Accident Analysis and Prevention 65 (2014) 114–122

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Bicyclist safety performance functions for a U.S. city

Krista Nordback[a,*], Wesley E. Marshall[b,1], Bruce N. Janson[c,2]

[a] Department of Civil Engineering, University of Colorado Denver, P.O. Box 173364, Campus Box 152, Denver, CO 80217-3364, United States
[b] Department of Civil Engineering, University of Colorado Denver, 1200 Larimer Street, Campus Box 113, Denver, CO 80217-3364, United States
[c] Department of Civil Engineering, University of Colorado Denver, P.O. Box 173364, Campus Box 113, Denver, CO 80217-3364, United States

ARTICLE INFO

Article history:
Received 31 May 2013
Received in revised form
26 November 2013
Accepted 25 December 2013

Keywords:
Safety
Bicyclist
Safety performance
Intersection

ABSTRACT

Efforts have intensified to apply a more evidence-based approach to traffic safety. One such effort is the Highway Safety Manual, which provides typical safety performance functions (SPFs) for common road types. SPFs model the mathematical relationship between frequency of crashes and the most significant causal factors. Unfortunately, the manual provides no SPFs for bicyclists, despite disproportionately high fatalities among this group. In this paper, a method for creating city-specific, bicycle SPFs is presented and applied to Boulder, Colorado. This is the first time a bicycle SPF has been created for a U.S. city. Such functions provide a basis for both future investigations into safety treatment efficacy and for prioritizing intersections to better allocate scarce funds for bicycle safety improvements. As expected, the SPFs show that intersections with higher bicyclist traffic and higher motorist traffic have higher motorist-cyclist collisions. The SPFs also demonstrate that intersections with more cyclists have fewer collisions per cyclist, illustrating that cyclists are safer in numbers. Intersections with fewer than 200 entering cyclists have substantially more collisions per cyclist.

1. Introduction

Bicycle trips in the United States account for one percent of all trips and less than one percent of commuter mode shares, but with more than two percent of the total road deaths, cyclists appear to have disproportionately higher numbers of fatalities (U.S. Department of Transportation, 2009). Despite the road safety disadvantages, cycling does provide a physical activity, which has been shown to help prevent obesity and obesity related diseases (National Institutes of Health, 1998). Reducing hazards to cycling is a worthy goal.

Toward this goal, efforts are being made to map motorist-cyclist collisions and identify locations for future safety improvements. While the total number of collisions at a given location is important to identify, a better understanding of the underlying relationship between the number of collisions and the exposure to collisions – also known as safety performance functions (SPFs) – can provide the basis for a more effective method to prioritize intersections (Kononov and Allery, 2004). A misunderstanding of the true relationship between collisions and exposure to collisions often causes analysts to simply calculate the collisions per vehicle at each intersection by dividing the number of collisions by the volume of bicyclists or motor vehicles. Using this metric to compare intersections represents a fundamental misunderstanding and can produce misleading results, misappropriated funds, and unnecessary roadway hazards (Hauer, 1995).

Consequently, efforts have intensified to apply a more evidence-based approach to traffic safety in general. One such undertaking is the publication of the first Highway Safety Manual (HSM), which provides typical motor vehicle SPFs for common roadway types (American Association of State Highway and Transportation Officials, 2010). This manual provides an evidence-based method for estimating motor vehicle collisions based on SPFs developed from hundreds of intersections throughout the country; unfortunately, the methods for estimating bicyclist collisions are not nearly as well developed. Because bicycle volume data are rare, too few studies have created bicycle specific SPFs. The current recommendation is that predicted bicyclist collisions should be computed by multiplying the predicted number of motor vehicle collisions by a factor that is based upon motor vehicle speed and road type. While the number of motorist collisions, speed, and road type may be important factors in estimating the number of cyclist collisions, none of these are measures of cyclist exposure. Since SPFs commonly describe the relationship of collisions to exposure, cyclist exposure must be measured in order to create a bicycle-specific

* Corresponding author. Present address: Oregon Transportation Research and Education Consortium (OTREC), Portland State University, P.O. Box 751, Portland, OR 97207, United States. Tel.: +1 503 725 2897.

E-mail addresses: krista.nordback@ucdenver.edu, nordback@pdx.edu, kristanordback@yahoo.com (K. Nordback), wesley.marshall@ucdenver.edu (W.E. Marshall), bruce.janson@ucdenver.edu (B.N. Janson).

[1] Tel.: +1 303 352 3741.
[2] Tel.: +1 303 556 2831.

0001-4575/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.aap.2013.12.016

SPF. Several studies document the importance of bicyclist exposure in estimating the number of motorist-cyclist collisions by showing that the relationship between the number of bicycle-related collisions and bicyclist traffic volume is non-linear. This is often called the "safety in numbers" effect, since it has been found that collisions per cyclist tends to decrease with increasing cycling (Ekman, 1996; Leden et al., 2000; Jacobsen, 2003; Jonsson, 2005; Robinson, 2005).

This study presents a method for creating bicycle-specific SPFs similar to that used for motor vehicles in the HSM and applies that method to motorist-cyclist collisions at intersections in Boulder, Colorado. To the knowledge of the authors of this paper, these are the first such bicycle-specific SPFs developed for a city in the United States. Such studies have been listed as needed research by the Transportation Research Board Committee on the Operational Effects of Geometrics (Transportation Research Board, 2010). This work is an important first step toward fulfilling this need.

Better understanding the fundamental relationship of traffic volume to collisions will help lay the groundwork for future studies and allow cities to investigate the impact of specific infrastructure, speed, or other potential factors that may impact bicyclist safety. The focus of this study is not to create a definitive SPF for bicycles in the U.S., but to make a first step toward this end and initiate a discussion of what such a relationship is, why it is important, and what it can be used for. We achieve this by presenting a case study that highlights the benefits of a safety performance function approach to bicyclist safety.

2. Literature review

In the traffic safety community, the discussion of the relationship of traffic volume to safety has been enduring for decades (Smeed, 1949). Researchers have discovered that the relationship of traffic volumes to the number of collisions is non-linear, and that the shape of the curve is such that the number of collisions per vehicle decreases with increasing volumes, often referred to as the "safety in numbers" effect.

The HSM documents many SPFs for motor vehicles at intersections and road segments, most of which demonstrate that vehicular traffic can be "safer in numbers" (American Association of State Highway and Transportation Officials, 2010). These relationships are developed from crash data for hundreds of locations with similar characteristics. The manual documents how to predict crashes at similar intersections or road segments by using the SPF as a base and adjusting it with "crash modification factors" based on the specific geometrics or other features of the location. The manual also provides a basic method for predicting motorist-cyclist crashes by multiplying the total predicted motorist crashes by a factor based on speed and road type, but it does not account for cyclist volume whatsoever. A better method would include cyclist volume, but developing such a SPF for cyclists has certain challenges including: insufficient crash data; insufficient cyclist volume data; and a considerable range of facility types, many of which are scarce, such as cycle tracks or bicycle boulevards. While crashes are rare for motor-vehicles, low bicyclist mode share makes them even rarer for cyclists in the U.S., which in turn makes the development of cyclist specific SPFs even more challenging.

That similar non-linear relationships (i.e. "safety in numbers") hold for cyclists as well as other vehicle types (Hauer, 1995) is not all that surprising, but at the same time, it fundamentally invalidates longstanding conventional wisdom that the number of cyclist collisions should increase in direct proportion to the number of cyclists. The concept of safety performance functions can and should be applied to cyclist safety as well as motor-vehicle traffic.

In the mid-1990s, Swedish studies recorded some of the first bicycle SPFs for intersections, which showed that collisions and conflicts per cyclist decrease with increasing bicyclists (Brüde and Larsson, 1993; Ekman, 1996). Other researchers in Europe, Australia, New Zealand, and Canada have continued investigating this relationship, also finding that safety per bicyclist increases with increasing bicycle volumes (Leden et al., 2000; Jonsson, 2005; Robinson, 2005; Miranda-Moreno et al., 2011; Schepers et al., 2011; Turner et al., 2011b; Strauss et al., 2013). These studies are summarized by Elvik (2009) and generally assume a functional form for the SPF, usually a power function, and often focus on intersection collisions in cities because most cyclist-motor vehicle collisions in the urban environment occur at intersections (Hunter et al., 1996; Ferrara, 2001; Hamann and Peek-Asa, 2013).

In the U.S. and Europe, Jacobsen studied crashes at both the state and national levels, finding that crashes per cyclist decrease as overall cyclist mode shares increase (Jacobsen, 2003). However, bicycle safety performance functions for specific cities in the U.S. have not yet been developed. Jacobsen's study did not use bicycle count data. Such studies with sufficient detail are needed in order to evaluate the safety impact of bicycle safety remediation efforts, including infrastructure such as bicycle lanes and paths.

The literature has identified bicycle specific infrastructure, street lighting, and angle of grade as influencing cyclist safety (Reynolds et al., 2009), but without properly accounting for exposure, it is difficult to know if accurate comparisons are being made. This research endeavors to tackle this void in the literature in order to create the first bicycle-specific SPFs for a U.S. city.

3. Materials and methods

While this study does not investigate specific infrastructure types, it does develop bicyclist intersection safety performance functions – and a methodology for developing such – for one U.S. city, Boulder, Colorado. Boulder was chosen for study because it has one of the highest bicycle mode shares of any city in the U.S., at roughly 12 percent, as well as a history of counting bicycles using both manual counters and automated inductive-loop detectors (Lewin, 2005; U.S. Department of Commerce, 2009; City of Boulder, 2010; Nordback and Janson, 2010; Nordback et al., 2011). Boulder also has databases of bicycle and pedestrian collisions that can be used to examine intersection safety (Gill, 2007; City of Boulder, 2012). Thus, Boulder is one of the few cities in the U.S. with both sufficient bicycle volumes and collision data. Fortunately, technology for counting bicycles is becoming more common and more cities are collecting bicycle counts and crash data to make similar studies possible in the near future.

Intersections were the chosen unit of analysis since over two-thirds of the motorist-cyclist collisions in the Boulder datasets occurred at intersections or were intersection related. To quantify exposure at intersections, annual average daily traffic (AADT) and annual average daily bicyclists (AADB) were computed based on turning movement counts collected by the city of Boulder.

Bicyclist safety was modeled as the number of motorist-cyclist intersection collisions reported in police reports during the five year period from 2001 to 2005 and the four year period from 2008 to 2011 because these were the available datasets (Gill, 2007; City of Boulder, 2012). These collisions were aggregated by intersection; non-intersection crashes were excluded from the dataset used to develop the intersection SPF.

The SPF was modeled as a negative binomial model using a generalized linear model with log link, to help depict trends in the data. Once a SPF is chosen, it theoretically becomes possible to then predict the expected number of collisions at each intersection, given the traffic volumes present. The predicted number of collisions can