TECH**BRIEF**

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Developing Crash Modification Factors for Bicycle-Lane Additions While Reducing Lane and Shoulder Widths

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INTRODUCTION

The Federal Highway Administration's (FHWA's) Development of Crash Modification Factors (DCMF) program was established in 2012 to address highway-safety research needs for evaluating new and innovative safety strategies (e.g., improvements) by developing reliable quantitative estimates of their effectiveness in reducing crashes. Forty-one State departments of transportation provide technical feedback on safety improvements to the DCMF program and implement new safety improvements to facilitate evaluations. These States are members of the Evaluation of Low-Cost Safety Improvements Pooled Fund Study (ELCSI-PFS) that functions under the DCMF program.

This project evaluated the addition of bicycle lanes achieved by reducing lane and shoulder widths as a safety improvement strategy (e.g., safety intervention). The ELCSI-PFS Technical Advisory Committee selected this evaluation as one of the priorities within its purview.

Study Objectives

This evaluation assessed the potential of the safety-improvement strategy (i.e., adding bicycle lanes while reducing shoulder and lane widths) to reduce crashes in terms of total, fatal and injury, property-damage only (PDO), and bicycle crash frequencies. The study's intent is to develop crash modification factors (CMFs) and benefit–cost (B/C) ratios for the evaluated safety improvement. Practitioners can use these CMFs and B/C ratios when deciding on project development and safety-planning processes.

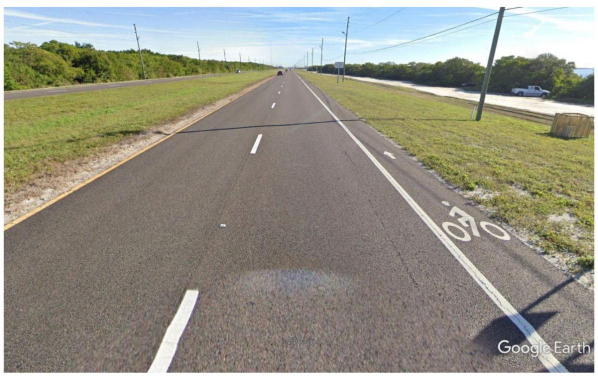
Background

Bicycle lanes are travel lanes dedicated to bicyclists along a street. Effective bicycle lanes promote a consistent separation between bicycles and passing motor vehicles. Implementing bicycle lanes can also benefit pedestrians because dedicated bicycle lanes shift some bicycles from adjacent sidewalks to the active travel way (American Association of State Highway and Transportation Officials [AASHTO] 1999; National Association of City Transportation Officials [NACTO] 2005). The presence of a bicycle lane can raise a motorist's awareness that bicyclists and pedestrians are present and that drivers of motor vehicles should be alert to these vulnerable users.

The basic design of dedicated bicycle lanes consists of striping and signing. Some agencies also apply colored pavement markings (e.g., green or red) to bicycle lanes. In a constrained environment and to accommodate bicycle lanes, an agency must consider reducing existing space previously dedicated to motor vehicles. This type of design is accomplished by reducing the width of motor-vehicle lanes or shoulders as needed for the bicycle lane.

Researchers expect that reducing motor-vehicle lanes to provide for bicycle lanes can be a common scenario within urban environments, and the shoulder can be either reduced or repurposed in suburban and rural environments. Figure 1 shows a bicycle lane in Tampa, FL, that replaces the right shoulder.

Figure 1. Graphic. Photograph. Bicycle lane in Tampa, FL.



AASHTO provides guidelines for restriping existing roads with bicycle lanes. These guidelines should be followed when considering tradeoffs between reducing the width of travel lanes and reducing the number of motor-vehicle travel lanes. Removing onstreet parking and restriping a wide curb lane are among the recommended strategies as well (AASHTO 1999). Safety should improve when travel lanes are offset from curbs, lanes are better defined, and parking spaces are removed or reduced. According to FHWA, adding bicycle lanes can often improve sight distance, and increasing turning radii at intersections and driveways—as well as restriping pavement—can extend pavement life because these measures laterally shift vehicle traffic, causing fewer vehicles driving on well-worn ruts (FHWA 2000).

In a report about active transportation (i.e., self-propelled or human-powered transportation modes), Litman (2017) suggests that space requirements per passenger-mile or kilometer—and therefore congestion impacts—vary depending on vehicle size, speed, occupancy, and number of interactions between roadway users. Shy distance (the space between a vehicle and other objects) increases exponentially with speed. Litman observed that there is little impact in terms of congestion at busy roads with space for bicyclists, where bicycling occurs on a road shoulder, a wide curb lane, or a bicycle lane. An exception to this trend is at intersections, where bicyclist activity might delay vehicle-turning maneuvers (Litman 2017).

Research has found mixed results in safety evaluations of bicycle-lane additions. For example, a study in Burlington, VT, evaluated the addition of onroad bicycle facilities and observed a negative safety impact associated with the 1.0- to 1.2-meter-wide bicycle lanes: an increase in the number of collisions from narrower motor-vehicle lanes (e.g., sideswipe and head-on collisions from motorists failing to maintain their lane) (NACTO 2005). A categorical analysis of before–after collision data indicated that an increase in the width of bicycle lanes coincided with a decrease in the proportion of rear-end collisions and single-motor-vehicle collisions and an increase in the proportion of turning collisions (NACTO 2005).

Park et al. (2015) evaluated the safety effects of adding a bicycle lane by using observational before–after studies and using empirical Bayes (EB) analysis and cross-sectional methods. This study focused on urban arterial data from Florida and was based on a set of 227 road segments with a known installation date of bicycle lanes. Full-negative binomial safety-performance functions specific to Florida were developed from another set of 517 roadway segments with similar characteristics. This analysis also incorporated socioeconomic parameters for use with the EB procedure.

The following trends were identified in this study:

- The addition of a bicycle lane corresponds to an increasing CMF as the traffic volume per lane increases.
- The addition of a bicycle lane corresponds to a decreasing CMF with increasing median widths.
- The CMF was statistically significant at subsets as small as 38 sites when subdividing findings based on bicycle-lane width (Park et al. 2015).

Park et al. suggest there could be a tradeoff when cross-sectional elements are reduced to add a bicycle lane. The apparent benefit regarding total crashes is larger when adding a bicycle lane.

METHODOLOGY

Safety studies are often limited to evaluations of observational data because randomization is not possible and true experiments are not feasible. Good observational studies rely on data from both treated and nontreated sites in a manner consistent with control-group experiments. A cross-sectional data analysis with no matching or control group is considered an inferior preexperimental design and is sometimes called a static-group comparison (Campbell and Stanley 1966). After reviewing potential data sources, the research team determined that obtaining before–after data from multiple jurisdictions on the installation of bicycle lanes was not feasible. Therefore, the research team developed a database for cross-sectional analysis. To incorporate comparison sites, team members adopted the use of propensity score (PS) methods to minimize imbalances between covariates. Under this framework, the PS of treatment cases and their corresponding control cases was estimated and compared. The PS is a metric of similarity between covariates in the two study groups (i.e., sites treated and comparison sites) (Sasidharan and Donnell 2013, 2014; Jovanis and Gross 2007; Guo and Fraser 2015).

In a balanced data sample, the distribution of PSs is expected to be similar for treated and comparison sites, which implies that the values of influential covariates are also similar. The research team examined these PS differences at various data-collection stages (i.e., initial, intermediate, and finalization) to direct data collection at additional comparison sites. In the analysis stage, researchers used PS weighting to estimate the CMFs. Balance in the comparison is achieved by defining appropriate weights so that the groups reflect their representation in an underlying target population of sites. The target population was set to be the overlap between the treated and control populations as proposed by Li et al. (2018). Under this scheme, the target population is the set of all sites that have comparable chances to be in either the treatment group or the control group. This approach effectively curbs the undue influence of control sites unlikely to be candidates for the treatment and of treated sites with unusual characteristics such that no comparable control sites are represented in the data.

The analyses used the statistical methods appropriate to the characteristics of the assembled datasets. The research team used appropriate generalized linear model variants (e.g., negative binomial, Poisson-lognormal mixture, and logistic-log normal mixture) for the different datasets and response variables. The research team estimated best-fit models and included the key variable (the presence of a bicycle lane) and influential covariates. The research team estimated CMFs and their standard errors from linear combinations of model coefficients to reflect changes in cross-sectional elements while holding the total cross-section width constant. In a few instances, alternate CMFs were estimated for scenarios of increased bicycle traffic.

DATA

The research team reviewed potential datasets from multiple States (e.g., Texas, Washington, Oregon, and Florida). The limited availability of locations with actual bicycle counts or a potential for estimating this variable (e.g., through proprietary data and direct-demand models) influenced the decision to narrow the evaluation to two States with the most promise to develop the dataset for analysis: Washington and Texas. The research team collected the following data elements to develop the databases:

- Bicycle and traffic count.
- Bikeway facility type.
- Multiple roadway design elements (e.g., functional class, number of lanes, and lane and shoulder widths).
- Posted speed limit.
- Crash data (e.g., location, year, type, and severity).

Washington

Researchers obtained bicycle-count data from the Washington State Department of Transportation Bicycle and Pedestrian Count Portal (WSDOT 2020). The Washington State Documentation Project collects bicycle- and pedestrian-usage data in various locations throughout the State. Counters and volunteers collected data from both permanent and temporary sites. The documentation project uses a data-collection protocol similar to and consistent with the National Bicycle and Pedestrian Documentation Project. Data were collected from a network of city staff, bicycle club members, and other volunteers to gather and document bicycle counts. For this study, the research team examined a dataset of historical counts from 398 locations, including segments, intersections, and shared-use paths.

The research team used data from the second Strategic Highway Research Program's Roadway Inventory Database (RID) and Google Earth. Team members then combined the coordinates of the bicycle counts with RID links. Fifty-five segments overlapped with a link, including all geometry and traffic characteristics. In addition to these segments, the research team verified that the locations extended at least the length of the corresponding geographic information system (GIS) links in the database. The research team increased the sample of sites to include adjacent segments (represented by the GIS-digitized vector links) after verifying that the cross section extended uniformly into those additional segments. As a result, this additional data assessment extended the number of segments in the Washington database to 87.

Data included crashes located at sites that were both on and off system (i.e, "on-system" locations are those maintained by DOT). The research team used 4 years of crash data for the analysis. Table 1 shows descriptive statistics of the resulting database after removing intersection- and driveway-related crashes.

Texas

The research team used estimated bicycle-count data from Strava, a crowdsourcing database, to produce average daily bicycle traffic (ADBT) in conjunction with direct-demand models developed for the Texas Department of Transportation (Turner et al. 2019). Data were collected during different times from 2016 to 2017. Turner et al. integrated site counts with the Strava sample and developed direct-demand models to estimate the average annual daily traffic (AADT) bicycle counts.

The research team also used a database of existing bikeway facilities from the Texas Department of Transportation Austin District as well as data from the North Central Texas Council of Governments. The research team selected the segments with and without bicycle lanes for analysis.

Researchers then combined the selected segments (with and without an onstreet bicycle lane) with Texas roadway inventory and crowdsourced data to estimate bicycle counts on these segments. As a result, 5,473 segments were identified and included in the initial database.

Safety Data

After identifying segments of interest, the research team identified crashes that occurred on selected roadway segments. Bicycle counts were estimated for the period between July 2016 and June 2017; therefore, the research team selected 2015–2018 crash data under the assumption that the bicycle lane remained present at the selected locations one year prior to data collection. The research team used a geolocation buffer to identify the segment crashes. Team members then applied filters to remove crashes from adjacent locations. After identifying crashes corresponding to the facilities under study, intersection-related crashes were removed from the database prior to analysis. Table 2 shows descriptive statistics of the resulting database.

The database described in table 2 was further filtered prior to subsequent analysis. From an initial set of 5,473 segments with ADBT estimates available, the research team identified and discarded segments unsuitable for analysis for reasons including having more than four cross-sectional lanes, curbed medians, and wide lane width used for parking space. Extensive quality control suggested that the variable indicating the presence of bicycle lanes was correct in 70 percent of the database. For the remaining 30 percent, the variable indicating the presence of bicycle lanes was corrected through model-based imputation procedures. The refined database reduced to 3,622 segments for analysis. The evaluation focused on cross sections with two or four lanes, which represent the most prominent conditions at locations with bicycle lanes in the database.

ANALYSIS

Safety Effectiveness

The Washington and Texas databases were analyzed separately to estimate various CMFs, focusing on differences in the data structure and available variables. For both evaluations, the study design was cross sectional with PS weights. Researchers used the negative binomial generalized linear models estimation method. All estimated CMFs from Washington were statistically insignificant. Table 3 shows total crash CMFs for Washington.

Although CMFs were developed for total crashes and fatal and injury crashes for Texas, only five CMFs for total crashes were found to be statistically significant. Table 4 summarizes the results from these five evaluations.

Economic Effectiveness

The research team conducted an economic analysis to estimate a B/C ratio for this strategy on urban arterials, collectors, and city streets. To perform a B/C analysis, the research team followed the procedures recommended in *Highway Safety Benefit-Cost Analysis Guide* (Lawrence et al. 2018). The methodology compiles the monetary equivalents of all benefits expected (e.g., crash and congestion reductions) and costs necessary to implement bicycle lanes (e.g., materials and maintenance). The B/C ratio is the ratio of all benefits to all costs and provides a metric of the economic feasibility of the intervention. Values larger than 1.0 indicate more benefits than costs (i.e., economic feasibility), while values smaller than 1.0 indicate costs are larger than benefits and therefore the implementation is not economically feasible.

The value of a statistical life (VSL) was obtained from a recent U.S. Department of Transportation memorandum (Trottenberg and Rivkin 2016). The recommended range for VSL is from $5.2 million to $12.9 million in 2012 dollars. Knowing the range for 2001 dollars allows the computation of the underlying geometric rate of inflation; therefore, the range for 2016 was determined to be between $5.7 million and $14.9 million. A nominal value of $10.08 million was adopted for this evaluation.

According to the Pedestrian and Bicycle Information Center (FHWA 2015), the cost of adding bicycle lanes depends on the specific project details. This source claims that providing narrow lanes and reducing the

Table 1. Descriptive statistics of segments in Washington.				
Variable Name	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
Segment length (ft)	65	3,766	572.01	562.40
Number of through lanes	1	6	2.72	1.14
Left-turn lane	0	2	0.29	0.50
Right-turn lane	0	1	0.21	0.41
Lane width (ft)	9.16	14.86	11.19	2.20
Shoulder width (ft)	0	11	1.40	2.89
Bike-lane width (when present) (ft)	4	6	1.65	2.60
Year	2010	2013	2011.50	1.12
ADBT (7 a.m.–9 a.m.)	0	279	28.28	55.59
ADBT (4 p.m.–6 p.m.)	0	468	34.61	68.81
ADBT (bicyclists per day)	4	739	63.20	119.31
AADT (vehicles per day)	1,000	160,504	22,894.99	28,240.16
VMT (vehicle miles per day)	0.54	152.57	11.13	19.41
Total crashes	0	83	6.50	11.35
Fatal crashes	0	5	0.02	0.29
Incapacitating injury crashes	0	10	0.10	0.91
Nonincapacitating injury crashes	0	17	0.47	1.58
Possible injury crashes	0	26	1.86	3.86
Fatal and injury crashes	0	41	2.45	5.13
Bike crashes	0	9	0.07	0.56

ADBT = average daily bicycle traffic; AADT = annual average daily traffic; VMT = vehicle miles traveled.

width of lanes by adding bicycle lanes costs at least $5,000 per mile. The cost, however, varies widely based on pavement condition. Restriping to reduce lanes, adding bicycle lanes, or adding onstreet parking is estimated to cost between $5,000 and $20,000 per mile. Interventions circumscribed to the existing right-of-way (as in this evaluation) are associated with lower costs (Weigand et al. 2013).

The research team used the Texas CMF for total crashes on collectors and local roads (CMF = 0.734), hypothesizing no increase in bicycle-traffic levels. This assumption is conservative because the increase in bicycle traffic tends to increase the size of the CMF.

Considering an adjusted VSL, the average crash cost in Texas at the facilities under study, with no additional right-of-way acquisition, only restriping and maintenance costs, and no costs of congestion, the B/C ratio was estimated for Texas collectors and local streets at 16.61 after the installation of bicycle lanes.

CONCLUSIONS

The objective of this study was to perform a rigorous safety-effectiveness evaluation of adding a bicycle lane while reducing lane and shoulder widths at urban and suburban locations that are candidates for the treatment. To accomplish the goals of this study, the research team compiled safety data from Washington and Texas. The evaluation included total, fatal and injury, property-damage-only, and bicycle crashes. Emphasis was given to locations with bicycle-traffic data available because past research on the safety effectiveness of the treatment of interest identified bicycle traffic as an influential variable. The research team developed estimates of ADBT using actual bicycle counts for Washington and direct-demand models for Texas. This study developed sets of CMF estimates under two assumptions: CMFs marginal of all exposure, and CMFs under hypothesized levels of induced bicycle traffic after the construction of bicycle lanes.

Table 2. Descriptive statistics of segments in Texas.

Variable Name	Minimum	Maximum	Mean	Standard Deviation
Number of lanes	1	8	3.03	1.27
Surface width (ft)	14	96	35.17	15.49
Roadbed width (ft)	18	131	39.17	20.96
Inside (left) shoulder width (ft)	0	18	0.99	2.81
Outside (right) shoulder width (ft)	0	20	1.67	4.74
Median width (ft)	0	312	3.26	14.34
Segment length (ft)	5.28	34,473.12	4,509.64	3,903.63
Land area (m^2)	0	106.1693	2.26	5.94
Number of households with income > $200,000	0	1,611	83.37	141.64
AADT 2016	10	92,462	13,001.15	14,756.86
AADT 2015	54	10,7121	12,435.06	14,390.35
Total annual number of Strava users	0	32,085	671.55	1,967.98
Annual average daily Strava users	0	87.90411	1.84	5.39
ADBT (estimated)	0	1,135	38.67	28.26
All crashes	0	266	4.77	14.40
Bicycle crash, all	0	6	0.04	0.25
Fatal and suspected serious injury, all	0	10	0.16	0.60

Table 3. Total crash CMFs for bicycle-lane additions in Washington (urban arterials).

Scenario	Crash Type	CMF[1]	Standard Error (CMF)	95% Confidence Interval	
				Lower Limit	Upper Limit
Bicycle-lane addition and shoulder reduction[2]	Total	0.7859	0.3009	0.3964	1.5583
Bicycle-lane addition by shoulder or lane reduction[2]	Fatal and injury	0.7717	0.3312	0.3635	1.6382
Bicycle-lane addition by shoulder or lane reduction[2]	Property-damage only	0.8851	0.2697	0.5048	1.552

[1]None of the three estimates were found statistically significant.
[2]Base condition: two 11.0-ft lanes, 2.0-ft shoulder, no median, and urban arterial road.

Table 4. Total crash CMFs for bicycle-lane additions in Texas (two-lane and four-lane undivided urban collectors and local roads).					
Scenario	Facility Type	CMF	Standard Error (CMF)	95% Confidence Interval	
				Lower Limit	Upper Limit
Bicycle-lane addition by shoulder or lane reduction (no change in ADBT)[1]	4LUCL	0.514*	0.258	0.283	0.901
Bicycle-lane addition by shoulder or lane reduction (20% increase in ADBT)[1]	4LUCL	0.542*	0.271	0.301	0.974
Bicycle-lane addition by shoulder or lane reduction (no change in ADBT)[2]	2LUCL	0.734*	0.091	0.595	0.904
Bicycle-lane addition by shoulder or lane reduction (20% increase in ADBT inch)[2]	2LUCL	0.694*	0.096	0.557	0.865
Bicycle-lane addition by shoulder or lane reduction (50% increase in ADBT)[2]	2LUCL	0.649*	0.108	0.507	0.830

*Indicates statistical significance.
[1]Base condition: 11.0-ft lanes, no shoulder, no median, and 4-lane urban collector or local road. Initial ADBT assumed 50 bicyclists per day (mean value in the dataset).
[2]Base condition: 12.0-ft lanes, no shoulder, no median, and 2-lane urban collector or local road. Initial ADBT assumed 40 bicyclists per day (mean value in the dataset).
4LUCL = four-lane undivided collector or local road; 2LUCL = two-lane undivided collector or local road.

Results from Washington were based on smaller sample sizes and showed that the addition of bicycle lanes did not yield statistical evidence of any changes in safety performance. In contrast, results from Texas were based on a larger sample size and produced CMFs indicating statistically significant reductions for total crashes for two facility types: two-lane undivided urban collectors and local streets, and four-lane undivided urban collectors and local streets.

Trends in the analyses generally indicate crash reductions at sites with bicycle lanes compared to sites without bicycle lanes. This trend was also true for the five CMFs found to be statistically significant. Additionally, the magnitude of the estimated CMF for four-lane collectors and local streets is sensitive to the expected increase in ADBT with bicycle lanes compared to ADBT without bicycle lanes. At these facilities, the magnitude of the CMF increases with increasing ADBT. Likewise, the statistical significance of the results tends to decrease with increasing ADBT. In the case of two-lane collectors and local streets, the safety effectiveness estimate is not as sensitive to the expected increase in ADBT.

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