Safety Performance of Edge Lane Roads

Marcial Lamera
Graduate Student
Department of Civil & Environmental Engineering
California Polytechnic State University, San Luis Obispo, CA 93407
Email: mlamera@calpoly.edu

Michael Williams (Corresponding author)
Principal
Michael Williams Consulting
Mt. Shasta, CA 96067
Email: bikepedx@gmail.com

Aleksander Bauranov
Doctoral student
Harvard Graduate School of Design
Harvard University, Cambridge, MA 02138
Email: bauranov@gsd.harvard.edu

Dr. Anurag Pande
Professor
Department of Civil & Environmental Engineering
California Polytechnic State University, San Luis Obispo, CA 93407
City, State or Country, Postcode
Email: apande@calpoly.edu

Dr. Carole Voulgaris
Assistant Professor of Urban Planning
Harvard Graduate School of Design
Harvard University, Cambridge, MA 02138
Email: cvoulgaris@gsd.harvard.edu

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ABSTRACT

This paper provides an observational analysis of the safety effects of Edge Lane Road (ELR) (also known as advisory bike lanes or advisory shoulders) installations in the United States. This analysis employs the following study designs: (a) yoked comparison where each ELR installation was matched with at least two comparable 2-lane roads to serve as comparison sites, and (b) an Empirical Bayes (EB) before/after analysis for ELR sites where requisite data on AADT and other relevant characteristics were available.

Crash data was collected and compiled into four different groups: ELR before implementation, ELR after implementation, comparison site before the implementation of the corresponding ELR, and comparison site after implementation of the corresponding ELR. Analysis of crash trends in the “before” period showed that most ELR sites had crash trends similar to their comparison sites.

A yoked comparison showed that nine of the thirteen ELRs nominally had crash counts that were either the same or lower than the counts expected based on the data from the comparison sites. However, at eight of nine sites, the differences were not statistically significant. After this inconclusive preliminary evaluation, an EB estimation of change in safety before and after the ELR installation at nine sites was performed. EB analysis showed eight of nine ELR sites demonstrated a reduction in crashes.

Keywords: Edge lane roads, Advisory Bike Lane, Advisory Bicycle Lane, Advisory Shoulder, Empirical Bayes Method, Before after safety evaluation.

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 alternatively referred to as 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 (See Figure 1).

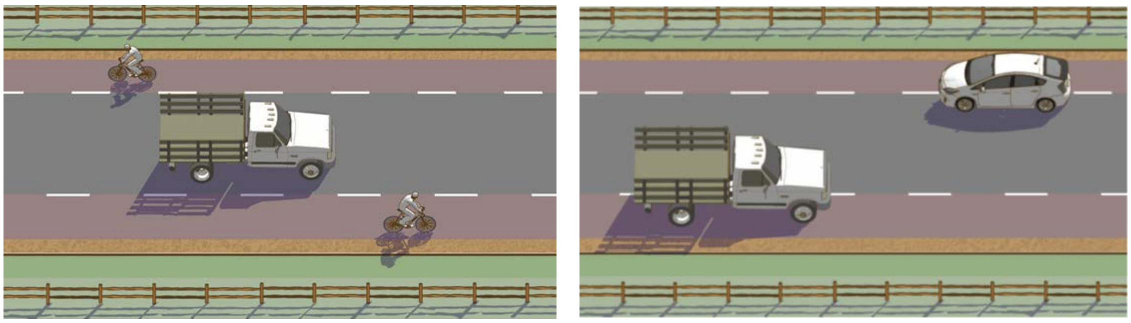

Figure 1. ELR operation from the FHWA Small Town and Rural Multimodal Networks Guide (*1*)

ELRs can inexpensively provide VRU facilities on millions of miles of local and collector roads in the US. This can be useful where roads are too narrow or lack the right-of-way for the addition of standard bicycle lanes or sidewalks. ELRs can provide more distance between VRUs and traffic than standard bicycle lanes in some situations and may be an excellent striping treatment for bicycle boulevard (*2*). Current North American installations are concentrated in urban areas. The most common application of ELRs is as a means to provide VRU facilities.

Another potential application for ELRs is on low-volume, high-speed two-lane roads as a means for reducing the rate of single-vehicle, roadway departure crashes (*3*). Higher speed ELRs in rural areas are found in Australia and Great Britain but have not seen use in the US or Canada. Given the millions of road-miles which are potential candidates for an ELR installation and its low cost, we contend that a comprehensive observational before/after safety evaluation of existing ELRs may help jurisdictions around the country consider this promising treatment.

This paper's primary focus will be the analysis of the safety effects of existing ELR installations in the US. The paper is organized as follows: The next section provides background and lessons from the literature review on past ELR installations from the US and abroad. Next, we provide the study designs and data preparation for the ELR installations used in the study. The results of the analysis follow along with the Conclusions at the end.

BACKGROUND

The first mention of edge lane roads in the United States was in Portland's 2010 bikeway design guidance (*4*). At the federal level, ELRs were first introduced as Advisory Shoulders in 2016 in the FHWA Small Town and Rural Multimodal Networks Guide (*1*). ELRs are currently classified as an experimental treatment by the FHWA (*5*).

Centerlines are required on all urban collectors and arterials with an Average Daily Traffic of 6,000 or greater (*6*). This precludes the use of ELRs on these roads, but millions of road-miles remain as potential candidates.

As of July 2020, the authors are aware of approximately 40 installations in the US and Canada (*7*). There are two sources of official North American guidance for designing and implementing ELRs:

The first is the FHWA's *Small Town and Rural Multimodal Networks* guide (*1*), and the second is the FHWA webpage addressing experimentation with 'dashed bicycle lanes'(*8*). The webpage 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 (*5*).

Jurisdictions in the United States have installed ELRs across a wide range of community character types, contexts, and roadway classifications, some of which can be found in a privately published white paper (*9*) and a website dedicated to the treatment (*7*). ELRs have been popular in other countries for several decades. A report from the 2013 International Transport Forum lists ten countries using this treatment with three countries reporting use predating 1970 (*10*). The Netherlands, the originator of the concept, has approximately a thousand kilometers of ELRs in their country (*11*). In the Netherlands, van der Kooi and Djikstra (*12*) found that both motorists and cyclists moved further away from the edge as a result of ELR installation. The performance of ELRs in the US and Canada was analyzed by Williams (*2*). Williams analyzed data from six installations and found a reduction or no change in speed and crash rate on these roads post-installation. The study relied on a simple comparison of data collected before and after ELR implementation.

As the oldest American ELR approaches its 10-year anniversary, there is currently no published, peer-reviewed research analyzing and identifying the safety effects of these facilities using the methods prescribed in the Highway Safety Manual (*13*). In this study, the authors assembled crash and relevant road design data from all ELRs with at least three years of post-ELR implementation crash data available. This is the most comprehensive before-after study of the safety performance of American ELRs.

EVALUATION APPROACH AND DATA PREPARATION

Two different study designs were used: (1) a site-by-site analysis using a yoked comparison design (each ELR site matched with at least two comparison sites); and (2) an Empirical Bayes before and after study, which is the HSM recommended approach to conduct observational safety analyses.

Yoked Comparison Analysis

This approach is similar to the one adopted by Huang et al. (*14*) for the evaluation of complete street, i.e., road diet, treatments. We selected an ELR group and a comparison group and assembled crash data for two time periods, one before the ELR installation and one after the ELR installation for each site in each group. The ELRs were matched with two-lane roads that were otherwise similar in terms of their characteristics; these are the comparison sites. Thus, crash data was assembled into four groups similar to the ones used by Huang et al. (*14*): (1) ELRs—"before" period, (2) ELRs—"after" period, (3) comparison sites—"before" period, and (4) comparison sites—"after" period.

The only criterion used in selecting a US ELR installation for this study was at least three years of post-installation crash data. The "before-period" length varied considerably from site to site, depending on how much data the responsible jurisdictions had available and when the ELRs were installed. Of the approximately 38 known American installations, 13 sites met the 3-year crash data criterion. For these installations, crash, traffic, and roadway design data were requested from the responsible jurisdictions. The final list of sites with the desired crash data contained 13 ELRs and 34 comparison sites (See Table 1). ELR facility lengths ranged from 1100 feet (0.08 miles) to 4800 feet (0.91 miles). Site numbers 5, 8, 11, and 13 were posted at 30 MPH, site number 10 was posted at 20 MPH, and the remainder were posted at 25 MPH. Eleven of the thirteen ELR installations are classified as urban facilities, as defined by the HSM (*13*). Also, note that only nine out of 13 had the ADT information available, and hence only those could be included in the EB analysis.

Table 1: ELR segments with available crash data

Group #	ELR Site	City	Rural or Urban	Facility Length (ft)	AADT
1	Bridge Street	Yarmouth, ME	Urban	2900	826
2	Eastern Road	Scarborough, ME	Rural	4800	1009
3	Morton Road	Yarmouth, ME	Urban	2900	170
4	Harvard Lane	Boulder, CO	Urban	1600	N/A
5	E. 54th Street	Minneapolis, MN	Urban	4250	3058
6	E. 7th Street	Bloomington, IN	Urban	2200	1397
7	Flynn Avenue	Burlington, VT	Urban	1600	4349
8	W. 54th Street	Edina, MN	Urban	1100	2400
9	Oak Street	Sandpoint, ID	Urban	1365	N/A
10	2nd Avenue	Hailey, ID	Urban	3580	3000
11	W. 46th Street	Minneapolis, MN	Urban	1300	4280
12	Lakeview Avenue	Cambridge, MA	Urban	1600	N/A
13	Quaker Street	Lincoln, VT	Rural	963	N/A

The 34 comparison sites were two-lane, undivided roads located near the corresponding ELR. Open Street Map (OSM) was used to select the comparison sites based on the following characteristics: functional classification, number of lanes, width, presence of sidewalk, presence, and type of parking (*15*). In some instances, OSM was missing some information. For those sites, Google satellite images were used for key/value identification (e.g., for measuring the width of the road or verifying the presence of a sidewalk). Each ELR had 2 or 3 comparison sites located in the same region. AADT and speed limit was not used as criteria for selection of comparison sites; the focus of this analysis was on the physical characteristics of the roads.

Empirical Bayes (EB) Analysis

AADT information was only available for nine of thirteen sites, and hence, the EB Analysis is only carried out for those sites. EB analysis was consistently applied with 5-years of "before-ELR" data and 3-years of "after-ELR" data. The premise of EB analysis is to estimate the counterfactual crash counts, i.e., the expected crashes in the three years following ELR installation if the facility had been left as a two-lane road. The CMF for each ELR installation may then be estimated as the ratio of the actual 3-year post-ELR crash counts to the counterfactual estimate. The procedure uses Safety Performance Functions (SPFs) and relevant CMFs for 2-lane roads provided in Chapter 12 of the HSM (*13*).

ANALYSIS AND RESULTS

Yoked Comparison

The first step in this analysis was to ensure that the crash count trends in the "before" period for the comparison groups were similar to their corresponding ELRs. Year-by-year crash counts in the "before" period were examined for all groups of ELRs and comparison sites. The results of the t-test comparing average annual crashes at each ELR site with its corresponding comparison site are provided in Table 2. For four sites (#2, #5, #9, and #12), the null hypothesis (of no significant difference between crash counts on treatment and control sites) could be rejected. There were no statistically significant differences in annual average crash counts between the ELR sites and their comparison sites for the other nine locations. Hence, we concluded that, overall, the ELR sites were similar to their comparison sites. Site #2, #5, #9, and #12, showed a different average annual crash frequency between the ELR and comparison sites in the "before" period. Hence, the differences, if any, observed difference in crash experience between ELR and control sites for these four locations in the "after" period may not be attributable to ELR installation but potentially to 'pre-existing' differences between the case and control sites.

Table 2: Statistical comparison annual "Before-period" crash counts between ELR sites and their comparison sites

CRASH TRENDS IN "BEFORE" PERIOD			
Site Number	ELR Site	# of Comparison Sites	p-value
1	Bridge Street	3	0.779
2	Eastern Road	2	0.003
3	Morton Road	3	0.056
4	Harvard Lane	3	0.890
5	E 54th Street	3	<0.001
6	E 7th Street	2	0.694
7	Flynn Avenue	3	0.301
8	W. 54th Street	3	0.318
9	Oak Street	3	0.001
10	2nd Avenue	3	0.730
11	W 46th Street	2	0.896
12	Lakeview Avenue	2	0.014
13	Quaker Street	2	0.410
Highlighted values significant at 95% CI.			

For standard yoked comparison, a two-way contingency table analysis (similar to (*14*)) was performed on the thirteen ELRs and their corresponding 34 comparison sites. Table 3 shows before and after crash counts along with the percentage of crashes occurring in the "after" period for each site. Note that before and after period durations are generally different for each site. However, the length of "before" (and "after") period for each ELR matches its corresponding comparison site. One way, then, to assess the effectiveness of the ELRs is to see how many of the ELRs report a lower percentage of crashes in the "after" period compared to their corresponding comparison site.

Nominally, it is the case for nine of thirteen ELRs (See sites with green highlights in Table 3). However, for four of those sites (#2, #5, #9, and #12), at least some of the differences may be attributable to the 'pre-existing' conditions and not to ELRs (See the Discussion in the last section and Table 2). Moreover, based on Fisher's exact test (appropriate because several of the sites have small crash counts; (*16*)), these differences are only statistically significant for one of those nine sites. One of the sites (Site #8) showed a significantly higher % of crashes occurring for ELRs in the "after" period, too. Hence, the results from the yoked comparison analysis were inconclusive. Next, a more robust EB approach to safety analysis was used to estimate the change in safety due to ELR installation.

Table 3: Results of the Yoked Comparison

		MONTHS OF DATA COLLECTED		***CRASHES***		***% After***	***Fisher's Exact test***
Site Number	**Site Type**	**Before**	**After**	**Before**	**After**	**% After**	**p-value**
1	ELR	87	36	3	0	0%	NA
	Comparison Sites	87	36	7	2	22%	
2	ELR	75	36	17	1	6%	0.134
	Comparison Sites	75	36	9	4	31%	
3	ELR	74	36	2	1	33%	1.000
	Comparison Sites	74	36	20	9	31%	
4	ELR	77	36	4	5	56%	0.159
	Comparison Sites	77	36	10	2	17%	
5	ELR	77	26	15	5	25%	1.000
	Comparison Sites	77	26	364	132	27%	
6	ELR	60	36	22	7	24%	<0.0001
	Comparison Sites	60	36	26	135	84%	
7	ELR	38	36	2	0	0%	NA
	Comparison Sites	38	36	18	7	28%	
8	ELR	42	36	5	11	69%	0.009
	Comparison Sites	42	36	34	15	31%	
9	ELR	91	36	29	9	24%	0.3645
	Comparison Sites	91	36	323	152	32%	
10	ELR	104	30	15	5	25%	0.3645
	Comparison Sites	104	30	55	11	17%	
11	ELR	80	36	8	1	11%	0.3932
	Comparison Sites	80	36	15	6	29%	
12	ELR	80	36	7	4	36%	1.000
	Comparison Sites	80	36	5	4	44%	
13	ELR	80	36	5	0	0%	NA
	Comparison Sites	80	36	5	0	0%	

Confidence Interval 95%

Empirical Bayes Analysis

For the site-by-site evaluation of treatments, the HSM recommends the EB approach documented by Hauer (*17*). For EB analysis, we consistently used 5-years of "before-period" crash data and three years of "after-period" crash data for each ELR. The EB analysis does not use the comparison sites used in the yoked comparison analysis. The EB approach requires estimation of expected counterfactual crash counts as a weighted average of two sets of crash counts:

- predicted crash counts obtained using the Safety Performance Function (SPFs) equations for urban/suburban or rural 2-lane roads from Chapter 12 of the HSM. SPF predictions were modified using the appropriate CMFs (Crash Modification Factors) for the site-specific characteristics, and

- average crash counts based on the 5-year crash history of the sites before ELR installation

Using the expected crash frequency for the 3-year post-installation period and the actual crash frequency post-ELR installation, we obtained the CMF for each site. A CMF less than 1 implies a crash reduction, and CMF more than 1 implies an increase in crashes post-ELR installation. Table 4 shows the Estimated CMF for each site, along with the segment lengths and AADT values.

Table 4: Results of the EB Analysis (sorted by estimated CMF)

Site #	ELR Location	Urban or Rural	Segment Length (ft.)	ADT (vpd)	Estimated Crash Modification Factor
1	Bridge Street	Urban	2900	826	0.00
7	Flynn Avenue	Urban	1600	4349	0.00
2	Eastern Road	Rural	4800	1009	0.10
11	W 46th Street	Urban	1300	4280	0.30
10	2nd Avenue	Urban	3580	3000	0.41
5	E. 54th Street	Urban	4250	3058	0.67
6	E. 7th Street	Urban	2200	1397	0.67
3	Morton Road	Urban	2900	170	0.81
8	W 54th Street	Urban	1100	2400	2.22

Based on the results from the EB procedure using the methods described by Hauer (*17*), eight of nine facilities showed a reduction in crashes. Sites #1 and #7 did not report any crashes in the 3-year "after-period." The estimated CMFs for these ELRs were not significantly correlated with either the segment length or AADT.

One facility, W 54th St in Edina, MN, had an increase in crashes (CMF=2.22). The installation is of the shortest length (1100 ft.), and its ADT is at the median value for the nine ELRs shown in Table 4. Neither seemed like an apparent reason for the abnormal increase in crashes. It prompted us to examine the crash data for the site. When examined more closely, the W. 54th Street crash data was found to be dominated by crashes which occurred within the intersection of W. 54th and France Avenue or on France Avenue near its intersection with W. 54th. The ELR terminates at this intersection and does not extend through it. All but one of the crashes in the dataset were categorized as occurring on France Avenue or within its intersection with W. 54th. This finding was consistent with the data reported in a safety study of the W. 54th St ELR performed by the City of Edina, MN. The study used a 2-year "before" period and a 2-year "after" period. That study found no crashes "before" the ELR installation and one crash "after" (*18*).

On further manual examination of the crash data at all ELR sites, we found a similar issue on Harvard Lane (Site #4). Note that since Harvard Lane (Boulder, CO) ELR did not have the ADT information available, no EB analysis was conducted for this location. An overwhelming number of crashes attributed to Harvard Lane actually occurred within a terminating intersection with a divided, multilane road or on the multilane road near the intersection. The true data for this facility consists of zero crashes in the "before" period and one crash in the "after" period. The one "after" period crash consisted of a car that backed into a parked car at three MPH. The report of a City-sponsored study (*19*) of this facility was unclear about the time durations used for crash analysis but concluded with a recommendation to keep the facility and consider the treatment for use in other locations.

A quick review of the crash data for the other 8 ELR sites (listed in Table 4) revealed that among those 8, a similar issue did not affect data from those sites. Crashes at the segment-terminating intersections may skew the data for the purposes of observational safety analysis, and therefore, crash data needs to be closely examined for such discrepancy in future research.

Summary of Findings

The results from the yoked comparison were inconclusive on the effectiveness of ELRs. However, a more robust EB analysis approach showed eight of nine ELRs resulted in crash reductions with CMF ranging from 0.0 (2 sites had no crash after ELR installations) to 0.89. The ELR site that showed an increase in crashes had data quality issues due to the misattribution of crashes that occurred on a large terminal intersection; the ELR was deemed safe by a City-sponsored safety study.

CONCLUSIONS

This study is the most comprehensive observational before/after evaluation of ELRs in the US to date. This work used a yoked comparison as well as the Empirical Bayes observational study design.

The EB analysis found eight of nine ELR installations resulted in crash reduction. A number of plausible reasons for these reductions can be hypothesized. They include speed reduction or increased attentiveness as a result of the treatment's novelty or drivers' concerns about approaching vehicles (See (*2*) for further discussion). Data quality for the one site with an estimated CMF above 2.0 was poor and was dominated by crashes on an intersecting road or in the intersection with that road.

Eight of nine sites used in the EB analysis and eleven of thirteen sites used in the yoked comparison were classified as urban. Other nations, including Australia and Scotland, have used ELRs on rural high-speed facilities. Analysis of those installations would provide evidence on whether ELRs can reduce roadway departure crashes by providing wider shoulders in the form of edge lanes. As data from more installations becomes available for conducting safety evaluations, one may consider a robust meta-analysis proposed by Elvik (*20*) to combine CMF estimates from multiple sites.

ELRs likely have non-safety benefits that were beyond the scope of this study to evaluate. These are similar to the benefits of road diets mentioned by Huang et al. (*14*), including creating the impression that cars are less dominant and improving the overall quality of movement along the street. These benefits should be evaluated more thoroughly in future research.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: Williams M., Pande A., Voulgaris C., Lamera M.; data collection: Lamera M., Williams M. analysis and interpretation of results: Williams M. Pande A., Voulgaris C., Lamera M., Baurnove A.; draft manuscript preparation: Williams M., Pande A., Voulgaris C., Lamera M., Baurnove A. All authors reviewed the results and approved the final version of the manuscript.

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