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Development of Crash Modification Factors for Bicycle Treatments at Intersections

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This document is a technical summary of the Federal Highway Administration report *Development of Crash Modification Factors for Bicycle Treatments at Intersections* (FHWA-HRT-23-020).

INTRODUCTION

The Federal Highway Administration's (FHWA) Development of Crash Modification Factors (DCMF) Program was established in 2012 to address highway safety research needs for evaluating new and innovative safety strategies by developing reliable quantitative estimates of their effectiveness in reducing crashes (FHWA 2022). Forty-one State departments of transportation (DOTs) provided technical feedback on safety improvements to the DCMF Program and implemented new safety improvements to facilitate evaluations. These States are members of the Evaluation of Low-Cost Safety Improvements Pooled Fund Study (ELCSI-PFS), which functions under the DCMF Program.

This project evaluated bicycle treatments at urban intersections. The ELCSI-PFS Technical Advisory Committee selected this evaluation as one of the priorities within its purview.

Study Objective

This evaluation assessed the potential safety improvements of various intersection geometric and traffic control device treatments to reduce fatal and injury vehicular crashes and bicycle-specific crashes. The intent was to develop crash modification factors (CMFs) and benefit–cost (B/C) ratios for each safety improvement. Practitioners can use the CMFs and B/C ratios for decisionmaking in the project development and safety planning processes.

Background

Intersections are particularly dangerous areas for bicyclists. According to the National Association of City Transportation Officials (NACTO), in 2017, 43 percent of bicyclist fatalities in urban areas occurred at intersections, based on their analysis of the National Highway Traffic Safety Administration's Fatality Analysis Reporting System data (NACTO 2019). Changes to traffic control devices, channelization, parking regulations, or roadway design could potentially reduce intersection crashes.

METHODOLOGY

Safety studies are often limited to evaluations of observational data since randomization is not possible and randomized comparison group experiments are not feasible. Good observational studies rely on data from both treated and nontreated sites in a manner consistent with control group experiments. After reviewing potential data sources, the research team deemed obtaining before–after data from multiple jurisdictions on the installation of bicycle lanes infeasible. Therefore, the research team developed a database for cross-sectional analysis. To incorporate comparison sites, team members adopted the use of propensity score (PS) weighting methods to minimize imbalances between covariates to make the sites more comparable. Under this framework, the PS of the treatment sites and their corresponding control sites are estimated and compared. The PS is a metric of similarity between covariates in the two study groups (i.e., sites treated and comparison sites).

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 comparison populations, as proposed by Li, Morgan, and Zaslavsky (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 comparison group. This approach effectively curbs the undue influence of control sites that are unlikely to be candidates for the treatment and of treated sites with unusual characteristics so that no comparable control sites are represented in the data.

The empirical analyses were conducted using the statistical methods appropriate to the characteristics of the assembled datasets. The research team used appropriate Poisson-lognormal and negative binomial generalized linear models for the different datasets and response variables. Best fit models were estimated, including the key variables (the various intersection treatments under evaluation) and other influential covariates. CMFs and their standard errors were estimated from linear combinations of model coefficients to reflect changes in cross-sectional elements at intersections of interest.

DATA

Obtaining enough bicycle volume data is essential in these evaluations. Since bicyclists do not necessarily follow the same travel patterns as passenger cars, actual large counts were preferred, when available, over the alternative of estimating the volumes from limited data. After the team reviewed potential datasets from multiple States (Texas, Washington, Oregon, Florida, and Virginia), the limited availability of locations with actual bicycle counts or a potential for estimation (e.g., through other variables) drove the decision to narrow the evaluation down to the two States with the most promise to develop the dataset for analysis. The research team used data from Virginia and Texas because of the number of potential locations with bicycle exposure estimates or direct measurements that could be obtained.

To develop the databases, the research team collected the following data elements:

- Bicycle and motor vehicle traffic count.
- Bicycle facility type.
- Multiple intersection design elements (e.g., number of approach lanes, presence of turn lane).
- Posted speed limit.
- Crash data (e.g., location, year, type, and severity).

The research team used geographic information systems tools to prepare, filter, and combine multiple datasets containing geolocation (typically in shapefile format) (Esri™ 2019). GIS tools allow the manipulation, combination, and display of data for different types of information, including crashes, road infrastructure, traffic volume, census tract, and land use, among others.

Bikeway Facility Type and Roadway Data

To better characterize the bicycle treatments applied at each intersection and its legs, the research team developed and refined a data structure and collection protocol. The database consisted of two Microsoft® Excel® spreadsheets: one for intersection characteristics, and the other for features of each intersection leg. The intersection-level spreadsheet contained 12 variables to describe the geolocation, control type (signed or signalized), and bicycle treatment presented over each intersection. The leg-level spreadsheet contained 24 variables to describe the roadway design characteristics and bicycle-lane-related features of road segments connected with each intersection.

The collected data can be broadly classified into three categories (table 1):

- Intersection characteristics category contains variables to describe the geolocation, control type (signed or signalized), and bicycle treatment presented for each intersection. In this study, the evaluations focused on bicycle treatments such as keyways or pockets, mixing zones at the approach, chevrons, extension lines, cross-markings, two-stage turn queue boxes, and bicycle boxes.

- Roadway design characteristics category contains road-related variables to characterize the road segments connected with each intersection. In this study, major legs/streets refer to the road segments with relatively higher annual average daily traffic (AADT) values, and minor legs/streets refer to the road segments with relatively lower AADT values.
- Bicycle lane characteristics category contains bicycle-lane-related variables to describe each intersection's connecting bicycle lanes, including the number of bicycle lanes and the existence of four types of treatments—keyways, mixing zones at the approach, buffered bicycle lanes, and separated bicycle lanes (SBLs). Additionally, the data collected include pavement markings, such as chevrons, extension lines, and green pavement markings through the intersection.

Table 1. Virginia intersections descriptive statistics (*n*=59 sites).

Variable	Mean	Std Dev	Median	Min	Max
MajADT	12,921.95	4,684.51	12,921.95	5,200	28,000
MinADT	10,458.54	5,077.33	10,458.54	1,900	28,000
ADBT	89.38	81.89	63	6.98	484.72
NumLegs	3.29	0.74	3	3	5
NLanes.mj (major)	2.32	1.12	2	1	6
NLanes.mn (minor)	1.42	0.7	1	1	4
Lane_Width (ft)	10.39	1.03	10	9	14
Inter_Length (major) (ft)	76.32	31.69	74.02	27.37	212.92
Inter_Length (minor) (ft)	57.58	22.97	53.99	22.63	127.66
Signalized	0.59	0.50	1.0	0	1
Chevrons	0.03	0.18	0	0	1
Cross_Markings	0.39	0.49	0	0	1
NumBikeL	0.53	0.3	0.5	0	1
Bike_L_Wid	2.33	1.85	2	0	10.5
Buffered_BikeL	0.04	0.14	0	0	0.67
Bike_Box	0.02	0.09	0	0	0.5
Two_Way_Cyc	0.06	0.16	0	0	0.5
Through_BikeL	0.31	0.32	0.33	0	1

Std Dev = standard deviation; Min = minimum; Max = maximum; MajADT = major annual daily traffic; MinADT = minor annual daily traffic; Num and N = number; mj = major; mn = minor; Inter = intersection; L = lane; Wid = width; Cyc = bicycle.

Virginia

The researchers obtained the bicycle count data from the Virginia DOT bicycle data online repository (VDOT 2021). A third-party company maintains and displays an online portal with bicycle and pedestrian usage data from counters across the State (Eco-Counter 2022). The data are collected from several cities from both permanent and temporary sites with the help of counters and are managed by personnel in the corresponding cities. After eliminating locations at bicycle dedicated paths, other locations out of the scope of this evaluation, and locations with a limited amount of data, the research team examined a dataset of historical counts from intersections at 59 locations with some level of bicycle treatments represented, as well as enough data to estimate daily bicycle volumes. The average daily bicycle volume at the intersections ranged from about 7 to 485 bicycles per day, with an average of 89.

The research team obtained crash data from Virginia's online repository to then integrate with the geometry data described at the beginning of this section (VDOT 2021). Specifically, team members identified and linked all the crashes within the vicinity of 200 ft of the intersections included in the database. To match the same period of geometry data and when bicycle counts were collected, the research team filtered crashes to represent only the period from 2015 to 2019. Therefore, the research team used 4 yr of crash data.

Texas

For the Texas sites, the research team used estimated bicycle count data from the crowdsourced database Strava to produce ADBT estimates (Strava 2018). The research team calibrated direct demand models similar to those developed by Turner et al. (2019) to estimate the bicycle counts from the crowdsourced database.

The research team identified crashes that had occurred on the selected intersections (table 2). Because the bicycle counts were estimated for a period between July 2016 and June 2017, the research team selected 2016–2019 crash data for analysis. This range of dates assumes that the bicycle intersection treatments were present at the selected locations 1 yr before the data collection. The research team used a geolocation buffer of 200 ft to initially identify the intersection crashes, as recommended by Avelar, Dixon, and Escobar (2015). After crashes corresponding to the facilities under study were identified, filters were applied to remove non-intersection-related crashes before analysis (e.g., driveway related).

Table 2. Texas descriptive statistics of intersections (*n*=126 sites).

Variable	Mean	Std Dev	Median	Min	Max
AADT.mj	16,132	13,109	12,517.75	2,678	46,640
AADT.mn	4,568	6,299	2,205.5	23.02	32,497
Maj.ADBT	105	139	37	19	826
Min.ADBT	70	96	29.25	17	569
NumLegs	3.63	0.5	4	2	4
Nlanes.mj	2.83	1.12	3	1	6
Nlanes.mn	1.73	0.83	2	1	4
Lane_Width	12.07	2.36	11.38	9.18	20.19
Signalized	0.58	0.5	1	0	1
Inter_Length1	74.97	30.78	67.75	22.1	204.8
Inter_Length2	53.61	22.5	46.95	23.3	143.6
NumBikeL	0.88	0.58	1	0	2
Bike_L_Wid	3.56	1.95	4	0	11.23

Table 2. Texas descriptive statistics of intersections (*n*=126 sites). (Continued)

Variable	Mean	Std Dev	Median	Min	Max
Buffered_BikeL	0.16	0.35	0	0	1.5
Through_BikeL	0.02	0.18	0	0	2
Treat_1B	0.05	0.31	0	0	2
Treat_2A	0.48	0.95	0	0	4
Treat_3	0.02	0.18	0	0	2
Treat_4	0	0	0	0	0
Chevrons	0.21	0.41	0	0	1
Cros_Markings	0.23	0.42	0	0	1

Treat = treatment; Cros = cross.

ANALYSIS

Safety Effectiveness

In general, the research team used entropy metrics (Akaike information criterion and Bayesian information criterion) to guide model development. In each case, the research team found the best fitting model for the response variable of interest, namely crash frequency by severity and type. The research team performed the analysis separately by State, given the differences observed in the descriptive statistics, especially on bicycle crashes. Additionally, the dataset from Virginia offered ADBT estimates directly from actual counts for multiple years at each location under study, whereas bicycle volumes were estimated for the Texas dataset.

Virginia

The trends in the safety analyses from Virginia suggested crash reductions in general. However, all analyses of this dataset yielded statistically insignificant results.

Texas

In contrast to the results in Virginia, the evaluations in Texas yielded three statistically significant results: two for designs that include SBLs, and one for the mixing zone configuration in figure 1. These results are shown in table 3.

This result indicates expected reductions of 44.8 percent and 54.4 percent for SBL installations in terms of total and non-weather-related crashes, respectively. Similarly, results indicate that a 42.9-percent reduction in fatal and injury crashes is associated with the mixing zone configuration shown in figure 1.

Table 3. Crash CMF estimates for bicycle treatments at intersections in Texas.

Treatment	Crash Type	CMF	Estimate	Std Error	*P* Value	Significance
SBL[a]	Total	0.552	−0.593	0.345	0.086	~
SBL[a]	Non-weather related	0.456	−0.786	0.253	0.002	**
Bicycle lane mixed with through and right-turn lane[a]	Fatal and injury	0.571	−0.560	0.264	0.034	*

~Statistically significant at the 0.1 level.
*Statistically significant at the 0.05 level.
**Statistically significant at the 0.01 level.
[a]Base condition is no bicycle lane.

Figure 1. Map. Sample intersection with mixing zone for a bicycle lane, multivehicle through lane, and right-turn movements.

Economic Effectiveness

To perform a B/C analysis, the research team followed the procedures recommended in FHWA's technical document entitled, *Highway Safety Benefit–Cost Analysis Guide* (Lawrence et al. 2018). The value of a statistical life (VSL) was obtained from the most recent memorandum on the U.S. DOT website (Putnam and Coes 2021). The recommended range for VSL is $10.9 million in 2019, the most recent year included in the evaluations of this study.

To estimate B/C ratios, the research team included the cost of installing and maintaining SBLs for a period of 20 yr. The total project cost of the improvement is estimated as $292,918, if no additional right-of-way (ROW) purchase is necessary. If ROW should be acquired, the total project cost over the period of analysis was estimated to escalate to $15,537,362. When the safety benefit is considered, the B/C ratio of adding SBLs was estimated as 30.9 if no additional ROW is acquired, whereas the B/C ratio drops to 5.9 in the scenario where ROW is added to accommodate the treatment.

The other treatment that was found beneficial according to the evidence in the dataset was the configuration that creates a mixing zone between the through and right-turn movement for motor vehicles and bicycle lanes (figure 1). Assuming that the treatment will not require acquiring additional ROW, the B/C ratio of this strategy was estimated as 113.3.

CONCLUSIONS

The objective of this study was to perform a rigorous safety effectiveness evaluation of adding bicycle treatments at urban intersections that are candidates for the treatment. To accomplish the goals of this study, the research team compiled safety data from Virginia and Texas. The evaluation included total, fatal and injury, and non-adverse-weather crashes.

Safety data collection was guided by the availability and location of bicycle traffic data, which is an influential variable identified in past research on the safety effectiveness of the treatment of interest. Similar to how AADT is used to account for motor vehicle exposure, bicycle traffic should reflect exposure for those vulnerable users. In the case of Virginia, the research team developed estimates of ADBT using actual bicycle counts. For Texas, direct demand models were developed and used to estimate bicycle volume.

Statistically significant CMFs were found from Texas for SBL construction with regard to total and non-weather-related crashes, as well as for providing a mixing zone configuration for bicyclists and motor vehicles at the approach with regard to fatal and injury crashes. The research team surmises that sample size for both States with enough treated sites and enough crash data might have been a contributing factor for all other evaluations that yielded statistically insignificant results.

In the case of the statistically significant CMFs for SBLs at intersections, this research found a 54-percent crash reduction in non-weather-related crashes in Texas (0.456 CMF, 0.002 *p* value) linked to this treatment. This CMF was used to calculate the benefits of bicycle through-lane treatments at intersections in the B/C ratio evaluations. The costs of construction and maintenance were found to be notably smaller than the benefit. The B/C ratio was estimated as 5.9 when the cost of additional ROW is assumed, and 30.9 without that assumption.

In the case of the mixing zone at the approach, the estimated CMF was a reduction of 42.9 percent in fatal and injury crashes (0.571 CMF, 0.034 *p* value). The research team estimated the B/C ratio in this case to be 113.3, assuming no additional ROW is required to construct and maintain this treatment.

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Researchers—This study was performed by Principal Investigator Raul Avelar, along with Boniphace Kutela and Xiao Li, Texas A&M Transportation Institute.

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