TECHBRIEF

Developing Crash Modification Factors for Separated Bicycle Lanes

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This document is a technical summary of the Federal Highway Administration report *Developing Crash Modification Factors (CMFs) for Separated Bicycle Lanes* (forthcoming).

INTRODUCTION

In 2020, the United States had 938 bicycle fatalities due to roadway-related crashes.(1) As bicycle use increases, transportation agencies are tasked with determining the optimal location and configuration for constructing on-road bicycle facilities. Several bicycle lane configurations are available, including the traditional bicycle lane, a buffered bicycle lane, and a separated bicycle lane (SBL). Recently, many U.S. transportation agencies have started implementing SBLs—also known as protected bicycle lanes—as a safety enhancement. Figure 1 provides an example of an installation. SBLs provide a bicycle lane that is separated from the adjacent motor vehicle lanes by including both a buffer and a vertical element between the motor vehicle lanes and the bicycle lane.

Figure 1. Photo. Example of an SBL on a two-way street.

Source: FHWA.

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STUDY OBJECTIVE

The large number of bicycle-involved collisions demonstrates the need to prioritize analyzing and enhancing the safety of bicyclists. In recent years, transportation agencies have constructed a variety of bicycle lane configurations, including SBLs, yet the associated influence that an SBL may have on reducing crashes has yet to be determined. This Federal Highway Administration (FHWA) project evaluated the safety effect for various on-street bicycle facilities. The research focused on the feasibility of developing a crash modification factor (CMF) for the placement of SBLs at roadway segment locations.

SITE IDENTIFICATION

The criteria established for a site to be included in this FHWA study are as follows:

- The study region, at a minimum, must include traditional bicycle lanes and SBLs.
- Data that can be used to estimate bicycle exposure must be available.
- Reported crash data are available for all bicycle-involved crashes, and the data must be multiyear data prior to 2020.
- The SBL configuration should be consistent throughout the study region.
- Site features, such as roadway cross-sectional characteristics and direction of travel, can be acquired from an online source.

First, the research team identified several candidate locations based on published literature and a bicycle database known as the Green Lane Project.[2] For that project, bicyclists were encouraged to document any locations they encountered with SBLs. Even though a database primarily developed by volunteers can be error-prone, this resource provided information about locations that were equipped with some sort of bicycle facility.

Based on the location information included in the Green Lanes database and other published literature, the research team was then able to identify several potential locations to study. Following additional site screening via aerial photographs and jurisdiction databases, the research team identified the following promising study locations:

- Cambridge, MA.
- San Francisco, CA.
- Seattle, WA.

In addition to these three cities, the team identified two locations with smaller sample sizes that could be used for CMF validation. These locations included the following:

- Austin, TX.
- Denver, CO.

DATA COLLECTION

The team compiled a list of data-related issues to consider when assessing the safety of an SBL facility. Table 1 identifies and defines these data requirements. To develop a CMF, there must be a base condition (e.g., no bicycle lane or traditional bicycle lane) and a target CMF (e.g., buffered bicycle lanes, SBLs). For this reason, site selection included all bicycle facilities within the study region. The research team populated the data needed for each study site segment, as summarized in table 1.

Table 1. Site information in database.

DATA NEED	TYPE OF DATA	COLLECTED SITE DATA ELEMENTS
Location description	Location	Street name, city, and State (including beginning and ending cross streets).
Starting latitude/longitude	Location	Measured to extended curb if at intersection.

Table 1. Site information in database. (Continued)

DATA NEED	TYPE OF DATA	COLLECTED SITE DATA ELEMENTS
Ending latitude/longitude	Location	Measured to extended curb if at intersection.
Length	Location	Distance in miles.
Cross streets	Location	Between beginning and ending points.
Number of motor vehicle lanes	Site characteristics	Total for both directions of travel.
Roadway facility type	Site characteristics	Urban arterial (two-way and one-way). Urban collector (two-way and one-way). Urban local street (two-way and one-way).
Intersection channelization and traffic control	Site characteristics	Islands (traditional, bend-in, bend-out, turn lanes, etc.). Motor vehicle and bicycle signalization. Signage and pavement markings.
Lighting	Site characteristics	Street light presence, placement, and type.
Corridor information	Site characteristics	Speed limit; driveway density; number, type, and width of lanes; number and type of intersections; street network configuration; vehicle parking restriction hours; presence and location of sidewalks.
Direction of bicycle traffic flow	Site characteristics	Approaching or departing field of view.
Traffic operations for motor vehicle lanes	Site characteristics	One-way or two-way.
Median	Site characteristics	Physical separation of opposing motor vehicle maneuvers.

Table 1. Site information in database. (Continued)

DATA NEED	TYPE OF DATA	COLLECTED SITE DATA ELEMENTS
Parking lane location	Site characteristics	Presence and location of parking lane; located left and/or right side of road if applicable.
Type of bicycle facility	Bicycle facility characteristics	No dedicated lane, traditional bicycle lane, buffered bicycle lane, or SBL.
Year of construction	Bicycle facility characteristics	SBLs constructed earlier than 2010 may not be suitable if exposure information and crash data are not available.
Width of buffer	Bicycle facility characteristics	Locations with on-street parking should be further assessed to determine actual and effective buffer widths.
Vertical element	Bicycle facility characteristics	Flexible posts, bollards, or light poles; curb or raised median; landscaping and planters; concrete (zebra/armadillo) bumps, buttons, and parking stops; parked cars; grade; concrete barrier, guardrail, or fence.
SBL facility configuration	Bicycle facility characteristics	Right side one-way, or two-way. Left side one-way, or two-way. Middle two-way.
Unique SBL features	Bicycle facility characteristics	Truck aprons, mixing zones, or elevated SBLs at driveways/crossings; green markings; bicycle facility continuity and operational consistency.
Crash data	Supplemental data from agency where sites are located	Total number of crashes and number of fatal and injury crashes (specific consideration to who is injured: motor vehicle drivers or passengers, bicyclists, and pedestrians).

Table 1. Site information in database. (Continued)

DATA NEED	TYPE OF DATA	COLLECTED SITE DATA ELEMENTS
Exposure	Supplemental data from agency where sites are located	Average daily traffic or peak-hour volumes for motor vehicles (passenger cars and trucks), bicycles, and pedestrians; land use and driveway types (as potential volume surrogates). The increase in bicyclists due to the placement of SBL facilities is also an important exposure consideration.

The project team included variables that potentially could influence the safety performance of SBL facilities and the bicycle exposure estimate. This supplemental information provided valuable insights into the operational characteristics of the facilities.

ANALYSIS APPROACHES

The research team used the initial site characteristic information to develop exposure models for each site. Because the available count data ranged from long-term hourly to short-term daily, the exposure model was unique to each jurisdiction. The team also acquired crash data for all of the study site locations and merged them into a data file that ultimately included estimated bicycle counts, site data information, and crash history. The regression analysis focused on bicycle-involved crashes. Note that data for 2020 and 2021 were excluded from the CMF development efforts because those data were atypical. The team could not locate a dataset that included the date of implementation for each site, so they elected to use a cross-sectional analysis with propensity score weights.

The team developed regression equations to create CMFs for the following combinations:

- SBLs versus traditional bicycle lanes.
- SBLs versus buffered bicycle lanes.
- SBLs versus either traditional bicycle lanes or buffered bicycle lanes.

Ultimately, this combination of CMFs will enable a user to assess the benefits of deploying an SBL when the base condition is either a traditional bicycle lane or a buffered bicycle lane. This CMF development activity focused on Cambridge, San Francisco, and Seattle. Following CMF development, the team then assessed if the CMFs could be applied to Austin and Denver.

FINDINGS

The research team developed several regression models for Cambridge, San Francisco, and Seattle (both independently and with a merged dataset). Following that effort, the team used the data from Austin and Denver to validate the models. The Austin model performed quite well, but the Denver model appeared to underpredict bicycle crashes. The research team conducted an equivalency test and could not rule out that the CMFs for the different jurisdictions were not equivalent, so the models passed the validation test; however, the CMF for Denver conditions should be applied cautiously. The team was not completely sure about why these data differed, but Colorado has different weather patterns (particularly in the winter) and has a greater elevation than the other study sites. Table 2 summarizes the research finding.

The CMFs for SBLs show a clear trend that, with their implementation, a transportation agency can expect to see a reduction in bicycle crashes. The individual city models suffer from smaller sample sizes; however, they continue to result in estimated crash reductions consistent with those of larger sample sizes. The combination of data from different cities also results in similar trends and, for the most part, greater statistical significance. For baseline conditions, the use of traditional bicycle lanes, bicycle lanes with buffers but no vertical elements, or bicycle lanes with a combination of traditional and buffers resulted in generally similar trends. The SBL treatments that were the most effective included flexible delineator post treatments and treatments that were blended (most often flexible delineator posts and other vertical elements).

Table 2. CMFs for Bicycle Crashes (San Francisco, Seattle, and Cambridge).

CONDITION	CMF	ESTIMATE	STANDARD ERROR ESTIMATE	PROBABILITY VALUE	SIGNIFICANCE
Flush buffer[a]	1.128	0.121	0.173	0.484	—
Flexible delineator posts[a]	0.498	-0.698	0.264	0.008	**
Flexible delineator posts[b]	0.441	-0.819	0.297	0.006	**
Flexible delineator posts[c]	0.468	-0.758	0.267	0.005	**
Blended[a]	0.822	-0.196	0.252	0.437	—
Blended[b]	0.729	-0.316	0.300	0.292	—
Blended[c]	0.774	-0.256	0.263	0.331	—
Flexible delineator posts[d]	0.605	-0.502	0.318	0.114	—
Flexible delineator posts or blended[a]	0.640	-0.447	0.203	0.028	*
Flexible delineator posts or blended[b]	0.567	-0.568	0.253	0.025	*
Flexible delineator posts or blended[c]	0.602	-0.507	0.212	0.017	*

[a]*Base condition: Traditional bicycle lane.*
[b]*Base condition: Flush buffered bicycle lane.*
[c]*Base condition: Traditional or flush buffered bicycle lane.*
[d]*Base condition: Blended vertical element.*
**Statistically significant at the 0.05 level.*
***Statistically significant at the 0.01 level.*
****Statistically significant at the 0.001 level.*
—Not statistically significant.

Table 3. Overview of significant variables in models.

SIGNIFICANCE LEVEL	BEFORE CONDITION	AFTER CONDITION	CMF	STANDARD ERROR ESTIMATE
0.01	Traditional bicycle lane.	SBL with flexible delineator posts.	0.498	0.173
0.01	Flush buffered bicycle lane.	SBL with flexible delineator posts.	0.441	0.297
0.01	Traditional or flush buffered bicycle lane.	SBL with flexible delineator posts.	0.468	0.267
0.05	Traditional bicycle lane.	SBL with blend of flexible delineator posts and other vertical elements.	0.640	0.203
0.05	Flush buffered bicycle lane.	SBL with blend of flexible delineator posts and other vertical elements.	0.567	0.253
0.05	Traditional or flush buffered bicycle lane.	SBL with blend of flexible delineator posts and other vertical elements.	0.602	0.212

CONCLUSIONS

In addition to developing an SBL CMF for bicycle-involved crashes, this research identified multiple statistically significant factors that could influence bicycle operations and safety. In general, the analysis indicates the following:

- Bicycle crashes are more likely to occur at locations with mixed land use and less likely to occur at locations with industrial or public land use.
- Bicycle crashes occur less frequently at locations with more motor vehicle lanes. This observation could be an indicator of route choice by the bicyclist.
- Bicycle crashes occur less frequently at locations where parking is not permitted in at least one direction compared to locations without parking restrictions.

The report documents exposure models and region-specific regression estimates. Collectively, the research yielded the summary of CMFs, based on a combined model, as shown in table 3. The use of flexible delineator posts consistently resulted in a decrease in total crashes. When flexible delineator posts are blended with another treatment, the crash reduction remains significant.

REFERENCES

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