TECHBRIEF

Safety Evaluation of Intersection Conflict Warning Systems (ICWS)

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This document is a technical summary of the forthcoming Federal Highway Administration report *Safety Evaluation of Intersection Conflict Warning Systems (ICWS)* (HRT-16-035).

Objective

The Federal Highway Administration (FHWA) organized 40 States to participate in the FHWA Evaluation of Low-Cost Safety Improvements Pooled Fund Study (ELCSI-PFS) as part of its strategic highway safety plan support effort. The goal of the ELCSI-PFS research is to identify new safety strategies that effectively reduce crashes and promote them for nationwide installation by providing measures of their safety effectiveness and benefit to cost ratios through research. One of the strategies selected by member States to be evaluated for this study is intersection conflict warning systems (ICWS). This strategy is intended to reduce the frequency of crashes by alerting drivers of conflicting vehicles on adjacent approaches at unsignalized intersections, particularly those with one-way or two-way stop control.

Few studies have explored the safety effectiveness of ICWS; the effectiveness has not been shown for four-legged intersections. This study sought to fill this knowledge gap.

Introduction

Providing an automated real-time system to inform drivers of suitability of available gaps for making turning

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and crossing maneuvers is a recommended strategy in Volume 5 of the NCHRP 500 Series Guidebooks.[1] These systems may be installed on the major and/or minor approaches of unsignalized intersections with stop-control on the minor approaches. They employ vehicle detectors to alert motorists of conflicting vehicles on an adjacent approach. Current installation practices use warning signs on the major approaches alerting motorists with a message stating "VEHICLE ENTERING WHEN FLASHING," "CROSSING TRAFFIC WHEN FLASHING," or "WATCH FOR ENTERING TRAFFIC." Signs on the minor approaches alert entering motorists with "TRAFFIC APPROACHING WHEN FLASHING," "LOOK FOR TRAFFIC" (with yellow light-emitting diode arrow-shaped flashers), or visual graphic displays.

A literature review revealed that few research studies have considered the effectiveness of ICWS systems, with most studies focusing on speed effects or conflict analyses. The Missouri Department of Transportation (MoDOT) conducted a simple before-after study of the safety effectiveness of post-mounted ICWS at 9 stop-controlled intersection major street approaches and 10 stop-controlled intersection minor street approaches.[2] The results showed a 28 percent reduction in total crashes, 72 percent reduction in severe crashes, 37 percent reduction in angle crashes, and a 75 percent reduction in severe angle crashes at the locations with the installation on the major street approach. MoDOT also found a 32 percent reduction in total crashes, 33 percent reduction in severe crashes, 44 percent reduction in angle crashes, and a 38 percent reduction in severe angle crashes at the locations with the minor street approach.

Simpson and Troy evaluated "Vehicle Entering when Flashing" signs at 56 two-lane at two-lane intersections in North Carolina.[3] A before-after analysis was conducted to assess the crash reduction factor for multiple crash types. The following definitions were provided for the four categories of signs used in North Carolina:

- Category 1 – Overhead signs and flashers on major; loop on minor.
- Category 2 – Overhead signs and flashers on minor; loop on major.
- Category 3 – Post mounted signs and flashers on major; loop on minor.
- Category 4 – Locations with combination of categories 1–3.

The authors found that deployments with alerts on the major road in advance of the intersection and locations with a combination of both major and minor road alerts were the most effective, with Crash Modification Factors (CMFs) for total crashes of 0.68 and 0.75, respectively. Intersections with four lanes on the major route were considered; however, no apparent reductions in crashes were found for these sites.

This study builds on these limited efforts using a multi-State database.

Introduction

This research examined the safety impacts of ICWS at rural four-leg intersections in Minnesota, Missouri, and North Carolina. Two-lane at two-lane intersections were considered separately from four-lane at two-lane intersections. All Minnesota installation sites were post-mounted, and all sites had a warning sign on the minor roadway approach. The four-lane at two-lane intersections had visual displays. All Missouri sites were post-mounted, with a mix of sites on the major approaches and the minor approaches. North Carolina sites were a mix of post-mounted and/or overhead ICWS signs. All North Carolina four-lane at two-lane intersections had ICWS on the major approaches.

The objective was to estimate the safety effectiveness of this strategy as measured by changes in the frequency of crashes. The following crash types were targeted:

- Total crashes (all types and severities combined).
- Injury crashes (K, A, B, and C injuries on KABCO scale).
- Right-angle crashes (all severities combined).
- Rear-end crashes (all severities combined).
- Nighttime crashes (all severities combined).

A further objective was to conduct a disaggregate analysis to investigate whether the safety effects vary by factors such as the type of installation, location of installation, the level of traffic volumes, the expected crash frequency before treatment, posted speed limit on the major and minor approaches, presence of turn lanes, presence of intersection lighting, and presence of "WHEN FLASHING" message.

The evaluation of overall effectiveness included the consideration of the installation costs and crash savings in terms of the benefit-cost (B/C) ratio.

The empirical Bayes (EB) methodology for observational before-after studies was used for the evaluation.[4] This methodology is considered rigorous in that it accounts for regression-to-the-mean using a reference group of similar but untreated sites. In the process, Safety Performance Functions (SPFs) are applied. SPFs are equations used to estimate the predicted crash frequency of a site based on its characteristics that influence crashes (e.g., traffic volumes). The use of SPFs in the EB methodology addresses the following:

- It overcomes the difficulties of using crash rates in normalizing for volume differences between the before and after periods.
- It accounts for time trends.
- It reduces the level of uncertainty in the estimates of safety effect.
- It properly accounts for differences in crash experience and reporting practice in amalgamating data and results from diverse jurisdictions.

The methodology also provides a foundation for developing guidelines for estimating the likely safety consequences of a contemplated strategy.

The SPFs used in the EB methodology were estimated through generalized linear modeling assuming a negative binomial error distribution, which is consistent with the state of research in developing these models. In specifying a negative binomial error structure, an overdispersion parameter—which is used in the EB calculations—was estimated iteratively from the model and the data. For a given dataset, smaller values of this parameter indicate relatively better models.

The full report includes a detailed explanation of the methodology, including a description of how the estimate of safety effects for target crashes was calculated.

Results

Based on the data for all three States combined, results are presented in two parts. The first part contains aggregate results, and the second part is based on a disaggregate analysis that attempted to discern factors that may be most favorable to the installation of ICWS.

Aggregate Analysis

The aggregate results for all three States are shown in table 1, which provides the estimates of predicted crashes in the after period without treatment, the observed crashes in the after period, and the estimated CMF and its standard error for all crash types considered. The percent change in crashes is 100×(1–Estimate of the CMF); thus, a CMF of 0.73 with a standard deviation of 0.035

Table 1. Combined results for Minnesota, Missouri, and North Carolina.

	Total	Fatal and Injury	Right-Angle	Rear-End	Nighttime
Two-Lane at Two-Lane					
EB estimate of crashes predicted in the after period without strategy	912.79	515.56	522.17	100.46	128.84
Count of crashes observed in the after period	670	362	420	43	116
Estimate of CMF	0.733	0.701	0.803	0.425	0.898
Standard error of estimate of CMF	0.035	0.045	0.049	0.073	0.096
Four-Lane at Two-Lane					
EB estimate of crashes predicted in the after period without strategy	464.50	263.56	295.47	33.07	85.52
Count of crashes observed in the after period	385	212	252	33	53
Estimate of CMF	0.827	0.802	0.850	0.973	0.612
Standard error of estimate of CMF	0.059	0.072	0.075	0.224	0.108

indicates a 27 percent reduction in crashes with a standard deviation of 3.5 percent.

For two-lane at two-lane intersections, the crash type with the smallest CMF (which translates to the greatest reduction) is rear-end with a CMF of 0.425, which is statistically significant at the 95 percent confidence level. Total, fatal and injury, and right-angle crashes have estimated CMFs of 0.733, 0.701, and 0.803, respectively, which are also statistically significant at the 95 percent confidence level. Nighttime crashes have an estimated CMF of 0.898, which is not statistically significant at the 95 percent confidence level. Consideration should be given to the sample size used to develop each CMF when interpreting the results. For example, the sample sizes used to develop CMFs for rear-end and nighttime crashes are relatively low, resulting in larger standard errors and confidence intervals compared to the CMFs for total, fatal and injury, and right-angle crashes.

For four-lane at two-lane intersections, the crash type with the smallest CMF (which was statistically significant at the 95 percent confidence level) is nighttime crashes, with a CMF of 0.612. Total, fatal and injury, and right-angle crashes have estimated CMFs of 0.827, 0.802, and 0.850, respectively, which are also statistically significant at the 95 percent confidence level. Rear-end crashes have an estimated CMF of 0.973, which is not statistically significant at the 95 percent confidence level.

As discussed in the literature review, the most comprehensive study to date of ICWS application was conducted by Simpson and Troy using data from North Carolina.[3]

This report includes recommended CMFs for two-lane at two-lane intersections but does not provide recommended CMFs for four-lane at two-lane intersections because the low sample size precluded a rigorous analysis. Simpson and Troy recommended a CMF of 0.897 for total crashes and 0.878 for injury crashes at two-lane at two-lane intersections.[3] Greater crash benefits were indicated in the present study, which are attributed to the following differences:

- Only four-legged intersections were included.
- The number of study years was limited to no more than five years before and five years after installation.
- SPFs were used to account for changes in traffic volumes.
- Annual multipliers were used to account for trends at reference sites.
- A multi-State database was used.

Disaggregate Analysis

The disaggregate analysis sought to identify those conditions under which the strategy is most effective. Since total, fatal and injury, and right-angle crashes are the focus of this strategy, these crash types are the focus of the disaggregate analysis. The following variables were identified as being of interest and available for all three States:

- Installation category.
- Sign message.
- Presence of turn lanes.
- Presence of lighting.
- Presence of additional countermeasures.

- Major and minor route average annual daily traffic.
- Major and minor route posted speed limit.
- Predicted crash frequency in the before period.

For installation category, the categories developed by the North Carolina Department of Transportation were expanded for use in this study. Categories for further analysis included the following:

- Category 1 – Overhead signs and flashers at the intersection on major; loop on minor.
- Category 2 – Overhead signs and flashers at the intersection on minor; loop on major.
- Category 3a – Post mounted signs and flashers in advance of the intersection on major; loop on minor.
- Category 3b – Post mounted signs and flashers at the intersection on minor; loop on major.
- Category 4 – Locations with combination of categories 1–3.

For two-lane at two-lane intersections, all categories were considered in the disaggregate analysis. For four-lane at two-lane intersections, categories 3a and 3b were included in the disaggregate analysis. Systems in categories 1 and 2 were found only in North Carolina, and these systems were installed at the intersection on both the major and minor road. Category 3a signs were found only in Missouri and North Carolina and were installed in advance of the intersection. Category 3b systems were found only in Minnesota and Missouri and were installed at the intersection.

Table 2 provides the disaggregate results by category for two-lane at two-lane intersections and four-lane at two-lane intersections. The number of intersections is indicated for each installation category. For each crash type, the estimated CMF and standard error (in parentheses) is provided. The sample size used to develop the CMFs should be considered when applying the CMFs.

For two-lane at two-lane intersections, the results indicate statistically significant reductions at the 95 percent confidence level for all crash types for systems in categories 1, 3a, and 4. Considering the standard errors of the CMFs, it is difficult to make a statement about the relative effectiveness of categories 1, 3a, and 4; with the exception of the CMFs for right-angle crashes, the results are not statistically different at the 95 percent level. The majority of the category 4 sites consist of a combination of categories 1 and 2 or a combination of categories 3a and 3b.

For four-lane at two-lane intersections, the results indicate statistically significant reductions at the 95 percent confidence level for all crash types for category 3a and for total crashes only for category 3b systems. The CMFs for categories 3a and 3b were not significantly different for any crash type.

It is not appropriate to compare the effectiveness of overhead versus post-mounted applications on the major route from the study results because the placement of treatment differed for the two groups. Post-mounted ICWS were installed in advance of the intersection, whereas all overhead signs were installed at the intersection. Ideally, to consider the difference between post-mounted and overhead signs, the placement should be taken into consideration. The Manual on Uniform Traffic Control Devices (MUTCD) states that warning signs should be placed to provide an adequate perception-response time.[5] This suggests that the findings in table 2 may be influenced by system placement, which could not be addressed in this research.

Table 3 presents the disaggregate results by predicted crash frequency in the before period. There was no apparent difference by predicted crash frequency for two-lane at two-lane intersections. For four-lane at two-lane intersections, the strategy was more effective when the predicted crash frequency was higher in the before period. This is logical because the strategy is often used at intersections with unusually high crashes or issues related to limited sight distance. For total crashes, there does not appear to be a benefit if the predicted crash frequency is less than or equal to three crashes per year before installation;

Table 2. CMFs by installation category.

Category	1	2	3a	3b	4
Two-Lane at Two-Lane					
N (sites)	16	15	14	8	16
Total	0.740 (0.070)	0.892 (0.075)	0.519 (0.056)	0.886 (0.162)	0.704 (0.087)
Fatal and Injury	0.600 (0.075)	0.944 (0.101)	0.450 (0.069)	1.064 (0.287)	0.742 (0.122)
Right-Angle	0.807 (0.096)	1.084 (0.110)	0.454 (0.067)	1.247 (0.299)	0.697 (0.113)
Four-Lane at Two-Lane					
N (sites)	N/A	N/A	12	7	N/A
Total	N/A	N/A	0.745 (0.068)	0.690 (0.127)	N/A
Fatal and Injury	N/A	N/A	0.734 (0.083)	0.896 (0.210)	N/A
Right-Angle	N/A	N/A	0.769 (0.082)	0.763 (0.173)	N/A

Table 3. CMFs by predicted crash frequency in the before period.						
Lanes	**Crash Type**	**Crashes Per Year**	**Predicted**	**Observed**	**CMF**	**SE**
4	Total	≤ 3	114.23	121	1.047	0.147
		> 3	350.27	264	0.751	0.062
	Fatal and Injury	≤ 2	66.28	74	1.101	0.179
		> 2	197.28	138	0.696	0.075
	Right-Angle	≤ 2.5	93.32	116	1.228	0.176
		> 2.5	202.15	136	0.669	0.075

however, there is a significant reduction for sites with more than three predicted crashes per year in the before period. The results for right-angle crashes are significantly different from each other for sites with less than or equal to 2.5 predicted crashes per year versus sites with more than 2.5 predicted crashes per year before installation. There does not appear to be a benefit if the predicted fatal and injury crash frequency is less than or equal to two crashes per year before installation; however, there is a significant reduction for sites with more than two predicted fatal and injury crashes per year in the before period.

Additional disaggregate analyses can be found in the full report.

Economic Analysis

An economic analysis was conducted to estimate the B/C ratio for this strategy for two-lane at two-lane intersections and four-lane at two-lane intersections. The statistically significant reduction in total crashes for combined States was used as the benefit for two-lane at two-lane intersections and for four-lane at two-lane intersections.

The average installation cost for all two-lane at two-lane intersections was $41,590. The average installation cost was $106,158 for four-lane at two-lane intersections. Additionally, a conservative annual maintenance and operations cost of $1,075 was assumed for two-lane at two-lane intersections. A value of $1,200 for annual maintenance and utility costs was assumed for four-lane at two-lane sites with loop detectors. An annual value of $3,400 was used for four-lane at two-lane sites with wireless communication. The analysis assumed that the useful service life for safety benefits was 10 years. The service life for loop detectors was assumed to be 5 years. In total, 69 two-lane at two-lane intersections and 24 post-mounted four-lane at two-lane intersections were installed.

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A-4 discount rate of 7 percent to calculate the annual cost of the treatment for the 10-year service life. With this information, the Capital Recovery Factor was computed to be 7.024 for all intersection types.

For the benefit calculations, the most recent FHWA mean comprehensive crash costs disaggregated by crash severity and location type were used as a base.[6] These costs were developed based on 2001 crash costs, and the unit cost (in 2001 dollars) for fatal and injury crashes was $158,177 and for property damage only (PDO) crashes was $7,428. This was updated to 2014 dollars by applying the ratio of the U.S. Department of Transportation (USDOT) 2014 value of a statistical life of $9.2 million to the 2001 value of $3.8 million.[7,8] Applying this ratio of 2.42 to the unit costs for PDO and fatal and injury crashes, and then weighting by the frequencies of these two crash types in the after period, resulted in an aggregate 2014 unit cost for total crashes of $202,060 for two-lane at two-lane intersections and $219,876 for four-lane at two-lane intersections.

The total crash reduction was calculated by subtracting the actual crashes in the after period from the predicted crashes in the after period had the strategy not been implemented. The total crash reduction was then divided by the average number of after period years per site to compute the total reduced crashes per year. The number of total reduced crashes per year was 65.69 for all two-lane at two-lane intersections and 19.08 for four-lane at two-lane intersections. Considering the number of intersections installed, this resulted in an average reduction of 0.95 crashes per intersection per year for two-lane at two-lane intersections and 0.79 crashes per intersection per year for four-lane at two-lane intersections.

The annual benefits (i.e., dollar value of crash savings) were obtained by multiplying the crash reduction per site per year by the cost of a crash, all severities combined. The B/C ratio is calculated as the ratio of the annual benefit to the annual cost. The B/C ratio is estimated to be 27:1 for two-lane at two-lane intersections and 10:1 for four-lane at two-lane intersections. USDOT recommends that a sensitivity analysis be conducted by assuming values of a statistical life of 0.57 and 1.41 times the recommended 2014 value.[7] These factors can be applied directly to the estimated B/C ratios to get a range of 16:1–39:1 for two-lane at two-lane intersections and 6:1–14:1 for four-lane at two-lane intersections. These results suggest that the strategy—even with conservative assumptions on cost, service life, and the value of a statistical life—can be cost effective for reducing total crashes at four-legged intersections with stop-control on the minor approaches.

Summary And Conclusions

The objective of this study was to undertake a rigorous before-after evaluation of the safety effectiveness of ICWS, as measured by crash frequency. The study used data from three States—Minnesota, Missouri, and North Carolina—to examine the effects for specific crash types including total, fatal and injury, right-angle, rear-end, and nighttime crashes. Based on the combined results, the CMFs shown in table 4 are recommended for the various crash types.

The aggregate results indicate statistically significant crash reductions at the 95 percent confidence level for all crash types except nighttime crashes for two-lane at two-lane intersections. The results also indicate statistically significant crash reductions in all crash types except rear-end crashes for four-lane at two-lane intersections.

The disaggregate analysis sought to identify those conditions under which the strategy is most effective. Since total, fatal and injury, and right-angle crashes are the focus of this strategy, these crash types are the focus of the disaggregate analysis. The disaggregate analysis of the results for two-lane at two-lane intersections indicated larger percentage crash reductions for sites installed on the major route, particularly for post-mounted ICWS in advance of the intersection. Additional benefit may be provided by including the "WHEN FLASHING" phrase as part of the message. The disaggregate CMFs may be used in prioritizing installation sites, but interpretations should be made with caution. Particular attention should be paid to the sample size used to develop the CMFs.

The disaggregate analysis for four-lane at two-lane intersections indicated larger percentage crash reductions for sites with intersection lighting and for sites with a higher predicted average crash frequency in the before period. There was no substantive difference for sites with warning on the major route versus warning on the minor route. The disaggregate CMFs may be used in prioritizing installation sites, but interpretations should again be made with caution.

Table 4. Recommended CMFs based on combined States.

	Total	Fatal and Injury	Right-Angle	Rear-End	Nighttime
Two-Lane at Two-Lane					
Estimate of CMF	0.733	0.701	0.803	0.425	0.898
Standard error of estimate of CMF	0.035	0.045	0.049	0.073	0.096
Four-Lane at Two-Lane					
Estimate of CMF	0.827	0.802	0.850	0.973	0.612
Standard error of estimate of CMF	0.059	0.072	0.075	0.224	0.108

The B/C ratio estimated with conservative cost and service life assumptions and only considering the benefits for total crashes is 27:1 for all two-lane at two-lane intersections and 10:1 for four-lane at two-lane intersections with post-mounted signs. These results suggest that the strategy—even with conservative assumptions on cost, service life, and the value of a statistical life—can be cost effective.

As this is an evolving strategy, this study reflects installation practices to date. Future studies may show different results as installation practices change. In particular, the use of overhead ICWS on the major route was limited to the installations at the intersection (i.e., no advance warning), while post-mounted ICWS on the major route were installed in advance of the intersection. Future research should compare these installation practices, considering placement of warning signs. Specifically, Section 2C.05 of the MUTCD provides guidance for the placement of warning signs so that they provide adequate perception-response time.[5]

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