Safety Performance of Edge-Lane Roads

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Abstract: This paper provides an observational before/after evaluation of the safety effects of edge-lane road (ELR) (also known as advisory bike lanes or advisory shoulders) installations in the United States. An ELR is a class of roadway that supports two-way automobile traffic within a single center lane and vulnerable road users (VRUs), i.e., bicyclists or pedestrians, in the edge lanes on either side. The use of a single lane by automobile users traveling in both directions is often a cause of potential safety concerns among the general public. This study employs a project-level empirical Bayes (EB) approach to before/after safety analysis for all US ELR sites where requisite crash data and other relevant characteristics were available. The analysis at 11 sites was performed with 8 years of crash data and more than approximately 60 million motor vehicle trips. Project-level EB analysis based on safety performance functions (SPFs) showed 8 of 11 ELR sites experienced a reduction in crash experience since installation. There was a ~44% reduction in crashes among all sites compared to the expected crashes on the traditional two-lane two-way design that existed before ELR installation. This estimation assumed the calibration factor for all SPFs used in the EB analysis was 1.0. Because of the geographical spread of the ELRs being analyzed in this study, estimation of specific calibration factors for all 11 sites was beyond the scope of this work. To address this limitation, we conservatively assumed the SPF calibration factors to be 0.50 for locations for which calibration factors were not available. This assumption was made for 7 of the 11 sites. Even with this conservative assumption, the ELRs were estimated to have a ~36% crash reduction. The results from this comprehensive evaluation of existing US ELRs should alleviate concerns the general public often has about the safety of ELRs for automobile users. **DOI: 10.1061/JTEPBS.0000739.** *© 2022 American Society of Civil Engineers.*

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Introduction

An edge-lane road (ELR) is a class of roadway that supports two-way automobile traffic within a single center lane and vulnerable road users (VRUs), i.e., bicyclists or pedestrians, in the edge lanes on either side. Automobiles may use the edge lanes to pass approaching vehicles after yielding to any VRUs there. ELRs are also called advisory bike lanes (ABLs), advisory shoulders, or dashed bicycle lanes. An ELR has no centerline. The center lane is separated from the edge lanes with broken line markings. The broken line markings indicate a permissive condition allowing motor vehicles to move into the edge lanes after yielding to any VRUs there (Fig. 1).

ELRs are most commonly used to provide VRU facilities (i.e., bicycle lanes) on limited rights of way where roads are too narrow for the addition of standard bicycle lanes or sidewalks. Hence, ELRs can inexpensively provide VRU facilities on millions of miles of local and collector roads in the United States. ELRs can also provide larger horizontal clearance between VRUs and motor vehicles than standard bicycle lanes in some situations and can be an excellent striping treatment for bicycle boulevards (Williams 2019).

A potential application of ELRs is on lower-volume, high-speed two-lane roads to reduce the rate of single-vehicle roadway departure crashes (Williams, n.d.). These higher-speed rural ELR applications exist in Australia and Great Britain. Rural ELRs on higher-speed facilities are practically nonexistent in the United States. Therefore, estimation of safety benefits associated with the reduction of single-vehicle roadway departure crashes for higher-speed rural facilities is beyond the scope of this work.

There are millions of road miles with slower speeds in urban and rural settings in the United States that are potential ELR sites, especially given the low installation cost of ELRs (Williams 2019). A key barrier to implementing this treatment often centers around concerns for the safety of motorists who are expected to share one lane despite traveling in opposite directions. A recent example of this was the reaction of public in the Mira Mesa neighborhood of San Diego. Neighbors were concerned about potential safety issues of ELR treatment implemented on Gold Coast Drive (Bowen 2022). We contend that a comprehensive before/after safety evaluation of existing ELRs will help jurisdictions consider this promising treatment for accommodating VRUs. The findings from this research may be used for public outreach to alleviate some of the concerns about automobile driver safety on ELRs.

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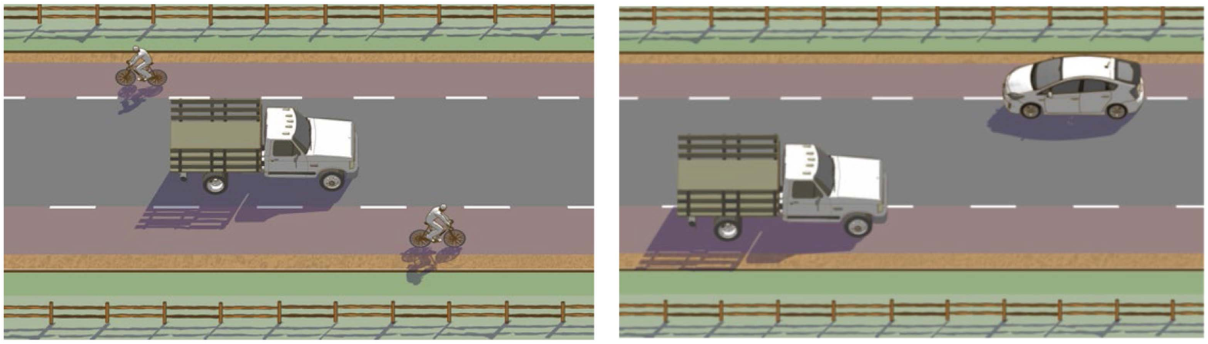

Fig. 1. ELR operation from FHWA small town and rural multimodal networks. (Reprinted from Dickman et al. 2016.)

Toward that end, this study used the statistically rigorous project-level empirical Bayes (EB) methodology from the *Highway Safety Manual* (HSM) (AASHTO 2010) to conduct such an evaluation of the ELRs. The paper is organized as follows: "Background" provides background and lessons from the literature review on past ELR installations from the United States and abroad. EB study design and data preparation to implement the EB evaluation are provided in "Evaluation Approach and Data Preparation." "Analysis and Results" provides results from the project-level EB evaluation using uncalibrated HSM safety performance functions (SPFs). "SPF Calibration Issues" addresses issues related to calibration and provides the results based on calibrated SPFs. The last section summarizes the findings, discusses potential limitations, and provide avenues for future research.

Background

The first mention of edge-lane roads in the United States was in Portland, Oregon's 2010 bikeway design guidance (City of Portland, Bureau of Transportation 2010). At the federal level, ELRs were first introduced as advisory shoulders in 2016 in the Federal Highway Administration (FHWA) *Small Town and Rural Multimodal Networks* document (Dickman et al. 2016). ELRs are currently classified as an experimental treatment by the FHWA (FHWA, n.d.). Given this experimental classification, evidence about the safety of existing installations would be of value to practitioners.

There are two sources of official North American guidance for designing and implementing ELRs: The first is FHWA's *Small Town and Rural Multimodal Networks* guide (Dickman et al. 2016). The second is the FHWA web page addressing experimentation with dashed bicycle lanes (FHWA 2017). The web page predates the *Small Towns and Rural Multimodal Networks* guide and is considered less authoritative. The FHWA has approved experimental ELR installations in at least eight US cities; these installations provide data on safety and performance, which the FHWA can use to evaluate this treatment (FHWA, n.d.).

As mentioned previously, ELRs do not include a yellow centerline separating automobile traffic traveling in opposing directions. Centerlines are required on all urban collectors and arterials with an average daily traffic (ADT) of 6,000 or greater per the *Manual on Uniform Traffic Control Devices* (MUTCD) (FHWA 2009). This would presumably preclude the use of ELRs on roads with ADT exceeding this threshold, but millions of road miles with lower ADT remain potential candidates for ELR implementation. As of July 2020, the authors are aware of approximately 40 installations in the US and Canada (Advisory Bike Lanes 2018).

Even though current North American installations are concentrated in urban areas, jurisdictions in the United States have installed ELRs across a wide range of community character types, contexts, and roadway classifications (Gilpin et al. 2017). More details on existing US installations may be found at Advisory Bike Lanes (2018).

ELRs have been popular in other countries for several decades. A report from the 2013 International Transport Forum lists 10 countries using this treatment, with three countries reporting use predating 1970 (Cycling, Health, and Safety 2013). The Netherlands, the origin of the concept, has approximately 1,000 km of ELRs (Institute for Road Safety Research 2007). In the Netherlands, van der Kooi and Djikstra (2003) found that both motorists and cyclists moved further away from the edge on average after the ELR installation. Williams (2019) analyzed results from the studies of six ELR installations in the US and Canada and found a reduction or no change in speed and crash rate on these roads postinstallation. These studies relied on a simple comparison of data collected before and after ELR implementation.

The literature review clearly demonstrates that as the oldest American ELR approaches its 10th anniversary, there is currently no published, peer-reviewed research analyzing the safety effects of these facilities using the methods prescribed in the *Highway Safety Manual* (AASHTO 2010). As a result, the CMF Clearinghouse has no crash modification factor (CMF) listed for this treatment (CMF Clearinghouse, n.d.). This study assembled crash, annual average daily traffic (AADT), and relevant road design data from all ELRs with at least 3 years of post-ELR implementation crash data. These data were used to conduct a project-level EB before/after evaluation described in the HSM, Appendix A.2.5 (AASHTO 2010). This most comprehensive evaluation of the safety performance of US ELRs to date would help engineers and planners address the perceived safety concerns of the community members before future installations.

Evaluation Approach and Data Preparation

EB before and after observational study design (Hauer et al. 2002) was used to evaluate the safety performance ELRs. The premise of the EB analysis is to estimate the number of crashes expected in the 3 years following ELR installation if the facility had been left as a two-lane road. This expected crash frequency may then be compared to the actual 3-year crash record following ELR installation (Fig. 2; Herbel et al. 2010). EB analysis is the approach recommended by HSM (AASHTO 2010) to conduct observational safety analyses for deriving CMF for treatments. The EB method is preferred over other methods because it accounts

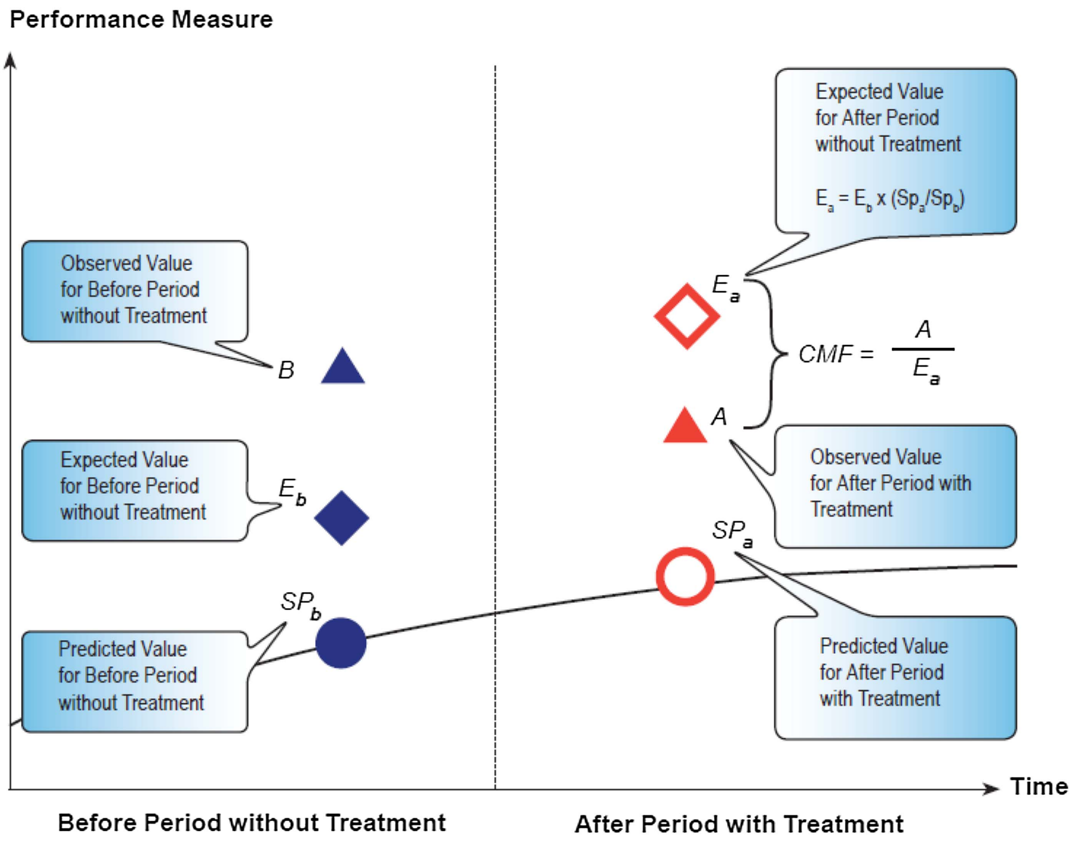

Fig. 2. EB method illustration. (Reprinted from Herbel et al. 2010.)

for regression-to-the-mean (RTM) bias in the crash data (Park and Abdel-Aty 2015).

According to the *Highway Safety Improvement Program Manual* (Herbel et al. 2010) and the HSM, the EB approach to evaluation requires the following input data for 10–20 treatment sites:

- 3–5 years of crash and volume data from before treatment (ELRs in this case),
- 3–5 years of crash and volume data from after treatment (ELRs in this case), and
- SPF for treatment site types.

Table 1 summarizes the ELR locations in the United States that met the collision data requirements.

Required ADT information at different segments and intersections was available for only 11 of the 13 sites with collision data. Therefore, the EB analysis was carried out only for those 11 sites. With one exception, none of the sites experienced significant changes in the posted speed limit, ADT, or roadside environment over the period of analysis. The exception was Lakeview Avenue in Cambridge, Masschusetts, where the speed limit changed from 48.3 to 40.2 km/h (30 to 25 mph) 6 months after ELR installation as a result of a citywide policy change. The impact of this change was expected to be small because Lakeview Avenue has a 10 m (33 ft)–wide right of way with two 2.7 m (9 ft)–wide parking lanes on each side. Lakeview Avenue provides access to a neighborhood dominated by single-family residences.

EB analysis was consistently applied with 5 year of before ELR and 3 years of after ELR data. Data used for the EB analysis excluded some crashes. The excluded crashes consisted of:

- All crashes involving pedestrians or bicyclists (most ELRs had no such crashes),
- All crashes occurring within a 3-month window centered on the ELR installation date (only one such crash was found over all 11 sites),
- All crashes occurring within the intersections at either end of a facility, and
- All crashes that could not be accurately located as on or off the facility.

All other reported crashes and crash types were used. Because pedestrian and bicyclist crashes were excluded, the safety performance function calculations also excluded the bicyclist and pedestrian SPFs included in the HSM (Tables 2 and 3). In all, there were 40 automobile-involved collisions over the 5-year before ELR period and 16 collisions over the 3-year after ELR period. As such, a naive comparison would suggest a ~33% reduction (from 8 collisions per year to 5.33) in crashes on these sites in the after ELR period. Also, the sample size of observed crashes on these sites is expectedly small because ELRs in the United States are primarily implemented on low-volume slower-speed facilities. Studies in the literature have used the EB approach with small crash sample sizes (e.g., Kay et al. 2015; Montella 2009). In fact, the small sample of observed crashes makes the EB analysis even more critical (Hauer et al. 2002).

EB analysis was performed using the project-level EB approach described in the *Highway Safety Manual*, Appendix A.2.5 (AASHTO 2010). As opposed to the site-level approach that examines each intersection and road segment independently, the project-level approach allows the aggregate analysis of a facility containing any number of segments and intersections. The project-level approach is recommended in lieu of the site-level approach when it is difficult to determine whether some crashes are intersection related or not. In other words, the project-level approach allowed

Table 1. ELR segments with crash data available for EB analysis

Group	ELR site	City	Rural or urban	Facility length (m)	AADT
1	Bridge Street	Yarmouth, Maine	Urban	76.2 (250 ft)	826
2	Eastern Road	Scarborough, Maine	Rural	1,463 (4,800 ft)	1,009
3	Morton Road	Yarmouth, Maine	Urban	883.9 (2,900 ft)	170
4	Harvard Lane	Boulder, Colorado	Urban	487.7 (1,600 ft)	380
5	E. 54th Street	Minneapolis	Urban	1,295.4 (4,250 ft)	3,058
6	E. 7th Street	Bloomington, Indiana	Urban	670.6 (2,200 ft)	1,397
7	Flynn Avenue	Burlington, Vermont	Urban	487.7 (1,600 ft)	4,349
8	W. 54th Street	Edina, Minnesota	Urban	335.3 (1,100 ft)	2,400
9	Oak Street	Sandpoint, Idaho	Urban	416.1 (1,365 ft)	810
10	2nd Avenue	Hailey, Idaho	Urban	1,091.2 (3,580 ft)	N/A
11	W. 46th Street	Minneapolis	Urban	396.2 (1,300 ft)	4,280
12	Lakeview Avenue	Cambridge, Massachusetts	Urban	487.7 (1,600 ft)	1,000
13	Quaker Street	Lincoln, Vermont	Rural	293.5 (963 ft)	N/A

Table 2. Summary of SPFs used in the analysis for rural location (Eastern Road ELR)

Roadway entity subtype	SPF equation (from HSM)	SPF figure no. (from HSM)
Two-lane, two-way roadway segments	Equation 10-6	Figure 10-3
Three-leg stop-controlled intersections	Equation 10-8	Figure 10-4
Four-leg stop-controlled intersections	Equation 10-9	Figure 10-5

us to use collision data aggregated over the ELR corridor. While the crash data were aggregated over each ELR location being analyzed, ADT for individual intersections was provided by the agencies responsible for the respective ELRs. At some unsignalized intersections, ADT information was not available for the minor streets. In that case, ADT for minor streets was estimated using a rate of two daily trips per dwelling unit served by the street. This is a conservative choice because it is substantially lower than the 9.44 and 7.32 trips per dwelling unit rate provided by the Institute of Transportation Engineers *Trip Generation Manual* (Institute of Transportation Engineers 2020) for single-family residences and multifamily housing, respectively. Alleys were classified as minor residential driveways for the analysis. As a result of these choices, the number of SPF-predicted crashes will likely be lower, leading to fewer expected crashes to be estimated for the counterfactual scenario for ELRs. This will lead to a more conservative assessment of the safety of ELRs. The project-level analysis described in HSM Appendix A.2.5 also requires data on roadway characteristics such as the number of driveways, amount of on-street parking, and presence of lighting to ensure that appropriate CMFs may be applied. These data were gathered using the latest information available on Google Streetview.

We used these data to apply the project-level EB evaluation framework described in Appendix A.2.5 of the HSM. For the sole rural ELR location, we used the SPFs provided in Chapter 10 of the HSM. SPFs from Chapter 12 of the HSM were used for the remaining locations. Tables 2 and 3 show the specific SPF equations, figures, and tables from the HSM used for each roadway entity subtype.

The project-level EB evaluation framework steps were implemented using the spreadsheets developed by Dr. Karen Dixon as part of the Project NCHRP 17-38 and documented in National Cooperative Highway Research Program (NCHRP) Report 715 (Dixon 2012).

Chapter 12 of the HSM (AASHTO 2010) is described as applying to arterials only. We did not determine the functional classification of any sites, but the ADT values and posted speeds make it clear that many of the sites may be local or collector roads. The impact of this difference is not known.

Analysis and Results

In this section, we describe the results of the project-level EB evaluation approach. The results of the completed EB analysis are provided in Table 4. These results are based on the direct application of

Table 3. Summary of SPFs used in the analysis for urban and suburban locations

Roadway entity subtype	SPF component by collision type (from HSM)	SPF equations, table, and no. (from HSM)
Roadway segments	Multiple-vehicle nondriveway collisions	Equations 12-10, 12-11, 12-12, Figure 12-3, Tables 12-3, 12-4
Roadway segments	Single-vehicle crashes	Equations 12-13, 12-14, 12-15, Figure 12-4, Tables 12-5, 12-6
Roadway segments	Multiple-vehicle driveway-related collisions	Equations 12-16, 12-17, 12-18, Figures 12-5, 12-6, 12-7, 12-8, 12-9, Table 12-7
Intersections	Multiple-vehicle collisions	Equations 12-21, 12-22, 12-23, Figures 12- 10, 12-11, 12-12, 12-13, Tables 12-10, 12-11
Intersections	Single-vehicle crashes	Equations 12-24, 12-25, 12-26, 12-27, Figures 12-14, 12-15, 12-16, 12-17, Tables 12-12, 12-13

Table 4. Results of the EB analysis (uncalibrated SPFs)

Site	ELR	Urban or rural	Length (m)	ADT (vehicles per day)	N_{exp} (3 years)	N_{obs} (3 years)	Site CMF
1	Bridge Street	Urban	76.2 (250 ft)	926	0.05	0.00	0.00
2	Flynn Avenue	Urban	426.7 (1,400 ft)	4,349	1.87	0.00	0.00
3	Eastern Road	Rural	1,452.7 (4,766 ft)	1,019	3.97	0.00	0.00
4	W. 54th Street	Urban	364.5 (1,196 ft)	2,400	1.00	0.00	0.00
5	Lakeview Ave	Urban	487.7 (1,600 ft)	1,741	1.31	2.00	1.53
6	W. 46th Street	Urban	397.5 (1,304 ft)	4,280	4.97	1.00	0.20
7	Harvard Lane	Urban	456.3 (1,497 ft)	380	0.46	1.00	2.19
8	E. 54th Street	Urban	1,295.4 (4,250 ft)	4,329	10.75	8.00	0.74
9	E. 7th Street	Urban	764.1 (2,507 ft)	200	1.55	2.00	1.29
10	Oak Street	Urban	278.3 (913 ft)	810	2.30	2.00	0.87
11	Morton Road	Urban	883.9 (2,900 ft)	200	0.16	0.00	0.00
Totals					28.39	16	

the HSM's SPFs. For each site, the table compares the number of crashes expected if the facility had remained a two-lane road (referred to as N_{exp}) with the reported crashes that actually happened on the ELR (referred to as N_{obs}), giving us a direct means of observing their safety effects. A CMF for each site was calculated using a simple ratio of the actual crash count for the 3 years post-ELR installation to the expected crash count for the same period estimated by the EB analysis [approach detailed in Herbel et al. (2010)]. A CMF less than 1 indicates a reduction in crashes, and CMF more than 1 indicates an increase in crashes post ELR installation.

Based on the results of the EB procedure, 8 of the 11 facilities showed a reduction in crashes, and three showed an increase in crashes. Sites 1, 2, 3, 4, and 11 reported no crashes in the 3-year after period, resulting in a CMF value of 0.00.

Because the site CMFs are based on small amounts of data and have limited applicability, an aggregate CMF was calculated by dividing the total number of observed crashes over 3 years by the total number of expected crashes for the same period. In this case, an aggregate CMF was estimated to be $16/28.39 = 0.56$. The aggregate CMF value of 0.56 represents a 44% crash reduction in the postinstallation period for ELRs. Among the individual sites, three have an estimated CMF greater than 1.0; while five have a CMF $=$ 0.0 because there were no crashes observed in the postinstallation period. Because the number of observed crashes can only take integer values, individual CMFs for sites with a small number of expected crashes may be biased in either direction. The aggregate CMF provides a more reliable estimate of the crash reduction. Summing all site ADTs and multiplying the result by 2,920 (the number of days in 8 years) shows that the aggregate CMF value is based on more than 60 million motor vehicle trips.

SPF Calibration Issues

The results are based on the crash prediction models (SPFs) in the first version of the HSM, and the spreadsheets developed as part of NCHRP Project 17-38 (Dixon 2012). Therefore, the SPFs used are applied without a calibration factor. The lack of calibration factors does represent a limitation of the analysis presented in the previous section. The HSM recommends that the crash prediction from SPFs should be calibrated for local conditions using the calibration factor estimated for the corresponding local jurisdiction (AASHTO 2010).

This limitation stems from the comprehensiveness of this research. We analyzed all ELRs with long-term required crash data that currently exist in the United States. Therefore, SPFs used in the study included crash predictions models for several site subtypes (full list in Tables 2 and 3) spanning seven different states. Estimating calibration factors for all different state jurisdictions and site subtypes was beyond the scope of this work because the HSM recommends detailed data from a minimum of 30–50 sites for all roadway entity subtypes. Furthermore, the latest research has shown even that to be insufficient to achieve the desired accuracy (Alluri et al. 2016).

To address this issue, we first conducted a review of the NCHRP projects addressing the development of the SPFs provided in the HSM. For urban street segments and intersections, the data used to develop SPFs included data from Minnesota (Harwood et al. 2008). Therefore, for the three ELRs from the state of Minnesota, it was reasonable to use the calibration factor of 1.0 ($C_r = 1.0$). For the rural locations, the data used to develop SPFs in the HSM were not from Maine (where the Eastern Road ERL is located). Fortunately, Maine was one of the jurisdictions where the state DOT provided the calibration factors for SPFs corresponding to rural two-lane two-way segments, three-way stop-controlled intersections, and four-way stop-controlled intersections in response to a request made as part of this work. We were still left with seven ELRs for which expected crashes were based on uncalibrated SPFs because the calibration factors for these states and/or entity subtypes were unavailable. Table 5 summaries the availability of calibration factors.

The aim of this study is to demonstrate if ELRs overall have led to an improvement in the safety of the corridors compared to their previous two-lane two-way design. Because we did not have state-specific calibration factors for the remaining seven locations (Table 5), we reestimated the expected crash frequency, assuming the HSM SPFs were overestimating the crashes on two-lane roads by 50%. This meant applying a calibration factor of 0.5 to all SPFs to analyze the seven remaining ELR locations. We believe that is a way to ensure that the resulting CMF provides a conservative estimate of the safety performance of ELRs. In summary, we used the following values for calibration factors:

- Maine DOT–specified values for SPFs corresponding to the Eastern Road location in rural Maine;
- 1.0 for three locations in the state of Minnesota; and
- 0.5 (an arbitrarily chosen conservative value) for the SPFs corresponding to remaining locations.

Table 6 gives the results of the analysis using these calibration factors. It shows that ELRs still lead to 36% fewer crashes (16) than would be conservatively expected (24.99) on the previously used two-lane two-way design.

This analysis still does not account for annual calibration for the national or regional collision trends. None of the agencies had this information available to apply to the SPFs. This lack of readily available calibration factors is consistent with other recent research showing that most agencies do not maintain this information

Table 5. Summary of calibration factor availability

Group	ELR site	City	Rural or urban	Calibration factors available
1	Bridge Street	Yarmouth, Maine	Urban	No
2	Eastern Road	Scarborough, Maine	Rural	Yes
3	Morton Road	Yarmouth, Maine	Urban	No
4	Harvard Lane	Boulder, Colorado	Urban	No
5	E. 54th Street	Minneapolis	Urban	Yes[a]
6	E. 7th Street	Bloomington, Indiana	Urban	No
7	Flynn Avenue	Burlington, Vermont	Urban	No
8	W. 54th Street	Edina, Minnesota	Urban	Yes[a]
9	Oak Street	Sandpoint, Idaho	Urban	No
10	W. 46th Street	Minneapolis	Urban	Yes[a]
11	Lakeview Avenue	Cambridge, Massachusetts	Urban	No

[a]Calibration factor = 1.0 was used because Minnesota data were used in the estimation of SPFs in the HSM.

Table 6. Results of the EB analysis (SPFs with calibration factors)

Site	ELR	Urban or rural	Length (m)	ADT (vehicles per day)	N_{exp} (3 years) estimate	N_{obs} (3 years)	Site CMF
1	Bridge Street	Urban	76.2 (250 ft)	926	0.02	0	0.00
2	Flynn Avenue	Urban	426.7 (1,400 ft)	4,349	1.05	0	0.00
3	Eastern Road	Rural	1,452.7 (4,766 ft)	1,019	2.58	0	0.00
4	W. 54th Street	Urban	364.5 (1,196 ft)	2,400	1.00	0	0.00
5	Lakeview Ave	Urban	487.7 (1,600 ft)	1,741	1.04	2	1.92
6	W. 46th Street	Urban	397.5 (1,304 ft)	4,280	4.97	1	0.20
7	Harvard Lane	Urban	456.3 (1,497 ft)	380	0.37	1	2.70
8	E. 54th Street	Urban	1,295.4 (4,250 ft)	4,329	10.75	8	0.74
9	E. 7th Street	Urban	764.1 (2,507 ft)	200	1.33	2	1.50
10	Oak Street	Urban	278.3 (913 ft)	810	1.79	2	1.12
11	Morton Road	Urban	883.9 (2,900 ft)	200	0.09	0	0.00
Totals				20,634	24.99	16	0.64

(Saleem et al. 2021). All ELRs analyzed here were installed after September 2012. The traffic collision trends in the United States during the postinstallation period (since 2013) have generally been increasing. Using an annual calibration factor of 1.0 (which essentially means not applying the factor at all) means underestimating the counterfactual number of crashes in the postinstallation period. Therefore, we are getting a more conservative estimate of the CMFs, and ELRs may be safer than the estimated CMF of 0.64 suggests.

Summary, Limitations, and Concluding Remarks

This study assembled a database of crash, traffic, and roadway characteristics to conduct a comprehensive project-level EB before/after safety evaluation of 11 ELRs located in the United States. Based on the project-level analysis methodology with SPFs provided in the HSM, an aggregate CMF value of 0.56 was estimated over all of the 11 sites analyzed. The analysis was repeated with location-specific SPF calibration factors, where available, or with a conservative value of $C_r = 0.5$ for SPFs for which calibration factor was not available. This analysis resulted in a CMF value of 0.64, still conservatively estimating a 36% reduction in collisions resulting from ELR conversion.

There are several limitations to the analysis. The EB methodology used here relies on the project-level implementation of the predictive method in the HSM Part C (Appendix A.2.5). Therefore, the variables in the SPFs used in the HSM have been limited to AADT and roadway segment length (for segments) and major and minor ADT (for intersections) because the rationale for these variables having a cause-and-effect relationship to crash frequency is strong. Moreover, the CMF is estimated using the direct comparison method recommended by the FHWA guide (Herbel et al. 2010). As such, it does not account for uncertainty resulting from the use of SPF and assumptions required to estimate overdispersion parameters and relative weights.

Furthermore, because the analysis was based on locations in seven different states and the SPFs involved corresponded to several different roadway entity subtypes, estimating all relevant calibration factors was beyond the scope of this work. Most relevant agencies did not have ready-to-use calibration factors and/or SPFs available. As these ELRs become more common and more of these treatments are located in jurisdictions where locally calibrated and validated SPFs are available along with long-term historical data, more accurate assessments of CMFs may be possible.

ELRs likely also have non-safety-related benefits, evaluation of which was beyond the scope of this study. These benefits include those conferred by the provision of facilities for vulnerable road users. The safety and performance of these VRU benefits should be evaluated more thoroughly in future research.

Despite these limitations, the project-level EB analysis from a nationwide set of installations that relies on conservative assumptions on annual and regional calibration factors does indicate that ELRs are a safe treatment to apply, especially on roads with lower ADT and slower speeds. The resulting safety improvement leads to the following conclusions: The first is that drivers' experience (or lack thereof) with the ELR treatment did not manifest in terms of increased crashes, indicating that most drivers could successfully transition to the novel street design. The second is that ELRs provide improved safety compared to their two-lane counterparts. These findings lead us to conclude that ELRs continue to be suitable for use in the United States and that a somewhat common perception among the public of ELRs as a treatment that risks life and limb is inaccurate.

A number of plausible reasons for these safety improvements can be hypothesized. They include speed reduction or increased attentiveness by the drivers because of the treatment's novelty and/or concerns about approaching vehicles [see Williams (2019) for further discussion]. For future research, it is also worth exploring if high-speed, low-volume rural ELRs may be effective in reducing the number of roadway departure crashes because of wider shoulders in the form of edge lanes. The data collected on the Eastern Road ELR in Scarborough, Maine, show the potential of this treatment for that purpose. Eastern Road is a rural road with no curb, gutter, or sidewalk. The road is straight and connects to individual homes on large lots and small clusters of housing. It has a posted speed limit of 40.2 km/h (25 mph), but the setting and crash history likely indicates higher observed speeds. From 2003 to 2016 inclusive (14 years), Eastern Road experienced 14 crashes, with 12 of these being coded as went-off-road crashes. Eastern Road was converted to an ELR in July 2016. Eastern Road reported zero crashes from its conversion to an ELR in July 2016 to mid-2020 (approximately 4 years). Despite being unable to generalize from the experience of one installation, it does provide additional support for the investigation of ELR use in rural locations. Other nations, including Australia and the UK (specifically the country of Scotland), have used ELRs on rural high-speed facilities; analysis of those installations may also provide evidence on whether ELRs can reduce roadway departure crashes. In conclusion, the results of the study show that ELRs are expected to provide safety improvements for motorists. This finding should help address the public's concerns about motorist safety on this treatment.

Data Availability Statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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