Evaluation of Centerline Rumble Strips for Prevention of Highway Crossover Accidents in Kansas

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ABSTRACT

Centerline rumble strips (CLRS) are raised or indented patterns installed in the centerline of undivided two-way highways. The function of the CLRS is to alert drivers who encroach on or cross the centerline by producing noise and vibration to reduce crossover accidents, which accounted for 12.5% of total U.S. highway fatalities in 2007. The objective of this study was to investigate the effectiveness of milled in CLRS in reducing crossover accidents in Kansas. The before-and-after empirical Bayes (EB) method and the Naïve before-and-after method were applied to existing accident data and compared. Two sections of highway were analyzed in this paper. The first was a 15.2-mile section of US-50, between Newton and Hutchinson. The second was a 10.8-mile section on US 40 between Lawrence and Topeka. The Naïve method showed an overall 50.69% reduction in the total number of accidents per mile year and a 92.1% reduction of crossover accidents after installation of CLRS. The EB method indicated an overall 49.4% reduction of total number of accidents and an 89.2% reduction of the crossover accidents. Results of the two methods were statistically comparable. This study showed that installing CLRS reduced crossover accidents in the sections of US 50 and US 40 in Kansas. Results from this study were comparable with results reported by other states, showing that installing CLRS is an effective countermeasure to reduce crossover accidents and potentially other accidents as well.

Key words: centerline rumble strips—empirical Bayes method—Naïve method—safety effectiveness

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PROBLEM STATEMENT

In the United States, 60% of fatal accidents occur on rural roads. Among these, 90% occur on two-lane roads, and 20% of these accidents involve two vehicles traveling in opposite directions, totaling 4,500 fatal accidents per year (Suzman 1999; cited by Russell and Rys 2005). Data from 2007 showed that 21,433 fatal accidents, or 57.5% of the total number of fatal accidents, occurred on undivided two-lane roads in the country (NHTSA 2007). Head-on (HO) and opposite-direction sideswipes (OPP SW) accidents represent 12.5% of fatal accidents and 10.3% of the total number of accidents in the country (NHTSA 2007).

In order to reduce the number of accidents, several state departments of transportation have installed rumble strips and other accident countermeasures on U.S. highways. Rumble strips are grooved or raised indentations placed on the shoulder or on the pavement of a travel lane. The primary purpose of the strips is to prevent accidents by providing noise and vibration when crossed by vehicles, warning drivers. In the United States, the following four different types of rumble strips have been used: milled, raised, rolled, and formed (Richards and Saito 2007).

- Milled—type of rumble strips made by a machine that cuts grooves in the pavement surface
- Rolled—type of rumble strips made by a roller machine that presses into hot asphalt surfaces to create grooves (they must be installed during pavement compaction)
- Formed—type of rumble strips that are formed in concrete pavements during the finishing process
- Raised—type of rumble strips installed over pavements by the adherence of various materials

Centerline Rumble Strips

Centerline rumble strips (CLRS) are primarily installed on the centerline of undivided two-way highways, and their main purpose is reducing crossover accidents, specifically head-on and opposite direction sideswipe accidents, which are usually caused by driver inattention and drowsiness.

After CLRS were accepted as an efficient method in reducing crossover accidents, use of them in the United States has been increasing over the years. Chen and Cottrell (2005) reported that 24 states in United States have installed CLRS. In addition, according to Richards and Saito (2007), there are more than 2,400 miles of CLRS installed in the country, and the most common pattern dimensions are length (dimension perpendicular to the travel lane) of 16 in., width (dimension parallel to the travel lane) of 7 in., depth of 0.5 in., and spacing (center to center) of 12 in. Several authors have reported advantages other than reducing accidents in installing CLRS, such as high benefit-cost ratio, improvement of lateral vehicle position to the right, low interference in passing maneuvers, versatile installation conditions, and public approval. However, some concerns involving CLRS, such as disturbing noise for nearby residents, decreased visibility of the painted strips, faster pavement deterioration, potential driver erratic maneuvers to the right after encountering CLRS, and ice formation in the grooves have been cited in the current literature (Russell and Rys 2005). For this reason, a better understanding of the balance needed between safety and practical effects of CLRS depends on future investigation of these concerns.

In Kansas, two different types of milled-in CLRS have been used: rectangular and football-shaped. The first two installations of CLRS in Kansas are the sections studied in this report. After these initial installations, the Kansas Department of Transportation (KDOT) has been increasing the number of sections of rural highways receiving CLRS. Currently, more than 230 miles of CLRS have been installed in 29 different locations in Kansas (Buckley 2009). In 2007, KDOT adopted an official policy of installation of the strips.
**Naïve Before-and-After Method**

The Naïve before-and-after method consists of a comparison between the number of accidents on a treated section in the after period and the number of accidents in the same section during the before period. This type of comparison is known to be biased due to the regression to the mean phenomenon, i.e., a section of highway that presented an elevated number of accidents in a period tends to have decreased number of accidents in a future period and vice versa, even with no improvement on the section. Although the Naïve method does not account for the regression to the mean bias, this method has been used in several studies of the effectiveness of CLRS in reducing accidents. Some results of studies that used the Naïve method are the following:

- Fitspatrick et al. (2000) reported a 90% reduction in fatal head-on accidents and 42% reduction in total head-on accidents after the installation of CLRS in a 23 mile section of a two-lane rural highway in California. The total period analyzed was 59 months.
- Outcalt (2001) reported a 34% reduction in head-on accidents (divided per million vehicles), and 36.5% in sideswipe opposite-direction accidents (divided per million vehicles), after the installation of CLRS in a 17 mile section of a two-lane rural highway in Colorado, even with an increase of 18% of annual average daily traffic (AADT). The total period was 44 months.
- Monsere (2002), cited by Russell and Rys (2005), reported an overall 69.5% reduction in crossover accidents after the installation of CLRS in two sections of approximately 8.5 miles each, one a four-lane rural highway and the other a two-lane rural highway in Oregon, using the Naïve before-and-after method.
- The Delaware Department of Transportation (DelDOT 2003) showed a 95% reduction in the average number of head-on accidents per year, 60% in the average per year of “drove left of the center” type of accident, and 8% in the average per year of all types of accidents after the installation of CLRS in a 2.9-mile section of a two-lane rural highway in Delaware. However, this study showed a 4% increase in the average per year of total number of accidents involving injuries and 13% in the average per year number of accidents involving only property damage. The AADT increased 4% from the before to the after period. The total period analyzed was 10 years.
- According to Kar and Weeks (2009), Arizona DOT reported a decrease in the number of fatal and serious injury head-on and opposite-direction sideswipe accidents from 18, in the before period (2000–2002), to seven in the after period (2003–2005). Crashes per million vehicle miles traveled (MVMT) were calculated as follows: MVMT = (number of accidents * 1,000,000) / (AADT * 365 * segment length). In the before period, MVMT was approximately 0.025, and in the after period, it was approximately 0.011. Thus, there was approximately a 56% reduction of these types of accidents after the installation of CLRS.

**Empirical Bayes Method**

The empirical Bayes (EB) method estimates the number of accidents for the after period, based on linear regression analysis, using information of sections with similar characteristics to the treated sections, and on historical information. The estimated number of accidents is compared to the actual number of accidents counted in the after period.

Even though the EB method can be considered the most acceptable method to evaluate the characteristics of a treatment in reducing accidents over time, only one study that applied the EB method to investigate the safety-effectiveness of CLRS in reducing accidents was found in the literature. In this study, Persaud et al. (2004) used data from seven states and found an estimated reduction of approximately 21% (95% CI
in frontal and sideswipe opposing-direction types of accidents in treated sections of undivided two-lane rural highways after the installation of CLRS. When injuries were involved in the same types of accidents, the reported reduction was estimated to be 25% (95% CI = 5-45%). Considering all types of accidents, the authors reported an estimated 14% (95% CI = 8-20%) reduction of injury accidents. All types of accidents were reduced by an estimated 15% (95% CI=15-25%). The total length of treated sections was 210 miles at 98 sites.

RESEARCH OBJECTIVE

The objective of this study was to investigate the effectiveness of milled-in CLRS in reducing the number of total and targeted crossover accidents in Kansas. The before-and-after EB method and the Naïve before-and-after method were applied and compared.

RESEARCH METHODOLOGY

The first installation of CLRS in Kansas occurred in June 2003, on approximately 15.2 miles of US 50, between Newton and Hutchinson, in Harvey County. Two different patterns of rectangular CLRS were installed in this location, alternated and continuous. In this report, this section will be referred to as section A. It consists of a two-lane undivided rural highway with lane width of 12 ft, and some passing zones on hills, on a generally straight alignment. Surface type of the lanes and shoulders was bituminous. Width of the shoulders ranged between 5 to 10 ft, and the AADT on this section ranged from 4,000 to 6,000. The second section studied in this report had football-shaped CLRS installed in May 2005 in a segment of approximately 10.8 miles on US 40 between Lawrence and Topeka. In this report, this section will be referred to as section B. It was a two-lane undivided rural highway with lane width of 11 ft. It had a high percentage of no-passing zones with many horizontal and vertical curves. Surface type of the lanes was bituminous, while the three ft shoulders had turf surface.

Naïve Before-and-After Method

This method calculates the proportion of accidents in the after period compared to the before period. For section A on US 50, the before period analyzed ran from January 1998 to June 2003. The after period considered for this section ran from July 2003 to December 2007. For section B on US 40, the before period analyzed was from January 1998 to May 2005. The after period studied for this section was from June 2005 to December 2007.

Since the before and after periods for the two studied sections had different durations, the counted number of accidents was divided by the duration of the period and by the length of the section. The comparable results were stated in annual accidents per mile.

Empirical Bayes Method

The methodology described in this section was based on Hauer (1997, 2002) and Harwood et al. (2002).

According to Patel et al. (2007), the concept of the EB method is to estimate the number of accidents that the sections of interest would have had in the after period if no treatment had been used and compare this number to the actual number of accidents in the after period on the section submitted to treatment. Therefore, it is possible to estimate the influence of the treatment (CLRS) on the final result. In this report, the expected number of accidents in the after period was corrected due to differences in traffic volume over the periods and due to the differences between the duration of the periods.
The estimated number of accidents in the after period if no treatment was used is not only based on historical information (accidents that occurred in the section of interest in the before period), but also uses data from a group of similar sites—highways without treatment with similar characteristics to the treated section (AADT, geometry, rate of accident per year, etc.) to calibrate a safety performance function (SPF). According to Hauer et al. (2002), methods that estimate the safety-effectiveness of a treatment, based only on the counted accidents in the section of interest in the before period, show results that can be inflated due to regression to the mean bias.

The SPF can be obtained by performing a regression analysis, generally using a negative binomial distribution. In this report, the regression analyses were done using AADT as the only predictor for the total number of accidents in one mile of a specific group of highways. As a result, the SPF should predict the number of accidents per mile on a highway with determined characteristics, according to the volume of traffic. The most difficult task for a researcher, in order to apply the EB method, is to find sections that are comparable in terms of traffic, number of accidents, and geometry to the studied sections. In this report, the geometry and volume of traffic were the most important factors used to choose the similar sites.

KDOT provided the total number of accidents from sections that were used as potential similar sites to match section A on US 50 and section B on US 40. The AADT were obtained from KDOT historical traffic count maps, available online (KDOT 2009).

In order to match section A on US 50, there were three potential similar sites available with the following characteristics: two-lane rural highways; lane width of 12 ft; surface type for lane and shoulder: bituminous; shoulder width ranging from 5 to 10 ft; AADT ranging from 3,800 to 6,500; and accident rate ranging from 1.926 to 4.259 accidents per 100 MVM (million vehicle-miles of travel). The three locations were the following:

- US 54 in Kiowa County from the junction of US 54 and US 400 to the Pratt county lane, excluding the cities of Greensburg and Haviland; it was divided into two sections, called Kiowa A, from county reference posts 6.443 to 14.410; and Kiowa B, from county reference posts 15.666 to 30.355
- US 75 in Montgomery County from SJCT US 75/US 166 to US 75/US 400; it was divided into three sections, called Montgomery A, from county reference posts 1.697 to 4.695; Montgomery B, from county reference posts 17.980 to 20.664; and Montgomery C, from county reference posts 26.311 to 33.493
- US 281 in Barton County from RS-981 to the transition 2L/4L undivided, about 1.5 miles north of RS-42; it was divided into three sections, called Barton A, from county reference posts 2.100 to 5.320; Barton B, from county reference posts 8.622 to 10.272; and Barton C, from county reference posts 12.330 to 17.059

In order to match section B on US 40, four potential similar sites were available, and they had the following characteristics: two-lane rural highways, lane width of 11 ft, surface type for lane was bituminous, turf shoulder with a width of 3 ft and AADT ranging from 2,000 to 5,100, and accident rate ranging from 0 to 3.375 accidents per 100 MVM (not considering US-24). The four locations were the following:

- Called Douglas, US 24 from Douglas/Leavenworth County line to Tonganoxie south city limit; county reference posts 0.000 to 8.625.
- Called Brown, KS-20 in Brown County from the JCT KS-20/RS-1265 to west city limit of Horton
- Called Cherokee, KS-7 in Cherokee County from the JCT KS-7/RS-1166 to JCT US 400/KS-7
• Called Franklin, KS-33 in Franklin County from the JCT I-35/KS-33 to south city limit of Wellsville

In this report, the GENMOD procedure in the commercial Statistical Analysis System (SAS) software version 9.1 was used to compute the SPF functions. Since SAS 9.1 uses the natural logarithm as a link function in the GENMOD procedure, the model of the SPF function is exponential, as presented by equation (1).

\[ ACC = e^{\beta_0} \times e^{(AADT_{Before} \times \beta_1)}, \]  

where \( ACC \) = expected number of accidents (per mile per year) in a section with the same characteristics to the section of interest, \( AADT_{Before} \) = average AADT for the before period, and \( \beta_0 \) and \( \beta_1 \) = intercept and slope of the regression analysis.

The negative binomial regression analysis also gives the overdispersion parameter \( (k) \) per mile. It is discussed in more details in Hauer (2001).

The result of the EB method depends on how much “weight” is given to accidents in similar sites (first part of equation [2]), and to the counted accidents in the treated sections during the before period (second part of equation [2]).

\[ \text{estimated } ACC = \rho \times ACC + (1 - \rho) \times ACC \text{ Before}, \]  

where \( \text{estimated } ACC \) = expected number of accidents in a period with the same duration of the before period, \( \rho \) = weight or how much influence is due to historical data or similar sites. This parameter was calculated using equation (3).

\[ \rho = \frac{1}{1 + (ACC/k)} \]  

The standard deviation of \( \text{estimated } ACC \), denoted by \( \sigma_{EST} \), was calculated by equation (4).

\[ \sigma_{EST} = \sqrt{\text{estimated } ACC \times (1 - \rho)} \]  

The corrected number of accidents that would have occurred in the after period if no treatment had been made was calculated by equation (5).

\[ \mu = \text{estimated } ACC \times C_1 \times C_2, \]  

where \( C_1 \) = ratio between the result of equation 1, using \( AADT_{After} \), and the result of the same equation, using \( AADT_{Before} \). It is clear that the relation between AADT and the number of accidents in a period is not linear (it follows the function given by equation 1). For this reason, \( C_1 \) was used to correct \( \text{estimated } ACC \), instead of the simple ratio between AADTs. \( C_2 \) = ratio between the duration of the after period and the duration of the before period.

The variance of \( \mu \) was calculated by equation (6).
An estimate of the safety-effectiveness of the CLRS treatment can be obtained by the ratio between $ACC_{After}$ and $\mu$. However, Hauer (1997) claims that an estimate like this is biased. A better estimate is obtained using equation (7).

$$\omega = \frac{ACC_{After}/\mu}{1 + (Var \mu/\mu^2)}$$

(7)

where $\omega$ = unbiased estimate of safety effectiveness of a treated site, or more than one site (using sums of the terms).

The variance of $\omega$ was obtained by equation (8).

$$Var \omega = \omega^2 \left[ \frac{(Var ACC_{After}/ACC_{After}^2) + (Var \mu/\mu^2)}{1 + (Var \mu/\mu^2)} \right]^2,$$

(8)

where $Var ACC_{After} = Variance of ACC_{After} = \sum ACC_{After}$.

Similar sites chosen and used to match section B on US 40 were US 24 in Douglas County and KS-33 in Franklin County. These were chosen the only ones used due to lack of convergence on the SAS algorithm when using the data of other potential similar sites available.

Data from all potential similar sites were used to calculate the SPF for section A on US 50, since the algorithm on SAS converged.

Parameters of the regression analysis and goodness-of-fit of the SPF functions are presented in Table 1. The goodness-of-fit was evaluated by deviance, scaled deviance, Pearson chi-square, and log likelihood statistics. The closer to 1 that value/DF reaches, the better the goodness-of-fit.
Table 1. Parameters of regressions and evaluation of goodness-of-fit of the SPF functions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SPF for US-40—Total Accidents</th>
<th>SPF for US-50—Total Accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>β₀</td>
<td>-1.2229</td>
<td>-1.4019</td>
</tr>
<tr>
<td>β₁</td>
<td>0.0007</td>
<td>0.0004</td>
</tr>
<tr>
<td>K</td>
<td>-0.0793</td>
<td>-0.1475</td>
</tr>
<tr>
<td>Deviance</td>
<td>16</td>
<td>62</td>
</tr>
<tr>
<td>Scaled Deviance</td>
<td>16</td>
<td>62</td>
</tr>
<tr>
<td>Pearson Chi-Square</td>
<td>16</td>
<td>62</td>
</tr>
<tr>
<td>Log Likelihood</td>
<td>92.6221</td>
<td>48.7775</td>
</tr>
</tbody>
</table>

In order to compute the head-on and opposite-direction sideswipe accidents that would be corrected by CLRS, all police accident reports for accidents in the treated sections of US 40 and US 50 were analyzed. Since this paper uses the total number of accidents to calibrate SPFs, police accident reports from the similar sites were not analyzed. The potentially correctable crossover accidents considered occurred on non-intersection zones due to drivers’ inattention, influence of alcohol, and drivers that fell asleep. All accidents that occurred due to other factors were not considered as CLRS correctable, and were not computed in the analysis of HO + OPP SW accidents.

Another analysis was done using the total number of accidents, excluding those involving animals, intersections, or related to intersections. The effect of the treatment could be over or under estimated due to the presence of these types of accidents on the calculation, because the incidence of animals and the number of intersections per mile of highway can be very different from one section to another, and there was no data available revealing these numbers.

In summary, two analyses were done. The first used total number of accidents excluding intersections and animals. The second computed only HO + OPP SW types of accidents. Both analyses had the SPFs generated using total number of accidents (all types) as input data.

**KEY FINDINGS**

**Naïve Before-and-After Method**

Table 2 shows results of the Naïve before-and-after method.
Table 2. Results of the Naïve before-and-after method

<table>
<thead>
<tr>
<th>Total</th>
<th>Section</th>
<th>Length (miles)</th>
<th>Installation</th>
<th>Years</th>
<th># Acc Before</th>
<th># Acc After</th>
<th>Rate Before</th>
<th>Rate After</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before</td>
<td>After</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A on US 50</td>
<td>15.18</td>
<td>June, 2003</td>
<td>5.5</td>
<td>4.5</td>
<td>75</td>
<td>38</td>
<td>0.90</td>
<td>0.56</td>
<td>38.07%</td>
</tr>
<tr>
<td>B on US 40</td>
<td>10.76</td>
<td>May, 2005</td>
<td>7.42</td>
<td>2.58</td>
<td>205</td>
<td>32</td>
<td>2.57</td>
<td>1.15</td>
<td>55.11%</td>
</tr>
<tr>
<td>Overall</td>
<td>25.94</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50.69%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HO + OPP SW Section</th>
<th>Length (miles)</th>
<th>Installation</th>
<th>Years</th>
<th># Acc Before</th>
<th># Acc After</th>
<th>Rate Before</th>
<th>Rate After</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>A on US 50</td>
<td>15.18</td>
<td>June, 2003</td>
<td>5.5</td>
<td>4.5</td>
<td>6</td>
<td>1</td>
<td>0.07</td>
<td>0.01</td>
</tr>
<tr>
<td>B on US 40</td>
<td>10.76</td>
<td>May, 2005</td>
<td>7.42</td>
<td>2.58</td>
<td>9</td>
<td>0</td>
<td>0.11</td>
<td>0.00</td>
</tr>
<tr>
<td>Overall</td>
<td>25.94</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>92.07%</td>
</tr>
</tbody>
</table>

During the before period on US 50 (section A), there were six HO or OPP SW accidents. Four of these were caused by drivers’ inattention, one occurred due to alcohol interference, and one due to driver falling asleep. During the after period in the same section, there was only one accident, caused by driver’s inattention. Considering the section of US 40, nine HO or OPP SW accidents occurred in the before period. Five of these occurred due to drivers’ inattention, two due to alcohol influence, and two due to drivers that fell asleep. No HO or OPP SW accident occurred in this section during the after period.

Results of the Naïve method showed that in section A on US 50, the number of total accidents per mile per year (excluding animals and intersections) decreased 38.07% in the after period compared to the before period. The number of crossover accidents (head-on and opposite-direction sideswipe) decreased 79.63% in this section after the installation of CLRS. In section B on US 40, the number of total accidents per mile per year decreased 55.11%. The number of crossover accidents decreased 100%, since no crossover accidents occurred in this section after the installation of CLRS. Overall, the number of total accidents per mile per year decreased 50.69%. The number of crossover accidents decreased 92.07%. It is clear that CLRS were not created with the purpose of reducing all types of accidents. However, results of the Naïve method provide evidence that CLRS are potentially effective in reducing total number of accidents, and are particularly effective in reducing head-on and opposite-direction sideswipe accidents.

**Empirical Bayes Method**

Table 3 presents the analysis of safety effectiveness in the sections treated with CLRS, using the EB method.
Table 3. Safety effectiveness in sections treated with CLRS – EB method

<table>
<thead>
<tr>
<th>Section</th>
<th>AADT Before</th>
<th>AADT After</th>
<th>Counted Accidents During After Period with Treatment</th>
<th>Expected Accidents During After Period in case of No Treatment</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>HO + OPP SW</td>
<td>Total (σ)</td>
</tr>
<tr>
<td>A on US 50</td>
<td>5524</td>
<td>5036</td>
<td>38</td>
<td>1</td>
<td>53.93 (6.23)</td>
</tr>
<tr>
<td>B on US 40</td>
<td>4255</td>
<td>4465</td>
<td>52</td>
<td>0</td>
<td>83.83 (5.86)</td>
</tr>
<tr>
<td>Overall</td>
<td>90</td>
<td>1</td>
<td>137.76 (8.55)</td>
<td>8.68 (2.21)</td>
<td>49.38% (47.58% - 51.18%)</td>
</tr>
</tbody>
</table>

Section A on US 50 presented a statistically significant reduction, estimated as 30.47%, in number of total accidents and 79.75% in number of HO+OPP SW accidents. Considering section B, the reduction of total accidents was significant and estimated as 62.01%. The targeted crossover accidents were reduced from 3.65 to zero (100% of reduction). Section B, treated with football-shaped CLRS, presented a potentially better effect when compared with section A, treated with rectangular CLRS. However, this comparison may have limited validity due to differences between all other variables relative to the sections.

Overall, considering both sections, reduction of total accidents (excluding animals and intersections) was significant and estimated as 49.38%, and reduction of the targeted crossover (HO + OPP SW) accidents was also significant and estimated as 89.18%. Thus, the treatments were effective in decreasing the number of total and crossover accidents.

Table 4 summarizes the results of this report, comparing the two methods.

Table 4. Comparison between results of the Naïve and EB methods

<table>
<thead>
<tr>
<th>Section</th>
<th>Naïve Total (95% CI)</th>
<th>EB Total (95% CI)</th>
<th>Naïve HO + OPP SW</th>
<th>EB HO + OPP SW (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A on US 50</td>
<td>38.07% (27.93% - 33.01%)</td>
<td>30.47% (27.93% - 33.01%)</td>
<td>79.63%</td>
<td>79.75% (68.03% - 91.46%)</td>
</tr>
<tr>
<td>B on US 40</td>
<td>55.11% (61.44% - 62.58%)</td>
<td>62.01% (61.44% - 62.58%)</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
<tr>
<td>Overall</td>
<td>50.69% (47.58% - 51.18%)</td>
<td>49.38% (47.58% - 51.18%)</td>
<td>92.07%</td>
<td>89.18% (66.70% - 111.67%)</td>
</tr>
</tbody>
</table>

The comparison between the results of the two methods reveals that the reduction in the total number of accidents, calculated by the Naïve method, is comparable with the reduction found by the EB method. Considering the targeted crossover accidents, results of the two methods are also comparable.

In summary, both methods showed a significant reduction in accidents after the installation of CLRS. It is concluded that the treatments had a positive effect in reducing both crossover accidents and total accidents in the two analyzed sections.
Comparison to Other States

Although there are a considerable number of studies about the effectiveness of CLRS in reducing accidents in the United States, types of accidents evaluated in these studies are not consistent. Therefore, in order to achieve a better comparison between the results found in Kansas and other studies, extra calculations were necessary in this study, using the same methodology previously cited for the Naïve and EB methods.

Table 5 summarizes the reduction of accidents per state after the installation of CLRS, calculated for other types of accidents.

Table 5. Reduction of accidents per state after installation of CLRS

<table>
<thead>
<tr>
<th>State / Accident Type</th>
<th>Naïve Method</th>
<th>EB Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal HO</td>
<td>HO + OPP SW</td>
</tr>
<tr>
<td>Arizona</td>
<td>56%</td>
<td></td>
</tr>
<tr>
<td>California</td>
<td>90%</td>
<td>12%</td>
</tr>
<tr>
<td>Colorado</td>
<td>34%</td>
<td>31%</td>
</tr>
<tr>
<td>Delaware</td>
<td>95%</td>
<td>81%</td>
</tr>
<tr>
<td>Maryland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minnesota</td>
<td>-12%</td>
<td>0%</td>
</tr>
<tr>
<td>Oregon</td>
<td></td>
<td>70%</td>
</tr>
<tr>
<td>Washington</td>
<td></td>
<td>21%</td>
</tr>
<tr>
<td><strong>Kansas</strong></td>
<td><strong>80%</strong></td>
<td><strong>59%</strong></td>
</tr>
</tbody>
</table>

Based on this limited data available from other states, it can be assumed that overall results found in Kansas are comparable to results found by other states, which reinforces the evidence that CLRS are effective in preventing crossover and possibly other types of accidents as well.

CONCLUSIONS

The results showed that installing CLRS reduced head-on and opposite-direction sideswipe types of accidents in the treated sections of US 50 and US 40. Although the CLRS were not expected to reduce all types of accidents, it appears they may have an effect on decreasing the total number of accidents as well. Results of the EB method were comparable to results found by the Naïve method for the analyses of CLRS correctable head-on, and sideswipe accidents and for the total number of accidents, excluding those involving animals and intersections.

The limitation of this study was the use of SPFs obtained for all types of accidents for predicting the number of the crossover accidents and total number of accidents.

Results of this report are comparable with results found in other states and evidence found in the literature, showing that installing CLRS is an effective way to reduce crossover accidents.
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REFERENCES