Recent U.S. Research on Safety Evaluation of Low-Cost Road Engineering Safety Countermeasures – Lessons for Canada

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ABSTRACT

This paper synthesizes results to date and assesses relevance to the Canadian context for the Federal High Administration's (FHWA's) "Evaluation of Low Cost Safety Improvements Pooled Fund Study" (ELCSI-PFS, http://www.tfhrc.gov/safety/evaluations/). The FHWA has organized the ELCSI-PFS, involving 28 States, to evaluate low-cost safety strategies as part of the Strategic Highway Safety Plan developed by the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Highway Traffic Safety. The purpose of the Pooled Fund Study is to evaluate the safety effectiveness of tried and experimental priority low-cost safety strategies through scientifically rigorous crash-based or simulation-based studies, and develop Crash Reduction Factors and benefit/cost ratios for nationwide applications of these low cost strategies. Currently, this PFS has six phases, each involving evaluations of four to six strategies. Based on inputs from the Pooled Fund Study Technical Advisory Committee and the availability of data, crash based evaluations have been recently conducted, or are underway, for a number of strategies, including signing enhancements to improve curve delineation, flashing beacons, stop ahead warning signs, offset left turn lanes, two-way left turn lanes, and increased retro-reflectivity stop signs. Simulator-based studies have been conducted for two sets of low-cost countermeasures for two-lane rural roads: nighttime delineation for curves, and traffic calming for small towns. The current phase of the study involves "build to evaluate" projects in which prospective evaluations are being considered for treatments such as surface friction treatments for curves and ramps, in-lane pavement marking for curve warning, enforcement lights (These are auxiliary lights connected to a traffic-control signal to help law enforcement officers identify when drivers violate the red phase of the signal.), edge line rumble stripes and large chevron signs. The next phase, starting Fall 2010, is also "build to evaluate", and will potentially evaluate intersection multi-strategy improvements, yield to pedestrian channelizing devices, centerline rumble strips and edge-line or shoulder rumble strips for 4-foot (1.2-m) shoulders with emphasis on curves, guardrail and/or median barriers (including guardrail on interstates and cable median barrier with rumble strips).

BACKGROUND ON THE RESEARCH

In 1997, the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Highway Traffic Safety, with the assistance of the Federal Highway Administration (FHWA), the National Highway Traffic Safety Administration (NHTSA), and the Transportation Research Board (TRB) Committee on Transportation Safety Management, met with safety experts in the field of driver, vehicle, and highway issues from various organizations to develop a strategic plan for highway safety. These participants developed 22 key areas that affect highway safety.

The National Cooperative Highway Research Program (NCHRP) published a series of guides to advance the implementation of countermeasures targeted to reduce crashes and injuries. Each guide addresses one of the 22 emphasis areas and includes an introduction to the problem, a list of objectives for improving safety in that emphasis area, and strategies (treatments or countermeasures) for each objective. Each strategy is designated as proven, tried, or experimental. Many of the strategies discussed in these guides have not been rigorously evaluated; about 80 percent of the strategies are considered tried or experimental.

The FHWA organized a pooled fund study of 28 States to evaluate low-cost safety strategies as part of this strategic highway safety effort. The purpose of the Pooled Fund Study is to evaluate the safety effectiveness of several tried and experimental, low-cost safety strategies through scientifically rigorous crash-based studies. This paper summarizes the results of 6 crash based before-after evaluations conducted.

The research for these evaluations typically involved the estimation of the effects on several potentially affected crash types and severities, and a disaggregate analysis to examine whether the effects vary with factors such as traffic volumes, the setting of the treatment and the crash experience before the treatment is applied. All studies involved an economic analysis to estimate a benefit-cost ratio for the treatment and/or to investigate the treatment application conditions that would yield a favorable benefit cost ratio. Recent FHWA crash costs disaggregated by site type and environment and crash type and severity were used for more precision.

The empirical Bayes (EB) methodology was used for the before-after evaluations. This enabled the analysis to account for changes in safety unrelated to the treatment; these include effects due to regression to the mean, traffic volume changes and time trends in factors such as crash reporting practices and weather.

Site selection and data collection were usually preceded by a study design that involved a sample size analysis and the prescription of needed data elements. The sample size analysis assessed the size of sample required to statistically detect an expected change in safety and also determined what changes in safety can be detected with likely available sample sizes. The sample size estimation procedure required assumptions of the expected treatment effect, which was based on a literature review, and the average crash rate at treatment sites in the period before treatment. Minimum and desired sample sizes were calculated based on ranges of the assumed values.

RESULTS

Research has been completed for the evaluation of eight strategies. Information and results for six strategies are summarized in the remainder of this paper. Several FHWA publications contain full details. These are available at http://www.tfhrc.gov/safety/evaluations/pubs.htm.

Flashing beacons

Data were acquired in two States, with a total of 64 sites in North Carolina, and 61 in South Carolina. In North Carolina, many of the evaluated flashing beacons were "standard" (i.e., flash 24 hours a day); however, there were also several "actuated" installations (i.e., flash only when a vehicle approaches an intersection). The beacons were installed either overhead or on a stop sign.

Of the 61 flashing beacons in South Carolina, 12 were mounted on STOP signs and 49 were mounted over the intersection. The majority of the flashing beacons were installed at 4-leg intersections on 2-lane roads. All the flashing beacons evaluated in South Carolina are standard (i.e., flash 24 hours a day).

The aggregate results for the two States combined are shown in Table 1. The economic analysis based on the combined results for angle and non-angle accidents from both States indicates that standard flashing beacons and the less expensive non-standard ones are economically justified, but that a benefit cost ratio of 2:1 may not be achievable for the more expensive of the other (non-standard) beacon types.

Table 1: Results for 106 North and South Carolina Flashing Beacon Strategy Sites

	Angle	**Injury & Fatal (K, A, B, C)**	**Rear-end**	**Total**
EB estimate of crashes expected in the after period without strategy	689.2	648.8	221.6	1297.0
Count of crashes observed in the after period	598	583	205	1232
Estimate of percent reduction in crashes (standard error)	**13.3% (4.6)**	**10.2% (4.8)**	7.9% (8.9)	5.1% (3.6)
Estimate of reduction in crashes per site-year	0.21	0.15	0.04	0.15

Stop-ahead pavement markings

Providing pavement markings with supplementary messages (such as "STOP AHEAD") can help alert drivers to the presence of an intersection. These markings may be particularly appropriate for unsignalized intersections with patterns of rear-end, right-angle, or turning collisions related to lack of driver awareness of the intersection. An example of a STOP AHEAD pavement marking, which is supplemented by a sign, is shown in Figure 1.

The evaluation results are shown in Table 2 for two States that were combined for an aggregate and disaggregate analysis. Based on these results and the economic analysis, it was concluded that this strategy has the potential to reduce crashes cost-effectively, particularly at three-legged and AWSC intersections.

Figure 1: Example of a Rural STOP AHEAD Installation

Table 2: Aggregate and Disaggregate Analysis Results for Stop Ahead Pavement Markings
(Note that a negative sign indicates an increase in crashes in crashes and bolded numbers indicate a significant change at the 95 percent level)

Crash Type	Group	Sites	EB estimate of crashes expected in the after period without strategy	Count of crashes observed in the after period	Estimate of percent reduction (standard error)
Injury Crashes	ALL	17	81.0	64	21.6% (12.0)
	3-legged	5	19.3	19	**54.7% (16.4)**
	4-legged	12	61.7	45	11.9% (15.0)
	AWSC	7	34.0	23	**42.3% (14.9)**
	OWSC/TWSC	10	47.0	41	7.7% (17.5)
Total Crashes	ALL	17	166.1	115	**31.1 (8.0)**
	3-legged	5	37.0	39	**60.1% (11.2)**
	4-legged	12	129.1	76	**23.0% (9.9)**
	AWSC	7	71.7	36	**55.9% (9.1)**
	OWSC/TWSC	10	94.4	79	12.8% (12.2)

Installing Center Two-Way Left-Turn Lanes on Two-Lane Roads

Two-way left-turn lanes for two-lane roads in Arkansas, California, Illinois, and North Carolina were chosen for evaluation based on the availability of installation data, including location and date. There were two methods used to install the TWLTLs used in the evaluation: repaving and reconstruction. Repaving reduces the shoulders and narrows the travel lanes to 11 feet (3.35 m). A 10-foot (3.05-m) center lane is then installed. Reconstruction widens the roadway in order to install an additional 11 or 12-foot (3.35 or 3.66-m) turn lane.

The aggregate and disaggregate combined results for four states are shown in the Table 3. The general conclusion that can be drawn from this research is that this is a cost-effective treatment for rural installations but that more research is required to ascertain if there are circumstances under which urban installations can be just as cost-effective. From the aggregate analysis and from logical considerations, locations with a high frequency of rear-end collisions, especially those involving a lead vehicle desiring to make a turn, would have a higher safety effectiveness for this treatment and would be prime candidates for installing two-way left-turn lanes.

Table 3: Aggregate and Disaggregate Analysis Results for Two-Way Left Turn Lanes
(Note that a negative sign indicates an increase in crashes and bolded numbers indicate a significant change at the 95 percent level)

Group	Sites	EB estimate of crashes expected in the after period without strategy	Count of crashes observed in the after period	Estimate of percent reduction (standard error)
ALL SITES – Total	144	1857.2	1481	**20.3 (3.0)**
ALL SITES – Injury		235.5	188	**26.1 (6.8)**
ALL SITES – Rear-end		700.2	430	**38.7 (4.0)**
Arkansas – rural – all	15	230.7	114	**51.2 (7.1)**
Arkansas – urban – all	10	349.6	337	3.8 (8.3)
California – rural – all	21	208.6	103	**50.8 (5.7)**
California – urban – all	10	92.8	96	-2.8 (13.4)*
Illinois – rural – all	5	111.1	93	16.7 (10.5)
Illinois – urban – all	5	125.3	114	9.4 (10.0)
North Carolina – rural – all	38	478.4	349	**27.3 (5.5)**
North Carolina – urban – all	40	260.9	275	-5.0 (8.8)*

* These negative effects are highly insignificant

Increased retro-reflectivity stop signs

Based on an evaluation of 339 sites in Connecticut and South Carolina, it was concluded that:

- There was a significant reduction (17.5%) in rear-end crashes in South Carolina.
- The strategy is more effective at lower volumes on the minor approaches.
- The strategy tended to be more effective at:
    - Rural installations in Connecticut
    - Urban installations in South Carolina.
- The strategy was more effective at 3-legged intersections.
- There were no detectable effects for nighttime crashes.
- The strategy can reduce crashes cost-effectively, particularly in situations identified.

Offset Left Turn Lanes

The motivation for this strategy is that the typical geometry of signalized intersections can present several challenges. Visibility of oncoming vehicles is important for drivers to identify acceptable gaps. Typical intersection alignments have opposing left-turn lanes directly across from one another and immediately adjacent to the through lanes. Thus, a left-turning vehicle in the opposite left-turn lane can obstruct the view of oncoming vehicles. The geometry at some intersections actually creates a negative offset, which further reduces sight distance for left-turning vehicles. Sight distance for left-turning vehicles can be improved by shifting the left-turn lanes to the left to create a positive offset.

Data were collected for a total of 105 installations at signalized intersections in three States: Wisconsin, Florida and Nebraska. During the data collection process, the project team identified variations in the design of offset left-turn lanes in the three States. Due to the variation in offset designs among the States, a classification scheme was devised to define the installations as one of three types of offset improvements. The adopted classification scheme is presented below and examples of the three types of offset improvements are provided in Figure 2.

- Type 1 – Positive Offset: The left-turn lanes are shifted to the left to enhance sight distance for opposing left-turn drivers (Figure 3, left).
- Type 2 – Lateral Separation with No Offset: Opposing left-turn lanes are directly aligned with no offset or a very slight positive offset (Figure 3, center).
- Type 3: Lateral Separation with Negative Offset: Opposing left-turn lanes are still negatively offset (Figure 3, right), although less negatively offset than in the before period.

Aggregate results are shown in the Table 4.

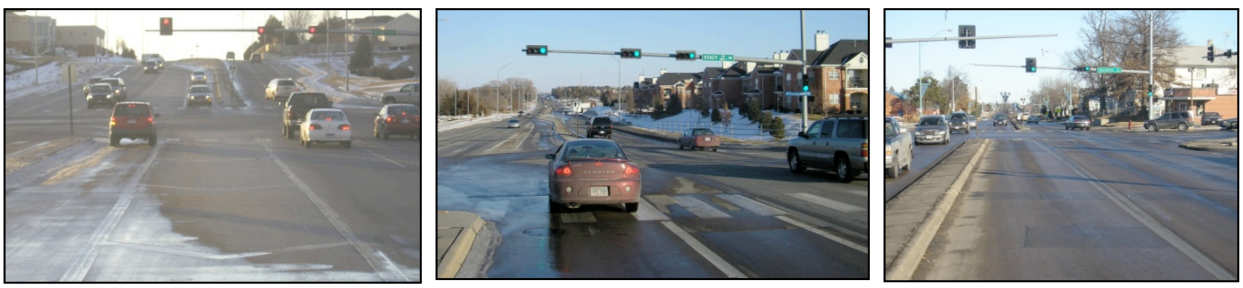

Figure 2. Example of Type 1 (left), Type 2 (center), and Type 3 (right) treatments

Table 4: Aggregate Results for Offset Left Turn Lanes Evaluation
(Negative sign indicates an increase in crashes and bolded text denotes effects that are significant at the 95% confidence level)

	State	Total	Injury	Left Turn*	Rear-End
EB estimate of crashes expected in the after period without strategy	Florida	969.9	471.7	118.8	257.9
	Nebraska	2795.81	1536.12	478.96	1248.64
	Wisconsin	233.77	95.88	94.85	72.76
Count of crashes observed in the after period	Florida	938	472	106	273
	Nebraska	2811	1441	695	1335
	Wisconsin	155	62.0	59	50
Estimate of percent reduction (and standard error)	Florida	3.4 (4.7)	0.2 (6.6)	11.4 (11.2)	-5.3 (9.9)
	Nebraska	-0.5 (2.4)	**6.2 (3.0)**	**-45.0 (6.7)**	**-6.9 (3.6)**
	Wisconsin	**33.8 (6.0)**	**35.6 (9.0)**	**38.0 (8.9)**	**31.7 (20.9)**

* Nebraska and Florida analyses were based on left-turn opposing crashes; For Wisconsin these could not be precisely identified; thus the analysis included all non-rear-end crashes involving a left-turning vehicle.

The economic analysis sought to identify the level of expected number of crashes that would yield a crash benefit that would justify the construction cost. Based on this analysis, Type 2 or Type 3 installations through reconstruction, as was undertaken in Florida, are cost-effective at intersections with at least nine expected crashes per year, for which the expected reduction in crashes is at least 8 percent. This information could be used by engineers in selecting and prioritizing locations for this treatment.

Improved Curve Delineation with Signing Enhancements

Options for enhanced delineation can include using higher durability/retro-reflectivity pavement markings, wider edge-lines, raised pavement markers and signing enhancements such as post-mounted delineators and chevrons. For the evaluation, data were collected in two States and involved signing enhancements to improve curve delineation. Aggregate results are shown in Table 5.

Table 5 Aggregate Results of Curve Signing Improvements

	State	**Non-Intersection**	**Non-Intersection Lane Departure**	**Injury and Fatal (K, A, B, C) Non-Intersection**	**Non-Intersection During Dark**	**Non-Intersection Lane Departure During Dark**
EB estimate of after period crashes without treatment	Connecticut	188.1	158.8	55.9	72.2	60.4
	Washington	374.8	308.6	211.8	169.5	147.7
	Two States combined	562.9	467.4	267.7	241.7	208.1
Count of crashes observed in the after period	Connecticut	155	131	42	47	40
	Washington	361	292	179	129	116
	Both States	516	423	221	176	156
Estimate of percent reduction (standard error)	Connecticut	**17.8% (7.7)**	**17.7% (8.4)**	**25.2% (12.7)**	**35.3% (10.5)**	**34.2% (11.5)**
	Washington	4.3% (8.9)	5.9% (8.8)	16.4% (10.4)	**24.5% (9.5)**	**22.1% (10.1)**
	Both States	8.6% (6.4)	9.7% (6.4)	**18.0% (8.6)**	**27.5% (7.3)**	**25.4% (7.8)**
Estimate of reduction in crashes per mile-year	Connecticut	1.54	1.29	0.64	1.17	0.95
	Washington	0.15	0.18	0.35	0.43	0.33
	Both States	0.40	0.38	0.40	0.56	0.45

Note: Bold denotes results that are statistically significant at the 95% confidence level.

In both States, the reductions appeared to be more prominent at locations with higher traffic volumes. An economic analysis revealed that improving curve delineation with signing enhancements is a very cost-effective treatment with the benefit cost ratio exceeding 8:1.

ASSESSMENT IN THE CANADIAN CONTEXT

Table 6 provides a comparison of the most significant results of the FHWA evaluations with information given in 3 key Canadian sources. (The TAC Geometric Design Guide, being design oriented, has information on only two treatments.) The comparison is based on crash reduction factors (CRFs), which are stated in terms of % reduction in crashes. The following observations can be made:

- For offset left turn lanes the information in the TAC Design Guide is only qualitative and pertains to the safety benefit of no offset (opposing) compared to negative offset (adjacent) lanes. Guidance is not provided for positive offset lanes, to which the FHWA CRF pertains. The CRF in the TAC In-service Road Safety Review Guide is similar to that derived in the FHWA evaluation for positive offset left turn lanes and should be retained.
- For flashing beacons, both the BC and the TAC In-service Road Safety Review Guide tend to have larger CRFs than were estimated in the FHWA evaluation. Consideration should be given to using the more conservative FHWA estimates.
- For stop ahead pavement markings the CRF in the TAC In-service Road Safety Review Guide is similar to that derived in the FHWA evaluation and should be retained.
- For two way left turn lanes, the CRF equation in the TAC Geometric Design Guide gives CRFs in the ballpark of that derived in the FHWA evaluation and should be retained, especially since, unlike the FHWA CRF, it logically provides variation with the density of access points.
- For increased retro-reflectivity stop signs, the only Canadian source (BC CRFs) is for increasing reflectivity of signs in general. The FHWA CRF information should therefore be adopted.
- For improved curve delineation, the FHWA CRFs, unlike the BC CRFs and those in the TAC In-service Road Safety Review Guide, pertain directly to target crashes (those during dark) and should therefore be adopted.

TABLE 6 Assessment of recent evaluation results in the Canadian context

Treatment	Summary of the most significant results from FHWA evaluations	Safety impact information in Canadian sources for similar or equivalent treatments		
		TAC Geometric Design Guide	**TAC Guide to In service Road Safety Reviews**	**British Columbia CRFs**
Flashing beacons	Reductions of 13.3% and 10.2 % in angle and fatal plus injury crashes, respectively.	Not covered	Up to 25% reduction in angle crashes and 10-15% reduction in rear-end and left turn crashes	10% reduction in all crashes; 20% reduction of night/poor weather crashes
Stop-ahead pavement markings	31.1 reduction in crashes overall, with the greatest reductions at 3-legged (60.1%) and at All-Way Stops (55.9%)	Not covered	Up to 30% reduction in all crashes at urban intersections; Up to 35% reduction in all crashes at rural intersections.	No CRF provided
Installing Center Two-Way Left-Turn Lanes on Two-Lane Roads (Add lane) (TWLTL)	20.3 in all crashes and 38.7% reduction in rear-end crashes	CRF= 35Y/(0.745+Y) where $Y = 0.0074X+0.0039X^2$ X= access points/km CRF ranges from 21% for 16 accesses/km to 5% for 5 accesses/km.	No CRF provided	30% reduction in "target" collisions – specified as all collisions for adding lane; 6% reduction on all collisions for converting 4-lane road to 2 lanes plus a center TWLTL
Increased retro-reflectivity stop signs	17.5% reduction in rear-end crashes in one State. More effective at lower volumes on the minor approaches and at 3-legged intersections	Not covered	No CRF provided	10% reduction in nighttime crashes for higher reflectivity signs in general
Offset Left Turn Lanes at Signalized Intersections	Major construction to provide positive offsets yielded reductions of 33.8% in all crashes mainly due to similar reductions in left turn and rear-end crashes	Only qualitative information provided. Opposing left turn lanes (no-offset) are suggested as being more desirable than adjacent (negative offset) lanes by increasing visibility of on-coming vehicles	CRF given for "re-align opposing lane approaches", which "may provide better sight distance for left turn drivers". 30% reduction in all crashes if "opposing left-turn lanes were offset"	No CRF provided
Improved Curve Delineation	27.5% reduction in crashes during dark; similar value for lane departure crashes	Not covered	5-35% reduction in all crashes; 30-40% reduction in off-road crashes	7% reduction in all crashes for installing curve and speed warning signs