

Bicyclist Crash Types on National, State and Local Levels: a New Look

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ABSTRACT

This paper presents an overview of prevalent bicyclist crash types in the U.S. providing insights for practitioners that may be useful in planning safer networks and taking other proactive and risk-based approaches to treatment. The study compares fatal bicyclist crash types from national data with serious injury and all severity bicyclist collisions from the state of North Carolina (NC) and the City of Boulder, Colorado. Overall bicyclist fatalities in the U.S. are more prevalent in urban areas (69%) than rural areas (29%). While the majority of all-severity crashes are at intersections, most fatal and disabling injury bicyclist crashes occur at non-intersection locations, including nearly one-third of bicyclists who died from collisions involving overtaking motorists. Top intersection crash types across national fatal, and all severity crashes in NC and Boulder include bicyclist failed to yield and motorist turning across a bicyclist path. However, many of the top all-severity types in the two jurisdictions differ from the top fatal crash types. These comparisons provide a fresh look at bicyclist crash type trends and have potential importance with respect to planning safer networks for Vision Zero communities, since a key finding is that locations and crash types most prevalent among fatal and serious injuries may differ from the most prevalent types for all severity crashes. Findings could be useful to agencies lacking their own resources for risk-based assessment, but also suggest it may be important to analyze higher severity crash types and jurisdiction-specific data when possible.

INTRODUCTION

Bicycling for transportation and recreation provides numerous benefits, including low-cost travel, fun, time spent outside, and physical activity – the latter of which has been shown to help prevent obesity and obesity-related diseases (1,2,3,4). Yet safety remains a barrier to increased bicycling in the U.S. Studies routinely find that people list safety as a reason why they don't bicycle or bicycle more (5,6), and crash statistics corroborate their perceptions: while less than 1% of all trips in the U.S. are by bicycle, more than 2% of the total (reported) traffic deaths are bicyclists – a disproportionate ratio compared to motor vehicle drivers and passengers (7).

To identify strategies to improve bicyclist safety, a better understanding of the most common crash types in the U.S. is needed. With this understanding, practitioners and researchers can work together to develop solutions to address these crash types and improve conditions for bicycle safety in various contexts.

Toward this goal, efforts are being made to use a consistent method to categorize the types of motorist-bicyclist collisions nationally, at the state level, and in some cities. However, a summary of the top crash types has not been published in more than two decades. This paper fills this gap by reporting the top fatal crash types across the U.S., and the top fatal and injury crashes in the state of North Carolina (NC) and the City of Boulder, Colorado. The latter statistics are provided to supplement fatality data and to demonstrate how various crash types differ with regard to severity and prevalence at different scales. Additionally, the inherent vulnerability of bicyclists means that the difference between a severe and fatal crash or an evident injury and a severe injury may be random; thus, injury data can help complete the safety picture for bicyclists.

This study aims to highlight similarities and differences in findings regarding fatal crashes nationwide, compared to different severity outcomes using complete data from one state and one local jurisdiction. These comparisons may aid understanding of crash types, crash location types, and injury risks more generally, and how these might vary with respect to injury outcomes, and potentially the type of jurisdiction (infrastructure and other differences). The findings may be a reference for cities deciding what crash types may be related to higher injury severities for jurisdictions that aim to further Vision Zero objectives, or those that wish to address crash risks more proactively.

After a brief review of published literature on bicyclist crash types, this paper explores fatal and disabling bicyclist crash types at the national and state levels, urban areas, and, separately, intersection bicyclist crashes across national, state and local levels, with a brief discussion of

applicable countermeasures. The paper concludes with a summary of findings and future research needs.

LITERATURE REVIEW

Crash types are variables that describe events and maneuvers of the involved parties that led up to a crash, such as head-on or roadway departure, and are available in most states' crash reporting systems to characterize single motor vehicle or multiple motor-vehicle involved crashes. However, when bicyclists or pedestrians are involved in collisions with motor vehicles, details on the maneuvers and events leading up to the crash are often lacking (8), or at least must be constructed using multiple variables. To create bicyclist crash types, variables on the relative maneuvers of the driver and bicyclist can be combined (if available), e.g., that a bicyclist or pedestrian crossing at midblock was struck by a vehicle traveling straight (9); this type of information is widely used by agencies to target appropriate treatments to address the specific crash types.

Early efforts at classifying motorist-bicyclist crash types occurred in the 1970s. One of the first efforts at bicycle crash typing was Cross and Fisher's 1977 NHTSA report, which studied 919 fatal and non-fatal crashes in 1975 sampled from select areas in California (Los Angeles area), Colorado (Denver/Boulder area), Florida (Tampa/Orlando area), and Michigan (Detroit/Flint area) (10). The study, building on crash reports, in-depth site investigations, and interviews with participants and witnesses (when possible and permission was granted), classified the crashes into 36 "unique problem types." Crashes in a crash type exhibited common characteristics with respect to several aspects of the crash - the traffic context where the crash occurred (location characteristics); the operators' functional failures (not fault, but the actions that led up to the crash); and combinations of factors associated with these failures (such as a building that obscured sight lines).

The study did not collect a proportionate sample of urban and rural crashes, but rather attempted to sample equal numbers of urban and rural crashes; fatal crashes were also over-sampled. The authors concluded that about 32% of fatal and 11% of non-fatal crashes occurred in rural areas. The report highlighted seven prominent crash types (descriptions condensed and slightly edited for this paper) which accounted for roughly half of the crashes studied:

- Bicyclist ride out of driveway or alley – perpendicular paths (7% fatal and 6% non-fatal).
- Bicyclist ride out at stop-controlled intersection – perpendicular paths (8% fatal and 10% non-fatal)
- Motorist drive out of driveway – perpendicular paths (0 fatal and 5% non-fatal)
- Motorist drive out two-way stop controlled – perpendicular paths (1% fatal; 10% non-fatal)
- Motorist overtaking – parallel paths, same direction (25% fatal; 4% non-fatal)
- Bicyclist turned left across motorist path – parallel paths same direction (8% fatal and 8% non-fatal)
- Motorist turned left across bicyclists path– parallel paths opposite direction (0 fatal and 8% non-fatal)

In this study, bicyclists between the ages of 12 and 15 years accounted for about 37% of the studied crashes, which may have affected some crash types such as riding out at driveways and swerving into the paths of motor vehicles.

Following this, John Forester published a third edition of his book, *Effective Cycling*, including information on bicyclist crash types in addition to providing basic information on how to bicycle safely, make basic bicycle repairs, and other practical matters (11). Forester's table of "car-bike" crashes in the U.S. reports that 85% of motorist-bicyclist crashes are turning and crossing, while only 10% are motorist overtaking bicyclist crashes. In rural areas, Forester reports 60% turning and crossing crashes and 30% motorist overtaking crashes, but neglects to provide important details on his methodological approach, like years or crash severity. (Forester states only

that the data in his book come from 1977 Cross and Fisher report, a 1975 Master's thesis by Kaplan (12), and the National Safety Council).

The 1990s saw a renewed interest in bicycling and bicyclist crash types, including a major study by Hunter et al. to document approximately 3,000 motorist-bicyclist crashes from California, Florida, Maryland, Minnesota, NC, and Utah (13). Crash types also evolved to reflect more 'location-specific' elements. This study found that 57% of motorist-bicyclist crashes occurred when the motorist and bicyclist were crossing paths, 36% occurred when motorists and bicyclists were on parallel paths, and 6% occurred in other circumstances. The most frequent crash types of the crossing paths crashes were motorist failed to yield and bicyclist failed to yield, both at intersections and midblock. The most frequent crash types of the parallel path crashes were motorist turn/merge into bicyclist's path, motorist over-taking, and bicyclist turn/merge into motorist path. Again, the sampling methodology was based on collecting an evenly distributed sample (same numbers) from each of the six states; the states themselves were somewhat based on a convenience sample, and the sample within each state was stratified to collect an even number from rural and small, medium, and larger towns and cities, as opposed to collecting the same based on actual frequency distributions (13). Thus, while providing important insights, some of the distributional factors and associated characteristics described in both of the prior widespread studies may have been affected by the pragmatic sampling methods, which may have led to unintended biases inherent when sampling.

This research later led to development of a major crash typing method and tool, the Pedestrian and Bicycle Crash Analysis Tool (PBCAT). PBCAT is a computer program designed to assist in coding pedestrian and bicycle crashes, developed in the late 1990s and refined in 2006 (8,14). States including NC and Wisconsin have used it (15,16), but no national reporting of crash types using the PBCAT method exists, and no bicycle-specific crash typing has been published across multiple states in the past two decades.

This is due in part to the difficulty of comparing records that may lack critical information used to identify crash types without combing through crash reports. This paper presents an overview of prevalent bicyclist crash types, so that communities can have an updated benchmark to reference. Without an understanding of the prevalence and severity of the various crash types, bicycle planning may miss opportunities to improve safety.

Other typologies have also been developed that may provide alternative typologies to PBCAT, such as the Location Movement Classification Method developed in Wisconsin (16). However, this study focuses on PBCAT crash types.

DATA

This study used three sources of data to develop and compare prevalent motorist-bicyclist crash types: NHTSA's Fatality Analysis Reporting System (FARS), North Carolina Department of Transportation (NCDOT)'s statewide database, coded by staff at the University of North Carolina Highway Safety Research Center (HSRC), and City of Boulder data coded by city staff or consultants. Each data source is discussed further below.

FARS Data

FARS is a nationwide census of crashes that contains records for all traffic-related crashes (involving a motor vehicle traveling on a public trafficway) that resulted in a fatality of anyone in the crash within 30 days (17). This paper uses data for three years, 2014-2016, of fatal bicyclist crashes, for which crash types were coded by FARS analysts using the PBCAT methodology. Note that FARS coders did not use the original source PBCAT tool, but integrated the typing methodology, with some minor definition changes to improve clarity for the coders, into the FARS data entry system (18).

There were 2,496 bicyclists and "other" cyclists involved in 2,403 crashes, of whom 2,398 bicyclists were killed nationwide from 2014-2016. (Fifty-one of the "other" cyclists

involved in fatal crashes were suspected to receive serious injuries.) The crash type variables and other information were entered for each pedestrian or each bicyclist involved in a fatal crash, and since the number of fatalities closely aligned with fatal crashes involving bicyclists, we used data for each fatally injured bicyclist for these analyses. HSRC also added variables associated with the roadway and vehicle for the motorist that struck each bicyclist along with other crash level characteristics to the analysis database. These statistics and analyses are based on FARS data files updated in October 2017.

North Carolina Data

The authors used crash-typed data for 4,620 crashes (97% of the total reported) from 2011-2015 from NC statewide. (HSRC researchers compiled the source data. They coded and combined PBCAT variables and spatial coordinates with crash data provided by NCDOT, including 4,750 total crashes of which 110 were fatal. However, 130 cases without sufficient location information or specifics of what occurred were not included.) In NC, only one bicycle crash type is coded for each reported collision, even if multiple bicyclists were struck; thus, the NC data represent ‘crashes’ whereas the U.S. fatality data represents individual bicyclists who were killed. For these analyses, non-roadway collisions are excluded from the NC data, since there are very few such cases in the national fatality data and the primary aim of these analyses is to explore roadway-related bicyclist injuries from crashes with motor vehicles.

Boulder Data

The City of Boulder has used the PBCAT methodology to code crashes since 2008 (19). City staff code the crashes based directly on information in police reports from the Boulder Police Department. For this paper the investigation provides another comparison for ‘urban’ collision types using 1,266 crashes of all severity for the period 2008-2014. The police generally do not report non-injury collisions with less than \$1,000 in property damage, so such non-injury, low-property damage reports are not usually included. Seven years of crash-typed data (2008-2014) are used in this analysis; Boulder data included only two fatalities.

METHODOLOGY

The three data sources were used to explore bicyclist crash types and related location and crash characteristics using descriptive methods. The data includes (essentially) complete (as reported) years of data from three jurisdictions - one national, one state, and one local (city) that had each used the PBCAT crash typing methodology to generate crash type, location, direction, and position variables to add to crash reporting-derived variables on the persons, time, vehicle types, and environmental conditions of the crash. The intent is not to statistically compare the distributions, since study years do not overlap completely among the different data sources, and the data vary in terms of severity and by agencies that coded the data and other characteristics. Rather, the intent is to identify prevalent bicyclist crash types, their severity, and the location types and other associated factors. The authors also assess more generally whether using all crashes for analyses may provide a good representation for fatal and more severe crash types.

PBCAT classifies crashes into 77 specific crash types which fall into 20 higher-level crash type groups, not counting an “other/unknown” category for when key information is missing (8). For this paper, the aggregated groups were used in various cross-tabulation analyses, instead of the specific crash types, in order to more readily identify the primary types of crashes and make comparisons across the different jurisdictions. In beta and inter-coder validity tests of PBCAT, the authors found that there is generally high agreement among coders at the crash group level; thus, unless discussing ‘specific’ crash types, hereafter, the term ‘crash type’ will be used to refer to the higher-level crash type group.

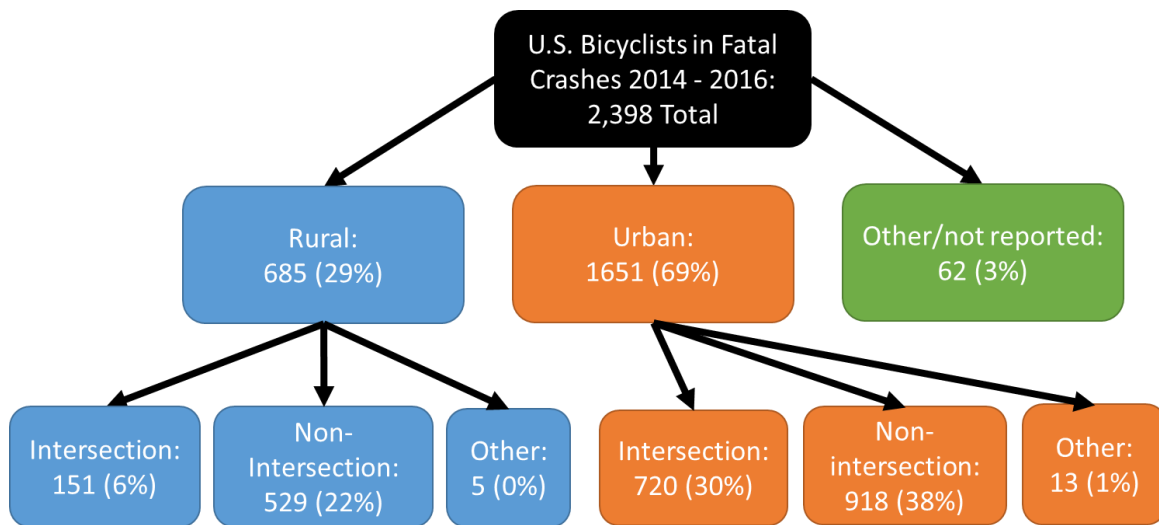
Bicyclist or motorist fault should not be inferred from crash type names. Local and state laws vary so fault cannot be reliably determined.

FINDINGS

Findings are organized into four sections. First, overall crash types and some key crash factors at the national (fatalities) and state level (all reported crashes) are discussed. Second, fatal and disabling injury crash types are examined, also at the national and state levels. Third, since most bicycle crashes occur in urban areas, urban crash types across all three data sources are compared. The fourth section focuses specifically on intersection crashes, which are more common in urban areas and are thus of particular interest to cities.

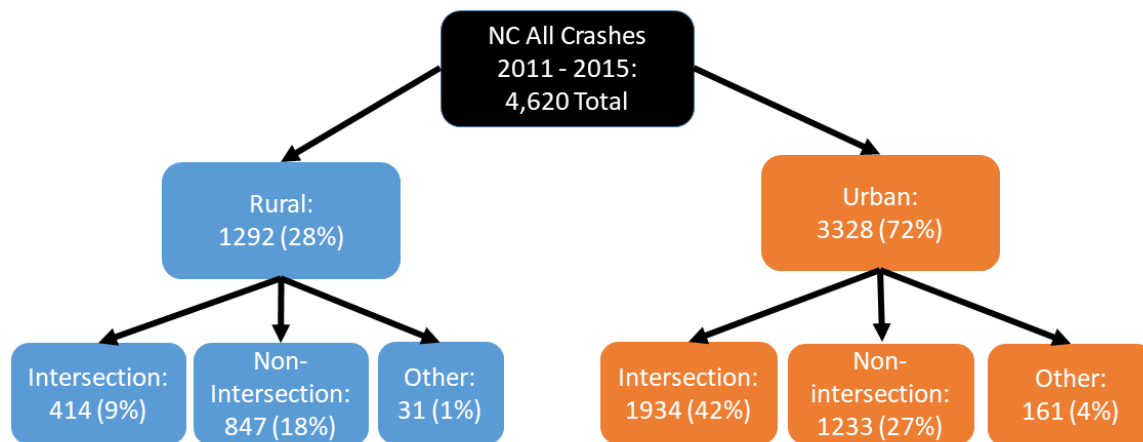
Overview of Bicycle Crashes

This section gives an overview of crash types involved in cyclist fatalities at the national level and all severity crashes in NC. Figures 1 and 2 show a breakdown of the crashes by urban vs. rural and intersection vs. non-intersection for the national and NC data, respectively. As might be expected, Figure 1 shows that most bicyclist fatalities in the US (69%) occur in urban locations. In contrast to earlier work on crash types (see Literature Review), however, 60% of bicyclist fatalities occurred at non-intersection locations, even in urban areas (38% compared to 22% in rural areas).



Note: Percentages do not add up to 100% due to rounding.

FIGURE 1 Bicyclist Fatality Crash Location Tree (2014-2016 data from FARS).



Note: Percentages do not add up to 100% due to rounding.

FIGURE 2 North Carolina Bicyclist All Crash Location Tree, 2011-15 Crashes (data from NCDOT & UNC-HSRC).

A similar distribution of all crashes across rural (28%) and urban locations (72%) is demonstrated in NC's data for all-severity bicycle collisions. However, a higher percentage of crashes occurred at intersections (51% of the total), with 45% occurring at non-intersection locations. When fatal and disabling injury crash proportions are examined for NC, it is clear, however, that serious injury collisions occur at double the proportional rate (9%) at non-intersection locations compared to intersection and intersection-related crashes (5%, combined) (Figure 3). The next section explores the prevalent crash types leading to fatalities and serious injuries.

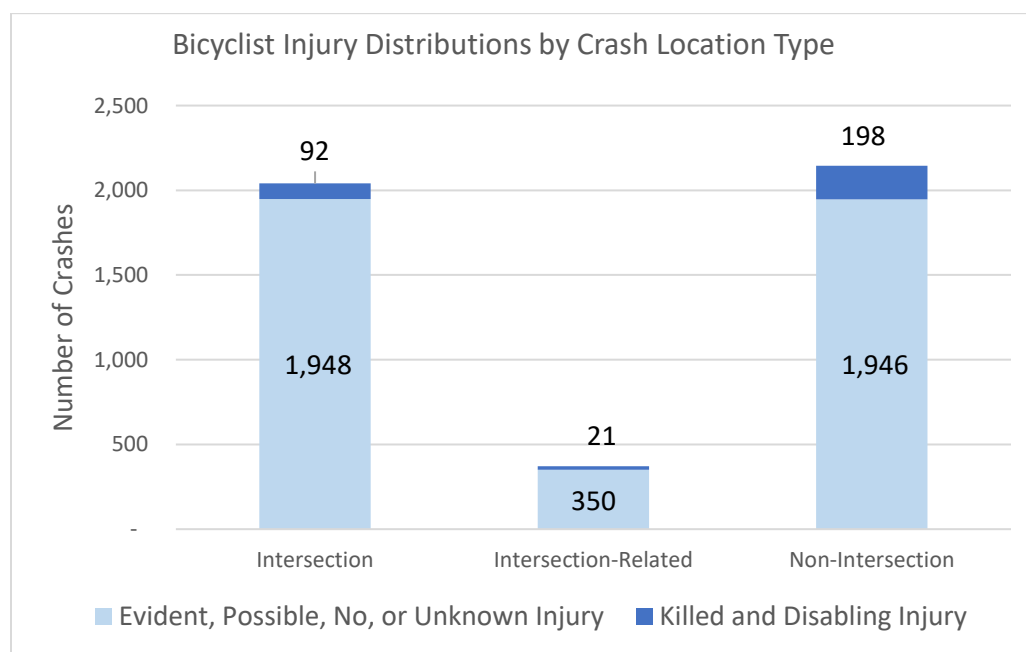


FIGURE 3 Distributions of injury severities by total bicycle-motor vehicle collisions in North Carolina by crash location type (roadway locations only, 2011-2015).

Fatal and Disabling Injury Crash Types

Table 1 shows bicyclist crash types as defined by PBCAT coding for bicyclists and other cyclists killed in U.S. crashes from high to low frequency of occurrence in the FARS data. The table compares these statistics to fatal and disabling injury crash types for NC.

In addition, Table 1 shows percentages for the proportions of bicyclists indicated to be riding meeting the following conditions:

- facing traffic (17%),
- riding in a regular (shared) travel lane (76% across all types),
- struck during non-daylight hours (50%), and
- involving a bicyclist less than 18 years old (10% across all types).

Young bicyclists are sometimes disproportionately associated with certain crash types (as in the Cross and Fisher study). Riding direction (wrong-way or facing traffic vs. with the direction of traffic), and the riding position (on a sidewalk or path vs. on a roadway or bicycle lane) are from variables derived from the crash typing process. Wrong-way and sidewalk riding are frequently mentioned circumstances associated with some types of bicyclist crashes at intersections, since bicyclists are approaching the intersection from an unexpected direction or location from the motorist's perspective. These behaviors are also thought to be possibly associated with discomfort with riding on the roadway facilities present, although we do not have the data to verify this in these analyses.

Dark conditions also tend to be over-represented among fatal and injury crashes and may be under-recognized as an important factor in bicyclist fatalities. Crash types were examined for instances involving greater than average involvement of any of the above factors. Overall, it is notable that nearly half of bicyclist fatalities occurred during non-daylight hours, which is likely higher than the amount of riding that occurs at night. Further examination of NC data shows that dark conditions are over-represented among bicyclist fatalities and serious injuries (35%) compared to the total crashes reported (21% at night).

Motorist Overtaking Bicyclists (Figure 4) is by far the most common group of fatal bicyclist crash types (28% of all fatalities) and fatal and disabling crash types (38%) in NC (Table 1). Figure 4 illustrates some of the specific ways that overtaking crashes included in this group can occur. In the specific overtaking crash types associated with the FARS numbers, the most frequent was Motorist Overtaking Bicyclist - Other/Unknown Circumstances (291 of this category), which means that the data available in the crash report and other documents did not allow coders to determine the specific circumstances. Other types include the motorist failed to detect the bicyclist in time to avoid or safely pass (229 were this type, illustrated by image 4A in the figure); the motorist misjudged the space and clearance needed to pass (125, see 4B); and bicyclist made a sudden swerve into the path of the overtaking motor vehicle (30 were this type, see 4C). Fifty-eight percent of fatalities involving motorist overtaking types occurred at night (or under non-daylight conditions, including dawn and dusk) compared to 50 percent over all types (Table 1). Data (not shown in the table) also revealed these types frequently involved hit and run drivers (27%). Since this is the most common type, we also examined roadway and land use variables and found that 70 percent of these occurred on two-lane roads, and 29% on roads with three or more lanes. Sixty percent occurred in urban areas.

The next most common crash type for national bicyclist fatalities is other Parallel Path circumstances types of crashes (9%). FARS coders could not determine specific circumstances or maneuvers of a majority of the additional parallel path fatal collisions. NC coders had less difficulty determining specific maneuvers for parallel paths, so less than 2% of NC fatal and disabling injury crashes are in this group. Slightly higher percentages in the FARS data for this group were indicated to be riding on a bicycle path, shoulder, or parking lane (31%) or on a sidewalk/sidepath (3%) compared to the better defined overtaking crashes.

Other common fatal crash types in Table 1 include:

- Bicyclist Failed to Yield – Midblock (7% of fatalities): This type involved a higher than average percentage of bicyclists younger than 18 years (15% compared to 10% over all types).
- Bicyclist Left Turn / Merge (7%): No particular factors stand out as being over represented for this type.
- Crossing Paths - Other Circumstances (7%): A vague type in which the motor vehicle and bicyclists were clearly on angle paths to each other before the collision, but not much else could be determined, or it doesn't fit the other crossing path types. This group involved a large percentage (30%) of bicyclists riding facing traffic prior to the crash (compared to 17% average over all types), and more occurred at uncontrolled intersections (from the motorist' perspective) (38%) and midblock locations (17%) compared to signalized (10%) intersections (data not shown). Bicyclists were also more often riding on a sidewalk or crossing in a crosswalk or driveway crossing (typical pedestrian locations) (29%) than the average (12%).
- Bicyclist Failed to Yield at Signalized Locations (7%): Bicyclists were more often riding facing traffic (30%) compared to all types, and a higher percentage (43%) were riding on a sidewalk or crossing in a crosswalk compared to the average.
- Bicyclists Failed to Yield at Sign-Controlled Intersection (7%): This type involved a higher than average percentage of bicyclists riding facing traffic (26%), although not on sidewalks. The crash type also involved a much higher percentage of younger riders (26%) than average (10%) across all groups. This crash type was also associated with no traffic control for the motorist in 74% of cases (not shown in table).
- Head-on Collisions (5%): One or the other party was on the wrong side or facing the wrong direction at the time of the collisions, most often the bicyclist (82%). A higher than average percentage of these occurred during non-daylight conditions (66%).

These data indicate a need to understand challenges for bicyclists having space to ride, but also crossing or entering roadways at both signalized and unsignalized intersections. Table 1 shows additional relationships for the remaining crash scenarios for lower frequency types of collisions. Exploring crash scenarios in urban areas is discussed next, since these are more common than rural crashes and of particular interest to cities.

TABLE 1 Bicyclist Crash Type for U.S. Fatal and NC Fatal and Disabling Bicycle Crashes

Bicyclist Crash Type (group)	U.S. Fatalities 2014-16 (Source data: FARS)						NC 2011-15 Fatal & Disabling Crashes		
	Freq - uency	% of Total Fatalities	% Facing Traffic *	% on Side-walk, Cross-walk or Driveway Xing *	% Non-Day-light *	% Bicyc- lists < 18 years *	Freq- uency	% of Total Fatal and Disabling Crashes	NC Rank
Motorist Overtaking Bicyclist	675	28.1%	0.9%	0.6%	58.2%	4.6%	114	38.0%	1
Parallel Paths - Other Circumstances	207	8.6%	11.6	2.9%	54.1%	7.7%	2	0.7%	15
Bicyclist Failed to Yield - Midblock	178	7.4%	12.9%	9.0%	57.3%	14.6%	27	9.0%	2
Bicyclist Left Turn / Merge	175	7.3%	5.1%	2.9%	34.9%	10.3%	22	7.3%	4
Crossing Paths - Other Circumstances	172	7.2%	30.2%	28.5%	56.4%	10.5%	13	4.3%	8
Bicyclist Failed to Yield - Signalized Intersection	166	6.9%	29.5%	43.4%	55.4%	9.6%	14	4.7%	7
Bicyclist Failed to Yield - Sign-Controlled Intersection	164	6.8%	25.6%	10.4%	38.4%	26.2%	25	8.3%	3
Wrong-Way / Wrong-Side (Head-on)	118	4.9%	82.2%	1.7%	66.1%	13.6%	15	5.0%	6
Loss of Control / Turning Error	104	4.3%	22.1%	13.5%	30.8%	12.5%	11	3.7%	9
Motorist Left Turn / Merge	73	3.0%	21.9%	32.9%	28.8%	1.4%	20	6.7%	5
Motorist Right Turn / Merge	66	2.8%	19.7%	43.9%	33.3%	10.6%	7	2.3%	12
Bicyclist Right Turn / Merge	50	2.1%	26.0%	0%	58.0%	8.0%	5	1.7%	13
Other / Unusual Circumstances	29	1.2%	13.8%	20.7%	24.1%	31.0%	3	1.0%	14
Motorist Failed to Yield - Signalized Intersection	26	1.1%	19.2%	61.5%	30.8%	11.5%	1	0.3%	17
Motorist Failed to Yield - Sign-Controlled Intersection	21	0.9%	38.1%	28.6%	38.1%	4.8%	11	3.7%	9
Bicyclist Overtaking Motorist	19	0.8%	5.3%	0%	10.5%	0.0%	1	0.3%	16
Backing Vehicle	11	0.5%	0.0%	63.6%	0.0%	45.5%	0	0.0%	n/a
Motorist Failed to Yield - Midblock	9	0.4%	66.7%	77.8%	22.2%	0.0%	8	2.7%	11
Non-Trafficway	3	0.1%	n/a	n/a	0.0%	33.3%	Not Included		
Parking / Bus-Related	1	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%	n/a
Other / Unknown - Insufficient Details	n/a	5.5%	14.5%	6.1%	59.5%	8.4%	1	0.3%	n/a
Total	2,398	100%	17.1%	12.0%	50.3%	10.0%	300	100%	

*Percent of Crash Type

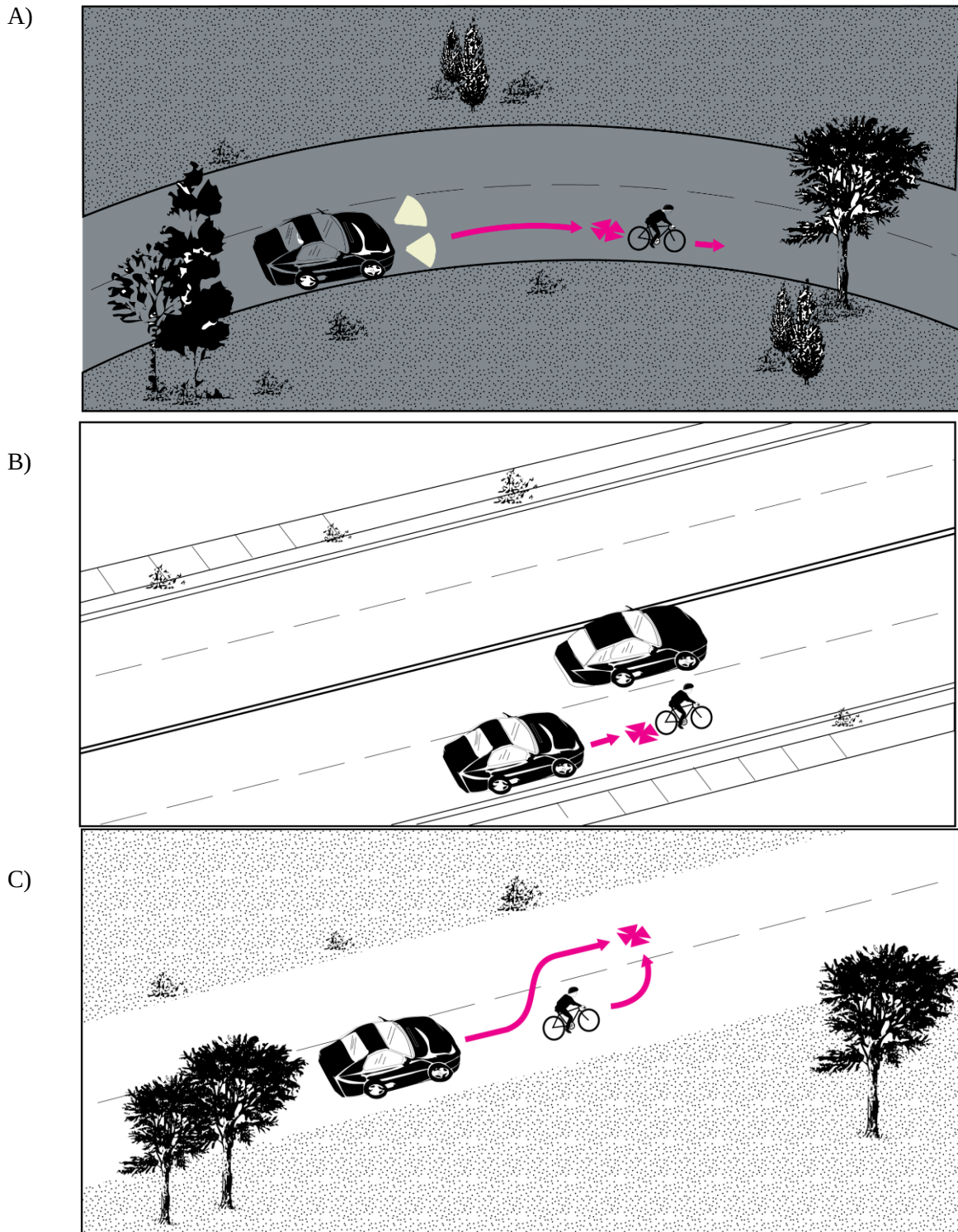


FIGURE 4 Types of Motorist Overtaking Bicyclist Crashes (Source: PBCAT).

Urban Crash Types

This section compares findings associated with urban bicyclist fatalities nationwide with those from all-severity crashes in urban locations in NC and in Boulder, and explores differences and similarities in crash types. Table 2 compares the top 10 most frequent national fatality bicyclist crash types in urban areas with all-severity crash types in urban areas in our study state (NC) and study city (Boulder).

While any type of collision can potentially lead to a fatality, the comparisons have potential importance with respect to Vision Zero jurisdictions and for systemic safety approaches that aim to treat more severe crash types, since there may be too few fatal and disabling or serious injury collisions in a specific jurisdiction to determine reliable prevalence of different types and associated risk factors for identifying potential treatments. Thus, agencies may analyze all crashes and target countermeasures toward the most frequent problem types among all crashes, as opposed to those most associated with severe injury risk.

Motorist Overtaking Bicyclist is the most frequent urban fatal crash type and most frequent type reported in NC for both fatal and disabling, and for all severity of reported crashes. However, this crash type was not in the top 10 in the Boulder data. Although the rank order varies, four of the crash types are in the top 10 nationally and for all severity of collisions reported in both NC and Boulder:

- Bicyclist Failed to Yield – Signalized Intersection,
- Crossing Paths – Other Circumstances,
- Motorist Left Turn / Merge, and
- Bicyclist Failed to Yield – Midblock.

The first three of these are associated with intersections, where cyclists and motorists are more likely to be crossing one another's paths. Two crash types are in the national fatalities and NC all severity top 10 urban crashes, but not in Boulder's top 10: Crossing Paths - Other Circumstances and Bicyclist Failed to Yield - Sign-Controlled Intersection.

In addition, four crash types are found in both the NC urban and Boulder all-severity top 10 lists, but not in the national urban fatality top 10:

- Motorist Failed to Yield – Sign-Controlled Intersection,
- Motorist Failed to Yield – Midblock,
- Motorist Right Turn / Merge, and
- Motorist Failed to Yield – Signalized Intersection.

Again, all of these tend to be associated with some type of intersection movements that involve bicyclists and motorists crossing one another at angles or during turns, and all four seem to involve a motorist failure, even if the bicyclist may have contributed by coming from the wrong direction in some of these cases. As previously described, this trait may affect crossing path crashes and certain types of parallel path (e.g., head-on) collisions more than others.

The differences in Table 2 underscore that the prevalent crash types most associated with fatalities may not always be those that are associated with less severe injuries, yet the prevalence of the latter types suggests warranted attention.

Most of the urban types in the top 10 lists tend to be related to intersections. For this reason, the next section investigates intersection crash types specifically.

Intersection Bicycle Crashes

This section examines intersection and intersection-related motorist-bicyclist crashes in urban areas, which will be referred to throughout this paper as “intersection” crashes, for simplicity. Though intersection crashes are not the majority of fatalities nationally or in either urban or rural areas (see Figure 1), they are still a high proportion of crashes, especially in urban areas, where they comprise nearly half of the crashes. When looking at all severity crashes in a given city,

intersection crashes may even be the highest proportion of motorist-bicyclist crashes, as demonstrated by the data from NC and Boulder.

Table 3 compares the top five fatal bicycle intersection crash types at the national level with the top five bicycle fatal and injury intersection crash types in NC. As in the previous sections, there are some overlapping crash types between groups, but the lists are not identical. Two intersection crash types are listed in the top five for all three data sources: Bicyclists failed to yield-signalized intersection and Motorist left turn/merge. These crash types are discussed below. While example countermeasures are briefly discussed, a thorough site investigation should precede countermeasures selection (see FHWA's BIKESAFE) (20).

Bicyclist Failed to Yield

All lists contain the crash type Bicyclist Failed to Yield – Signalized Intersection (22% of fatalities). When combined with Bicycle Failed to Yield – Sign-controlled Intersection (14% of fatalities), these two types comprise over one-third of fatal bicycle crashes in the U.S. (Table 3). These crash types are also prevalent in NC, although less so, comprising approximately 22% of fatal and injury crashes and 11% of all-severity crashes; only the signalized intersection type is in Boulder's top five, comprising 7% of crashes. Figure 5 presents an example of a specific crash type in this broader category: Bicyclist Ride Out - Signalized Intersection.

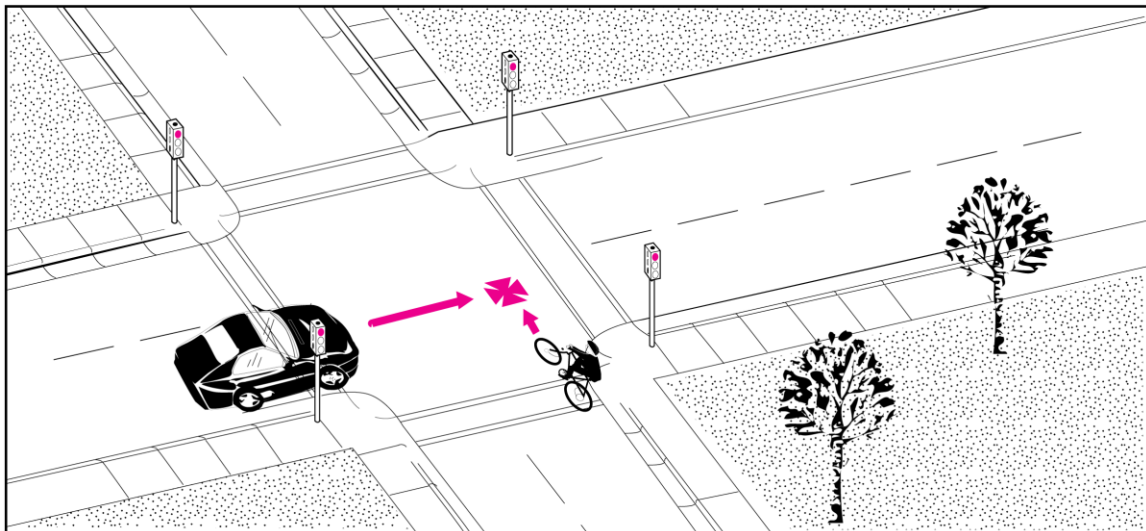


FIGURE 5 Bicyclist Ride Out - Signalized Intersection (Source: PBCAT).

While these crash types seem similar in nature (and indeed, they all represent a bicyclist trying to cross an intersection and being struck while doing so), the countermeasures for each are different. Signalized intersections can be made more responsive to bicyclists by installing bicyclist detection. Further examination of crash locations may reveal a need for adjusted signal timing; if the signal is too short for bicyclists to make it across before the signal turns red, they will be left potentially vulnerable to oncoming traffic mid-intersection.

For sign-controlled intersections, consideration should be given to traffic volumes and visibility as well as facilities on the connecting streets. For example, if bicyclists need to cross a heavily trafficked, multi-lane intersection where the motorist has no stop or sign control (frequently the case in the fatality data), they may have difficulty accurately assessing gaps and may be struck while trying to cross. This situation is even worse on undivided roads, where no median provides a refuge to break up the crossing. Countermeasures such as pedestrian hybrid beacons or rapid rectangular flashing beacons may be help by stopping or pausing the main flow of traffic and providing a clearer indication of right-of-way when activated.

1 **TABLE 2 Top 10 Bicyclist Crash Types in Urban Areas***

U.S. Urban Fatalities 2014-2015				N.C. Urban All-severity Crashes 2011-2015				Boulder All-severity Crashes 2008-2014			
Rank	Crash Type (group)	Freq.	%	Rank	Crash Type (group)	Freq.	%	Rank	Crash Type (group)	Freq.	%
1	Motorist Overtaking Bicyclist	397	24.0	1	Motorist Overtaking Bicyclist	409	12.9	1	Motorist Right Turn / Merge	194	16.1
2	Bicyclist Failed to Yield - Signalized Intersection	155	9.4	2	Motorist Failed to Yield - Sign-Controlled Intersection	369	11.7	2	Motorist Left Turn / Merge	180	15.0
3	Crossing Paths - Other Circumstances	140	8.5	3	Motorist Left Turn / Merge	347	11.0	3	Motorist Failed to Yield - Sign-Controlled Intersection	178	14.8
4	Bicyclist Failed to Yield - Midblock	133	8.1	4	Motorist Failed to Yield - Midblock	310	9.8	4	Motorist Failed to Yield - Signalized Intersection	128	10.6
5	Parallel Paths - Other Circumstances	128	7.8	5	Bicyclist Failed to Yield - Signalized Intersection	219	6.9	5	Motorist Failed to Yield - Midblock	116	9.7
6	Bicyclist Left Turn / Merge	115	7.0	6	Crossing Paths - Other Circumstances	214	6.8	6	Other / Unusual Circumstances	79	6.6
7	Bicyclist Failed to Yield - Sign-Controlled Intersection	103	6.2	7	Bicyclist Failed to Yield - Midblock	204	6.4	7	Bicyclist Failed to Yield - Signalized Intersection	61	5.1
8	Loss of Control / Turning Error	71	4.3	8	Bicyclist Failed to Yield - Sign-Controlled Intersection	203	6.4	8	Crossing Paths - Other Circumstances	41	3.4
9	Wrong-Way / Wrong-Side	71	4.3	9	Motorist Right Turn / Merge	199	6.3	9	Bicyclist Overtaking Motorist	36	3.0
10	Motorist Left Turn / Merge	61	3.7	10	Motorist Failed to Yield - Signalized Intersection	155	4.9	10	Bicyclist Failed to Yield - Midblock	32	2.7
	Subtotal Top 10 Urban	1374	83.2		Subtotal Top 10 Urban	2629	80.0		Subtotal Top 10	1045	86.9
	All other types	277	16.8		All other types	540	17.0		All other types	159	13.2
	Total	1651	100		Total	3167	100		Total	1204	100
* Dark shading means crash type is in all three top 10.				Medium shading means type is in US and NC top 10.				Light shading and bold means type is in NC and Boulder top 10.			

TABLE 3 Top Five Bicycle Intersection Crash Types, FARS, North Carolina Data, and Boulder*

US Urban Intersection Fatalities				NC Urban All-severity Intersection Crashes			Boulder All-Severity Intersection Crashes		
Rank	Crash Type (group)	Freq.	%	Crash Type (group)	Freq.	%	Crash Type (group)	Freq.	%
1*	Bicyclist Failed to Yield - Signalized Intersection	155	21.5	Motorist Failed to Yield - Sign-Controlled Intersection	369	19.1	Motorist Failed to Yield - Sign-Controlled Intersection	167	20.1
2	Crossing Paths - Other Circumstances	115	16	Motorist Left Turn / Merge	278	14.4	Motorist Right Turn / Merge	144	17.3
3	Bicyclist Failed to Yield - Sign-Controlled Intersection	103	14.3	Bicyclist Failed to Yield - Signalized Intersection	219	11.3	Motorist Left Turn / Merge	141	17.0
4	Motorist Left Turn / Merge	55	7.6	Bicyclist Failed to Yield - Sign-Controlled Intersection	203	10.5	Motorist Failed to Yield - Signalized Intersection	128	15.4
5	Motorist Right Turn / Merge	53	7.4	Crossing Paths - Other Circumstances	202	10.4	Bicyclist Failed to Yield - Signalized Intersection	61	7.3
* Dark gray shading means crash type is in all three top five.				Medium gray shading means type is in US and NC top five.			Light gray shading and bold means type is in NC and Boulder top five.		

Another aspect of these crashes may be blocked sight-lines from the bicyclist's perspective. Daylighting intersections by prohibiting parking within a certain distance of the intersection can give bicyclists additional information about the speed and volume of approaching cars, thus helping them to better assess gaps. This countermeasure also applies for the Motorist Fail to Yield - Sign-Controlled Intersection crash type, which was the top crash type in the NC and Boulder data.

Motorist Left or Right Turn Across Path of Through Bicyclist

Motorist turning crashes at urban intersections are also in the top five nationally (15%), in NC (14%), and in Boulder (34%). The lower frequency in the fatality data may be due to a generally lower speed when motor vehicles are turning in comparison to when they are proceeding straight, given that speed is a critical contributor to injury severity (21). However, the general prevalence of these crashes suggest that they still need to be addressed, particularly for left turns, which were much more prevalent in the datasets and tend to have higher speeds than right turns due to wider turning radii.

There are many countermeasures to address left- and right-turning crashes, depending on the context. Operationally, separate phasing using protected left turn phasing, no-right-on-red signs or signals, a bicycle signal or leading bicycle interval may protect bicyclists. Raised crosswalks can slow turning drivers, while center medians can discourage sharp turns and colored pavement through intersections can provide greater visibility for bicyclists. New York City found a protective effect from separated bicycle lanes (22). Countermeasures that slow turning drivers may also benefit crossing pedestrians.

CONCLUSION

This paper provides an update to prior national studies of motorist-bicyclist crashes. It compares fatal and severe crash types to those of all-severity crashes in two jurisdictions and discusses differences and similarities between top intersection crash types at the state and local levels.

Below is a list of specific observations of interest:

- Most bicyclist crashes occur in urban areas. This is true for both fatalities and all-severity crashes in our study state.
- Motorist Overtaking Bicyclists is by far the most common bicyclist fatality crash type group in both urban and rural areas nationally, comprising 28% overall, and 25% in urban areas . It is also the top all-severity crash in urban areas in the study state, NC. However, it is not in the top ten all-severity crash types for the study city, Boulder.
- Most fatal and disabling injury bicyclist crashes are at non-intersection locations, but the majority for all-severity crashes at the state (NC) and local (Boulder) levels are at intersections.
- Overall bicyclist fatalities in the U.S. are more prevalent in urban areas (69%) than rural areas (29%). The percentages are similar at the state level in NC for all-severity crashes.
- Nearly half of fatalities occurred during non-daylight hours, which is likely higher than the amount of riding that occurs at night.
- Two intersection crash types are listed in the top five for all three data sources: Bicyclists Failed to Yield-signalized Intersection and Motorist Left Turn/Merge.

Fatal vs. all-severity crash types

Comparison of bicyclist crashes at intersection vs. non-intersection locations shows that most fatalities occur at non-intersection locations, while most all-severity crashes occur at intersections. This shows that one should not assume that what is true for all-severity crashes is necessarily true for fatalities and visa-versa.

Comparison of the top 10 urban crash types for national fatalities and NC and Boulder all-severity crashes reveal differences in the crash types that cause fatalities vs. those that cause

less severe crashes. While there is some commonality between fatal and all-severity crashes, all-severity crash types are not necessarily predictive of crash types causing fatalities if these three databases offer an apt comparison. In 2016, NHTSA began coding crash types for each pedestrian or bicyclist involved in crashes included in the Crash Report Sampling System database, which is intended to be a nationally representative probability sample representing the more than seven million police-reported crashes that occur annually, which should enhance analysts ability to examine the relative severities of different crash types and associated circumstances of the crashes.

State vs. local level comparison

Comparing urban crash types for all-severity crashes between the study state (NC) and study city (Boulder) shows much commonality, with eight of the top 10 found in both lists. This suggests a commonality among bicyclist crash types across cities, with intersection related crash types comprising most of the crash types.

However, despite this commonality, communities have unique crash circumstances as well as likely differences in reporting that may affect distributions. For example, conspicuously absent from the Boulder top crash types is “Motorist Overtaking Bicyclist”, perhaps due to slower traffic and a higher number of separated bicycle facilities in the city. Instead, Boulder’s top 10 list includes, “Bicyclist Overtaking Motorist”, a crash type more common in Boulder than might be expected in other communities, and which includes bicyclists approaching from the rear and striking moving or parked vehicles, including extended doors.

Considerations

None of the statistics for the crash types examined account for exposure, or the percentage of bicyclists riding in these different situations. Additional data are needed to illuminate how exposure to different crash types is affected by the built environment, roadway infrastructure and traffic operations, amounts, and speeds, and many other factors. Crash data alone provide little information to assess the roadway and traffic conditions affecting bicyclists, such as the actual speed of traffic, the distance to the nearest controlled intersection to access or cross a major road, the way sidepaths are connected to street networks, or other factors that may lead to, for example, cycling wrong-way on a sidewalk, or what appear to be contributing behavioral factors. These behaviors may be adaptations to deal with uncomfortable circumstances, and that sometimes contribute to crashes.

Next Steps

This study provides the first update in decades of motorist-bicyclist fatality crash types, although on the state and local levels, only one state and one city are examined. This one state is not representative of all states, and this one city is not representative of all or even most cities. The authors hope broader application of crash typing methods will allow more consistent and widespread typing of bicycle crashes, and additional research on motorist-bicyclists crash types.

Next steps include adding more years to the FARS data. FARS coding could be improved by coding the roadway variables for the road or path on which the bicyclists and pedestrians are traveling (not just the road the driver is on). In addition, the authors encourage the development of a national database which includes severe injury crashes in addition to fatalities. Since bicycle crashes are known to be under reported and fatalities may occur beyond 30 days following a crash, linking emergency services and hospital data to the crash database would improve the completeness of the database and the accuracy and consistency of injury coding (23).

Crash typing alone is not sufficient for understanding and addressing bicyclist safety, but it is an important aspect currently missing from most state crash databases. Knowing the prevalent crash types, jurisdictions can more effectively select and implement applicable and effective countermeasures.

AUTHOR CONTRIBUTION STATEMENT

The authors confirm contribution to the paper as follows: study conception and design: Thomas, Nordback, Sanders; data collection: Thomas; analysis and interpretation of results: Thomas, Nordback, Sanders; draft manuscript preparation: Nordback, Thomas, Sanders. All authors reviewed the results and approved the final version of the manuscript.

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