North Carolina
Bicycle Crash Types
2011 - 2015

Prepared for

The North Carolina Department of Transportation
Division of Bicycle and Pedestrian Transportation

Prepared by

The University of North Carolina Highway Safety Research Center

Libby Thomas
Mike Vann
Daniel Levitt

January 2018

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Introduction and Purpose

During the five-year period of 2011-2015, an average of 951 bicycle-motor vehicle crashes were reported to the North Carolina Division of Motor Vehicles each year. On average, 22 bicyclists were killed and many more were injured each year.

This report summarizes bicycle-motor vehicle crash type information developed for 2011-2015 for the entire State. UNC Highway Safety Research Center staff reviewed diagrams and narratives and other details on copies of all crash report forms submitted to NCDOT, and used PBCAT software to code crash type, bicyclist position and direction, and crash location variables for each bicycle-motor vehicle crash. These data elements were combined with the crash data elements already available in the State's crash database. The results of analyzing the crash type data and other elements are summarized in the tables, figures, and text in the following sections.

The report provides information about typical safety issues across the state, and suggests types of countermeasures that might be appropriate. Local agencies can use the information as a guide to analyze and understand their own specific crash issues and potential treatments. The information is for summary purposes only. Appropriate diagnosis and other procedures are necessary before implementing treatments at any location. Additional information on crash characteristics including locations, person, environmental, and roadway factors is provided in the companion *North Carolina Bicycle Crash Facts* summary report.

Background on Crash Typing

The information from the State crash report forms and reported by public safety officials across the State is stored in electronic crash databases. Analysis of these data can provide information on *where* bicycle-motor vehicle crashes occur (city street, two-lane roadway, intersection location, etc.), *when* they occur (time of day, day of week, etc.), and *to whom* they occur (age of victim, gender, level of impairment, etc.). Reported crash data were compiled and used to describe such bicycle-motor vehicle crash characteristics for the companion, *North Carolina Bicycle Crash Facts* summary report.

However, the data contained in the crash database provides little information about the actual sequence of events leading to crashes between motor vehicles and bicyclists. The development of effective countermeasures to help prevent and reduce the severity of these crashes is limited by this lack of detail on events that led up to crashes. To address this type of situation, the National Highway Traffic Safety Administration (NHTSA) developed a system of "typing" pedestrian and bicycle crashes. Each identified crash type is defined by a specific sequence of events, and each has precipitating actions, predisposing factors, and characteristic populations and/or locations that can be targeted for interventions. The original pedestrian crash typology was developed and applied during the early 1970's (Snyder and Knoblauch, 1971; Knoblauch, 1977; Knoblauch, Moore and Schmitz, 1978). Cross and Fisher (1977) later developed a similar typology for bicycle crashes. Harkey, Mekemson, Chen, and Krull (2000) created the Pedestrian and Bicycle Crash Analysis Tool (PBCAT) that enabled both pedestrian and bicycle crash typing to be done by software. Harkey, Tsai, Thomas, and Hunter updated this tool in 2006 in a project sponsored by the Federal Highway Administration (FHWA). For more information on PBCAT and crash typing, including detailed descriptions and images of typical crash scenarios, see the PBCAT webpage. BIKESAFE: Bicycle Countermeasure Selection System, also sponsored by FHWA, is a companion tool that helps to identify potentially appropriate countermeasures for the types of crashes and other problems identified by analyzing data from PBCAT and state crash files. Another FHWA tool that can assist with diagnosing problems is the Bicycle Road Safety Audit Guidelines and Prompt Lists.

Crash Events and Description

Crash Location

Table 1 shows the frequency and percentage of bicycle crashes by the general crash location of the bicyclist as determined during the crash typing process. 45 percent of the collisions occurred in non-intersection (i.e., mid-block) sections along streets and roadways. These include crashes that occurred at or related to non-signalized commercial and private driveways. Another 43 percent occurred at intersections (i.e., within the motor vehicle stop bars or pedestrian crosswalks), and 8 percent were intersection-related (i.e., close enough that an intersection maneuver such as slowing traffic may have led to the crash). About 4 percent occurred in non-roadway locations (typically parking lots).

Table 1 NC bicycle-motor vehicle crashes by location type [1]

Crash Location	2011	2012	2013	2014	2015	Total
Intersection	448	466	377	354	394	2,039
	43.5[1]	45.5	42.0	41.6	41.4	42.9 [2]
Intersection-Related	67	89	89	57	71	373
	6.5	8.7	9.9	6.7	7.5	7.8
Non-Intersection	470	437	386	401	450	2,144
	45.6	42.7	43.0	47.2	47.4	45.1
Non-Roadway	46	31	46	38	35	196
	4.5	3.0	5.1	4.5	3.7	4.1
Unknown Location	0	1	0	0	0	1
	0.0	0.1	0.0	0.0	0.0	0.0
Total	1,031	1,024	898	850	950	4,753
	21.3 [3]	17	19.8	21	20.9	

[1] In this and all subsequent tables, the percentages are as shown:
[1] Row percent of column total
[2] Row total percent of total
[3] Column percent of row total

Figure 1 shows how the proportion of crash location types vary from rural to urban crash locations in NC, and may also vary from city to city, depending on how closely-spaced intersections are, and other factors. Non-intersection crash locations make up a higher percentage, 66 percent, of the total bicycle crashes in rural areas but account for 37 percent of crashes in urban areas. Non-roadway (parking lot crashes) are understandably a lower percentage (2 percent) of crashes in rural areas than in urban areas (5 percent). Intersections and crashes near intersections account for 58 percent of urban area crashes and 32 percent of those in rural areas.

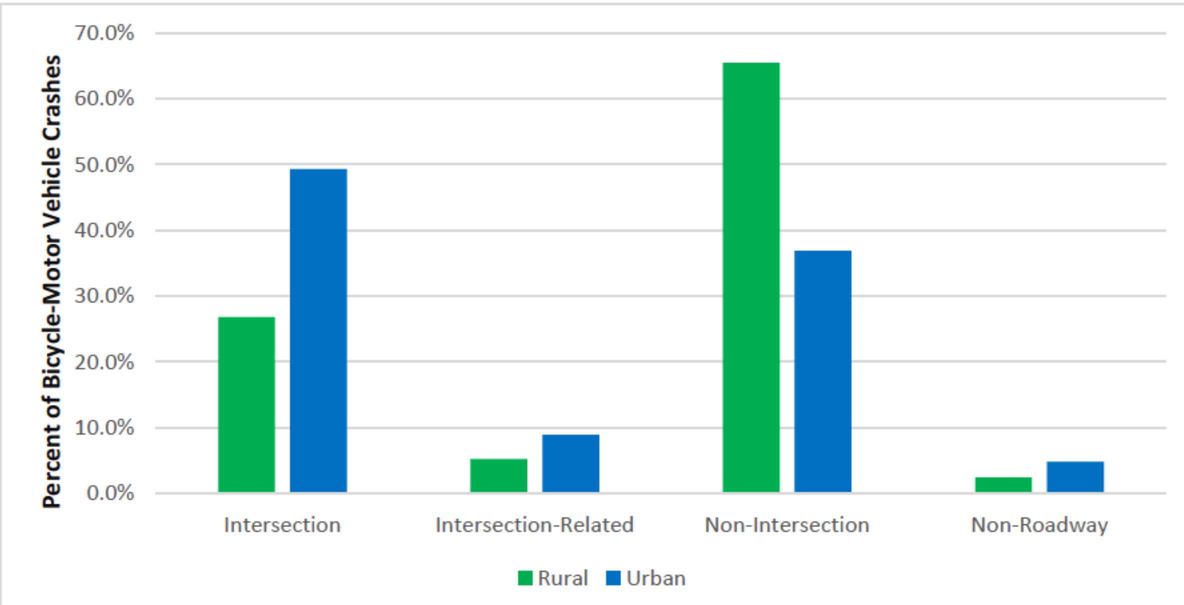


Figure 1 Percentages of NC rural and urban bicycle crashes by location type, 2011-2015 (n = 1,357 rural, 3,397 urban crashes)

Statewide, however, urban intersection locations accounted for 35 percent of all bicycle-motor vehicle crash locations (1,676/4,754; Table 2). Table 2 shows the combined distributions for rural and urban locations for all five years. Urban, non-intersection locations accounted for the next highest number of crashes among rural/urban combined with location type. However, because many more bicycle crashes in rural areas occur at non-intersection locations (889 compared with 364 at rural intersections), in total non-intersection roadway locations account for the larger numbers across the State.

Table 2 Crash Location type by rural or urban area type, 2011-2015

Crash Location Type by Rural / Urban	Rural	Urban	Total
Intersection	364	1,676	2,040
	26.8	49.3	42.9
Intersection-Related	71	302	373
	5.2	8.9	7.8
Non-Intersection	889	1,255	2,144
	65.5	36.9	45.1
Non-Roadway	33	163	196
	2.4	4.8	4.1
Unknown Location	0	1	1
	0.0	0.0	0.0
Total	1,357	3,397	4,754
	28.5	71.5	

In addition to greater total numbers of crashes at all non-intersection locations across the state, the rate of fatal and serious injuries for bicyclists struck along these road sections is more than twice as high (9 percent) as the rate for those struck at intersection locations (5 percent of the total struck). In part, the higher fatalities resulting from non-intersection crashes reflect that a large percentage of bicyclists are struck at non-intersection locations in rural areas, as already shown, where speeds are typically higher, travel lanes are typically shared, and rural roadway sections often have no paved shoulders or supplemental lighting. Motorists may also be expecting interactions with other road users at intersections (especially those with traffic controls), or slowing for turns and other maneuvers, compared with mid-block/segment locations.

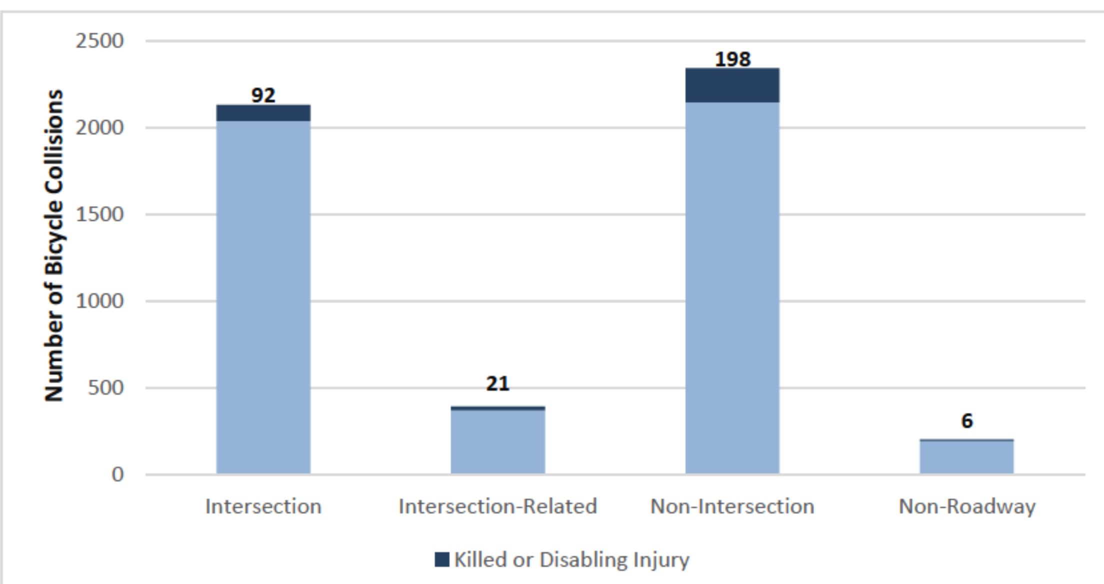


Figure 2 Bicyclist injury severity by location type, 2011-2015

Bicyclist Position

Table 3 shows the initial position of the (primary) bicyclist involved the crash and indicates that 64 percent of the bicyclists were on a street in a lane shared with motor vehicle traffic just prior to the crash. On average, 18 percent were on a sidewalk, crosswalk, or driveway crossing just prior to the collision. According to data available in crash reports, bicyclists were riding on paved shoulders or bicycle lanes 6 percent of the time prior to their collisions. 2 percent were on a driveway or alley before any maneuvers such as the bicyclist riding out into a street, or a motor vehicle turning in. Another 6 percent were in other non-roadway areas such as parking lots. Unfortunately, we lack data on exposure, or amounts of riding on these different facility types. The initial position of the bicyclist was unknown/unable to be determined in 2 percent of the crashes.

Table 3 Bicyclist position prior to the crash, NC bicycle-motor vehicle crashes

Bicyclist Position	2011	2012	2013	2014	2015	Total
Travel Lane	701	691	568	544	558	3,062
	68.0	67.5	63.3	64.0	58.7	64.4
Bike Lane / Paved Shoulder	47	51	47	65	61	271
	4.6	5.0	5.2	7.6	6.4	5.7
Sidewalk / Crosswalk / Driveway Crossing	173	170	163	155	203	864
	16.8	16.6	18.2	18.2	21.3	18.2
Multi-use Path	7	7	7	7	8	36
	0.7	0.7	0.8	0.8	0.8	0.8
Driveway / Alley	24	17	25	24	25	115
	2.3	1.7	2.8	2.8	2.6	2.4
Non-Roadway	57	54	62	43	53	269
	5.5	5.3	6.9	5.1	5.6	5.7
Other	5	3	4	5	9	26
	0.5	0.3	0.4	0.6	0.9	0.5
Unknown	14	31	22	7	34	108
	1.4	3.0	2.4	0.8	3.6	2.3
Total	1,031	1,024	898	850	951	4,754
	21.7	21.5	18.9	17.9	20.0	

Bicyclist Direction of Travel

Table 4 shows that 61 percent of the bicyclists were riding with traffic (i.e., in the same direction as traffic). Twenty-four percent were riding opposed or facing traffic. The percentage riding opposed to traffic was 24 percent when including only applicable crashes on the roadway network for which direction was known. Direction was considered not applicable for parking lot, driveway, and other off-road locations. Bicyclist travel direction was not applicable or unknown/not determinable for 15 percent of the crashes.

Riding facing traffic is against the rules of the road and may contribute to crash occurrence since bicyclists are approaching from an unexpected direction.

Table 4 Bicyclist travel direction in NC bicycle-motor vehicle crashes

Bicyclist Direction	2011	2012	2013	2014	2015	Total
With Traffic	658	640	546	512	558	2,914
	63.8	62.5	60.8	60.2	58.7	61.3
Facing Traffic	212	255	225	209	224	1,125
	20.6	24.9	25.1	24.6	23.6	23.7
Not Applicable	138	95	98	115	129	575
	13.4	9.3	10.9	13.5	13.6	12.1
Unknown	23	34	29	14	40	137
	2.2	3.3	3.2	1.6	4.2	2.9
Total	1,031	1,024	898	850	951	4,754
	21.7	21.5	18.9	17.9	20.0	

Individual Crash Types

Table 5 shows a complete listing of all the individual crash types generated by the coding for each of the five years, and totals for all five years. (Nine of the crashes during this period lacked sufficient information to be typed even to a general location type.) The table shows the 78 different ways bicycle-motor vehicle collisions can occur, including various turning and merging maneuvers in traffic, overtaking events, ride outs and drive outs, bicyclists and motorists losing control of their vehicle, motorists intentionally striking bicyclists, unusual circumstances, and parking lot/non-roadway events, etc. The names are reasonably self-explanatory, but more details as to the meaning of each crash type are available on the software web page, in the manual that accompanies in the software.

There is some year-to-year variability in the frequencies and proportions of each crash type, especially those with smaller numbers. Much of this variation is likely explained by chance, but some variation is potentially attributable to changes in behaviors including effects of roadway treatments or education and enforcement measures. Also, numbers in some categories vary significantly from year to year due to different interpretations of crash reports.

Table 5 NC bicycle crash types by year

Crash Type	2011	2012	2013	2014	2015	Total
Motorist Turning Error - Left Turn	4	8	6	8	4	30
	0.4	0.8	0.7	0.9	0.4	0.6
Motorist Turning Error - Right Turn	4	0	6	2	1	13
	0.4	0.0	0.7	0.2	0.1	0.3
Motorist Turning Error - Other	1	1	1	3	1	7
	0.1	0.1	0.1	0.4	0.1	0.1
Bicyclist Turning Error - Left Turn	3	3	0	0	2	8
	0.3	0.3	0.0	0.0	0.2	0.2
Bicyclist Turning Error - Right Turn	2	3	6	2	0	13
	0.2	0.3	0.7	0.2	0.0	0.3
Bicyclist Turning Error - Other	0	0	0	2	0	2
	0.0	0.0	0.0	0.2	0.0	0.0
Bicyclist Lost Control - Mechanical Problems	10	16	6	12	6	50
	1.0	1.6	0.7	1.4	0.6	1.1
Bicyclist Lost Control – Oversteering, Improper Braking, Speed	4	0	1	0	0	5
	0.4	0.0	0.1	0.0	0.0	0.1
Bicyclist Lost Control - Alcohol / Drug Impairment	2	1	0	1	0	4
	0.2	0.1	0.0	0.1	0.0	0.1
Bicyclist Lost Control - Surface Conditions	0	0	1	4	1	6
	0.0	0.0	0.1	0.5	0.1	0.1
Bicyclist Lost Control - Other / Unknown	10	7	0	7	2	26
	1.0	0.7	0.0	0.8	0.2	0.5
Motorist Lost Control - Mechanical Problems	0	0	1	0	0	1
	0.0	0.0	0.1	0.0	0.0	0.0
Motorist Lost Control – Oversteering, Improper Braking, Speed	0	1	1	3	1	6
	0.0	0.1	0.1	0.4	0.1	0.1
Motorist Lost Control - Alcohol / Drug Impairment	1	0	0	2	0	3
	0.1	0.0	0.0	0.2	0.0	0.1
Motorist Lost Control - Surface Conditions	0	0	0	0	3	3
	0.0	0.0	0.0	0.0	0.3	0.1
Motorist Lost Control - Other / Unknown	7	15	11	8	3	44
	0.7	1.5	1.2	0.9	0.3	0.9
Motorist Drive Out - Sign-Controlled Intersection	102	97	75	80	69	423
	9.9	9.5	8.4	9.4	7.3	8.9
Bicyclist Ride Out - Sign-Controlled Intersection	25	9	8	6	3	51
	2.4	0.9	0.9	0.7	0.3	1.1
Motorist Drive Through - Sign-Controlled Intersection	2	5	8	10	2	27
	0.2	0.5	0.9	1.2	0.2	0.6
Bicyclist Ride Through - Sign-Controlled Intersection	39	64	42	41	40	226
	3.8	6.3	4.7	4.8	4.2	4.8
Multiple Threat - Sign-Controlled Intersection	0	0	0	1	0	1
	0.0	0.0	0.0	0.1	0.0	0.0

Crash Type	2011	2012	2013	2014	2015	Total
Sign-Controlled Intersection - Other / Unknown	6	7	10	5	31	59
	0.6	0.7	1.1	0.6	3.3	1.2
Motorist Drive Out - Right Turn on Red	12	23	21	14	24	94
	1.2	2.2	2.3	1.6	2.5	2.0
Motorist Drive Out - Signalized Intersection	11	8	9	12	11	51
	1.1	0.8	1.0	1.4	1.2	1.1
Bicyclist Ride Out - Signalized Intersection	20	9	18	4	1	52
	1.9	0.9	2.0	0.5	0.1	1.1
Motorist Drive Through - Signalized Intersection	6	2	3	5	7	23
	0.6	0.2	0.3	0.6	0.7	0.5
Bicyclist Ride Through - Signalized Intersection	25	31	27	34	50	167
	2.4	3.0	3.0	4.0	5.3	3.5
Bicyclist Failed to Clear - Trapped	4	6	5	3	5	23
	0.4	0.6	0.6	0.3	0.5	0.5
Bicyclist Failed to Clear - Multiple Threat	0	2	1	1	0	4
	0.0	0.2	0.1	0.1	0.0	0.1
Signalized Intersection - Other / Unknown	12	43	8	7	20	90
	1.2	4.2	0.9	0.8	2.1	1.9
Bicyclist Failed to Clear - Unknown	0	0	2	1	1	4
	0.0	0.0	0.2	0.1	0.1	0.1
Crossing Paths - Uncontrolled Intersection	10	14	12	8	7	51
	1.0	1.4	1.3	0.9	0.7	1.1
Crossing Paths - Intersection - Other / Unknown	17	13	8	3	5	46
	1.6	1.3	0.9	0.3	0.5	1.0
Motorist Left Turn - Same Direction	10	5	10	11	12	48
	1.0	0.5	1.1	1.3	1.3	1.0
Motorist Left Turn - Opposite Direction	83	87	87	72	64	393
	8.1	8.5	9.7	8.5	6.7	8.3
Motorist Right Turn - Same Direction	47	41	38	41	38	205
	4.6	4.0	4.2	4.8	4.0	4.3
Motorist Right Turn - Opposite Direction	7	3	5	10	5	30
	0.7	0.3	0.6	1.2	0.5	0.6
Motorist Drive In / Out - Parking	0	1	0	1	1	3
	0.0	0.1	0.0	0.1	0.1	0.1
Motorist Right Turn on Red - Same Direction	4	0	1	0	0	5
	0.4	0.0	0.1	0.0	0.0	0.1
Motorist Right Turn on Red - Opposite Direction	0	0	0	0	1	1
	0.0	0.0	0.0	0.0	0.1	0.0
Motorist Turn / Merge - Other / Unknown	2	1	1	2	2	8
	0.2	0.1	0.1	0.2	0.2	0.2
Bicyclist Left Turn - Same Direction	54	32	25	27	22	160
	5.2	3.1	2.8	3.2	2.3	3.4
Bicyclist Left Turn - Opposite Direction	5	7	3	8	6	29
	0.5	0.7	0.3	0.9	0.6	0.6
Bicyclist Right Turn - Same Direction	13	8	8	4	9	42
	1.3	0.8	0.9	0.5	0.9	0.9

Crash Type	2011	2012	2013	2014	2015	Total
Bicyclist Right Turn - Opposite Direction	0	3	2	1	0	6
	0.0	0.3	0.2	0.1	0.0	0.1
Bicyclist Ride Out - Parallel Path	14	10	10	1	12	47
	1.4	1.0	1.1	0.1	1.3	1.0
Motorist Overtaking - Undetected Bicyclist	30	17	41	34	61	183
	2.9	1.7	4.6	4.0	6.4	3.8
Motorist Overtaking - Misjudged Space	57	37	15	14	0	123
	5.5	3.6	1.7	1.6	0.0	2.6
Motorist Overtaking - Bicyclist Swerved	21	33	23	29	21	127
	2.0	3.2	2.6	3.4	2.2	2.7
Motorist Overtaking - Other / Unknown	83	119	104	81	126	513
	8.1	11.6	11.6	9.5	13.2	10.8
Bicyclist Overtaking - Passing on Right	8	5	4	0	2	19
	0.8	0.5	0.4	0.0	0.2	0.4
Bicyclist Overtaking - Passing on Left	4	1	0	0	0	5
	0.4	0.1	0.0	0.0	0.0	0.1
Bicyclist Overtaking - Parked Vehicle	4	5	10	11	13	43
	0.4	0.5	1.1	1.3	1.4	0.9
Bicyclist Overtaking - Extended Door	0	4	2	8	2	16
	0.0	0.4	0.2	0.9	0.2	0.3
Bicyclist Overtaking - Other / Unknown	5	6	6	4	4	25
	0.5	0.6	0.7	0.5	0.4	0.5
Head-On - Bicyclist	20	23	12	21	12	88
	1.9	2.2	1.3	2.5	1.3	1.9
Head-On - Motorist	5	4	2	6	6	23
	0.5	0.4	0.2	0.7	0.6	0.5
Head-On - Unknown	2	1	0	1	1	5
	0.2	0.1	0.0	0.1	0.1	0.1
Parallel Paths - Other / Unknown	10	5	16	2	4	37
	1.0	0.5	1.8	0.2	0.4	0.8
Bicyclist Ride Out - Residential Driveway	20	13	20	16	19	88
	1.9	1.3	2.2	1.9	2.0	1.9
Bicyclist Ride Out - Commercial Driveway / Alley	9	8	7	9	18	51
	0.9	0.8	0.8	1.1	1.9	1.1
Bicyclist Ride Out - Other Midblock	26	20	13	19	21	103
	2.5	2.0	1.4	2.2	2.2	2.2
Bicyclist Ride Out - Midblock - Unknown	6	13	10	8	18	55
	0.6	1.3	1.1	0.9	1.9	1.2
Motorist Drive Out - Residential Driveway	4	3	2	6	14	29
	0.4	0.3	0.2	0.7	1.5	0.6
Motorist Drive Out - Commercial Driveway / Alley	63	60	46	61	70	300
	6.1	5.9	5.1	7.2	7.4	6.3
Motorist Drive Out - Other Midblock	8	3	1	4	9	25
	0.8	0.3	0.1	0.5	0.9	0.5

Crash Type	2011	2012	2013	2014	2015	Total
Motorist Drive Out - Midblock - Unknown	1	1	0	0	2	4
	0.1	0.1	0.0	0.0	0.2	0.1
Multiple Threat - Midblock	5	2	0	2	1	10
	0.5	0.2	0.0	0.2	0.1	0.2
Crossing Paths - Midblock - Other / Unknown	1	3	9	0	2	15
	0.1	0.3	1.0	0.0	0.2	0.3
Bicycle Only	1	0	1	0	1	3
	0.1	0.0	0.1	0.0	0.1	0.1
Motorist Intentionally Caused	0	1	1	1	2	5
	0.0	0.1	0.1	0.1	0.2	0.1
Bicyclist Intentionally Caused	0	0	0	0	0	0
	0.0	0.0	0.0	0.0	0.0	0.0
Backing Vehicle	5	10	11	3	7	36
	0.5	1.0	1.2	0.4	0.7	0.8
Play Vehicle-Related	1	0	2	4	0	7
	0.1	0.0	0.2	0.5	0.0	0.1
Unusual Circumstances	1	1	3	1	3	9
	0.1	0.1	0.3	0.1	0.3	0.2
Non-Roadway	46	31	46	38	35	196
	4.5	3.0	5.1	4.5	3.7	4.1
Unknown Approach Paths	7	8	4	0	5	24
	0.7	0.8	0.4	0.0	0.5	0.5
Unknown Location	0	1	0	0	0	1
	0.0	0.1	0.0	0.0	0.0	0.0
Total	1,031	1,024	898	850	951	4,754
	21.7	21.5	18.9	17.9	20.0	

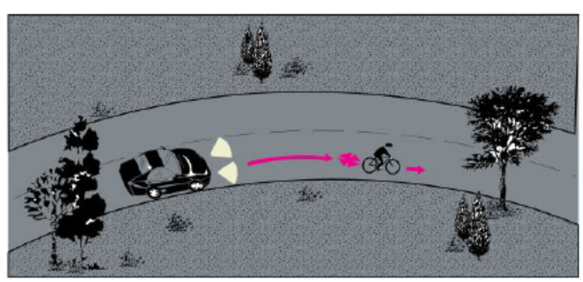
Table 6 shows the top ten most frequently occurring types of bicycle-motor vehicle crashes for all five years combined. Together, these ten types accounted for 58 percent of all of NC's bicycle collisions. These types could therefore be among the priorities for targeting safety treatments. Other crash types, some closely related to the top ten also account for sizable numbers and may be targets for similar measures or others. The resources mentioned in the Background and at the end of this report, provide further guidance for selecting appropriate treatments.

Table 6 Top ten most frequent NC bicycle crash types, 2011-2015

Rank	Crash Type	Total	Percent of NC Total
1	Motorist Overtaking – Other / Unknown	513	10.8
2	Motorist Drive Out – Sign-Controlled Intersection	423	8.9
3	Motorist Left Turn - Opposite Direction	393	8.3
4	Motorist Drive Out - Commercial Driveway / Alley	300	6.3
5	Bicyclist Ride Through – Sign-Controlled Intersection	226	4.8
6	Motorist Right Turn – Same Direction	205	4.3
7	Non-Roadway	196	4.1
8	Motorist Overtaking – Undetected Bicyclist	183	3.8
9	Bicyclist Ride Through – Signalized Intersection	167	3.5
10	Bicyclist Left Turn – Same Direction	160	3.4
Subtotal for top ten types for frequency		2,766	58.2

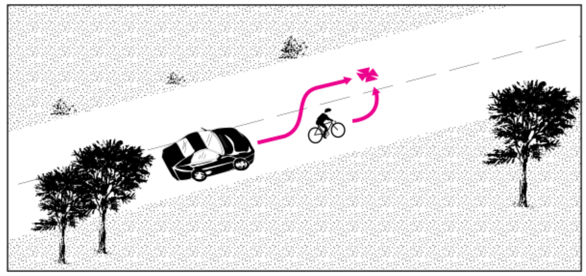
Among the top ten types, crashes in which the motorist and bicyclist were initially on parallel paths before any turns or other maneuvers that led to the crash (numbers 1, 3, 6, 8, and 10) accounted for 31 percent. Crashes in which the motorist and bicyclist were initially on crossing or perpendicular paths (numbers 2, 4, 5, and 9) accounted for 24 percent. Non-roadway types of crashes, such as those occurring in parking lots or on public or private driveways, accounted for 4 percent of total crashes.

Motorist Overtaking – Other/Unknown, which is the most frequent crash type coded over the five-year period, describes events where the motorist and bicycle were on parallel paths in the same direction, but there was no information to indicate whether the motorist misjudged the space needed to pass, failed to detect the bicyclist, or the bicyclist swerved into the path of the motorist.

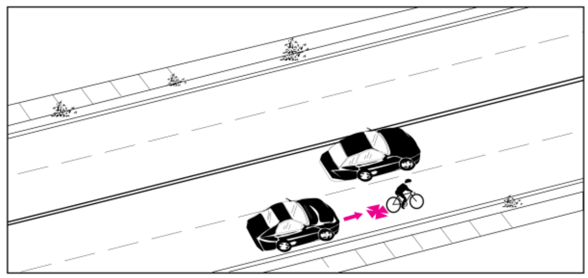


One other **Motorist Overtaking** crash is in the top 10: **Undetected Bicyclist** (number 8). These are crashes in which the motorist was overtaking, but according to information in the crash report, did not see the bicyclist ahead until it was too late to avoid a crash.

In addition, the 11th most frequent type (not shown in the table) was **Motorist Overtaking - Bicyclist Swerved**, which accounted for 127 crashes. This crash type describes cases where the bicyclist suddenly swerved (apparently not an intentional merge or turn) into the path of the overtaking motorist. This type accounted for another 3 percent of crashes statewide.



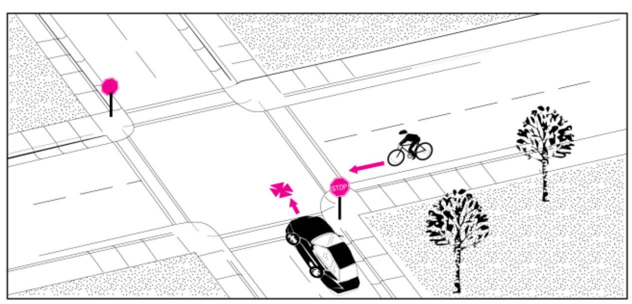
Also, **Motorist Overtaking - Misjudged Space** was the 12th most frequent type with 123 crashes (3 percent). This implies that the motorist misjudged the space or distance needed to safely pass the bicyclist.



Thus, these four motorist overtaking crash types combined accounted for 20 percent of all of NC's bicycle-motor vehicle collisions statewide.

Potential Countermeasures. Treatments would generally be similar for all four types of motorist overtaking crashes. Providing for sufficient sight distance for the speed of traffic, separated space to ride such as wide shoulders or bike lanes (or even separated facilities), and keeping shoulders or lanes clear of debris, overhanging branches, and well-maintained are countermeasures that can help to address overtaking crash types. These crash types can be severe, particularly when motorized speeds are high. If separate space (paved shoulders, lanes, or paths) or adequate sight distance cannot be provided, then it is important to consider whether speed limits should be lower so that overtaking motorists have sufficient sight distance and time to react to any slower vehicles ahead, including bikes or pedestrians walking along the roadway. Intermittent passing lanes could also be considered in some situations. Both motorist education and enforcement of safe passing rules; and bicyclist education about safe riding practices and using appropriate lights and being conspicuous at night could also be considered.

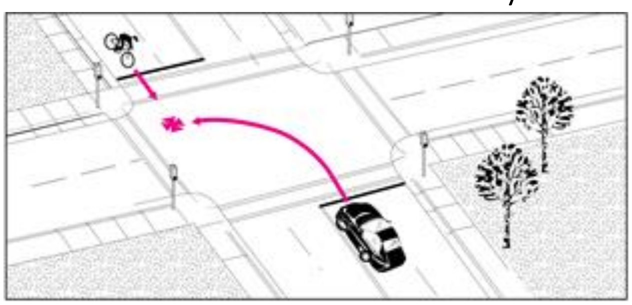
The second most frequent event coded over this period, **Motorist Drive Out – Sign-Controlled Intersection,** refers to a motorist who apparently obeyed a stop sign but then drove out into the path of the bicyclist. In 56.5 percent of the crashes of this type, bicyclists were riding wrong-way (facing against traffic) and therefore may have contributed to the crash by coming from an unexpected direction where the driver was less likely to notice them before pulling out.



Potential Countermeasures. Intersection improvements include providing mini-roundabouts or roundabouts, narrowing curb radii to reduce turning speeds, improving lighting, improving sight distance and visibility. Motorist and bicyclist education are also among the important countermeasures for this crash type. In addition, bicyclists may be uncomfortable riding on the roadway sections leading up to the intersection or there may be limited connectivity to paths or other bicycle origins/destinations. Cyclists using the sidewalk were at least four times as likely to be riding wrong-way compared to those riding on a travel lane on the roadway before their crash. (About half of all wrong-way cyclists were on the sidewalk.) Therefore, measures that improve the overall bicycle level or quality of service on roadway sections, making it more appealing for riders to ride on the road in the correct direction of traffic, may help reduce this crash type.

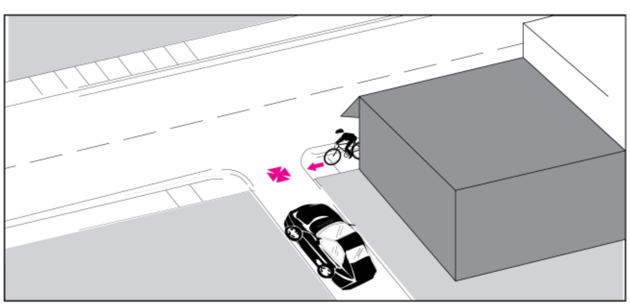
Cyclists riding on multi-use paths (which may be adjacent sidepaths intended for two-way riding), may also come from an unexpected direction when motorists cross these paths. Care should be taken in designing such junctions and providing for safe interactions.

Motorist Left Turn – Opposite Direction (#3 in the list) involves events where the motorist turns left at an intersection or driveway in front of an oncoming bicyclist.



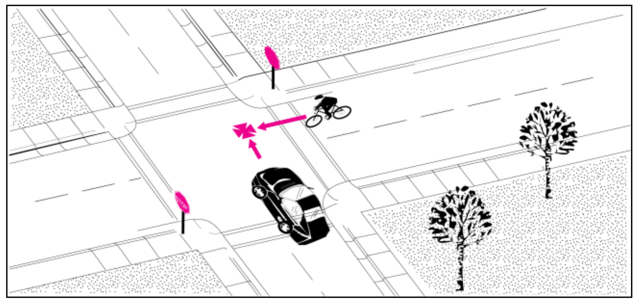
These types of crashes may occur on multi-lane roads when the motorist's view of the bicyclist is block by other traffic lanes, or the driver may fail to look for or notice an oncoming bicyclist. About 76 percent of these occurred at intersections; many of those that occurred at a non-intersection would be at a driveway. The vast majority (94percent) of bicyclists involved in this collision type were riding in the correct direction - with traffic - at the time of the crash.

Potential Countermeasures. Providing protected-only left-turn phasing at signalized locations, restricting left turns at midblock locations, reducing conflicting movements by providing roundabouts (especially one-lane) at intersections, are among potential treatments for these types of collisions. Again, motorist education, which could include the use of MUTCD-approved regulatory or warnings signs (such as Yield when Turning or Watch for Bikes types of signs) could potentially help to reduce this crash type, at least at the locations where implemented. However, signs may lose effectiveness over the longer term.



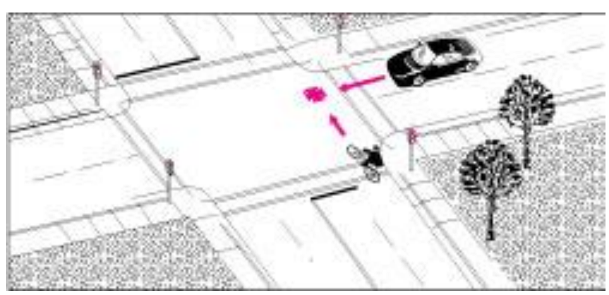
Motorist Drive Out – Commercial Driveways (#4 in list) involves motorists driving out at these locations and failing to yield right-of-way to approaching bicyclists. As was the case with motorist drive-outs at sign-controlled junctions, this type also has an over-representation (81 percent of the cases) of bicyclists traveling from the motorist's right, facing against traffic. More than two thirds of all such cyclists are also riding on sidewalks or paths.

Potential Countermeasures. Sight distance issues may be contributing factors at driveways and should be addressed. In addition, driveway design and narrow turning radii can help to ensure that drivers stop and yield before pulling out. Measures that improve bicyclists' comfort on the road, as well as training and education of cyclists are also needed. Drivers should be reminded to look both ways before pulling out. If bicyclists use sidewalks for riding in neighborhoods, or before roadway or other improvements are in place, they should be trained to ride like pedestrians, slowly, and watching for traffic at each junction.



The 5th most frequent collision type over this period, **Bicyclist Ride Through – Sign-Controlled Intersection**, is typically an event where the bicyclist ignored the sign controlling the bicyclist's direction. A lack of on-road bicycling experience, failure to notice the sign or look for conflicting traffic, a lack of sufficient gaps in traffic or a misjudgment of the available gap, or a reluctance to lose momentum are factors that could be present in such a crash type. Wrong-way riding (present in about 15 percent of the cases) could increase the chances that a bicyclist would not notice the traffic control. There may be no controls on the motorists' (main) road, and there may be challenges for bicyclists to cross or access a busier road.

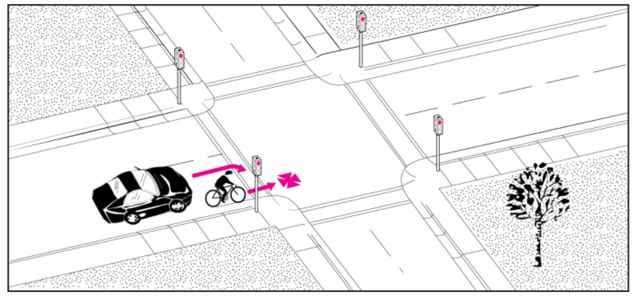
Potential Countermeasures. Consider whether additional treatments including, roundabouts, installing signals or hybrid beacons, and/or calming speeds on the road being crossed, are needed to assist bicyclists in crossing or accessing a main road from a stop-controlled side street. It may also be possible to create gaps for crossing (which could benefit all modes) by coordinating signal timing at traffic signals along the main corridor.



The 9th most frequent crash type is **Bicyclist Ride Through – Signalized Intersection**. In this situation, the bicyclist ignores a red light and rides into an intersection. Wrong-way riding accounts for around 40 percent of these crashes.

Potential Countermeasures. In addition to educational/training measures, intersection treatments such as improved sight distance, implementing roundabouts or mini-roundabouts, installing a signal with bike detection, or providing alternate routes for bicyclists, are improvements that may be warranted to safely accommodate bicyclist traffic, depending on the road and area type. Bicycle boulevards, described in the National Association of City Transportation Officials, is a measure that could be tried to provide a priority route for bicyclists where they do not have to stop as frequently.

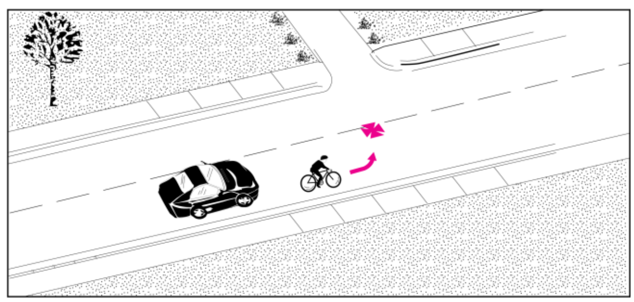
Sixth on the list, **Motorist Right Turn – Same Direction** involves motorists passing and turning right (sometimes known as the "right-hook") in front of bicyclists who were traveling along the same roadway (or an adjacent path or walkway) in the same direction.



Potential Countermeasures. Conspicuous bike lanes combined with bike boxes or advance stop bars at intersections may be appropriate in some situations to allow bicyclists to proceed to the front of the queue at signalized locations. Turn and through lane design and merge areas, intersection markings, narrower curb radii, and other treatments may be suitable, depending on the context. BIKESAFE describes some of these treatments.

The 7th most frequent crash type is a catch-all category for all **Non-Roadway** collisions that were reported (image not shown). This type means the crash occurred off the roadway network and typically refers to parking lot crashes, but may also include crashes on public and private driveways and other off-roadway areas.

Bicyclist Left Turn – Same Direction (#10) involves a bicyclist traveling along the right side of the roadway (usually) in the same direction as a motor vehicle and turning or merging left in front of, or into the side of, the motor vehicle traveling in the same direction. The rider fails to see or yield to a motorist coming from behind. This crash type could also involve a bicyclist riding out from a sidewalk or path beside the road. Speed of overtaking vehicles may be a factor in this group of crashes. The motorist also may not see the bicyclist, or may not suspect that the bicyclist will turn in front in time to react.



Potential Countermeasures. A variety of countermeasures may help reduce the occurrence of this crash type, specific to the situation. Bicyclists should be educated to use proper hand signals and check behind before changing position, and use lights at night. Motorists should be encouraged to allow ample space and be alert for when bicyclists may need to merge or turn. Speed enforcement and other efforts to control traffic speeds may also be needed. Special facilities or designs may be warranted in certain circumstances, such as if there are many bicyclists needing to merge to make left turns for a particular destination.

Bicyclist Age Group and Crash Type (group)

Although all ages can be involved in virtually any type of crash, there are patterns of association by age group. Children and young adults are more often involved in riding out at sign-controlled intersections as well as riding out from midblock locations. See Table 7 in Appendix A for a table of age group by crash type interactions. As with pedestrians, the youngest bicyclists are over-represented in crashes on non-roadway areas. When cycling, adults tend to be over-

represented in crashes where the motorist turned across their path, or pulled out at an intersection or midblock location.
Potential Countermeasures. Educational messages, training and enforcement could focus on the most common types of errors and situations that lead to the most common types of collisions, targeted by age group.

Children should also be closely supervised by parents and other caregivers, provided safe places to ride and to learn safe cycling, and taught about hazards when riding on driveways or around any motor vehicle, even those that seem parked. Adults also need to ride with youngsters and provide training as they learn to ride on paths and neighborhood streets when they mature enough to ride in these locations. If taught to ride on sidewalks, young riders should be coached to ride slowly and watch for traffic turning in and out at driveways, give way to pedestrians, and to obey traffic controls at intersections, regardless of where they ride. Young riders should also be taught to observe all traffic rules and regulations as they progress to riding on streets as well as to watch out for common types of conflicts. More information on behavioral countermeasures is available in Countermeasures That Work (Goodwin et al. 2013).

Education and enforcement efforts toward motorists should target safe driving around bicyclists and reinforce both motorists and bicyclists following traffic laws. Motorists need to understand and apply safe passing maneuvers, to watch out for bicyclists before making turns, and to obey all traffic controls.

Both children and adults should be encouraged to properly use safety helmets when riding to help prevent injuries in crashes. Helmet use is required by law statewide in North Carolina for children 15 and younger when riding on public thoroughfares.

High Frequency Crash Scenarios

Increasingly, states and local jurisdictions are seeking ways to be more proactive in addressing bicycle and pedestrian safety issues. It may help to identify common crash scenarios that might be addressed by implementing treatments or designs at many locations that can help prevent these types of crashes in the future. A systemic safety process seeks to identify common or focus crash types and to treat locations that have characteristics that have been associated with common types across the network. This can complement a ‘hotspot’ approach that seeks to treat locations where crashes have already occurred. See Appendix B for a tree diagram that illustrates this approach to begin identification of focus crash types. The diagrams have identified some common crash location and crash type scenarios for North Carolina as a whole. However, these designations may not fully reflect the development extent or density in all cases.

Further analysis at local or regional levels of these or other high crash scenarios could be used to help identify specific roadway, built environment, and population characteristics associated with these common scenarios in order to identify potential countermeasures.

Additional Resources

For complete crash type definitions, see the PBCAT Manual, Images and Tech Support Information. More information on crash types and engineering countermeasures is available from BIKESAFE, developed for the U.S Department of Transportation, Federal Highway Administration.
In order to develop countermeasures for particular locations, crash data specific to those locations would need to be examined. Identification of the specific problems and treatments should include site visits, such as through interdisciplinary roadway safety audits before any treatments are selected or implemented. See the Bicycle Road Safety Audit Guidelines and Prompt Lists for more information (Nabors et al., 2012).

For designing facilities, see the North Carolina Department of Transportation, Complete Streets Planning and Design Guidelines, and the *Guide for the Development of Bicycle Facilities* available from AASHTO, and the NACTO Urban Bikeway Design Guide, among others.

References & Resources

AASHTO (2012). *Guide for the Development of Bicycle Facilities, 4th Edition*. Available at: https://nacto.org/wp-content/uploads/2015/04/AASHTO_Bicycle-Facilities-Guide_2012-toc.pdf

BIKESAFE 2014: Bicycle Safety Guide and Countermeasure Selection System. Prepared for the Federal Highway Administration, Office of Safety. [Online] Available at: http://www.pedbikesafe.org/bikesafe/

Cross, K.D. and Fisher, D. (1977). A study of bicycle / motor vehicle accidents: identification of problem types and countermeasure approaches. Santa Barbara, California: Anacapa Sciences, Inc. [DOT HS-803-315]

Goodwin, A., Kirley, B., Sandt, L., Hall, W., Thomas, L., O'Brien, N., & Summerlin, D. (2013). *Countermeasures that work: A highway safety countermeasures guide for State Highway Safety Offices.* 7th edition. (Report No. DOT HS 811 727). Washington, DC: National Highway Traffic Safety Administration.

Harkey, D.L., Mekemson, J., Chen, M-C., and Krull, K. (2000). Pedestrian and Bicycle Crash Analysis Tool (PBCAT) User's Manual. McLean, Virginia: Office of Safety Research and Development, Federal Highway Administration. [FHWA-RD-99-192]

Harkey, D.L., Tsai, S., Thomas, L., and Hunter, W.W (2006). Pedestrian and Bicycle Crash Analysis Tool (PBCAT): Version 2.0 Application Manual, Report no. FHWA-HRT-06-089, Federal Highway Administration, Office of Safety Research and Development: McLean, VA, 241 pp. Manual and software available at: http://www.pedbikeinfo.org/pbcat_us/

Knoblauch, R.L. (1977). Causative factors and countermeasures for rural and suburban pedestrian accidents: accident data collection and analysis. Falls Church, Virginia: BioTechnology, Inc. [DOT HS-802-266]

Knoblauch, R.L., Moore, W., and Schmitz, P.R. (1978). Pedestrian accidents occurring on freeways: an investigation of causative factors, accident data collection, and analysis. Washington, DC: Federal Highway Administration. [FHWA RD-78-169/171]

Nabors, D., E. Goughnour, L. Thomas, W. DeSantis, M. Sawyer & K. Moriarty (2012). *Bicycle Road Safety Audit Guidelines and Prompt Lists.* Report No. FHWA-SA-12-018, Office of Safety, Federal Highway Administration: Washington, D.C. Available http://safety.fhwa.dot.gov/ped_bike/tools_solve/fhwasa12018/

NACTO (n.d.) NACTO Urban Bikeway Design Guide. National Association of City Transportation Officials. Available http://nacto.org/cities-for-cycling/design-guide/

National Highway Traffic Safety Administration (n.d.). Manual accident typing for pedestrian accidents: coder's handbook. Washington, DC: National Highway Traffic Safety Administration.

North Carolina Department of Transportation. (2012). Complete Streets Planning and Design Guidelines. Available http://www.completestreetsnc.org/

PBCAT. Pedestrian and Bicycle Information Center Webpage, PBCAT sponsored by the Federal Highway Administration, Available at: http://www.pedbikeinfo.org/pbcat_us/

Snyder, M.B. and Knoblauch, R.L. (1971). Pedestrian safety: the identification of precipitating factors and possible countermeasures. Vol. I and II – Appendices. Silver Spring, Maryland: Operations Research, Inc. [DOT/ NHTSA. FH-11-7312]

Appendix A - Crash Group by Bicyclist Age Group Interactions

Table 7 Crash type (group) involvement by age group of bicyclist, 2011-2015

Crash Type by Bicyclist Age	5 or less	6 to 10	11 to 15	16 to 19	20 - 29	30 - 59	60 +	Total
Backing Vehicle	5.4 % [1]	1.7 %	0.4 %	1.2 %	0.4 %	0.6 %	1.1 %	0.8 %
Bicyclist Failed to Yield - Midblock	30.4 %	26.3 %	11.3 %	9.0 %	2.1 %	2.9 %	3.2 %	6.4 %
Bicyclist Failed to Yield - Sign-Controlled Intersection	14.3 %	22.9 %	13.6 %	6.4 %	3.5 %	2.6 %	4.1 %	5.8 %
Bicyclist Failed to Yield - Signalized Intersection	0.0 %	2.4 %	7.6 %	6.0 %	6.0 %	5.0 %	3.2 %	5.3 %
Bicyclist Left Turn / Merge	0.0 %	2.0 %	7.3 %	6.2 %	2.4 %	3.1 %	6.7 %	4.0 %
Bicyclist Overtaking Motorist	0.0 %	1.4 %	0.8 %	2.6 %	3.2 %	2.1 %	3.5 %	2.3 %
Bicyclist Right Turn / Merge	0.0 %	2.0 %	2.3 %	0.8 %	0.5 %	1.0 %	0.5 %	1.0 %
Crossing Paths - Other Circumstances	3.6 %	5.8 %	6.1 %	6.2 %	6.1 %	4.7 %	4.5 %	5.5 %
Head-On	1.8 %	2.0 %	3.4 %	2.2 %	3.1 %	2.2 %	1.3 %	2.4 %
Loss of Control / Turning Error	3.6 %	3.8 %	5.4 %	5.6 %	4.9 %	4.4 %	4.3 %	4.6 %
Motorist Failed to Yield - Midblock	0.0 %	0.3 %	5.5 %	7.2 %	10.1 %	8.1 %	7.2 %	7.5 %
Motorist Failed to Yield - Sign-Controlled Intersection	0.0 %	2.7 %	6.9 %	9.6 %	10.1 %	10.1 %	12.0 %	9.5 %
Motorist Failed to Yield - Signalized Intersection	0.0 %	0.3 %	1.9 %	3.6 %	5.8 %	3.2 %	4.1 %	3.5 %
Motorist Left Turn / Merge	0.0 %	1.4 %	3.3 %	6.2 %	12.5 %	11.8 %	8.6 %	9.3 %
Motorist Overtaking Bicyclist	3.6 %	3.4 %	12.8 %	16.0 %	14.9 %	26.9 %	28.9 %	19.9 %
Motorist Right Turn / Merge	0.0 %	1.4 %	2.9 %	4.0 %	6.5 %	5.9 %	5.1 %	5.1 %
Non-Roadway	25.0 %	16.0 %	5.2 %	4.6 %	2.6 %	2.5 %	1.6 %	4.1 %
Other / Unknown - Insufficient Details	3.6 %	0.7 %	0.8 %	0.4 %	0.4 %	0.5 %	0.5 %	0.5 %
Other / Unusual Circumstances	8.9 %	0.3 %	0.2 %	0.0 %	0.8 %	0.4 %	0.0 %	0.5 %
Parallel Paths - Other Circumstances	0.0 %	3.1 %	2.5 %	2.2 %	1.8 %	1.7 %	1.3 %	1.9 %

Crash Type by Bicyclist Age	5 or less	6 to 10	11 to 15	16 to 19	20 - 29	30 - 59	60 +	Total
Parking / Bus-Related	0.0 %	0.0 %	0.0 %	0.0 %	0.3 %	0.0 %	0.0 %	0.1 %
Total	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %

Appendix B - Tree Diagram of North Carolina Rural and Municipal Bicycle Crash Scenarios

Figure 3 shows a tree diagram of bicycle crashes divided by Rural and Municipal locations. The purpose of this diagram is to highlight the most common combinations of bicycle crash location and crash type factors to aid targeting of potential further efforts to reduce these crashes. Rural locations are defined here as areas which are outside of Municipal limits and some crashes in this group may be in areas of mixed development (i.e. between 30 percent and 70 percent developed) or even urban development (for example, a subdivision outside of Municipal limits). Note that municipal crashes are those which occurred within municipal and may also not fully refle the degree of development. The data used reflect crashes which could be geolocated and mapped on the NCDOT Bicyclist and Pedestrian Crash Map. A few crashes lacked adequate information to be located. Crash types were derived through coding using PBCAT software, described in the main text.

Predominant rural bicycle-motor vehicle crash scenarios. A little more than one-fifth (21.7 percent) of crashes took place outside of Municipal limits over the five years. Among these rural crashes, 71.7 percent occurred at **non-intersection locations**, which are defined here as areas greater than 50 feet from an intersection. Roadway configuration is an important design consideration for mid-block crashes, especially in rural areas where speed limits are greater and roadways are less likely to have lighting. A large majority (84.3 percent) of these rural non-intersection crashes occurred along two-lane, undivided roadways with 16.2 percent of these crashes leading to fatal or disabling injury for a bicyclist. The most common crash types on these two-lane rural roads involve a motorist overtaking a bicyclist including situations where the motorist misjudged the space needed to pass a cyclist, the motorist failed to detect the cyclist, the cyclist swerved into the path of the overtaking motorist or it was unknown as to the actions of the motorist or cyclist. These overtaking crashes accounted for 60.1 percent of collisions on rural, two-lane roads at non-intersection locations. The most apt treatment for this crash type is space for bicyclists to ride, separated from motor vehicle traffic such as a bike lane, paved shoulder or off-road path. Intermittent facilities in areas with frequent curves or sight distance issues could also help.

Intersection and Intersection-Related crashes accounted for 26.3 percent of rural bicycle-motor vehicle collisions with the most common intersection traffic control being a stop sign (39.5 percent of such crashes). Non-roadway crashes were only 2 percent of the rural total.

Predominant urban bicycle-motor vehicle crash scenarios. More than three-fourths (78.3 percent) of crashes occurred within Municipal limits. Intersection and intersection-related crashes were the most prevalent in urban areas (58 percent) The most common intersection traffic controls were a stop and go signal (37 percent of urban intersection crashes; 28percent of these involved a bicyclist failing to yield to the signal at the intersection) and a stop sign (36.3 percent of urban intersection crashes; 45 percent of these involved a motorist failing to yield at the sign). Bicyclists may ride out or through a signalized intersection if they are not detected. Bike detection loops and bicycle signals are among treatments that could be considered. A motorist failing to yield to a cyclist occurred around 20 percent of urban, signalized intersection crashes. A motorist turning left across a through bicyclist's path was also a common crash scenario at urban, signalized intersections (16 percent). Turn lanes and separated turning phases as well as design features – including an innovative ‘protected’ intersection design, are among countermeasures that may be considered to treat this crash type. See BIKESAFE and other resources for further ideas.

When considering non-intersection crashes (38 percent of urban total), the most prevalent road configuration again was two-way, not divided (72 percent with two-lane roadways being 62 percent of these). Again, a motorist overtaking a bicyclist with was the most common crash group here with 28 percent, however this is considerably lower than in rural areas. Five percent of urban crashes occurred off a roadway.

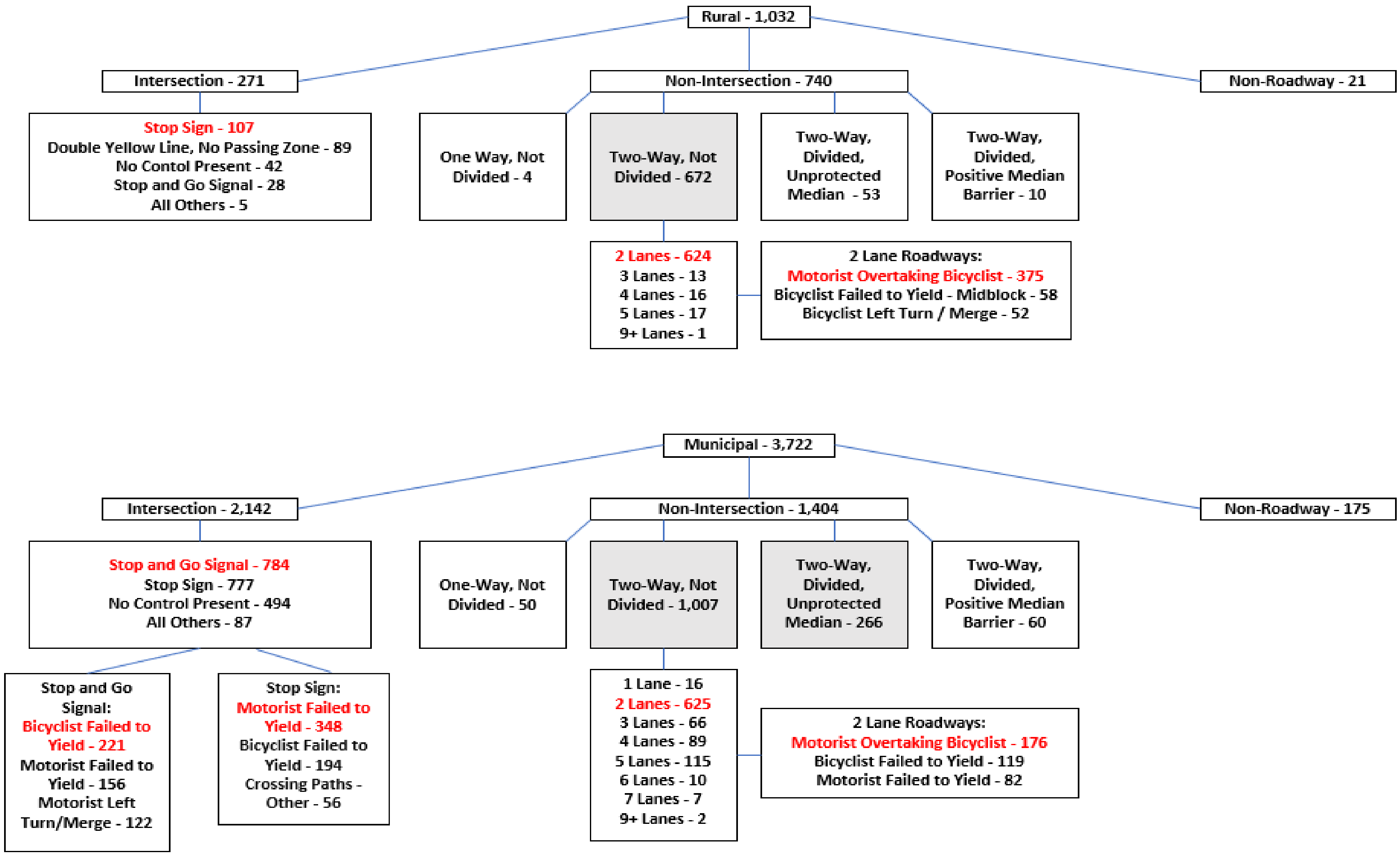


Figure 3 Tree diagram of Rural and Municipal crashes

Red font indicates common scenarios that might be a focus for a systemic approach to pedestrian safety.