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

Word Count: 4943 words + 5 tables (250 words per table) = 6,193 words

Submitted December 1, 2020

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 two 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 an Empirical Bayes (EB) before/after analysis for ELR sites where requisite crash data 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.

An EB analysis of change in safety before and after ELR installation at eleven sites was performed. EB analysis showed eight of eleven ELR sites demonstrated a reduction in crash experience and the aggregate CMF over all sites was calculated to be 0.56.

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).

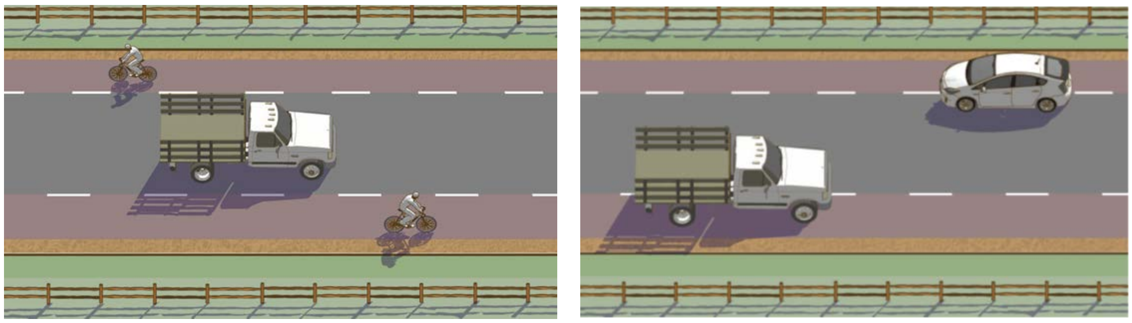

Figure 1. ELR operation from FHWA Small Town and Rural Multimodal Networks (*1*)

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 greater horizontal clearance 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.

A potential application of ELRs is on lower-volume, high-speed two-lane roads as a means for reducing the rate of single-vehicle, roadway departure crashes (*3*). Higher speed rural ELRs exist in Australia and Great Britain. Because higher speed, rural ELRs do not yet exist in the U.S., this study will not be able to assess that benefit.

Given the millions of road-miles that are potential ELR sites and the treatment's low installation cost, we contend that a comprehensive observational before/after safety evaluation of existing ELRs will help jurisdictions with their consideration of this promising treatment.

Because objections to this treatment often center around concern for the safety of motorists that are expected to share one lane despite traveling in opposite directions and because insufficient data existed to evaluate vulnerable road user safety, this paper's focus will be the analysis of motorist safety on 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. Then we provide the study designs and data preparation for the ELR installations used in the study. Analysis results and conclusions are found 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 document (*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 results from the studies of six installations and found a reduction or no change in speed and crash rate on these roads post-installation. These studies 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 study of the safety performance of American ELRs to date.

EVALUATION APPROACH AND DATA PREPARATION

Two different study designs were used: a site-by-site analysis using a yoked comparison design (each ELR site matched with at least two comparison sites); and an Empirical Bayes before and after study. Empirical Bayes analysis is the HSM (*13*) 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*). With one exception, none of the sites experienced significant changes in posted speed limit, ADT, or roadside environment. The exception was Lakeview Avenue in Cambridge, MA which changed speed limit from 30 to 25 MPH six months after ELR installation as a result of a citywide policy change. The impact of this change was expected to be small since Lakeview Avenue is 33 feet wide with two 9 foot wide parking lanes on each side. Lakeview Avenue provides access to a neighborhood dominated by single family residences.

Table 1: ELR segments with available crash data

Group #	ELR Site	City	Rural or Urban	Facility Length (feet)	AADT
1	Bridge Street	Yarmouth, ME	Urban	250	826
2	Eastern Road	Scarborough, ME	Rural	4800	1009
3	Morton Road	Yarmouth, ME	Urban	2900	170
4	Harvard Lane	Boulder, CO	Urban	1600	380
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	810
10	2nd Avenue	Hailey, ID	Urban	3580	N/A
11	W. 46th Street	Minneapolis, MN	Urban	1300	4280
12	Lakeview Avenue	Cambridge, MA	Urban	1600	1000
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

The premise of the EB analysis is to estimate the number of crashes expected in the three years following ELR installation if the facility had been left as a two-lane road. This crash rate would then be compared to the actual three year crash record following ELR installation.

ADT information was available for only eleven of the thirteen sites; the EB Analysis is carried out only for those sites. EB analysis was consistently applied with 5-years of "before-ELR" data 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 eleven 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 crash rate additions.

EB analysis was performed using the project-level approach described in section A.2.5 of the Highway Safety Manual (*13*). 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 used in lieu of the site-level approach when it is difficult to determine whether some crashes are intersection related or not.

Because ADT information was not available for all of the intersecting streets, ADT was estimated using a value of 2 ADT per dwelling unit served by the street. This is a conservative choice and is significantly lower than the 9.44 and 7.32 trips per dwelling unit quoted by the ITE Trip Generation Manual (*16*) 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 predicted crashes will likely be lower than if more accurate data had been used. This may cause ELR safety to be underestimated.

Analysis requires data on road characteristics such as number of driveways, amount of on-street parking, presence of lighting, etc. This data was gathered using the latest information available on Google Streetview.

The use of the EB approach in Chapter 12 of the HSM (*13*) is described as applying to arterials only. Per the HSM, “The term "arterial" refers to facilities that meet the FHWA definition of "roads serving major traffic movements (high-speed, high volume) for travel between major points".” 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 are local or collector roads. The impact of this difference is not known.

The process made use of spreadsheets created by Dr. Karen Dixon of Texas A&M Transportation Institute that implement the worksheets described in Chapters 10 and 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. Sites #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; (*17*)), 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 (EB) Analysis

For the evaluation of treatments, the HSM recommends the EB approach documented by Hauer (*18*). The EB analysis does not use the comparison sites used in the yoked comparison analysis. The EB approach estimates the expected number of crashes per year based on the weighted average of two sets of crash data:

- predicted crash counts obtained using the Safety Performance Function (SPF) equations for urban/suburban or rural 2-lane roads from Chapters 10 and 12 of the HSM. SPF predictions were modified using the appropriate CMFs (Crash Modification Factors) for the site-specific characteristics, and

- the 5-year "before-period" crash history of the sites.

The results of the completed EB analysis are provided in Table 4. For each site, the table compares the number of crashes expected if the facility had remained a 2-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 the ratio of the actual crash count for the 3-year post-ELR installation to the expected crash count for the same period estimated by the EB analysis. A CMF less than 1 indicates a reduction in crashes, and CMF more than 1 indicates an increase in crashes post-ELR installation.

Table 4 Results of the EB Analysis

Site	**ELR**	**Urban or Rural**	**Length** (feet)	**ADT** (vehicles per day)	N_{exp} (3 years)	N_{obs} (3 years)	**Site CMF**
1	*Bridge Street*	Urban	250	926	0.05	0.00	0.00
2	*Flynn Avenue*	Urban	1400	4349	1.87	0.00	0.00
3	*Eastern Road*	Rural	4766	1019	3.97	0.00	0.00
4	*W 54th Street*	Urban	1196	2400	1.00	0.00	0.00
5	*Lakeview Ave*	Urban	1600	1741	1.31	2.00	1.53
6	*W 46th Street*	Urban	1304	4280	4.97	1.00	0.20
7	*Harvard Lane*	Urban	1497	380	0.46	1.00	2.19
8	*E. 54th Street*	Urban	4250	4329	10.75	8.00	0.74
9	*E. 7th Street*	Urban	2507	200	1.55	2.00	1.29
11	*Oak Street*	Urban	913	810	2.30	2.00	0.87
12	*Morton Road*	Urban	2900	200	0.16	0.00	0.00
Totals				**20,634**	**28.39**	**16**	

Based on the results of the EB procedure, eight of the eleven facilities showed a reduction in crashes and three showed an increase in crashes. Sites #1, #2, #3, #4, and #12 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 three years by the total number of expected crashes for the same period. In this case:

$$16.00/28.39 = 0.56$$

The aggregate CMF value of 0.56 represents a 44% crash reduction in the post-installation period for ELRs. Among the individual sites, there are three that have an estimated CMF greater than 1.0; while five have a CMF=0.0 since there were no crashes observed in the post-installation period. Since 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 2920 (the number of days in 8 years) shows that the aggregate CMF value is based on more than 60 million motor vehicle trips.

Summary and Discussion of Findings

The yoked comparison results on ELR safety were inconclusive.

The more rigorous EB analysis produced results worthy of discussion. An aggregate CMF value of 0.56 was estimated over all of the eleven sites analyzed. While the authors doubt that this value is the true CMF for the ELR treatment, it does indicate that the somewhat common perception of ELRs as a treatment that risks life and limb unnecessarily is inaccurate. Individually, eight of the eleven ELRs saw crash rate reductions and three ELRs saw a slight increase in crashes. The small amounts of data on which the site CMFs are based indicates that these values are not worthy of independent consideration.

These results indicate two things. The first is that drivers' experience (or lack thereof) with the ELR treatment did not manifest itself in terms of increased crashes indicating that most drivers were able to successfully transition to the novel street design. This mirrors findings in previous studies. The second is that ELRs provide improved safety compared to their 2-lane counterparts. These findings lead us to conclude that ELRs continue to be suitable for use in the United States.

A number of plausible reasons for these safety improvements 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).

As described in the introduction, high-speed, low-volume rural ELRs may be effective in reducing the number of roadway departure crashes due to wider shoulders in the form of edge lanes. The data collected on the Eastern Road ELR in Scarborough, ME shows 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 is signed as 25 MPH but the setting and crash history implies a road that likely sees higher 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. From its conversion to an ELR in July 2016 to mid-2020 (approximately 4 years), Eastern Road reported zero crashes. Despite being unable to generalize from the experience of one installation, it does provide additional support for investigation of ELR use in this domain.

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 an Empirical Bayes observational study design.

The EB analysis estimated a CMF value for the ELR treatment of 0.56. ELRs are expected to provide a safety improvement for motorists at speeds below 35 MPH and at volumes currently recommended by American guidance for this treatment. This finding helps address the concerns raised about motorist safety on this treatment.

The EB analysis found crash reductions on eight of eleven ELRs (including five with no post-installation crashes) and a small increase in crashes on three ELRs. Due to the low frequency and discrete nature of the variable representing the observed crashes, these site CMF values are likely not reliable. The aggregate CMF more accurately characterizes ELR safety performance.

The reduction of roadway departure crashes on the Eastern Road ELR supports further investigation into the use of ELRs on higher speed, rural roads as a means to reduce that crash type. Other nations, including Australia and Scotland, have used ELRs on rural high-speed facilities; analysis of those installations may provide evidence on whether ELRs can reduce roadway departure crashes.

ELRs likely have non-safety benefits that were beyond the scope of this study to evaluate. 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.

ACKNOWLEDGMENTS

This study was conducted as part of a study funded by California SB1 funds provided via the Mineta Transportation Institute. The data collection effort was assisted by the following students: Abigail Matheny, Blake Thomas, Emily Lin, Eza Gaigalas, Ashley Yao, and Jacob Hamada.

Help with obtaining crash data on U.S. facilities was kindly provided by: Derek Leuer and Ian Saari of the State of Minnesota; Stephen Buckley of Scarborough, Maine; Scott Robinson and Michael Stewart of Bloomington, Indiana; Kelly Campbell of the State of Idaho; and Andrew Hogle of the State of Colorado.

Dr. Karen Dixon of the Texas A&M Transportation Institute created, and commented on the use of, the spreadsheets that implemented the HSM worksheets used in the EB analysis.

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., Bauranov A.; draft manuscript preparation: Williams M., Pande A., Voulgaris C., Lamera M., Bauranov A. All authors reviewed the results and approved the final version of the manuscript.

REFERENCES

1. Dickman, D., N. Falbo, S. Durrant, J. Gilpin, G. Gastaldi, C. Chesston, P. Morrill, C. Ward, W. Walker, B. Jones, C. Cheng, J. Portelance, D. Kack, R. Gleason, T. Lonsdale, K. Nothsine, J. Morgan, and R. Pressly. *Small Town and Rural Multimodal Networks*. Publication FHWA-HEP-17-024. Federal Highway Administration, Washington DC, 2016, p. 134.
2. Williams, M. M. Advisory Bike Lanes and Shoulders: Current Status and Future Possibilities. *Institute of Transportation Engineers. ITE Journal*, Vol. 89, No. 12, 2019, pp. 44–49.
3. Williams, Michael. Rural Edge Lane Roads. *advisorybikelanes.com*. https://www.advisorybikelanes.com/rural-edge-lane-roads.html. Accessed Jul. 22, 2020.
4. Portland Bicycle Plan for 2030, Bikeway Facility Design: Survey of Best Practices. https://www.portlandoregon.gov/transportation/article/699453.
5. FHWA MUTCD Official Rulings. https://mutcd.fhwa.dot.gov/orsearch.asp. Accessed Jul. 31, 2020.
6. MUTCD. *Manual on Uniform Traffic Control Devices (MUTCD)*. Federal Highway Administration, US Department of Transportation, Washington DC, 2009.
7. Advisory Bike Lanes - Home. *Advisory Bike Lanes*. https://www.advisorybikelanes.com/. Accessed Jul. 31, 2020.
8. Dashed Bicycle Lanes - MUTCD - Guidance - Bicycle and Pedestrian Program - Environment - FHWA. https://www.fhwa.dot.gov/environment/bicycle_pedestrian/guidance/mutcd/dashed_bike_lanes.cfm. Accessed Jul. 31, 2020.
9. Gilpin, J., N. Falbo, and M. Williams. *Alta Planning + Design: Lessons Learned: Advisory Bike Lanes in North America*. 2017.
10. *Cycling, Health, and Safety*. International Transport Forum, 2013.
11. SWOV Fact Sheet.
12. van der Kooi, R. M., and A. Dijkstra. Some Behavioural Effects of Non-Compulsory (Bicycle) Lanes on Narrow Rural Roads. *SWOV (Netherlands)*, 2003.
13. American Association of State Transportation Officials. *Highway Safety Manual*. American Association of State Highway and Transportation Officials, 2010.
14. Huang, H. F., J. R. Stewart, and C. V. Zegeer. Evaluation of Lane Reduction “Road Diet” Measures on Crashes and Injuries. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1784, No. 1, 2002, pp. 80–90. https://doi.org/10.3141/1784-11.
15. Bennett, J. *OpenStreetMap*. Packt Publishing Ltd, 2010.
16. Institute of Transportation Engineers. *Trip Generation Manual, 10th Edition,*. 2020.
17. Fisher, R. A. On the Interpretation of χ 2 from Contingency Tables, and the Calculation of P. *Journal of the Royal Statistical Society*, Vol. 85, No. 1, 1922, pp. 87–94.
18. Hauer, E., D. W. Harwood, F. M. Council, and M. S. Griffith. Estimating Safety by the Empirical Bayes Method: A Tutorial. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1784, 2002, pp. 126–131.