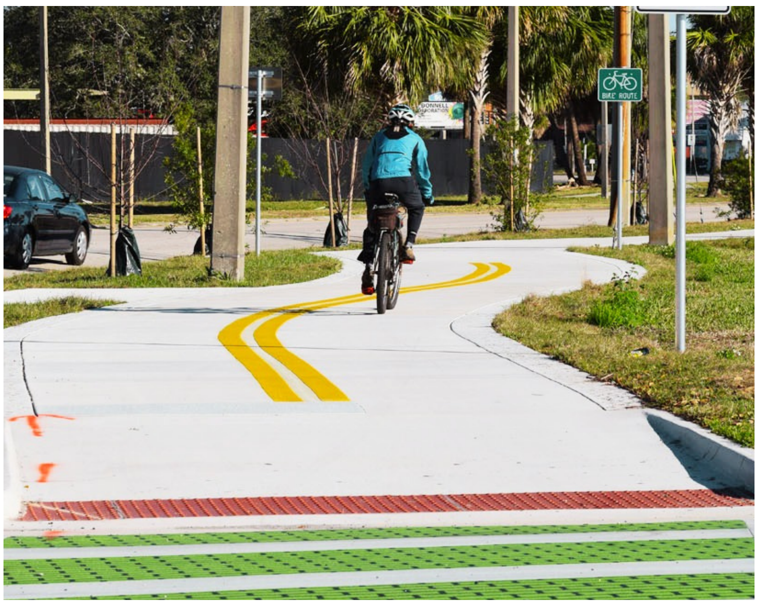
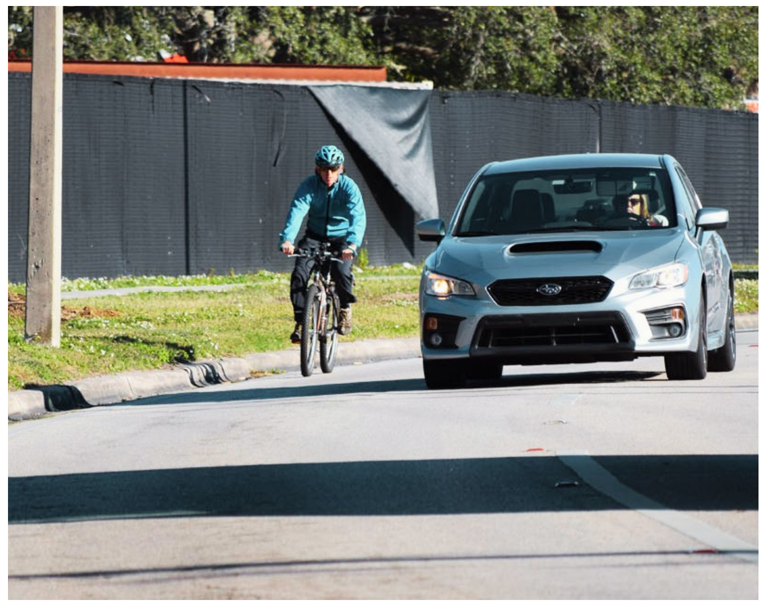
metroplan orlando
A REGIONAL TRANSPORTATION PARTNERSHIP

# Bicycling Facilities, Crash Types & Bicyclist Risk





# Bicycling Facilities, Crash Types, & Bicyclist Risk

White Paper by: Mighk Wilson, Senior Transportation Planner at MetroPlan Orlando
MWilson@MetroPlanOrlando.org | 407-481-5672 | Published July 2021

## Background and Need for Improved Research

In recent years there have been numerous studies showing lower overall crash rates for bikeways, and it is generally assumed that improved motorist behavior is primarily responsible for those reductions; but questions remain on the relative crash risk for bicyclists using bicycle lanes or shared use sidepaths compared to regular travel lanes and sidewalks. Such reports have not differentiated between motorist-caused crashes and bicyclist-caused, nor have they examined which crashes might have been relevant to the presence or absence of a bikeway. Making such distinctions entails analyzing and cataloging the relevant motorist and bicyclist behaviors contributing to the crashes. Having a more comprehensive understanding of bicyclist crash risks will help planners and engineers select the best treatment for a given environment, help educators provide more effective training to bicyclists and motorists, and help lawmakers craft the most appropriate statutes governing bicyclist and motorist behavior.

HAVING A MORE COMPREHENSIVE UNDERSTANDING OF BICYCLIST CRASH RISKS WILL HELP PLANNERS & ENGINEERS ***SELECT THE BEST TREATMENT*** FOR A GIVEN ENVIRONMENT, HELP EDUCATORS ***PROVIDE MORE EFFECTIVE TRAINING*** TO BICYCLISTS AND MOTORISTS, AND HELP LAWMAKERS ***CRAFT THE MOST APPROPRIATE STATUTES*** GOVERNING BICYCLIST AND MOTORIST BEHAVIOR.

In order to get a comprehensive understanding of how bicyclist/motorist crashes occur and how different bikeway types might mitigate (or aggravate) such crashes, we need to classify crashes by bicyclist position and direction, and by the initiating motorist or bicyclist actions that lead to crashes. This "crash typing" method got its start in 1974 with "Identifying Critical Behavior Leading to Collisions Between Bicycles and Motor Vehicles" by Ken Cross.[i] The method has been improved since then by the Federal Highway Administration and the University of North Carolina Highway Safety Research Center, with the development and improvement of the Pedestrian & Bicyclist Crash Analysis Tool (PBCAT)[ii] during the 1990s and early 2000s. In 2017, the University of Florida integrated the PBCAT crash typology and typing process into its Signal Four Analytics crash database for the State of Florida. MetroPlan Orlando (the Metropolitan Planning Organization for Orange, Osceola, and Seminole Counties in Central Florida) has used this system to produce a local database of over 7,300 bicyclist and over 8,200 pedestrian crashes as of the end of 2019.

Table 1: Comparison With Prior Studies

| Study | Location/Years | Total Crashes | Overtaking Motorist | Motorist Right Hook | Motorist Left Cross | Motorist Drive-Out | Wrong-Way Bicyclist |
|---|---|---|---|---|---|---|---|
| State of California: Ken Cross | Santa Barbara, CA 1971-1973 | 384 | 3.3% | 7.7% | 12.3% | 13.5% | 14.3% |
| MetroPlan Orlando | Orlando Metro Area 2003-2004 | 773 | 7.5% | 3.3% | 2.4% | 20.9% | 6.4% |
| MetroPlan Orlando | Orlando Metro Area 2011-2017 | 4,956 | 6.2% | 5.0% | 4.1% | 38.6% | 4.6% |
| MetroPlan Orlando | This Study: 10 Bicycle Lane & 10 Control Streets 2007-2016 | 560 | 1.8% | 8.4% | 3.2% | 56.1% | 7.9% |

Table 1 illustrates the percentages of the crash types featured extensively later in this study. Comparisons between this study and earlier ones are challenging due to varying scopes.

The Cross/Santa Barbara study covered a single municipality, while the 2003-2004 and 2011-2017 MetroPlan Orlando studies covered an entire metropolitan area including high-speed rural roads. Santa Barbara prohibited sidewalk bicycling while metro Orlando does not. The Orlando metro area also completed many miles of missing sidewalks from the 1990s to the present day, and all of these included curb ramps to accommodate wheelchair users, while curb ramps were quite rare in the early 1970s. So sidewalk bicycling would be far more practical, attractive and prevalent in the Orlando time and area compared to Santa Barbara. Santa Barbara has significant grades compared to flat Orlando.

These differing circumstances may explain the differences in crash type percentages. Overtaking crashes are more likely on rural roads, which are more common in the Orlando area studies. Left cross crashes are more likely with higher-speed cyclists, such as those coming down hills, which is far more likely in Santa Barbara. Motorist drive-out crashes are more likely for sidewalk bicyclists, which we see both when comparing Orlando to Santa Barbara, and when looking at how sidewalk crashes increased in the Orlando area over time. Sidewalk crashes in the Orlando area increased from 60% in 2003-2004 to 64% for the period 2011-2017. A less comprehensive metro Orlando study from 1993-1994 estimated 36% of crashes involved sidewalk bicyclists. Bicyclists who would have been cycling against traffic on the roadway in Santa Barbara would have likely been cycling on the sidewalk facing traffic in metro Orlando, shifting the crash type from Wrong-Way Bicyclist to Motorist Drive-Out.

In a 2003 paper in Injury Prevention, Peter Jacobsen found a correlation between higher bicyclist (and pedestrian) exposure levels and lower crash rates. In the discussion section, Jacobsen wrote: *"It seems unlikely that people walking or bicycling obey traffic laws more or defer to motorists more in societies or time periods with greater walking and bicycling. Indeed it seems less likely, and hence unable to explain the observed results. Adaptation in motorist behavior seems more plausible and other discussions support that view."* No causal evidence was given to support this assumption, and yet it has become a consensus view among some bikeway proponents. The causal and exposure data in this study can be used to test this assumption.

By targeting crash types that are most relevant to the characteristics of bikeways and bicyclists, transportation planners and engineers can get a much clearer understanding of how and why crash rates increase or decrease, which should inform improvements to bikeway design and to education of bicyclists and motorists.

## This Study

This report describes a study of ten (10) streets with bicycle lanes and ten control streets without bicycle lanes. Ten years of crash data was used (five years would have been statistically inadequate). Bicyclists were counted along all twenty streets, recording both bicyclist position (travel lane, bicycle lane, sidewalk) and direction (with the flow of traffic or against the flow). From this data, we were able to estimate bicyclist crash risk by crash type and position. Bicyclist average travel speeds for the three different positions were also calculated.

THIS REPORT DESCRIBES A STUDY OF 10 YEARS OF CRASH DATA ON 10 STREETS WITH BICYCLE LANES, 10 CONTROL STREETS WITHOUT BICYCLE LANES, & 5 SHARED USE SIDEPATHS

Five (5) shared use sidepaths adjacent to roadways were also studied. As with the bicycle lane and control streets, these paths have all been in place for over ten years, and ten years of crash data was collected and analyzed.

This report will detail the data collection methods, analysis and findings, and discuss ramifications for street design, bicyclist training, and laws governing bicyclist roadway use.

### Data Collection and Raw Numbers

#### *Study Streets*

Ten (10) streets with bicycle lanes in place for at least ten years were studied from across the Orlando metropolitan area. The streets varied by numbers of lanes, posted speeds, and adjacent land uses. A control street was identified for each bicycle lane street, chosen to be as similar as possible based on number of lanes, posted speed, land use, median type, and proximity.

Table 2 describes the characteristics of the bicycle lane streets and control streets. As more than 90% of bicyclist/motorist crashes involve one participant crossing the path of the other, either perpendicularly or while turning, the numbers of intersections and commercial driveways is of particular importance. The control streets had on-average only 9% fewer intersections and commercial driveways per mile than the bicycle lane streets. While the total lengths of the bicycle lane streets were 14% longer than the control streets, the calculations for bicyclist exposure and risk account for this by multiplying the bicyclist counts by the study street lengths.

### Table 2: Study Streets

| Bicycle Lane Streets in Gray | | | | | Control Streets in White | | | |
|---|---|---|---|---|---|---|---|---|
| Street Name | Limits | | # of Thru Lanes | Median Type | Posted Speed (MPH) | Length (Miles) | Intersections & Commercial Driveways per Mile | Land Use |
| Alafaya | Chapman | SR 50 | 6 | Raised | 45 | 5.1 | 14.3 | Medium-Intensity Commercial & Medium-Density Residential |
| University | Semoran | Alafaya | 6 | Raised | 45 | 7 | 12.4 | High-Intensity Commercial & Low-Density Residential |
| W Colonial | Hiawassee | Tampa | 6 | Raised | 45 | 4.8 | 32.5 | Medium-Intensity Commercial |
| Lee | US 441 | I-4 | 6 | Raised | 45 | 2.4 | 29.2 | Medium-Intensity Commercial & Low-Density Residential |
| Orange | Pineloch | Prince | 4 | Raised/Center Turn Lane | 45 | 3.3 | 27.0 | Medium-Intensity Commercial |
| Curry Ford | Bumby | Semoran | 4 | Raised/Center Turn Lane | 40 | 2.9 | 33.1 | Medium-Intensity Commercial & Low-Density Residential |
| Pine Hills | Silver Star | Sun Ray | 4 | Center Turn Lane | 45 | 1.9 | 15.3 | Low-Intensity Commercial & Low-Density Residential |
| Pine Hills | Beggs | Silver Star | 4 | Center Turn Lane | 45 | 2.6 | 17.3 | Medium-Intensity Commercial & Low-Density Residential |
| Columbia | Dyer | Central | 2 | Center Turn Lane | 40 | 2 | 17.5 | Low-Intensity Commercial & Medium-Density Residential |
| Carroll | E of John Young | S Orange Blossom | 2 | Center Turn Lane | 35 | 0.63 | 23.8 | Low-Intensity Commercial & Low-Density Residential |
| Edgewater | Par | Lakeview | 2 | Center Turn Lane | 35 | 1.7 | 44.7 | Medium-Intensity Commercial & Medium-Density Residential |
| Orange | Princeton | Virginia | 2 | None | 30 | 0.6 | 30.0 | Medium-Intensity Commercial |
| Glenridge | Laurel | Lakemont | 2 | None | 30 | 1.2 | 10.0 | Low-Density Residential, School |
| Kaley | Orange | Fern Creek | 2 | None | 25 | 1.1 | 13.6 | Low-Density Residential, School |
| Par | Edgewater | Formosa | 2 | None | 30 | 0.75 | 18.7 | Low-Intensity Commercial & Low-Density Residential |
| Clay | Par | Fairbanks | 2 | None | 30 | 0.75 | 28.0 | Low-Intensity Commercial & Low-Density Residential |
| Lakemont | Dundee | Glenridge | 2 | None | 30 | 1.1 | 11.8 | Low-Intensity Commercial, Low-Density Residential, School |
| Winter Park | Glenridge | Corrine | 2 | None | 30 | 0.9 | 21.1 | Low-Intensity Commercial, Low-Density Residential, School |
| Livingston | Garland | Maguire | 2 | None/ Center Turn Lane | 30 | 2.5 | 14.0 | Cen. Bus. District & Medium-Density Residential |
| Summerlin | Colonial | Briercliff | 2 | None | 30 | 2 | 16.5 | Cent. Bus. District & Medium-Density Residential |
| **Averages** | | | | | **Posted Speed** | **Length** | **Inters. & Driveways per Mile** | |
| Bicycle Lane Streets | | | | | 37.5 | 2.4 | 20.6 | |
| Control Streets | | | | | 35.5 | 2.1 | 22.5 | |
| % Difference | | | | | 5% | 14% | 9% | |

*Crash Data and Bicyclist Positions*

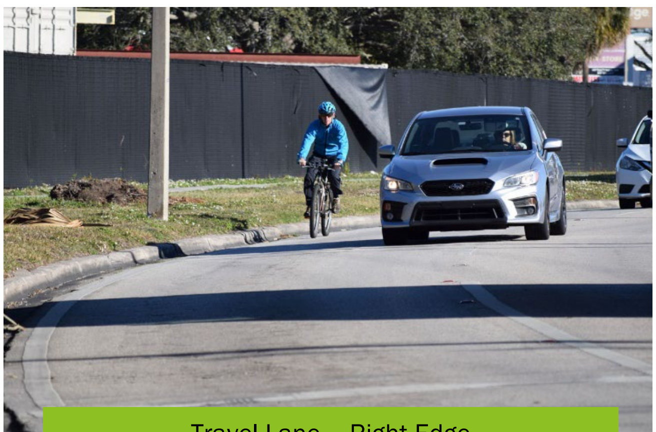
All available reports from 2007 through 2016 for crashes involving bicyclists on the twenty (20) streets were reviewed and crash typed using the PBCAT crash typology system through Florida's Signal Four Analytics crash database. Only crashes involving bicyclists traveling on or across the study streets were included. Parking lot and other non-right-of-way crashes were excluded. A total of 560 crashes were typed. On the bicycle lane streets, 27% of the crashes involved a bicyclist using the bicycle lane, 63% were using the sidewalk or crosswalk, and 6% were entering the roadway from a driveway or other mid-block location. On the control streets, 9% of the crashes involved a bicyclist using the travel lane, 85% were using the sidewalk or crosswalk, and 4% were entering the roadway from a driveway or other mid-block location. Table 3 provides additional detail on bicyclist position based on which party caused the crash.

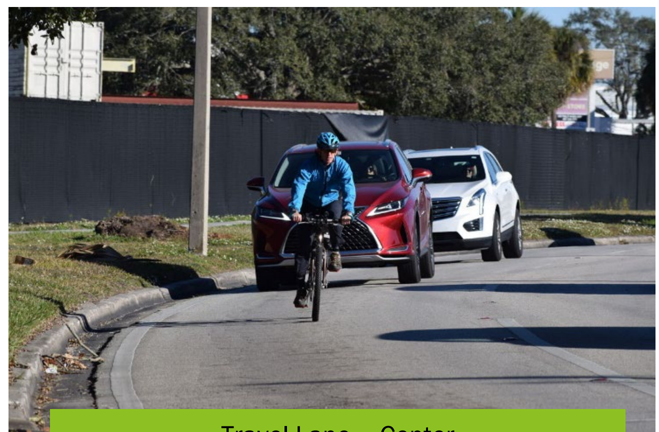
**Table 3: Crashes by Fault and Bicyclist Position**

| | | Bicycle Lane Streets | Control Streets | Combined |
|---|---|---|---|---|
| | Total Crashes | 322 | 238 | 560 |
| Motorist-Caused Crashes | All Motorist-Caused Crashes | 222 | 181 | 403 |
| | Bicyclist in Travel Lane | | 12 | 12 |
| | Bicyclist in Bicycle Lane | 55 | | 55 |
| | Bicyclist on Sidewalk/Crosswalk | 167 | 169 | 336 |
| | % in Travel Lane | | 5% | 2% |
| | % in Bicycle Lane | 17% | | 10% |
| | % on Sidewalk/Crosswalk | 52% | 71% | 60% |
| | Motorist-Caused % of Total | 69% | 76% | 72% |
| Bicyclist-Caused Crashes | All Bicyclist-Caused Crashes | 72 | 41 | 113 |
| | Bicyclist in Travel Lane | | 13 | 13 |
| | Bicyclist in Bicycle Lane | 32 | | 32 |
| | Bicyclist on Sidewalk/Crosswalk | 28 | 23 | 51 |
| | Bicyclist: Other Position | 12 | 5 | 17 |
| | % in Travel Lane | | 5% | 2% |
| | % in Bicycle Lane | 10% | | 6% |
| | % on Sidewalk/Crosswalk | 9% | 10% | 9% |
| | % in Other Position | 4% | 2% | 3% |
| | Bicyclist-Caused % of Total | 22% | 17% | 20% |
| Other Crashes | | 28 | 16 | 44 |
| | | 9% | 7% | 8% |

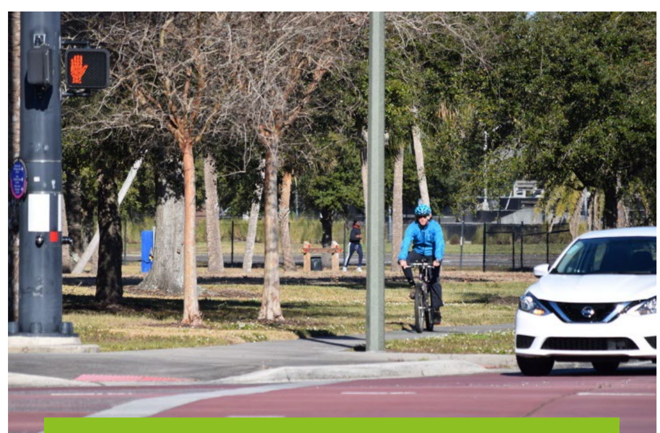
For both crash typology and bicyclist counts, bicyclist positions were categorized as Travel Lane, Bicycle Lane, and Sidewalk/Crosswalk. (For crashes only, an Other position is also used.) For the purposes of analyzing the relative effectiveness of facilities, these positions are defined this way:

> *Travel Lane* – bicyclist is traveling near the rightmost edge of a general use travel lane. While some bicyclists drive towards the center of a travel lane – a practice known as "lane control," "driver position," or "taking the lane" – both the numbers of bicyclists who do so and the numbers of crashes involving that position are so small as to be statistically irrelevant for the purposes of this study.
>
> *Bicycle Lane* – bicyclist is traveling in a bicycle lane immediately prior to a crash. The actual collision could occur in an adjacent travel lane, or in the intersection where the actual bicycle lane striping is dropped.
>
> *Sidewalk/Crosswalk* – bicyclist is traveling on a sidewalk or crosswalk immediately prior to a crash.


Travel Lane – Right Edge


Travel Lane – Center


Bike Lane


Sidewalk

While bicycle lanes do provide some increased passing clearance from overtaking vehicles, bicycling along the right edge of a travel lane and within a conventional bicycle lane are functionally very similar, particularly in respect to line-of-sight, blind spots, and bicyclist maneuverability for turning and crossing conflicts.

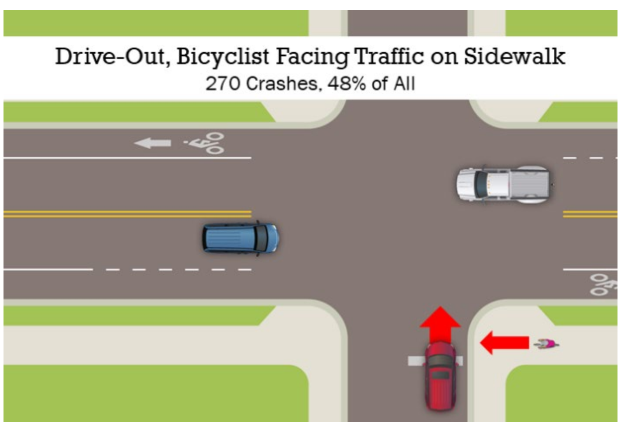
## *Crash Types and Relevance to Bicycle Facilities*

Table 4 shows the major crash types, grouped by motorist-caused and bicyclist-caused, and by bicyclist position.

### Table 4: Major Crash Types

| Major Crash Types | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| % of Total (560) | | | | | | | | | | | |
| Bicyclist Position | Motorist-Caused | | | | | Bicyclist-Caused | | | | Fault Unk. | Totals |
| | Drive-Out/ Through | Right Hook | Left Cross | Over-taking | Other | Wrong -Way | Ride-Out/ Through | Left Hook | Other | | |
| Bicycle Lane | 11 | 25 | 10 | 6 | 3 | 38 | 2 | 3 | 10 | 1 | 109 |
| | 2.0% | 4.5% | 1.8% | 1.1% | 0.5% | 6.8% | 0.4% | 0.5% | 1.8% | 0.2% | 19.5% |
| Travel Lane | 1 | 2 | 3 | 4 | 2 | 6 | 5 | 0 | 1 | 0 | 24 |
| | 0.2% | 0.4% | 0.5% | 0.7% | 0.4% | 1.1% | 0.9% | 0.0% | 0.2% | 0.0% | 4.3% |
| Sidewalk | 302 | 19 | 5 | 0 | 34 | NA | 28 | 3 | 8 | 1 | 400 |
| | 53.9% | 3.4% | 0.9% | 0.0% | 6.1% | NA | 5.0% | 0.5% | 1.4% | 0.2% | 71.4% |
| Other/ Unk. | 0 | 1 | 0 | 0 | 0 | NA | 18 | 0 | 0 | 8 | 27 |
| | 0.0% | 0.2% | 0.0% | 0.0% | 0.0% | NA | 3.2% | 0.0% | 0.0% | 1.4% | 4.8% |
| Totals | 314 | 47 | 18 | 10 | 39 | 44 | 53 | 6 | 19 | 10 | 560 |
| | 56.1% | 8.4% | 3.2% | 1.8% | 7.0% | 7.9% | 9.5% | 1.1% | 3.4% | 1.8% | 100% |

The following are descriptions of the crash types, their relative frequency, and their relevance to the presence or absence of bicycle lanes or shared use paths.


Drive-Out, Bicyclist Facing Traffic on Sidewalk
270 Crashes, 48% of All

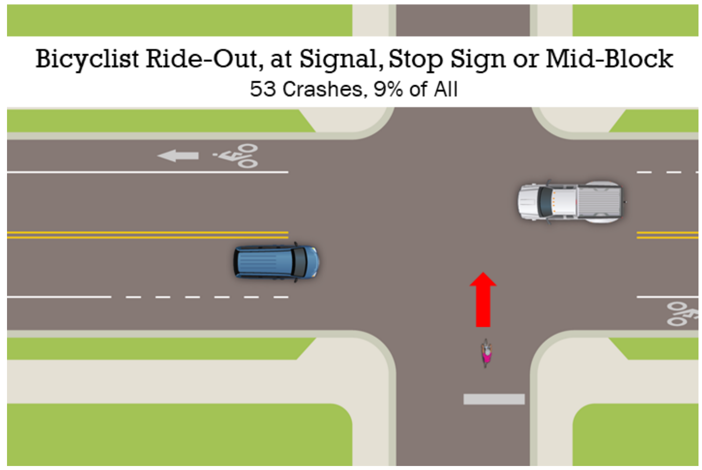

Drive-Out, Bicyclist With Traffic
44 Crashes, 8% of All (Travel Lane 1, Bike Lane 11, Sidewalk 32)

#### *Motorist Drive-Out/Through*

The most common crash type is the motorist drive-out (or drive-through), in which the motorist perpendicularly enters the path of an approaching bicyclist from a cross street or driveway and violates the bicyclist's right-of-way. (In a drive-out, the motorist stops before crossing the bicyclist's right-of-way; in a drive-through, the motorist does not stop.) This type represented 314 crashes (56% of total). 302 involved sidewalk and crosswalk cyclists, and of those 270 (48% of total) involved bicyclists traveling facing traffic. Eleven (11) involved bicycle lane users, and one (1) a travel lane user.

Drive-outs are relevant to a bicyclist's position (bicycle lanes, sidewalk or shared use sidepath) in that the bicyclist's lateral position can affect line-of-sight to motorists entering the road, which affects bicyclist reaction time and stopping distance.

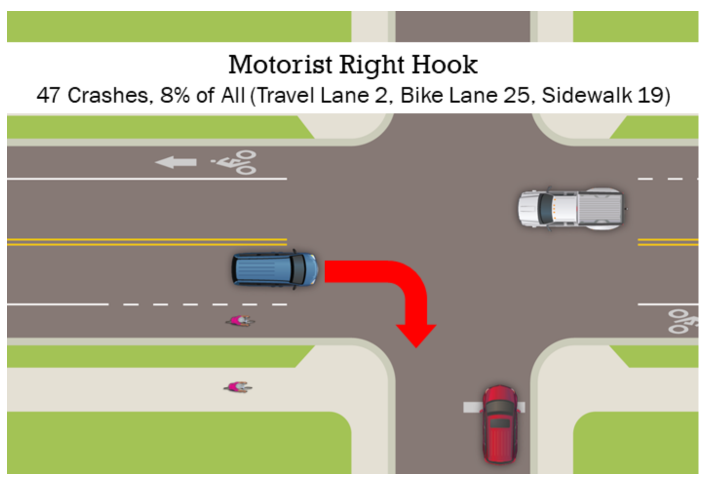
*Bicyclist Ride-Out/Through*




The second most common crash type is the bicyclist ride-out (or ride-through), in which the bicyclist enters the path of an approaching motorist from a cross street, driveway or other mid-block location, and violates the motorist's right-of-way. (In a ride-out, the bicyclist stops before crossing the motorist's right-of-way; in a ride-through, the bicyclist does not stop.) This type represented 53 crashes (9% of total), including: 28 involving sidewalk cyclists, 2 involving bicycle lane users, 5 involving travel lane users, and 18 involving bicyclists entering the roadway from other positions.

Ride-outs are not relevant to the presence or absence of bicycle lanes or paths as this type of crash is not relevant to the bicyclist's position lateral to the roadway.

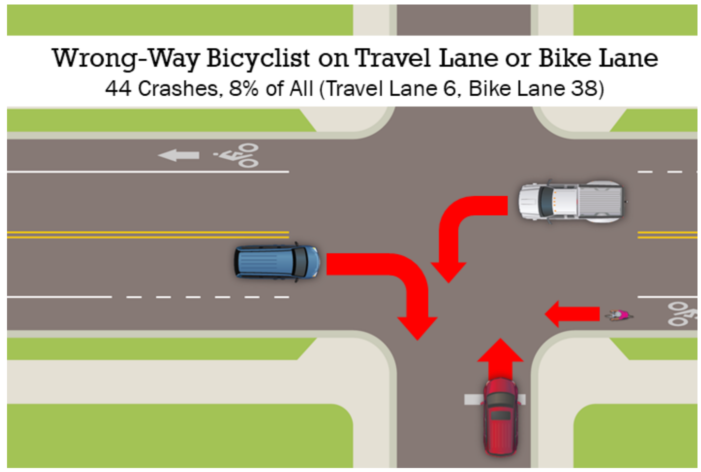
*Motorist Right Hook*




The third most common crash type is the motorist right hook. There are two subtypes of right hooks; in one, an overtaking motorist turns right across the path of a same-direction bicyclist going straight; in the other, the bicyclist is overtaking the motorist on the right as the motorist turns right. This type represented 47 crashes (8% of total), including: 19 involving sidewalk and crosswalk cyclists, 25 involving bicycle lane users, and two (2) involving travel lane users.

Right hooks are relevant to bicycle facilities and sidewalks in that they allow or direct bicyclists to pass to the right of right-turning motorists, and they do not discourage motorists from turning across the bicyclist's path. Bicyclists in bicycle lanes, along the right-most edge of travel lanes, and on sidewalks or paths can often be in the right rear blind spots of motorists.

*Wrong-Way Bicyclist*

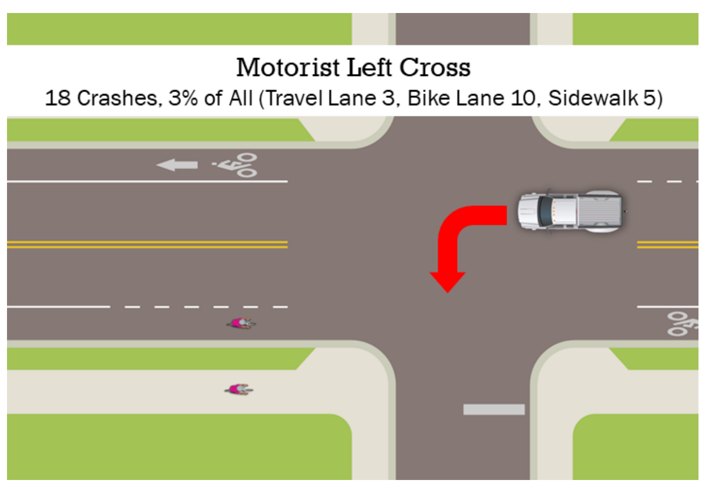



The fourth most common crash type involves bicyclists traveling against the flow of traffic in a travel lane or bicycle lane. Bicycling against traffic on a sidewalk or path is not illegal, as bicyclists on sidewalks and paths have the same rights and duties as pedestrians, while bicyclists on roadways have the rights and duties of drivers. Most wrong-way crashes involve motorists entering the road from a cross street or driveway, and a lesser number involve motorists turning across the path of the bicyclist. Head-on crashes involving wrong-way bicyclists are very rare. Wrong-way crashes represented 44 crashes (8% of total), including: 38 involving bicycle lane users, and six (6) involving travel lane users.

Wrong-way crashes are relevant to bicycle lanes in that they may encourage this behavior by providing a dedicated space and reducing the perceived risk of a head-on crash compared to a regular travel lane. Conversely, they may encourage correct-direction travel by providing a dedicated space and reducing the perceived risk of an overtaking crash compared to a regular travel lane; they also generally include a directional arrow indicating the correct direction of travel.

While bicycling facing traffic in a travel lane or standard bicycle lane is against the law in all 50 U.S. states, doing so on a sidewalk or shared use sidepath is not. As will be shown later, this legal discrepancy has little or no bearing on the relative risks for bicycling facing traffic compared to traveling with the flow. Most facing traffic crashes involving sidewalk or path cyclists are classified as motorist drive-outs.

*Motorist Left Cross*

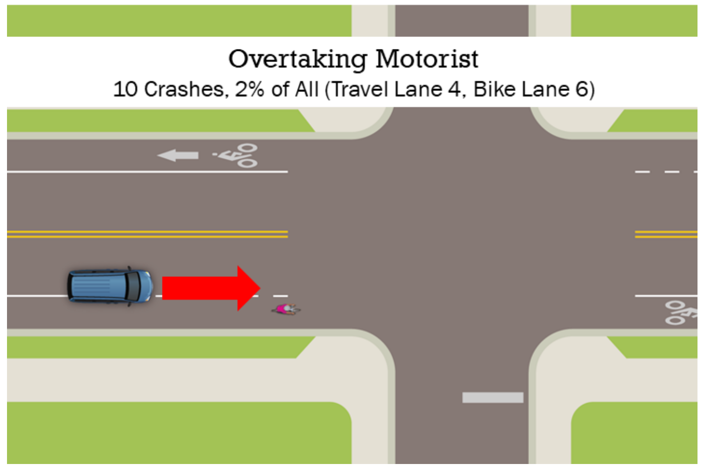



The fifth most common crash type involves bicyclists traveling with the flow of traffic and motorists turning left across their paths. In some cases, the motorist has a clear view of the bicyclist; in others, the bicyclist is screened from view by same-direction traffic or other environmental elements. This type represented 18 crashes

(3% of total), including: 10 involving bicycle lane users, three (3) involving travel lane users, and five (5) involving sidewalk/crosswalk users.

Left cross crashes are relevant to bicycle facilities and sidewalks in that they encourage bicyclists to pass to the right of stopped traffic, potentially screening them from the view of on-coming motorists. They may also move bicyclists farther away from the motorist's routine cone of attention, where there are other oncoming motor vehicles.

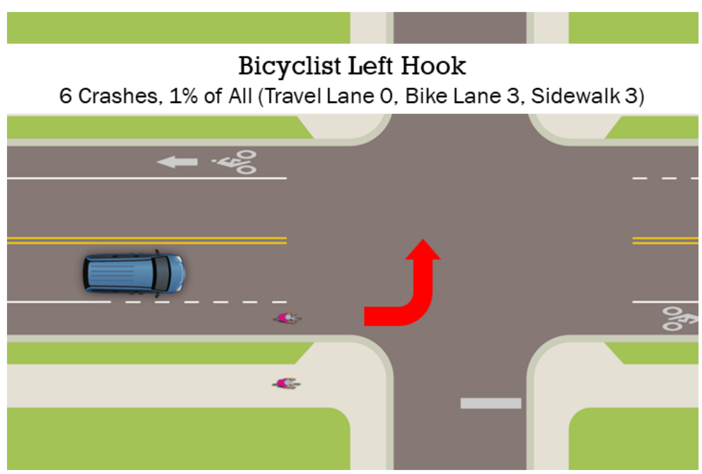
*Overtaking Motorist*




The sixth most common crash type involves bicyclists struck from behind by motorists going straight. These crashes can be sideswipes in which the motorist misjudges the passing clearance, or can be crashes in which the bicyclist is hit squarely from behind by a driver who did not see the bicyclist due to visibility conditions, impairment, or distraction. This type represented 10 crashes (2% of total), including: six (6) involving bicycle lane users and four (4) involving travel lane users.

Overtaking crashes are relevant to bicycle lanes in that the additional pavement width and lane striping should discourage motorists from inadvertently drifting into the bicyclist's space.

*Bicyclist Left Hook*




The final common crash type in this report involves a bicyclist suddenly making a left turn in front of same direction motorists from the right edge, bicycle lane or sidewalk. This type represented six (6) crashes (1% of total), including: three (3) involving bicycle lane users and three (3) involving sidewalk users.

Bicyclist left hook crashes are relevant to bicycle lanes in that the lane striping may communicate to bicyclists that they must stay in the bicycle lane until they make the left turn, rather than changing lanes in advance and turning left from the lane normally used by vehicles for doing so.

Other motorist-caused crashes include:

- Opening a car door into the path of a passing bicyclist. This is a common crash in denser urban areas with much more high-turnover on-street parking. Only one such crash occurred in this study.
- Various improper motorist turning and merging movements
- Motorists turning left or right across the paths of bicyclists riding facing traffic

Other bicyclist-caused crashes include:

- Bicyclist turning errors
- Bicyclist loss of control
- Bicyclist failure to clear a signalized intersection before cross traffic began moving

Other crash reports gave insufficient information to determine cause or fault, or were so unusual as to have no specific crash type.

### *Bicyclist Counts*

In order to estimate the relative risks for bicyclists by their positions and by crash types, accurate counts must be conducted that differentiate between bicyclists, pedestrians and motor vehicles. Counts should also record the bicyclist's position (travel lane, bicycle lane, sidewalk or shared use sidepath) and the bicyclist's direction relative to normal vehicular travel (with or facing traffic).

MioVision video cameras were deployed at mid-block locations for all bicycle lane streets and control streets for 48-hour counts. Cameras were deployed in pairs during the same time periods; one for the bicycle lane street and one for the control street. Wider multi-lane streets were counted twice, once for each side of the road. Counts were stratified by bicyclist position and direction.

Table 5 shows counts for all twenty streets, showing the numbers and percentages of bicyclists using bicycle lanes, travel lanes, and sidewalks.

The streets with the highest bicycle lane use were two-lane collector streets near downtown Orlando (Edgewater, 168; and Livingston, 143) and a six-lane arterial near the University of Central Florida (Alafaya, 118). Streets with the highest travel lane use were also two-lane collector streets near downtown Orlando (Orange, 47; and Summerlin, 28) and a street without sidewalks (Carroll, 31).

Streets with the highest total bicycle use were six-lane arterials near colleges – Alafaya (496), near the University of Central Florida, and University Boulevard (337) near Full Sail University.

The differences in usage between bicycle lanes and travel lanes is far greater for four-lane and six-lane arterials than for two-lane streets. Bicycle use was 7.8 times greater on the bicycle lanes than the travel lanes on the 4- and 6-lane streets, while 3.6 times greater on two-lane streets.

*MioVision video camera control box*

Table 5: Bicyclist Counts by Position

| Bicycle Lane Streets in Gray | | Control Streets in White | | |
|---|---|---|---|---|
| **48-Hour Bicyclist Counts** | **Bicyclist Count Positions** (% of Street Total) | | | |
| **Street** | **Bicycle Lane** | **Travel Lane** | **Sidewalk** | **All Bicyclist Positions** |
| Alafaya | 118 (24%) | | 378 (76%) | 496 |
| University | | 5 (1.5%) | 332 (98.5%) | 337 |
| W Colonial | 95 (44%) | | 121 (56%) | 216 |
| Lee | | 5 (3%) | 203 (97%) | 209 |
| Orange | 33 (50%) | | 33 (50%) | 66 |
| Curry Ford | | 4 (3%) | 120 (97%) | 124 |
| Pine Hills | 72 (53%) | | 65 (47%) | 137 |
| Pine Hills | | 6 (2%) | 311 (98%) | 317 |
| Columbia | 38 (16%) | | 205 (84%) | 243 |
| Carroll | | 31 (100%) | 0 | 31 |
| Edgewater | 168 (74%) | | 60 (26%) | 228 |
| Orange | | 47 (37%) | 80 (63%) | 127 |
| Glenridge | 63 (47%) | | 72 (53%) | 135 |
| Kaley | | 11 (31%) | 25 (69%) | 36 |
| Par | 26 (58%) | | 19 (42%) | 45 |
| Clay | | 7 (27%) | 19 (73%) | 26 |
| Lakemont | 113 (47%) | | 125 (53%) | 238 |
| Winter Park | | 25 (16%) | 130 (84%) | 155 |
| Livingston | 143 (84%) | | 27 (16%) | 170 |
| Summerlin | | 28 (17%) | 141 (83%) | 169 |
| Bicycle Lanes Total | 869 (44%) | | 1,105 (56%) | 1,974 |
| Control Streets Total | | 170 (11%) | 1,361 (89%) | 1,531 |

### *Bicyclist Speeds*

Bicyclist speed is relevant to bicyclist crash risk. When a motorist is crossing the path of an approaching bicyclist, the bicyclist's speed affects both the motorist's and the bicyclist's perception, reaction and braking time and distance. A motorist with less perception and reaction time to see an approaching bicyclist would be more prone to violate the bicyclist's right-of-way. Motorists may also be more likely to misjudge the speed of faster bicyclists, especially ones approaching the motorist from the front. A faster moving bicyclist would need more perception, reaction and braking distance to avoid colliding with a motorist who violates their right-of-way.

While this analysis was unable to obtain the speeds of bicyclists in the reported crashes, we can measure the range and averages of the speeds of bicyclists as they travel on travel lanes, bicycle lanes and sidewalks.

ON AVERAGE, BICYCLISTS WHO TRAVEL ON SIDEPATHS, SIDEWALKS AND BIKE LANES TRAVEL SLOWER THAN THOSE WHO USE REGULAR TRAVEL LANES

Bicyclist speeds were calculated by timing bicyclists in the MioVision videos as they traversed a marked, measured distance. Table 6 shows the results of these measurements.

The 85th percentile speed for travel lane bicyclists was 17% higher than for bicycle lane users, and 48% higher than for sidewalk users. Bicycle lane users were 27% faster than sidewalk users. Shared use sidepath users were roughly the same speed as bicycle lane users.

**Table 6: Bicyclist Speeds by Position**

| | **Bicyclist Speeds** (Miles Per Hour) | | | | | **Number of Bicyclists Measured** |
|---|---|---|---|---|---|---|
| **Bicyclist Position** | **Average (Mean)** | **85th Percentile** | **Maximum** | **Minimum** | **Range** (Max. to Min.) | |
| Travel Lane | 14.5 | 18.4 | 26.4 | 9.5 | 16.9 | 44 |
| Bicycle Lane | 11.8 | 15.7 | 21.2 | 5.8 | 15.4 | 70 |
| Sidewalk | 9.3 | 12.4 | 17.1 | 4.6 | 12.5 | 89 |
| Sidepath | 11.7 | 16.3 | 21.2 | 5.0 | 16.2 | 127 |

Bicyclist speed is not merely a function of physical fitness. Bicyclists can go faster on downhill stretches, with strong tailwinds, and with supplemental electric motors. Hillier streets would have significantly higher maximum speeds and much higher average speed on the downhill sides of streets. (The terrain in the Orlando metropolitan area is generally flat.) Aspects of the bicycle itself that can decrease bicyclist speed are:

- Bicycle fit and saddle height – improper fit can reduce the amount of power a bicyclist can transmit to the pedals
- Tire type and air pressure – knobby tires such as those found on mountain bikes, and low tire pressure in any type of tire can significantly increase rolling resistance
- Improper use of the bicycle's gears can compromise power output
- The type of bicycle can affect the wind resistance experienced by the bicyclist by putting the rider in a more or less aerodynamic position

Each of these bicycle characteristics could increase or decrease a bicyclist's speed by 1 to 3 miles per hour given the same physical output. Less experienced bicyclists are more likely to exhibit one or more of these factors in a manner that would decrease their speeds.

The characteristics of regular sidewalks may also contribute to lower bicyclist speeds. As sidewalks are not designed for bicyclist use, they often present surface hazards and obstacles that encourage lower speeds.

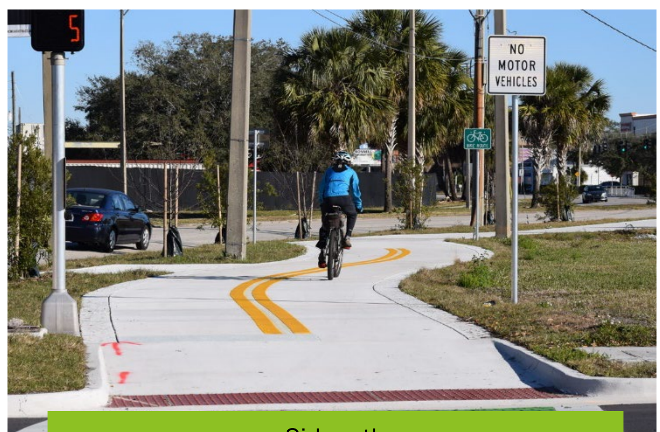
### *Shared Use Sidepaths*

Five (5) shared use sidepaths in the Orlando metropolitan area that are adjacent to roadways have been in place for at least 10 years (Table 7).

**Table 7: Shared Use Sidepaths Studied**

| Path Name | Adjacent Street Name | Limits | | Length (Miles) | Path Width (Feet) | Sidewalk Width (Feet) | Intersections & Commercial Driveways per Mile | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Path | Sidewalk |
| Cross Seminole Trail | Aloma Ave. | Mikler Rd. | Mitchell Hammock Rd. | 1.90 | 14 | 5 | 4.2 | 8.9 |
| Daniels Road Trail | Daniels Road | Grovehurst Ave. | Stoneybrook W. Pkwy. | 0.67 | 10 | 5 | 11.9 | 13.4 |
| Cross Seminole Trail | Rinehart Road | CR 46A | Sun Dr | 2.70 | 14 | 5 | 6.3 | 9.3 |
| West Orange Trail | Park Ave. | Lester Road | Lake McCoy Dr. | 2.00 | 12 | 5 | 11.5 | 14.5 |
| Pleasant Hill Road Trail | Pleasant Hill Road | US 17/92 | Poinciana Road | 7.50 | 8 | None | 4.1 | None |
| Totals & Averages | | | | 14.77 | 11.6 | | 5.9 | |
| Totals & Averages w/o Pleasant Hill Road Path | | | | 7.27 | 10.0 | 5.0 | 8.5 | 11.5 |

The same type of crash typology, bicyclist count and speed collections were conducted for them as for the bicycle lane and control streets. Four of the five had regular sidewalks on the opposite side of the roadway, and crashes, counts and speeds were also collected for those. One of the streets (Pleasant Hill Road) had only the shared use sidepath on one side, and very little usable sidewalk on the opposite side, so there are no crashes or counts for the sidewalk side. Since – as with sidewalk crashes – virtually all path crashes occur at intersections and driveways, the frequency of intersections and commercial driveways is also indicated.



Sidepath

For streets that had both shared use sidepaths and sidewalks, the paths had:

- 2.9 times as many total crashes as the sidewalks
- 2.4 times as many motorist-caused crashes
- 4 times as many bicyclists

Table 8: Shared Use Sidepath Crashes

| Crash Factors and Types | All Shared Use Sidepaths | Shared Use Sidepaths w/o Pleasant Hill Road | Opposing Sidewalks |
|---|---|---|---|
| All Crashes | 60 | 35 | 12 |
| Bicyclist Traveling With the Flow of Adjacent Traffic | 9 | 7 | 5 |
| Bicyclist Traveling Facing the Flow of Adjacent Traffic | 48 | 26 | 7 |
| Motorist Caused | 48 | 24 | 10 |
| Bicyclist Caused | 10 | 10 | 2 |
| Motorist Drive-Out | 42 | 20 | 6 |
| Motorist Turn Conflict | 6 | 4 | 4 |

Table 9: Shared Use Sidepath Counts, Speeds, and Intersections & Commercial Driveways per Mile

| Path Name | Adjacent Street Name | Path Count (48 Hours) | Path Average Speed (MPH) | Sidewalk Count (48 Hours) | Sidewalk Average Speed (MPH) | Intersections & Commercial Driveways per Mile | |
|---|---|---|---|---|---|---|---|
| | | | | | | Path | Sidewalk |
| Cross Seminole Trail | Aloma Ave. | 191 | 13.6 | 19 | 11.3 | 4.2 | 8.9 |
| Daniels Road Trail | Daniels Road | 11 | 12.0 | 11 | 9.4 | 11.9 | 13.4 |
| Cross Seminole Trail | Rinehart Road | 164 | 12.9 | 42 | 7.8 | 6.3 | 9.3 |
| West Orange Trail | Park Ave. | 109 | 10.8 | 47 | 9.5 | 11.5 | 14.5 |
| Pleasant Hill Road Trail | Pleasant Hill Road | 112 | 9.9 | None | None | 4.1 | None |
| Totals & Averages | | 587 | 11.6 | NA | NA | 5.9 | NA |
| Totals & Averages w/o Pleasant Hill Road Path | | 475 | 12.3 | 119 | 9.5 | 8.5 | 11.5 |

Table 8 shows the numbers and generalized types of crashes for the shared use sidepaths and their opposing sidewalks; Table 9 shows bicyclist counts and average speeds.

The opposing sidewalks consistently had more intersections and commercial driveways per mile than the shared use sidepaths; the paths averaged 5.9 intersections and driveways per mile, while the sidewalks averaged 11.5 (95% higher).

Pathway bicyclists traveled 31% faster than sidewalk bicyclists. Average bicyclist speeds did not vary much by intersection and commercial driveway frequency. High-frequency path (Daniels and West Orange) cyclists averaged 11.1 MPH, and lower-frequency path (both Cross Seminole and Pleasant Hill) cyclists averaged 11.7 MPH. The higher path speeds compared to the sidewalk speeds are likely due to a greater proportion of better-equipped recreational cyclists.

# Analysis

*Determining the Extent to Which Bikeways Protect Bicyclists from Motorist-Caused Crashes*

While it's commonly presumed that bikeways discourage motorists from behaving in ways that lead to crashes with bicyclists, recent U.S. bikeway studies have not specifically shown that. Instead they have merely counted overall crashes and overall bicyclist exposure to calculate relative risk rates between bikeway streets and non-bikeway streets. This approach ignores the extent to which bicyclist behaviors may affect crash rates.

A study to explore how bikeways might protect bicyclists must determine how many crashes are due primarily to motorist behavior, how many are due primarily to bicyclist behavior, and also explore what bicyclist behaviors might protect them from motorist errors. These factors must then be analyzed in respect to the characteristics of the different spaces in which bicyclists operate. Determining how well different bicycle facilities protect bicyclists from crashes entails understanding:

- the motorist and bicyclist behaviors that contribute to or mitigate crashes
- the numbers of bicyclists and their behaviors
- the numbers of crashes by behavior type and bicyclist position

*Estimating Risk*

With both the numbers of crashes by type and the bicyclist exposure by position and direction, we can estimate the frequency at which a bicyclist would experience a crash. Exposure was estimated by multiplying the 48-hour bicyclist count by the length of the study corridor, and then by 1,825, which extends the exposure from 48 hours to 10 years, to match the 10 years of crash data (10 years = 3,650 days; 48 hours = 2 days; 3,650/2 = 1,825). Estimated risk is expressed as bicyclist miles between crashes (estimated miles of exposure/number of crashes), so a higher number means a lower risk. Table 10 outlines bicyclist exposure mileage by bicyclist position and direction.

**Table 10: Bicyclist Exposure by Position and Direction (In Thousands of Miles)**

| | Miles of Bicycle Lane Exposure | | Miles of Travel Lane Exposure | | Miles of Sidewalk Exposure | | | Miles of Total Exposure |
|---|---|---|---|---|---|---|---|---|
| Bicyclist Direction | With Traffic | Facing Traffic | With Traffic | Facing Traffic | With Traffic | Facing Traffic | Both Directions | |
| Bicycle Lane Street | 3,509 | 582 | | | 3,440 | 3,053 | 6,494 | 10,586 |
| Control Street | | | 366 | 34 | 4,361 | 3,771 | 8,133 | 8,695 |
| Totals | 3,509 | 582 | 354 | 207 | 7,802 | 6,824 | 14,627 | 19,281 |
| Percent of Totals | | | | | | | | |
| % of Bicycle Lane Street | 33% | 6% | | | 33% | 29% | 61% | 100% |
| % of Control Street | | | 4% | 2% | 50% | 43% | 94% | 100% |
| % of Total | 18% | 3% | 2% | 1% | 40% | 35% | 76% | 100% |

*Comparing Risk for Same Direction Bicyclists*

The baseline for comparison is a bicyclist traveling with the flow of traffic along the right edge a regular travel lane. The overall relative risk for motorist-caused crashes for bicyclists traveling with the flow of traffic is (rounded to nearest thousand miles):

**Table 11: Miles Between Motorist-Caused Crashes: Bicyclist Traveling With Flow of Traffic (In Thousands of Miles)**

| Bicyclist Position | Number of Crashes | Miles of Exposure | Miles Between Crashes (Exposure/ Crashes) | Risk Compared to Travel Lane |
|---|---|---|---|---|
| Travel Lane | 12 | 367 | 31 | NA |
| Bicycle Lane | 55 | 3,509 | 64 | 106% lower |
| Sidewalk | 64 | 7,803 | 122 | 294% lower |
| Sidepath | 8 | 1,702 | 213 | 587% lower |

**Table 12: Miles Between Overtaking Motorist Crashes: Bicyclist Traveling With Flow of Traffic (In Thousands of Miles)**

| Bicyclist Position | Number of Crashes | Miles of Exposure | Miles Between Crashes (Exposure/ Crashes) | Risk Compared to Travel Lane |
|---|---|---|---|---|
| Travel Lane | 4 | 367 | 92 | NA |
| Bicycle Lane | 6 | 3,509 | 585 | 536% lower |
| Sidewalk | 0 | NA | NA | NA |

**Table 13: Miles Between Motorist Right Hook Crashes: Bicyclist Traveling With Flow of Traffic (In Thousands of Miles)**

| Bicyclist Position | Number of Crashes | Miles of Exposure | Miles Between Crashes (Exposure/ Crashes) | Risk Compared to Travel Lane |
|---|---|---|---|---|
| Travel Lane | 2 | 367 | 184 | NA |
| Bicycle Lane | 25 | 3,509 | 140 | 24% higher |
| Sidewalk | 20 | 7,803 | 390 | 112% lower |

**Table 14: Miles Between Motorist Left Cross Crashes: Bicyclist Traveling With Flow of Traffic (In Thousands of Miles)**

| Bicyclist Position | Number of Crashes | Miles of Exposure | Miles Between Crashes (Exposure/ Crashes) | Risk Compared to Travel Lane |
|---|---|---|---|---|
| Travel Lane | 3 | 367 | 122 | NA |
| Bicycle Lane | 10 | 3,509 | 351 | 188% lower |
| Sidewalk | 6 | 7,803 | 1,300 | 966% lower |

**Table 15: Miles Between Motorist Drive-Out Crashes: Bicyclist Traveling With Flow of Traffic (In Thousands of Miles)**

| Bicyclist Position | Number of Crashes | Miles of Exposure | Miles Between Crashes (Exposure/ Crashes) | Risk Compared to Travel Lane |
|---|---|---|---|---|
| Travel Lane | 1 | 367 | 367 | NA |
| Bicycle Lane | 12 | 3,509 | 292 | 20% higher |
| Sidewalk | 32 | 7,803 | 245 | 33% higher |

**Table 16: Miles Between Combined Motorist Right Hook, Left Cross & Drive-Out Crashes: Bicyclist Traveling With Flow of Traffic (In Thousands of Miles)**

| Bicyclist Position | Number of Crashes | Miles of Exposure | Miles Between Crashes (Exposure/ Crashes) | Risk Compared to Travel Lane |
|---|---|---|---|---|
| Travel Lane | 6 | 367 | 61 | NA |
| Bicycle Lane | 47 | 3,509 | 75 | 23% lower |
| Sidewalk | 64 | 7,803 | 122 | 100% lower |
| Sidepath | 8 | 1,702 | 213 | 249% lower |

While overtaking motorist crashes for travel lane bicyclists show the highest risk per specific crash type, highly-experienced bicyclists have long argued that turning and crossing conflict crashes are collectively a higher risk, and this position is supported when comparing the risk for combined right hook, left cross and drive-out crashes (61,000 miles between crashes) compared to overtaking crashes (92,000 miles) for travel lane cyclists. One would expect to see reduced risk for overtaking crashes for bicycle lanes compared to travel lanes, and we see above that the risk is 536% lower.

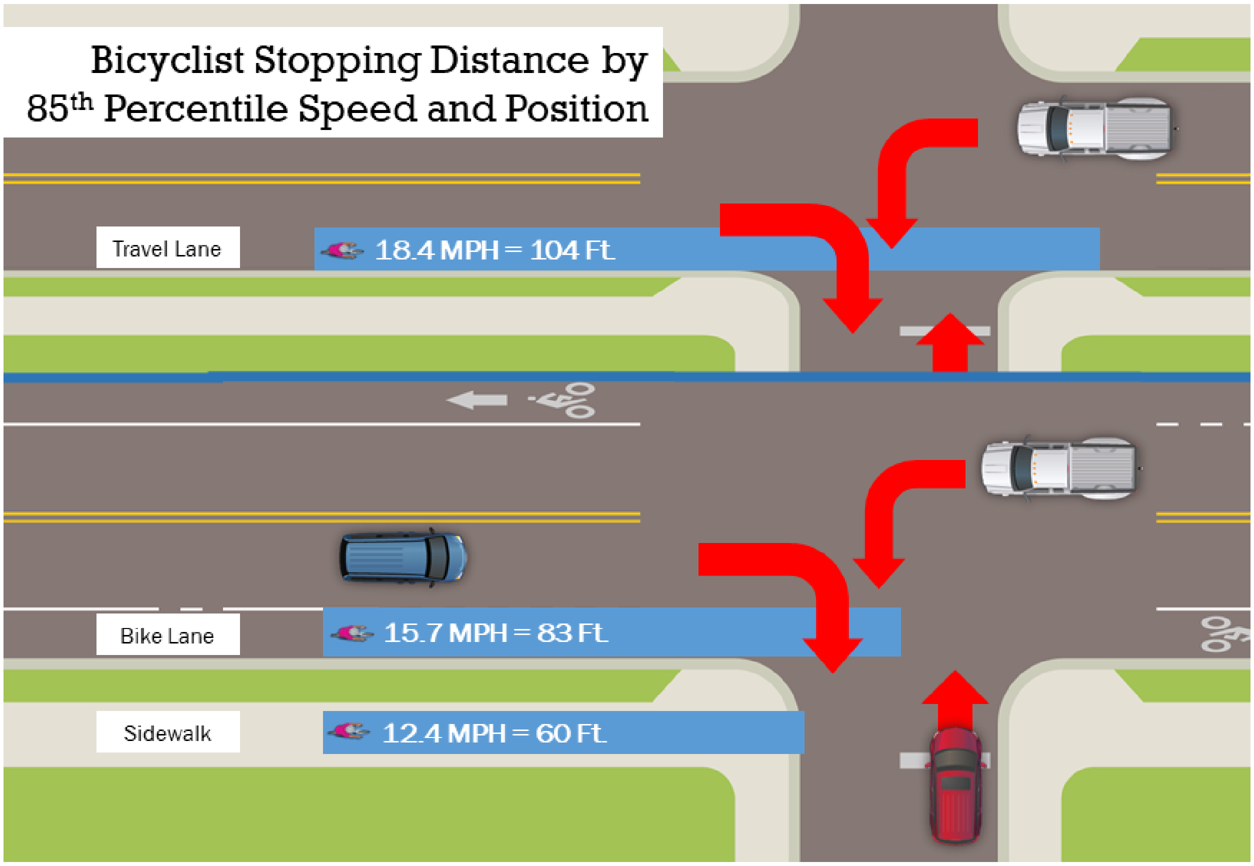
Other key points from the above data:

- Sidewalk users have the lowest risk for right hook and left cross crashes
- Travel lane users have the lowest risk for drive-out crashes
- Shared use sidepaths have the lowest overall crash risk, but – as will be explained below – this is a function of the number of conflict points

While the tendency of bicycle lanes (and sidewalks) to mitigate overtaking motorist crashes is rather straightforward, their impact on motorist-caused turning and crossing conflicts has been debated extensively. A common assumption is that the designated space provided by the bicycle lane encourages motorists to scan for and yield to bicyclists. However, the above data calls this assumption into question. First, for right hook and left cross crashes, the risk for sidewalk bicyclists was lower than for bicycle lane users, and sidewalks are neither visibly designated for bicycling, nor designed for the use of bicyclists. Secondly, if designation encourages better motorist scanning and yielding, why do bicycle lanes have higher risk than travel lanes for right hook and drive-out crashes, but lower risk for left cross crashes? Some other factor must account for the reduced risk.

### *Bicyclist Speeds Compared to Crash Risks*

As noted in Table 6, bicyclists using regular travel lanes in this study had an average (mean) speed of 14.5 miles per hour (MPH) and an 85$^{th}$ percentile speed of 18.4 MPH. Bicycle lane users averaged 11.8 MPH and their 85$^{th}$ percentile speed was 15.7 MPH. Sidewalk bicyclists averaged 9.3 MPH and their 85th percentile speed was 12.4 MPH. Such speed variations can result in differences in stopping distances comparable to the width of a two-lane, or even a four-lane roadway.




An 18.4 MPH travel lane bicyclist would require approximately 104 feet of perception, reaction and braking distance when confronted with a motorist violating their right-of-way. (Distance based on 2.5 seconds of perception/reaction time and .3gs of braking force, representative of an untrained bicyclist with dual handbrakes.) A 15.7 MPH bicycle lane user would need 83 feet (20% less than the travel lane), and a 12.4 MPH sidewalk rider would need 60 feet (42% less than the travel lane).

To put this into the context of a potential crash, the bicycle lane user would need twenty-one (21) fewer feet of stopping distance compared to the travel lane bicyclist, about the width of a narrow two-lane street; the bicycle lane user could more likely stop before the point of contact. The sidewalk bicyclist would need 44 fewer feet of stopping distance, about the width of four travel lanes.

Considering braking distance alone, the difference between the bicycle lane users and the travel lane users is a full lane width, and the difference between sidewalk users and travel lane users is two lane widths.

Based on this data it appears that each additional mile per hour of bicyclist speed above 9 MPH (the average sidewalk bicyclist) increases bicyclist risk for turning and crossing crashes by about 9%.

**Table 17: Bicyclist Position, 85th Percentile Speed, Stopping Distance, and Crash Risk (With Flow of Traffic Only)**

| Bicyclist Position | Bicyclist 85th Percentile Speed | Perception/ Reaction Distance (2.5 Seconds) | Braking Distance (.3gs of Braking Force) | Bicyclist Average Stopping Distance | Miles Between Motorist-Caused Turning & Crossing Crashes (Nearest Thousand) |
|---|---|---|---|---|---|
| Travel Lane | 18.4 MPH | 64 feet | 40 feet | 104 feet | 59,000 |
| Bicycle Lane | 15.7 MPH | 55 feet | 28 feet | 83 feet | 75,000 |
| Sidewalk | 12.4 MPH | 43 feet | 17 feet | 60 feet | 122,000 |

This data strongly suggests that it is primarily lower bicyclist speeds that are responsible for reduced risks for bicycle lane and sidewalk users.

Note that for motorist drive-out crashes, the risk increases as the position moves from travel lane to bicycle lane to sidewalk. The relative positions of the conflict points would likely contribute to this difference. For right hook and left cross crashes, the bicycle lane and sidewalk conflict points are farther from the motor vehicle's original position in the parallel travel lane compared to the travel lane edge, giving those users more time to perceive and react to the impending conflict. For motorist drive-out crashes, the reverse is true; the sidewalk conflict points are closer to the motor vehicle's original position compared to the bicycle lane or travel lane edge, giving the sidewalk bicyclist less time to perceive and react to the drive-out. In some circumstances, sightlines for the sidewalk will contribute to this limitation, but this level of detail was not explored in this study.

THE DATA STRONGLY SUGGESTS LOWER BICYCLIST SPEEDS ARE PRIMARILY RESPONSIBLE FOR REDUCED RISKS FOR BICYCLE LANE AND SIDEWALK RIDERS.

### *Comparing Risks for Bicyclists Facing Traffic*

The American Association of State Highway and Transportation Officials (AASHTO) Guide for the Development of Bicycle Facilities[iii] has for many years warned – regarding the installation of shared use paths adjacent to roadways -- "before committing to this option for longer distances on urban and suburban streets with many driveways and street crossings, practitioners should be aware that two-way sidepaths can create operational concerns." (2012 edition)

The section describes fourteen problems likely to be encountered, the first of which is, "At intersections and driveways, motorists entering or crossing the roadway often will not notice bicyclists approaching from their right, as they do not expect wheeled traffic from this direction. Motorists turning from the roadway onto the cross street may likewise fail to notice bicyclists traveling the opposite direction from the norm."

Data from this study can illustrate the relative risks not only between riding with traffic and facing traffic, but also between shared use sidepaths and other facilities.

Table 18: Miles Between Motorist-Caused Crashes: Shared Use Sidepath (In Thousands of Miles)

| Bicyclist Direction | # of Crashes | Miles of Exposure | Miles Between Crashes (Exposure/ Crashes) | Risk Compared to With Traffic |
|---|---|---|---|---|
| With Traffic | 8 | 1,703 | 213 | NA |
| Facing Traffic | 43 | 1,712 | 40 | 433% (5.3X) higher |
| Combined | 51 | 3,415 | 67 | 218% (3.2X) higher |

Table 19: Miles Between Motorist-Caused Crashes: Sidewalk (In Thousands of Miles)

| Bicyclist Direction | # of Crashes | Miles of Exposure | Miles Between Crashes (Exposure/ Crashes) | Risk Compared to With Traffic |
|---|---|---|---|---|
| With Traffic | 64 | 7,803 | 122 | NA |
| Facing Traffic | 299 | 6,825 | 23 | 430% (5.3X) higher |
| Combined | 363 | 14,628 | 40 | 205% (3.1X) higher |

Table 20: Miles Between Motorist-Caused Crashes: Travel Lane (In Thousands of Miles)

| Bicyclist Direction | # of Crashes | Miles of Exposure | Miles Between Crashes (Exposure/ Crashes) | Risk Compared to With Traffic |
|---|---|---|---|---|
| With Traffic | 12 | 367 | 31 | NA |
| Facing Traffic | 6 | 35 | 5.8 | 434% (5.3X) higher |

Table 21: Miles Between Motorist-Caused Crashes: Bicycle Lane (In Thousands of Miles)

| Bicyclist Direction | # of Crashes | Miles of Exposure | Miles Between Crashes (Exposure/ Crashes) | Risk Compared to With Traffic |
|---|---|---|---|---|
| With Traffic | 55 | 3,509 | 64 | NA |
| Facing Traffic | 38 | 583 | 15 | 327% (4.3X) higher |

Tables 18 through 21 show a relative risk for facing traffic bicycling that is significantly higher than found in prior studies. Wachtel and Lewiston[iv] found facing traffic to be 3.6 times riskier. A 2007 study by Huang and Petritsch[v] for MetroPlan Orlando found the risk on sidewalks to be 4.4 times higher. Shared use sidepaths, sidewalks and travel lanes in this study all had risk levels for facing traffic 5.3 times greater than for bicyclists traveling with the flow. For bicycle lanes, the risk was 4.3 times greater.

While the facing traffic risk for these sidepaths is significantly lower (74%) than for regular sidewalks, there is a critical factor that explains the difference – the frequency of conflict points.

*Frequency of Intersections and Commercial Driveways*

The five sidepaths experienced the lowest motorist-caused crash rates of all for same-direction bicyclists (seven times lower than for travel lanes), but the numbers of conflict points varies greatly between those paths and the bicycle lane and control streets studied. Three paths had an average of 4.6 intersections and commercial driveways per mile, and their crash rates averaged 81,000 miles (for both directions of travel) compared to the regular sidewalks on the bicycle lane and control streets, with 10.5 intersections and commercial driveways per mile and 40,000 miles between motorist-caused crashes. The other two paths had an average of 11.6 conflict points per mile and a crash rate of 29,000 miles. Path users on the two high-conflict paths were about 1/3rd faster than regular sidewalk users.

The overall better crash rate for the sidepaths is due to fewer conflict points per mile. Installing shared use paths along the twenty bicycle lane and control streets would be unlikely to reduce bicyclist risk, as the numbers of intersections and driveways would not be significantly reduced, and bicyclist speeds would likely increase.

**Table 22: Miles Between Motorist-Caused Crashes: Shared Use Sidepath (In Thousands of Miles)**

| Three Low Conflict Paths (Avg. 4.6 Intersections & Commercial Driveways per Mile) | | | | |
|---|---|---|---|---|
| Bicyclist Direction | # of Crashes | Miles of Exposure | Miles Between Crashes (Exposure/ Crashes) | Path Risk Compared to Sidewalks (10.5 Conflicts per Mile) |
| With Traffic | 2 | 1,482 | 494 | 305% Lower |
| Facing Traffic | 34 | 1,521 | 45 | 96% Lower |
| Combined | 36 | 3,003 | 81 | 103% Lower |

| Two High Conflict Paths (Avg. 11.6 Intersections & Commercial Driveways per Mile) | | | | |
|---|---|---|---|---|
| Bicyclist Direction | # of Crashes | Miles of Exposure | Miles Between Crashes (Exposure/ Crashes) | Path Risk Compared to Sidewalks (10.5 Conflicts per Mile) |
| With Traffic | 5 | 220 | 44 | 64% Higher |
| Facing Traffic | 9 | 191 | 21 | 9% Higher |
| Combined | 14 | 411 | 29 | 28% Higher |

In the above pair of tables we can see the interplay between the frequency of conflict points and bicyclist direction. For the high-conflict paths, the combination of frequent conflict points and users traveling facing traffic results in a combined crash rate that is 28% higher than for sidewalk bicyclists.

The risk for facing traffic on the high-conflict paths was more than twice as high as for the low-conflict paths, and the risk for with-traffic travel was more than eleven (11) times higher. The with-traffic risk on the high-conflict sidepaths was 2.7 times higher than for regular sidewalks, though the risk for facing traffic was only 10% higher. Bicyclist speeds were about one third faster on the high-conflict paths than on the regular sidewalks (85th percentile speeds 16.7 MPH for high-conflict paths versus 12.4 MPH on sidewalks).

*Safety In Numbers*

In a 2003 paper in Injury Prevention, Peter Jacobsen found a correlation between higher bicyclist (and pedestrian) exposure levels and lower crash rates. The correlations were across geographies (European nations and California cities), and over time (United Kingdom and The Netherlands). In the discussion section, Jacobsen wrote: *"It seems unlikely that people walking or bicycling obey traffic laws more or defer to motorists more in societies or time periods with greater walking and bicycling. Indeed it seems less likely, and hence unable to explain the observed results. Adaptation in motorist behavior seems more plausible and other discussions support that view."*

With the combination of crash typology and bicyclist exposure data, we can test Jacobsen's hypothesis. The twenty study streets were divided into quintiles of four streets each ranked by the total bicyclist exposure. Ten years of estimated exposure ranged very widely, from 205,000 bicyclist miles along the four lowest quintile streets, to over 12 million miles along the highest quintile. Table 23 shows the bicyclist exposure and risk for motorist-caused and bicyclist-caused crashes by quintile (rounded to the nearest thousand).

**Table 23: Bicyclist Crash Risk by Fault and Exposure Level (In Thousands of Miles)**

| | Four Streets per Quintile | | | | |
|---|---|---|---|---|---|
| **Quintile Streets by Bicyclist Exposure** | **Lowest Quintile** | **2nd Quintile** | **3rd Quintile** | **4th Quintile** | **Top Quintile** |
| Total Bicyclist Miles Traveled – All Positions | 205 | 1,087 | 2,226 | 3,285 | 12,318 |
| Miles Between Motorist-Caused Crashes | 19 | 46 | 39 | 49 | 45 |
| Miles Between Bicyclist-Caused Crashes | 13 | 73 | 125 | 205 | 198 |

The lowest quintile can be ignored, as two of those four streets experienced only one and zero motorist-caused crashes, and the entire quintile had far lower exposure numbers (roughly one-fifth the exposure of the 2nd quintile). Table 23 shows that the rate of motorist-caused crashes remains essentially unchanged as bicyclist exposure increases.

The rate for bicyclist-caused crashes improved by 171% from the 2nd quintile to the top quintile, and 180% higher from the 2nd to the 4th quintile. It is therefore generally safer bicyclist behavior that is responsible for the reduced overall crash rate, and not improved motorist behavior.

The top quintile is comprised of one four-lane and three six-lane arterials, all posted at 40 MPH or higher, with bicycle lanes on two of the six-lane streets. Three of the four 4th quintile streets are two-lane streets with bicycle lanes, all serving commercial areas, while the fourth street is a 6-lane arterial without a bicycle lane.

Another measure that may inform the question of whether motorist behavior improves with increased bicyclist exposure is the change over time. Assuming Jacobsen's assumption is correct, motorist yielding should improve over time on streets with more bicyclists as drivers get more experience seeing and interacting with bicyclists. But comparing the last five years to the first five years, the number of motorist-caused crashes for bicycle lane users *increased* by 89% (from 19 to 36. For the control streets motorist-caused crashes for travel lane cyclists *decreased* by 50%, from eight to four. These results are the inverse of what is predicted by Jacobsen's hypothesis. Overall, for all bicyclist positions, motorist-caused crashes increased 43% on the bicycle lane streets and 22% on the control streets.

It remains plausible that motorist behavior might improve with bicycle use significantly higher than experienced in the Orlando metro area. On the top quintile streets a bicyclist would pass a given point on-average once every eight (8) minutes. The chance that an Orlando-area motorist will actually encounter a bicyclist while crossing the path of a potential bicyclist is very low. Frequencies on many European streets no doubt greatly exceed these rates, to the extent that in some areas bicyclists would almost constantly be in view.

The likelihood of such bicycling levels in the Orlando metropolitan area is extremely low. This area's bicycle commute rate from the U.S. census has shown only a 30% increase from 1990 through 2017 (from 0.6% to 0.8%), in spite of adding over 600 miles of bicycle lanes and nearly 200 miles of shared use paths.

### *Crash Severity and Crash Types*

Bikeway proponents have argued that primary attention should be placed on mitigating overtaking motorist crashes, as they are most likely to result in serious and fatal injuries. Fatal overtaking crashes are most associated with high posted speeds, darkness, and low-density and rural land use.

In an areawide analysis of 5,122 bicyclist crashes from 2011 through 2017, a total of 793 resulted in fatal (92) or incapacitating injuries (701). The ratio of serious and fatal injuries due to overtaking crashes compared to motorist-caused turning and crossing crashes changes significantly with posted speed.

**Table 24: Fatal and Incapacitating Injuries by Posted Speed; Overtaking Versus Turning and Crossing (Areawide Crashes, 2011 Through 2017)**

| | Number of Fatal & Incapacitating Injuries | | Ratio: Motorist Failure to Yield/ Overtaking |
|---|---|---|---|
| Posted Speed | Overtaking Motorist | Motorist Failure to Yield* | |
| <35 MPH | 8 | 107 | 13.4 |
| 35 to 40 MPH | 23 | 59 | 2.6 |
| 45+ MPH | 47 | 79 | 1.7 |
| Combined | 78 | 245 | 3.1 |

* Includes bicyclists facing traffic on sidewalk

If the focus is to be put on reducing serious and fatal motorist-caused injuries, then more attention should be given to reducing turning and crossing failure-to-yield crashes than to overtaking crashes, particularly on lower-speed streets.

In this narrower study of bicycle lane and control streets, ten (10) out of 428 motorist-caused crashes involved overtaking motorists, with one of these resulting in a serious injury, and no fatalities. Of the 418 other motorist-caused crashes involving turning and crossing conflicts, sixty (60) resulted in serious injuries and one was a fatality. The Failure to Yield/Overtaking ratio for serious and fatal injuries for these twenty streets is 61 to 1.

Table 25: Years Between Motorist-Caused Crashes per Average Centerline Mile by Bicyclist Position

| | Years Between Motorist-Caused Crashes per Average Centerline Mile | | |
|---|---|---|---|
| **Bicyclist Position** | **Overtaking** | **Turning & Crossing: Bicyclist With Traffic Only** | **Turning & Crossing: Both Directions** |
| Travel Lane | 52 | 35 | NA |
| Bicycle Lane | 41 | 5 | NA |
| Sidewalk | NA | 7 | 1.2 |

Another way to compare overtaking crashes with turning and crossing crashes is to estimate the length of time between such crashes. Table 25 shows that overtaking crashes involving travel lane bicyclists occur only once every 52 years for an average mile of control street. Turning and crossing crashes for bicycle lane users by comparison were more than ten times more frequent, and crashes for sidewalk bicyclists traveling in both directions were forty-three (43) times as frequent.

### *Crash Reduction Versus Risk Reduction*

Risk reduction does not necessarily result in a reduced number of crashes. While bicycle lane, sidewalk, and sidepath users going with the flow of traffic had lower crash risk rates, the numbers of motorist-caused crashes on those facilities were significantly higher, and were many times greater when both directions of travel are included for sidewalks and sidepaths.

Table 26: Crash Reduction Versus Risk Reduction

| | | Travel Lane | Bicycle Lane | Sidewalk | | Shared Use Sidepath | |
|---|---|---|---|---|---|---|---|
| | | | | **With Traffic** | **Both Directions** | **With Traffic** | **Both Directions** |
| **Motorist-Caused Crash Risk** | Bicyclist Miles per Crash | 31,000 | 64,000 | 122,000 | 40,000 | 213,000 | 67,000 |
| | Compared to Travel Lane | NA | 106% Lower | 294% Lower | 29% Lower | 587% Lower | 116% Lower |
| **Number of Motorist-Caused Crashes** | Crashes per Center Line Mile per Year | 0.06 | 0.23 | 0.14 | 0.80 | 0.05 | 0.35 |
| | Compared to Travel Lane | NA | 283% Higher | 133% Higher | 1233% Higher | 17% Lower | 483% Higher |

Overall, the bicycle lane streets had 28% more bicyclist travel, an 11% higher motorist-caused crash rate, and 34% more motorist-caused crashes than the control streets. They also had six times as many wrong-way bicyclist crashes. Since sidewalk cycling facing traffic has the highest risk and highest number, it overwhelms the more modest gains made by same direction bicycle lane use.

# Discussion

## Importance of Bicyclist Speed as a Safety Factor for Risk Assessment, Design, and Policy Decisions

*Risk Assessment*

Two key behavioral factors are potentially responsible for the lower motorist-caused crash risks found for bicycle lane and sidewalk users traveling with the flow of traffic: lower bicyclist speeds and improved yielding by motorists.

While measuring bicyclist speeds is a straightforward effort, measuring motorist yielding is far more problematic. Failure-to-yield rates may change based on a number of variables aside from the presence or lack of a bikeway, such as lighting, land use, number of lanes, presence of a median, motor vehicle traffic volume, type of conflict, and type of conflict point (signalized intersection, stop controlled intersection, commercial driveway, or residential driveway). So, for example, a yield rate for drive-out conflicts at a high-volume signalized intersection may not be comparable to the yield rate for a right hook conflict at a commercial driveway.

Bicyclist speed and position also play roles in whether or not a motorist yields. Faster bicyclists who travel along the right edge, bicycle lane, or sidewalk will inevitably spend more time in the right-rear blind spots of passing motorists, increasing their risk for right hook crashes, compared to slower bicyclists. Anecdotal reports from fitness bicyclists suggests that faster bicyclists are also more likely to encounter left cross and drive-out conflicts. In order to reduce and manage those motorist-caused conflicts, bicyclists receiving formal bicycle traffic safety training are taught to drive near the center of a regular travel lane (a technique called “lane control” in the U.S. and “the primary position” in the United Kingdom), and report that this strategy is very effective. Being in the center of the lane improves sight distance for both the motorist and the bicyclist, as well as giving the bicyclist more maneuvering space and braking distance to avoid conflicts.

Determining whether failure-to-yield has even occurred is also a challenge. One would need to see that the bicyclist had to take evasive action -- either braking or turning -- to avoid the conflict in order to determine that the motorist violated the bicyclist’s right-of-way.

As noted earlier, bicycle lane proponents suggest that the designation of the lane encourages motorists to yield better, but motorist right hook and left cross crash rates were much lower for sidewalk bicyclists going with the flow than for bicycle lane users, in spite of the fact that regular sidewalks are neither designated nor designed for use by bicyclists. Anecdotal stories from experienced bicyclists suggest that motorist failure-to-yield conflicts are more common on bicycle lanes, sidewalks and sidepaths. This is likely due to the higher speeds at which those experienced bicyclists travel.

Since bicyclist speed and stopping distance are shown in this study to vary significantly for travel lane, bicycle lane and sidewalk bicyclists, and motorist drive-out crashes at intersections and driveways are more likely for bicycle lane and sidewalk users than for travel lane cyclists, we should assume that slower bicyclist speed is the more likely reason for the reduced motorist-caused crash risks found on bicycle lanes and sidewalks for bicyclists going with the flow of traffic.

The question “How fast is too fast?” inevitably arises. As this is a multivariate problem and the key risk factors vary widely from street to street, and even from block to block and hour to hour, it is simply not possible to set a speed threshold below which bicycle lane, sidewalk or sidepath use is "safe." Only an informed and trained bicyclist can determine where he or she should operate (within the bounds of normal vehicular movement) based on their speed. We should assume that some bicyclists will have the capacity or opportunity to travel at higher speeds and have valid reasons to avoid operating on sidewalks, bicycle lanes, sidepaths, or the right edge of a regular travel lane, preferring instead full use of a regular travel lane in the same manner as other vehicle drivers.

*Design*

Designers of separated bicycle lanes and channelized intersections understand the benefit of slowing bicyclists on the approaches to intersections and providing separate signal phasing for bicyclists to reduce conflicts (AASHTO – see reference 5, page 172). Such slowing is usually accomplished by introducing curves into the path on the approach to the intersection. Without such treatment a separated bicycle lane is operationally little different from a regular sidewalk for same-direction bicyclist travel.

But motorist failure-to-yield crashes are widely dispersed along corridors, with the majority of them occurring at driveways and minor unsignalized intersections.

**Table 27: Locations of Motorist Turning and Crossing Crashes**

| **Motorist Right Hook, Left Cross and Drive-Out Crashes: Bicyclist With Traffic Only**<br>Entire Metro Orlando Area, 2011 through 2017 | | | |
|---|---|---|---|
| **Crash Locations** | **Signalized Intersection** | **Unsignalized Intersection** | **Driveway** |
| Number of Crashes | 206 | 305 | 222 |
| Percent of Motorist-Caused | 28% | 42% | 30% |

Reducing bicyclist speeds at all of these locations would be both impractical and expensive. For those who need to travel longer distances, it would also reduce the utility of bicycling by significantly increasing travel time. Bicyclists cross an intersection or commercial driveway roughly every 250 feet on the twenty bicycle lane study and control streets. Faster users would need to repeatedly slow to reduce their risk at those points. Such repeated slowing and accelerating greatly increases the bicyclist's effort to maintain a higher average speed.

Faster bicyclists should not be considered as intended users for sidewalks, bicycle lanes or shared use sidepaths, as their speed makes avoidance of motorist-caused crashes much more difficult. Furthermore, such bicyclists should be supported as normal users of regular travel lanes through the installation of shared lane markings and "Bicyclists May Use Full Lane" signs.

*Policy*

All of the above evidence supports the argument that bicyclists should not be compelled to use a facility, roadway position, or direction of travel that increases their crash risk. Laws that require mandatory use of sidepaths should be rescinded as they require half of the users to travel facing traffic, increasing their crash risk more than five-fold. Laws that require mandatory use of bicycle lanes and to drive "as close as practicable to the right-hand edge" should also be rescinded; the combination of a higher bicyclist speed and a more rightward position increases their risk for the most common motorist-caused crashes.

While there is reduced risk for traveling at lower speeds on bicycle lanes and sidepaths compared to bicycling along the rightmost edge of a travel lane, it has not been shown that such risk is lower than for bicyclists using lane control. Authorities cannot determine what constitutes a "safe" bicyclist speed or position at any given place and time, and -- aside from the regular roadway posted speed and the requirement for drivers to use the right half of the roadway – should leave that to the discretion of the bicyclist.

## Bicyclist and Motorist Training

*Bicyclists*

Bicyclists should be taught to understand how their direction, position and speed affect their safety. All bicyclists will benefit from avoiding traveling against the flow of traffic, whether on the roadway or on a sidewalk or sidepath, especially on corridors with frequent intersections and driveways. For bicyclists traveling with the flow, understanding the relationship between their speed, their position, and the likelihood of motorist-caused crashes is essential. Faster cyclists would benefit most from such training, but slower bicyclists benefit significantly as well. The increasing popularity of electric-assist bicycles should be of special concern, as they allow novice bicyclists to travel much faster than they would normally be able.

It might be argued that priority should be directed at motorists to reduce their tendency to violate bicyclists' right-of-way, as that is the direct cause of the crash, but we expect that motorists will make mistakes and also violate the right-of-way of other motorists, so we value and teach defensive driving strategies. For the same reason we should teach defensive bicycling strategies.

*Motorists*

Motorists should expect bicyclists to come from either direction on a sidewalk or sidepath, and understand that they need to scan farther to each side to account for their faster speed. They should also understand that bicyclists may be traveling faster than they appear to, and give ample time and space when crossing the path of an approaching cyclist. When passing bicyclists who are using regular travel lanes, motorists should default to making a full lane change rather than attempting to judge the three-foot passing clearance required by many states.

Motorists should also understand that when bicyclists choose to use an entire travel lane – even if a bicycle lane or shared use sidepath is available -- they are doing so as a defensive driving strategy, to protect themselves against motorist turning and crossing errors as well as against close passes.

## Limits of This Study

This crash analysis approach should be replicated in other metropolitan areas and regions. The streets in this study, and in the Orlando metropolitan area in general, are predominantly suburban in character. Areas with denser urban, or with more rural characteristics, would likely exhibit different risk outcomes.

The numbers of motorist-caused crashes in this study involving travel lane bicyclists (10) and bicycle lane users (55) is still fairly small in spite of ten years of crash data. Understanding of these factors and risks would benefit from additional study corridors and crash data.

# Conclusions

Earlier studies of bikeways have found correlations between the presence of a bicycle lane or path, and reduced overall bicyclist crash rates. But since those studies did not measure key causal and environmental factors such as relevant motorist behaviors, relevant bicyclist behaviors, or the numbers of conflict points, they cannot conclude that bikeways cause a reduction in rates of motorist-caused crashes.

The combination of detailed bicyclist crash typology and detailed exposure data including bicyclist position, direction and speed provides a much clearer understanding of the most important factors contributing to crashes between bicyclists and motorists, especially those caused by motorists. The number of intersections and commercial driveways, the direction of bicyclists in relation to normal vehicular movement, bicyclist speed, and bicyclist lateral position are the key factors for motorist-caused crashes.

## Key Findings

The factors most likely to contribute to motorist crashes with bicyclists are:

***Bicyclist Direction***: bicyclists traveling facing the flow of normal vehicular movement, whether on a sidepath, sidewalk, bike lane or travel lane, are 5 times more likely to be involved in a crash.

***Frequency of Intersections and Commercial Driveways***: since 95% of urban and suburban bicycle crashes involve turning and crossing conflicts at intersections and driveways, the frequency of those conflict points is a key contributing factor. Reduced crash rates attributed to bicycle facilities are likely due more to this underlying factor than to the bikeway itself.

***Bicyclist Speed***: on average, bicyclists who travel on sidepaths, sidewalks and bike lanes travel slower than those who use regular travel lanes. Slower cyclists need less time and distance to stop when a motorist violates the bicyclist's right-of-way.

The "safety-in-numbers" correlation – which shows reduced crash rates as the numbers of bicyclists increases – is due to a *lower rate of bicyclist-caused* crashes, rather than a broadly-assumed reduction in motorist-caused crashes.

Since more than 95% of motorist-caused crashes in urban and suburban areas involve turning and crossing conflicts at intersections and commercial driveways, the frequency of those conflict points corresponds closely to the crash rate. A 152% increase in intersections and commercial driveways per mile on sidepaths corresponded to a 179% increase in risk for motorist-caused crashes. Crash reduction should therefore focus on the strategies that best mitigate those conflicts. Mitigation efforts should be focused on the practical factors speed, geometry, physics, and the limits of human perception rather than bicyclist attitudes or demographics.

As has been found in a number of prior studies, traveling facing the flow of normal vehicular traffic along two-way streets increases a bicyclist crash risk five-fold, no matter the bicyclist's lateral position. Facilities that encourage or require bicyclists to travel facing traffic should be avoided except for along corridors with very few intersections or commercial driveways, and bicyclists should be taught to understand this greatly increased risk.

Higher bicyclist operating speeds increase the risk for motorist-caused turning and crossing crashes, since faster bicyclists require significantly more time and distance to perceive, react and brake when a motorist violates his or her right-of-way. For bicyclists going with the flow, each additional mile per hour increases a bicyclist's risk for motorist-caused turning and crossing crashes by approximately 9%.

For bicyclists traveling with the flow, a more rightward position increases the risk for motorist drive-out crashes. Faster bicyclists using more rightward positions would experience still-greater risk. The faster a bicyclist travels, the more important it is for the bicyclist to use a lane control position to mitigate most motorist-caused crashes.

The safety-in-numbers correlation is best explained – at least in the predominantly suburban context of metro Orlando -- by safer bicyclist behavior rather than improved motorist behavior.

In short, the data in this study strongly suggests that bicycle lanes, sidewalks and shared use sidepaths do not make bicyclists significantly safer from motorist-caused crashes; rather, the context in which the facility exists (land use, numbers of intersections and commercial driveways) and the behaviors of the bicyclists who use them make some facilities safer.

## References

[i] Identifying Critical Behavior Leading to Collisions Between Bicycles and Motor Vehicles; Kenneth Cross; 1974;,https://www.johnforester.com/Articles/Safety/Cross01.htm

[ii] http://www.pedbikeinfo.org/pbcat_us/about.cfm

[iii] Guide for the Development of Bicycle Facilities; American Association of State Highway and Transportation Officials; 2012; https://njdotlocalaidrc.com/perch/resources/aashto-gbf-4-2012-bicycle.pdf

[iv] Risk Factors for Bicycle-Motor Vehicle Collisions at Intersections; Alan Wachtel, Diane Lewiston; ITE Journal; 1994; http://www.bicyclinglife.com/Library/riskfactors.htm

[v] Pedestrian and Bicycle Crash Plotting and Counts and Behaviors Observations; Herman Huang, Theodore Petritsch; MetroPlan Orlando; 2007; https://metroplanorlando.org/wp-content/uploads/MetroPlanOrlando_PedestrianAndBicycleCrashAndBehaviors_Report_7-17-2007.pdf