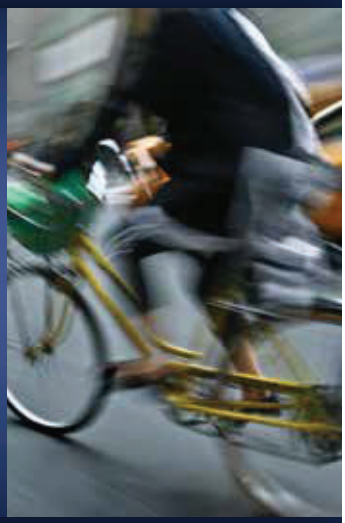
North Carolina
Bicycle Crash Types
2015 - 2019



Prepared for

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

THE UNIVERSITY OF NORTH CAROLINA
HIGHWAY SAFETY RESEARCH CENTER

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April 2021

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Introduction and Purpose

During the five-year period of 2015-2019, 4,711 bicycle-motor vehicle crashes were reported to the North Carolina Division of Motor Vehicles. A total of 107 crashes led to a cyclist fatality with another 272 resulting in one or more disabling or serious injuries for a cyclist. See the companion North Carolina Bicycle Crash Facts report for a summary of bicyclist injuries and fatalities, including 10-year trends.

This report summarizes bicycle-motor vehicle crash information developed for 2015-2019 for the entire State. For the data summarized in this report, UNC Highway Safety Research Center staff obtained copies of crash report forms submitted to NCDMV by law enforcement officers and reviewed diagrams, narrative summaries of the crash events, and other details in the reports. The study team used PBCAT version 2 software to code crash type, bicyclist position and direction, and crash location variables for each bicycle-motor vehicle crash, and also geo-coded the crash location. These data elements were combined with crash data elements already available from the State's crash database. The results of analyzing the crash group and other data elements are summarized in the tables, figures, and text in the following sections.

This report provides information about typical safety issues across the State. 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. Further safety analysis and risk assessment, diagnosis, and other procedures are necessary before implementing treatments at any location.

Background on Crash Typing

The information from the State crash report forms (DMV-349) 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 (e.g., city street, two-lane roadway, intersection location, etc.), *when* they occur (e.g., time of day, day of week, etc.), and *to whom* they occur (e.g., age of victim, gender, level of impairment). However, the data contained in the crash database provides little information about the actual sequence of events leading to crashes between bicyclists and motor vehicles. The development of effective countermeasures to help prevent and reduce the severity of these crashes is limited by this lack of detail. To address this 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 may have precipitating actions or behaviors, 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. A Federal Highway Administration (FHWA) study in the 1990s contributed to the evolution of the current PBCAT typologies with a somewhat greater focus on roadway location elements (Hunter et al., 1996). Following the FHWA study, 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 analysts using a software application to help determine crash types. Harkey et al. updated this tool in 2006 in a project also sponsored by FHWA. The 2006 version of PBCAT has been used to type crashes from 2007 - 2019.

For more information on PBCAT and crash typing, including detailed descriptions and images of typical crash scenarios, see the PBCAT webpage (https://www.pedbikeinfo.org/pbcat_us/). More resources are mentioned in the final section of this report and in the crash facts summary report.

Crash Events and Description

This report examines crash groups instead of the more specific crash types, and the relationship of other variables to these groups. Some police reports are not detailed enough to arrive at a crash type (for example, being unclear as to a motorist's or cyclist's actions in an overtaking collision) leaving a coder to select "other/unknown." In previous years, it was discovered that due to numerous specific crash types, some with very low frequency, it can be challenging to identify trends and patterns that may provide the largest targets for treatment. Additionally, many countermeasures can be developed based on the broader crash groups.

Crash Group

Table 1 shows a listing of 21 crash groups generated by the coding for each of the most recent five cash years, with their totals and percentages ordered from most to least frequent. The names of crash groups are reasonably self-explanatory, but more details as to the meaning of each crash group, and the more specific crash types associated with each group, are available on the PBCAT software web page, in the manual that accompanies in the software. For a complete description of crash-typing-related variables and other variables discussed in these summary reports, see the Bike and Pedestrian databooks provided by the Carolina Center for Health Informatics (https://cchi.web.unc.edu/data-sources-for-motor-vehicle-crash-injury-in-north-carolina/)

Motorist Overtaking Bicyclist is the most prevalent group over the study period with more than twice the frequency of the next group, *Motorist Failed to Yield – Sign-Controlled Intersection*, and the third most common group, *Motorist Failed to Yield - Midblock*. A similar number of crashes resulted from *Motorist Left Turn / Merge*, a group that most often involves motorists turning left across the path of an oncoming cyclist. Motorist overtaking crashes include situations where the motorist and cyclist were on a parallel path prior to the crash, or any turns to avoid a crash, with the motorist overtaking the cyclist from behind.

There is year-to-year variability in the frequencies and proportions of each crash group, especially those with smaller numbers. Much of this variation is likely explained by chance, but some variation is potentially attributable to changes in riding amounts, locations, and behaviors including effects of roadway treatments or education and enforcement measures. Numbers in some categories may vary somewhat due to different interpretations of information available in crash reports that is used to type the crashes.

Table 1 NC bicyclist crash group by year, 2015-2019 [1]

Crash group	2015	2016	2017	2018	2019	Total
Motorist Overtaking Bicyclist	208	193	232	173	189	995
	21.9%[1]	20.2%	23.2%	19.2%	20.8%	21.1%[2]
Motorist Failed to Yield – Sign-Controlled Intersection	71	91	88	70	98	418
	7.5%	9.5%	8.8%	7.8%	10.8%	8.9%
Motorist Failed to Yield - Midblock	95	88	64	84	80	411
	10.0%	9.2%	6.4%	9.3%	8.8%	8.7%
Motorist Left Turn / Merge	76	93	82	82	75	408
	8.0%	9.7%	8.2%	9.1%	8.3%	8.7%
Bicyclist Failed to Yield - Midblock	77	65	54	50	64	310
	8.1%	6.8%	5.4%	5.6%	7.1%	6.6%
Crossing Paths – Other Circumstances	65	60	70	58	42	295
	6.8%	6.3%	7.0%	6.5%	4.6%	6.3%
Motorist Right Turn / Merge	44	49	56	51	56	256
	4.6%	5.1%	5.6%	5.7%	6.2%	5.4%
Bicyclist Failed to Yield – Signalized Intersection	57	50	38	52	58	255
	6.0%	5.2%	3.8%	5.8%	6.4%	5.4%
Bicyclist Failed to Yield – Sign-Controlled Intersection	43	39	60	37	51	230
	4.5%	4.1%	6.0%	4.1%	5.6%	4.9%
Non-Roadway	35	47	58	44	35	219
	3.7%	4.9%	5.8%	4.9%	3.9%	4.6%
Motorist Failed to Yield – Signalized Intersection	41	29	32	45	29	176
	4.3%	3.0%	3.2%	5.0%	3.2%	3.7%
Loss of Control / Turning Error	24	35	41	26	31	157
	2.5%	3.7%	4.1%	2.9%	3.4%	3.3%
Bicyclist Left Turn / Merge	28	30	32	42	24	156
	2.9%	3.1%	3.2%	4.7%	2.6%	3.3%
Head-On	19	30	22	23	27	121
	2.0%	3.1%	2.2%	2.6%	3.0%	2.6%
Bicyclist Overtaking Motorist	21	16	20	26	16	99
	2.2%	1.7%	2.0%	2.9%	1.8%	2.1%
Parallel Paths – Other Circumstances	18	13	12	18	10	71
	1.9%	1.4%	1.2%	2.0%	1.1%	1.5%
Bicyclist Right Turn / Merge	9	9	16	6	6	46
	0.9%	0.9%	1.6%	0.7%	0.7%	1.0%
Backing Vehicle	7	4	12	7	6	36
	0.7%	0.4%	1.2%	0.8%	0.7%	0.8%
Other / Unusual Circumstances	6	9	3	4	1	23
	0.6%	0.9%	0.3%	0.4%	0.1%	0.5%
Other/Unknown – Insufficient Details	5	3	6	1	6	21
	0.5%	0.3%	0.6%	0.1%	0.7%	0.4%
Parking / Bus-Related	1	2	2	0	3	8
	0.1%	0.2%	0.2%	0.0%	0.3%	0.2%
Total	950	955	1,000	899	907	4,711[4]
	20.2%[3]	20.3%	21.2%	19.1%	19.3%	

The remaining analyses focuses on those crashes that occurred on the roadway system and excludes those where the crash location was indicated to be 'non-roadway' or was unknown (219 crashes). A smaller proportion of bicycle than pedestrian crashes are reported from parking lots and other non-trafficway areas. The remainder of this report focuses on crashes that occurred on or along trafficways that are under the purview of State and local transportation system providers.

Crash Group and Severity

An average of 8 percent of all crashes result in fatal or suspected serious injury (Table 2). *Motorist Overtaking Bicyclist* is the group that is also most highly represented among crashes resulting in fatal or suspected serious injury by a substantial margin. Over 42 percent of all crashes resulting in a fatal or suspected serious injury are in this group, nearly 5 times as many as the next most prevalent group. Other types of crashes that are over-represented for fatal and suspected serious injuries compared to all types include *Bicyclist Failed to Yield Midblock* and *Bicyclist Left Turn / Merge* (and struck by a parallel path motorist). *Loss of Control / Turning Error*, *Head-On*, *Bicyclist Right Turn / Merge* and *Other / Unusual Circumstances* were also somewhat over-represented for severe crashes.

[1] The format for this and subsequent tables, unless otherwise noted:
[1] = Row percent of yearly (column) total
[2] = Row total percent of total
[3] = Column total percent of total
[4] = Total in each table is based on cases with no missing data for that variable

Table 2 Crash group and bicyclist injury severity for on-trafficway crashes

Crash group	Fatal and Suspected Serious Injury	% of Fatal and Suspected Serious Injury	Other / Unknown Injury	Total	% of Column Total
Motorist Overtaking Bicyclist	156	42.2%	839	995	22.2%
Motorist Failed to Yield – Sign-Controlled Intersection	7	1.9%	411	418	9.3%
Motorist Failed to Yield - Midblock	6	1.6%	405	411	9.1%
Motorist Left Turn / Merge	26	7.0%	382	408	9.1%
Bicyclist Failed to Yield - Midblock	32	8.6%	278	310	6.9%
Crossing Paths – Other Circumstances	12	3.2%	283	295	6.6%
Motorist Right Turn / Merge	5	1.4%	251	256	5.7%
Bicyclist Failed to Yield – Signalized Intersection	17	4.6%	238	255	5.7%
Bicyclist Failed to Yield – Sign-Controlled Intersection	19	5.1%	211	230	5.1%
Motorist Failed to Yield – Signalized Intersection	7	1.9%	169	176	3.9%
Loss of Control / Turning Error	21	5.7%	136	157	3.5%
Bicyclist Left Turn / Merge	20	5.4%	136	156	3.5%
Head-On	20	5.4%	101	121	2.7%
Bicyclist Overtaking Motorist	5	1.4%	94	99	2.2%
Parallel Paths – Other Circumstances	5	1.4%	66	71	1.6%
Bicyclist Right Turn / Merge	7	1.9%	39	46	1.0%
Backing Vehicle	1	0.2%	35	36	0.8%
Other / Unusual Circumstances	3	0.8%	20	23	0.5%
Other/Unknown – Insufficient Details	1	0.2%	20	21	0.5%
Parking / Bus-Related	0	0.0%	8	8	0.2%
Total	370		4,122	4,492	

Trafficway Location

A slight majority of trafficway crashes occurred at an *Intersection* (45%) or within 50 feet of an intersection (*Intersection-Related;* over 8%). Around 46 percent occurred at a *Non-Intersection* location (Table 3). Crashes that occurred at *Non-Intersection* locations were apt to be more severe (64% of killed and serious injury crashes). At these locations, motorists may be traveling at higher speed, not slowing for turns or anticipating traffic controls.

Table 3 Crash location and bicyclist injury status - trafficway crashes only

Crash Location	Fatal and Suspected Serious Injury	Suspected Minor, Possible, No, and Unknown Injury	Total
Intersection	108	1,928	2,036
	29.2%	46.8%	45.3%
Intersection-Related	27	355	382
	7.3%	8.6%	8.5%
Non-Intersection	235	1,839	2,074
	63.5%	44.6%	46.2%
Total	370	4,122	4,492
	8.2%	91.8%	

The injury severity trends of different types of crashes may be affected by a combination of factors including where these crashes typically occur, mediated by other specific circumstances. Rural crashes accounted for 28 percent of the total bicycle crashes, but 55 percent of fatal and serious injury crashes are in rural areas. Table 4 has more details on trafficway crash locations and rural/urban settings.

Table 4 Bicycle crashes by rural/urban and trafficway location

Crash Location	Rural	Urban	Total
Intersection	312	1,724	2,036
	26.8%	51.8%	45.3%
Intersection-Related	69	313	382
	5.9%	9.4%	8.5%
Non-Intersection	783	1,291	2,074
	67.3%	38.8%	46.2%
Total	1,164	3,328	4,492
	25.9%	74.1%	

Bicyclist Riding Position and Direction

While 59 percent of all roadway bicycle collisions involved a bicyclist who was riding in a regular, shared *Travel Lane* (as best can be determined from reviews of crash reports) just prior to the collision, over 75 percent of crashes involving fatal or serious injury involved cyclists riding in a (shared) traffic lane (Table 5). The next most common riding position prior to the crash was riding on a *Sidewalk, Crosswalk, or Driveway Crossing* (21 percent of total crashes). These facility types tended, however, to be associated with smaller proportions of fatal or serious injuries (6.5 percent of killed and seriously injured crashes). *Non-Roadway* in this table indicates that the bicyclist was riding in a yard or other off-roadway location prior to riding into the trafficway where the crash occurred. Similarly, *Multi-Use Path* implies that the cyclist approached the roadway area from a path facility.

Table 5 Bicyclist riding position just prior to crash and bicyclist injury status - trafficway crashes

Bike Position prior to crash	Fatal and Suspected Serious Injury	Suspected Minor, Possible, No, and Unknown Injury	Total
Travel Lane	279	2,371	2,650
	75.4%	57.5%	59.0%
Sidewalk / Crosswalk / Driveway Crossing	24	939	963
	6.5%	22.8%	21.4%
Bike Lane / Paved Shoulder	29	287	316
	7.8%	7.0%	7.0%
Non-Roadway	5	70	75
	1.4%	1.7%	1.7%
Driveway / Alley	8	57	65
	2.2%	1.4%	1.4%
Multi-use Path	4	34	38
	1.1%	0.8%	0.8%
Other / Unknown	2	59	61
	0.5%	1.4%	1.3%
Unknown	19	305	324
	5.1%	7.4%	7.2%
Total	370	4,122	4,492
	8.2%	91.8%	

Nearly 30 percent of bicyclists in all crashes were riding facing against the direction of traffic prior to their crashes. When bicyclists were riding facing against the direction of adjacent traffic, they were, however, less likely to be fatally or seriously injured (Table 6). However, that is at least partly because most bicyclists (55 percent) who were cycling facing traffic, were also riding on a *Sidewalk / Crosswalk / Driveway Crossing* (see Table 7), and these collisions tend to occur at driveways and intersections where motorists are turning or entering traffic and speeds are low.

Table 6 Bicyclist riding direction relative to motorized traffic and injury status - trafficway crashes

Bike Direction	Fatal and Suspected Serious Injury	Suspected Minor, Possible, No, and Unknown Injury	Total
Facing Traffic	60	1,240	1,300
	16.2%	30.1%	28.9%
Not Applicable	24	269	293
	6.5%	6.5%	6.5%
Unknown	8	134	142
	2.2%	3.3%	3.2%
With Traffic	278	2,479	2,757
	75.1%	60.1%	61.4%
Total	370	4,122	4,492
	8.2%	91.8%	

Table 7 Bicyclist riding direction on different trafficway facility types (when known)

Bike Position	Facing Traffic	With Traffic	Not Applicable	Unknown	Total
Bike Lane / Paved Shoulder	56	207	2	3	268
	6.0%	9.6%	0.5%	2.9%	7.5%
Driveway Alley	0	2	83	0	85
	0.0%	0.1%	21.7%	0.0%	2.4%
Multi-use Path	13	5	12	0	30
	1.4%	0.2%	3.1%	0.0%	0.8%
Non-Roadway	1	1	196	0	198
	0.1%	<0.1%	51.2%	0.0%	5.5%
Other	13	29	7	1	50
	1.4%	1.3%	1.8%	1.0%	1.4%
Sidewalk / Crosswalk / Driveway Crossing	513	235	32	14	794
	54.7%	10.9%	8.4%	13.7%	22.2%
Travel Lane	342	1,679	51	84	2,156
	36.5%	77.8%	13.3%	82.4%	60.2%
Total	938	2,158	383	102	3,581
	26.2%	60.3%	10.7%	2.8%	

As shown above, sidewalk riding and multi-use paths were associated with much lower rates of fatal and serious injuries compared with those riding in travel lanes or even bike lanes or shoulders. Riding on walkways may indicate discomfort with conditions on the roadway, and it appears from these data, that riding on facilities other than shared motor vehicle lanes leads to a lower chance for a cyclist to be involved in high-injury crash groups such as *Motorist Overtaking Bicyclist* and *Head-On*.

Interactions of Crash Group with Initial Position and Direction of Bicyclist

Table 8 isolates bicycle-motor vehicle crashes where the cyclist was riding either with (the preferred direction) or facing traffic. Collisions where the cyclist's direction of travel was not applicable (for instance, exiting a driveway) or unknown are not included in this table. In the cases where direction was known or applicable, 68 percent of cyclists traveled with traffic. However, there are crash groups which are over-represented in crashes where the cyclist was travelling facing traffic. The most notable groups include types in which the motorist drove into the path of the bicyclist at sign-controlled or signalized intersections, and at midblock locations. Nearly 80 percent of head-on collisions involved the cyclists riding wrong-way. The other 20 percent involved the motorist being in the wrong lane/direction or it was unknown which party was traveling in the wrong direction.

Table 8 Crash group by bicyclist direction of travel

Crash group	Facing Traffic	With Traffic	Total
Motorist Overtaking Bicyclist	18	974	992
	1.4%	35.3%	24.5%
Motorist Failed to Yield – Sign-Controlled Intersection	227	182	409
	17.5%	6.6%	10.1%
Motorist Failed to Yield – Midblock	320	85	405
	24.6%	3.1%	10.0%
Motorist Left Turn / Merge	39	361	400
	3.0%	13.1%	9.9%
Bicyclist Failed to Yield – Midblock	59	3	62
	4.5%	0.1%	1.5%
Crossing Paths – Other Circumstances	129	116	245
	9.9%	4.2%	6.0%
Motorist Right Turn / Merge	47	208	255
	3.6%	7.5%	6.3%
Bicyclist Failed to Yield – Signalized Intersection	112	121	233
	8.6%	4.4%	5.7%
Bicyclist Failed to Yield – Sign-Controlled Intersection	48	157	205
	3.7%	5.7%	5.1%
Motorist Failed to Yield – Signalized Intersection	125	49	174
	9.6%	1.8%	4.3%
Loss of Control / Turning Error	28	118	146
	2.2%	4.3%	3.6%
Bicyclist Left Turn / Merge	5	150	155
	0.4%	5.4%	3.8%
Head-On	91	23	114
	7.0%	0.8%	2.8%
Bicyclist Overtaking Motorist	7	91	98
	0.5%	3.3%	2.4%
Parallel Paths – Other Circumstances	12	42	54
	0.9%	1.5%	1.3%
Bicyclist Right Turn / Merge	22	21	43
	1.7%	0.8%	1.1%
Backing Vehicle	6	25	31
	0.5%	0.9%	0.8%
Other / Unknown	5	18	23
	0.4%	0.7%	0.6%
Parking / Bus-Related	0	8	8
	0.0%	0.3%	0.2%
Total	1,300	2,757	4,057
	32.0%	68.0%	

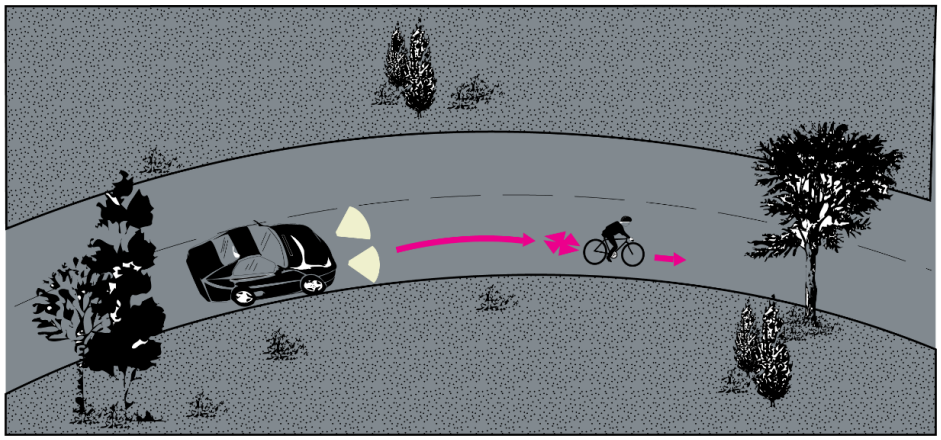
Crash groups by the initial position of the bicyclist can be found in Table 9 in Appendix A. For the most prevalent crash group, *Motorist Overtaking Bicyclist*, bicyclists were deemed to be riding in a shared Travel Lane 84 percent of the time, with only 10 percent on a Bike Lane / Paved Shoulder, less than 1 percent of cyclists were riding on a Sidewalk / Crosswalk / Driveway Crossing or a Driveway / Alley / Multi-use Path (note that two position categories were combined for the table). A Sidewalk / Crosswalk / Driveway Crossing was the initial position in 60 percent of Motorist Failed to Yield – Midblock crashes. Motorist Failed to Yield at Signalized and Sign-controlled intersections also involved significant proportions of sidewalk bicyclists. In 22 percent of Bicyclist Failed to Yield – Midblock crashes, a bicyclist rode out from a Driveway / Alley / Multi-use path.

Motorist Overtaking Bicyclist Crashes

As discussed previously, the most prevalent bicycle-motor vehicle crash group over the five-year period was a motorist overtaking a cyclist riding on a parallel path. In the vast majority of cases, the bicyclist was travelling in a shared travel lane in the same direction as other traffic per traffic rules. This crash group accounted for 995 collisions, or more than one-fifth of all reported crashes and 42 percent of bicycle crashes that led to fatal or suspected serious injuries.

Figure 1 illustrates three ways this collision can occur. These include A) the motorist failed to detect the bicyclist in time to avoid or safely pass (nighttime, curves, other traffic could obscure the motorist's view); B) the motorist misjudged the space needed to safely pass; and C) the bicyclist made a sudden swerve into the path of the overtaking motor vehicle. Often the specific scenario cannot be determined from information on the crash report. In 63 percent of the cases, none of these specific type scenarios could be determined from the information available on the crash report form, in part because 29 percent of overtaking crashes involved hit and run drivers.

A)



B)

C)

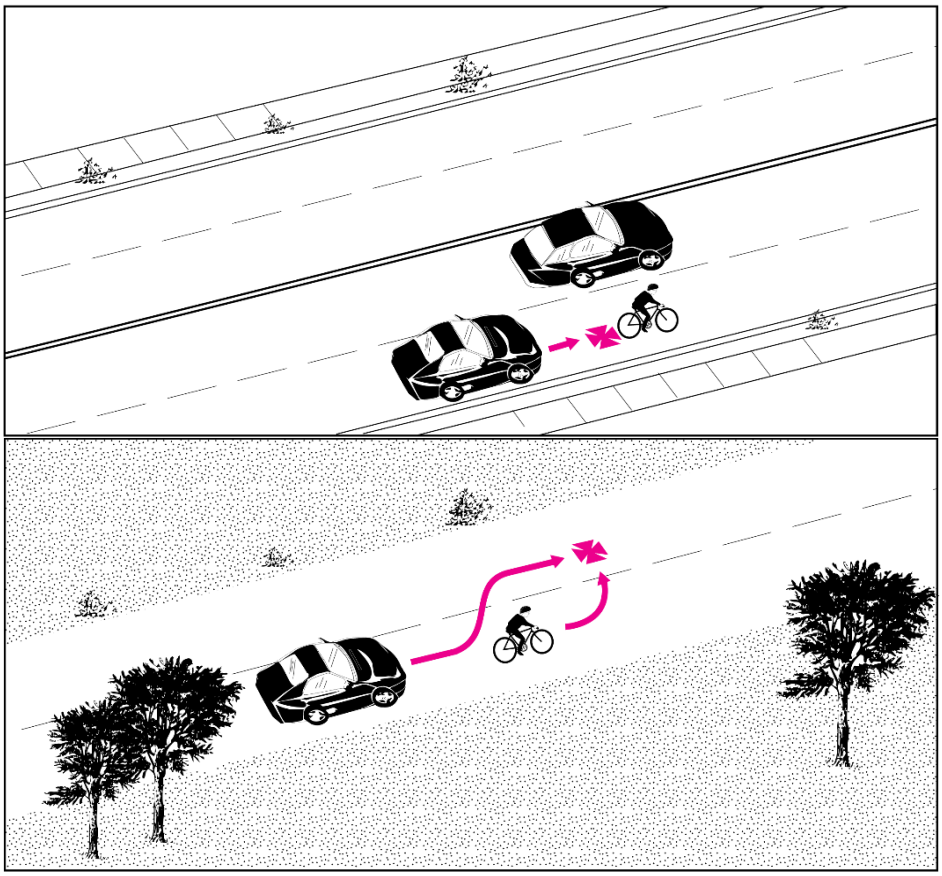


Figure 1 Three examples of how *Motorist Overtaking Bicyclist* crashes may occur

The following characteristics were noted for *Motorist Overtaking Bicyclist* crashes:

- 53 percent occurred in rural areas.
- 79 percent occurred at a *Non-Intersection* location.
- 24 percent occurred under *Dark – Roadway Not Lighted* (compared with around 9 percent for all bicycle crashes) and 13 percent *Dark – Lighted Roadway* conditions.
- 77 percent occurred on *Two-way, Not Divided* roads.
- 66 percent occurred on 40 mph and higher speed limit roads.
- 60 percent occurred on roads with *No Control Present* and 33 percent occurred on roadways with a *Double Yellow Line, No Passing Zone* control.

Motorist Overtaking Bicyclist crashes are significantly more likely to occur in rural areas compared with bicycle crashes overall (Figure 2).

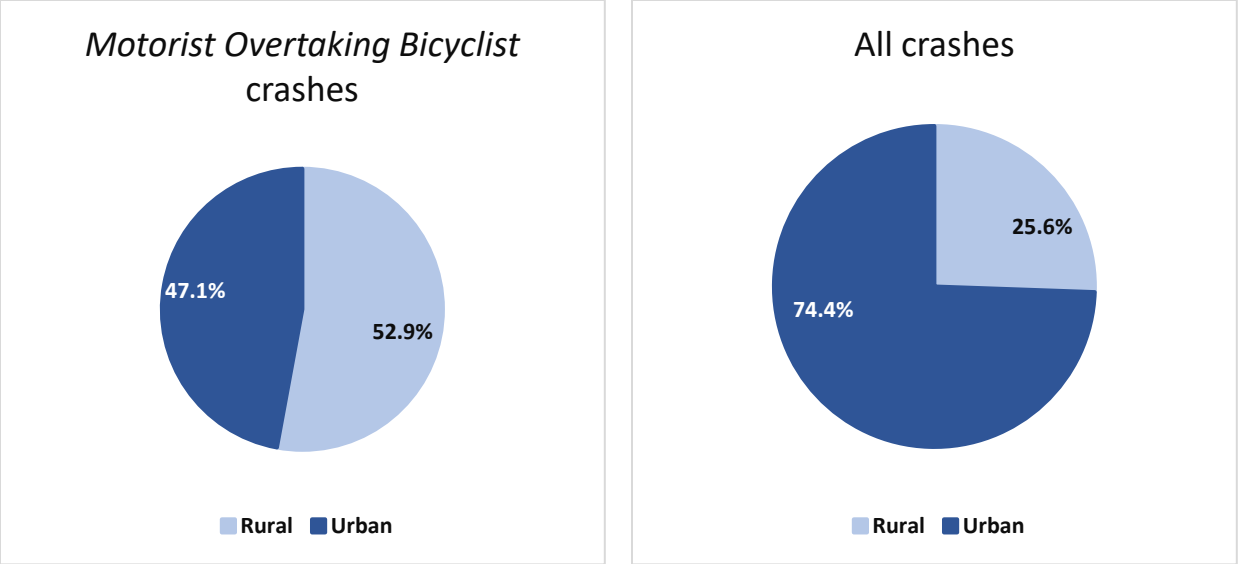


Figure 2 Percent rural/urban for *Motorist Overtaking Bicyclist* compared with all crashes

Potential Countermeasures

Regardless of inter-related factors, providing sufficient space to ride, separated from motorized traffic, is a primary countermeasure to *Motorist Overtaking Bicyclist* and other parallel path types of crashes. An example of a specific measure is well-maintained bike lanes (or separated bike lanes) that are kept clear of debris and overhanging branches. If separate lanes or paths 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. Intermittent passing lanes or wide shoulders could also be considered in some situations. Enhanced lighting may be considered in areas where bicyclists frequently ride at night. Enforcement of safe passing laws, and encouraging bicyclists to use appropriate lighting and being conspicuous at night are other potential strategies. Countermeasures resources are mentioned at the end of this report.

Motorist Overtaking Bicyclist Crash Tree

To take a closer look at some of these combinations of factors most associated with *Motorist Overtaking Bicyclist* crashes in North Carolina, the analysts developed a crash tree that identifies hierarchical combinations of prevalent crash factors that were also associated with higher rates of severe injuries for the crash group (Figure 3). The combination of bicyclists riding on two-way, undivided, two-lane roads, cycling in a travel lane, speed limits of 40 mph and higher, and with only a double yellow line as traffic control accounted for 24 percent of the total crashes of this group, but 38 percent of those killed and seriously injured (K + A in diagram) in this crash group. This suggests that locations with this combination of factors may be priorities for facility improvements. Further examination revealed that 32 percent of the all-severity crashes and 39 percent of this combination where the cyclist was killed or received disabling injuries, involved dark, unlighted roadways. Other information about where cyclists ride, and the specific locations of some of these crashes may be examined to look for potential ways to provide better facilities.

Motorist Overtaking Bicyclist crash type prevalence was compared with all crash types in counties across the state by frequency and by population-based rates. These data and maps are presented in Appendix B and show that a few counties are over-represented for this type based on population. These results can be compared with similar maps showing where all bicycle crashes are concentrated (and also included in Appendix B). These differences may reflect the types of roads and riding conditions in those counties as well as exposure (or amounts of riding, and other behaviors) by bicyclists and motorists. Further, more in-depth studies would be needed to identify the specific risk factors that are associated with increased risk of this type (or other types) of crashes.

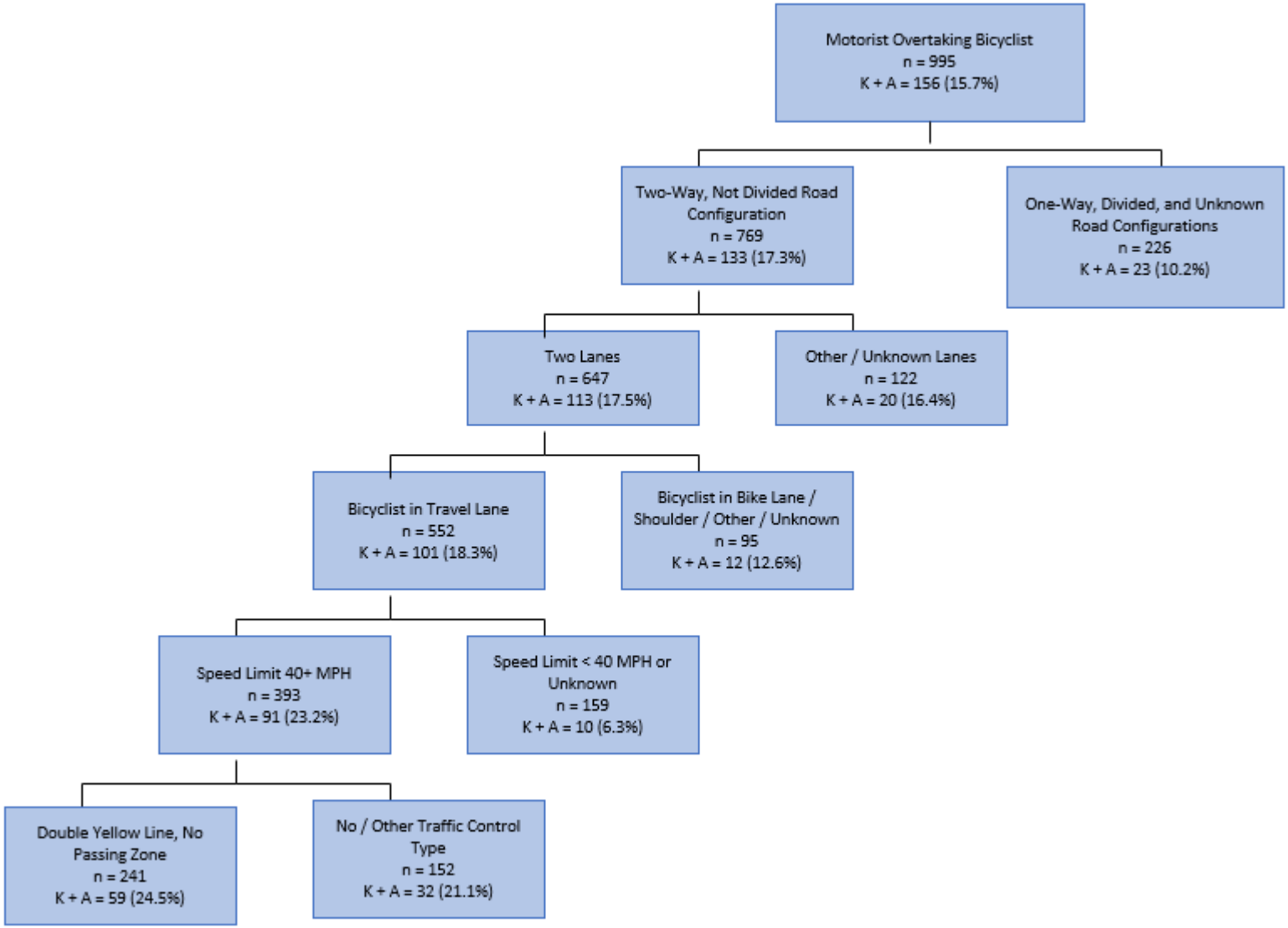


Figure 3 Tree Diagram of interacting roadway and bicyclist riding position variables with crash frequencies and frequencies of killed (K) and disabling injury (A)

Additional Resources

NC pedestrian and bicycle crash data are available in GIS format for local agencies and their partners to explore (on the website) https://www.arcgis.com/home/item.html?id=b4fcdc266d054a1ca075b60715f88aef or for download and more in-depth analysis.

Complete documentation of the variables available in the above database, as well as variables analyzed and discussed in these summaries is available from the Carolina Center for Health Informatics website (https://cchi.web.unc.edu/data-sources-for-motor-vehicle-crash-injury-in-north-carolina/). The PBCAT Manual, Images and Tech Support Information website (https://www.pedbikeinfo.org/pbcat_us/manual.cfm) also provides more information, including images of many of the crash types.

In order to develop countermeasures for particular locations, crash and other data specific to those locations should be examined. Diagnosis of the specific problems and treatments should include professional site visits during different times of day and night, and collection of data and input from the community. This process may be done through a formal interdisciplinary road safety audit, which is an ideal way to gather insights on the safety issues on a particular road or area. For more information on analyzing and diagnosing safety problems and identifying potential treatments, see the following resources:

- *North Carolina Pedestrian and Bicycle Road Safety Assessment Guide* (Thomas et al. 2018) – Available at: https://connect.ncdot.gov/projects/research/RNAProjDocs/RSA_Guide_FINAL.pdf
- *Pedestrian and Bicyclist Road Safety Audit (RSA) Guide* (Goughnour, et al. 2020) – Available at: (https://safety.fhwa.dot.gov/ped_bike/tools_solve/docs/fhwasa20042.pdf)
- *Guidance to Improve Pedestrian and Bicyclist Safety at Intersections* (Sanders, et al., 2020) – Available at: - https://www.nap.edu/catalog/25808/guidance-to-improve-pedestrian-and-bicyclist-safety-at-intersections and other NCHRP reports.
- BIKESAFE interactive tool and website, developed for the U.S. Department of Transportation, Federal Highway Administration – Available at: http://www.pedbikesafe.org/bikesafe/index.cfm)

For designing facilities, several resources include:

- North Carolina Department of Transportation's Complete Streets webpage – Available at: https://www.ncdot.gov/divisions/bike-ped/Pages/complete-streets.aspx
- AASHTO Guide for the Development of Bicycle Facilities (2012) – Available from AASHTO
- NACTO Urban Bikeway Design Guide – Available at: https://nacto.org/publication/urban-bikeway-design-guide/

Resources to help agencies improve interactions and safe behaviors among road users include:

- *Advancing Pedestrian and Bicyclist Safety: A Primer for Highway Safety Professionals* (Brookshire et al., 2016) – Available from NHTSA's website: https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/812258-peds_bike_primer.pdf
- Watch for Me - NC webpage – Available at: https://www.watchformenc.org/

- NHTSA's *Countermeasures That Work*, which is updated frequently with information on effective behavior change programs.

For assistance with safety planning and assessment see *How to Develop a Pedestrian and Bicycle Safety Action Plan* (Gelinne et al., 2017) – Available at: https://safety.fhwa.dot.gov/ped_bike/ped_focus/docs/fhwasa17050.pdf

References

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]

Gelinne, D., Thomas, L. Lang, K., Zegeer, C., Goughnour, E. (2017). *How to Develop a Pedestrian and Bicycle Safety Action Plan.* Report No. FHWA-SA-17-050, Federal Highway Administration: Washington, D.C. Available https://safety.fhwa.dot.gov/ped_bike/ped_focus/docs/fhwasa17050.pdf

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/

Hunter, W.W., W.E. Pein, J.C. Stutts, and C.L. Cox (1996). *Pedestrian and Bicycle Crash Types of the Early 1990's*. Report No. FHWA-RD-95-163, Federal Highway Administration, McLean, VA.

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. Complete Streets Website, last updated 9/1/2020. Available at: https://www.ncdot.gov/divisions/bike-ped/Pages/complete-streets.aspx

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

Richard, C.M., Magee, K., Bacon-Abdelmoteleb, P., & Brown, J.L. (2018, April). *Countermeasures that work: A highway safety countermeasure guide for State Highway Safety Offices, Ninth Edition* (Report No. DOT HS 812 478). Washington, DC: National Highway Traffic Safety Administration.

Sanders, R., et.al. (2020). *Guidance to Improve Pedestrian and Bicyclist Safety at Intersections*. (NCHRP Research Report 926). Retrieved from Transportation Research Board website: https://trid.trb.org/view/1706222

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]

Thomas, L., D. Gelinne, K. Brookshire, C. Sundstrom, and S. LaJeunesse (2018). *North Carolina Pedestrian and Bicycle Road Safety Assessment Guide.* NC Department of Transportation, Project RP 2016-14. Available at: https://connect.ncdot.gov/projects/research/RNAProjDocs/RSA_Guide_FINAL.pdf

Watch for Me-NC. NCDOT, UNC Highway Safety Research Center, and NHTSA. Website. Access at: https://www.watchformenc.org/

Appendix A – Where Bicyclists were Riding Before Crash

Table 9 Crash group by initial position of bicyclist

Crash Type	Travel Lane	Bike Lane / Paved Shoulder	Sidewalk/ Crosswalk/ Driveway Crossing	Driveway /Alley or Multi-use Path	Non-Roadway area	Other or Unknown	Total
Motorist Overtaking Bicyclist	837	97	3	2	0	56	995
	84.1% [i]	9.7%	0.3%	0.2%	0.0%	5.6%	22.1% [ii]
Motorist Failed to Yield – Sign-Controlled Intersection	209	23	153	4	0	29	418
	50.0%	5.5%	36.6%	1.0%	0.0%	6.9%	9.3%
Motorist Failed to Yield - Midblock	99	47	247	5	0	13	411
	24.1%	11.4%	60.1%	1.2%	0.0%	3.2%	9.1%
Motorist Left Turn / Merge	277	32	65	8	0	26	408
	67.9%	7.8%	15.9%	2.0%	0.0%	6.4%	9.1%
Bicyclist Failed to Yield - Midblock	89	3	17	69	69	63	310
	28.7%	1.0%	5.5%	22.3%	22.3%	20.3%	6.9%
Crossing Paths - Other Circumstances	147	12	86	5	1	44	295
	49.9%	4.1%	29.9%	1.7%	0.3%	14.9%	6.5%
Motorist Right Turn / Merge	89	53	88	1	0	25	256
	34.8%	20.7%	34.4%	0.4%	0.0%	9.8%	5.7%
Bicyclist Failed to Yield - Signalized Intersection	107	4	103	1	0	40	255
	42.0%	1.6%	40.4%	0.4%	0.0%	15.7%	5.7%
Bicyclist Failed to Yield – Sign-Controlled Intersection	204	1	18	2	0	5	230
	88.7%	0.4%	7.8%	0.9%	0.0%	2.2%	5.1%
Motorist Failed to Yield – Signalized Intersection	34	3	108	2	2	27	176
	19.3%	1.7%	61.4%	1.1%	1.1%	15.3%	3.9%
Loss of Control / Turning Error	117	2	23	2	3	10	157
	74.5%	1.3%	14.6%	1.3%	1.9%	6.4%	3.5%
Bicyclist Left Turn / Merge	125	14	7	0	0	10	156
	80.1%	9.0%	4.5%	0.0%	0.0%	6.4%	3.5%
Head-On	97	10	2	0	0	12	121
	80.2%	8.3%	1.7%	0.0%	0.0%	9.9%	2.7%
	89	7	0	0	0	3	99

Crash Type	Travel Lane	Bike Lane / Paved Shoulder	Sidewalk/ Crosswalk/ Driveway Crossing	Driveway /Alley or Multi-use Path	Non-Roadway area	Other or Unknown	Total
Bicyclist Overtaking Motorist	89.9%	7.1%	0.0%	0.0%	0.0%	3.0%	2.2%
Parallel Paths - Other Circumstances	28	4	30	1	0	8	71
	39.4%	5.6%	42.3%	1.4%	0.0%	11.3%	1.6%
Bicyclist Right Turn / Merge	35	2	4	1	0	4	46
	76.1%	4.3%	8.7%	2.2%	0.0%	8.7%	1.0%
Other and Unknown Circumstances	29	1	4	0	0	10	44
	65.9%	2.3%	9.1%	0.0%	0.0%	22.7%	1.0%
Backing Vehicle	31	0	5	0	0	0	36
	86.1%	0.0%	13.9%	0.0%	0.0%	0.0%	0.8%
Parking / Bus-Related	10	0	1	0	0	10	21
	47.6%	0.0%	4.8%	0.0%	2.0%	47.6%	0.5%
Total	2,653	315	964	103	75	395	4,505
	58.9%	7.0%	21.4%	2.3%	1.7%	8.8%	100.0%
[i] = col. % of row total; [ii] = row total % of total							

Appendix B – Bicycle-Motor Vehicle Crashes by County

These North Carolina maps visualize the total number of bicycle-motor vehicle by county and the standard deviation of the average annual rate per 10,000 residents for all crashes (Figure 4 and Figure 5). The total number of *Motorist Overtaking Bicyclist* crashes and their average annual rate per 10,000 residents are also visualized (Figure 6 and Figure 7).

More populous, urbanized counties have the highest total number of all crashes (Table 10).[2] This is generally true when considering *Motorist Overtaking Bicyclist* crashes as well, with one exception being Robeson County, which is more rural (Table 11). Robeson County also has the highest proportion of motorist overtaking crashes of any in the Top 10 with close to 42 percent of all crashes being this category.

Table 12 shows the three counties which have a rate of greater than 1.5 standard deviations from the median for total crashes, they are in the coastal region. When considering *Motorist Overtaking Bicyclist* crashes, eight counties have standard deviations greater than 1.5, all but one (Scotland) are in the coastal plain (Table 13).

Table 10 Top 10 NC counties for all bicycle crashes

County	Total Bicycle Crashes
Mecklenburg	720
Wake	560
New Hanover	330
Guilford	284
Durham	244
Cumberland	166
Pitt	148
Forsyth	142
Buncombe	118
Dare	110

Among the top 10 counties for frequency of motorist overtaking crashes, some have high proportions of this type compared to others in the list Table 11.

[2] There may have been some anomalies in reporting of data for at least one urban jurisdiction. In 2016, additional efforts were undertaken to identify all possible bicycle-motor vehicle crashes to help overcome these reporting differences but reported crash data are always subject to accuracy and completeness issues.

Table 11 Top 10 NC counties for *Motorist Overtaking Bicyclist* crashes

County	Total Motorist Overtaking Bicyclist Crashes	Proportion of Total Crashes in County
Mecklenburg	94	13.1%
Wake	84	15.0%
Durham	45	18.4%
New Hanover	45	13.6%
Guilford	40	14.1%
Robeson	32	41.6%
Forsyth	29	20.4%
Cumberland	27	16.3%
Pitt	26	17.6%
Buncombe	25	21.2%

Table 12 Counties with standard deviation > 1.5 for all crashes

County	Average Annual Rate per 10,000 Residents	Standard Deviation
Dare	5.94	> 2.5
New Hanover	2.88	> 2.5
Carteret	1.77	1.5 – 2.5

Table 13 Counties with standard deviation > 1.5 for *Motorist Overtaking Bicyclist* crashes

County	Average Annual MOT Rate per 10,000 Residents	Standard Deviation
Hyde	0.74	> 2.5
Scotland	0.61	> 2.5
Pamlico	0.60	> 2.5
Lenoir	0.56	1.5 – 2.5
Pasquotank	0.50	1.5 – 2.5
Washington	0.49	1.5 – 2.5
Robeson	0.49	1.5 – 2.5
Craven	0.46	1.5 – 2.5

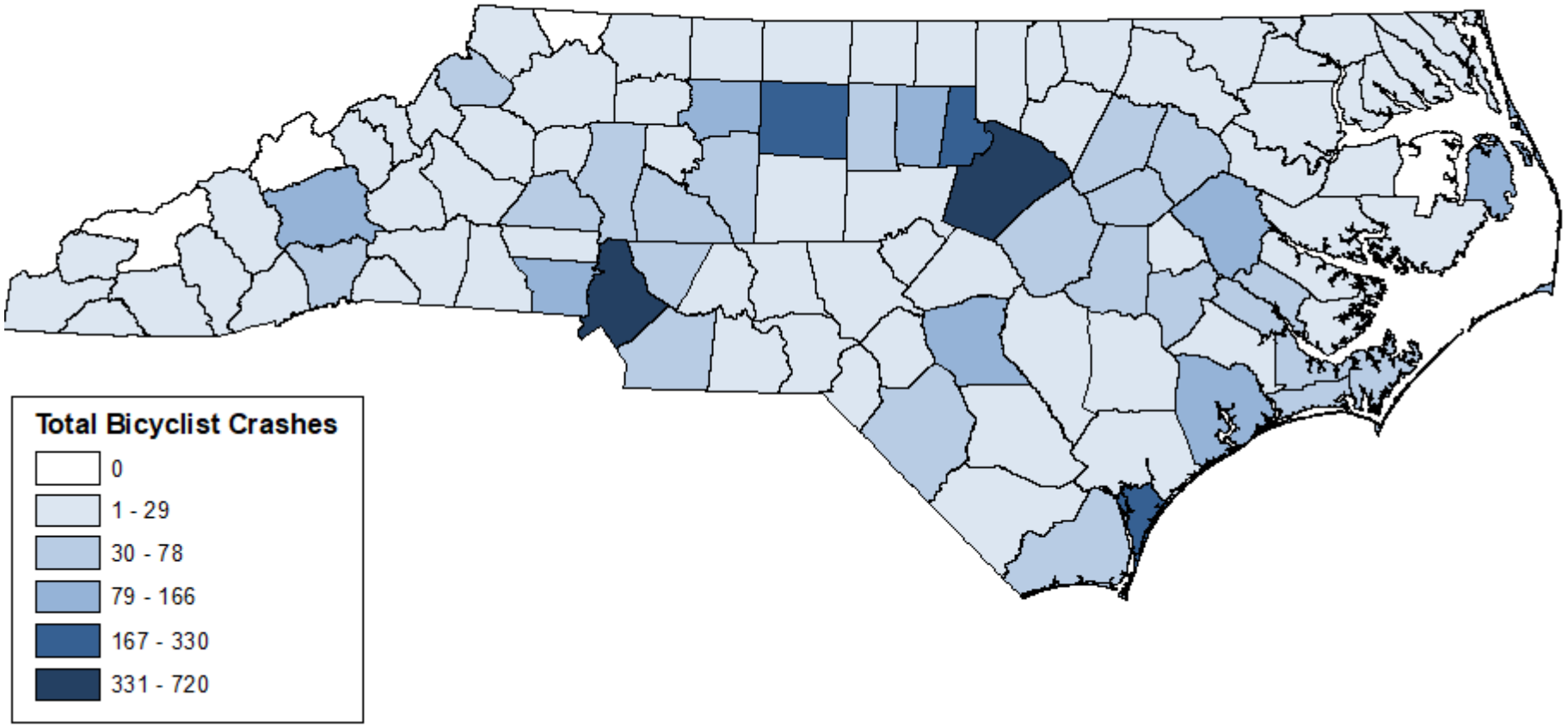


Figure 4 Total bicycle crashes by NC County – classified using Natural Breaks (Jenks) method

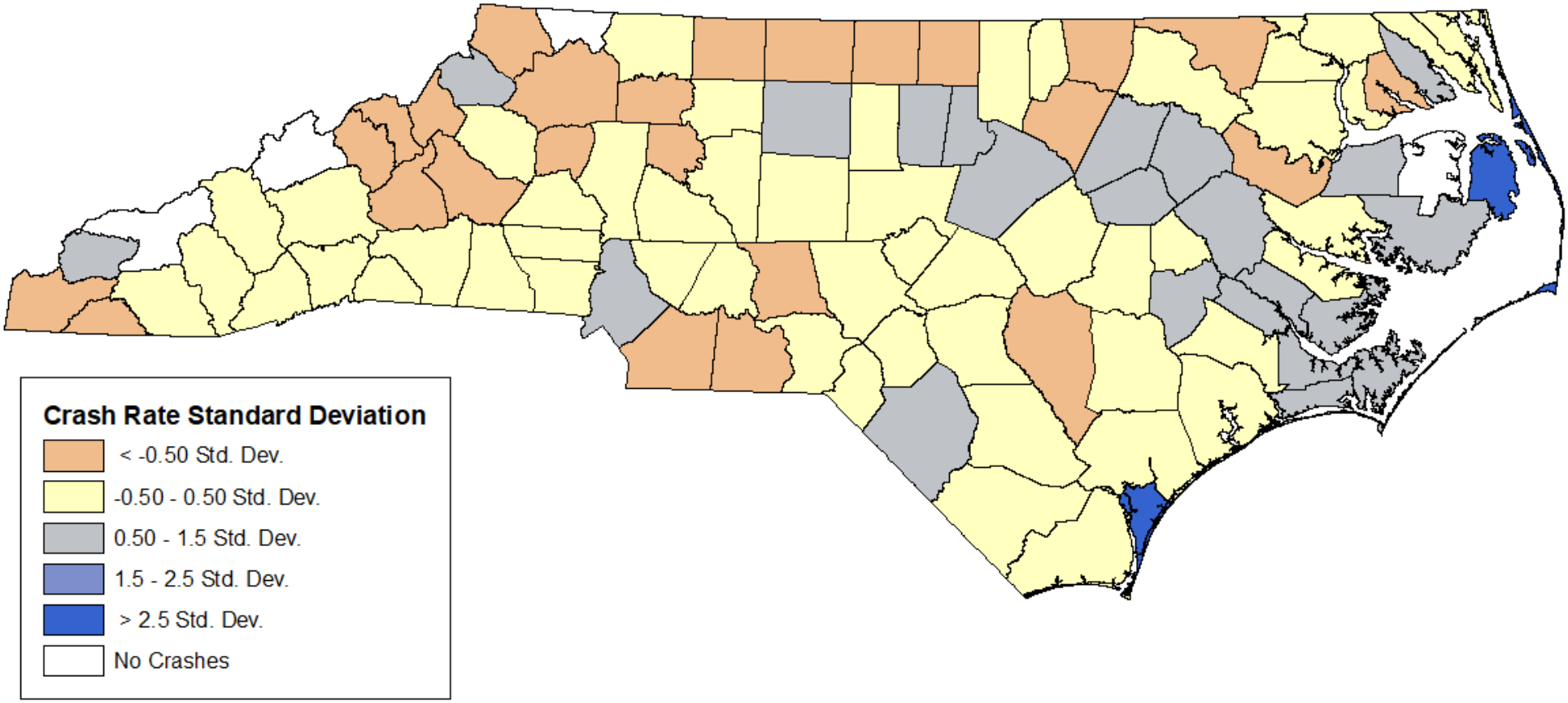


Figure 5 Standard deviation of average annual rate of total bicycle crashes per 10,000 residents

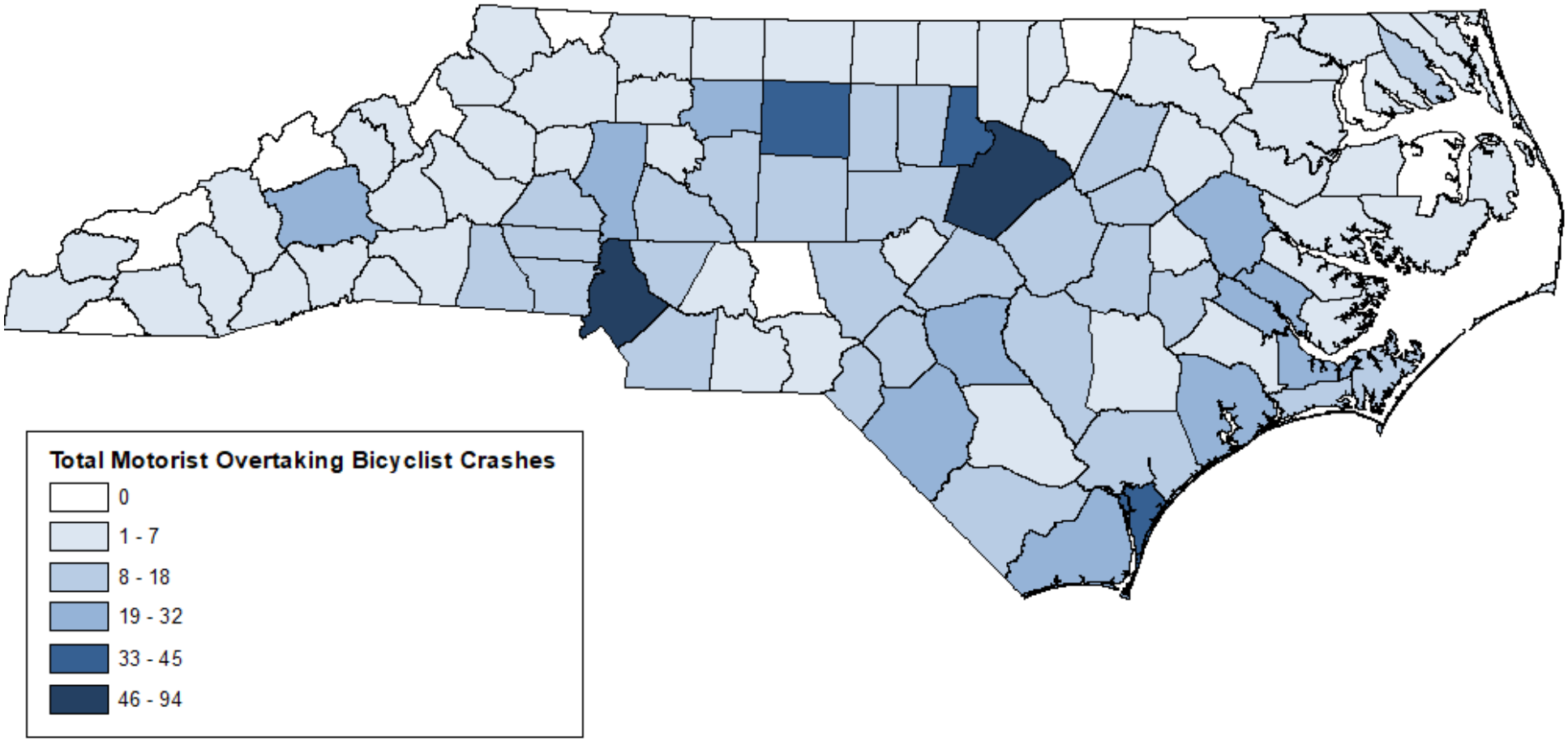


Figure 6 *Motorist Overtaking Bicyclist* crashes by County

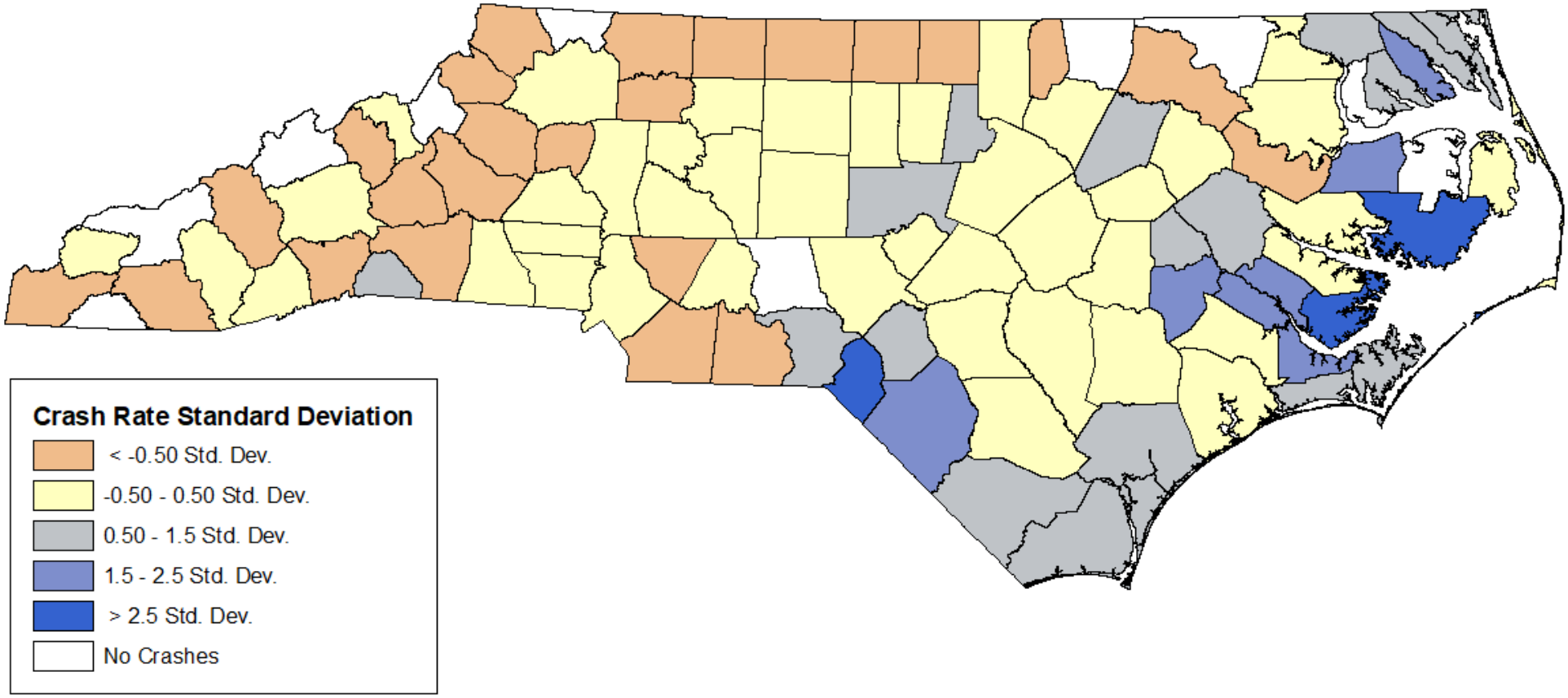


Figure 7 Standard deviation for *Motorist Overtaking Bicyclist* crashes per 10,000 residents

Figure 8 Map of NC Counties