property damage only (commonly signified as o) or no Injury (crash-involved person reported as not receiving bodily harm from the motor vehicle crash; also known as property damage only (PDO) crash).

### *4.1.1 Comparison of All types of Crashes before and After by Crash Severity and Crash Type*

This section accounts for all types of crashes taken together regardless if it was a crash related to unsafe pavement edge. In order to examine the effects of Safety Edge being installed on all types of crashes, the frequency and severity of the crashes occurring annually in the before and after periods for each installation was determined. The average annual crashes in the before and after periods by crash severity and installation period were calculated for each of the treatment segments. It should be noted that these summary of crashes do not consider changes in traffic volume or other geometric features such as median width or horizontal curvature. Nonetheless, some clear trends that was observed are as follows:

- Figure 4.1 1 depicts the scenario of average annual all types of crashes in the before and after periods for all the treatment segments taken together. It can be observed that the average annual all types of crashes went down for all crash severities. The percentages of these reduction is depicted by Figure 4.1 2. The percentage of reduction was highest (about 50%) for fatal (K) crashes followed by incapacitating injury (A) (about 22%) and property damage only (PDO) Crashes (about 19%).
- Figure 4.1 3 , Figure 4.1 4, Figure 4.1 5, Figure 4.1 6 and Figure 4.1 7 Figure 4.1 3were made to visualize the observed trends in annual average combination of crashes of

different severity levels for each of the treatment segments for the before and after periods. The segment identities for each of the treatment segments appeared at the x-axis and the average annual crashes appeared at the y-axis. It can be seen from these figures that average annual KABCO, PDO, K, KABC, ABC crashes in the after periods are less than that of the before periods for majority of the treatment segments.

- No specific difference in patterns were observed between the scenarios of total crashes (KABCO) and all types of injury (KABC) crashes and All types of injuries except fatalities (ABC) crashes. Only, it can be observed from Figure 4.1 5 that average annual fatal (K) crashes in the after periods are significantly less than that of the before periods for majority of the treatment segments. In most of the treatment segments there were no fatal crashes in the after period compared to non-zero values in before period. Similarly for PDO crashes, it can be seen from Figure 4.1 4 that there are segments where no PDO crashes occurred in the after period.

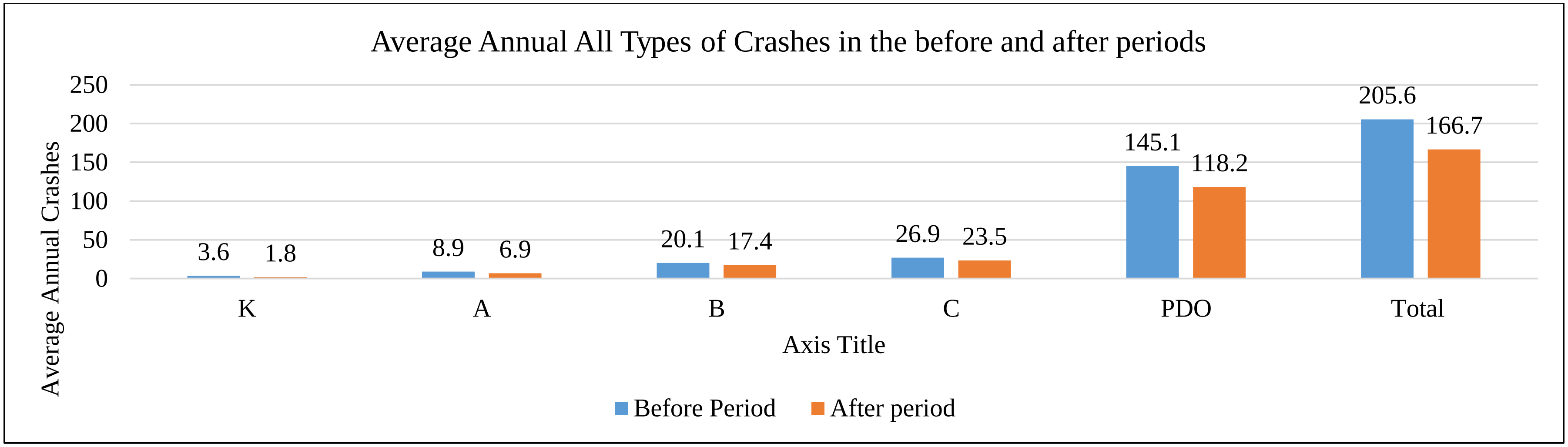


Figure 4.1 1 Average Annual All Types Of Crashes in the Before and After Periods

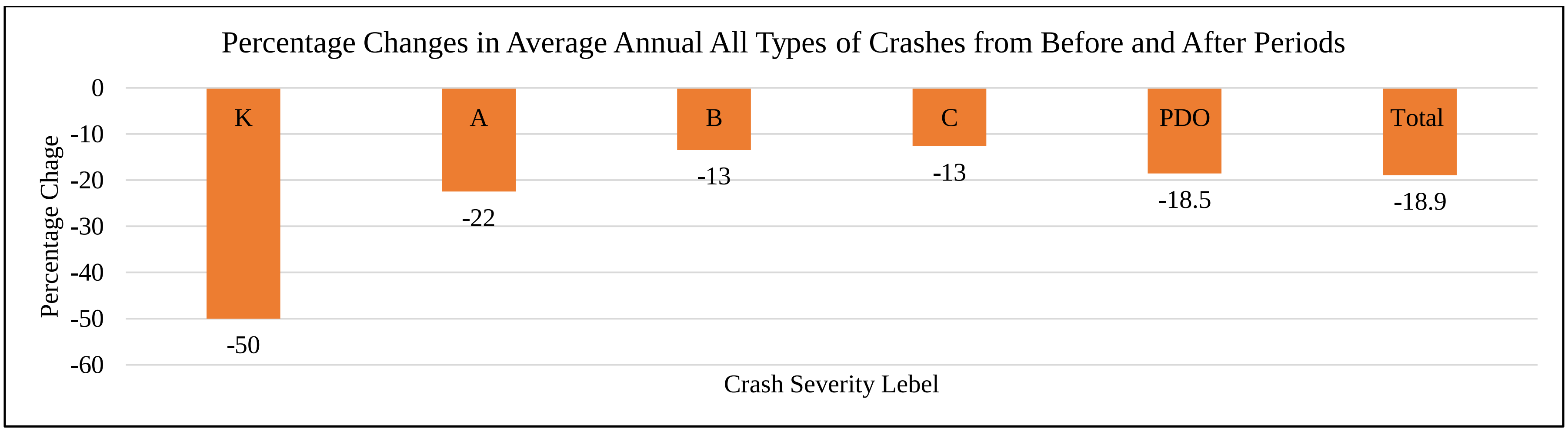


Figure 4.1 2 Percentage Changes in Average Annual All Types of Crashes from Before and After Periods

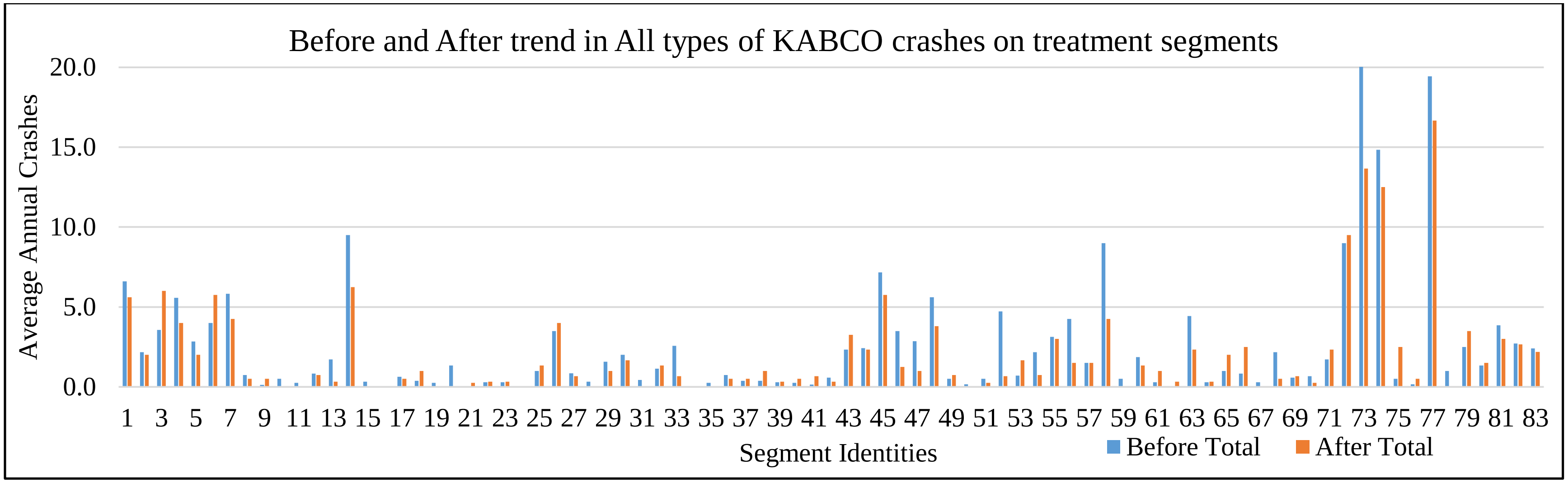


Figure 4.1 3 Before and After Trend in KABCO Crashes on Treatment Segments

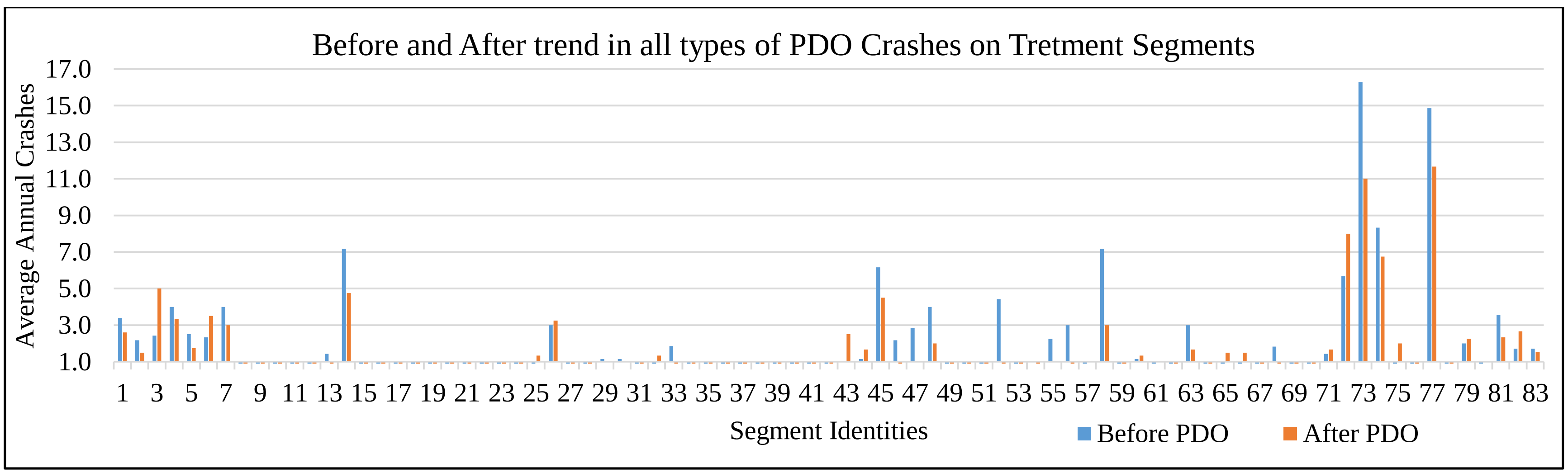


Figure 4.1 4 Before and After Trend in PDO Crashes on Treatment Segments

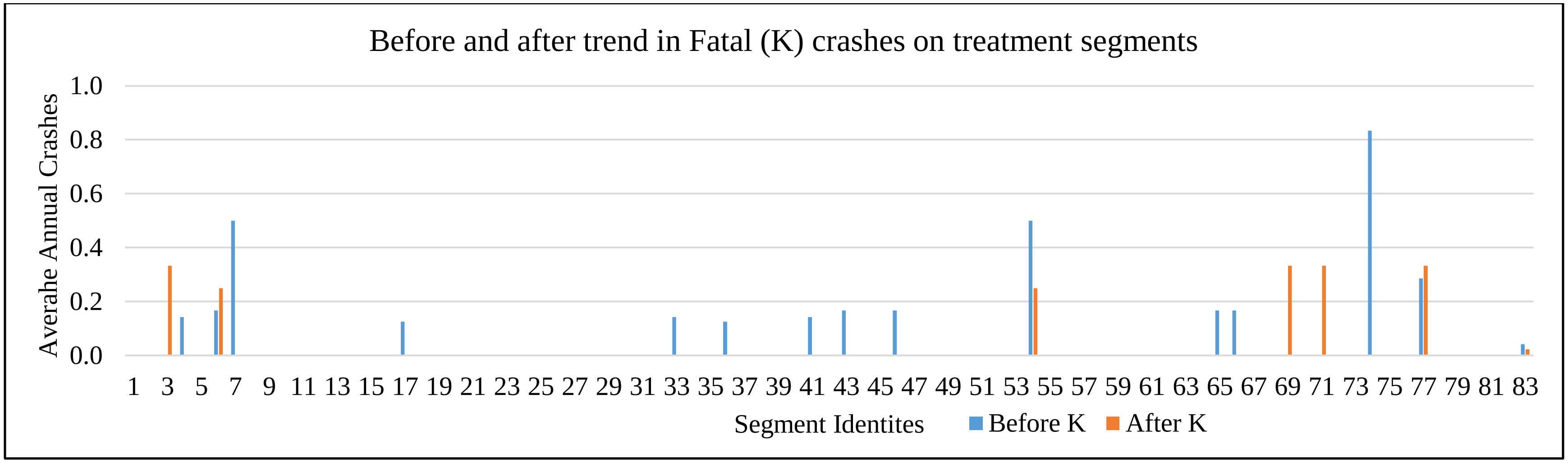


Figure 4.1 5 Before and After Trend in Fatal Crashes on Treatment Segments

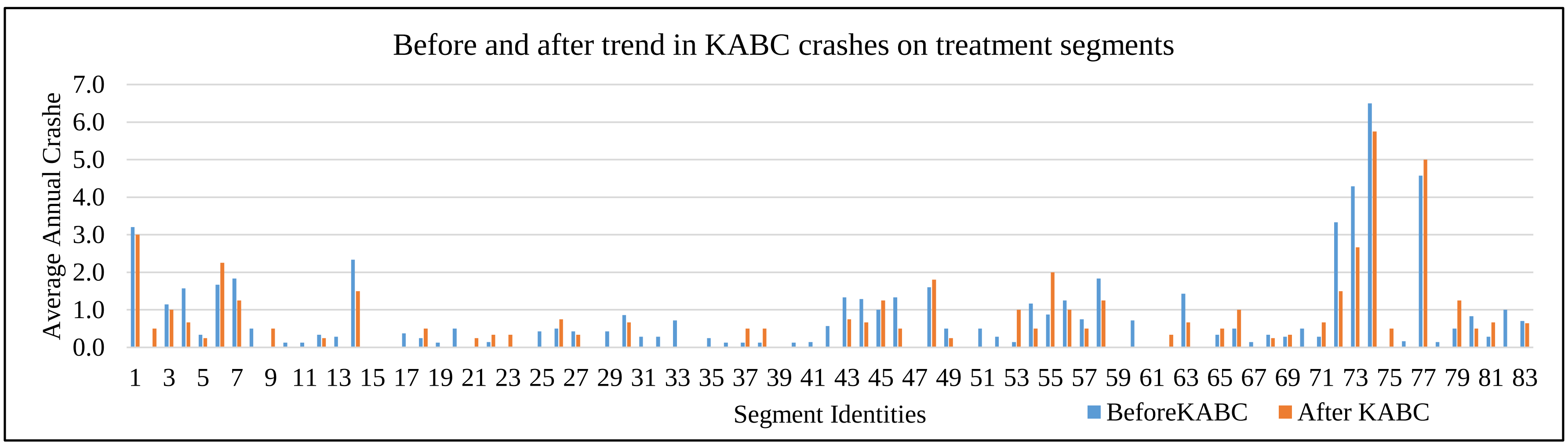


Figure 4.1 6 Before and After Trend in KABC Crashes on Treatment Segments

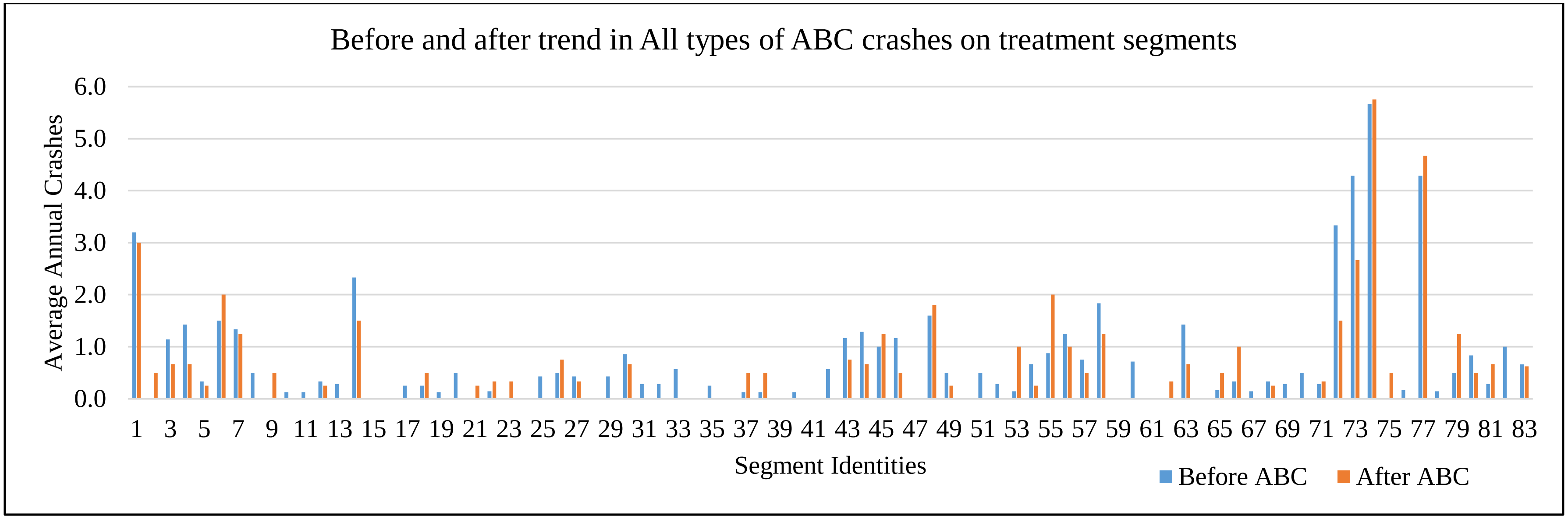


Figure 4.1 7 Before and After Trend in ABC Crashes on Treatment Segments

### *4.1.2 Comparison of Crashes/ Length for All Types of Crashes*

In order to gauge the severity of crashes in the KABCO scale by rural or urban areas, two-lane or multilane roadways and paved and unpaved shoulders for the before and after periods leaving out the year of construction, crashes per unit length for each of the following categories were calculated, rural two-lane paved shoulder, rural two-lane unpaved shoulder, rural multi-lane paved shoulder, rural multi-lane unpaved shoulder, urban two-lane paved shoulder, urban two-lane unpaved shoulder, urban multi-lane paved shoulder, urban multi-lane unpaved shoulder. Table 4. 1 All Types of Crashes/Length during Before Study Period by Rural or Urban Areas, Two-Lane or Multilane Roadways and Paved and Unpaved Shoulders for different severity levels for treatment segments. Table 4. 2 All Types of Crashes/Length during the After Study Period by Rural or Urban Areas, Two-Lane or Multilane Roadways and Paved and Unpaved Shoulders for different severity levels for treatment segments. A few trends that was observed from these tables are illustrated in Figure 4.1 8, Figure 4.1 10 and Figure 4.1 11. Figure 4.1 8 shows total (all KABCO crashes taken together) before and after crashes per unit length by rural or urban area, two-lane or multilane roadways and paved and unpaved shoulders. It was observed that the KABCO crashes for rural multi-lane unpaved shoulder roadways had dropped from 19.2 in the before period to 3.8 in the after period, a percentage reduction of 80.2%. Again from the same graph, for urban multi-lane paved shoulders the decrease was 100 percent from the before to the after period. There were considerable percentage reductions for all the other categories as well. For rural two-lane paved shoulder the percentages reduction was seen to be 54%, the same for rural two-lane unpaved shoulder was 63%, for rural multi-lane paved shoulder it was again 54%, for urban two-lane paved shoulder it was 55%, for urban two-lane unpaved shoulder it was again a 100 % reduction. Figure 4.1 10 shows all PDO before and after crashes per unit length by rural or urban areas, two-lane or multilane roadways and paved and unpaved shoulders. It was observed that the PDO crashes for rural multi-lane unpaved shoulder roadways had dropped from 11.5 in the before period to 3.8 in the after period, a percentage reduction of 67%. Again from the same graph, for urban multi-lane paved shoulders the decrease was again 100 percent from the before to the after period. There were considerable percentage reductions for all the other categories as well. For rural two-lane paved shoulder the percentages reduction was seen to be 57%, the same for rural two-lane unpaved shoulder was 56%, for rural multi-lane paved shoulder it was again 53%, for urban two-lane paved shoulder it was 53%, for urban two-lane unpaved shoulder it was again a 100 % reduction. Figure 4.1 9 Percentage Changes in All Types of KABCO Crashes Per Mile by Area and Roadway Type from before and after periods. It can be seen from the figure that there are reduction of crashes in all cases. The reduction is higher for urban roadways than rural.

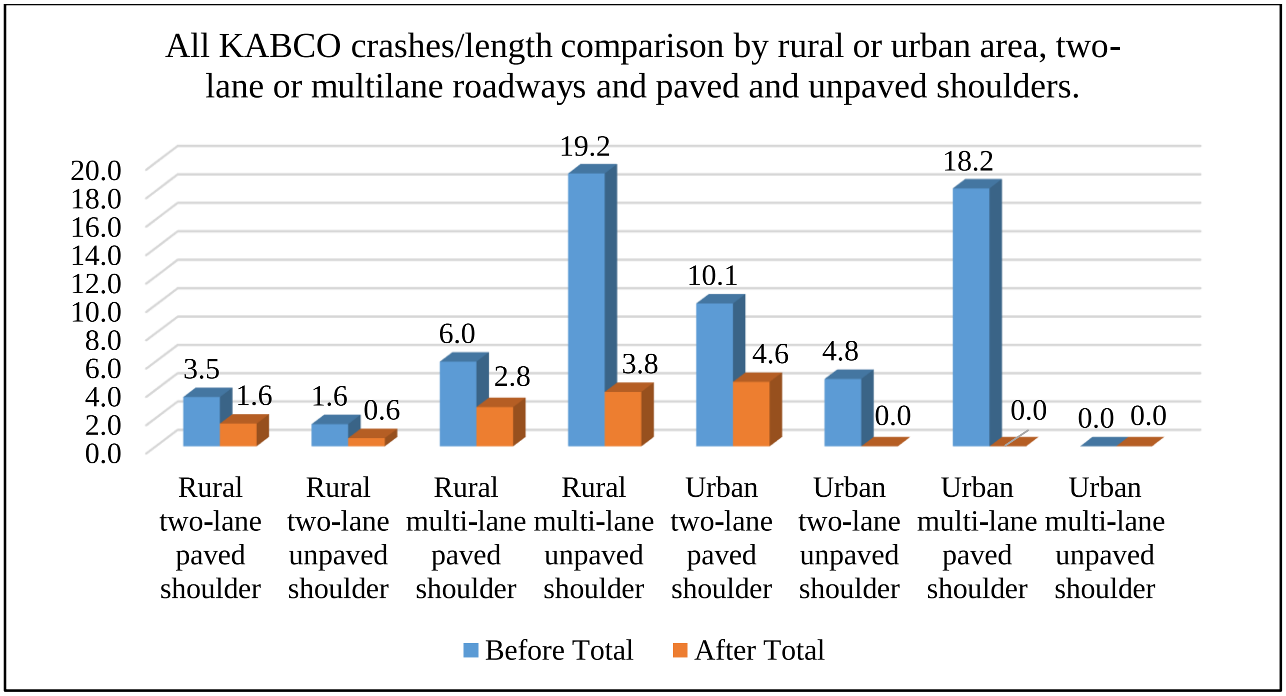


Figure 4.1 8 Total KABCO Crashes/ Length by Rural or Urban Area, Two-Lane or Multilane Roadways and Paved and Unpaved Shoulders

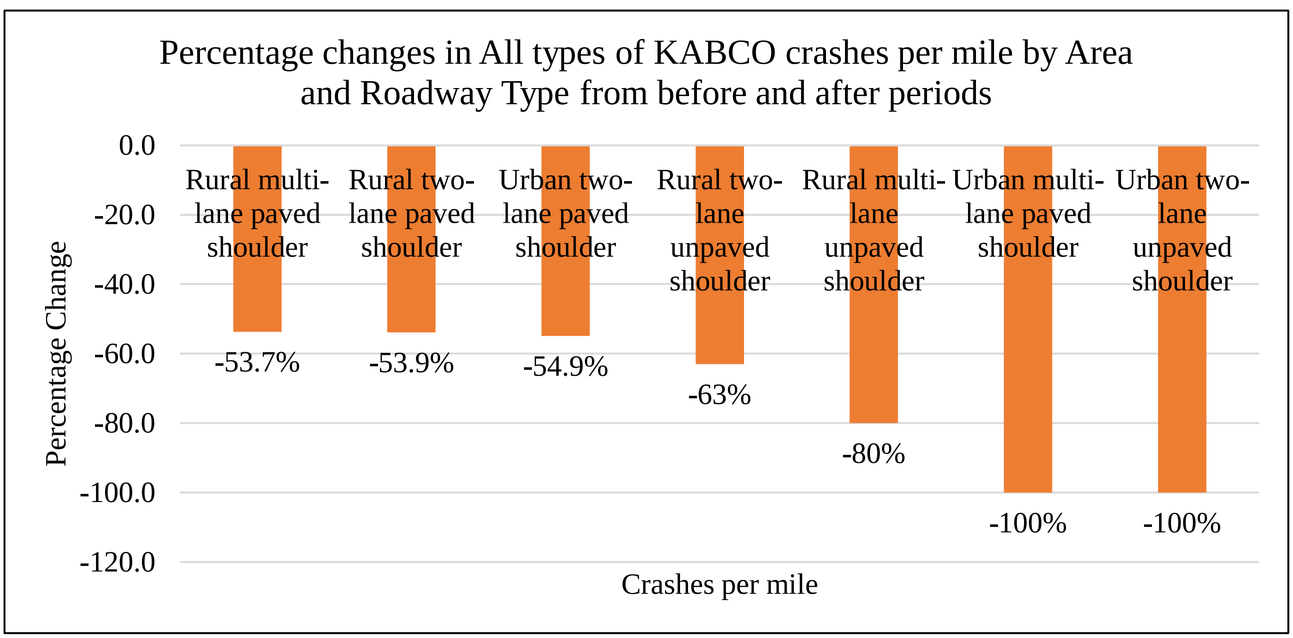


Figure 4.1 9 Percentage Changes in All Types of KABCO Crashes Per Mile by Area and Roadway Type

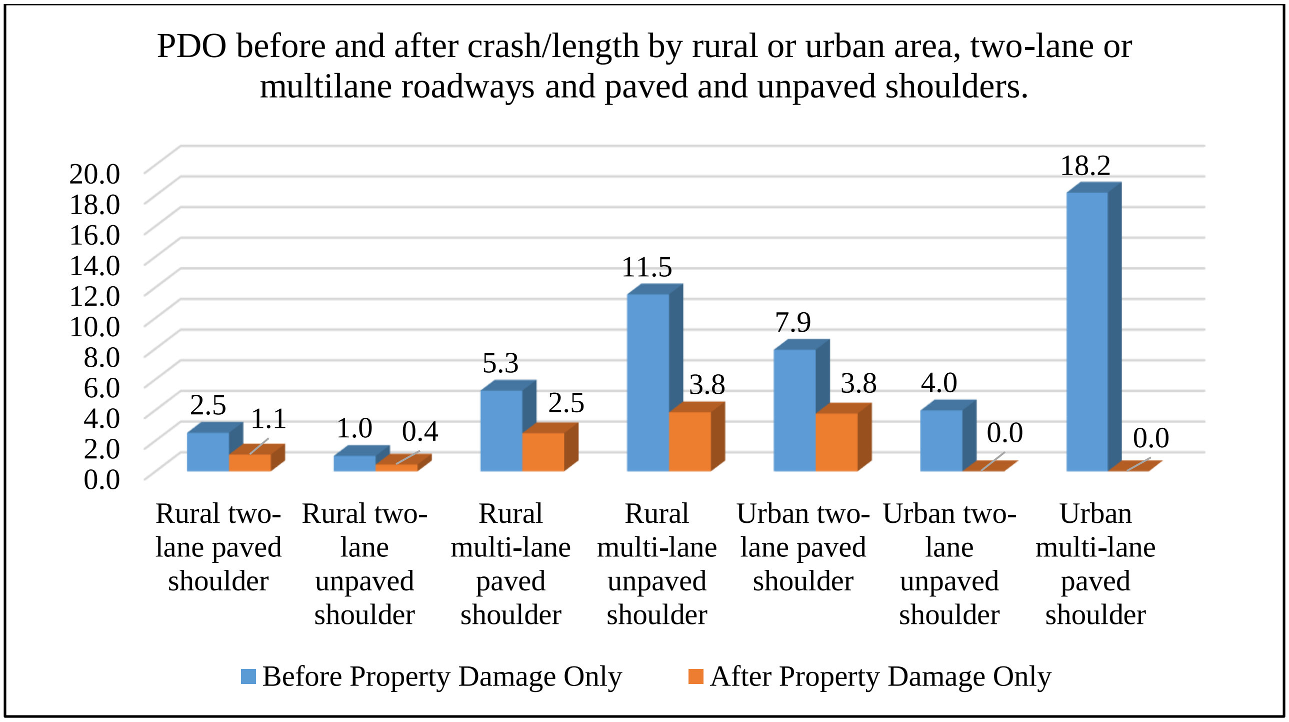


Figure 4.1 10 PDO Before and After Crash/Length by Rural or Urban Area, Two-Lane or Multilane Roadways and Paved and Unpaved Shoulders.

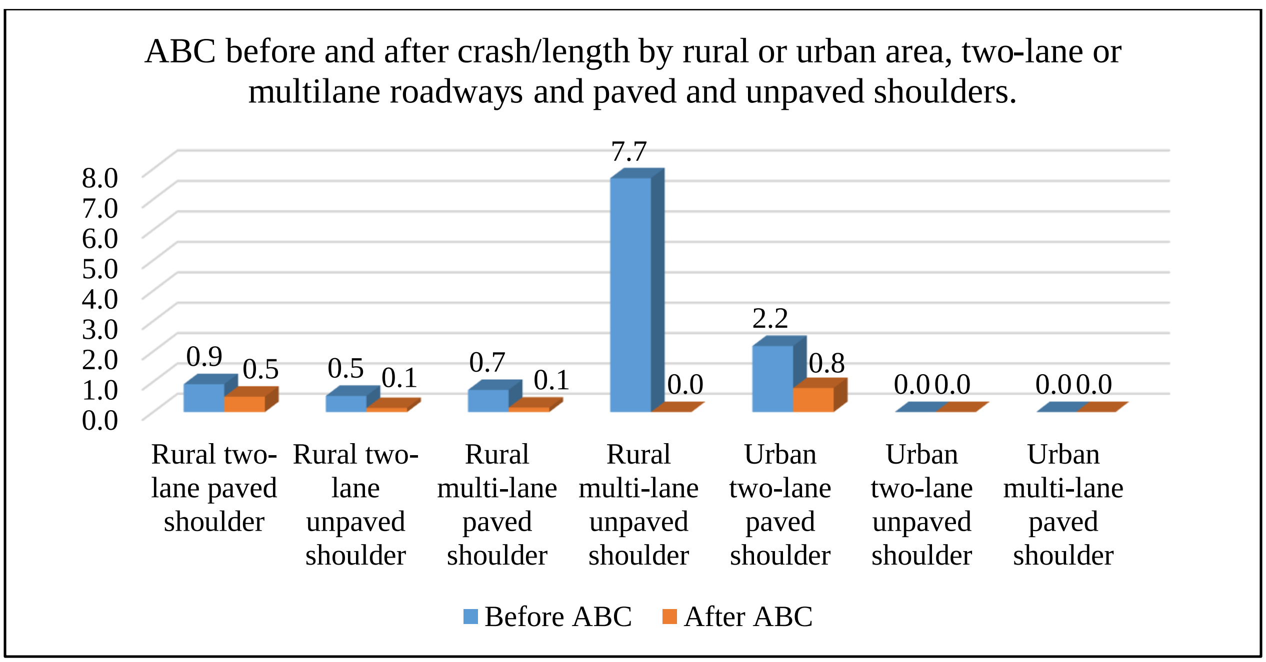


Figure 4.1 11 ABC Before and After Crash/Length by Rural or Urban Area, Two-Lane or Multilane Roadways and Paved and Unpaved Shoulders.

Figure 4.1 11 shows all types of injury crashes (ABC crashes) per unit length for the before and after periods by rural or urban areas, two-lane or multilane roadways and paved and unpaved shoulders. It was observed that the ABC crashes for rural multi-lane unpaved shoulder roadways had dropped from 7.7 in the before period to zero in the after period, that is a percentage reduction of 100%. There were considerable percentage reductions for all the other categories as well. For rural two-lane paved shoulder the percentages of reduction in crashes, about 45% which was seen to be less compared to the previous cases. Reduction in crashes for the rural two-lane unpaved shoulder was 75% which in turn was high compared to that for all types of PDO crashes, similarly, rural multi-lane paved shoulder showed a reduction of 80% which was higher compared to the previous cases, again same was in the case for urban two-lane paved shoulder as it was 64% compared to 55% and 53% for the previous cases.

Table 4. 1 All Types of Crashes/Length during Before Study Period by Rural or Urban Areas, Two-Lane or Multilane Roadways and Paved and Unpaved Shoulders

| | | | | | All types of Crashes/length during before study period | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Length | Percentage | Fatal Injury | Disabling Injury | Visible Injury | Possible Injury | Property Damage Only | Total |
| Rural | Two-Lane | Paved Shoulder | 266.42 | 51.8 | 0.06 | 0.16 | 0.32 | 0.44 | 2.51 | 3.48 |
| | | Unpaved Shoulder | 193.15 | 42.9 | 0.04 | 0.07 | 0.20 | 0.26 | 1.00 | 1.57 |
| | Multilane | Paved Shoulder | 6.85 | 3 | 0.00 | 0.44 | 0.15 | 0.15 | 5.26 | 5.99 |
| | | Unpaved Shoulder | 0.26 | 0.4 | 0.00 | 0.00 | 3.85 | 3.85 | 11.54 | 19.23 |
| Urban | Two-Lane | Paved Shoulder | 5.05 | 0.8 | 0.00 | 0.40 | 0.79 | 0.99 | 7.92 | 10.10 |
| | | Unpaved Shoulder | 1.26 | 0.8 | 0.79 | 0.00 | 0.00 | 0.00 | 3.97 | 4.76 |
| | Multilane | Paved Shoulder | 0.11 | 0.3 | 0.00 | 0.00 | 0.00 | 0.00 | 18.18 | 18.18 |
| | | Unpaved Shoulder | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | | | 473.1 | | 0.89 | 1.06 | 5.31 | 5.68 | 50.37 | 63.31 |

Table 4. 2 All Types of Crashes/Length during the After Study Period by Rural or Urban Areas, Two-Lane or Multilane Roadways and Paved and Unpaved Shoulders

| | | | | | All types of crashes/length during the after study period | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Length | Percentage | Fatal Injury | Disabling Injury | Visible Injury | Possible Injury | Property Damage Only | Total |
| Rural | Two-Lane | Paved Shoulder | 266.42 | 56.3 | 0.01 | 0.07 | 0.20 | 0.24 | 1.09 | 1.61 |
| | | Unpaved Shoulder | 193.15 | 40.8 | 0.01 | 0.03 | 0.04 | 0.07 | 0.43 | 0.58 |
| | Multilane | Paved Shoulder | 6.85 | 1.4 | 0.15 | 0.00 | 0.00 | 0.15 | 2.48 | 2.77 |
| | | Unpaved Shoulder | 0.26 | 0.1 | 0.00 | 0.00 | 0.00 | 0.00 | 3.85 | 3.85 |
| Urban | Two-Lane | Paved Shoulder | 5.05 | 1.1 | 0.00 | 0.00 | 0.20 | 0.59 | 3.76 | 4.55 |
| | | Unpaved Shoulder | 1.26 | 0.3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Multilane | Paved Shoulder | 0.11 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Unpaved Shoulder | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | | | 473.1 | | 0.17 | 0.09 | 0.44 | 1.05 | 11.61 | 13.36 |

4.2 Comparison of Target Crashes for Before and After Periods on Treatment Segments.

This section focused on target crashes. As discussed previously the target crashes included the following types of crashes chosen from all the crashes:

5. Ran off road, right.
6. Ran off road, straight.
7. Ran off road, left.
8. Evasive action (swerve, panic braking, etc.)

Target crashes in the before and in the after periods on the Safety Edge segments were analyzed. For obtaining a preliminary rough idea about the overall changes in target crashes, the difference in the total target crashes on the before and on the after period for all the segments taken together were calculated. Table 4. 3 Percentage Change for Fatal, All Types of Injury and PDO Target Crashes From Before to After Period. It was observed from Table 4. 3 that percentage changes in all "K", "A", "B", "C" and "PDO" target crashes were positive indicating that the after period target crashes were less compared to that of the before period. Reduction in K crashes (87.5%) was seen to be the maximum among all other severity levels followed by "A" crashes (75%) and "B" crashes (58.97%). Reduction in total crashes was found to be 54.59%. Reduction in K crashes for all types of crashes taken together shown previously in section 4.1 was around 73.9%, thus it can be seen that when target crashes were analyzed this reduction went up to 87.5%. This was a positive sign as target crashes are more representative of pavement edge drop-off related crashes, having a higher reduction percentage meant drop-off related crashes were reduced to higher extents after the installation of Safety Edge. Percentage changes for the combinations of the crash severity levels from before to after periods were also examined for the target crashes. Table 4. 4 shows these percentage changes for "K", "ABC", "KABC", "PDO" and "KABCO" crashes from the before to after period. All types of Injury Crashes (target) that is "ABC" target crashes showed a 60.99% reduction in the after period and the fatal and all injury crashes together, that is "KABC" target crashes showed a reduction of 61.90% in the after period. Both of the "ABC" and "KABC" target crashes percentages were higher than that for all types of crashes, implying that the drop-off related crashes were reduced to a higher extent after the installation of Safety Edge.

Table 4. 3 Percentage Change for Fatal, All Types of Injury and PDO Target Crashes From Before to After Period

| | Before | After | Percentage Change |
|---|---|---|---|
| Fatal Injury Crashes (K) | 8 | 1 | -87.50% |
| Disabling Injury Crashes (A) | 44 | 11 | -75.00% |
| Visible Injury Crashes (B) | 78 | 32 | -58.97% |
| Possible Injury Crashes (C) | 101 | 44 | -56.44% |
| Property Damage Only Crashes (PDO) | 194 | 105 | -45.88% |
| Total Crashes (KABCO) | 425 | 193 | -54.59% |

Table 4. 4 Percentage Change for Combinations of the Crash Severity Levels From Before To After Period

| | Before | After | Percentage Change |
|---|---|---|---|
| Fatal Injury Crashes (K) | 8 | 1 | -87.50% |
| All types of Injury Crashes (ABC) | 223 | 87 | -60.99% |
| Fatal and Injury Crashes (KABC) | 231 | 88 | -61.90% |
| Property Damage Only Crashes (PDO) | 194 | 105 | -45.88% |
| Total Crashes (KABCO) | 425 | 193 | -54.59% |

*4.2.1 Comparison of All types of Target Crashes Before and After by Crash Severity and Type*

The percentages of target crashes for each severity level were also calculated for all treatment segments combined for before and after periods. Figure 4.2 1 depicts these percentages of target crashes by crash severity and analysis period. Percentages of “K”, “A”, “B” and “C” target crashes in the after period were less compared to the corresponding percentages of these severity levels for before period of installation of Safety Edge which can be observed from the Figure 4.2 1. It was also observed that the percentages of “PDO” target crashes were higher in the after period compared to that of the before period. After examining target crashes in an aggregate level on all treatment segments taken together, average annual target crashes for the before and after periods for each of the treatment segments were also examined. The average annual target crashes in the before and after periods by crash severity and installation period were calculated. It should also be noted that these summary of crashes do not consider changes in traffic volume or other geometric features such as median width or horizontal curvature.

- Figure 4.2.3 depicts the scenario of average annual all types of crashes in the before and after periods for all the treatment segments taken together. It can be observed that the average annual all types of crashes went down for all crash severities except for PDO crashes. The percentages of these reduction is depicted by Figure 4.2.2. The percentage of reduction was highest (about 75%) for fatal (K) crashes followed by incapacitating injury (A) (about 44%). The percentage increase in property damage only (PDO) Crashes was about 1%.
- Some clear trends that was observed for target crashes for treatment segments are shown in Figure 4.2 4, Figure 4.2 5, Figure 4.2 6, Figure 4.2 7, and Figure 4.2 8. It was observed from the above mentioned tables that average annual “KABCO”, “KABC” , “ABC”,

"PDO" and "K" target crashes in the after periods were less than that of the before periods for majority of the treatment segments.

- Similar to the results for all types of crashes, that indicated average annual fatal (K) crashes in the after periods were significantly less than that of the before periods for almost all of the treatment segments (except for segments ID 77) of the treatment segments, the results from Figure 4.2 6 indicated that in most of the treatment segments, there were no fatal crashes in the after period compared to non-zero values in before period. The above mentioned observation was more pronounced for the target crashes.

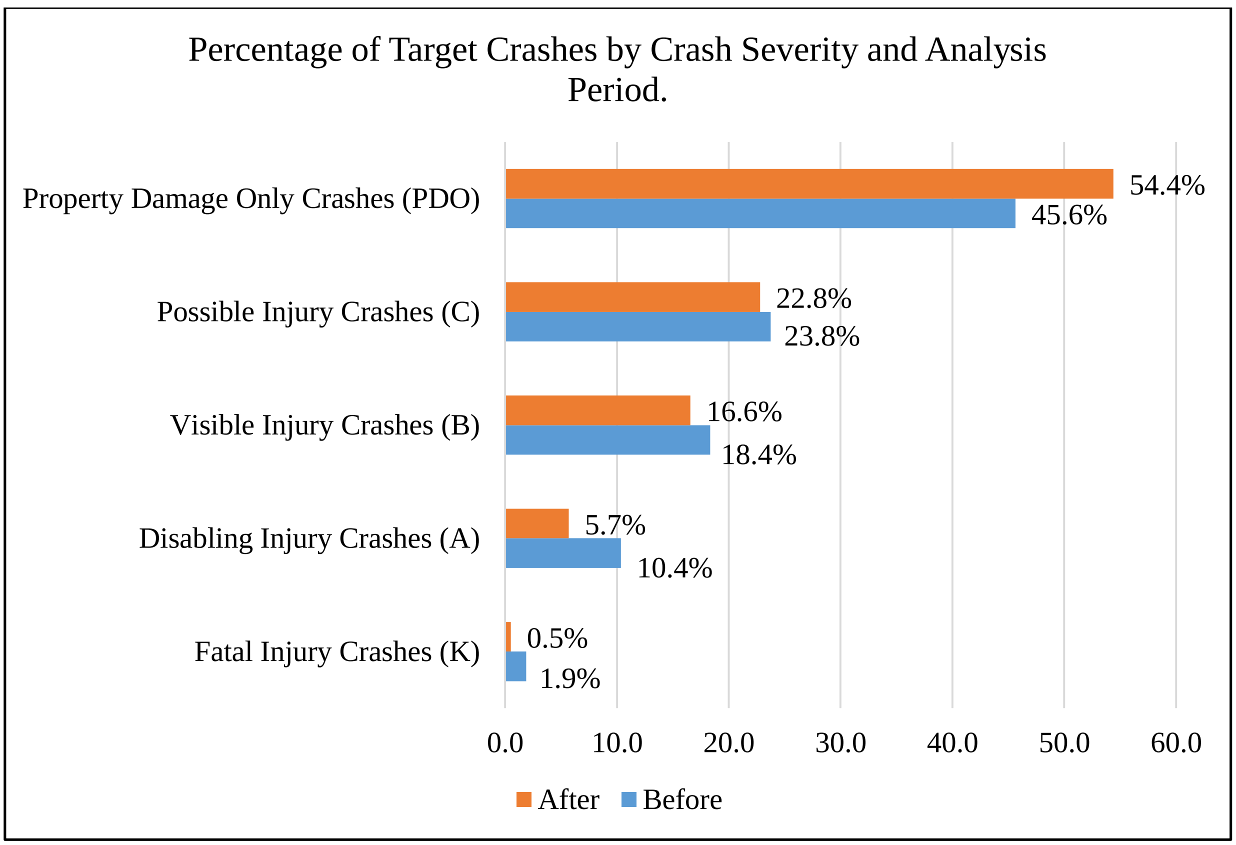


Figure 4.2 1 Percentage of Target Crashes By Crash Severity and Analysis Period.

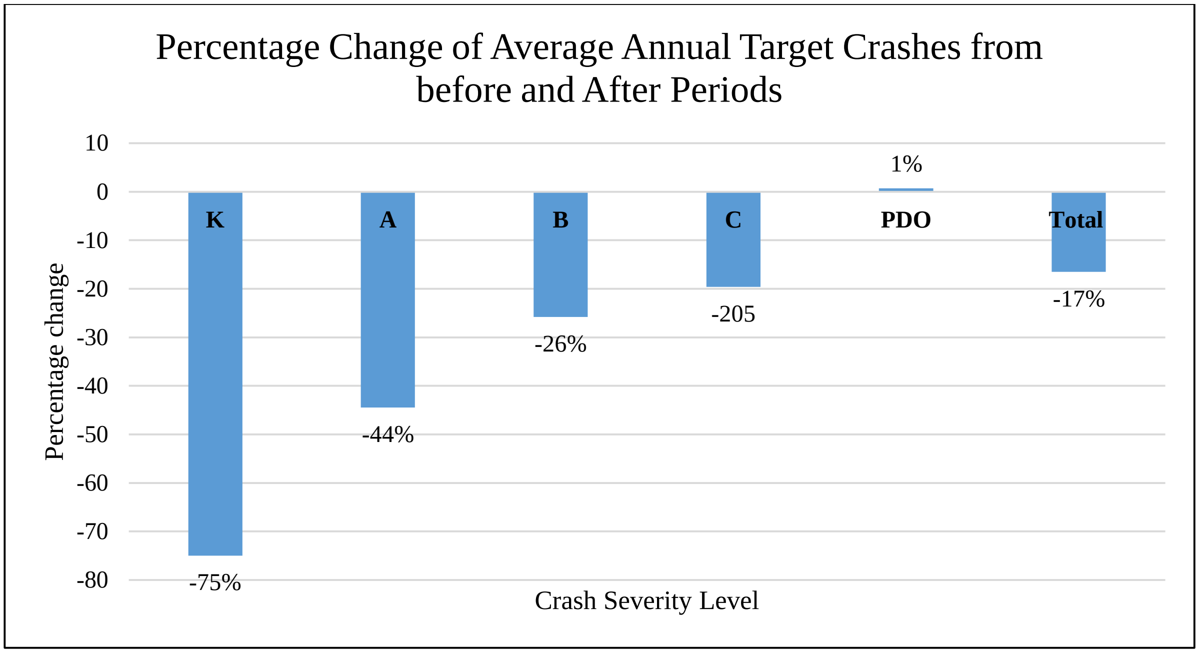


Figure 4.2 2 Percentage Change of Average Annual Target Crashes from Before and After Periods

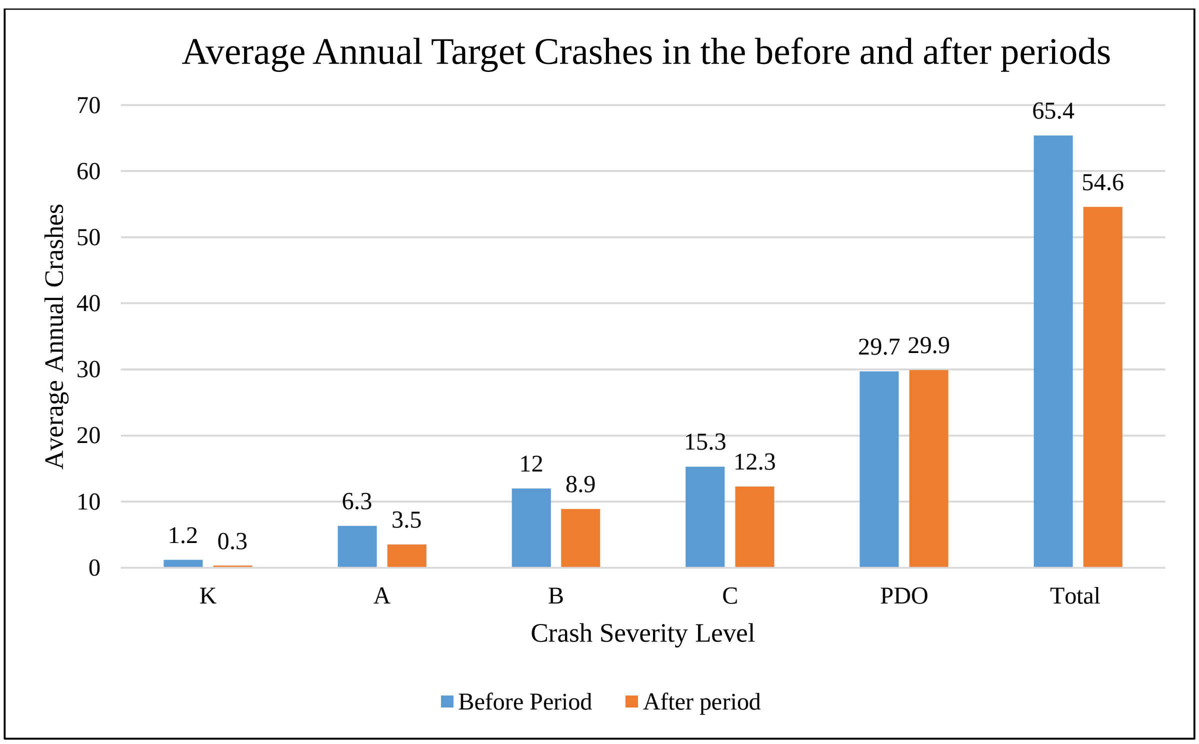


Figure 4.2 3 Average Annual Target Crashes in the Before and After Periods

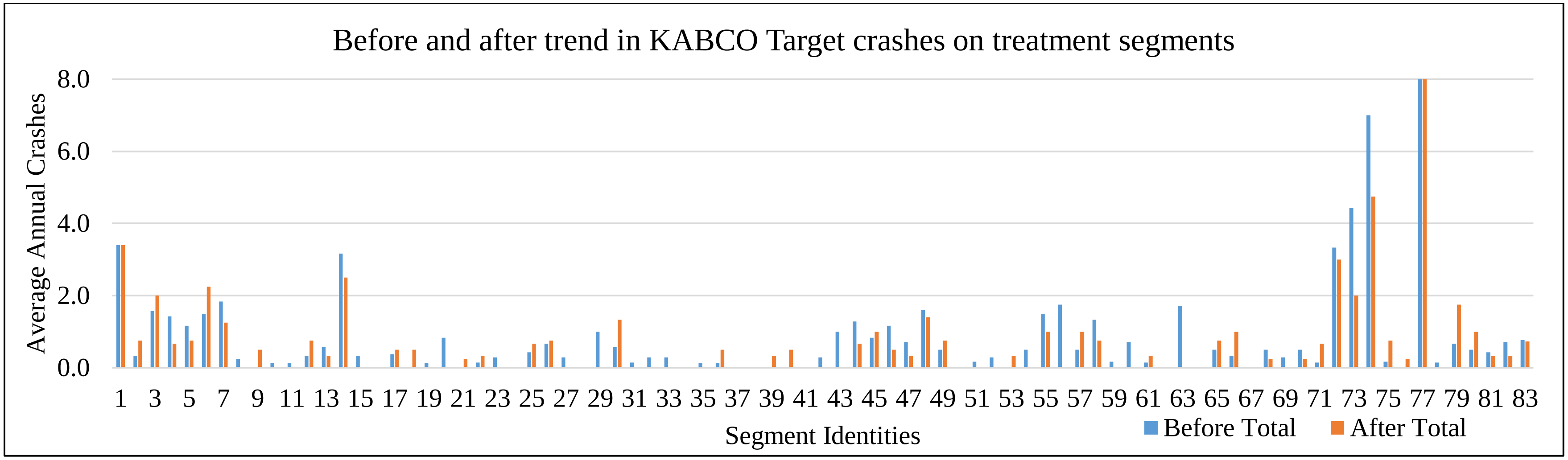


Figure 4.2 4 Before and After Trend in KABCO Crashes on Treatment Segments

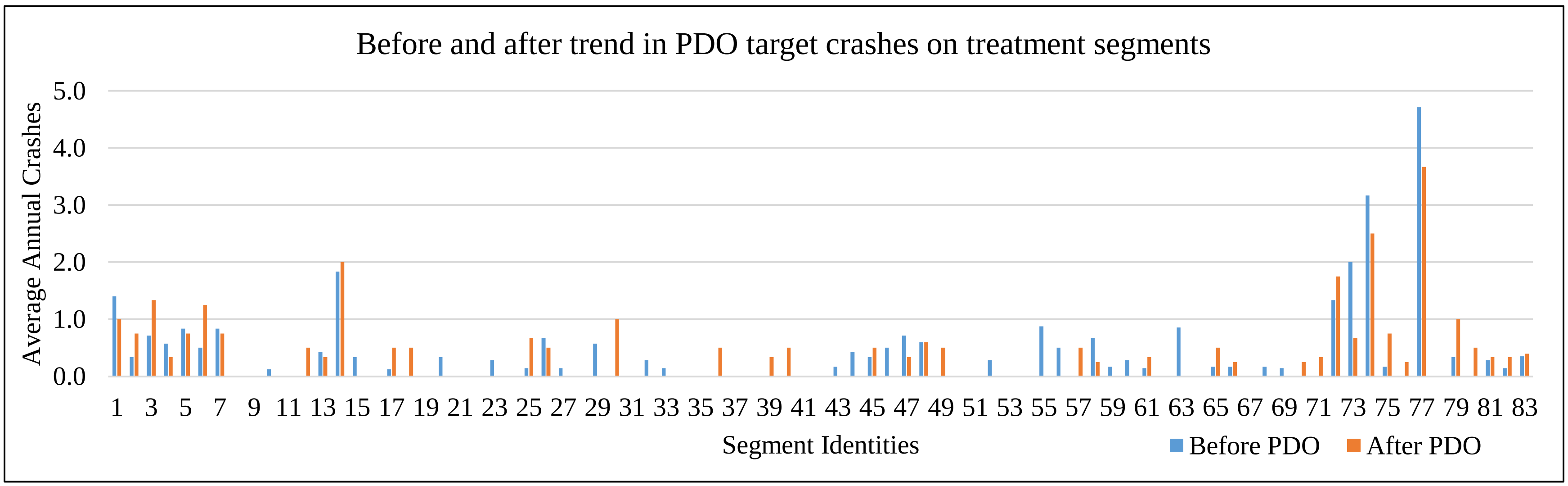


Figure 4.2 5 Before and After Trend in PDO Crashes on Treatment Segments

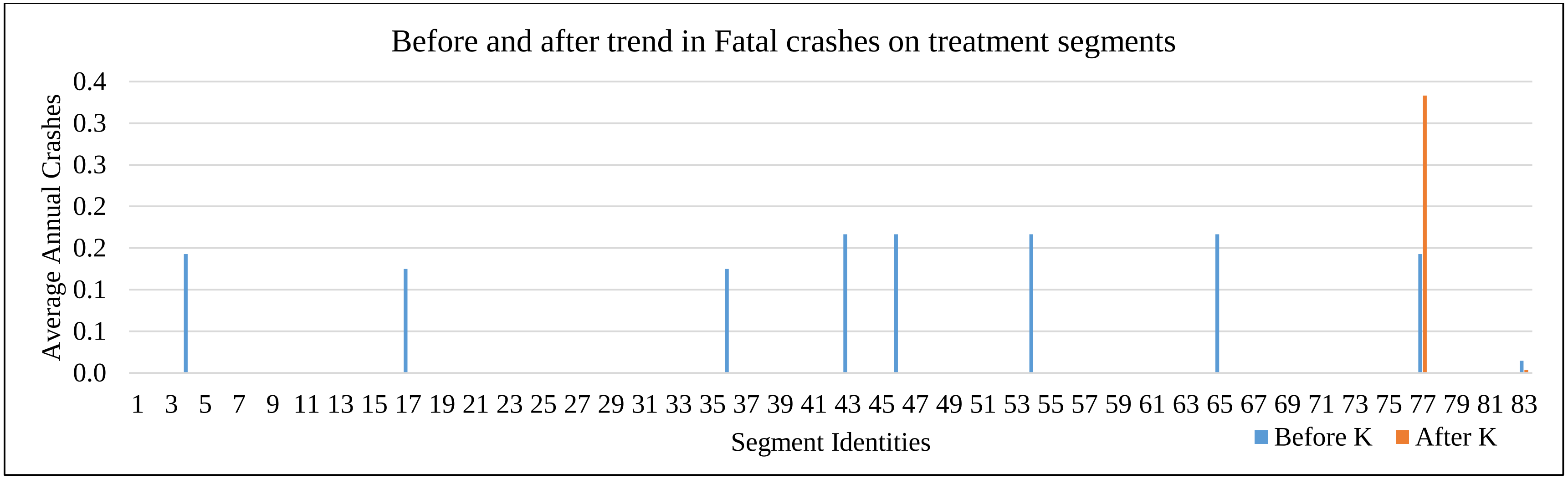


Figure 4.2 6 Before and After Trend in Fatal Crashes on Treatment Segments

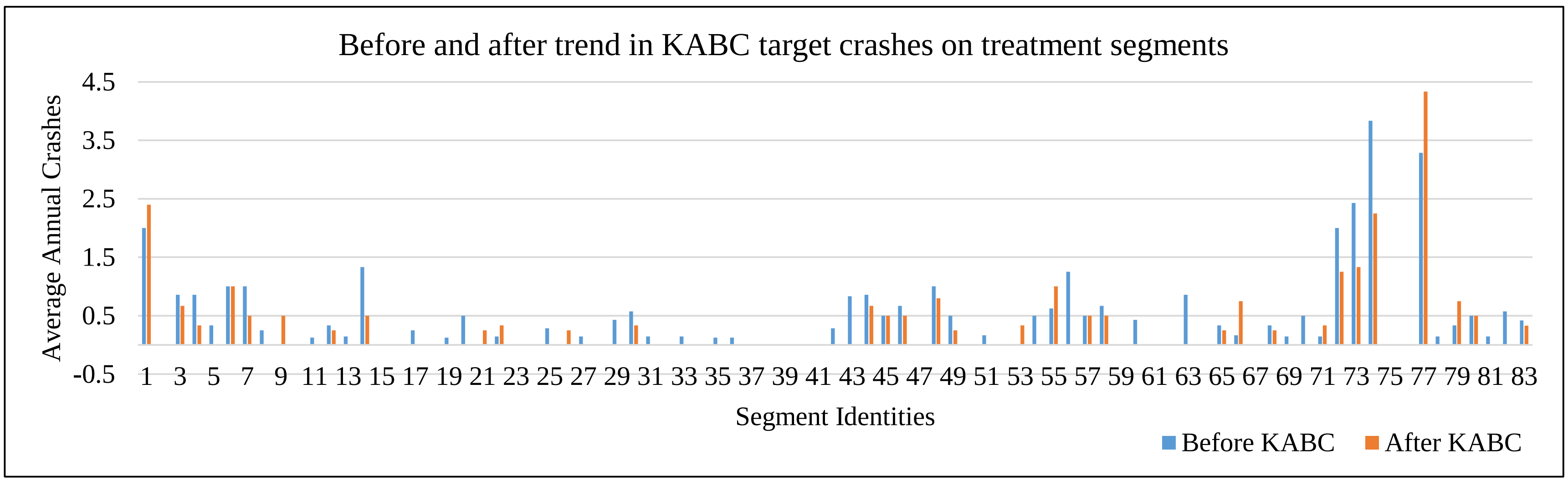


Figure 4.2 7 Before and After Trend in KABC Crashes on Treatment Segments

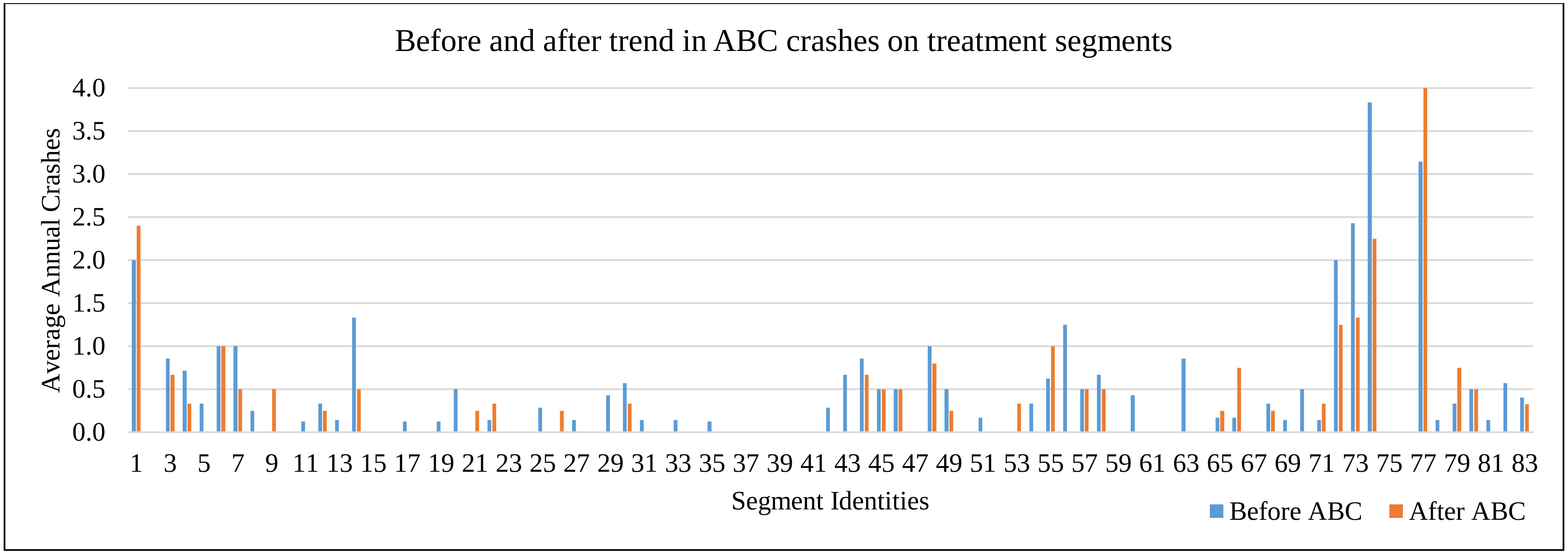


Figure 4.2 8 Before and After Trend in ABC Crashes on Treatment Segments

*4.2.3 Comparison of Crashes/ length for Target Crashes*

In order to observe the severity of target crashes in the KABCO scale by rural or urban areas, two-lane or multilane roadways and paved and unpaved shoulders for the before and after periods leaving out the year of construction, target crashes per unit length for each of the following categories were calculated. This included rural two-lane paved shoulder, rural two-lane unpaved shoulder, rural multi-lane paved shoulder, rural multi-lane unpaved shoulder, urban two-lane paved shoulder, urban two-lane unpaved shoulder, urban multi-lane paved shoulder, and urban multi-lane unpaved shoulder. Table 4. 5 and Table 4. 6 shows these target crashes per unit length for the before and after periods respectively for each of the above mentioned categories respectively. A few trends that were observed from Table 4. 5 and Table 4. 6 is illustrated in Figure 4.2 9, Figure 4.2 10, Figure 4.2 11. Figure 4.2 9 shows total target (all KABCO target crashes taken together) before and after crashes per unit length by rural or urban area, two-lane or multilane roadways and paved and unpaved shoulders. It was observed that the KABCO target crashes for rural multi-lane unpaved shoulder roadways and for urban two-lane unpaved shoulder had a percentage reduction of 100 percent from before to after crashes. There were considerable percentage reductions for all the other categories as well. For rural two-lane paved shoulder the percentages reduction was seen to be 52%, the same for rural two-lane unpaved shoulder was 62%, for rural multi-lane paved shoulder it went down to 33% from 54% when compared to that for all types of KABCO crashes. For urban two-lane paved shoulder it was 65% (went up by 10 percentage points from that of all types of KABCO crashes), for urban two-lane unpaved shoulder it was again a 100 % reduction same as for all types of KABCO crashes. Figure 4.2 10 shows target PDO crashes before and after crashes per unit length by rural or urban areas, two-lane or multilane roadways and paved and unpaved shoulders. It was observed that the PDO crashes for rural multi-lane paved shoulder roadways remained same in the before and in the after periods. Again from the same graph, for urban two-lane unpaved shoulders the decrease was 100 percent from the before to the after period. There were considerable percentage reductions for all the other categories as well. For rural two-lane paved shoulder the percentages reduction was seen to be 49%, the same for rural two-lane unpaved shoulder was 34% that went down from 56% for that of all types of crashes, for urban two-lane paved shoulder it was 57%.

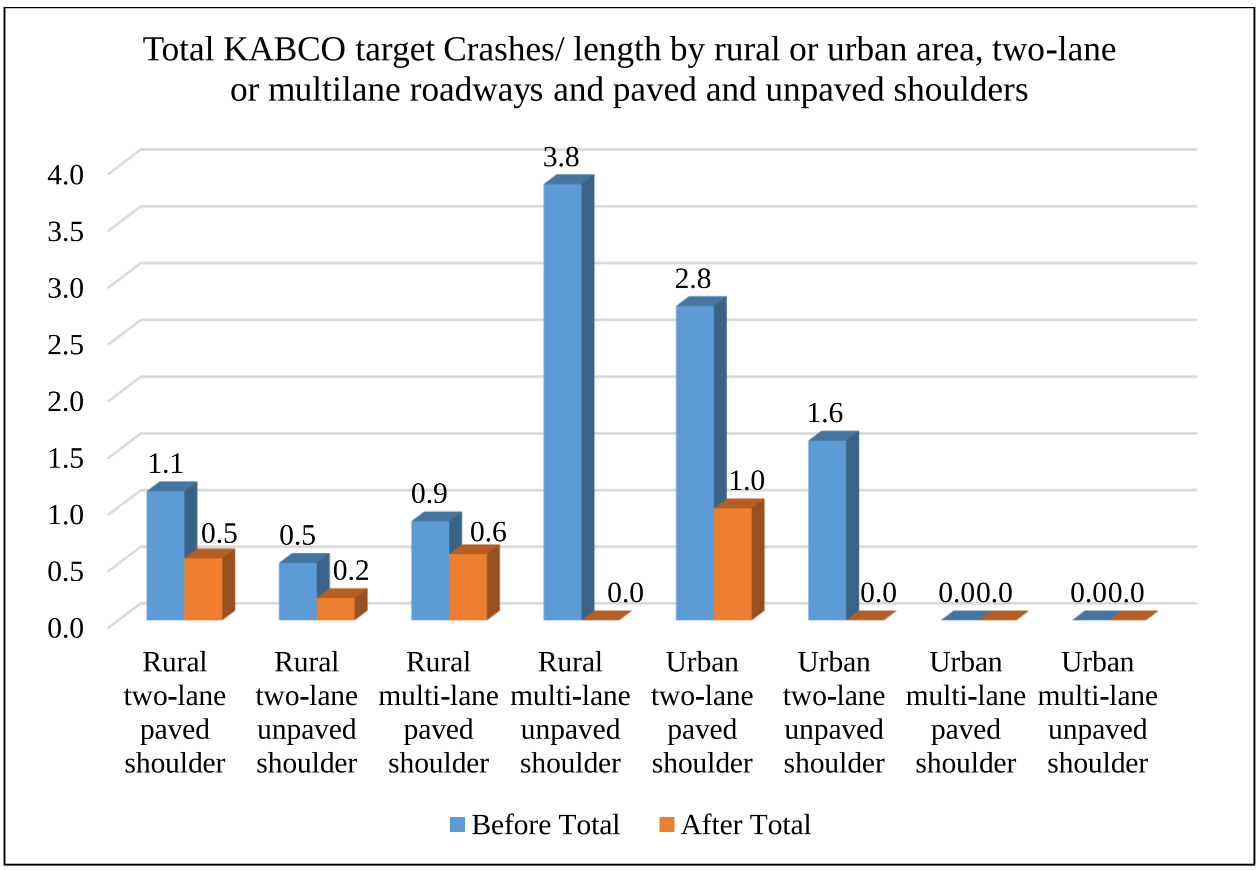


Figure 4.2 9 Total KABCO Target Crashes/ Length by Rural or Urban Area, Two-Lane or Multilane Roadways and Paved and Unpaved Shoulders

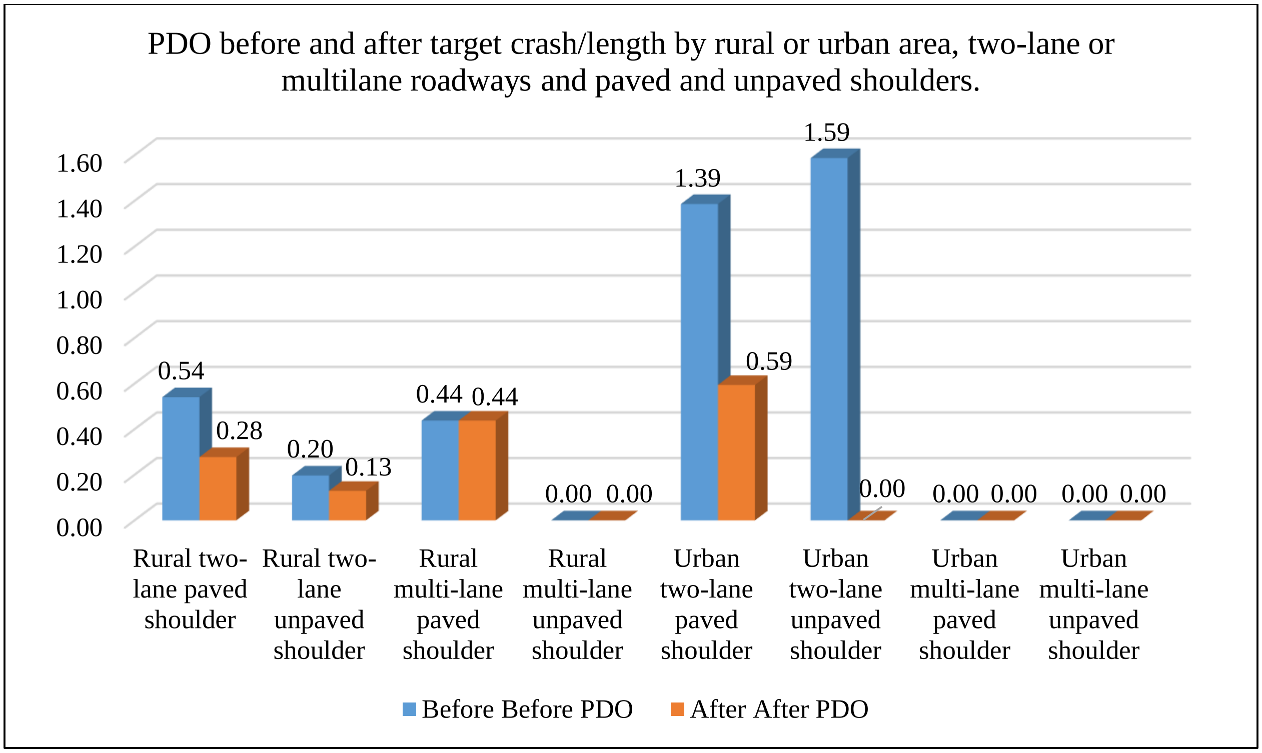


Figure 4.2 10 PDO Before and After Target Crash/Length by Rural or Urban Area, Two-Lane or Multilane Roadways and Paved and Unpaved Shoulders.

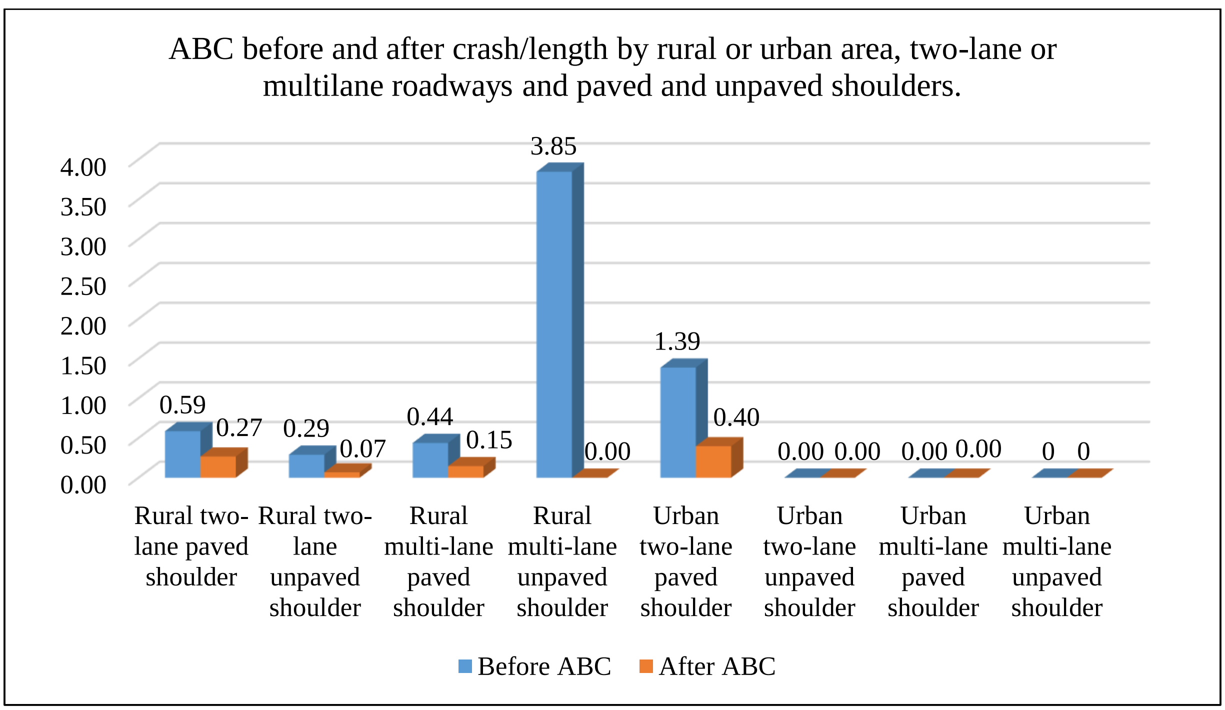


Figure 4.2 11 ABC Before and After Crash/Length by Rural or Urban Area,

Two-Lane or Multilane Roadways and Paved and Unpaved Shoulders.

Figure 4.2 11 shows target injury crashes (ABC crashes) per unit length for the before and after periods by rural or urban areas, two-lane or multilane roadways and paved and unpaved shoulders. It was observed that the ABC crashes for rural multi-lane unpaved shoulder roadways had dropped from 3.85 in the before period to zero in the after period, that is a percentage reduction of 100%. There were considerable percentage reductions for all the other categories as well. For rural two-lane paved shoulder the percentages of reduction in crashes was about 54% (10 percentage points greater than that for all types of ABC). Reduction in crashes for the rural two-lane unpaved shoulder was 77% which in turn was high compared to that for PDO target crashes, similarly, rural multi-lane paved shoulder showed a reduction of 66% which was lower compared to that for all types of ABC crashes, again for urban two-lane paved shoulder as it was 71% reduction.

Table 4. 5 Target Crashes/length during before study period by rural or urban areas, two-lane or multilane roadways and paved and unpaved shoulders

| | | | | | Target Crashes/length during before study period | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Length | Percentage | Fatal Injury | Disabling Injury | Visible Injury | Possible Injury | Property Damage Only | Total |
| Rural | Two-Lane | Paved Shoulder | 266.42 | 51.8 | 0.02 | 0.12 | 0.21 | 0.26 | 0.54 | 1.14 |
| | | Unpaved Shoulder | 193.15 | 42.9 | 0.02 | 0.05 | 0.10 | 0.14 | 0.20 | 0.51 |
| | Multi lane | Paved Shoulder | 6.85 | 3 | 0.00 | 0.29 | 0.15 | 0.00 | 0.44 | 0.88 |
| | | Unpaved Shoulder | 0.26 | 0.4 | 0.00 | 0.00 | 0.00 | 3.85 | 0.00 | 3.85 |
| Urban | Two-Lane | Paved Shoulder | 5.05 | 0.8 | 0.00 | 0.00 | 0.40 | 0.99 | 1.39 | 2.77 |
| | | Unpaved Shoulder | 1.26 | 0.8 | 0.00 | 0.00 | 0.00 | 0.00 | 1.59 | 1.59 |
| | Multi lane | Paved Shoulder | 0.11 | 0.3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Unpaved Shoulder | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | | | 473.1 | | 0.04 | 0.46 | 0.85 | 5.23 | 4.15 | 10.73 |

Table 4. 6 Crashes/length during the after study period by rural or urban areas, two-lane or multilane roadways and paved and unpaved shoulders

| | | | | | Crashes/length during the after study period | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Length | Percentage | Fatal Injury | Disabling Injury | Visible Injury | Possible Injury | Property Damage Only | Total |
| Rural | Two-Lane | Paved Shoulder | 266.42 | 56.3 | 0.00 | 0.02 | 0.11 | 0.14 | 0.28 | 0.55 |
| | | Unpaved Shoulder | 193.15 | 40.8 | 0.00 | 0.03 | 0.02 | 0.03 | 0.13 | 0.20 |
| | Multilane | Paved Shoulder | 6.85 | 1.4 | 0.00 | 0.00 | 0.00 | 0.15 | 0.44 | 0.58 |
| | | Unpaved Shoulder | 0.26 | 0.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Urban | Two-Lane | Paved Shoulder | 5.05 | 1.1 | 0.00 | 0.00 | 0.20 | 0.20 | 0.59 | 0.99 |
| | | Unpaved Shoulder | 1.26 | 0.3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Multilane | Paved Shoulder | 0.11 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Unpaved Shoulder | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | | | 473.1 | | 0.00 | 0.05 | 0.32 | 0.51 | 1.44 | 2.32 |

# CHAPTER 5

# STATISTICAL METHODS

The research also developed quantitative models to understand the road and traffic characteristics that significantly affected the total and target crashes for road segments having Safety Edge installed on them. This chapter presents the statistical methods that were used to accomplish this. In specific, count data models were used to estimate crash frequency relating to road and traffic characteristics.

## 5.1 Statistical Methods for Crash Frequency

The most common models to evaluate crash data are Poisson model and Negative binomial regression model. A Poisson distribution model was first considered for modeling the probability of crash frequency on road segments. But Poisson model requires certain conditions to be satisfied, the most important one of which is that the average of observations should be approximately equal to their variance. Since this condition was not fulfilled, and there existed some over dispersion in the data of the project, negative binomial distribution was used to represent the distribution of crash counts. Negative binomial method accounts for the over dispersion in the model by taking into consideration the unobserved heterogeneity in the model. As negative binomial distribution was used to model the crash frequency for before and after periods of installation of Safety Edge, the next section discusses the functional formulation of negative binomial regression model.

## 5.2 Negative Binomial Regression Model

The negative binomial is similar to the Poisson model in which the probability of road segment i experiencing $y_i$ number of crashes during a year is given by equation (1):

$$P(y_i) = \frac{EXP(-\lambda_i)\lambda_i^{y_i}}{y_i!}, \qquad (1)$$

where $\lambda_i$ is the Poisson parameter for road segment i, which is equal to the expected number of crashes per year in the segments, $E[y_i]$. The Poisson parameter is a function of the explanatory variables. The exploratory variables are the road, lane and traffic characteristics discussed earlier in chapter-3 that were considered for the study.

The equation for Poisson parameter is given by equation (2).

$$\lambda_i = EXP(\beta X_i), \qquad (2)$$

where $X_i$ is a vector of explanatory variables and $\beta$ is a vector of estimable parameters.

The log linear form of the above equation is given by $\ln \lambda_i = (\beta X_i)$. But the Poisson distribution restricts the mean and variance to be equal, that is the above equations are only valid when E[yi] = VAR [yi]. If this equality does not hold, the data are said to be under dispersed (E[yi] > VAR [yi]) or over dispersed (E[yi] < VAR [yi]), and the parameter vector is biased if corrective measures are not taken (Washington e al., 2003). The negative binomial parameter which addresses the over dispersion in the model is derived from the Poisson parameter which can be rewritten as shown in equation (3).

$$\lambda_i = EXP(\beta X_i + \varepsilon_i), \qquad (3)$$

where $EXP(\varepsilon_i)$ is the error term which is gamma-distributed having mean equal to 1 and a constant variance.

An additional parameter alpha (α) is introduced into the negative binomial model, such that VAR [yi] = E[yi] (1+ α E[yi]), when α= 0, the model "collapses" to the Poisson model. This constant variance term α is the over-dispersion parameter. The log linear form of the negative binomial model with the unobserved heterogeneity term $u_i$ is given by $\ln \lambda_i = \ln \lambda_i + \ln \mu_i$.

The negative binomial distribution is given by equation (4) where the probability $P(y_i)$ of $y_i$ number of crashes occurring on segment i is as follows:

$$P(y_i) = \frac{\Gamma\left(\left(\frac{1}{\alpha}\right) + y_i\right)}{\Gamma\left(\frac{1}{\alpha}\right) y_i!} \left(\frac{\frac{1}{\alpha}}{\frac{1}{\alpha} + \lambda_i}\right)^{\frac{1}{\alpha}} \left(\frac{\lambda_i}{\left(\frac{1}{\alpha}\right) + \lambda_i}\right)^{y_i}, \qquad (4)$$

where, Γ(.) is a gamma function.

The natural log of Length of Segments were given as offset in the models so that the models are standardized to a per mile analysis length. The final model form presents the expected number of crashes per segment per year as shown in equation (5).

$$\lambda_i = X_{Li} EXP(\beta_0 + \beta_1 X_1 + \beta_i X_i), \qquad (5)$$

where $\lambda_i$ is the expected number of crashes per mile per year on road segment i, $X_{Li}$ is the length of segment i in miles, $\beta_0$ is the estimated intercept term, and $\beta_i$ and $X_i$ are vectors of estimable parameters and explanatory variables, respectively.

# CHAPTER 6

# DATA CLEANING AND AGGREGATION, SUMMARY STATISTICS, DATA ANALYSIS, BEFORE AND AFTER CRASH MODEL RESULTS AND INTERPRETATION

The statistical method used for analyzing count data models like that of crash frequency was described in Chapter-6. A detailed description of the process of data cleaning and aggregation, process of analysis, summary statistics of the datasets and the negative binomial model results and its interpretation are contained in this chapter. The chapter describes the underlying factors that influences crash frequency on road segments provided with Safety Edge from model results. Separate models were developed for all types of crashes and target crashes. Again separate models for total, PDO, KABC crashes for both all types of crashes and target crashes were built.

## 6.1 Data Cleaning and Aggregation

As mentioned earlier that each of the treatment segments (introduced in Chapter-3) were actually made up of several smaller GIMS segments, each having a unique ID called “MSLINK”. These abnormalities found when merging multiple GIMS segments can be listed as: firstly, some GIMS segments or in other words some “MSLINKs” were not consistently of similar length throughout the eleven years. Thus the lengths of the segments varied over the years, which was not a desirable condition for analysis purposes. As can be seen from Figure 6. 1 that the “MSLINK” identified as “2279” happened to be a single segment before 2010 but was divided into two segments “2279” and “329667” after 2010. Similarly, there were cases were a single segments were divided into more than two segments in some years. Some cases were the other way round where two or more segments were joined together in some later years. These splitting up and joining of several segments were done by GIMS over the years to account for constant changes in road networks every year. These differences in the data was taken care of by adding the crashes of the newly created “MSLINK” after the division of the single segment to the “MSLINK” which was present throughout the eleven years and adopting the length of the single segment as the constant length for the eleven years throughout. There were other cases were completely new roadways were introduced with unique “MSLINKS” or unique identities in some later years of GIMS files, this meant construction of new roads which were absent previously. For these types of “MSLINKS” eleven years of data was not possible to obtain, so the values of attributes for the missing years were interpolated as per the values of the available years.

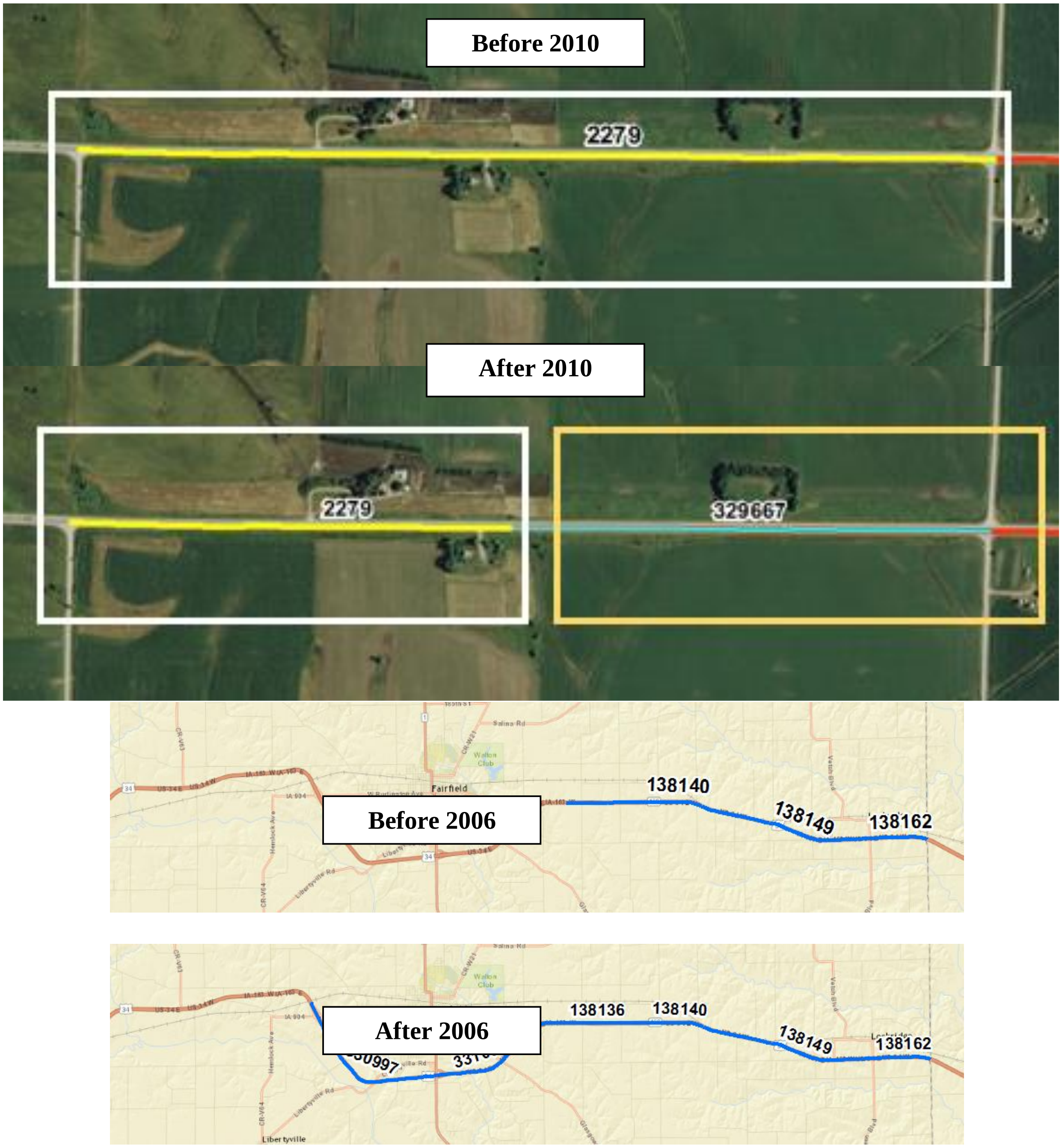


Figure 6. 1 Anomalies Detected for Study Segments Over Eleven Years 2004-2014

After building up the dataset containing roadway, traffic, and crash information of both treatments and control segment as described in the previous chapters, it was observed that there were a considerable number of “MSLINKS” having reasonably small length (even less than 500 feet). It has been pointed out by Pande et. al. (2010) that crash frequency analysis may be affected by the length of the segments over which crash data are analyzed. It has been also pointed out by Illinois Department of Transportation in the Highway Safety Improvement Program (HSIP) that the minimum length of a segments for calculating crash rates is 0.1 mile (HSIP, 2006). Thus there was a need to aggregate the data to obtain segment lengths for every segment greater than 0.1 miles. It was decided by the research team that the minimum length of the study segments to be 0.2 miles. The method of aggregation can be described as follows: first the "MSLINKS" that were less than 0.2 miles were identified. The goal was to combine the identified short links to their adjacent "MSLINKS" based on surface width, shoulder type, and speed limit. Among these three variables, the speed limit was considered to be the most important variable that determined if the links should be combined to the adjacent "MSLINK" or not. The short "MSLINKS" were manually analyzed one by one and decision if the short link should be combined to which adjacent "MSLINK" was taken. The continuous variables like surface width, AADT, shoulder widths, speed limits, etc. were summarized by weighted average method.  For categorical variables such as county number, number of lanes, federal functional class, surface type, shoulder type, rural/urban area, before/after installation year; unique values based on the "MSLINK" with longer length were assigned. For example, if an "MSLINK" fell into two counties say 77 and 78, the county number in which the majority of the segment fell was considered. Crashes were aggregated by adding the number of crashes of the corresponding adjacent segments that were aggregated. Unique identities were provided to the aggregated data.

### 6.2 Summary Statistics for Treatment Segments Aggregated Data

The summary statistics for the main roadway and traffic variables of the aggregated data over eleven years of data for all the treatment segments are provided in Table 6. 1. The year of construction was a very important variable for performing the before and after analysis. Natural log of two variables AADT and lengths were also calculated and treated as variables.

Table 6. 1 Summary Statistics for Aggregated Treatment Segments over Eleven Years

| Variables | | Mean | Standard Deviation | Range | Minimum | Maximum |
|---|---|---|---|---|---|---|
| COUNTY NO | County Number | 53 | 28 | 91 | 6 | 97 |
| RURAL/URBAN | Rural or Urban area | 0 | 0 | 1 | 0 | 1 |
| AADT | Annual Average Daily Traffic | 1526 | 1080 | 8175 | 25 | 8200 |
| LNAADT | Natural log of AADT | 7.04 | 0.87 | 5.79 | 3.22 | 9.01 |
| NUMLANES | Number of Lanes | 2 | 0 | 3 | 2 | 5 |
| SURFWIDTH | Lane Width | 24 | 3 | 42 | 18 | 60 |
| SURFTYPE | Surface Type | 69 | 9 | 32 | 60 | 92 |
| SHDTYPER | Right Shoulder Type | 6 | 3 | 8 | 0 | 8 |
| SHDWIDTHR | Right Shoulder Width | 7 | 3 | 16 | 0 | 16 |
| SHDTYPEL | Left Shoulder Type | 6 | 3 | 8 | 0 | 8 |
| SHDWIDTHL | Left Shoulder Width | 7 | 3 | 16 | 0 | 16 |
| LIMITMPH | Speed Limit | 53 | 5 | 45 | 20 | 65 |
| LENGTH | Length of aggregated segments | 0.62 | 0.33 | 1.87 | 0.02 | 1.89 |
| LNLENGTH | Natural log of aggregated segments | -0.66 | 0.64 | 4.55 | -3.91 | 0.64 |
| DATE OF CONSTRUCTION | Year of installation of Safety Edge. | 2011 | 1 | 3 | 2009 | 2012 |
| CRASH YEAR | Year of occurrence of crash | 2009 | 3 | 10 | 2004 | 2014 |

Table 6. 2 Correlation between Right and Left Shoulder Type and Widths

| | SHDWIDTHR | SHDWIDTHL | SHDTYPER | SHDTYPEL |
|---|---|---|---|---|
| SHDWIDTHR | 1 | | | |
| SHDWIDTHL | 0.968430331 | 1 | | |
| SHDTYPER | 0.523207255 | 0.498068426 | 1 | |
| SHDTYPEL | 0.507071869 | 0.509116453 | 0.979456786 | 1 |

Correlation between left and right shoulder types and widths are provided in Table – 6.2. It was seen from Table 6. 2 that strong correlation existed between right shoulder width and left shoulder width and also for right shoulder type and left shoulder type. Thus it was decided that shoulder type and width of only one side will be used. For building up statistical models some new indicator variables were created from the main variables. Summary statistics and descriptions of these indicator variables are provided in Table 6. 3. Since there were five types of federal functional roadway classes in the dataset indicating five different classes of highways namely principal arterial roads, minor arterial roads, major collectors, minor collectors (rural only) and local respectively. For these different types of highways with different level of service or access, five different indicator variables were created for them. Two types of pavement surfaces (asphalt and concrete) existed in the dataset which were indicated separately. Several variables were created for shoulder type and shoulder width which were not considered at the same time for building statistical models as then some variables would show endogeneity with one another and the model will show anomalous results. There existed three different types of shoulders (roadway sections with no shoulders, paved shoulders and unpaved shoulders) that were indicated separately. Again the variables shoulder width was generalized by taking shoulders less than and equal to 4 ft. as a category and shoulders greater than 4 ft. as another category. Combination variables of Shoulder width and types were created by multiplying indicator variables for paved and unpaved shoulders and indicator variables for shoulders less than and equal to 4 ft. as a category and shoulders greater than 4 ft. to get paved and unpaved shoulders less than and equal to 4 ft. and greater than 4 ft. Similarly number of lanes were divided into two-lane roads and multi-lane roads. All the variables were not introduced into the models at the same time as there existed high correlation between some variables. The variables number of lanes and surface (lane) width were not taken together in the model as both would mean redundant information. Similarly, the shoulder type and width variables for left and right sides of the roads were highly correlated, so only one side of variables were considered.

Table 6. 3 Description and Summary Statistics for Indicator Variables Created from Main Variables

| Variables | Description | Minimum | Maximum |
|---|---|---|---|
| TWO LANES | If the road has two lanes or not | 0 | 1 |
| MULTILANES | If the road has more than two lanes or not | 0 | 1 |
| ASPHALT | Asphalt road surface | 0 | 1 |
| CONCRETE | Concrete road surface | 0 | 1 |
| NO SHOULDER | Absence of any shoulder | 0 | 1 |
| UNPAVED | Unpaved shoulder | 0 | 1 |
| PAVED | Paved shoulder | 0 | 1 |

## 6.3 Statistical Models for Different Combinations of Before and After Crashes for Treatment Segments

Generalized linear models were used to investigate the relationship between crash reduction and implementation of Safety Edge. The models were developed using SPSS statistical software. And each model was offset by natural log of the segment length. This was done to normalize the models to a per mile analysis length as the study segments varied in length. As discussed previously that count data models can be best modelled by Poisson or Negative binomial methods. The means and variances of the numbers of crashes were first observed to choose between the two methods. Table 6. 4 shows the means and variances of KABCO all types of crashes. It was seen that the mean and the variances were very close to one another.

Table 6. 4 Means and Variance of crashes

| | Means | Variance |
|---|---|---|
| K | 0.004 | 0.004 |
| A | 0.011 | 0.011 |
| B | 0.025 | 0.028 |
| C | 0.033 | 0.036 |
| O | 0.177 | 0.235 |
| Total | 0.250 | 0.349 |

Thus looking into this, it seemed that the Poisson model should be chosen over Negative binomial model for analyzing the crash data. But another aspect that was looked into for choosing which model to use was the over dispersion factor. If the over dispersion factor is significantly greater than zero then choosing a negative binomial distribution would be appropriate. The over dispersion factors for all the models were seen to be significantly greater than zero. Table 6. 5 shows the values of the over dispersion factors for the several model built for the study. Thus it was decided to use the negative binomial method so that whatever variability that existed in the data would be captured anyhow. The values for the log likelihood which provides the goodness of fit is also provided in Table 6. 5. Table 6. 5 also provides information on all the twelve statistical models built to compare the before and after trends of crashes per year per mile for the study.

Table 6. 5 Values of Over Dispersion Factor and Log-Likelihood for All Models

| Model Number | Model Description | Over Dispersion factor | 95% Confidence interval (lower) | 95% Confidence interval (Upper) | Log likelihood value |
|---|---|---|---|---|---|
| 1 | Treatment segments all types of Total KABCO crashes for before period with all significant variables | 0.510 | 0.361 | 0.722 | -2992.47 |
| 2. | Treatment segments all types of Total KABCO crashes for after period with all significant variables | 0.395 | 0.210 | 0.744 | -1384.27 |
| 3. | Treatment segments Total target KABCO crashes for before period with all significant variables | 0.982 | 0.556 | 1.732 | -1359.68 |
| 4. | Treatment segments Total Target KABCO crashes for after period with all significant variables | 0.544 | 0.137 | 2.163 | -655.58 |
| 5. | Treatment segments Total all types of KABC crashes or all types of injury crashes for before period with all significant variables | 0.557 | 0.212 | 1.462 | -1313.12 |
| 6. | Treatment segments Total all types of KABC crashes or all types of injury crashes for after period with all significant variables | 0.073 | .00001343 | 399.714 | -592.22 |
| 7. | Treatment segments Total all types of PDO crashes or all types of property damage only crashes for before period with all significant variables | 0.700 | 0.485 | 1.010 | -2390.92 |

| | | | | | |
|---|---|---|---|---|---|
| 8. | Treatment segments Total all types of PDO crashes or all types of property damage only crashes for after period with all significant variables | 0.477 | 0.235 | 0.965 | -1108.77 |
| 9. | Treatment segments Total Target KABC crashes or all types of injury crashes for before period with all significant variables | 1.407 | 0.626 | 3.163 | -889.230 |
| 10. | Treatment segments Total Target KABC crashes or all types of injury crashes for after period with all significant variables | - | - | - | -359.451 |
| 11. | Treatment segments Total Target PDO crashes or all types of property damage only crashes for before period with all significant variables | 1.495 | 0.664 | 3.365 | -746.162 |
| 12. | Treatment segments Total Target PDO crashes or all types of property damage only crashes for after period with all significant variables | - | - | - | -423.946 |

As mentioned in previous chapters, the response variable or dependent variable in the study was the crash frequency per year per segment. The explanatory variables or the independent variables that were significant across all the models were among the variables already listed in Table 6. 1 and Table 6. 3. The variable natural log of length of the segments was taken as offset for all the negative binomial models.

*6.3.1 Comparison of Statistical Models for Treatment Segments for All Types of Total KABCO Crashes for Before and After Period with All Significant Variables.*

The parameter estimates of the results of the first model for all types of total "KABCO" crashes for "before" period for the Treatment segments and the second model with all types of KABCO crashes for "after" period with all significant variables for the Treatment segments is provided in Table 6. 6.

Table 6. 6 Before and After Parameter Estimates for All Types of KABCO Crashes for Treatment Segments

| Variables | Before Parameter Estimates | Before data Std. Error | Hypothesis Test Sig. | After Parameter Estimates | After Data Std. Error | Hypothesis Test Sig. |
|---|---|---|---|---|---|---|
| (INTERCEPT) | -7.37 | 0.32 | 0.00 | -7.52 | 0.49 | 0.00 |
| LNAADT | 0.98 | 0.05 | 0.00 | 1.03 | 0.07 | 0.00 |
| SHDWIDTHR | -0.08 | 0.01 | 0.00 | -0.14 | 0.02 | 0.00 |
| RURAL/URBAN | 0.71 | 0.15 | 0.00 | 0.53 | 0.23 | 0.02 |

From the Table 6. 6, it can be seen that the variables AADT that is annual average daily traffic, Shoulder width, and the RURAL/URBAN indicator variable were the most statistically significant factors affecting all types of KABCO crashes in the treatment segments with less than equal to 0.02 significance level. It can be seen that all types of Total KABCO crashes for the before as well as the after crashes are negatively correlated with the variable shoulder width indicating that increase in shoulder width reduces crashes and vice versa which is a feasible result. Natural log of AADT has a positive Beta value or parameter estimate which indicates more crashes will takes place if AADT increases. Rural roads were indicated with 0 and urban as 1, thus with a positive coefficient for the RURAL/URBAN indicator variable signified more crashes on urban roadways than on rural. The expected number of KABCO crashes per mile and per year for before and after period obtained from the two statistical models respectively are shown below. The model results showed an overall decrease of 45 percent for all types of expected KABCO crashes in the treatment segments.

$$\text{Crashes}_{\text{All KABCO BEFORE}} = \text{ADT}^{0.981}\exp(-7.365 - 0.080 \times \text{SHDWIDTHR} + 0.707 \times \text{RURAL/URBAN})$$

$$\text{Crashes}_{\text{All KABCO AFTER}} = \text{ADT}^{1.034}\exp(-7.518 - 0.138 \times \text{SHDWIDTHR} + 0.525 \times \text{RURAL/URBAN})$$

*6.3.2 Comparison of Statistical Models for Treatment Segments Total Target KABCO Crashes for Before and After Period with All Significant Variables*

The parameter estimates of the results of the third model for Total Target “KABCO” crashes for “before” period for the Treatment segments and the fourth model for Total Target “KABCO” crashes for “after” period with all significant variables for the Treatment segments is provided in Table 6. 7.

Table 6. 7 Before and After Parameter Estimates for Total Target KABCO Crashes for Treatment Segments

| Variables | Before Parameter Estimates | Before data Std. Error | Hypothesis Test Sig. | After Parameter Estimates | After Data Std. Error | Hypothesis Test Sig. |
|---|---|---|---|---|---|---|
| (INTERCEPT) | -5.51 | 0.82 | 0.00 | -4.59 | 1.25 | 0.00 |
| LNAADT | 1.03 | 0.08 | 0.00 | 0.95 | 0.12 | 0.00 |
| SHDWIDTHR | -0.10 | 0.02 | 0.00 | -0.12 | 0.03 | 0.00 |
| SURFWIDTH | -0.14 | 0.04 | 0.00 | -0.15 | 0.06 | 0.01 |

From the Table 6. 7, it can be seen that the variables AADT that is annual average daily traffic, Shoulder width, and the Surface width that is the lane width variable were the most statistically significant ones with less than equal to 0.007 significance level. Unlike for the previous two models for all types of KABCO crashes, the third significant variable is SURFWIDTH. Similar to models 1 and 2, it can be seen that Total Target KABCO crashes for the before as well as the after crashes are negatively correlated with the variable shoulder width indicating that increase in shoulder width reduces crashes and vice versa which is a feasible result. Natural log of AADT has a positive Beta value or parameter estimate which indicates more crashes will takes place if AADT increases. Again a negative coefficient for the SURFWIDTH variable signifies more crashes with lower lane widths. The expected number of target KABCO crashes per mile and per year for before and after period was calculated by the following two statistical models respectively:

$$\text{Crashes}_{\text{Target KABCO BEFORE}} = \text{ADT}^{1.032}\exp(-5.514 - 0.097 \times \text{SHDWIDTHR} - 0.138 \times \text{SURFWIDTH})$$

$$\text{Crashes}_{\text{Target KABCO AFTER}} = \text{ADT}^{0.950}\exp(-4.589 - 0.120 \times \text{SHDWIDTHR} - 0.150 \times \text{SURFWIDTH})$$

The model results showed an overall decrease of 45 percent for target KABCO crashes in the treatment segments.

### *6.3.3 Comparison of Statistical Models for Treatment Segments Total All Types of KABC Crashes (or All Types of Injury Crashes) For Before and After Period with All Significant Variables*

The parameter estimates of the results of the fifth model for all types of total “KABC” crashes or all types of injury crashes for “before” period for the Treatment segments and the sixth model with all types of “KABC” crashes for “after” period for the significant variables for Treatment segments are provided in Table 6. 8.

Table 6. 8 Before and After Parameter Estimates for All Types of "KABC" Crashes for Treatment Segments

| Variables | Before Parameter Estimates | Before data Std. Error | Hypothesis Test Sig. | After Parameter Estimates | After Data Std. Error | Hypothesis Test Sig. |
|---|---|---|---|---|---|---|
| (INTERCEPT) | -7.87 | 0.52 | 0.00 | -8.72 | 0.85 | 0.00 |
| LNAADT | 0.93 | 0.07 | 0.00 | 1.02 | 0.12 | 0.00 |
| SHDWIDTHR | -0.13 | 0.02 | 0.00 | -0.12 | 0.03 | 0.00 |

From the Table 6. 8, it can be seen that the variables AADT that is annual average daily traffic and Shoulder width are the most statistically significant ones with less than equal to 0.001 significance level. Unlike other models only the variables AADT shoulder width are significant in these two models. It can be seen that all types of Total "KABC" crashes or in other words all types of total injury crashes for the before as well as the after period are negatively correlated with the variable shoulder width indicating that increase in shoulder width reduces crashes and vice versa which is a feasible result. Natural log of AADT has a positive Beta value or parameter estimate which indicates more crashes will takes place if AADT increases. The expected number of target KABCO crashes per mile and per year for before and after period was calculated by the following two statistical models respectively:

$$\text{Crashes}_{\text{All KABC BEFORE}} = \text{ADT}^{0.930}\exp(-7.871 - 0.127 \times \text{SHDWIDTHR})$$

$$\text{Crashes}_{\text{All KABC AFTER}} = \text{ADT}^{1.017}\exp(-8.721 - 0.121 \times \text{SHDWIDTHR})$$

*6.3.4 Comparison of Statistical Models All Types of Total PDO or Property Damage Only Crashes For Before and After Period with All Significant Variables for Treatment Segments*

The parameter estimates of the results of the seventh model for all types of total “PDO” crashes for “before” period for the Treatment segments and the eighth model with all types of “PDO” crashes for “after” period with all significant variables for the Treatment segments is provided in Table 6. 9.

Table 6. 9 Before and After Parameter Estimates for All Types of PDO Crashes for Treatment Segments

| Variables | Before Parameter Estimates | Before data Std. Error | Hypothesis Test Sig. | After Parameter Estimates | After Data Std. Error | Hypothesis Test Sig. |
|---|---|---|---|---|---|---|
| (INTERCEPT) | -8.11 | 0.39 | 0.00 | -7.90 | 0.58 | 0.00 |
| LNAADT | 1.02 | 0.06 | 0.00 | 1.05 | 0.08 | 0.00 |
| SHDWIDTHR | -0.06 | 0.01 | 0.00 | -0.15 | 0.02 | 0.00 |
| RURAL/URBAN | 0.83 | 0.18 | 0.00 | 0.66 | 0.26 | 0.01 |

From the Table 6. 9, it can be seen that the variables AADT that is annual average daily traffic, Shoulder width, and the RURAL/URBAN indicator variable are the most statistically significant factors affecting all types of PDO crashes with less than equal to 0.01 significance level. It can be seen that all types of Total PDO crashes for the before as well as the after crashes are negatively correlated with the variable shoulder width indicating that increase in shoulder width reduces crashes and vice versa which is a feasible result. Natural log of AADT has a positive Beta value or parameter estimate which indicates more crashes will takes place if AADT increases. With a positive coefficient for the RURAL/URBAN indicator variable signifies more crashes in rural roadways than in urban. The expected number of KABCO crashes per mile and per year for before and after period was calculated by the following two statistical models respectively:

$$\text{Crashes}_{\text{All PDO BEFORE}} = \text{ADT}^{1.017}\exp(-8.107 - 0.063 \times \text{SHDWIDTHR} + 0.830 \times \text{RURAL/URBAN})$$

$$\text{Crashes}_{\text{All PDO AFTER}} = \text{ADT}^{1.045}\exp(-7.895 - 0.146 \times \text{SHDWIDTHR} + 0.656 \times \text{RURAL/URBAN})$$

*6.3.5 Comparison of Statistical Models for Total Target KABC Crashes (or All Target Injury Crashes) For Before and After Period with All Significant Variables for Treatment Segments*

Previously in models 5 and 6, comparison of statistical models for all types of KABC crashes for before and after period was made. This section provides the comparison of statistical models for Total target KABC crashes (or all target injury crashes) for before and after period with all significant variables for Treatment segments. The parameter estimates of the results of the ninth model for total target "KABC" crashes or all target injury crashes for "before" period for the Treatment segments and the tenth model with all target "KABC" crashes for "after" period with all significant variables for the Treatment segments is provided in Table 6. 10.

Table 6. 10 Before and After Parameter Estimates Target "KABC" Crashes for Treatment Segments

| Variables | Before Parameter Estimates | Before data Std. Error | Hypothesis Test Sig. | After Parameter Estimates | After Data Std. Error | Hypothesis Test Sig. |
|---|---|---|---|---|---|---|
| (INTERCEPT) | -8.24 | 0.68 | 0.00 | -9.57 | 1.20 | 0.00 |
| LNAADT | 0.90 | 0.10 | 0.00 | 1.03 | 0.16 | 0.00 |
| SHDWIDTHR | -0.12 | 0.03 | 0.00 | -0.11 | 0.04 | 0.01 |

From the Table 6. 10, it can be seen that the variables AADT that is annual average daily traffic and Shoulder width are the most statistically significant ones with less than equal to 0.01 significance level. It can be seen that all target "KABC" crashes or in other words total injury target crashes for the before as well as the after period are negatively correlated with the variable shoulder width indicating that increase in shoulder width reduces crashes and vice versa which is a feasible result. Natural log of AADT has a positive Beta value or parameter estimate which indicates more crashes will takes place if AADT increases. The expected number of KABCO crashes per mile and per year for before and after period was calculated by the following two statistical models respectively:

$$\text{Crashes}_{\text{TARGET KABC BEFORE}} = \text{ADT}^{0.898}\exp(-8.242 - 0.115 \times \text{SHDWIDTHR})$$

$$\text{Crashes}_{\text{ TARGET KABC AFTER}} = \text{ADT}^{1.032}\exp(-9.573 - 0.110 \times \text{SHDWIDTHR})$$

The model results showed an overall decrease of 92 percent for target KABC crashes in the treatment segments.

*6.3.6 Comparison of Statistical Models Total Target PDO or Property Damage Only Target Crashes For Before and After Period with All Significant Variables for Treatment Segments*

Previously in models 7 and 8, comparison of statistical models for all types of PDO crashes for before and after period was made. This section provides the comparison of statistical models for target PDO crashes (or property damage only target crashes) for before and after period with all significant variables for Treatment segments. The parameter estimates of the results of the seventh model for total target "PDO" crashes for "before" period for the Treatment segments and the eleventh model with total target "PDO" crashes for "after" period with all significant variables for the Treatment segments is provided in Table 6. 11.

Table 6. 11 Before and After Parameter Estimates Target PDO Crashes for Treatment Segments

| Variables | Before Parameter Estimates | Before data Std. Error | Hypothesis Test Sig. | After Parameter Estimates | After Data Std. Error | Hypothesis Test Sig. |
|---|---|---|---|---|---|---|
| (INTERCEPT) | -5.22 | 1.26 | 0.00 | -3.65 | 1.66 | 0.03 |
| LNAADT | 1.14 | 0.12 | 0.00 | 0.82 | 0.15 | 0.00 |
| SHDWIDTHR | -0.09 | 0.03 | 0.01 | -0.14 | 0.04 | 0.00 |
| SURFWIDTH | -0.22 | 0.06 | 0.00 | -0.17 | 0.08 | 0.02 |

From the Table 6. 11, it can be seen that the variables AADT that is annual average daily traffic, SHDWIDTH Shoulder width, and the SURFWIDTH or lane width variable are the most statistically significant factors affecting all types of PDO crashes with less than equal to 0.025 significance level. This is different from models for all types of total PDO crashes where instead of SURFWIDTH, the third most significant variable the rural/urban indicator was. It can be seen that Total target PDO crashes for the before as well as the after crashes are negatively correlated with the variable shoulder width indicating that increase in shoulder width reduces crashes and vice versa which is a feasible result. Natural log of AADT has a positive Beta value or parameter estimate which indicates more crashes will takes place if AADT increases. Again a negative coefficient for the SURFWIDTH variable signifies more crashes with lower lane widths. The expected number of KABCO crashes per mile and per year for before and after period was calculated by the following two statistical models respectively:

$$\text{Crashes}_{\text{TARGET PDO BEFORE}} = \text{ADT}^{1.142}\exp(-5.215 - 0.087 \times \text{SHDWIDTHR} - 0.223 \times \text{SURFWIDTH})$$

$$\text{Crashes}_{\text{TARGET PDO AFTER}} = \text{ADT}^{0.821}\exp(-3.648 - 0.140 \times \text{SHDWIDTHR} - 0.170 \times \text{SURFWIDTH})$$

6.4 Effect on AADT

Graphs were drawn for all the above mentioned statistical models for the annual crashes per mile before and after the installation of Safety Edge in Iowa. Models with only AADT and offset length were used for these graphs. As same variables were not significant over all the models, the most common variables that were significant across all the models were AADT and segment length. Thus to provide a uniform scale of comparison among all the graphs, only AADT and length was considered for building the graphs.

Figure 6. 2 shows a graph for annual all types of KABCO crashes per mile before and after installation. Positive safety impacts of Safety Edge were observed from the graph as the crashes in the after period went down from the before period. The percentage of changes in crashes with respect to AADT ranges from -14 % to -22%, which means a reduction of crashes in the after periods for all types of KABCO crashes. It can be observed that for lower AADT

values from 20 to 600 the reduction of crashes are more compared to AADT values beyond 600 till 8140.

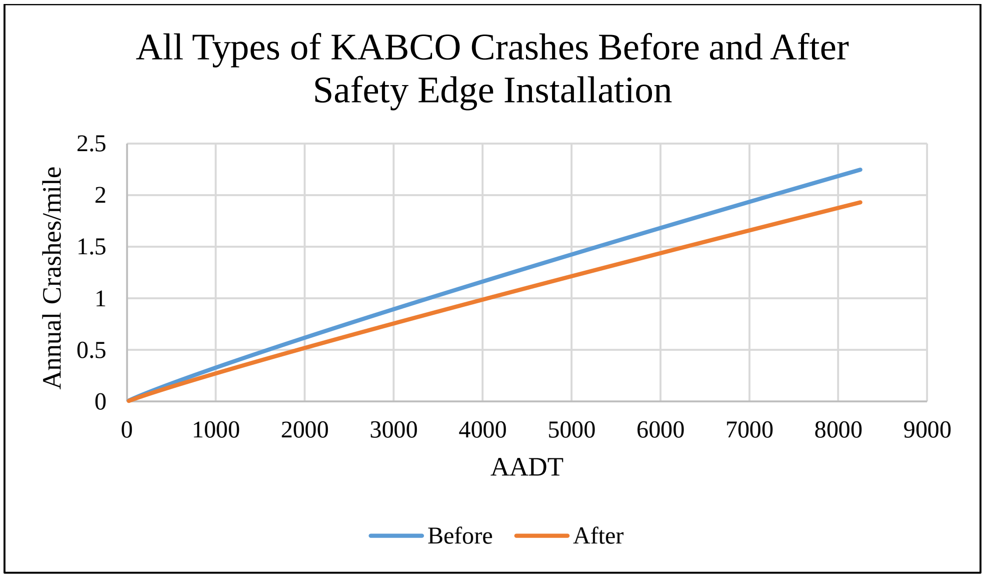


Figure 6. 2 Graph for Annual All Types of KABCO Crashes per Mile Before And After Installation

Graphs for models 3 and 4 for the annual crashes per mile before and after the installation of Safety Edge in Iowa with respect to AADT are shown in the following section. Figure 6. 3 shows a graph for annual Target KABCO crashes per mile before and after installation. Here also positive safety impacts of Safety Edge were observed from the graph as the crashes in the after period went down from the before period. It can be observed from

Figure 6. 2 and Figure 6. 3 that the after period trend line dropped more for target KABCO crashes which would in turn indicate that installation of Safety Edge reduces pavement edge drop off related crashes. The percentage of changes in crashes with respect to AADT ranges from +30 % to -25%, which means a reduction of crashes in the after periods for target KABCO crashes. It can be observed that for lower AADT values from 20 to 600 there is an increase instead of reduction of crashes compared to AADT values beyond 600 till 8140.

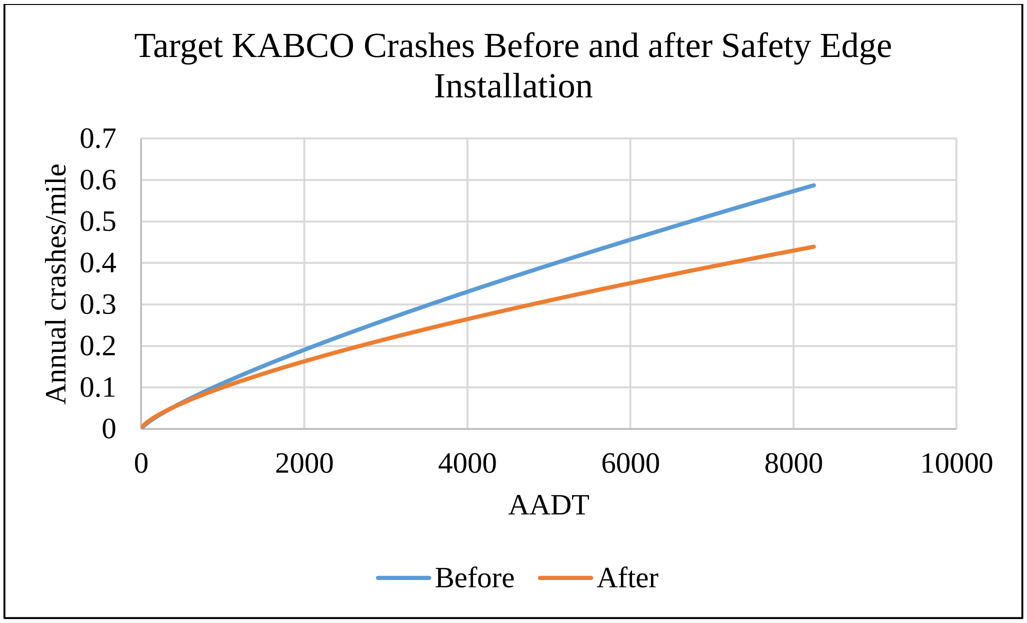


Figure 6. 3 Graph for Annual Target KABCO Crashes per Mile Before And After Installation

Figure 6. 4 shows the trend lines for annual all types of KABC crashes (all types of injury crashes) per mile before and after installation. Positive safety impacts of Safety Edge were again observed from the graph as the crashes in the after period went down from the before period. But unlike the other graphs which clearly exhibited less annual crashes per mile in the after periods, the after period trend observed from Figure 6. 4 is not clear and not pronounced. It was observed that all types of injury crashes went down in the after period for higher AADT values and for lower AADT values the annual crashes per mile in the after period got increased. The percentage of changes in crashes with respect to AADT ranges from +7 % to -55%, which means a reduction of crashes in the after periods for target KABCO crashes. It can was observed that for lower AADT values from 20 to 5250 there are reduction of crashes compared to AADT values beyond 600 till 8140.

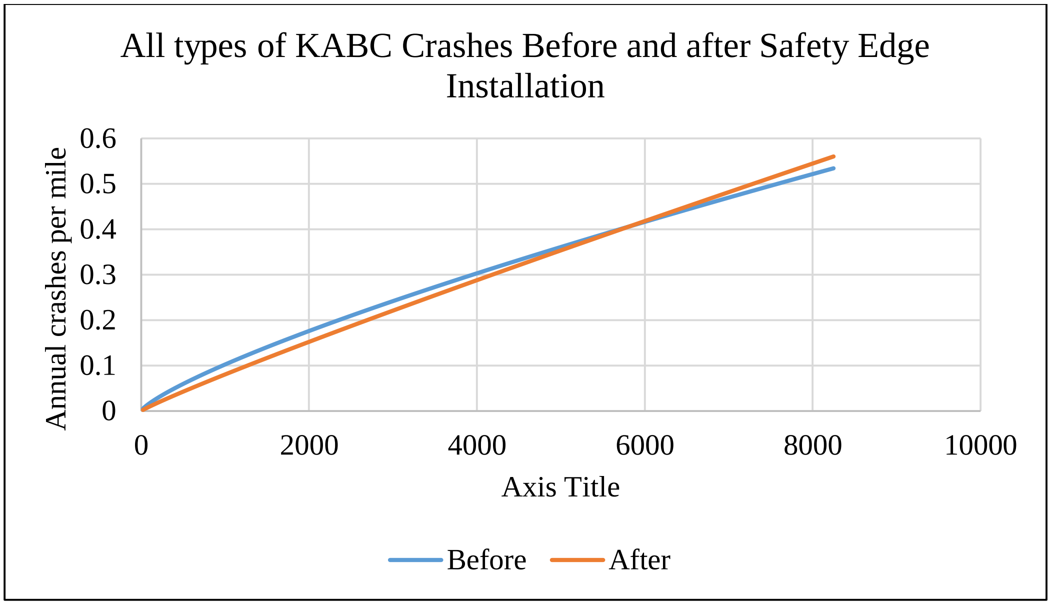


Figure 6. 4 Graph for Annual All Types of KABC Crashes per Mile Before And After Installation

Figure 6. 5 shows a graph for annual all types of PDO crashes per mile before and after installation. Positive safety impacts of Safety Edge were observed from the graph as the crashes in the after period went down from the before period. Figure 6. 6 shows a graph for annual target KABC or target all injury crashes per mile before and after installation. Positive safety impacts of Safety Edge were observed from the graph as the crashes in the after period went down from the before period. Comparing Figure 6. 4 and Figure 6. 6, the later provides a more pronounced and uniform drop of crashes in the after period and in Figure 6. 4 which shows less crashes only for higher AADT and more crashes for lower values of AADT. Thus it can be said that for target injury crashes provides better results which means that the installment of Safety Edge might have positive effects on all injury crashes due to pavement edge drop off.

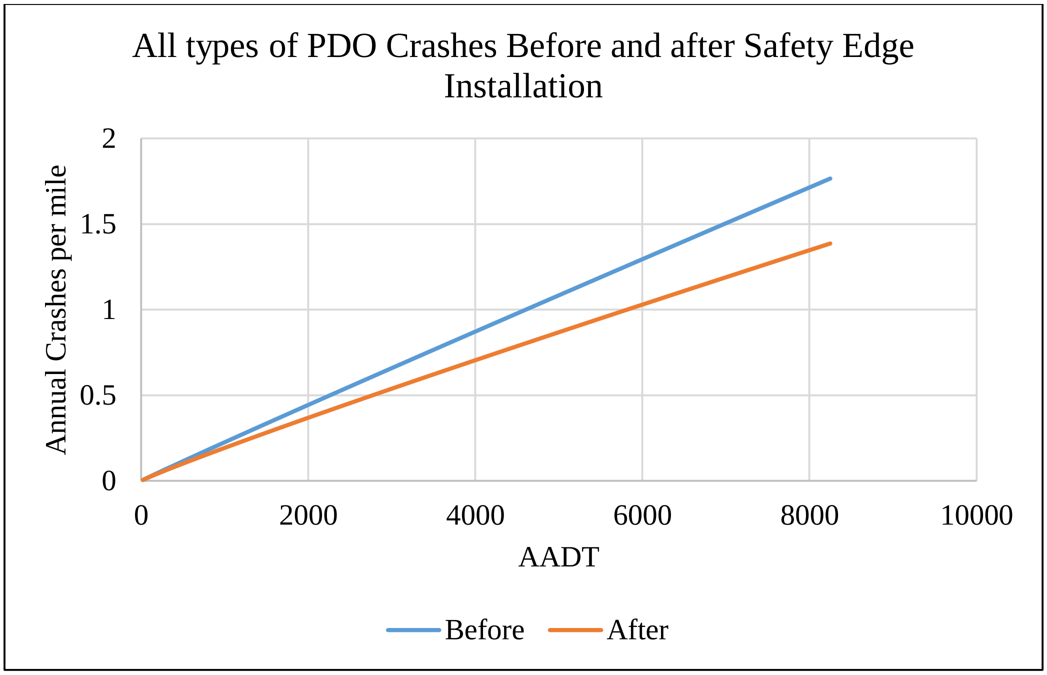


Figure 6. 5 Graph for Annual All Types of PDO Crashes per Mile Before And After Installation

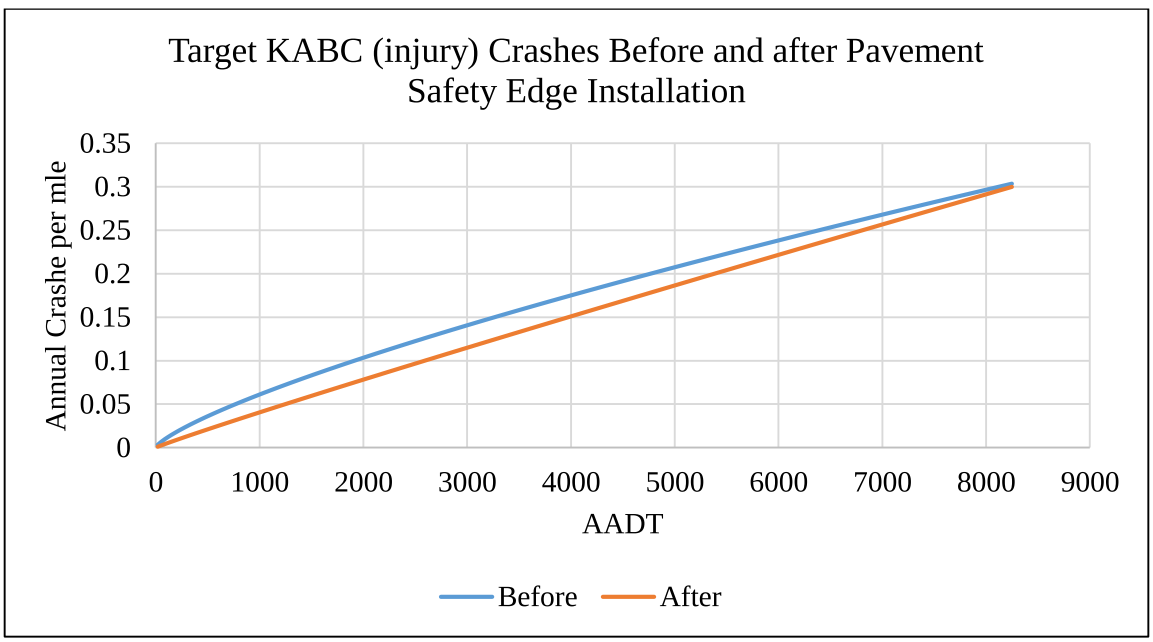


Figure 6. 6 Graph for Annual Target KABC Crashes per Mile Before And After Installation

Figure 6. 7 shows a graph for annual Target PDO crashes per mile before and after installation. Positive safety impacts of Safety Edge were observed from the graph as the crashes

in the after period went down from the before period. But there can be seen a slight bend in the after period curve as the crashes went up for AADTs less than 1000 but shows clear decrease for values of AADTs more than 1000. Comparing Figure 6. 5 and Figure 6. 7, the later provides a more pronounced and drop of crashes in the after period compared to that in Figure 6. 5. Thus it can be said that for target property damage only crashes provides better results which means that the installment of Safety Edge might have positive effects on all injury crashes due to pavement edge drop off. But Figure 6. 5 shows a uniform reduction in crashes with respect to the values of AADTs unlike that of Figure 6. 7.

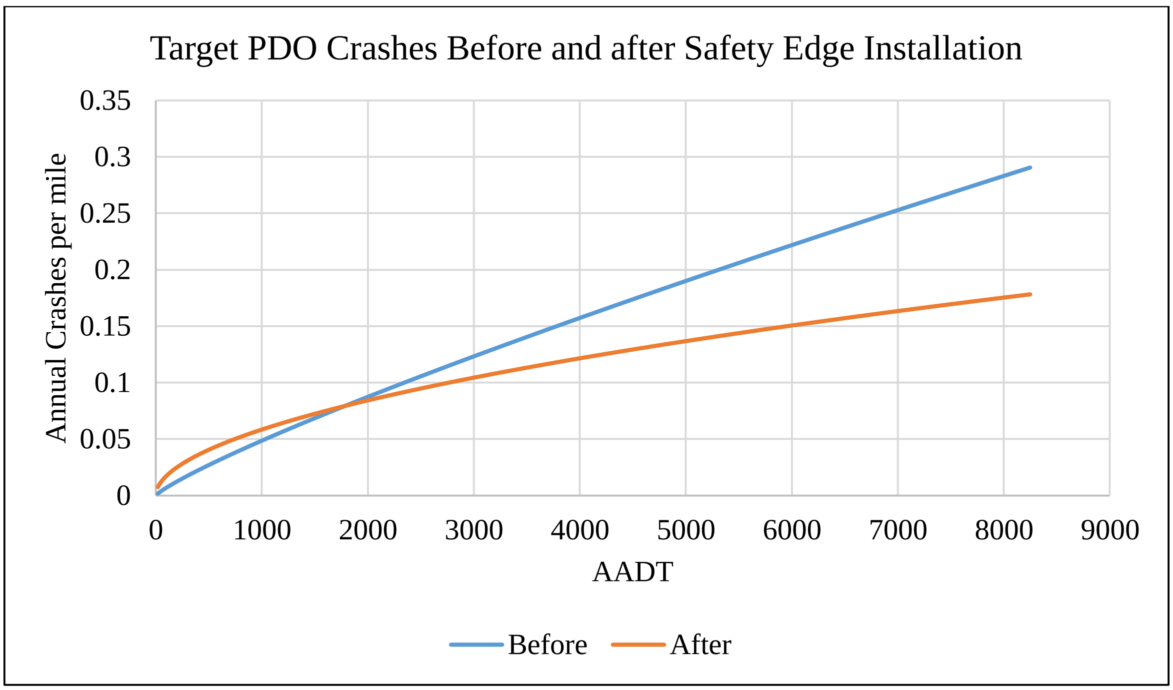


Figure 6. 7. Graph for Annual Target PDO Crashes per Mile Before and After Installation

6.5 Crash Reduction Factors and Percentages

Finally, for visualizing the magnitude of changes in crashes in the after period from the before periods, crash reduction factors and percentage changes for all the above mentioned models were calculated, the results are shown below:

*6.5.1 Results for All Types of Crashes*

Table 6. 12 and the percentage reduction was seen to be 21%. It can be also observed from the table that the percentage reduction for all types of injury or KABC crashes was 20%. For all types of PDO crashes the reduction was seen to be 20%. The percentage reduction magnitudes can be visualized from Figure 6. 8 Percentage Changes in Expected All Types of Crashes.

Table 6. 12 Crash Reduction Factors for All Types of Crashes

| | Expected before | Expected after | Percentage change |
|---|---|---|---|
| KABCO | 208.7 | 164.9 | -21.0 |
| KABC | 60.3 | 48.1 | -20.1 |
| PDO | 140.8 | 112.7 | -20.0 |

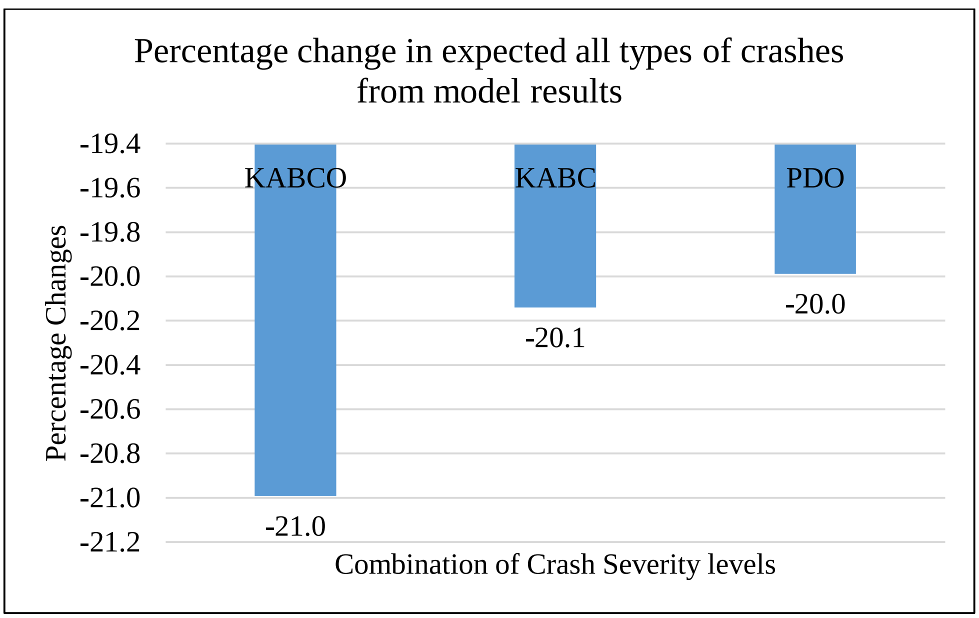


Figure 6. 8 Percentage Changes in Expected All Types of Crashes

*6.5.2 Results for Target Crashes*

For total target Crashes that is for target KABCO crashes the overall expected number of before and after crashes for can be observed from Table 6. 13 and the percentage reduction was seen to be 16.3%. It can be also observed from the table that the percentage reduction for target injury or KABC crashes was 24.4%. On the contrary the target PDO crashes went up by 2.4 %. The results hinted that the Safety Edge might have potential to reduce the crash severity by reducing some injury crashes and shifting it to property damage only crash. As Safety Edge cannot resist a vehicle from a run off road action but it can safely remount back an errant vehicle on the pavement track. So from the results it was seen that for all types of crashes reduction in crashes were observed for all injury crashes as well as all PDO crashes but for target crashes PDO crashes went up and injury crashes went further below indicating capability of Safety Edge installation in reducing severe fatal and injury crashes.

Table 6. 13 Percentage Changes and Crash Reduction Factors for Expected Target Crashes

| | Expected before | Expected after | Percentage change |
|---|---|---|---|
| KABCO | 65.0 | 54.4 | -16.3 |
| KABC | 5.4 | 4.1 | -24.4 |
| PDO | 29.4 | 30.1 | 2.4 |

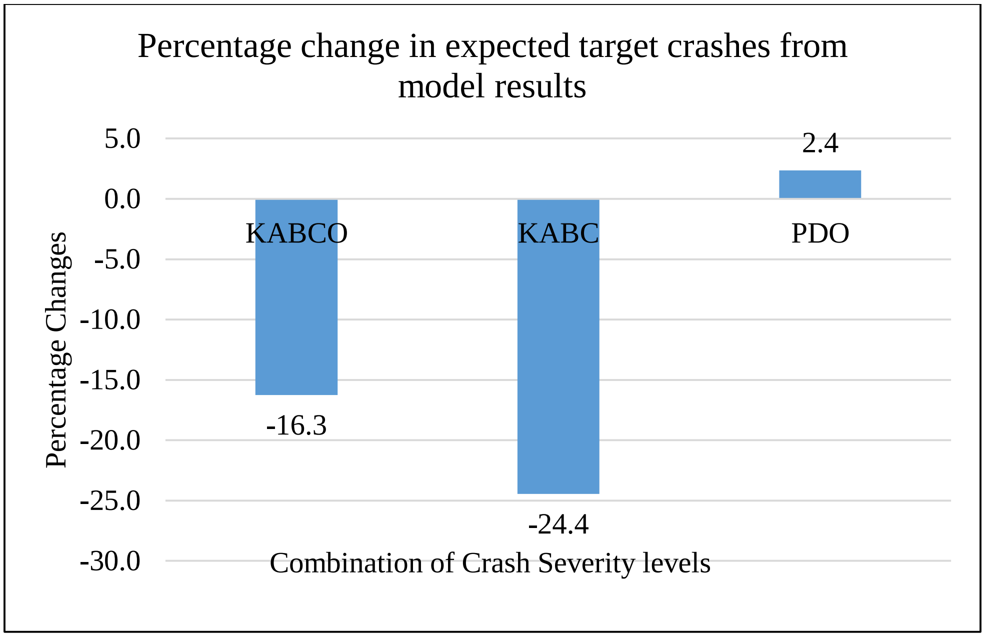


Figure 6. 9 Percentage Change in Expected Target Crashes from Model Results

# CHAPTER 7

# CONCLUSION, LIMITATIONS AND FUTURE RESEARCH

The primary objective of the study was to conduct a before and after analysis to evaluate safety effectiveness of Safety Edge treatment in Iowa. This chapter summarizes the major findings and conclusions from the study followed by limitations of the studies and recommendations for future research.

## 7.1 Major Findings and Conclusions

The study performed a before and after crash analysis of installation of Safety Edge in Iowa. Analysis was conducted both for all types of crashes as well as target crashes. Crash severity was designated by the KABCO scale: Fatal Injury Crashes (K), Disabling Injury Crashes (A), Visible Injury Crashes (B), Possible Injury Crashes (C), and Property-Damage-Only (PDO).

- A Preliminary before and after crash analysis for all types of crashes showed that average annual all types of crashes in the after period of installation of Safety Edge were less compared to that of the before period for all crash severity levels. The percentage reduction showed 50% reduction in all types of fatal crashes, 18.5% reduction in all types of PDO crashes and an overall decrease of 19% for all types of total crashes.
- A Preliminary before and after crash analysis taking only target crashes into account showed a 75% reduction in Target fatal crashes, 1% increase in target PDO crashes and overall 17% reduction in total target crashes.
- Negative binomial regression models for all types of crashes as well as target crashes were also created to find out the variables that significantly affected the crashes on the segments. Length of the segments were taken as offsets for all the models, so it was

assumed that doubling the lengths of the segments the crashes also doubled. It was seen that the variable addressing Average Annual Daily Traffic (AADT) count was statistically significant for all the crash count models for before and after periods. Parameter estimates of AADT possessed a positive coefficient which meant that with increase in AADT on the segments, the crashes would also increase, thus AADT positively affected the crashes on the Safety Edge segments. The variable shoulder width was found to be statistically significant with a negative coefficient for all types of KABCO crashes and PDO crashes. The negative coefficient indicated less crashes for broader shoulders. Rural/Urban indicator was found to be statistically significant for all types of KABCO and PDO crash models and indicated more crashes in rural roadways than in urban. Unlike models for all types of crashes surface width was also found to be statistically significant for the all target crashes and target PDO crashes had a negative coefficient signifying more crash for narrower lanes.

- Examination of expected crashes from Negative Binomial Models for All types of KABCO crashes for the before and after periods showed a percentage reduction of 21%. The percentage reduction for all types of injury crashes or KABC crashes was 20%. For all types of PDO crashes the reduction was seen to be 20%.
- Expected crashes from Negative Binomial Models for target crashes showed 16.3% reduction in target KABCO crashes and 2.4% increase in target PDO crashes.
- Results for target crashes showed a rise in PDO crashes in contrast to fall in the number of injury crashes. This indicated that Safety Edge installation may be capable of reducing severity of a crash by transforming it to a less severe crash such as property damage only crash instead of a fatal one.

- Overall, installation of Safety Edge showed improvement in safety for not only run-off-road crashes but also all types of crashes. This was evident from the observed reduction in crashes in the after period of installation of the Safety Edge in road segments in Iowa.

## 7.2 Limitations and Recommendations for Future Research

The quality of the variables that were used for the study had several limitations. There existed very few ways to verify the provided values for each of the variables over the eleven years of study period. Another limitation of the study was that the geographic extents of the Safety Edge Segments could not be verified using Google earth and the study had to rely on information obtained from previous studies and construction plans from the Iowa Department of Transportation. Site visits were conducted for some of the Safety Edge Segments and not for all. Though control segments were chosen in this study, but they were not actually used as a comparison group. All these issues are being taken care of in an on-going project and as an extension of the same project, an Empirical Bayesian before and after study using comparison groups is being conducted. Performing an Empirical Bayes before and after analysis may mitigate issues related to using simple before and after analysis. A statistical analysis on effect of Safety Edge Installation on crash severity levels can be done in future to understand if Safety Edge have any role in reducing the severity of a crash. A cost benefit analysis of installation of Safety Edge can also be done in future to evaluate its cost effectiveness.

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