Bicyclist Safety on US Roadways: Crash Risks and Countermeasures

Safety Research Report

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National Transportation Safety Board

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National Transportation Safety Board

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Abstract: This safety research report updates our understanding of bicyclist safety in the United States by examining the prevalence and risk factors of bicycle crashes involving motor vehicles on US roadways and assessing the most applicable countermeasures. To conduct this research, the National Transportation Safety Board (NTSB) used the following combination of quantitative and qualitative methods: reviewing countermeasures and research literature; analyzing crash and injury data; and interviewing national, state, and local traffic safety stakeholders.

The NTSB identified three bicyclist safety issue areas in this report: (1) improving roadway infrastructure for bicyclists, (2) enhancing conspicuity, and (3) mitigating head injury. Other safety issues that repeatedly emerged during stakeholder interview sessions are also discussed.

As a result of this safety research report, the NTSB makes new recommendations to the Intelligent Transportation Systems Joint Program Office; the National Highway Traffic Safety Administration (NHTSA); the Federal Highway Administration; the US Consumer Product Safety Commission; the 50 states, the District of Columbia, and the Commonwealth of Puerto Rico; and the American Association of State Highway and Transportation Officials. The NTSB also reiterates 10 recommendations to NHTSA.

For more detailed background information on this report, visit the NTSB investigations website and search for NTSB accident ID DCA18SS002. Recent publications are available in their entirety on the NTSB website. Other information about available publications also may be obtained from the website or by contacting—
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Executive Summary

Safety Research Topic

It has been 47 years since the National Transportation Safety Board (NTSB) analyzed bicyclist safety in the United States (NTSB 1972). Recently, several safety issues involving bicyclists and other vulnerable road users have emerged in NTSB reports (NTSB 2013a, 2017a, 2017b, 2018a, 2018b). In 2017 alone, 806 bicyclists died in crashes with motor vehicles on US roadways, which was comparable to the deaths resulting from railroad or marine accidents and more than twice the number of deaths resulting from aviation accidents in the same year (NCSA 2019; NTSB 2017c).[1] The increasing availability of bicycles, their growing use as a means of transportation, and the resulting trends and safety issues require attention. This NTSB safety research report updates our understanding of bicyclist safety in the United States by examining the prevalence and risk factors of bicycle crashes involving motor vehicles on US roadways and assessing the most applicable countermeasures.[2]

Bicyclists, like pedestrians and motorcyclists, are considered vulnerable road users because they are unprotected by an enclosed vehicle compartment, leaving them more vulnerable to injury or death in the event of a crash. In 2018, the NTSB issued reports addressing pedestrian and motorcyclist safety, and with this safety research report on bicyclist safety, the NTSB again expands its effort to increase awareness of and address safety issues affecting vulnerable road users (NTSB 2018a, 2018b). To conduct this research, the NTSB used the following combination of quantitative and qualitative methods: reviewing countermeasures and research literature; analyzing crash and injury data; and interviewing national, state, and local traffic safety stakeholders. The research goals were to (1) describe fatal and nonfatal injury trends associated with bicycle crashes involving motor vehicles, (2) examine the scope and nature of bicyclist crash and injury risk factors and assess data limitations, (3) identify proven countermeasures that may be underused, (4) assess obstacles that may interfere with the full use of the identified countermeasures, and (5) explore emerging issues that are relevant to bicycling safety.

Bicyclists involved in crashes with motor vehicles are more likely to sustain severe injuries than bicyclists involved in any other crash type. As a result, this research focuses on bicycle crashes involving motor vehicles and specifically examines existing and emerging countermeasures designed to improve bicyclist safety on public roads, such as roadway and infrastructure designs to separate bicycles from motor vehicle traffic; rider and bicycle conspicuity enhancements; vehicle technologies designed to reduce collisions between motorists and bicyclists when they are sharing the road; and protective equipment for reducing the severity of injuries to bicyclists involved in crashes with motor vehicles. Single-bicycle crashes and bicycle collisions with pedestrians are not addressed; however, many of the safety countermeasures examined have the potential to prevent other bicycle crash types or reduce injury severity.

[1] In 2017, 761 people died as a result of railroad accidents, 694 people died as a result of marine accidents, and 350 people died as a result of aviation accidents.

[2] Additional information about this safety research can be found in the NTSB Docket Management System, using the NTSB ID DCA18SS002. For more information about NTSB safety recommendations, see the Safety Recommendation Database at www.ntsb.gov.

Safety Issues

The safety issues identified in this report include the following:

- **Improving roadway infrastructure for bicyclists.** Although more bicycle crashes involving motor vehicles occur at intersections, crash severity is higher when a crash occurs at a midblock location. The travel speeds of motor vehicles at midblock locations tend to be higher compared to intersections where there may be traffic lights, stop signs, or turning vehicles. Improving public roadway infrastructure with separated bike lanes, intersection treatments, and road diets can reduce crashes at midblock and intersection locations by separating bicycle and motor vehicle traffic, and by lowering motor vehicle travel speeds in areas where traffic speed and volume are high.[3]

- **Enhancing conspicuity.** There are different reasons why motorists and bicyclists may not detect each other in time to prevent a collision. In about one third of cases in which bicyclists died in crashes involving a motor vehicle overtaking a bicycle, the motorist reported not detecting the bicyclist before the crash. Improving the ability to see other road users can reduce the likelihood of collisions when motorists and bicyclists are sharing public roadways. Bicyclists wearing bright or reflective clothing, bicycles with lights or reflective materials, enhanced motor vehicle headlights, and in-vehicle crash warning and prevention systems are all countermeasures that could potentially alert motorists to bicycle traffic and help them avoid collisions with bicyclists.

- **Mitigating head injury.** Head injury is the leading cause of bicycle-related deaths, and head injuries are prevalent in bicycle crashes with motor vehicles. A bicycle helmet is an effective way to mitigate head injury when a bicycle crash occurs. However, the underutilization of helmets continues to contribute to the incidence of deaths and serious injuries among crash-involved bicyclists. A comprehensive national strategy to increase helmet use among riders of all ages is needed. The strategy should focus on evidence-based approaches for state and local governments to increase helmet use among all bicyclists, such as a helmet requirement for bicyclists of all ages; helmet distribution programs; and effective educational campaigns.

[3] According to the FHWA, a *road diet* repositions pavement markings to better meet the needs of all road users. Examples of road diets include reducing the number of through lanes, a wider shoulder, a two-way left turn lane, and providing a dedicated space for bicycle facilities (FHWA 2014).

Findings

- Current available data likely underestimate the level of bicycling activity in the United States.
- Combining traditional and innovative data collection approaches could improve measures of bicycling activity.
- Police crash report data likely underestimate the scope of bicyclist nonfatal injuries.
- Bicycle crashes involving motor vehicles at midblock locations are more likely to result in fatal and serious injuries for the bicyclists.
- Separated bike lanes could prevent bicycle crashes involving motor vehicles at midblock locations and, thereby, also reduce the number of fatalities and serious injuries associated with such crashes.
- Combining proven countermeasures to improve bicyclist safety at intersection and midblock locations can create a network of safer roadways for bicyclists.
- Consolidating guidance concerning separated bike lanes, intersection treatments, and the transition between them may increase the implementation of separated bike lanes by transportation planning and engineering practitioners.
- Reducing traffic speeds can improve bicycle safety by reducing the likelihood of fatal or serious injury in the event of a crash.
- The road diet is a proven safety countermeasure that both reduces traffic speeds and provides space on the roadway for the implementation of bicycle facilities, such as separated bike lanes.
- Including separated bike lanes and intersection safety treatments in the Federal Highway Administration’s Proven Safety Countermeasures initiative and Every Day Counts program could help accelerate their adoption and improve bicyclist safety.
- Improving bicycle conspicuity may reduce the likelihood of collisions between bicycles and motor vehicles.
- The existing requirements for bicycle conspicuity, established in 1980, are outdated and do not adequately reflect modern advances in bicycle conspicuity materials and technologies.
- Revising Federal Motor Vehicle Safety Standard 108 to allow adaptive headlight systems and to require evaluating headlights in real-world settings rather than in a laboratory would likely result in headlights that improve drivers’ ability to detect other road users, including bicyclists.
- Collision avoidance system technologies could be modified to detect bicycles, which would likely reduce the incidence of collisions between motor vehicles and bicycles and mitigate injuries caused by collisions when they occur.

- The National Highway Traffic Safety Administration’s delays in updating the New Car Assessment Program have likely slowed the development of important safety systems for vulnerable road users and their implementation into the vehicle fleet.

- The US Department of Transportation’s slow progress in developing standards for connected vehicle technology has delayed the implementation of potentially lifesaving technology.

- The larger blind spots of large vehicles make it more difficult for their drivers to detect vulnerable road users.

- There continues to be a need for performance standards to ensure blind spot detection systems are capable of detecting vulnerable road users, including bicyclists.

- Head injury is the leading cause of bicycle-related deaths, and bicyclists involved in crashes with motor vehicles sustain a higher proportion of head injuries.

- Bicycle helmets provide effective protection and mitigate head injuries in the event of a crash.

- The underutilization of bicycle helmets has contributed to the incidence of deaths and serious injuries among crash-involved bicyclists.

- Requiring helmet use is the most effective means for increasing helmet use and reducing bicyclist head injuries.

- A comprehensive strategy that includes both helmet legislation and complementary nonlegislative interventions is most likely to increase overall helmet use among bicyclists of all ages.

Recommendations

New Recommendations

To the Intelligent Transportation Systems Joint Program Office

In collaboration with the National Highway Traffic Safety Administration and the Federal Highway Administration, expand vehicle-to-pedestrian research efforts to ensure that bicyclists and other vulnerable road users will be incorporated into the safe deployment of connected vehicle systems. (H-19-35)

To the National Highway Traffic Safety Administration

Incorporate into the New Car Assessment Program tests to evaluate a car’s ability to avoid crashes with bicycles. (H-19-36)

In collaboration with the Intelligent Transportation Systems Joint Program Office and the Federal Highway Administration, expand vehicle-to-pedestrian research efforts to ensure that bicyclists and other vulnerable road users will be incorporated into the safe deployment of connected vehicle systems. (H-19-37)

(1) Convene a bicycle safety coalition of stakeholders to develop a comprehensive national strategy to increase bicycle helmet use among bicyclists of all ages that would include, at a minimum, a model all-ages bicycle helmet law; (2) disseminate the strategy to all states and make it available on your website. (H-19-38)

After Safety Recommendation H-19-38 is completed, include the model all-ages bicycle helmet law in *Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices*. (H-19-39)

To the Federal Highway Administration

(1) Develop methods to combine traditional and innovative bicycle-counting approaches that capture bicycling activity data generated by bicyclists and bikeshare operations; (2) disseminate the methods to state transportation departments. (H-19-40)

Include separated bike lanes and intersection safety treatments on the list of Proven Safety Countermeasures. (H-19-41)

Include separated bike lanes and intersection safety treatments in the Every Day Counts program. (H-19-42)

In collaboration with the Intelligent Transportation Systems Joint Program Office and the National Highway Traffic Safety Administration, expand vehicle-to-pedestrian research efforts to ensure that bicyclists and other vulnerable road users will be incorporated into the safe deployment of connected vehicle systems. (H-19-43)

To the US Consumer Product Safety Commission

Conduct an evaluation to determine whether bicycle conspicuity could be improved by modifying the requirements described in Title 16 *Code of Federal Regulations* 1512.16; if so, revise the regulation accordingly. (H-19-44)

To the 50 states, the District of Columbia, and the Commonwealth of Puerto Rico

Require that all persons shall wear an age-appropriate bicycle helmet while riding a bicycle. (H-19-45)

To the American Association of State Highway and Transportation Officials

Include geometric design guidance materials on separated bike lanes, intersection treatments, and the transition between them in the next revision of the *Guide for the Development of Bicycle Facilities*. (H-19-46)

Previously Issued Recommendations Reiterated in This Report

To the National Highway Traffic Safety Administration

H-13-11

Develop performance standards for visibility enhancement systems to compensate for blind spots in order to improve the ability of drivers of single-unit trucks with gross vehicle weight ratings over 10,000 pounds to detect vulnerable road users, including pedestrians and cyclists, in their travel paths.

H-13-12

Once the performance standards requested in H-13-11 have been developed, require newly manufactured single-unit trucks with gross vehicle weight ratings over 10,000 pounds to be equipped with visibility enhancement systems meeting the performance standards.

H-13-30

Develop minimum performance standards for connected vehicle technology for all highway vehicles.

H-13-31

Once minimum performance standards for connected vehicle technology are developed, require this technology to be installed on all newly manufactured highway vehicles.

H-14-1

Require that newly manufactured truck-tractors with gross vehicle weight ratings over 26,000 pounds be equipped with visibility enhancement systems to improve the ability of drivers of tractor-trailers to detect passenger vehicles and vulnerable road users, including pedestrians, cyclists, and motorcyclists.

H-15-6

Expand the New Car Assessment Program 5-star rating system to include a scale that rates the performance of forward collision avoidance systems.

H-15-7

Once the rating scale, described in Safety Recommendation H-15-6, is established, include the ratings of forward collision avoidance systems on the vehicle Monroney labels.

H-18-39

Revise Federal Motor Vehicle Safety Standard 108 to include performance-based standards for vehicle headlight systems correctly aimed on the road and tested on-vehicle to account for headlight height and lighting performance.

H-18-40

Revise Federal Motor Vehicle Safety Standard 108 to allow adaptive headlight systems.

H-18-43

Incorporate pedestrian safety systems, including pedestrian collision avoidance systems and other more-passive safety systems, into the New Car Assessment Program.

References

FHWA (Federal Highway Administration). 2014. *Road Diet Informational Guide*, FHWA-SA-14-028. Washington, DC: FHWA.

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Figures

Tables

Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ACS	American Community Survey
AIP	All-Injury Program
API	Application Programming Interface
CAS	collision avoidance system
CDC	Centers for Disease Control and Prevention
CFR	*Code of Federal Regulations*
CPSC	US Consumer Product Safety Commission
CRSS	Crash Reporting Sampling System
DOT	US Department of Transportation
FARS	Fatality Analysis Reporting System
FAST Act	Fixing America's Surface Transportation Act
FHWA	Federal Highway Administration
FMVSS	Federal Motor Vehicle Safety Standard
FTA	Federal Transit Administration
GES	General Estimates System
GHSA	Governors Highway Safety Association
GIS	geographic information system
GPS	global positioning system
IIHS	Insurance Institute for Highway Safety
ITS JPO	Intelligent Transportation Systems Joint Program Office
LED	light-emitting diode
MUTCD	*Manual on Uniform Traffic Control Devices*
NACTO	National Association of City Transportation Officials

NASS	National Automotive Sampling System
NCAP	New Car Assessment Program
NEISS	National Electronic Injury Surveillance System
NHTS	National Household Travel Survey
NHTSA	National Highway Traffic Safety Administration
NPRM	notice of proposed rulemaking
NTD	National Transit Database
NTSB	National Transportation Safety Board
PMT	person miles of travel
V2I	vehicle-to-infrastructure
V2P	vehicle-to-pedestrian
V2V	vehicle-to-vehicle

Glossary of Bicycling-Related Terms

The following are bicycling-related terms used in this report. Several of the terms are also defined as they appear in the report. Illustrative photographs also accompany some of the terms in the report as well.

Bicycle: A nonmotorized, pedal-driven vehicle with one or more tires attached to a thin frame, such as a unicycle, a bicycle, or a tricycle.

Bicycle box: A designated area at the head of a traffic lane, in front of the stop line, at a signalized intersection location that provides bicyclists with a safe and visible way to get ahead of queuing traffic during the red signal phase. This designated area can be visibly marked using pavement markings, green paint, or a combination of both.

Bicycle facility: Any infrastructure improvement that facilitates the safe use of bicycles as one mode of transportation among many.

Bicycle signal face: A traffic-control device used to provide for separate control of bicycle movement at a signalized intersection location.

Bicyclist: The operator or rider of a bicycle, a passenger on a bicycle, or even a person being pulled by a bicycle, for example, in a wagon or trailer.

Buffered bike lane: A conventional bike lane with additional buffer space separating the bicycle lane from an adjacent vehicle travel and/or a parking lane.

Conventional bike lane: A preferential or exclusive space for bicycle travel along a roadway. It can be visually delineated by pavement marking, paint, and signage. It is located between a vehicular travel lane and a curb, a roadway edge, or a parking lane. It is typically placed on the right side of the roadway, and bicycles travel in the same direction as motor vehicles. It can be placed on the left side of the roadway if it is a one-way street.

One-way separated bike lane with parking as barrier: A separated bike lane that is restricted to one-way bicycle traffic and uses on-street parking as a barrier to separate bicycle traffic from vehicular traffic.

Painted one-way separated bike lane with vertical barrier: A separated bike lane that is restricted to one-way bicycle traffic and uses a vertical element, such as bollards, as a barrier along with paint to separate bicycle traffic from vehicular traffic.

Protected intersection: An intersection safety treatment for bicycle travel, typically designed for the continuation of separated bike lanes that carry bicycle traffic through a signalized or stop-controlled intersection. Typical design involves positioning the pedestrian crossing and bike lane farther in advance of the intersection area and installing islands.

Road diet: A roadway reconfiguration that removes travel lanes from a roadway and utilizes the space for other uses and travel modes, such as bicycles.

Separated bike lane: An exclusive space for bicycle travel along a roadway that is physically separated from vehicular traffic, parking lanes, and sidewalks by a raised median, on-street parking, or other vertical barrier, such as bollards. A separated bike lane is also known as a cycle track or a protected bike lane. It can be installed at street level or raised. It can be placed on the right side, the left side, or the center of a roadway. It can be restricted to one-way bicycle traffic, most typically with the vehicular traffic flow. If it allows for one-way bicycle traffic opposite the direction of vehicular traffic flow, it is known as a contraflow separated bike lane. It can also accommodate two-way bicycle traffic.

Two-stage bicycle turn box: A designated area at a signalized intersection for bicyclists to position themselves outside of the traveling path of motor vehicles and other bicycles. A bicyclist traveling in a bike lane along with the traffic on the right side of the roadway can travel through the intersection with the green signal, make the left turn inside the two-stage bicycle turn box, and wait for the green signal of the vehicular traffic or the pedestrian crossing signal. This designated area can be visibly marked using pavement markings, green paint, or a combination of both. A two-stage bicycle turn box can be implemented with a bicycle signal face.

Two-way separated bike lane, complete separation from vehicular traffic: A raised separated bike lane that allows for two-way bicycle traffic that is completely separated from vehicular traffic.

Two-way separated bike lane with parking as barrier: A separated bike lane that allows for two-way bicycle traffic and uses on-street parking as a barrier to separate bicycle traffic from vehicular traffic.

Two-way separated bike lane with vertical barrier: A separated bike lane that allows for two-way bicycle traffic and uses a vertical element, such as bollards, as a barrier to separate bicycle traffic from vehicular traffic.

Two-way separated bike lane with vertical barrier (center of roadway): A separated bike lane positioned in the center of a roadway that allows for two-way bicycle traffic and uses a vertical element, such as bollards, as a barrier to separate bicycle traffic from vehicular traffic.

1 Introduction

It has been 47 years since the National Transportation Safety Board (NTSB) analyzed bicyclist safety in the United States (NTSB 1972). Recently, several safety issues involving bicyclists and other vulnerable road users have emerged in NTSB reports (NTSB 2013a, 2017a, 2017b, 2018a, 2018b). In 2017 alone, 806 bicyclists died in crashes with motor vehicles on US roadways, which was comparable to the deaths resulting from railroad or marine accidents and more than twice the number of deaths resulting from aviation accidents in the same year (NCSA 2019; NTSB 2017c).[1] The increasing availability of bicycles, their growing use as a means of transportation, and the resulting trends and safety issues require attention. This NTSB safety research report updates our understanding of bicyclist safety in the United States by examining the prevalence and risk factors of bicycle crashes involving motor vehicles on US roadways and assessing the most applicable countermeasures.

Bicyclists, like pedestrians and motorcyclists, are considered vulnerable road users because they are unprotected by an enclosed vehicle compartment, leaving them more vulnerable to injury or death in the event of a crash.[2] In 2018, the NTSB issued reports addressing pedestrian and motorcyclist safety, and with this safety research report on bicyclist safety, the NTSB again expands its effort to increase awareness of and address safety issues affecting vulnerable road users (NTSB 2018a, 2018b). To conduct this research, the NTSB used the following combination of quantitative and qualitative methods: reviewing countermeasures and research literature; analyzing crash and injury data; and interviewing national, state, and local traffic safety stakeholders.

1.1 Scope

Bicyclists involved in crashes with motor vehicles are more likely to sustain severe injuries than bicyclists involved in any other crash type. As a result, this research focuses on bicycle crashes involving motor vehicles and specifically examines existing and emerging countermeasures designed to improve bicyclist safety on public roads, such as roadway and infrastructure designs to separate bicycles from motor vehicle traffic; rider and bicycle conspicuity enhancements; vehicle technologies designed to reduce collisions between motorists and bicyclists when they are sharing the road; and protective equipment for reducing the severity of injuries to bicyclists involved in crashes with motor vehicles. Single-bicycle crashes and bicycle collisions with pedestrians are not addressed; however, many of the safety countermeasures examined have the potential to prevent other bicycle crash types or reduce injury severity.

1.2 Goals

The goals of this research were to (1) describe fatal and nonfatal injury trends associated with bicycle crashes involving motor vehicles; (2) examine the scope and nature of bicyclist crash and injury risk factors and assess data limitations; (3) identify proven countermeasures that may

[1] In 2017, 761 people died as a result of railroad accidents, 694 people died as a result of marine accidents, and 350 people died as a result of aviation accidents.

[2] In this report, *vulnerable road users* refer to pedestrians, bicyclists, and motorcyclists.

be underused; (4) assess obstacles that may interfere with the full use of the identified countermeasures; and (5) explore emerging issues that are relevant to bicycling safety.

1.3 Previous NTSB Reports and Recommendations

The NTSB has not studied bicyclist safety since 1972. In that year, the NTSB published a special study, *Bicycle Use as a Highway Safety Problem*, and issued recommendations addressing the training and education of bicyclists and drivers, particularly focusing on young drivers and children who ride bicycles (H-72-6 and H-72-7); bicycle design (H-72-8 and H-72-9); and the importance of safety when encouraging the public to use bicycles (H-72-10, NTSB 1972).[3] At the time, most bicyclist deaths and injuries involved bicyclists between the ages of 5 and 14.

Other more recent NTSB reports have addressed bicycle safety indirectly. The NTSB safety study, *Crashes Involving Single-Unit Trucks that Resulted in Injuries and Deaths*, was published in 2013 (NTSB 2013a). The study highlighted the existence of large blind spots around large trucks and noted that bicyclists were more likely than pedestrians to have an impact with the right side of single-unit trucks. As a result of the study, the NTSB recommended that the National Highway Traffic Safety Administration (NHTSA) develop performance standards for and require visibility enhancement systems to compensate for blind spots in order to improve the ability of drivers of single-unit trucks to detect vulnerable road users, such as bicyclists and pedestrians (H-13-11 and H-13-12, NTSB 2013a).[4] In a 2014 standalone recommendation letter, the NTSB issued a similar recommendation to NHTSA addressing trucks over 26,000 pounds (H-14-1).[5]

In 2016, the NTSB investigated a collision between a pickup truck and multiple bicycles in Cooper Township, Michigan (NTSB 2017a). In this crash, nine bicyclists were traveling single file on a 4-foot-wide paved outside shoulder when they were struck from behind by the front of a pickup truck. Five bicyclists died and four were injured. The NTSB determined that the probable cause of the collision was the "impairing effects of the driver's polysubstance abuse in the hours before the crash" (NTSB 2017a).

The NTSB's 2017 safety study, *Reducing Speeding-Related Crashes Involving Passenger Vehicles*, addressed several safety issue areas, including the need to rethink how speed limits are set (NTSB 2017b). When considering vulnerable road users, such as pedestrians and bicyclists, the study emphasized the benefits of a safe system approach for setting speed limits, which

[3] (a) The NTSB issued five safety recommendations as a result of the 1972 special study. Safety Recommendations H-72-6 through -8 were issued to the National Highway Traffic Safety Administration (NHTSA); they are all classified "Closed—Acceptable Action." Safety Recommendation H-72-9 was issued to the US Department of Health, Education, and Welfare, which is now known as the US Department of Health and Human Services; the recommendation is classified "Closed—Acceptable Alternate Action." Safety Recommendation H-72-10 was issued to the US Department of Transportation and is classified "Closed—Acceptable Action." (b) All recommendations referenced in this report, as well as relevant excerpts of associated correspondence exchanged to determine a recommendation status, are available via the NTSB Safety Recommendations Database. The database also provides a chart explaining all of the possible recommendation statuses.

[4] The two safety recommendations issued to NHTSA were H-13-11 and H-13-12; both are classified "Open—Unacceptable Response." See section 4.2.4 for further discussion.

[5] Safety Recommendation H-14-1 is classified "Open—Unacceptable Response." See section 4.2.4 for further discussion.

considers likely crash types and the human body's ability to withstand crash forces. The NTSB recommended that the Federal Highway Administration (FHWA) revise the *Manual on Uniform Traffic Control Devices* (*MUTCD*) to, at a minimum, incorporate the safe system approach for urban roads to strengthen protection for vulnerable road users (H-17-28).[6] The study also identified other safety issues pertaining to the effective application of proven and emerging countermeasures aimed at reducing speeding-related fatalities and injuries. These issues included the need for data-driven approaches for speed enforcement, automated speed enforcement, intelligent speed adaptation, and national leadership to increase public awareness about speeding. Motorists traveling at higher speeds increase vulnerable road users' crash and injury risk as well as their own. The NTSB generally contends that the safety recommendations issued as a result of the 2017 study would also reasonably improve the traffic safety environment for bicyclists and other vulnerable road users as well (NTSB 2017b).

In 2018, the NTSB published a special investigation report, *Pedestrian Safety*, which was informed by a 2016 safety forum and 15 investigations of fatal pedestrian crashes (NTSB 2018a).[7] The report focused on three areas: vehicle-based designs, including vehicle lighting systems and pedestrian safety systems; infrastructure planning; and safety data. Recommendations made in these areas also benefit bicyclists. For example, safety recommendations made to NHTSA regarding vehicle headlight systems are intended to improve a driver's ability to see pedestrians as well as bicyclists (NTSB 2018a).[8]

Also in 2018, the NTSB published a safety report on *Select Risk Factors Associated with Causes of Motorcycle Crashes* (NTSB 2018b). The report identified motorcycle safety issue areas concerning crash warning and prevention, braking and stability, alcohol and other drug use, and licensing procedures. The NTSB acknowledged motorcyclists as being vulnerable road users and recommended that NHTSA "incorporate motorcycles in the development of performance standards for passenger vehicle crash warning and prevention systems" (H-18-29).[9]

Finally, the NTSB's 2019–2020 Most Wanted List emphasizes several changes that can be made to prevent accidents, mitigate injury, and save lives. Although bicycle safety has not been specifically named on the list, many of the improvements listed help bring attention to issues that can affect bicyclist safety, such as reducing speeding-related crashes; increasing implementation of collision avoidance systems (CASs) in motor vehicles; and reducing fatigue, distraction, and alcohol and other drug impairment.[10]

[6] Safety Recommendation H-17-28 is classified "Open—Acceptable Response."

[7] (a) See the NTSB *Special Investigation Report: Pedestrian Safety* webpage, which includes details of the 15 fatal crash investigations and the supplemental data report. (b) See also the NTSB Forum: Pedestrian Safety webpage for information about the 2016 forum.

[8] Safety Recommendations H-18-39 through -49 are all classified "Open—Acceptable Response." See sections 4.2.2 and 4.2.3 for further discussion.

[9] Safety Recommendation H-18-29 is classified "Open—Acceptable Response."

[10] See the NTSB's Most Wanted List.

2 Methodology

This section discusses the combination of quantitative and qualitative methods the NTSB used to conduct this research: reviewing countermeasures and research literature; analyzing crash and injury data; and interviewing national, state, and local traffic safety stakeholders. These three research components complemented each other, helped identify proven safety countermeasures that are underused, and guided the safety recommendation development process. The definitions of bicycle and bicyclist used in this report are also discussed.

2.1 Review of Countermeasures and Research Literature

The NTSB reviewed the following key resources on bicycle-related countermeasures as well as scientific research literature focused on the effectiveness and limitations of those countermeasures.[11] Information gathered from the literature review was also used to guide stakeholder interviews and inform the recommendation development process.

In 2008, the FHWA began the Proven Safety Countermeasures initiative, which promotes the widespread implementation of infrastructure-oriented safety improvements and strategies based on their effectiveness.[12] The FHWA updated the initiative in 2012 and 2017 and has identified 20 proven countermeasures (FHWA 2018a). Although some of the FHWA's 20 countermeasures provide indirect safety benefits for bicyclists, none of them directly address bicyclist safety. In 2014, the FHWA published the *Bicycle Safety Guide and Countermeasure Selection System*, which includes 46 engineering, education, and enforcement countermeasures (Sundstrom and others 2014). The FHWA's 2014 *Evaluation of Bicycle-Related Roadway Measures: A Summary of Available Research* further documents empirical evidence of safety improvements attributed to infrastructure-based countermeasures (Mead and others 2014).

NHTSA's *Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices* offers 12 behavioral traffic safety countermeasures specific to bicycle safety (Richard and others 2018). In its document *Bicycle Safety: How Can Bicycle-related Injuries and Deaths be Prevented*, the Centers for Disease Control and Prevention (CDC) has identified and advocated for effective and promising interventions, such as the use of active lighting, highly visible clothing, and helmets to prevent bicycle-related injuries and deaths (CDC 2017). Finally, the Governors Highway Safety Association's (GHSA) *A Right to the Road: Understanding and Addressing Bicyclist Safety* provides states and their traffic safety partners 30 action steps to address a wide range of issues relevant to bicyclist safety (GHSA 2017).

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[11] Appendix A provides a complete list of the countermeasures identified by the FHWA, NHTSA, the CDC, and the Governors Highway Safety Association (GHSA).

[12] See the FHWA's Proven Safety Countermeasures website.

2.2 Data Analysis

The NTSB analyzed data from several national databases to summarize bicyclist fatal and nonfatal crash and injury trends for bicycle crashes involving motor vehicles, and to illustrate crash risk and injury severity factors. Because each of the datasets has advantages and limitations, multiple sources from many government agencies were used. Although the long-term trend for bicyclist fatalities is presented for the period from 1980 through 2016, most data analyses focused on the period from 2014 through 2016. Starting in 2014, NHTSA supplemented the Fatality Analysis Reporting System (FARS) and the National Automotive Sampling System (NASS) General Estimates System (GES)/Crash Report Sampling System (CRSS) data with a data file dedicated to nonmotorized road users, such as pedestrians and bicyclists. This supplemental dataset provides detailed pedestrian and bicyclist crash characteristics that the NTSB used extensively throughout this report. Although NHTSA has released data for 2018, they are preliminary in nature. In addition, information resulting from these data analyses was evaluated alongside viewpoints expressed in the stakeholder interview sessions.

The data sources used in this report are described below; see table 1 for an overview.[13]

- The **Fatality Analysis Reporting System (FARS)** is a census of fatal motor vehicle crashes occurring on US public roads since 1975, which is maintained by NHTSA and based on data extracted from police crash reports (NHTSA 2016a). All motor vehicle crashes occurring on US public roads in which at least one person died within 30 days are captured in FARS. NHTSA most recently released the 2018 preliminary FARS data along with the 2017 final data. Some 2018 preliminary data were included in fatality trend descriptions; detailed data analyses focused on data from 2014 through 2016.

- The **National Automotive Sampling System (NASS) General Estimates System (GES)** is a nationally representative sample of fatal and nonfatal motor vehicle crashes occurring on US public roads from 1988 through 2015. This system was replaced by the **Crash Report Sampling System (CRSS)** in 2016. Both systems are maintained by NHTSA and are based on data extracted from police crash reports (NHTSA 2016b). The 2017 CRSS data were included in trend descriptions only. Detailed data analyses focused on data from 2014 through 2016.

- The **National Electronic Injury Surveillance System (NEISS)** uses a sample of 100 hospitals that include very large inner-city hospitals with trauma centers as well as large urban, suburban, rural, and children's hospitals in the United States to monitor consumer product-related injuries (CPSC 2018). The NEISS began in 1971 and it is maintained by the US Consumer Product Safety Commission (CPSC). The NTSB used the NEISS data from 2014 through 2017 to describe injury risk in bicycle crashes involving motor vehicles.

[13] The data files used in the development of this report can be found in the NTSB Docket Management System, using the NTSB ID DCA18SS002.

- The **National Electronic Injury Surveillance System-All Injury Program (NEISS-AIP)** is a collaborative effort by the CDC National Center for Injury Prevention and Control and the CPSC. Beginning in 2000, the NEISS-AIP expanded upon the NEISS to collect data about all types and external causes of nonfatal injuries and poisonings treated in US hospital emergency departments, even if the injury was not related to a consumer product (CDC 2019a). This dataset was used to describe trend, risk, and injury patterns in bicycle crashes involving motor vehicles.

- The **National Transit Database (NTD)** is maintained by the Federal Transit Administration (FTA). The NTSB obtained data based on the NTD's Major Event Report, which captures detailed information about severe safety and security events that occur within a transit environment. The FTA categorizes an event as a severe safety event if it includes a fatality, an injury, or property damage at or above $25,000 (FTA 2016). For this report, the NTSB examined event and casualty data involving bicyclist fatalities and injuries resulting from crashes with transit buses from 2014 through 2017.

- The NTSB obtained bicycle crash data for **Pennsylvania, Minnesota, Texas, and Washington** for the calendar year 2017. These four states were selected to represent the northeastern, midwestern, southwestern, and western United States. These data were used to evaluate bicycle crash risks involving posted speed, intersection location, and helmet use. Crash data were provided directly by the Minnesota and Washington Departments of Transportation; data for Texas and Pennsylvania were extracted using their public online crash data portals.

- The **American Community Survey (ACS)** is a national survey that includes a series of monthly samples of about 3.5 million addresses to produce annual estimates for small areas such as census tracts and block groups. The US Census Bureau administers the survey and maintains the data (US Census Bureau 2018a). The NTSB used two 5-year periods to evaluate changes of the levels of bicycling to work. The periods were from 2008 through 2012 and from 2013 through 2017. For each of these two periods, the NTSB downloaded the corresponding *Means of Transportation to Work* tables.

- The **National Household Travel Survey (NHTS)** provides estimates of travel behavior, including trips made by all modes of travel, including bicycling, and for all purposes, including travel to work, school, and recreation (FHWA 2019). The FHWA conducts the NHTS. The NTSB used the 2017 NHTS data provided by the FHWA. These data were used to complement estimates provided by the US Census Bureau's ACS.

Table 1. Overview of data sources used in this safety research report.

Name of Data Source (Collected By)	Fatal Crashes	Nonfatal Crashes	Crash Details	Injury Details	Used in This Report For	Time Period Analyzed
FARS (NHTSA)	Yes (census)	No	Yes	No	Trend, risk, geographic pattern	1980–2018 **(primarily 2014–2016)**
NASS GES/CRSS (NHTSA)	Yes (sample of police crash reports)	Yes (sample of police crash reports)	Yes	Limited (only have injury levels)	Trend, risk	2007–2016 **(primarily 2014–2016)**
NEISS (CPSC)	No	Yes (sample of emergency department records)	No	Yes (diagnoses, dispositions, injury levels, case narrative)	Risk, injury pattern	2014–2017
NEISS-AIP (CPSC/CDC)	Yes (sample of emergency department records)	Yes (sample of emergency department records)	No	No	Trend, risk, injury pattern	2007–2017
NTD (FTA)	Yes (reportable incident by transit agencies)	Yes (reportable incident by transit agencies)	Limited (case narrative)	Limited (case narrative)	Scope	2014–2017
Bicycle crash data from four selected states (PA, MN, TX, and WA)	Yes (police crash reports)	Yes (police crash reports)	Yes (police crash reports)	Limited	Risk	2017
ACS (US Census Bureau)	No	No	No	No	Bicycling level	2008–2017 **(divided into two 5-year periods)**
NHTS (FHWA)	No	No	No	No	Bicycling by trip purpose	2017

Descriptive statistics, in the form of crash counts, fatalities, and nonfatal injuries, were prepared to establish the scope of bicycle crashes involving motor vehicles. Bicyclist fatalities were also expressed as rates per 100,000 people and percentages of total traffic fatalities. National trends of bicyclist fatalities were examined from 1980 through 2016. To assess the level of bicycling activity in the United States, the NTSB examined the period from 2008 through 2017. This period was further divided into two 5-year subperiods from 2008 through 2012 and from 2013 through 2017, and the 5-year averages of the estimated numbers of workers and workers bicycling to work were calculated. Comparisons between those two periods were made to evaluate changes in bicycling activity at the national, state, and city levels.

The NTSB examined crash risks attributed to select crash characteristics, such as crash type, lighting conditions, crash location, posted speed limit, urban-rural classification, and city size. The percentage share of bicyclists involved in crashes, bicyclist fatalities, and bicyclists with serious injuries were computed by each crash characteristic. Similar approaches were used in analyzing emergency department-based injury estimates provided in the NEISS data. However, the NEISS data analyses primarily focus on bicycle helmet use and injury severity. Because the NEISS data include nonfatal injuries sustained by bicyclists involved in all crash types—that is, crashes involving a motor vehicle as well as those not involving a motor vehicle, and crashes occurring on public roads and private properties—data analyses involving the NEISS data help illuminate the differences in injury patterns among different bicycle crash scenarios. All nonfatal injury estimates are rounded up to the thousands using the NASS GES/CRSS convention. The same approach is used with respect to the NEISS data.

The NTSB also used logistic regression analysis to assess select risk factors in bicyclist crashes. Data from four states, Pennsylvania, Minnesota, Texas, and Washington, were used to examine bicyclists involved in motor vehicle crashes, and to evaluate the influence of factors such as posted speed and location on bicyclist crash risk and injury severity. Logistic regression is used to determine if the presence of a particular factor, for example, intersection location, increases or decreases the odds of a given outcome, such as a bicyclist sustaining a serious or fatal injury.[14] Using Washington state data, the NTSB also used this statistical model to compute the odds of a crash-involved bicyclist wearing a helmet based on helmet requirements and bicyclist age. In these analyses, only 2017 data were used.

[14] Odds ratio estimates provide an approximation of the relative risk. An estimate greater than 1 indicated that the factor being analyzed was overrepresented, and an estimate less than 1 indicated that the factor was underrepresented. Statistical significance was then determined using a 95% confidence interval, which is a range of values above and below an estimate used to interpret the estimate's accuracy and precision. The estimates with intervals that did not include 1 were considered significant and predictive in terms of changes in risk. For example, if the 95% confidence interval for the estimate 2.096 was (1.750, 2.511), that estimate would be considered a statistically significant result because the interval does not include 1.

2.3 Stakeholder Interviews

The NTSB conducted 41 stakeholder interview sessions; 155 participants took part, providing local-, county-, regional-, state-, and national-level perspectives. The interview sessions were 1 to 2 hours long, they were conducted either in person or by phone, and they involved groups of 2 to 20 stakeholders. The interviews followed a semi-structured format, covering the topics below:[15]

- roles and responsibilities of the organization in the area of bicyclist safety
- impressions of national-level resources and guidance materials
- degree of collaboration among agencies, for example, within a state or across different levels of government
- key aspects of bicyclist safety locally, for example, any specific problems facing bicyclists in a state or city
- emerging issues in bicyclist safety
- barriers hindering the full implementation of safety countermeasures

The stakeholders included traffic engineers, transportation planners, safety advocates, bicycle advocates, educators, law enforcement, researchers, pedestrian-bicycle advisory committee members, and industry representatives.

The NTSB recorded, transcribed, and analyzed the interviews. The stakeholders provided many valuable insights about issues affecting bicyclist safety, in particular, discussing countermeasures that have the potential to improve safety and suggesting ways to overcome barriers to countermeasure implementation. Stakeholders often mentioned the health and environmental benefits that could result from increasing bicycle ridership. Some stakeholders also noted that increasing ridership could have an indirect beneficial effect on overall bicyclist safety. This concept was typically referred to as "safety in numbers" (Elvik 2009; Schepers 2012), or the FHWA's *Bikeway Selection Guide* (Schultheiss and others 2019) explains it as follows:

> Greater safety attracts more bicyclists, resulting in safer cycling conditions overall. Multiple studies show that the presence of bikeways, particularly low stress, connected bikeways, positively correlates with increased bicycling. This in turn results in improvements in bicyclists' overall safety.

Consequently, many stakeholders promoted efforts that could lead to increases in bicycle ridership and opposed policies they believed would lead to reductions in ridership. Although the NTSB acknowledges the potential indirect safety benefit of increasing the numbers of bicyclists, in this report, it focused on analyzing stakeholder comments and perspectives concerning countermeasures that could directly improve bicyclist safety.

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[15] The general questions that were asked during the semi-structured interview sessions can be found in the NTSB [Docket Management System](), using the NTSB ID DCA18SS002.

2.4 Defining Bicycle and Bicyclist in This Report

A *bicycle* is defined as a nonmotorized, pedal-driven vehicle with one or more tires attached to a thin frame, such as a unicycle, a bicycle, or a tricycle.[16] *Bike* is another common term used for bicycle in this report.

A *bicyclist* is defined as the operator or rider of a bicycle, a passenger on a bicycle, or even a person being pulled by a bicycle, for example, in a wagon or trailer. *Cyclist* is another common term used for bicyclist in this report.[17]

[16] See typical bicycle dimensions and diagrams in section 3.2 of the American Association of State Highway and Transportation Officials' (AASHTO) *Guide for the Development of Bicycle Facilities* (2012). Several photographs showing examples of bicycles and bicyclists can also be found in figures 7 and 8 in sections 4.1.2 and 4.1.3 of this report.

[17] The term *pedalcyclist* is also used in the many databases that were analyzed for this report, such as FARS and NASS GES/CRSS. Pedalcyclist is another term often used interchangeably with bicyclist or cyclist. Appendix B provides additional information about how FARS and NASS GES/CRSS define bicyclists.

3 Results

This section discusses the prevalence of bicycling in the United States and bicycle-related crash and injury data trends, time trends, and geographical patterns. Relevant issues associated with estimating bicycling activity at local, state, and national levels are also addressed.

3.1 Bicycling Activity in the United States

The NTSB used several different sources to try to gain accurate insights about current bicycling activity in the United States. The data that exist to assess the level of bicycling activity in the United States are limited, and what data are available show that the level of bicycling in the United States is low compared to other countries with a similar level of economic development (Santacreu 2018). For instance, in 2018, the Office for Economic Co-operation and Development's International Transport Forum published a summary table consolidating the bicycling levels of 14 countries, including the United States (Santacreu 2018). Figure 1 shows that the level of bicycling in the United States was the lowest among the 14 countries.

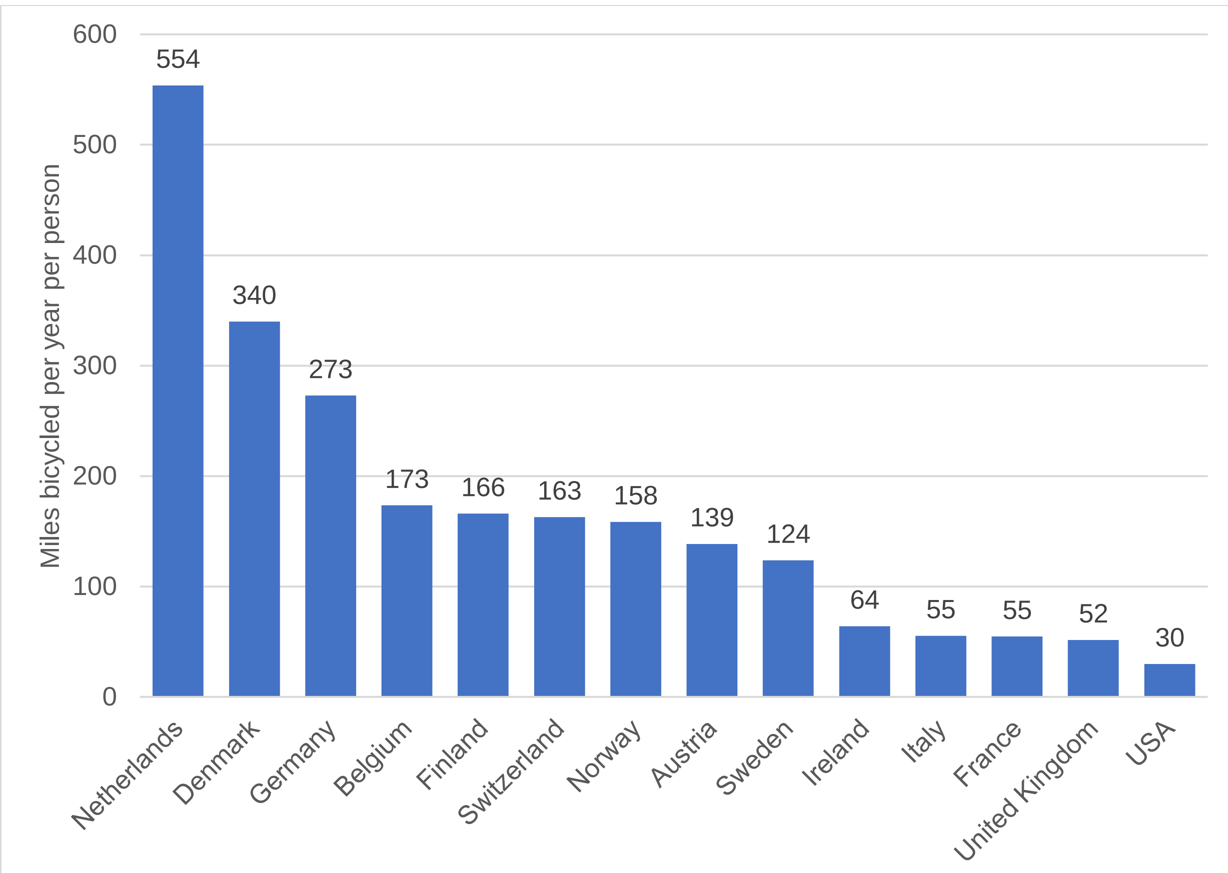

Figure 1. Distance bicycled per year/per person in miles among 14 countries, adopted from table 1 in Santacreu 2018.

The FHWA has promoted bicycling for its health and environmental benefits since the 1990s in the United States (FHWA 1993, 1994, 2010). The US Census Bureau's ACS data provide snapshots of the levels of bicycling to work in the United States at common geographical scales, such as city, state, and national levels, and the FHWA's NHTS data provide snapshots of the overall bicycling activity levels at the national level. The ACS is conducted yearly among a rotating set of communities. The NHTS is conducted on a periodic basis; the last two were conducted in 2009 and 2017, 8 years apart. The objectives, questions, and measurement units for both surveys are different. For example, the ACS estimates the number of bicyclists and the NHTS estimates the number of bicyclists, trips, and miles of travel. Still, using the data from both surveys helps establish the following rough estimates of bicycle travel in the United States.

The ACS data, which provide the best estimates about the levels of bicycling to work, suggest that the number of workers commuting by bicycle in the United States is increasing (McKenzie 2014). In 2014, an analysis of the ACS data estimated that 0.56% of about 140 million US workers bicycled to work from 2008 through 2012 (McKenzie 2014). Adopting the same methods used in the 2014 analysis, the NTSB analyzed the ACS data from 2013 through 2017 and found that 0.59% of about 148 million US workers bicycled to work.[18] Although an increase of 0.03 percentage points was small, the increase of an estimated 86,000 US workers commuting to work by bicycle amounted to an 11% increase between the two periods. Analyzing the same ACS data at the state level showed that 33 states and the District of Columbia experienced increases in workers bicycling to work, and 13 of them had a percent increase greater than 11%. The District of Columbia had the largest increase of 74%, followed by Arkansas with 62%, New York with 41%, Louisiana with 32%, and Virginia with 24%.

Figure 2 shows the percentage of workers commuting by bicycle by state and the District of Columbia from 2013 through 2017. Compared to the national average of 0.59% of workers bicycling to work, the District of Columbia had the highest percentage at 4.58%, followed by Oregon with 2.33%, Montana with 1.34%, Colorado with 1.22%, and California with 1.06%. Five states—Arkansas, West Virginia, Tennessee, Alabama, and Mississippi—had less than 0.20% of workers bicycling to work. As shown in figure 2, four of these states form a cluster in the southern United States.

[18] See pages 3–10 for a description of how the ACS data were analyzed to understand nonmotorized commuting to work (McKenzie 2014), which the NTSB replicated for this comparative analysis of subsequent years.

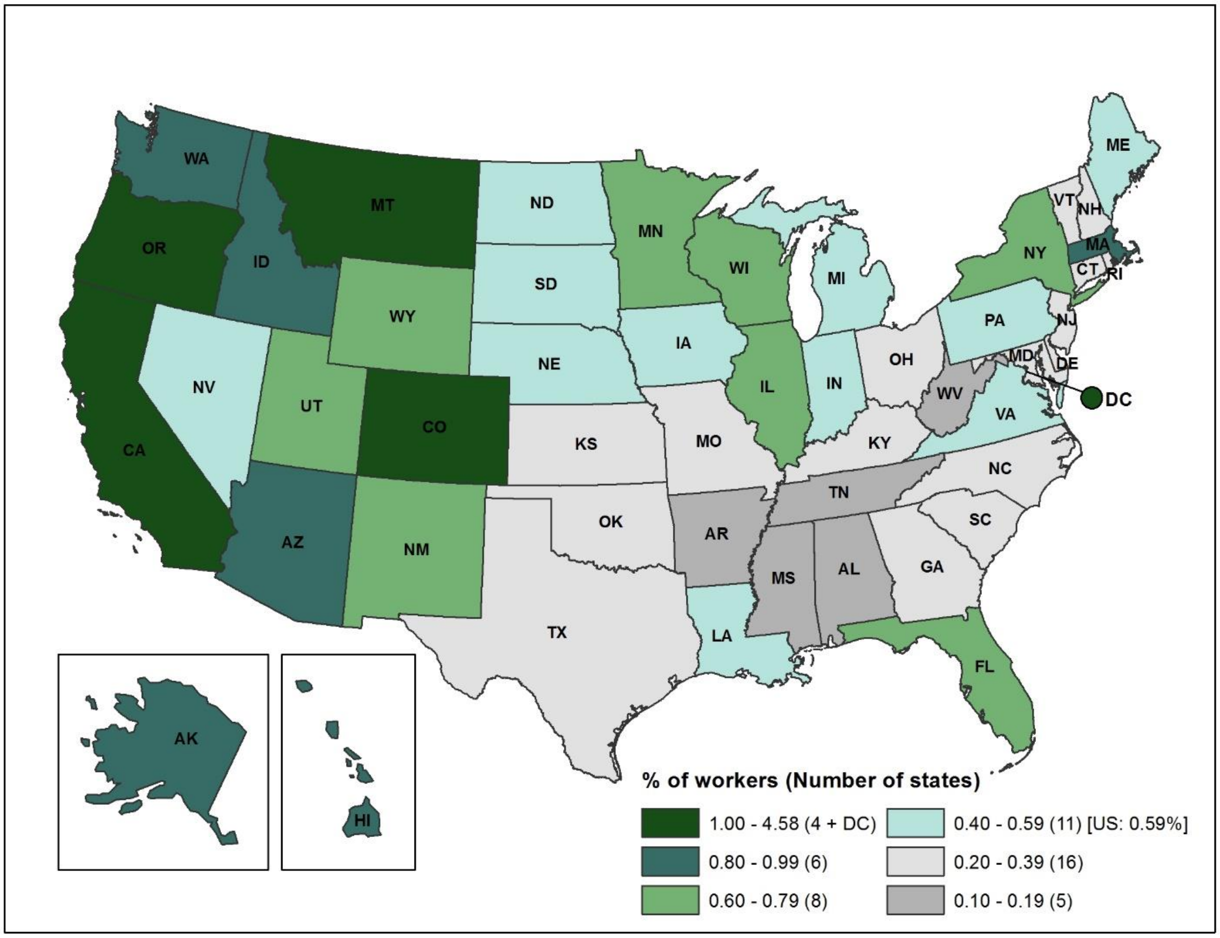

Figure 2. Percentage of workers bicycling to work by state and the District of Columbia, based on ACS data from 2013 through 2017.

The NTSB also looked at city-level percentages of workers bicycling to work according to the ACS data from 2013 through 2017. As in the 2014 analysis (McKenzie 2014), the NTSB stratified cities with a population of at least 20,000 into three categories: large cities with a population of 200,000 or greater; medium-sized cities with a population between 100,000 and 199,999; and small cities with a population between 20,000 and 99,999. Table 2 lists the top 5 cities and their bicycle-to-work percentages by the two 5-year periods—that is, from 2008 through 2012 and from 2013 through 2017—and by city size.

Among the larger cities, Portland, Oregon, had the highest percentage of workers bicycling to work at 7%. Comparing the two periods, Portland experienced an 18% increase in the number of workers bicycling to work. Portland was followed by Madison, Wisconsin (5%, 1% increase); the District of Columbia (5%, 74% increase); Minneapolis, Minnesota (4%, 13% increase); and San Francisco, California (4%, 31% increase). San Francisco replaced Boise, Idaho, which had ranked fourth from 2008 through 2012. Boulder, Colorado, ranked first among the medium-sized cities with a 10% bicycling-to-work percentage and 9% increase, followed by Berkeley, California (8%, 11% increase); Cambridge, Massachusetts (7%, 6% increase); Eugene, Oregon (7%, 18% decrease); and Fort Collins, Colorado (6%, 5% increase). Davis, California, had the highest bicycling-to-work percentage among small cities at 20%. Table 2 illustrates that compared to the US average of 0.59% of workers bicycling to work from 2013 through 2017 and the 11% increase between the periods from 2008 through 2012 and from 2013 through 2017, cities tend to have considerably higher levels of workers bicycling to work, and this trend does not appear to be limited to larger cities. In fact, Davis had the highest bicycling-to-work percentage among all cities regardless of population size, and it experienced a 9% increase.

Table 2. Percent of city workers that bicycle to work by city size according to ACS data from 2008 through 2017.

		ACS 2008–2012		ACS 2013–2017		Difference Between 2008–2012 and 2013–2017
Rank	**City**	**Bicycling to Work**	**% of Workers**	**Bicycling to Work**	**% of Workers**	**% Change in Bicycling to Work**
Larger cities (population of 200,000 or greater)						
1	**Portland, OR**	18,315	6	21,673	7	18
2	**Madison, WI**	6,793	5	6,854	5	1
3	**Washington, DC**	9,347	3	16,257	5	74
4	**Minneapolis, MN**	8,334	4	9,438	4	13
5	**San Francisco, CA**	14,833	3	19,410	4	31
Medium-sized cities (population of 100,000 to 199,999)						
1	**Boulder, CO**	5,507	11	5,984	10	9
2	**Berkeley, CA**	4,348	8	4,844	8	11
3	**Cambridge, MA**	4,173	7	4,424	7	6
4	**Eugene, OR**	6,066	9	4,987	7	-18
5	**Fort Collins, CO**	5,182	7	5,427	6	5
Smaller cities (population of 20,000 to 99,999)						
1	**Davis, CA**	5,691	19	6,174	20	9
2	**Santa Cruz, CA**	2,697	9	2,841	9	5
3	**Palo Alto, CA**	2,562	9	2,689	8	5
4	**Somerville, MA**	2,048	5	3,631	7	77
5	**Missoula, MT**	2,160	6	2,478	6	15

Although the ACS data provide valuable insights about bicyclists commuting to work at the state and city levels across the United States, the ACS data have limitations. For example, the ACS journey-to-work question only accepts one answer as the primary mode of transportation used.[19] So, if a worker combines bicycling and taking public transit to work, only the mode with the longest distance is recorded. Therefore, the ACS data underestimate the level of bicycling to work in the United States. Also, the journey to work is only one of many activities accomplished by bicycling.

The 2017 NHTS data showed that the most common trip purpose among bicyclists was home-related (42%) followed by social or recreational purposes (24%), and more than half of the person miles of travel (PMT) for social or recreational purposes were for exercise.[20] Only 13% of all PMT on bicycles were completed for the purpose of work. Therefore, the NHTS data suggest that focusing only on bicycling for work remarkably underestimates the overall level of bicycling activity in the United States.

Although the 2017 NHTS data provide a more comprehensive assessment of bicycling activities, the data also have limitations. For example, there was a substantial change between the 2017 and 2009 surveys—the 2017 NHTS used Google Maps Application Programming Interface (API) to automatically generate path distance, whereas the 2009 survey used self-reported distance (FHWA 2019). This methodological change limited the use of the data to examine changes in the level of bicycling activity over time. Another limitation was that the data only provide estimates for the nation. Therefore, unlike the ACS data, the NHTS data did not allow for comparisons among states or cities.

Although the level of bicycling in the United States remains low compared to many European countries, in recent years more people have started bicycling as an alternative mode of transportation to work and for health and recreational purposes. The NTSB's analyses show that the growth of bicycling is unevenly distributed, with the most rapid growth occurring in urban areas. Further, although complementary, the NHTS data and the ACS data may not provide an accurate assessment of the growing bicycling activity levels in the United States. Therefore, the NTSB concludes that current available data likely underestimate the level of bicycling activity in the United States.

[19] The specific ACS question asked was "How did this person usually get to work last week? If this person usually used more than one method of transportation during the trip, mark (X) the box of the one used for most of the distance" (US Census Bureau 2008).

[20] The NTSB analyzed the 2017 NHTS data and found that an estimated 8,499 million PMT were completed by US residents riding bicycles. Broken down by trip purposes, the top three purposes were home (3,547 million PMT), social/recreational (2,048 million PMT), and work (1,102 million PMT). Of the 2,048 million PMT for social or recreational purposes, 1,103 million PMT (54%) were for exercising, roughly the same number of PMT for work purposes.

3.1.1 Activity Monitoring

To better understand bicycling activity in the United States, more accurate ways of obtaining information about it are needed. The US Census Bureau's ACS and the FHWA's NHTS data discussed in sections 2.2 and 3.1 provide rough estimates of bicycling activity in the United States. However, they do not provide detailed information that can be used to accurately document bicycling activity and evaluate bicycle safety improvement projects. To improve bicycle safety, more street-level bicycling activity measures that will provide more useful data are required.

Technologies and methods used to monitor motorized travel are well established, and states are required to capture performance metrics, such as the annual average daily traffic and vehicle miles traveled on federally funded roadways. However, that is not the case for nonmotorized travel. Currently, there is no federal requirement to monitor bicycle travel. Yet, understanding the level of bicycling activity at different geographical scales is critical. During the stakeholder interviews, representatives from state and local agencies often discussed the importance of bicycle counting and most stated they were actively engaged in developing and implementing bicycle-counting projects and programs. The stated goals of such bicycle counting ranged from gauging changes in bicycling activity levels, assessing shifts in transportation modes used, and evaluating bicycle infrastructure projects.

The FHWA and the National Academies of Sciences, Engineering, and Medicine have identified automated and manual (nonautomated) technologies and methods commonly used for bicycle counting; however, selecting the best approach depends on a number of factors, such as how long the counting will be conducted, local conditions at the count locations, and cost (Baas, Galton, and Biton 2017; FHWA 2016; NAS 2014, 2017). For example, permanent bicycle counters can only be placed in limited locations within a jurisdiction, and often those locations are along well-established bicycle routes. To supplement them, temporary counters are used on an ad hoc basis, typically associated with specific infrastructure implementation projects. Data captured from these temporary, short-duration counters are then used to provide annual estimates of bicycling activity. However, many adjustments must be made to use and interpret such data, and, although some methodology and guidance materials exist to help state and local agencies do this, agencies still may not obtain accurate bicycling activity estimates (Nordback, O'Brien, and Blank 2018).

There is, however, a rapidly developing approach known as crowdsourcing currently being used to supplement traditional bicycle-counting methods. Crowdsourcing refers to certain web and mobile applications that generate information from a large number of people to capture and monitor bicycling activity data. Crowdsourcing is built on a combination of communication; a global positioning system (GPS); and geospatial technologies, such as a geographic information system (GIS). One example is using a GPS-enabled portable electronic device, such as a smartphone or a smartwatch, to trace a bicyclist's activity and movements with a web application, such as Strava.[21] By using data from web applications like Strava to aggregate thousands of bicycle routes and overlay them onto a digital map using a GIS, planners and engineers obtain a more complete understanding of bicycling activity in their jurisdictions (Strauss, Mirana-Moreno, and

[21] See the Strava website for more information about what data its web application collects and how that data can be tracked, analyzed, and shared.

Morency 2015; Boss and others 2018). The advantages of crowdsourcing include (1) minimizing time and location constraints for data collection; (2) readily integrating geospatial data into advanced spatial analyses; and (3) directly engaging active transportation users, such as bicyclists, in the activity-monitoring process (Smith 2015). Additionally, although the data are anonymized, general user characteristics, such as age and gender, can be obtained. These characteristics are typically not captured using traditional bicycle-counting methods.

Research has shown that crowdsourced data can predict ridership and show detailed geographic variation, especially in urban areas, despite having a nonrandom sample of ridership (Jestico, Nelson, and Winters 2016; Boss and others 2018). However, crowdsourced data, such as Strava-based data, can introduce bias into a dataset, as the underlying technology may not be available to all bicyclists. For example, CyclePhilly is a smartphone-based crowdsourcing application that captures trip data along with self-reported trip purposes. Yet, the CyclePhilly website cautions that their users' trip patterns "may not reflect those of all cyclists."[22] As a result, crowdsourcing approaches that rely on self-reporting, such as those implemented by Vision Zero programs in various cities that allow users to interactively enter locations on online maps to indicate "near misses" or "safety concerns," may have quality-control issues.[23]

Another new source of data that could be used to develop a more complete picture of bicycling activity is trip data captured by bikeshare operations. Bikeshare operations refer to the expanding public transportation option of providing shareable bikes that can be rented for a daily, monthly, annual, or trip-based fee. These operations can have fixed docking stations, or they can operate as dockless operations without fixed locations (PBIC 2019). At a minimum, bikeshare trip information includes origin, destination, mileage, and time. Even without precise route information, city and state agencies could use such trip information to improve understanding of the spatial and temporal patterns of bicycling activity. Bikeshare operational data, in addition to crowdsourced data, capture different components of bicycling activity and add to the existing manual or automated fixed-location bicycle-counting data. Therefore, the NTSB concludes that combining traditional and innovative data collection approaches could improve measures of bicycling activity.

Although chapter 4 of the FHWA's *Traffic Monitoring Guide* focuses on nonmotorized traffic, it "does not address technologies that collect other attributes of nonmotorized travel, such as the use of GPS-enabled mobile devices for trip traces or the use of Bluetooth-enabled devices for origin-destination or travel time" (FHWA 2016). Therefore, the NTSB recommends that the FHWA (1) develop methods to combine traditional and innovative bicycle-counting approaches that capture bicycling activity data generated by bicyclists and bikeshare operations; (2) disseminate the methods to state transportation departments. The FHWA can engage all state bicycle and pedestrian coordinators through the Pedestrian and Bicycle Information Center to disseminate such methods.

[22] See the CyclePhilly website for an example of crowdsourced bicycling activity data.

[23] (a) Vision Zero is a multinational safety initiative to eliminate all traffic fatalities and injuries; many large, urban, US cities actively support it. (b) For example, users may forget to report near misses or may report the location incorrectly.

3.2 Bicyclist Fatalities and Nonfatal-Injury Estimates

Bicyclist fatality data and nonfatal injury estimates provide information about the size of the bicycle safety problem relative to other modes of transportation. They also provide different insights about trend and geographic patterns, serving as indicators of bicyclist safety issues as well as signaling the need for safety countermeasures.

3.2.1 Fatalities

In its 1972 study, the NTSB found that from 1968 to 1970, more fatalities—about 800 or more each year—resulted from crashes between motor vehicles and bicycles than from railroad transportation accidents (NTSB 1972). Although the number of such fatalities has fluctuated over the past several decades, the number of fatalities resulting from crashes between motor vehicles and bicycles is comparably increasing again in relation to railroad and marine accident fatalities and markedly surpassing fatalities in aviation (NTSB 2017c).

In 1980, 965 bicyclists died in bicycle crashes involving motor vehicles in the United States. By 2010, bicyclist fatalities had reached their lowest level at 623 (Coleman and Mizenko 2018). Figure 3 shows bicyclist fatality rates per 100,000 people and fatalities as a percent of total traffic fatalities by year from 1980 to 2016. In 2003, bicyclist fatalities represented 1.5% of total traffic fatalities; since then, that percentage has gradually increased to 2.3% in 2016 (see the left axis in red on figure 3). In 2008, the bicyclist fatality rate was 0.24 per 100,000 people. That year, the US Department of Health and Human Services, Office of Disease Prevention and Health Promotion set the Healthy People 2020 goal for the bicyclist fatality rate at 0.22 per 100,000 people (see the black line on figure 3).[24] Figure 3 also shows that the bicyclist fatality rate has been mostly increasing since 2010, with a slight decline in 2014. By 2016, it reached 0.26 deaths per 100,000 people.

[24] The main Healthy People 2020 goal is to "prevent unintentional injuries and violence, and reduce their consequences." Its specific injury prevention objective IVP-20 is to "reduce pedalcyclist deaths on public roads."

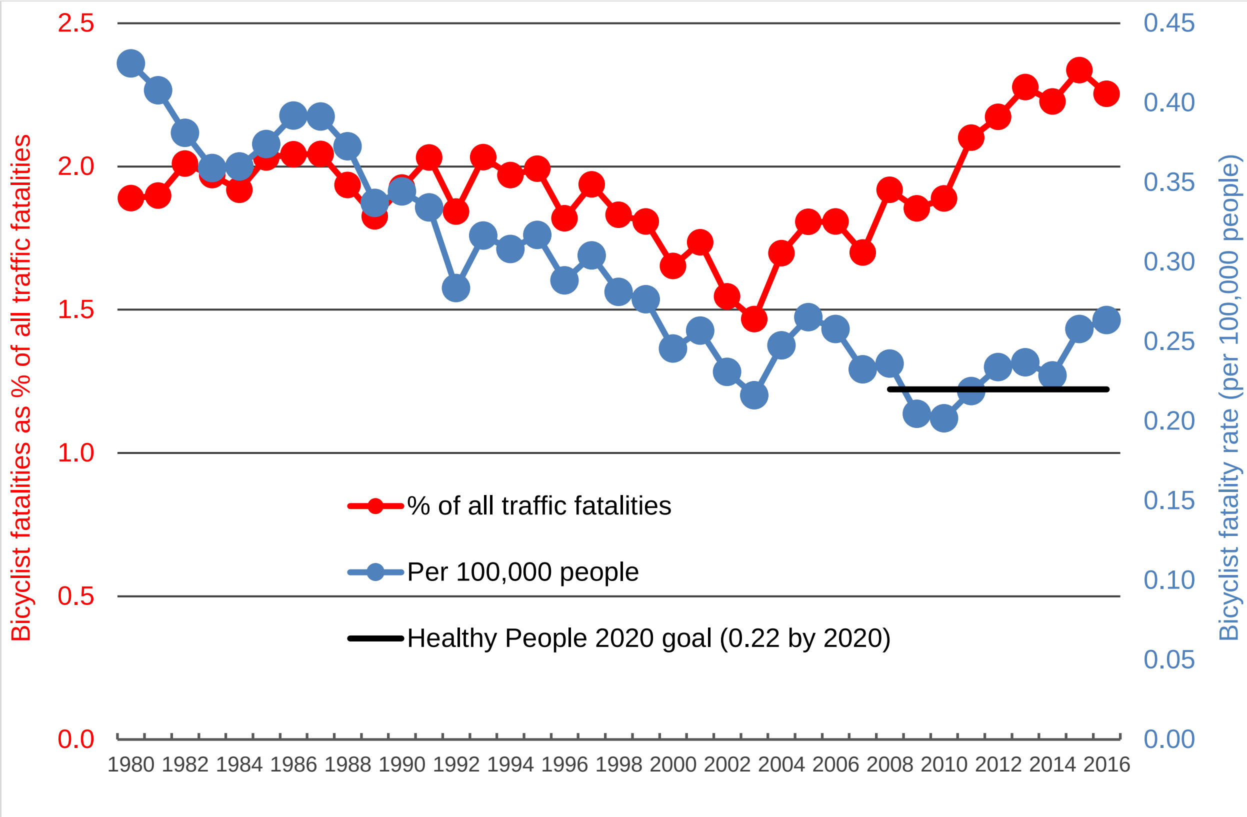

Figure 3. Trends of bicyclist fatality rates and bicyclist fatalities as a percentage of all traffic fatalities from 1980 through 2016, using FARS and US Census Bureau data.

Table 3 focuses on the most recent 12 years of bicyclist and total traffic fatality data. From 2007 through 2018, FARS data show that motor vehicle crashes accounted for 8,908 bicyclist fatalities, averaging 742 per year, or 2 per day. Total traffic fatalities declined to 36,560 in 2018, but bicyclist fatalities increased by 6% from 2017 to 2018, reaching 857 bicyclist fatalities. Comparing the years 2007 and 2018, table 3 shows that, although total traffic fatalities decreased by 11%, bicyclist fatalities increased by 22%.

Table 3. US bicyclist fatalities and total traffic fatalities from 2007 through 2018.

Year	Bicyclist Fatalities	Total Traffic Fatalities
2007	701	41,259
2008	718	37,423
2009	628	33,883
2010	623	32,999
2011	682	32,479
2012	734	33,782
2013	749	32,894
2014	729	32,744
2015	829	35,485
2016	852	37,806
2017	806	37,473
2018[a]	857	36,560
2007–2018 (12 years)	8,908	424,787
% Change 2007–2018	22	-11

[a] FARS data for 2018 are considered preliminary.

Santacreu (2018) provided bicyclist fatalities data per distance bicycled for 13 European countries and the United States from 2011 through 2015. Figure 4 shows that the yearly US bicyclist fatality rate of 79 bicyclist fatalities per billion miles bicycled ranked second only to Italy. In comparison, the Netherlands and Norway had the lowest rate of 13 bicyclist fatalities per billion miles bicycled.

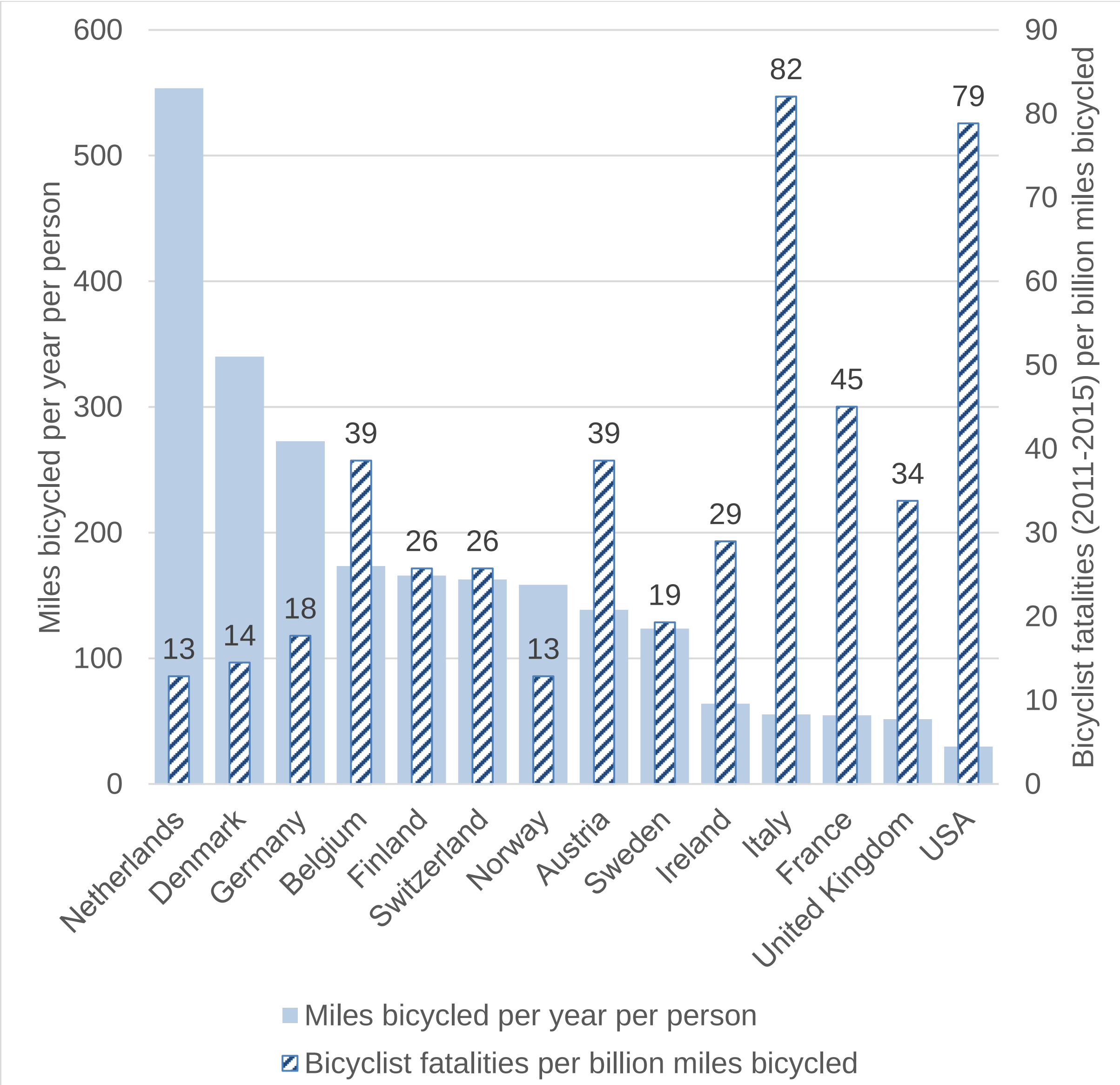

Figure 4. Yearly bicyclist fatalities per billion miles bicycled among 14 countries, from 2011 through 2015, adopted from table 1 in Santacreu 2018.

3.2.1.1 Geographic Patterns

Over the 3-year period from 2014 through 2016, 2,410 bicyclists died on US roadways. These fatalities were not distributed evenly across the United States; 50% of them occurred in the following five states: Florida, California, Texas, New York, and Michigan. Although these are populous states, they made up only about 36% of the US population based on 2016 population estimates (US Census Bureau 2018b).[25] The US bicyclist fatality rate was 0.25 per 100,000 people from 2014 through 2016. The five states with the highest bicyclist fatality rates were Florida (with a bicyclist fatality rate of 0.70 per 100,000 people), followed by Louisiana (0.49), Arizona (0.43), South Carolina (0.37), and California (0.36).

Bicyclist fatalities can also be expressed as percentages of all traffic fatalities. The 2,410 bicyclist fatalities represented 2.27% of all traffic deaths from 2014 through 2016. Figure 5 shows a large degree of state-to-state variation for bicyclist fatalities as percentages of all traffic deaths. The top five states were Florida (4.96%), California (4.07%), New York (3.76%), Arizona (3.36%), and Michigan (3.17%). In the District of Columbia, bicycle fatalities represented 4.11% of all traffic fatalities. Some states, such as California, Arizona, Louisiana, and Florida, have warmer climates that may encourage longer bicycling seasons. Other states like New York and Michigan presumably have shorter bicycling seasons; therefore, their higher percentages may be the result of other factors.

[25] The state population estimates for the period from 2010 through 2017 were obtained from the US Census Bureau. The combined total population in 2016 for California, Florida, Michigan, New York, and Texas was 117,370,080, which was 36% of the US population of 323,071,342 for that year.

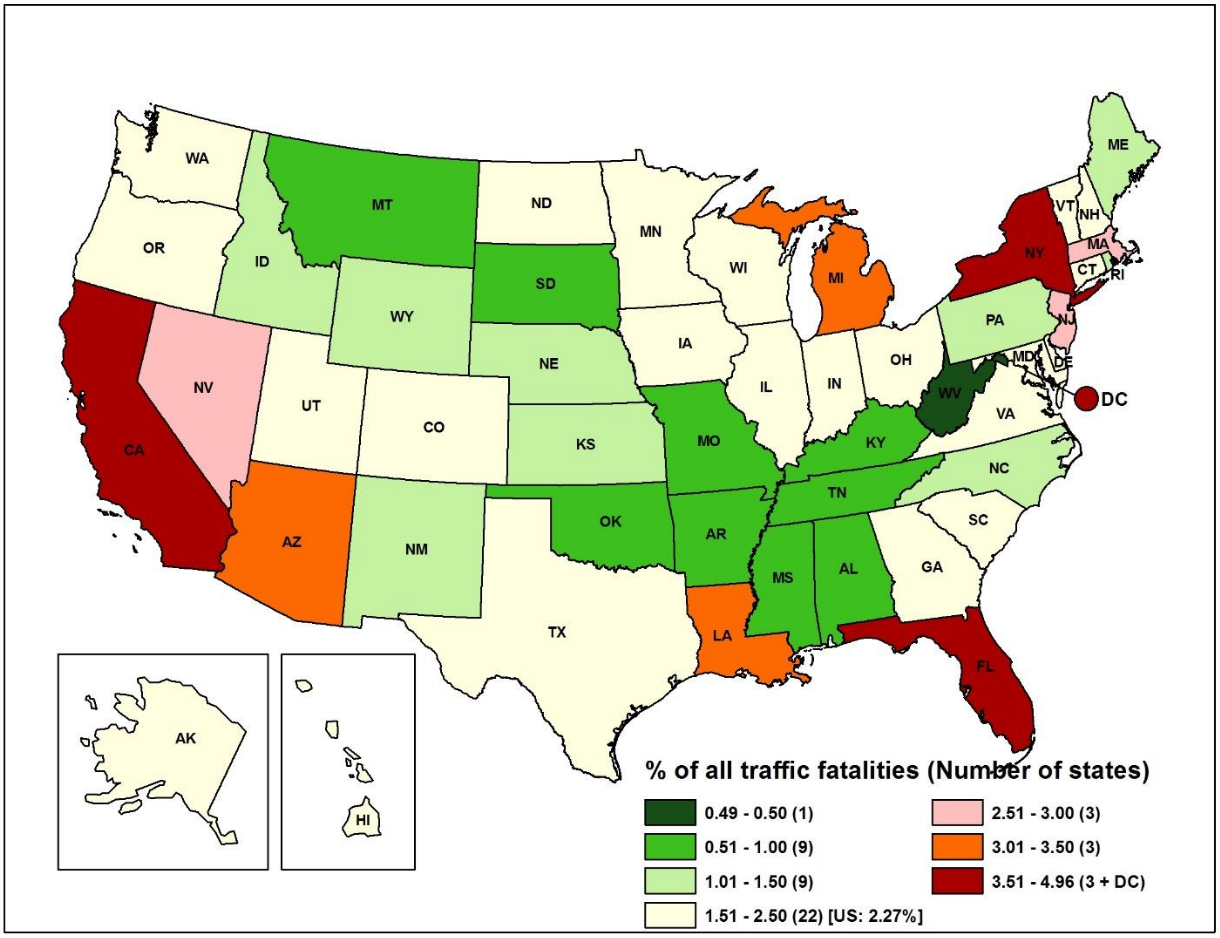

Figure 5. Map of bicyclist fatalities as percentages of all traffic fatalities by state and the District of Columbia from 2014 through 2016.

FARS data categorize bicyclist fatalities as rural or urban based on roadway classification.[26] Bicyclist fatalities are often considered an urban issue; however, many cities have roadways that are classified as rural, especially smaller cities. Table 4 shows that of the 2,410 bicyclist deaths that occurred from 2014 through 2016, 71% were categorized as urban. Table 4 also shows the distribution by city size based on 2016 population estimates. Twenty-four percent of all US bicyclist deaths occurred in larger cities—that is, cities with a population of at least 200,000—and 10% occurred in medium-sized cities with a population of 100,000 to 199,999. About half, or 49%, of US bicyclist deaths took place in smaller cities with a population of less than 100,000. Almost a thousand bicyclists were fatally injured in motor vehicle crashes in cities with a population of less than 50,000. Finally, 16% of all bicyclist deaths occurred outside of cities. Therefore, although bicyclists are more likely to be fatally injured in motor vehicle crashes on urban roads, bicyclist safety issues are not limited to large cities.

[26] Land use classification is based on the roadway classification that was designated in the police crash reports.

Table 4. US bicyclist fatalities by land use and city size from 2014 through 2016.

City Population (2016)	Land Use				% Share of US Total[a]
	Rural	Urban (% of Total)	Unknown or Not Reported	Total	
≥ 500,000	3	315 (96%)	10	328	14
200,000–499,999	11	226 (95%)	1	238	10
100,000–199,999	17	215 (91%)	5	237	10
50,000–99,999	32	244 (88%)	1	277	11
10,000–49,999	102	412 (79%)	9	523	22
<10,000	184	190 (51%)	2	376	16
Not in a City	295	93 (24%)	1	389	16
Unknown or Not Reported	24	17 (40%)	1	42	2
US Total	668	1,712 (71%)	30	2,410	100

[a] Total percent may not add up to 100 due to rounding.
Sources: FARS data from 2014 through 2016 and US Census Bureau population estimates for 2016.

3.2.2 Nonfatal-Injury Estimates

National-level estimates of nonfatal injuries come from samples of police reports and emergency department records. Table 5 provides nonfatal injury estimates from two such data sources from 2007 through 2016: one based on samples of police reports (NASS GES/CRSS) and the other based on samples of emergency department records (NEISS-AIP). Over the 10-year period, an estimated 504,000 bicyclists sustained nonfatal injuries, according to police reports. According to emergency department records, about 2.2 million bicyclists sustained nonfatal injuries in traffic-related crashes (CDC 2019b) during the same period.[27] There are various reasons why the NEISS-AIP bicyclist injury estimates are considerably higher than the NASS GES/CRSS estimates. For example, the NEISS-AIP data include all crashes that occur on a public highway, street, or road regardless of whether a motor vehicle was involved. By contrast, the NASS GES/CRSS data only include crashes that involve a motor vehicle. Another reason for the discrepancy comes from underreporting bicycle crashes, which is a well-known problem among bicycle safety advocates and public health officials (Richard and others 2018). For example, in San Francisco, California, public health statistics have shown that 39% of bicyclists who were injured and required transportation by ambulance were not reported in police records (San Francisco Department of Public Health 2017).[28]

[27] In the NEISS-AIP data, a traffic-related crash was defined as any vehicle incident occurring on a public highway, street, or road (CDC 2019c). Therefore, the estimated 2.2 million injured bicyclists included those involved in all crashes, even those in which a motor vehicle was not involved. However, they do not include bicyclist injuries resulting from crashes involving a motor vehicle in parking lots or on private properties.

[28] According to the report, of the 346 bicyclists with severe injuries transported by ambulance and treated at the hospital, 136 were not captured in the San Francisco Police Department database. Potential reasons include: (1) the bicyclists chose not to file a report with the police department; (2) the police department did not respond or did not file a collision report; (3) the collision was reported to other agencies, such as the California Highway Patrol; and (4) the data linkage process was unable to complete the match.

Table 5. Estimated US bicyclist nonfatal injuries based on samples of police reports and emergency department records from 2007 through 2016.

Year	Bicyclists with Nonfatal Injuries in Motor Vehicle Crashes Based on Police Reports (NASS GES/CRSS)	All Bicyclists with Nonfatal Injuries Based on Emergency Department Records (NEISS-AIP)
2007	44,000	210,000
2008	53,000	204,000
2009	51,000	200,000
2010	52,000	213,000
2011	48,000	229,000
2012	49,000	234,000
2013	48,000	221,000
2014	50,000	225,000
2015	45,000	247,000
2016	64,000	199,000
2007–2016 (10 years)[a]	504,000	2,183,000

[a] Yearly estimates are rounded to the nearest thousand. The 10-year total is computed by summing the original yearly estimates before rounding to the nearest thousand. Therefore, the 10-year total is larger than the sum of the yearly estimates.

Although imperfect, comparing the NEISS-AIP and the NASS GES/CRSS data concerning bicyclist nonfatal injury estimates shows that there were more than four times as many bicyclist injuries recorded in emergency department records compared to those recorded in police reports. Therefore, the NTSB concludes that police crash report data likely underestimate the scope of bicyclist nonfatal injuries.

4 Safety Issues

As a result of this research, the NTSB identified the following bicyclist safety issue areas: (1) improving roadway infrastructure for bicyclists, (2) enhancing conspicuity, and (3) mitigating head injury. Other safety issues that repeatedly emerged during stakeholder interview sessions are also discussed.

4.1 Improving Roadway Infrastructure for Bicyclists

Bicycle facilities are defined as "improvements and provisions to accommodate or encourage bicycling, including parking and storage facilities, and shared roadways not specifically defined for bicycle use" (AASHTO 2012).[29] More simply, a bicycle facility is any infrastructure improvement that facilitates the safe use of bicycles as one mode of transportation among many. The US Department of Transportation (DOT) explains its position concerning the use of bicycle facilities as follows—

> The DOT policy is to incorporate safe and convenient walking and bicycling facilities into transportation projects. Every transportation agency, including DOT, has the responsibility to improve conditions and opportunities for walking and bicycling and to integrate walking and bicycling into their transportation systems. Because of the numerous individual and community benefits that walking and bicycling provide—including health, safety, environmental, transportation, and quality of life—transportation agencies are encouraged to go beyond minimum standards to provide safe and convenient facilities for these modes (FHWA 2017a).

The DOT further clarified that the design and selection of safe and convenient bicycling facilities are dependent on the local context and should be integrated into overall transportation systems (FHWA 2017a).

Existing street and highway systems form the basic network needed for bicycle travel in the United States. Most jurisdictions do not allow bicycles on fully access-controlled facilities, such as interstates or expressways, unless no other alternative route is available. Some highway agencies allow bicycles on partially access-controlled facilities, such as high-speed, multilane, or divided highways (AASHTO 2018). However, unless explicitly prohibited, bicycles are expected to be present on all streets and highways. Common bicycle facilities used on US roadways to accommodate bicyclist traffic and improve safety include paved shoulders; wide, outside traffic lanes; bicycle-compatible drainage grates; maintenance hole covers adjusted to grade level; and a smooth, clean riding surface (AASHTO 2018). More advanced bicycle facilities, such as separated

[29] In the 2012 AASHTO *Guide for the Development of Bicycle Facilities*, shared lanes, sidewalks, signed routes, or shared lanes with shared lane markings are all considered bicycle facilities. In contrast, in the 2019 FHWA *Bikeway Selection Guide*, a bikeway is defined as "a facility intended for bicycle travel which designates space for bicyclists distinct from motor vehicle traffic" (Schultheiss and others 2019).

bike lanes and intersection treatments, have the potential to mitigate or prevent traffic interactions, conflicts, and crashes between bicycles and motor vehicles at known frequent crash locations.[30]

4.1.1 Bicyclist Crashes and Injuries at Midblock and Intersection Locations

Based on the NTSB's analysis of FARS and NASS GES/CRSS data from 2014 through 2016, table 6 shows bicyclist fatalities, nonfatal injuries, and crashes by crash location. About 173,000 bicycle crashes involving motor vehicles occurred from 2014 through 2016, and 65% of those crashes occurred at intersection locations, resulting in about 103,000 nonfatal bicyclist injuries.[31] Among the 2,410 bicyclist fatalities that occurred during the same period, 1,361 or 56% of all of those bicyclist fatalities occurred at midblock locations.[32] This finding suggests that although there are more bicycle crashes occurring at intersections, crash severity is higher when a crash occurs at a midblock location.

Table 6. US bicyclist fatalities, nonfatal injuries, and crashes by crash location from 2014 through 2016.

	Based on FARS Data		Based on NASS GES/CRSS Data			
Location	**Fatalities**	**%**	**Nonfatal Injuries**	**%**	**Crash Counts**	**%**
Midblock	1,361	56	31,000	19	34,000	19
Intersection	898	37	103,000	64	113,000	65
Others[a]	151	6	26,000	16	26,000	15
All[b]	2,410	100	160,000	100	173,000	100

[a] The category *Others* includes driveway access areas and entrance/exit ramps.
[b] Total percent may not add up to 100 due to rounding. For estimates based on NASS GES/CRSS data, the percentages were computed using the actual weight while nonfatal injury and crash estimates were rounded to the nearest thousand. Values for the category *All* were computed using the actual weights before rounding; therefore, adding the rounded individual values may not equal the column totals.

[30] (a) A *separated bike lane* is an exclusive space for bicycle travel along a roadway that is physically separated from vehicular traffic, parking lanes, and sidewalks by a raised median, on street parking, or other vertical barrier, such as bollards. A separated bike lane is also known as a cycle track or a protected bike lane. It can be installed at street level or raised. It can be placed on the right side, the left side, or the center of a roadway. It can be restricted to one-way bicycle traffic, most typically with the vehicular traffic flow. If it allows for one-way bicycle traffic opposite the direction of vehicular traffic flow, it is known as a contraflow separated bike lane. It can also accommodate two-way bicycle traffic. (b) *Intersection treatments* refer to additional improvements to the roadway infrastructure at intersection locations that help improve bicycle safety, such as delineating designated space for bicycles to make left turns or installing special bicycle signal faces. (c) The term *interaction* refers to the confluence—the meeting or merging—of at least two traveling units, in this case, a motor vehicle and a bicycle. The term *conflict* refers to a potentially risky interaction that occurs when one or both units take an action, such as changing direction, speed, or both, in order to avoid a collision (Schroeder and others 2010).

[31] The term *intersection* refers to the point at which two or more roadways cross each other, which is typically managed by traffic controls.

[32] The term *midblock location* refers to any point along a roadway between intersections. It does not include the approach areas leading into or out of an intersection. It also excludes driveway access areas and entrance/exit ramps.

Beginning in 2014, NHTSA began categorizing FARS and NASS GES/CRSS data on bicyclist crashes into 19 bicycle crash groups, such as “bicyclist failed to yield at signalized intersection” or “motorist overtaking bicyclist.” Figure 6 shows bicyclist fatalities attributed to the 10 most frequent bicycle crash groups from 2014 through 2016. Each bar in figure 6 is further divided into midblock, intersection, or other locations. Of the 1,361 fatalities that occurred at midblock locations (indicated by the blue bars), 614 bicyclists died when motorists were overtaking bicyclists, representing 45% of all midblock bicyclist fatalities. The second and third most frequently cited crash groups were “parallel paths—other circumstances,” which resulted in 165, or 12%, of bicyclist deaths; and “bicyclist failed to yield—midblock,” which resulted in 127, or 9%, of bicyclist deaths.[33] Another 125, or 9%, of bicyclists died at midblock locations when the “bicyclist turned or merged left.” The top two crash groups accounted for 779 of all bicyclist fatalities, and they involved both bicyclists and motorists traveling midblock in the same direction. Therefore, separating bicycle and motor vehicle traffic could potentially prevent such crashes.

Figure 6 also shows that the three most common fatal bicycle crash groups at intersection locations (indicated by the pink bars) were “bicyclist failed to yield—signalized intersection” which resulted in 170, or 19%, of all intersection bicyclist deaths; “bicyclist failed to yield—sign-controlled intersection,” which resulted in 165, or 18%, of all intersection bicyclist deaths; and “crossing paths—other circumstances,” which resulted in 131, or 15%, of all intersection bicyclist deaths. These three crash groups together accounted for 466 bicyclist fatalities.

[33] “Bicyclist failed to yield—midblock” typically involves a bicyclist riding out from somewhere, such as a driveway or sidewalk, and entering the main traffic stream.

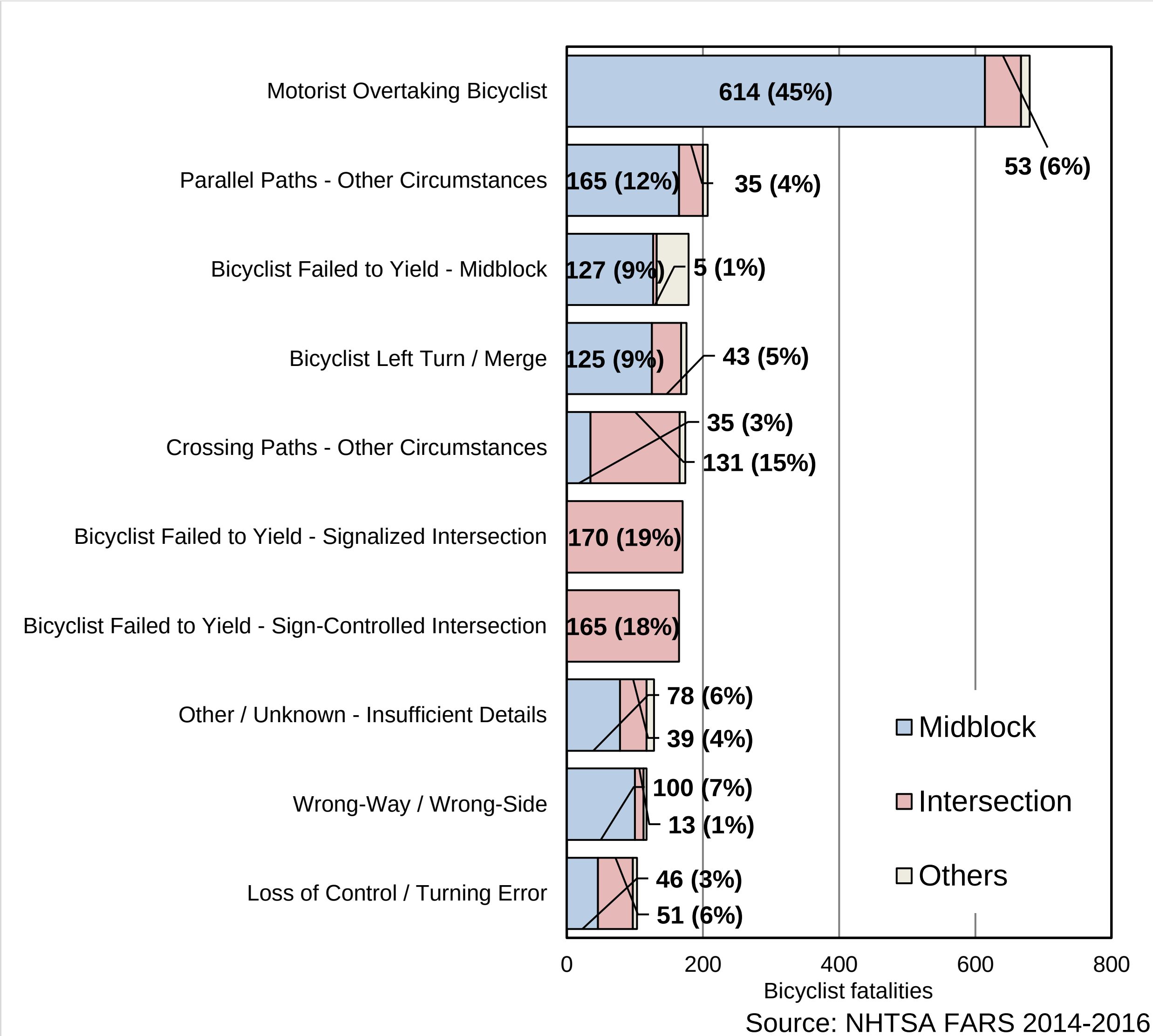

Figure 6. US bicyclist fatalities and percentages by 10 most frequent bicycle crash groups and location types from 2014 through 2016.

Table 7 shows the number of bicycle crashes involving motor vehicles that occurred from 2014 through 2016 based on a sample of police reports (NASS GES/CRSS); the data were also distributed by bicycle crash groups with at least 100 bicyclist fatalities (FARS) during the same period (see figure 6). Crashes at midblock locations involving a motorist overtaking a bicyclist accounted for most of the bicyclist fatalities, or 25%, but only 7% of bicyclist crashes; whereas, crashes at intersection locations involving "crossing paths—other circumstances" were more frequent, representing 11% of bicycle crashes, but not nearly as lethal, representing 5% of bicyclist fatalities. This comparison shows that, although there were more bicycle crashes involving motor vehicles at intersection locations, serious crashes resulting in fatalities occurred more frequently at midblock locations.

Table 7. US bicyclist fatalities and crashes by high-fatality crash group from 2014 through 2016.

	Based on FARS		Based on NASS GES/CRSS	
Bicycle Crash Group (Location)	**Fatalities**	**%**	**Crashes**	**%**
Motorist Overtaking Bicyclist (Midblock)	614	25	12,000	7
Bicyclist Failed to Yield—Signalized Intersection (Intersection)	170	7	14,000	8
Bicyclist Failed to Yield—Sign-Controlled Intersection (Intersection)	165	7	9,000	5
Parallel Paths—Other Circumstances (Midblock)	165	7	5,000	3
Crossing Paths—Other Circumstances (Intersection)	131	5	20,000	11
Bicyclist Failed to Yield—Midblock (Midblock)	127	5	3,000	2
Bicyclist Left Turn/Merge (Midblock)	125	5	3,000	2
Wrong-Way/Wrong-Side (Midblock)	100	4	3,000	2
All Crash Groups[a]	2,410	100	177,000	100

[a] Because only 8 bicycle crash groups with at least 100 bicyclist fatalities were included in this table, the sum of the 8 values does not add up to the total values.

The NTSB obtained 2017 bicycle crash data for the following four states: Pennsylvania, Minnesota, Texas, and Washington. As shown in table 8, the NTSB determined there were 6,611 bicyclists involved in collisions with motor vehicles across the four states. The NTSB further categorized the injury severity level of each bicyclist involved in the collisions using the KABCO scale, which was developed by the National Safety Council and is commonly used by law enforcement to classify injuries in motor vehicle crashes. The KABCO scale injury classification levels are as follows: K is used for fatal, A is used for incapacitating injury, B is used for suspected serious injury, C is used for possible injury, and O is used for no apparent injury. The NTSB also categorized the crash locations as follows: driveway, intersection, midblock, and other locations. For each location, the posted speed limit was categorized into four groups as well: at or below 25 mph, 30 to 35 mph, 40 to 45 mph, and at or above 50 mph. Geographic coordinates of the crash locations were available for 92% of all bicyclists involved, and when examined in conjunction with US Census Bureau data, the locations were categorized as urban or rural. As a result, table 8 also shows the number and percentage of bicyclists involved in crashes according to these four constructed variables: injury severity level, location, posted speed limit, and urban-rural classification. Of all bicyclists involved in crashes with motor vehicles, 59% were struck at intersection locations, 30% were struck at midblock locations, and 11% were struck at driveways. Crashes most commonly occurred in urban areas (82%) and at locations with a posted speed limit of 30 to 35 mph (45%). Further, 2% of all bicyclists involved in crashes with motor vehicles sustained a fatal injury and another 9% sustained incapacitating injuries.

Table 8. Number of bicyclists involved in motor vehicle crashes in four selected states by injury severity level, location, posted speed limit, and urban-rural classification in 2017.

Variable	Number of Bicyclists	%[a]
Injury Severity Level		
Fatal (K)	98	2
Incapacitating Injury (A)	609	9
Suspected Serious Injury (B)	1,297	20
Possible Injury (C), Including Injury with Unknown Severity	3,860	58
No Apparent Injury (O)	631	10
Unknown	116	2
Location		
Midblock	1,949	30
Intersection and Intersection-related	3,892	59
Driveway and Driveway-related	695	11
Others (for example, on or off ramp)	72	1
Unknown	3	0
Posted Speed Limit		
≤25 mph	1,349	20
30–35 mph	2,941	45
40–45 mph	1,064	16
≥50 mph	284	4
Unknown	973	15
Urban-Rural Classification		
Rural	680	10
Urban	5,422	82
Unknown	509	8
Bicyclists Involved in Motor Vehicle Crashes	6,611	100

[a] Total percent may not add up to 100 due to rounding.

Of the 6,611 bicyclists involved in motor vehicle crashes across the four states, 5,266 bicyclists, or 80%, had valid data for the following three variables in table 8: block location, posted speed limit, and urban-rural classification. As mentioned in section 2.2, the NTSB used a logistic regression analysis to examine the effects these three variables had on the likelihood of experiencing a fatal or serious injury. Consistent with earlier findings, table 9 shows that a bicyclist was twice as likely to sustain a fatal or serious injury if the crash occurred at a midblock location compared to all other locations, given the same posted speed limit and urban-rural category. One possible explanation may involve the traveling speeds of the motor vehicles at midblock locations. Compared to intersection locations where vehicles may encounter traffic controls, such as lights or stop signs, and where there may be more turning vehicles, vehicles in midblock locations tend to travel at higher speeds even in road segments with the same posted speed limit. Therefore, when a collision occurs between a motor vehicle and a bicycle, it is likely to involve a higher travel speed at midblock locations, leading to a higher injury severity level for the bicyclist. Therefore, the NTSB concludes that bicycle crashes involving motor vehicles at midblock locations are more likely to result in fatal and serious injuries for the bicyclists.

Table 9. Likelihood of a crash-involved bicyclist sustaining a fatal or serious injury based on location, urban-rural, and posted speed limit category, using a logistic regression model of 2017 crash data from four selected states.

	Odds Ratio	95% Confidence Limits
Midblock (Compared to All Other Locations)	2.096	(1.750, 2.511)
Rural (Compared to Urban Areas)	1.874	(1.485, 2.364)
≥50 mph (Compared to ≤25 mph)	5.484	(3.828, 7.855)
40–45 mph (Compared to ≤25 mph)	2.844	(2.131, 3.796)
30–35 mph (Compared to ≤25 mph)	1.654	(1.268, 2.158)

4.1.2 Separated Bike Lanes

One way to reduce the chance of the most serious bicycle crash types, such as those occurring at midblock locations, is to install separated bike lanes. Separated bike lanes are an on-road bicycle facility exclusively designed for bicyclists.[34] Such lanes are located within or directly adjacent to the roadway, they are physically separated from motor vehicle traffic by a vertical element, and they can be one-way or two-way facilities (FHWA 2015). Separated bike lanes are often implemented at grade with the roadway or at the sidewalk level. At the roadway level, they can be separated by raised medians; vertical elements, such as bollards; or on-street parking. At the sidewalk level, they can be delineated by a curb, a median, or a different pavement color or texture (NACTO 2014). The FHWA has identified separated bike lanes as an on-road engineering countermeasure (Sundstrom and others 2014).[35]

Many European countries, most notably the Netherlands and Denmark, have been using separated bike lanes for decades and are among the safest in terms of bicycling fatalities per distance traveled (Santacreu 2018).[36] Cities like Amsterdam and Copenhagen have been recognized as the most bicycle-friendly cities, with more than 30% of yearly trips in these cities being completed by bicycle.[37] Residents felt safe to ride and most attributed that to their bicycle infrastructure, specifically the networks of separated bike lanes (Chataway and others 2014; City of Copenhagen 2017).

[34] *Separated bike lanes* are also often referred to as cycle tracks or protected bike lanes.

[35] The FHWA uses the term *engineering countermeasure* to refer to an on-road infrastructure improvement.

[36] For more information, see the European Cyclists' Federation website.

[37] According to the European Cyclists' Federation website, 35% of trips in Copenhagen were completed by bicycle in 2010 and 32% of trips in Amsterdam were completed by bicycle in 2012; see the dropdown menu for Capital Cities under Bicycle Usage.

In the United States, separated bike lanes are one of many bicycle facilities that traffic engineers and planners can implement. Others include wide curb lanes, paved shoulders, conventional bike lanes, and buffered bike lanes (Sundstrom and others 2014; NACTO 2014).[38] Figure 7 provides photographic examples of common bicycle facilities used at midblock locations to separate bicycle and vehicular traffic.[39] During interview sessions, stakeholders often shared their belief that decisions about bicycle facilities—such as those about whether a bike facility is needed and what type of bike facility would work best in a certain location—should consider context and rely on data analysis. For example, some context factors that stakeholders mentioned to consider included traffic volume, speed, number of vehicular travel lanes, and whether an intersection or a driveway access was present.

During the interview sessions, most stakeholders stated that they would like to install separated bike lanes wherever they deemed appropriate. Although a nationwide bicycle facility inventory does not currently exist, PeopleForBikes has established a voluntary process for state and local officials to add their separated bike lanes to a shared inventory database.[40] A review of the PeopleForBikes data show that local US agencies have begun to install separated bike lanes in recent years. Between 2008 and 2017, more than 80 miles of separated bike lanes were constructed. The database also indicates that there are 130 bike lane projects planned or under construction that are expected to be completed between 2018 and 2022 (PeopleForBikes 2019). Because submission to the database is voluntary, it likely underestimates the actual number of separated bike lanes; however, the overall trend shows a substantial increase in separated bike lanes across the United States.

Many local transportation officials also discussed their separated bike lane projects during the stakeholder interview sessions. Some local and state DOT representatives indicated that the implementation of separated bike lanes is often hindered by the lack of agency commitment or the lack of policies that actually designate the necessary funding for them. As of 2018, 35 state DOTs reported recommending separated bike lanes during the planning and design phase of their state roadway projects, but only 4 of those states had separated bike lanes installed along their state roadways (League of American Bicyclists 2019). According to the PeopleForBikes database of separated bike lanes, only 82 US cities have at least one separated bike lane.

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[38] (a) A *conventional bike lane* is a preferential or exclusive space for bicycle travel along a roadway. It can be visually delineated by pavement marking, paint, and signage. It is located between a vehicular travel lane and a curb, a roadway edge, or a parking lane. It is typically placed on the right side of the roadway, and bicycles travel in the same direction as motor vehicles. It can be placed on the left side of the roadway if it is a one-way street. (b) A *buffered bike lane* is a conventional bike lane with additional buffer space separating the bicycle lane from an adjacent vehicle travel and/or a parking lane.

[39] Larger versions of all photographs in figure 7 can be found in the NTSB Docket Management System, using the NTSB ID DCA18SS002.

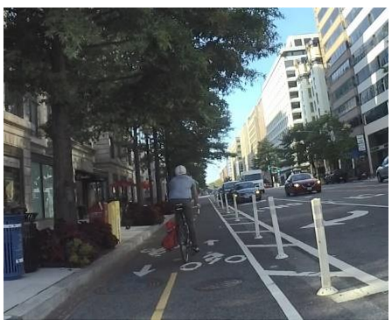
[40] PeopleForBikes is a bicycle industry advocacy group. The original data collection project, called the Green Lane Project began in 2012. It was designed to help accelerate the implementation of separated bike lanes. The project used the term *protected bike lanes* in lieu of separated bike lanes. See the PeopleForBikes database.

Separated Bike Lanes (also known as Cycle Tracks and Protected Bike Lanes)

a. Painted one-way separated bike lane with vertical barrier

b. One-way separated bike lane with parking as barrier

c. Two-way separated bike lane with parking as barrier



d. Two-way separated bike lane with vertical barrier

e. Two-way separated bike lane with vertical barrier (center of roadway)

f. Two-way separated bike lane, complete separation from vehicular traffic

Conventional and Buffered Bike Lanes

g. Conventional bike lane on arterial road

h. Conventional bike lane on residential street

i. Painted conventional bike lane

j. Buffered bike lane

Figure 7. Common bicycle facilities found at midblock locations (hyperlinks provide access to larger versions of all photographs).

Research on separated bike lanes in the United States has been limited and, thus far, has yielded mixed results. For example, in 2014, a study of separated bike lanes conducted in five US cities—Austin, Texas; Chicago, Illinois; Portland, Oregon; San Francisco, California; and the District of Columbia—found that installing separated bike lanes increased bicycle ridership and bicyclist compliance with intersection rules (Monsere and others 2014). In general, bicyclists reported feeling more comfortable riding in a separated bike lane, even if the bike lane was separated only by flexible posts. The study also noted that no collisions were observed during its 144 hours of video recordings of nearly 13,000 bicyclists traveling through the study area (Monsere and others 2014).

Conversely, a 2013 study that evaluated two separated bike lanes in the District of Columbia found that bicyclist crash frequency increased by one crash per year. However, bicycle volume also increased 200% during peak hours over the same period (Goodno and others 2013). A study of 839 injured bicyclists conducted in New York City, from December 2008 to August 2014, found that separated bike lanes were associated with 23% fewer bicyclist injuries, but an increased chance of sustaining more than a mild injury (Walls and others 2016). The crashes that produced more serious injuries were clustered near bridges and tunnel portals, suggesting that when installing separated bike lanes, traffic engineers and planners may have to incorporate different design features to customize these bike facilities to local traffic characteristics (Walls and others 2016). Transportation professionals participating in the NTSB stakeholder interviews routinely stressed the importance of geometric design guidance when designing and implementing separated bike lanes.

There has been more research done on separated bike lanes in other countries where such bicycle facilities are more common. Research in those countries has shown that separated bike lanes improve safety. For example, one study in Montreal, Canada, analyzed emergency medical records and found that, compared to roads with similar characteristics, bicyclists on roads with separated bike lanes had 28% less injury risk (Lusk and others 2011). A study conducted in Toronto and Vancouver, Canada, of 690 bicyclists injured along 14 types of bicycle routes with specific bicycle facilities, found that, among all bicycle facilities, bicyclists using separated bike lanes had the lowest injury risk; as much as nine times lower than those riding on major streets with on-street parking but no bicycle facility (Teschke and others 2012b). A separate study, using the same dataset collected in Toronto and Vancouver, focused on injuries at nonintersection locations and found that bicyclists had a 95% less chance (that is, an odds ratio of 0.05) of being injured when traveling on separated bike lanes. Local streets with diverters at the nearest intersection to reduce vehicle traffic were associated with the least risk of injury (Harris and others 2013).[41] In a 2013 meta-analysis of 23 research papers on separated bike lanes in Europe and Canada, researchers found that those papers that examined injury severity indicated that constructing separated bike lanes reduced injury severity because they help eliminate crashes at

[41] *Diverters* are traffic-control devices that direct nonlocal vehicle traffic away from local, neighborhood streets so as to deflect and discourage cut-through vehicle traffic. Such local streets do not have separated bike lanes.

midblock locations, such as when bicyclists are hit from behind, which has the highest fatality rate (Thomas and DeRobertis 2013).[42]

In addition, the FHWA's own 2019 *Bikeway Selection Guide* also shows that separated bike lanes, with or without protected intersections, all but eliminate three key bicycle crash types: hit from behind, overtaking, and sideswipes (Schultheiss and others 2019).[43] Separated bike lanes, which separate motor vehicle and bicycle traffic with a physical barrier, are an effective but underused bicycle facility. Therefore, the NTSB concludes that separated bike lanes could prevent bicycle crashes involving motor vehicles at midblock locations and, thereby, also reduce the number of fatalities and serious injuries associated with such crashes.

4.1.3 Safety Treatments at Intersection Locations

Although separated bike lanes can improve safety for bicyclists by reducing the chance of traffic conflicts between bicycles and motor vehicles, these lanes ultimately come to intersections where potential traffic conflicts are unavoidable. As shown in table 6 in section 4.1.1, 65% of nonfatal injuries and bicycle crashes occurred at intersections. The 2017 crash data obtained from four states also showed that 59% of bicyclists were involved in motor vehicle crashes at intersections or intersection-related locations (see table 8 in section 4.1.1). Even though bicyclists struck by motor vehicles at intersection locations do not sustain fatal or serious injury as often as those struck at midblock locations, the high crash frequency in these locations warrants attention. Stakeholders also revealed concerns about intersection safety, especially as more separated bike lanes are expected to be implemented.

Treatments at intersection locations are discussed in the American Association of State Highway and Transportation Officials' (AASHTO) 2012 *Guide for the Development of Bicycle Facilities*, the National Association of City Transportation Officials' (NACTO) 2014 *Urban Bikeway Guide*, and the FHWA's 2009 *Manual on Uniform Traffic Control Devices* (*MUTCD*) (FHWA 2012). In general, intersection treatments are intended to reduce crashes between motor vehicles and bicycles by increasing visibility and clearly denoting right-of-way using color, signage, medians, signals, and pavement markings (NACTO 2014). In recent years, through the FHWA interim approval process for the *MUTCD*, new bicycle-specific traffic-control devices at intersections have become available for implementation (FHWA 2018b).[44] Figure 8 shows photographic examples of select intersection treatments.[45]

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[42] Another identified common collision type occurring at midblock locations is known as "dooring," which occurs when a bicyclist strikes a motor vehicle door as the motorist is opening it. This type of collision can produce serious injuries.

[43] A *protected intersection* refers to an intersection safety treatment for bicycle travel, typically designed for the continuation of separated bike lanes that carry bicycle traffic through a signalized or stop-controlled intersection. Typical design involves positioning the pedestrian crossing and bike lane farther in advance of the intersection area and installing islands.

[44] The FHWA has the authority to issue interim approvals of new traffic-control devices or revised applications. Approvals are based on the results of successful experimentation, studies, or research. Such interim approvals will typically be included in the next revision of the *MUTCD*. See the FHWA interim approval process.

[45] Larger versions of all photographs in figure 8 can be found in the NTSB Docket Management System, using the NTSB ID DCA18SS002.

a. Bicycle signal face

b. Bicycle box using paint

c. Bicycle box using marking

d. Two-stage bicycle turn box

e. Two-stage bicycle turn box with bicycle signal face

f. Protected intersection with four islands that (1) separate right-turning bicycles from motor vehicles and (2) position left-turning bicycles along the pedestrian crossing facing the traffic signal

Figure 8. Examples of intersection treatments for bicyclists (hyperlinks provide access to larger versions of all photographs).

Since the 2009 *MUTCD* was first published, the FHWA has granted three interim approvals for the following bicycle-relevant intersection treatments: bicycle signal face, bicycle box, and two-stage bicycle turn box.[46]

- **Bicycle Signal Face.** The first intersection treatment was the bicycle signal face. Between 2009 and 2013, at least 14 state, county, and local agencies experimented with the use of a bicycle signal face (see figure 8) to provide separate control of bicycle movements at intersections. The evaluation showed that there was increased compliance by bicyclists with the traffic controls, and depending on the specific application, the device reduced the overall bicycle crash rate up to 45%. As a result, the FHWA granted interim approval for the use of bicycle signal faces in 2013.[47] As of 2018, 13 states have traffic signals with a bicycle signal face on their state roadways (League of American Bicyclists 2019).

- **Bicycle Box.** The second intersection treatment was the bicycle box (see figure 8). This treatment typically consists of an advance stop line before an intersection with a bicycle symbol marking on the pavement or green paint indicating that the "box" is designed for bicyclists. A clear path designates a bicycle lane to enter the bicycle box. More than 25 experiments conducted by state, county, and local agencies assessed bicycle box effectiveness and found they were generally successful at reducing the number of conflicts between bicycles and turning motor vehicles, the number of avoidance maneuvers by bicyclists and motorists, and the number of encroachments by bicyclists and motorists into pedestrian crosswalks. The results of the experiments showed that road users appeared to understand the purpose and proper use of the bicycle box. The FHWA granted interim approval for the use of bicycle boxes in 2016.[48] As of 2018, 14 states have bicycle boxes installed on their state roadways (League of American Bicyclists 2019).

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[46] (a) A *bicycle signal face* is a traffic-control device used to provide for separate control of bicycle movement at a signalized intersection location. (b) A *bicycle box* is a designated area at the head of a traffic lane, in front of the stop line, at a signalized intersection location that provides bicyclists with a safe and visible way to get ahead of queuing traffic during the red signal phase. This designated area can be visibly marked using pavement markings, green paint, or a combination of both. (c) A *two-stage bicycle turn box* is a designated area at a signalized intersection for bicyclists to position themselves outside of the traveling path of motor vehicles and other bicycles. A bicyclist traveling in a bike lane along with the traffic on the right side of the roadway can travel through the intersection with the green signal, make the left turn inside the two-stage bicycle turn box, and wait for the green signal of the vehicular traffic or the pedestrian crossing signal. This designated area can be visibly marked using pavement markings, green paint, or a combination of both. A two-stage bicycle turn box can be implemented with a bicycle signal face.

[47] See the FHWA memorandum for "Interim Approval for Optional Use of a Bicycle Signal Face (IA-16)," dated December 23, 2014.

[48] See the FHWA memorandum for "Interim Approval for Optional Use of an Intersection Bicycle Box (IA-18)," dated October 12, 2016.

- **Two-Stage Bicycle Turn Box.** The third intersection treatment, which is also the most relevant to separated bike lanes, was the two-stage bicycle turn box. It is sometimes also called a two-stage queue box (see figure 8). Because many separated bike lanes are installed on the right side of roadways, bicyclists can encounter difficulties when turning left, especially on multilane roadways. Twelve experiments involving two-stage bicycle turn boxes showed no adverse impact on safety but significantly improved consistency in how bicyclists navigated two-stage turns at intersections.[49] The FHWA granted interim approval for the use of the two-stage bicycle turn box in 2017.

Some states are further exploring the use of additional intersection treatments. For example, in addition to the use of two-stage turns, some states have found that physical separation between bicyclists and motorists can be improved by installing refuge islands, also known as protected intersections (see figure 8). According to the Massachusetts DOT *Separated Bike Lane Design Guide*, a protected intersection "maintains the physical separation through the intersection, thereby eliminating the merging and weaving movements inherent in conventional bike lane and shared lane designs" (Massachusetts DOT 2015). Between 2016 and 2017, 12 such protected intersections were installed in the United States (Andersen 2017).

New York City also recently conducted pilot testing of two intersection treatments: (1) a delayed turn, also known as a split-leading bicycle interval, and (2) an offset crossing (NYC DOT 2018). A delayed turn uses a bicycle signal to provide bicyclists a 10-second head start before motorists begin their turns. An offset crossing follows a practice from the Netherlands that slows the turning vehicle by reducing turning radii and providing a slight deflection of the bike lane through the intersection. Based on crash data and observations of traffic conflicts from 2014 through 2016 during the pilot testing, the two intersection treatments were found to be associated with fewer conflicts per turning vehicle when compared to the more widely implemented treatments known as mixing zones (see figure 8) (NYC DOT 2018). Mixing zones refers to planned traffic areas where motor vehicles may merge into bike lanes when making a turn.

The benefits of separated bike lanes cannot be fully realized unless consideration is also given to improving the safety of intersections. In recent years, through experimentation and the interim approval process, the FHWA has identified intersection treatments that are proven countermeasures to improve bicyclist safety at intersection locations. Implementing improvements at intersections and midblock locations can further improve bicyclist safety by creating networks of safer roadways for bicyclists. The NTSB concludes that combining proven countermeasures to improve bicyclist safety at intersection and midblock locations can create a network of safer roadways for bicyclists.

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[49] See the FHWA memorandum for "Interim Approval for Optional Use of Two-Stage Bicycle Turn Boxes (IA-20)," dated July 13, 2017.

4.1.4 Design Guides and Standards for Separated Bike Lanes and Intersection Treatments

All bike lanes, conventional or separated, are considered on-road bicycle facilities; therefore, multiple standards and design guides apply to their use. Concerning separated bike lanes, specifically, AASHTO's 2018 edition of *A Policy on Geometric Design of Highways and Streets* states that—

> In many instances, design features of separate bike facilities are controlled by the adjoining roadway and by the design of the highway itself. For further guidance, refer to AASHTO's *Guide for the Development of Bicycle Facilities* and other current research (AASHTO 2018).[50]

AASHTO's latest *Guide for the Development of Bicycle Facilities* was published in 2012, and AASHTO is currently revising it. Chapter 4 of the *Guide for the Development of Bicycle Facilities* provides guidance for several on-road bicycle facilities, including shared lanes, marked or unmarked; paved shoulders; bicycle lanes, including intersections; and bicycle boulevards. However, it does not address separated bike lanes (AASHTO 2012).

The FHWA's *MUTCD* contains national standards governing all traffic-control devices, such as signs and on-road markings used in bicycle facilities. Because separated bike lanes are not considered a traffic-control device, the current *MUTCD* does not contain standards specific to separated bike lanes.[51] During the interview sessions, many stakeholders indicated that the lack of information about separated bike lanes in the current *MUTCD* and in AASHTO's *Guide for the Development of Bicycle Facilities* and *A Policy on Geometric Design of Highways and Streets* has led many state and local agencies to look elsewhere for guidance on separated bike lanes.

In 2014, NACTO published the *Urban Bikeway Design Guide* that includes guidance on separated bike lanes.[52] In 2017, NACTO published *Designing for All Ages & Abilities*. It provides guidance on the selection of bicycle facilities based on roadway context, such as vehicle speed, vehicle volume, number of lanes, and operational characteristics, like curbside activity (NACTO 2017). Many stakeholders discussed how their agencies rely on NACTO's guidance documents when selecting bicycle facilities and view them as more innovative, flexible, and inclusive when compared to AASHTO's 2012 *Guide for the Development of Bicycle Facilities*. Some state DOT representatives among the stakeholders reported that their states had not yet adopted the 2014 NACTO *Urban Bikeway Design Guide*. According to the League of American Bicyclists (2019), only eight states have endorsed the NACTO guide. Although the adoption of the NACTO guide could increase the implementation of separated bike lanes on state roadways, guidance on geometric design and other engineering information officially endorsed and published by AASHTO is still needed to fully expand their implementation.

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[50] *A Policy on Geometric Design of Highways and Streets* is also commonly known as "The Green Book."

[51] The *MUTCD* refers to separated bike lanes as separated bikeways. Although the *MUTCD* does not contain standards specific to separated bike lanes, state and local DOTs are expected to use traffic-control devices that are compliant with the *MUTCD*, such as signs and on-road markings used on separated bike lanes.

[52] NACTO refers to separated bike lanes as cycle tracks.

Based on lessons learned from practitioners designing and implementing separated bike lanes across the country, the FHWA developed the *Separated Bike Lane Planning and Design Guide* in 2015 (FHWA 2015). This guide represents the first national-level design and planning recommendations for separated bike lanes. Also in 2015, the Massachusetts DOT published its own *Separated Bike Lane Planning and Design Guide* (Massachusetts DOT 2015). Many stakeholders stated that the problem is not the lack of guidance materials for bicycle facilities, but rather the variability, inconsistency, and sometimes conflicting content of the available guidance. Therefore, consolidating and harmonizing guidance documents at the national level would likely assist state and local agencies when selecting, planning, implementing, and funding bicycle facilities, including separated bike lanes.

In 2019, the FHWA published its *Bikeway Selection Guide*, which builds on and supplements other existing resources and guidance materials and also serves as a decision support tool. This publication focuses on policy, planning, and selection processes. It also incorporates many concepts, such as safety in numbers (Schultheiss and others 2019).[53] However, it does not include guidance on geometric design elements associated with bicycle facilities.

Separated bike lanes can reduce bicycle crashes involving motor vehicles, but they also cross vehicle traffic at intersections and driveways. Therefore, bicyclist crash risk while traveling on separated bike lanes depends on many factors, such as the placement of the separated bike lane, whether it is at street level or raised; the direction of travel within the separated bike lane, whether it is one-way or two-way; and the frequency of intersections and driveways it crosses. Cicchino and others (2018) showed that street-level two-way separated bike lanes with a higher frequency of intersections and driveways have a higher crash risk for bicyclists relative to major roadways. This suggests that not all separated bike lanes produce the desired safety benefit without appropriate planning; consequently, guidance on both selection of location and geometric design is needed.

Many stakeholders discussed issues with obtaining adequate and clear guidance about (1) how to determine if a separated bike lane is the most appropriate bicycle facility countermeasure to use, and (2) the specific geometric design elements of separated bike lanes. Stakeholders also expressed concerns regarding intersection treatments, particularly when implementing separated bike lanes and the transition between different bicycle lanes. During interview sessions, many stakeholders specifically stated that they are waiting for AASHTO to complete and publish its latest revision of the *Guide for the Development of Bicycle Facilities*. They also noted that the FHWA's *MUTCD* does not contain standards for or guidance on separated bike lanes, and that AASHTO's 2018 *A Policy on Geometric Design of Highways and Streets* redirects practitioners to AASHTO's 2012 *Guide for the Development of Bicycle Facilities*, which also does not address separated bike lanes. As of August 2019, the revision of the *Guide for the*

[53] Stakeholder interviews were conducted before the FHWA published its 2019 *Bikeway Selection Guide*. The guide also discusses other concepts, such as level of traffic stress, bicyclist design user types, bicycle network, and equity issues.

Development of Bicycle Facilities is in progress.[54] Although the revision is not complete, the draft version contains information addressing separated bike lanes and intersection treatments.[55]

All state and local DOTs rely on AASHTO's guidance documents to help design highways and streets, which includes incorporating bicycle facilities, such as separated bike lanes, into those geometric design plans. However, because AASHTO does not directly address separated bike lanes in its current *Guide for the Development of Bicycle Facilities*, federal and state agencies along with nongovernmental organizations have recently developed their own guidance for planning and designing separated bike lanes and the associated intersection treatments. Such a variety of variable guidance makes it challenging for state and local transportation planning and engineering practitioners to consistently and safely expand the implementation of separated bike lanes. Shared, common, consolidated guidance would likely facilitate increased implementation of these specific bicycle facilities across the United States. Therefore, the NTSB concludes that consolidating guidance concerning separated bike lanes, intersection treatments, and the transition between them may increase the implementation of separated bike lanes by transportation planning and engineering practitioners. The NTSB recommends that AASHTO include geometric design guidance materials on separated bike lanes, intersection treatments, and the transition between them in the next revision of the *Guide for the Development of Bicycle Facilities*.

4.1.5 Reducing Traffic Speeds and Improving Roadway Infrastructure for Bicyclists

Transportation officials, safety and bicycle advocates, and law enforcement representatives who took part in the stakeholder interview sessions frequently mentioned concerns about speed, speeding, and speed management in connection to bicyclist safety and crashes. A recent Office for Economic Co-operation and Development International Transport Forum publication presents strong evidence that higher travel speed is associated with increased occurrence and severity of road crashes (ITF 2018). With respect to bicycle safety, as shown in table 9 in section 4.1.1, bicyclist crashes at locations with speed limits set at or above 50 mph were more than 5 times more likely to result in fatal or serious injuries to the bicyclists compared to locations with posted motor vehicle speed limits of 25 mph or less. Even locations with posted speed limits of 30 to 35 mph yielded a 65% higher chance of the bicyclist sustaining a fatal or serious injury in a crash with a motor vehicle. Therefore, the NTSB concludes that reducing traffic speeds can improve bicycle safety by reducing the likelihood of fatal or serious injury in the event of a crash.

Reducing speeding-related crashes is currently an issue area on the NTSB's 2019–2020 Most Wanted List, as mentioned in section 1.3. Also, the NTSB issued a safety study on *Reducing Speeding-Related Crashes Involving Passenger Vehicles* in 2017, which included a recommendation to incorporate the safe system approach for urban roads to strengthen protection for vulnerable road users (H-17-28, NTSB 2017b).[56] The safe system approach considers likely

[54] Information about the guide update and revision process is available via the Transportation Research Board website.

[55] In a presentation at the 2018 Institute of Transportation Engineers Western District Annual Meeting, separated bike lanes and intersection treatments, such as bicycle boxes and two-stage bicycle turn boxes, were identified by state and local transportation practitioners as key topics. Further, according to the presentation, one chapter of the draft guide is dedicated to separated bike lanes.

[56] Safety Recommendation H-17-28 was issued to the FHWA; it is classified "Open—Acceptable Response."

crash types and the forces the human body can tolerate and survive when setting speed limits (Forbes and others 2012; Jurewicz and others 2014). More commonly practiced in Europe, the safe system approach recommends a maximum speed limit of about 18 mph where motor vehicles and vulnerable road users share the same space, such as in residential areas (ITF 2018). One way to reduce traffic speeds is to lower speed limits, especially for local streets. Some cities, most notably Boston, Massachusetts; New York City, New York; and Seattle, Washington, have lowered speed limits as part of their comprehensive strategy to improve pedestrian and bicyclist safety (IIHS 2018). For example, in Boston, the default speed limit was reduced from 30 mph to 25 mph in 2017, and the odds of vehicles exceeding 30 mph and 35 mph were reduced by 8.5% and 29.3%, respectively (Hu and Cicchino 2019).

In cases where reducing speed limits is not possible or desirable, installing separated bike lanes can improve bicycle safety. For example, in its 2017 *Designing for All Ages & Abilities*, NACTO recommends using a separated bike lane when the target vehicle speed is above 25 mph and when the daily motor vehicle volume is more than 6,000. For lower traffic volumes but with vehicles traveling above the 25-mph target speed, NACTO recommends either installing separated bike lanes or reducing speeds, which may include lane reduction (NACTO 2017).

Reducing the number of travel lanes or their widths, referred to as a "road diet," can result in both speed reductions and additional space for bicycle facilities (Huang and Zegeer 2002; Thomas 2013).[57] For example, compared to a two-lane street where drivers may change lanes to pass slower vehicles, a road diet might restrict drivers to one lane, in which the speed is set by a lead vehicle. The reclaimed space may then be used to accommodate different road users, such as bicyclists and pedestrians (AASHTO 2010). The FHWA recognized the road diet as a proven safety countermeasure in 2008, stating that it can improve safety by reducing total crashes by 19% to 47%. Road diets also provide better mobility and access for all road users, including bicyclists (FHWA 2017b). Therefore, the NTSB concludes that the road diet is a proven safety countermeasure that both reduces traffic speeds and provides space on the roadway for the implementation of bicycle facilities, such as separated bike lanes.

4.1.6 FHWA Proven Safety Countermeasures and Every Day Counts

Broader and appropriate implementation of certain bicycle facilities and intersection safety treatments could potentially reduce the likelihood of bicycle crashes involving motor vehicles as well as injury severity in such crashes. The FHWA oversees two programs that could strategically encourage the implementation of specific bicycle facilities and intersection safety treatments: (1) Proven Safety Countermeasures and (2) Every Day Counts.

As mentioned in section 2.1, the FHWA began its Proven Safety Countermeasures initiative in 2008. The initiative promotes the widespread implementation of infrastructure-oriented safety improvements and strategies based on their effectiveness. The countermeasures and strategies on the Proven Safety Countermeasures list are aligned with

[57] According to the FHWA, a *road diet* repositions pavement markings to better meet the needs of all road users. Examples of road diets include reducing the number of through lanes, a wider shoulder, a two-way left turn lane, and providing a dedicated space for bicycle facilities (FHWA 2014).

the FHWA's Focused Approach to Safety, which is currently focused on roadway departure, intersection crashes, and pedestrian/bicycle crashes.[58] In 2008, the initiative had 9 countermeasures on the list; it was updated in 2012 and 2017 and currently has 20 proven safety countermeasures on the list (FHWA 2018a). Through this initiative, the FHWA provides guidance and technical assistance to encourage state, tribal, and local road authorities to use these countermeasures (FHWA 2018a). Some of the 20 proven safety countermeasures involve strategies intended to improve safety for multiple types of road users, including bicyclists (FHWA 2018a). For example, the FHWA has been promoting road diets as a proven safety countermeasure through the initiative since 2008. As discussed in section 4.1.5, although a road diet program is not specifically aimed at improving bicyclist safety, by reducing traffic speeds and in some cases, opening space for the installation of bike lanes, such programs can improve bicyclist safety. Still, there are currently no bicycle-specific countermeasures on the FHWA's Proven Safety Countermeasures list, despite the DOT's 2010 policy calling for the improvement of bicycle and pedestrian safety and the full integration of bicycling and walking into the US transportation system.

The FHWA's other program that helps accelerate countermeasure adoption by state and local authorities is the Every Day Counts program. The Every Day Counts program is focused on identifying and rapidly deploying proven, yet underutilized, innovations to enhance safety, reduce congestion, and integrate automation. Since 2011, the FHWA's Office of Innovative Program Delivery, Center for Accelerating Innovation has administered the Every Day Counts program, which provides free technical assistance and resources to states to promote innovation. Although the Every Day Counts program is not limited to safety, it can serve as another way to accelerate proven safety countermeasures. Currently, the Every Day Counts program includes road diets.[59]

However, to further improve bicyclist safety, the FHWA could use the Proven Safety Countermeasures initiative and the Every Day Counts program to help increase the implementation of separated bike lanes and intersection safety treatments throughout the United States. To be included in either program, there must be well-established evidence supporting a countermeasure as proven and underutilized. The FHWA has stated that separated bike lanes can all but eliminate hit from behind, overtaking, and sideswipe crashes (Schultheiss and others 2019). Sections 4.1.2 and 4.1.3 in this report provide strong evidence of the safety benefits of separated bike lanes and intersection safety treatments, such as the bicycle signal face, the bicycle box, and the two-stage bicycle turn box, which have already received FHWA interim approvals. This suggests that the justification to include and promote separated bike lanes and intersection safety treatments in both the Proven Safety Countermeasures initiative and the Every Day Counts program already exists. Therefore, the NTSB concludes that including separated bike lanes and intersection safety treatments in the FHWA's Proven Safety Countermeasures initiative and Every Day Counts program could help accelerate their adoption and improve bicyclist safety. The NTSB recommends that the FHWA include separated bike lanes and intersection safety treatments on the list of Proven

[58] See the FHWA's Focused Approach to Safety website.

[59] The current FHWA Every Day Counts program is in its fifth 2-year cycle—from 2019 through 2020—and it includes 10 innovations. Road diets were first included on the Proven Safety Countermeasures list in 2008, and they were included in the third Every Day Counts cycle—from 2013 through 2014. Currently, road diets are included in the fifth Every Day Counts cycle as part of the Safe Transportation for Every Pedestrian program, along with other safety countermeasures, such as pedestrian hybrid beacons, pedestrian refuge islands, raised crosswalks, and crosswalk visibility enhancements.

Safety Countermeasures. The NTSB further recommends that the FHWA include separated bike lanes and intersection safety treatments in the Every Day Counts program.

4.2 Enhancing Conspicuity

There are different reasons why drivers and bicyclists may not be able to detect each other in time to prevent a collision, such as darkness or visual obscuration from objects in the environment. About 45% of all bicyclist fatalities occur in dark conditions even though national travel survey data estimate that fewer than 20% of bicycle trips take place at night.[60] Additionally, drivers may fail to detect a bicyclist in their path even though they are scanning the environment (Mack and Rock 1998). In about one third of cases in which bicyclists died in crashes involving a motorist overtaking a bicyclist, the driver reported not detecting the bicyclist before the crash (231 of 680 bicyclist fatalities from 2014 through 2016). Improving the ability to see other road users can reduce the likelihood of collisions. This section discusses three countermeasures—bicyclists wearing bright or reflective clothing, adding lights or reflective materials to bicycles, and improving motor vehicle headlights—that could improve bicycle and rider conspicuity to other road users. It also discusses other in-vehicle systems that could prevent or mitigate collisions between bicycles and motor vehicles.

4.2.1 Improving Bicycle and Rider Conspicuity

Conspicuity treatments generally refer to lights or retroreflective material designed to improve the detectability of objects. Several studies have shown that drivers are more likely to detect bicycles and bicyclists with conspicuity treatments compared to those without (Kwan and Mapstone 2006; Wood and others 2012). Additionally, research has generally shown that the use of conspicuity treatments is associated with reductions in crashes (Madsen, Andersen, and Lahrmann 2013; Lahrmann and others 2018) and injuries (Chen and Shen 2016). Conspicuity enhancements are most pronounced when retroreflective material is placed on the parts of the body that move during cycling, such as on a rider's ankles (Kwan and Mapstone 2006; Hemeren and others 2017). Humans are more readily able to detect this type of motion than a static source of reflection.

Several efforts have been made to increase the use of conspicuity treatments among bicyclists. Since the early 1970s, reflectors have been required on certain newly manufactured bicycles.[61] Many states and communities have laws requiring the use of bicycle lights at night (for example, Oregon and Virginia).[62] The North American Bikeshare Association recommends that cities implementing bikeshare programs require front and rear lights on all bikeshare bicycles.[63] New York City, New York, regulations require that businesses provide delivery bicyclists with

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[60] Based on FARS data from 2014 through 2016, 1,084 bicyclist fatalities occurred in dark conditions, representing 45% of all bicyclist fatalities. An analysis of the 2017 NHTS trip data showed there were 8,027 bicycle trips in the sample, of which 1,515, or 18.9%, had taken place between 6:00 p.m. and 5:59 a.m.

[61] See *Federal Register* 38, no. 90 (May 10, 1973):12302.

[62] See Oregon's law and Virginia's law concerning using bicycle lights at night.

[63] See the North American Bikeshare Association's Dockless Bikeshare Regulation Preliminary Guidance, Version 1, January 2018.

retroreflective upper body apparel.[64] Bicycles used for commercial purposes in New York City must also have a bell, a white front light, a red taillight, and reflectors on each wheel and on the front and back of the bicycle.[65] Some schools distribute reflective vests to their students who ride bicycles.[66] In Chicago, Illinois, a group called the Bicycling Ambassadors distributed 2,000 reflective ankle straps and arm bands to pedestrians and bicyclists in 2015. The group also regularly distributes bicycle headlights to bicyclists.[67] Finally, many safety campaigns have included materials to encourage motorists to look out for bicyclists and to encourage riders to use conspicuity treatments.[68]

Although there is evidence that conspicuity treatments can improve visibility and reduce crashes, there is less evidence to show whether efforts to increase their use have been successful. An Australian study found that although bicyclists report awareness of the benefits of using conspicuity aids, relatively few of them regularly use lights or reflective clothing (Wood and others 2009). An observational study of bicyclist clothing conducted in the greater Indianapolis, Indiana, area found that, apart from the summer months when riders wore lighter colored clothing, most riders wore dark colored clothing during the rest of the year (Yi and others 2017). An analysis of FARS data from 2014 through 2016 found that 1,209 bicyclists were fatally injured at night. Among the 911 bicyclists with known safety equipment information, 63, or 6.9%, were identified as having bicycle lights, and 26, or 2.9%, wore reflective clothing. One study found that riders overestimate their level of conspicuity to other road users (Wood and others 2013). Other studies have shown that bicycle light usage is relatively low even when it is required (Teschke and others 2012a; Ferguson and Blampied 1991). This may be partly because aftermarket removable bicycle lights are susceptible to being forgotten or stolen. Because of the challenges inherent in increasing rider use of conspicuity treatments, such as clothing or lighting, materials included on the bicycle at the time of manufacture may be the most reliable bicycle-conspicuity enhancement for most riders.

The requirements for bicycle reflectors on newly manufactured bicycles described in Title 16 *Code of Federal Regulations* (*CFR*) 1512 are set by the CPSC and were last updated in 1980. The requirements state that bicycles must have front, side, pedal, and rear-facing reflectors. The regulations include requirements for the color and placement of reflectors as well as for their reflective performance and resistance to damage from impacts and heat. The requirements permit reflective rims in lieu of side spoke-mounted reflectors as long as the reflective material forms a continuous circle on the rim and meets standards concerning abrasion and peeling.

Since the reflector standards were established in 1980, bicycle lighting systems and materials have improved. There have been improvements in the retroreflective properties of signage materials and fabrics (Berces and Robertson 2012). Also, light-emitting diode (LED)

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[64] See Do You Deliver? A Business Owner's Guide to Commercial Bicyclist Law, November 2012.

[65] More specifically, the bicycle must have a bell or an audible device, see Do You Deliver? A Business Owner's Guide to Commercial Bicyclist Law, November 2012.

[66] See the Safe Routes to School: the Health, Safety and Transportation Nexus, Promising Examples webpage.

[67] See the Chicago Complete Streets, Targeted Safety Events webpage.

[68] See Street Smart's Safety Tips for Biking; the League of American Bicyclists' Smart Cycling Quick Guide; and the Bikes Belong Foundation's A Review of Bicycle Safety Campaigns for some examples.

bicycle lights, which are lighter and more durable than their predecessors, have largely replaced bulb-based lights, and some bicycle manufacturers have begun incorporating lights into the originally manufactured bicycle.[69] Bicycle lights may also include different settings for brightness or for flashing lights. Although there is limited research on the effectiveness of different conspicuity treatments, one recent study showed that the application of reflective tape that met European motor vehicle reflector standards on the rear frame and pedal cranks of a bicycle made it visible from a significantly greater distance than using a traditional prismatic red rear reflector or a high-visibility jacket (Costa and others 2017).[70]

The NTSB concludes that improving bicycle conspicuity may reduce the likelihood of collisions between bicycles and motor vehicles. Further, the NTSB concludes that the existing requirements for bicycle conspicuity, established in 1980, are outdated and do not adequately reflect modern advances in bicycle conspicuity materials and technologies. Therefore, the NTSB recommends that the CPSC conduct an evaluation to determine whether bicycle conspicuity could be improved by modifying the requirements described in 16 *CFR* 1512.16; if so, the CPSC should revise the regulation accordingly.

4.2.2 Motor Vehicle Headlights

The risk of pedestrian fatalities, like bicyclist fatalities, increases in darkness. The NTSB's 2018 special investigation report, *Pedestrian Safety*, described advances in vehicle headlight technology and also described how organizations, such as Consumer Reports and the Insurance Institute for Highway Safety (IIHS), have designed tests to evaluate their real-world performance (NTSB 2018a). Yet, the current Federal Motor Vehicle Safety Standard (FMVSS) for headlights, FMVSS 108, does not include minimum illumination distance or on-vehicle performance testing of lighting systems. Rather, manufacturers self-certify that their lights meet criteria for bulb output, using the results of component tests—that is, operating tests carried out on parts that have been removed from a vehicle. Additionally, DOT rules permit a low beam and a high beam; however, unlike European standards, they do not allow vehicles manufactured for sale in the United States to continuously adjust the light pattern and provide high-beam illumination except within a segment of the beam that is adjusted to limit glare for oncoming drivers. As a result of its *Pedestrian Safety* report, the NTSB recommended that NHTSA—

> Revise Federal Motor Vehicle Safety Standard 108 to include performance-based standards for vehicle headlight systems correctly aimed on the road and tested on-vehicle to account for headlight height and lighting performance. (H-18-39)
>
> Revise Federal Motor Vehicle Safety Standard 108 to allow adaptive headlight systems. (H-18-40)

In October 2018, NHTSA published a notice of proposed rulemaking (NPRM) to amend FMVSS 108 to permit certification of adaptive driving beam headlight systems.[71] This represents

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[69] See Trek Lync Review: Built-In Bike Lights Are Great (When They're Charged).

[70] See Regulation 104 of the Economic Commission for Europe of the United Nations Uniform provisions concerning the approval of retro-reflective markings for vehicles of category M, N, and O, July 2012.

[71] See *Federal Register* 83, no. 198 (October 12, 2018):51766.

an important step toward revising the standard. Pending the publication of a final rule that allows installation of advanced vehicle lighting systems that have been shown to have safety benefits, Safety Recommendation H-18-40 is classified “Open—Acceptable Response.”

In March 2019, NHTSA stated that the agency was working on additional vehicle-level headlighting performance requirements; however, the agency’s actions to date have been limited to proposed tests for adaptive beam headlights. The NTSB classified Safety Recommendation H-18-39 “Open—Unacceptable Response” and urged NHTSA to issue performance-based standards for *all* vehicle headlight systems.

The NTSB continues to believe that motor vehicle safety standards should allow advanced vehicle lighting systems that have been shown to have safety benefits and that on-vehicle headlight system testing is needed to account for headlight height and lighting performance. Therefore, the NTSB concludes that revising FMVSS 108 to allow adaptive headlight systems and to require evaluating headlights in real-world settings rather than in a laboratory would likely result in headlights that improve drivers’ ability to detect other road users, including bicyclists. Consequently, the NTSB reiterates Safety Recommendations H-18-39 and H-18-40 to NHTSA.

4.2.3 In-Vehicle Systems to Detect Bicyclists

Although conspicuity typically connotes detectability to the human eye, increasingly cars and other motorized vehicles are being designed with systems that allow them to “see” or detect obstacles in their environment. Two types of systems—collision avoidance systems (CASs) and connected technologies have the potential to reduce crashes and injuries by providing advance warning and mitigations of potential collisions before they occur. These technologies were originally developed to address collisions between passenger vehicles, but they are evolving to include detection of other road users, including motorcyclists, pedestrians, and bicyclists. A typical CAS incorporates camera-, radar-, and lidar-based sensors to detect potential conflicts, such as slow-moving or stopped vehicles. When a conflict is identified, the system provides warnings. If the conflict persists, the system may initiate autonomous emergency braking or provide additional braking force if the driver brakes too late or not strongly enough.

Connected technologies allow vehicles to communicate with one another, with road infrastructure, or with road users to help warn drivers of risks and avoid crashes. They are designed to have a greater range of detection compared to CAS technologies, thus providing more time to detect and react to potential crash risks. Vehicle-to-pedestrian (V2P) systems are also used to describe communications between vehicles and bicyclists, either directly between vehicles and portable electronic devices or through infrastructure.[72] They are predicated on the use of dedicated short-range communication radios or cellular technology to send and receive information about the movement of transportation system users with the goal of preventing collisions. V2P systems have the potential to alert both the driver and the bicyclist or pedestrian, which may increase the likelihood that an action will be taken to avert a collision.

[72] Vehicle-to-pedestrian systems are commonly referred to as V2P systems. The terms vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) are also commonly used.

Since the 1990s, the NTSB has issued numerous recommendations to promote the development of multiple vehicle-based collision avoidance technologies, and the topic "Increase Implementation of Collision Avoidance Systems in All New Highway Vehicles" is currently on the NTSB 2019–2020 Most Wanted List.[73] Systems such as CAS and V2P will continue to be vitally important, especially as manufacturers develop and implement automated and autonomous driving systems.

4.2.3.1 Collision Avoidance Systems

CASs were originally designed to prevent or mitigate collisions between motor vehicles, such as rear-end collisions. In 2001, the NTSB published a special investigation report, *Vehicle- and Infrastructure-Based Technology for the Prevention of Rear-End Collisions*, that made several recommendations to NHTSA to develop performance standards for collision warning systems and adaptive cruise control for commercial and passenger vehicles (H-01-6 and H-01-8) and to then require such systems in new commercial vehicles (H-01-7, NTSB 2001).[74] In the ensuing years, little progress was made on these recommendations or on other recommendations pertaining to vehicle technology to prevent rear-end crashes.

In 2015, the NTSB published another special investigation report, *The Use of Forward Collision Avoidance Systems to Prevent and Mitigate Rear-End Crashes*, to examine the real-world and predicted efficacy of currently available CAS technologies (NTSB 2015). The report concluded that CAS technologies for passenger and commercial vehicles show clear safety benefits; however, more effort was needed to speed deployment of the technologies in all vehicle types. As a result, the NTSB recommended that manufacturers install forward CASs as standard features on all newly manufactured motor vehicles (H-15-8 and H-15-9).[75] The NTSB also recommended that NHTSA develop protocols for the assessment of CASs (H-15-4 and H-15-5) and that the agency expand its New Car Assessment Program (NCAP) to include a graded rating of CASs on new vehicle window stickers, also known as Monroney labels (H-15-6 and H-15-7).[76] In 2018, the NTSB issued recommendations designed to expand the use of CAS technologies to additional vehicles, including school buses and motorcycles (H-18-8, H-18-19, and H-18-29).[77] Also, the 2018 *Pedestrian Safety* report included two recommendations to NHTSA aimed at fostering the development, evaluation, and implementation of pedestrian CASs (H-18-42 and H-18-43).[78]

It is likely that the previous recommendations the NTSB has made concerning CASs, if implemented, would lead to safety improvements for bicyclists. It is also worth considering whether vehicle manufacturers should implement specific CASs or modify existing systems to

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[73] See the NTSB MWL topic Increase Implementation of Collision Avoidance Systems in All New Highway Vehicles.

[74] Safety Recommendation H-01-6 is classified "Closed—Unacceptable Action/Superseded"; H-01-7 is classified "Closed—Unacceptable Action"; and H-01-8 is classified "Closed—Acceptable Alternate Action."

[75] Safety Recommendations H-15-8 and H-15-9 are both classified "Open—Acceptable Response."

[76] Safety Recommendations H-15-6 and H-15-7 are both classified "Open—Acceptable Response."

[77] Safety Recommendations H-18-8 and H-18-29 are both classified "Open—Acceptable Response." Safety Recommendation H-18-19 is classified "Open—Await Response."

[78] Safety Recommendations H-18-42 and H-18-43 are both classified "Open—Acceptable Response."

enable detection of bicycles. There is evidence that such systems could reduce the incidence of collisions between motor vehicles and bicycles. For example, in 2015, IIHS researchers used data on crashes between motor vehicles and bicycles from several national highway crash databases to identify common crash scenarios that could benefit from the development of bicyclist-detection systems (MacAlister and Zuby 2015). They identified three crash modes that accounted for 74% of bicyclist fatalities in crashes involving a collision with the front of a motor vehicle. The IIHS researchers suggested that existing CASs could, with minor modifications, be designed to detect bicyclists, potentially mitigating or preventing up to 26% of bicyclist injuries and 52% of fatalities. Some automakers have already taken steps to incorporate bicyclist-detection systems into their CAS technology. For example, Volvo's City Safety system has a bicyclist-detection capability that uses radar and camera data.[79] Additionally, automakers are developing US-based bicycle and bicyclist surrogates that could be used to evaluate the effectiveness of bicyclist precollision systems (Yi and others 2016). Therefore, the NTSB concludes that CAS technologies could be modified to detect bicycles, which would likely reduce the incidence of collisions between motor vehicles and bicycles and mitigate injuries caused by collisions when they occur.

Although in-vehicle bicycle detection systems are a relatively new technology, some organizations have taken steps to promote their implementation. For example, the European New Car Assessment Program, known as Euro NCAP, provides overall vehicle safety ratings based on (1) adult occupant protection; (2) child occupant protection; (3) vulnerable road user protection, including pedestrians and bicyclists; and (4) "safety assist," which evaluates driver assistance and crash avoidance technologies. Since 2018, Euro NCAP has included two scenarios for bicyclist detection: one in which a bicyclist crosses a vehicle's path and one in which a bicyclist is traveling in the same direction as the vehicle.[80] The test uses a specially designed dummy bicyclist on a moving bicycle platform.[81] Although no published studies have yet evaluated whether the bicycle test scenarios have improved safety, research has shown that cars with better scores on the Euro NCAP pedestrian assessment are less likely to be involved in crashes that involve severe pedestrian injury (Pastor 2013).

New car ratings assessment programs, such as NCAP and Euro NCAP, provide a valuable service by evaluating and sharing information about the performance of vehicle safety systems. In the United States, research has shown that consumers are more likely to buy cars that receive high safety ratings (Cicchino 2015). Since 2015, the NTSB has recommended that NHTSA update NCAP to include ratings on the performance of CASs. Specifically, the NTSB recommended that NHTSA—

[79] However, Volvo lists several caveats in its vehicle owner's manuals. For example, if major parts of the bicyclist's body are not visible to the camera or if the bicyclist is transporting a large object, it may not detect the bicyclist. It is also only designed to detect adult bicyclists on adult-sized bicycles. For more information, see this sample owner's manual.

[80] As of January 2018, the Australasian NCAP has adopted Euro NCAP's standards and tests. See the Australasian NCAP's Future Requirements webpage.

[81] See Euro NCAP's AEB Cyclist webpage describing the tests and how they are performed.

> Expand the New Car Assessment Program 5-star rating system to include a scale that rates the performance of forward collision avoidance systems. (H-15-6)
>
> Once the rating scale, described in Safety Recommendation H-15-6, is established, include the ratings of forward collision avoidance systems on the vehicle Monroney labels. (H-15-7)
>
> Incorporate pedestrian safety systems, including pedestrian collision avoidance systems and other more-passive safety systems, into the New Car Assessment Program. (H-18-43)

In December 2015, as part of the Fixing America's Surface Transportation (FAST) Act, Public Law 114-94, Congress directed NHTSA to "promulgate a rule to ensure that crash avoidance information is indicated next to crashworthiness information on stickers placed on motor vehicles by manufacturers."[82] Since then, NHTSA has, on two occasions, solicited public comments on potential changes to NCAP. In response, several commenters asked NHTSA to include bicycle safety in NCAP. For example, the League of American Bicyclists and the Association of Pedestrian and Bicycle Professionals asked NHTSA to create crash avoidance and mitigation testing procedures for bicyclists and pedestrians and to harmonize its testing with Euro NCAP as the Australasian NCAP program has done.

In a March 2018 letter to the NTSB, NHTSA stated that the agency was reviewing public comments concerning revisions to NCAP. Although NHTSA has sought public comment on the future of NCAP, it has not yet taken any meaningful steps to modify the program to rate CASs or to incorporate tests to evaluate vehicle safety with respect to vulnerable road users, such as pedestrians and bicyclists. Therefore, the NTSB concludes that NHTSA's delays in updating NCAP have likely slowed the development of important safety systems for vulnerable road users and their implementation into the vehicle fleet. Therefore, the NTSB reiterates Safety Recommendations H-15-6, H-15-7, and H-18-43 to NHTSA. The NTSB also recommends that NHTSA incorporate into NCAP tests to evaluate a car's ability to avoid crashes with bicycles.

4.2.3.2 Vehicle-to-Pedestrian Systems

In 1999, the Federal Communications Commission set aside 75 MHz of radio spectrum in the 5.9-GHz band for vehicle-communications-based CASs. Since then, the DOT has sponsored voluntary standards, conducted cost-benefit analyses, and sponsored fleet operational testing. In 2011, NHTSA analyses showed that dedicated short-range communication-based connected vehicle technology could address about 80% of crash scenarios involving nonimpaired drivers. In 2013, the NTSB recommended that NHTSA develop minimum performance standards for connected vehicle technology for all highway vehicles and require that the technology be installed on all newly manufactured vehicles (H-13-30 and H-13-31, NTSB 2013b). In January 2017, NHTSA issued an NPRM to mandate vehicle-to-vehicle (V2V) communications for new light

[82] See the Fast Act, Public Law 114-94.

vehicles.[83] The NTSB responded that connected vehicle technology should apply to all highway vehicles and not just light-duty vehicles. In 2018, the NTSB made specific recommendations to NHTSA and the FHWA to incorporate motorcycles into the development of performance standards for V2V and vehicle-to-infrastructure (V2I) systems (H-18-30, H-18-31, and H-18-37, NTSB 2018b).[84]

Because of the lack of significant action toward accomplishing the recommended actions concerning connected vehicle technology, Safety Recommendations H-13-30 and H-13-31 are classified "Open—Unacceptable Response." With respect to the motorcycle-specific recommendations on V2V and V2I, in March 2019, NHTSA responded that that the agency has undertaken several efforts, such as a project examining motorcycle precrash scenarios, participation in a motorcycle safety research consortium, and a collaboration with FHWA to publish a report identifying gaps in motorcycle safety research and intelligent transportation systems (Flanigan and others 2018). However, NHTSA also noted that "bandwidth is an increasingly sought-after resource (for both Federal and commercial users), and the President has called for Government and industry to seek methods for increasing spectral efficiency." NHTSA also stated it is researching the concept of "spectrum sharing."

In addition to its research on motorcycle safety and advanced technologies, NHTSA has sponsored research to identify key scenarios in which V2P systems could potentially reduce the likelihood or severity of crashes (Swanson and others 2016). The research has identified scenarios in which V2P systems would be better suited to identify potential collisions than a CAS that used forward-looking detection sensors, such as when pedestrians are not "visible" to sensors due to obstruction or roadway geometry. The research also identified areas where more development is needed before V2P systems can be effectively implemented, such as reducing the likelihood of false warnings and improving the accuracy and speed of communications among users. Such issues, as well as issues concerning system reliability and partial implementation, will be particularly important as automated driving systems continue to be developed and implemented (Sandt and Owens 2017).

In 2017, the DOT's Intelligent Transportation Systems Joint Program Office (ITS JPO) published a white paper describing its V2P research (Craig, Fraser, and Campos 2017). According to the paper, the V2P approach taken by the DOT "encompasses a broad set of road users including pedestrians, children being pushed in strollers, people using wheelchairs and other mobility devices, passengers embarking and disembarking buses and trains, and people riding bicycles." However, of the 14 different research projects described in the paper, all of them address pedestrians and only 1 stated that it could also apply to bicyclists (when those bicyclists are traversing crosswalks).

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[83] According to the NPRM, "Light vehicles include passenger cars, vans, minivans, sport utility vehicles, crossover utility vehicles and light pickup trucks with a gross vehicle weight rating (GVWR) less than or equal to 10,000 pounds." See *Federal Register* 82, no. 8 (January 12, 2017):3854.

[84] Specifically, the NTSB called upon NHTSA to "incorporate motorcycles in the development of performance standards for connected vehicle-to-vehicle systems" (H-18-30), and "work with the Federal Highway Administration to incorporate motorcycles in the development of performance standards for connected vehicle-to-infrastructure systems" (H-18-31). A companion recommendation was issued to the FHWA (H-18-37). Safety Recommendations H-18-30, H-18-31, and H-18-37 are all classified "Open—Acceptable Response."

Connected vehicle technologies have great potential, particularly considering the emergence of automated driving systems. There are currently numerous different V2P systems being developed and evaluated around the world (Sewalkar and Seitz 2019). The current DOT research portfolio concerning V2P systems primarily focuses on pedestrian safety. However, it is critical to include consideration of all vulnerable road users in these efforts to ensure that the systems that result will have broad applicability. Therefore, the NTSB concludes that the DOT's slow progress in developing standards for connected vehicle technology has delayed the implementation of potentially lifesaving technology. The NTSB reiterates Safety Recommendations H-13-30 and H-13-31 to NHTSA. Additionally, the NTSB recommends that the ITS JPO, in collaboration with NHTSA and the FHWA, expand V2P research efforts to ensure that bicyclists and other vulnerable road users will be incorporated into the safe deployment of connected vehicle systems. The NTSB recommends that NHTSA, in collaboration with the ITS JPO and the FHWA, expand V2P research efforts to ensure that bicyclists and other vulnerable road users will be incorporated into the safe deployment of connected vehicle systems. The NTSB recommends that the FHWA, in collaboration with the ITS JPO and NHTSA, expand V2P research efforts to ensure that bicyclists and other vulnerable road users will be incorporated into the safe deployment of connected vehicle systems.

4.2.4 Addressing Large-Vehicle Blind Spots

Crash data have shown that large vehicles pose a specific problem for bicycle safety. Large vehicles, such as truck-tractors, single-unit trucks, motor coaches, school buses, or transit buses, tend to have larger blind spots than smaller vehicles, which can make it difficult for their drivers to detect and maneuver around bicyclists. This can be particularly problematic in urban areas where large vehicles operate near bicyclists and other vulnerable road users. The NTSB examined data from the FTA NTD for the period from 2014 through 2017 and found that 511 bicyclists were involved in crashes involving transit operations. Among them, 374 bicyclists, or 73%, collided with transit buses. Twenty-three bicyclists, or 6%, died in these crashes.

In 2013, the NTSB report, *Crashes Involving Single-Unit Trucks that Resulted in Injuries and Deaths*, concluded that onboard systems and equipment that compensate for blind spots and allow drivers of single-unit trucks to detect vulnerable road users could prevent fatalities and injuries that occur in crashes involving single-unit trucks (NTSB 2013a). Such systems and equipment could include enhanced mirror systems or sensors that can alert drivers if there is another vehicle, bicyclist, or pedestrian in the blind spot after the driver activates the turn signal.

As a result of its 2013 study, the NTSB recommended that NHTSA—

> Develop performance standards for visibility enhancement systems to compensate for blind spots in order to improve the ability of drivers of single-unit trucks with gross vehicle weight ratings over 10,000 pounds to detect vulnerable road users, including pedestrians and bicyclists, in their travel paths. (H-13-11)

The NTSB also recommended that—

> Once the performance standards requested in H-13-11 have been developed, require newly manufactured single-unit trucks with gross vehicle weight ratings over 10,000 pounds to be equipped with visibility enhancement systems meeting the performance standards. (H-13-12)

In a 2014 standalone recommendation letter, the NTSB issued a similar recommendation to NHTSA to—

> Require that newly manufactured truck-tractors with gross vehicle weight ratings over 26,000 pounds be equipped with visibility enhancement systems to improve the ability of drivers of tractor-trailers to detect passenger vehicles and vulnerable road users, including pedestrians, cyclists, and motorcyclists (H-14-1).[85]

To date, NHTSA has not developed performance standards or required visibility enhancements on single-unit trucks or truck-tractors. Safety Recommendations H-13-11, H-13-12, and H-14-1 are all classified "Open—Unacceptable Response."

Although neither CASs nor blind spot detection systems are currently required on large trucks and buses, some manufacturers have developed and are marketing systems that can be retrofitted on large vehicles. For example, a pilot study was conducted in Washington in which several transit buses were equipped with a collision warning system (Spears and others 2017). The system, Rosco/Mobileye Shield+, was designed to provide alerts to transit bus operators under several conditions, including when a pedestrian or bicyclist was within a certain range of the front or side of the bus. During the 3-month pilot study, none of the buses equipped with the collision warning system were involved in bicycle or pedestrian collisions. Among the buses not equipped with the system, there were six bicycle collisions and three pedestrian collisions during the same period (Spears and others 2017).

Therefore, the NTSB concludes that the larger blind spots of large vehicles make it more difficult for their drivers to detect vulnerable road users. The NTSB further concludes that there continues to be a need for performance standards to ensure blind spot detection systems are capable of detecting vulnerable road users, including bicyclists. Therefore, the NTSB reiterates Safety Recommendations H-13-11, H-13-12, and H-14-1 to NHTSA.

[85] See the NTSB's April 3, 2014, letter to NHTSA issuing Safety Recommendations H-14-1 through -7. The letter also included two recommendations calling for NHTSA to require side underride protection on certain newly manufactured truck tractors and truck trailers (H-14-2 and H-14-3). Although those recommendations addressed side underride protection to prevent underride by passenger vehicles, such systems also have the potential to mitigate the severity of truck side impacts with pedestrians, bicyclists, or motorcycles. Safety Recommendations H-14-2 and H-14-3 are both classified "Open—Acceptable Response."

4.3 Mitigating Head Injury

Improving roadway infrastructure, motor vehicle headlights, and in-vehicle CASs can prevent bicycle crashes involving motor vehicles. Bicyclists can also reduce the likelihood of getting in a crash by obeying traffic rules and traffic controls, such as traffic signals, and enhancing conspicuity, such as using bicycle lights. In the event of a crash, the most effective method for a bicyclist to mitigate head injury is to properly wear a bicycle helmet that is compliant with the federal safety standard for bicycle helmets described in 16 *CFR* Part 1203.[86]

Research has consistently shown that head injury is the leading cause of bicycle-related deaths. Based on a review of death certificates from the National Center for Health Statistics and emergency department injury data from the NEISS, researchers found that, over the 5-year period from 1984 through 1988, 62% of bicycle-related fatalities and 32% of bicycle-related emergency department visits were related to head injuries (Sacks and others 1991). Analysis of the 2012 National Trauma Data Bank, which contains information about 6,267 patients with an intracranial hemorrhage after a bicycle crash, showed that 52% of those patients had severe traumatic brain injury and that the mortality rate was 2.8% (Joseph and others 2017). Researchers also examined the NEISS data from 1998 through 2013 and found a 28% increase in bicycle-related injuries, and a 120% increase in hospital admissions (Sanford, McCulloch, and Callcut 2015). Focusing on a 2-year period from 2012 through 2013, researchers illustrated that the most prevalent injury region was an extremity at 52%, followed by the torso at 17%, the head at 16%, and other body parts at 16%. However, head injuries represented the most dramatic increase throughout the period from 1998 through 2013, showing a 60% increase (Sanford, McCulloch, and Callcut 2015). The lethality of head injuries has also been observed in other countries. For example, among the 271 bicyclist fatalities examined from 2005 through 2015 in Sweden, 82% sustained at least one fatal or severe head injury in any type of bicycle crash; but the highest occurrence of head injuries was found among crashes between passenger cars and bicycles (Ekstrom and Linder 2017). Researchers in Korea analyzed 205 admitted patients in a neurosurgery department for bicycle-related injuries for a 10-year period, from 2007 through 2016, and found that collisions between motor vehicles and bicycles increased the risk of severe head injury for the bicyclist (Park and others 2017).

The NTSB analyzed data from the NEISS database for the period from 2014 through 2017.[87] Table 10 shows the number of bicyclists by body region injury and accident type. Like earlier research discussed (Sanford, McCulloch, and Callcut 2015), the NEISS data from 2014 through 2017 showed that 46% of all bicyclists sustained extremity injuries, mostly to the knees and wrists, and 28% of bicyclists sustained injuries to the head or face. Although 14% of bicyclists not involved in motor vehicle crashes sustained head injuries, 21% of those in motor vehicle crashes sustained such injuries. Therefore, proportionally, more head injuries resulted from crashes between motor vehicles and bicycles.

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[86] Title 16 *CFR* Part 1203, which became effective in 1999, defines minimum performance criteria for all bicycle helmets.

[87] A detailed description of the NTSB's methods for analyzing the NEISS data from 2014 through 2017 for bicyclists' head injury and helmet use can be found in the NTSB Docket Management System, using the NTSB ID DCA18SS002.

Table 10. Number of bicyclists by injury body region and accident type, NEISS data from 2014 through 2017.

	Number of Bicyclists			% of all Bicyclists		
Body	**All Cases**	**In Motor Vehicle Crashes**	**Not in Motor Vehicle Crashes**	**All Cases**	**In Motor Vehicle Crashes**	**Not in Motor Vehicle Crashes**
Extremity	**882,000**	**148,000**	**735,000**	**46**	**38**	**48**
Knee	152,000	33,000	119,000	8	8	8
Wrist	121,000	12,000	108,000	6	3	7
Lower Arm	104,000	29,000	76,000	5	7	5
Elbow	96,000	15,000	81,000	5	4	5
Lower Leg	94,000	11,000	83,000	5	3	5
Ankle	79,000	14,000	66,000	4	4	4
Finger	69,000	7,000	62,000	4	2	4
Hand	59,000	11,000	49,000	3	3	3
Foot	52,000	7,000	45,000	3	2	3
Upper Leg	33,000	9,000	24,000	2	2	2
Toe	22,000	1,000	21,000	1	0	1
Head and Face	**541,000**	**119,000**	**422,000**	**28**	**31**	**27**
Head	302,000	80,000	221,000	16	21	14
Face	187,000	31,000	156,000	10	8	10
Mouth	40,000	5,000	35,000	2	1	2
Eyeball	7,000	1,000	6,000	0	0	0
Ear	5,000	1,000	4,000	0	0	0
Torso	**435,000**	**101,000**	**334,000**	**22**	**26**	**22**
Upper Arm	159,000	30,000	129,000	8	8	8
Shoulder	132,000	31,000	101,000	7	8	7
Upper Trunk	122,000	36,000	87,000	6	9	6
Lower Trunk	21,000	4,000	17,000	1	1	1
Others	**76,000**	**20,000**	**56,000**	**4**	**5**	**4**
Neck	29,000	12,000	16,000	1	3	1
25%–50% of Body	21,000	4,000	18,000	1	1	1
Pubic Region	17,000	1,000	16,000	1	0	1
Not Stated/Unknown	9,000	3,000	5,000	0	0	0
Total[a]	**1,934,000**	**388,000**	**1,546,000**	**100**	**100**	**100**

[a] All estimates were rounded to the nearest thousand. The subtotals for each body region and overall total were computed by summing the original estimates before rounding to the nearest thousand. Therefore, they may be different from simply adding the rounded estimates.

Table 11 shows that, among those bicyclists involved in crashes with motor vehicles, 15% were hospitalized, treated and transferred, or held for observation, indicating a serious injury level. In comparison, only 7% of bicyclists in other crashes received the same treatments. This difference suggests that crashes between motor vehicles and bicycles produce more severe injury outcomes for the bicyclists. This may be a result of the higher proportion of bicyclists in motor vehicle crashes that sustain head injuries. Therefore, the NTSB concludes that head injury is the leading cause of bicycle-related deaths, and bicyclists involved in crashes with motor vehicles sustain a higher proportion of head injuries.

Table 11. Disposition of injured bicyclists by accident type, NEISS data from 2014 through 2017.

Disposition	Number of Bicyclists			% of Total	
	All	In Motor Vehicle Crashes (% of all)	Not in Motor Vehicle Crashes (% of all)	In Motor Vehicle Crashes	Not in Motor Vehicle Crashes
Hospitalized, Treated and Transferred, and Held for Observation	171,000	57,000 (33%)	115,000 (67%)	15	7
Treated and Released and Left Unseen	1,761,000	330,000 (19%)	1,432,000 (81%)	85	93
Total[a]	1,934,000	388,000 (20%)	1,546,000 (80%)	100	100

[a] Total includes “died in emergency department” and “unknown.” Further, the total was calculated using the actual estimates before rounding. Therefore, adding up the rounded values may not equal the total value in this table.

4.3.1 Effectiveness of Bicycle Helmets

There have been multiple meta-analyses conducted to examine the effectiveness of bicycle helmets in preventing or mitigating head injury (Attewell, Glase, and McFadden 2001; Elvik 2011, 2013; Olivier and Creighton 2017; Hoye 2018). These analyses reported that bicycle helmets were effective at reducing head injury. For example, Attewell, Glase, and McFadden (2001) examined 16 studies published between 1987 and 1998, using data from Australia, Canada, the United Kingdom, and the United States; they found that bicycle helmets could be expected to reduce the likelihood of head injury and brain injury by 60% and 58%, respectively.[88] Hoye (2018) analyzed 55 studies from 12 countries conducted between 1989 and 2017 and found that bicycle helmets reduced the likelihood of all head injuries by 48%, serious head injuries by 60%, and traumatic brain injuries by 53%. Based on a nationally representative sample of children aged 5 to 17 who were treated in emergency departments for bicycle-related injuries from 2006 through 2015, McAdams and others (2018) showed that helmet use at the time of injury was significantly associated with a lower likelihood of head and neck injuries, traumatic brain injuries, and hospitalizations.

[88] Attewell, Glase, and McFadden (2001) presented summary odds ratio estimates for helmet efficacy, which were 0.40 for head injury and 0.42 for brain injury; both were statistically significant at the 95% confidence level.

The NTSB examined the NEISS data from 2014 through 2017 and found that only 15% of crashes between motor vehicles and bicycles indicated whether the bicyclist was wearing a helmet or not wearing a helmet. These cases represented about 60,000 bicyclists. Figure 9 divides those 60,000 bicyclists into 4 categories based on helmet use and head injury. Thirty-five percent of the bicyclists were wearing a helmet, and among them, 24% sustained a head injury. In comparison, 65% of the roughly 60,000 bicyclists were not wearing a helmet and 36% of them sustained a head injury. This suggests that among all bicyclists involved in crashes with motor vehicles with known helmet use status, those wearing helmets had a considerably lower chance of sustaining a head injury. This is a similar observation to that presented by McAdams and others (2018).

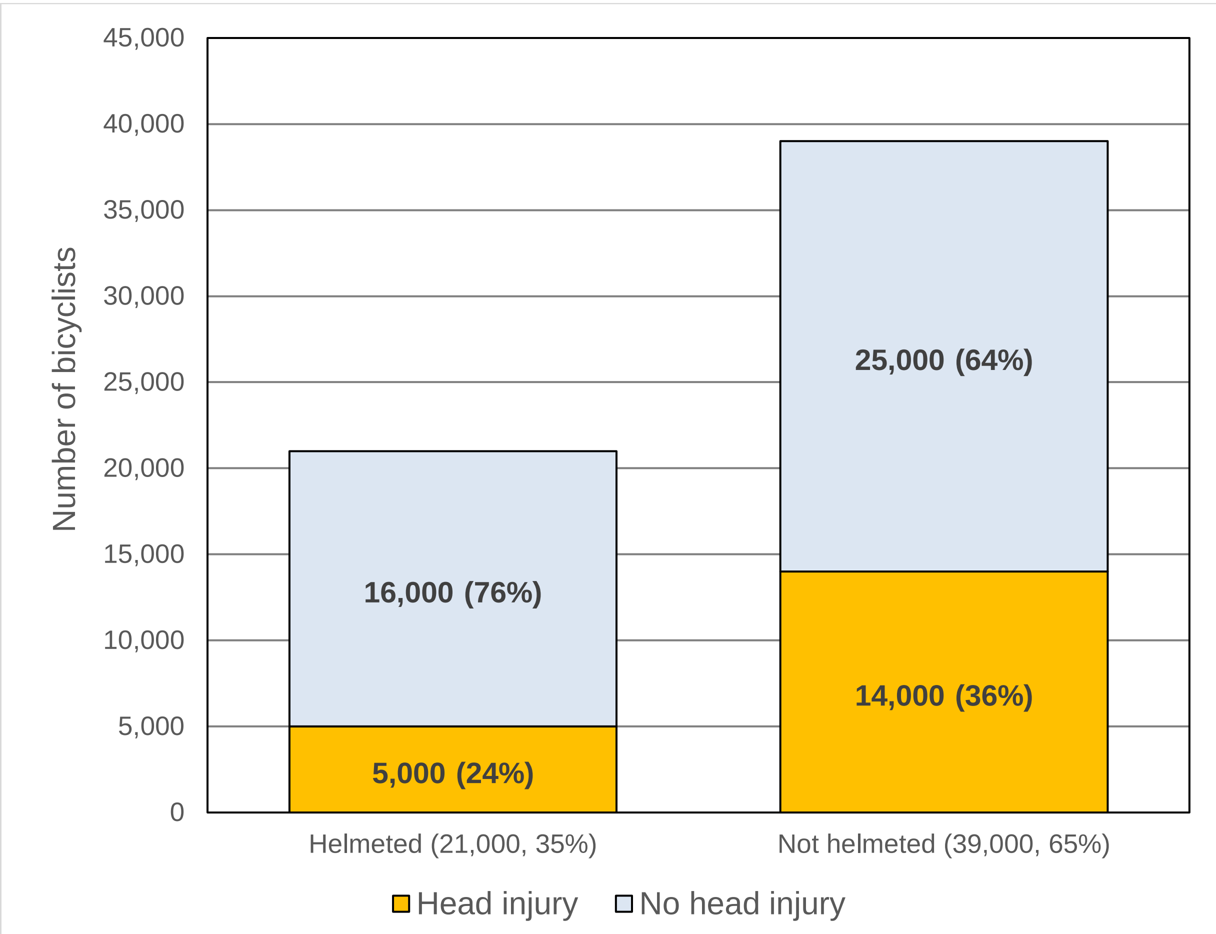

Figure 9. Helmeted versus not helmeted bicyclists in motor vehicle crashes with or without head injuries, NEISS data from 2014 through 2017.

The CDC's National Center for Injury Prevention and Control identified bicycle helmets as an effective intervention for all bicyclists, regardless of age.[89] According to the CDC, it identifies effective interventions based on systematic reviews of studies conducted by specialists and subject matter experts. For the CDC to recommend an intervention, the systematic review must provide strong evidence that the intervention is effective and has a beneficial effect (CDC 2019d). Further, all participants in the stakeholder interviews agreed that there was an injury prevention benefit to wearing a bicycle helmet. All state and local DOTs, as well as bicycle advocacy groups, discussed how they encourage the use of bicycle helmets. Therefore, the NTSB concludes that bicycle helmets provide effective protection and mitigate head injuries in the event of a crash.

4.3.2 Helmet Use

Although there is strong and consistent evidence demonstrating the effectiveness of helmets for protecting bicyclists from head injuries during bicycle-related crashes, helmet use in the United States remains low. There are no national-level observational data that capture overall bicycle helmet use. However, in 2012, based on a nationally representative sample, NHTSA published the *National Survey of Bicyclist and Pedestrian Attitudes and Behavior*. The survey results showed only 28% of respondents reported that they always wore a helmet when riding a bicycle, and 46% of respondents reported that they never wore a helmet (Schroeder and Wilbur 2013). Table 12 depicts estimated helmet use levels for bicyclists in crashes involving motor vehicles by age group from FARS and NASS GES/CRSS data from 2010 through 2017. It shows that overall, among those with known helmet use status, 79% of fatally injured bicyclists and 63% of all crash-involved bicyclists were not wearing helmets.[90] Among fatally injured bicyclists, the groups least likely to be wearing a helmet were those between the ages of 15 and 19 (94%) and those between the ages of 10 and 14 (92%). Among crash-involved bicyclists, the groups least likely to be wearing a helmet were those under the age of 10 (76%) and those between the ages of 20 and 24 (74%). These data analyses show that helmet use among bicyclists is low overall—and particularly low for children and young adults—despite the proven benefit of head injury mitigation. Therefore, the NTSB concludes that the underutilization of bicycle helmets has contributed to the incidence of deaths and serious injuries among crash-involved bicyclists.

[89] See the CDC's Bicycle Safety webpage.

[90] Seventy-nine percent, or 4,721 of 5,979, fatally injured bicyclists involved in motor vehicle crashes, and 25%, or 115,000 of 452,000, sampled bicyclists involved in motor vehicle crashes (regardless of injury severity), had known helmet use status in FARS and NASS GES/CRSS data for 2010 through 2017.

Table 12. Numbers of fatally injured bicyclists and crash-involved bicyclists, percentages of bicyclists with known helmet use status, and percentages of bicyclists not wearing helmets by age groups based on FARS and NASS GES/CRSS data from 2010 through 2017.

	Fatally Injured Bicyclists (FARS)				Crash-Involved Bicyclists (NASS GES/CRSS)[a]			
Age Group	Total	% Helmet Status Known	Not Wearing Helmet	% Among Known Status	Total	% Helmet Status Known	Not Wearing Helmet	% Among Known Status
Under 10	171	77	112	85	16,000	19	2,000	76
10–14	264	81	197	92	47,000	22	6,000	63
15–19	392	78	285	94	64,000	20	9,000	72
20–24	382	74	244	87	59,000	27	12,000	74
25–29	338	79	225	85	46,000	25	7,000	61
30–34	331	78	210	81	34,000	24	5,000	60
35–39	300	79	180	76	28,000	31	5,000	61
40–44	392	79	241	78	29,000	25	4,000	58
45–49	563	83	378	81	30,000	27	5,000	61
50–54	752	78	472	81	31,000	26	5,000	67
55–59	715	77	436	79	24,000	31	4,000	57
60–64	507	79	278	70	18,000	34	2,000	39
65–69	336	82	173	63	10,000	31	1,000	44
70–74	218	80	109	63	7,000	28	1,000	57
75+	271	85	163	71	7,000	36	1,000	49
All Ages[b]	5,979	79	3741	79	452,000	25	72,000	63

[a] For NASS GES/CRSS data, percentages were computed before rounding.
[b] *All Ages* includes bicyclists with unknown ages.

4.3.3 Mandatory Helmet Requirements

In 2018, NHTSA determined that, among the 12 bicycle safety countermeasures it evaluated, bicycle helmet laws for children were the most effective behavioral countermeasure, and bicycle helmet laws for adults were the second most effective (Richard and others 2018). Head injuries are prevalent and most common among fatally and seriously injured bicyclists involved in crashes with motor vehicles. The intent of bicycle helmet laws is to reduce the number of severe and fatal injuries in bicycle crashes through increased helmet use.

As of March 2019, 21 states and the District of Columbia have laws requiring young bicyclists to wear helmets, and no states have mandatory helmet requirements for bicyclists of all ages (IIHS 2019). Figure 10 shows a map of bicycle helmet requirements for the 50 states and the District of Columbia. Sixteen states and the District of Columbia require helmets for bicyclists 15 years old and younger, the most common age requirement. Using a cross-sectional survey design, a study found that in 2001, helmet use among children and adolescents was significantly higher in states with helmet laws (19 states and the District of Columbia), even after adjusting for household income and education (Rodgers 2002). These results suggest that state helmet laws increased average helmet use by almost 20%. NHTSA's 2012 *National Survey of Bicyclist and Pedestrian Attitudes and Behavior* also showed that 50% of adult respondents from states with bicycle helmet laws stated that their child wore a bicycle helmet for all rides. In states without helmet laws, the percentage was lower at 39%, and the difference between the two percentages was statistically significant (Schroeder and Wilbur 2013).

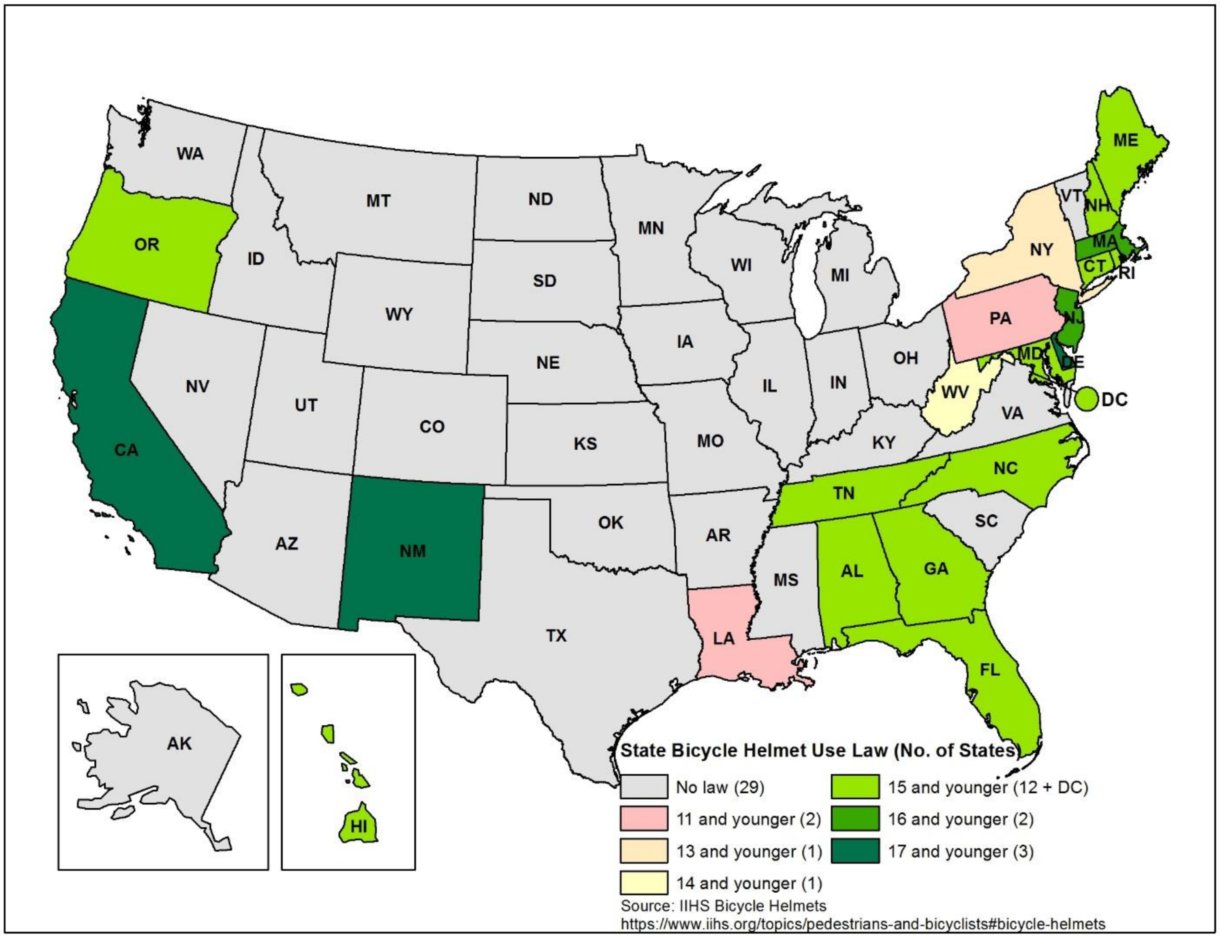

Figure 10. Map of bicycle helmet requirement laws by state, as of August 2019.

A systematic review of 11 studies published between 1992 and 2005 and conducted in 4 countries, including the United States, showed an increase in helmet use as a result of helmet legislation (Karkhaneh and others 2006).[91] The effects ranged from a 10% increase in helmet use found in one study, to a 10% to 30% increase found in four of the studies, and a more than 30% increase found in seven of the studies (Karkhaneh and others 2006). Another systematic review of three studies found that helmet use increased significantly, from between 45% to 84%, with the introduction of helmet laws (Macpherson and Spinks 2008).[92] More recently, Carpenter and

[91] The US study examined bicycle helmet laws in Maryland, Oregon, North Carolina, and Florida.

[92] Two of the studies were conducted in the United States, specifically in Georgia and California, and the third study was conducted in Canada.

Warman (2018) used public health survey data collected from 1994 to 2014 to confirm that helmet laws in Canada led to increased helmet use among young bicyclists, and that bicycle helmet laws that applied to all age groups increased helmet use among adults and young people.

To explore the relationship between helmet requirements and helmet use among crash-involved bicyclists, the NTSB examined 2017 bicycle crash data from Washington. There were 1,306 bicyclists involved in crashes with motor vehicles in Washington that year. Helmet use was known for 92% of the bicyclists. Although there is no state law requiring bicycle helmets, according to the Washington DOT, many cities and counties have helmet requirements for bicyclists of all ages in Washington.[93] Table 13 shows the results of a logistic regression model. The dependent variable was the outcome "wore helmet." The model results showed that crash-involved injured bicyclists were more than twice as likely to be wearing a bicycle helmet in localities where a helmet was required, while controlling for age. (The odds ratio was 2.198.) Therefore, the NTSB concludes that requiring helmet use is the most effective means for increasing helmet use and reducing bicyclist head injuries.

Table 13. Logistic regression model results for helmet use in Washington, 2017.

	Odds Ratio	95% Confidence Limits
Helmet Required (Compared to Not Required)	2.198	(1.700, 2.842)
Adult (Compared to 18 and Younger)	1.969	(1.403, 2.763)

Since 2010, the US Department of Health and Human Services, Office of Disease Prevention and Health Promotion has tried to increase the number of states with laws requiring bicycle helmets for all bicycle riders, regardless of age, by including the issue on its Healthy People 2020 agenda for improving US public health.[94] Although no states currently have laws that mandate helmet use for all bicyclists, several cities and counties have such laws.[95] The NTSB analysis of jurisdictions in Washington with all-ages bicycle helmet laws indicated that local laws were successful at increasing the likelihood of helmet use among bicyclists of all ages in those jurisdictions. A 2005 NHTSA report that described the enactment and implementation of bicycle helmet laws in two states, one county, and three cities noted that at the local level, ordinances were adopted relatively quickly compared to those accomplished at the state level. The report provided several lessons learned from those jurisdictions for those hoping to enact bicycle helmet legislation, including the value of a multidisciplinary coalition including medical professionals, safety advocates, and law enforcement. It also included examples of existing and model mandatory helmet legislation language developed by others and other resources communities could use as part of a campaign to enact bicycle helmet use laws and increase bicycle helmet use (NHTSA 2005).

[93] For example, see the Washington State Department of Transportation 2019 "Bicycle Helmet Requirements in Washington" webpage.

[94] See injury prevention objective IVP-21, which also includes the District of Columbia.

[95] A list of cities, counties, and other municipalities with all-ages helmet laws may be found at the Bicycle Helmet Safety Institute website.

4.3.4 Comprehensive Strategy to Increase Helmet Use for All Bicyclists

During the stakeholder interview sessions, some participants expressed concerns that a mandatory helmet requirement for bicyclists of all ages could result in an overall reduction in bicycling in the United States. However, all of the stakeholders generally agreed about the importance of bicycle helmets and supported efforts to increase voluntary helmet use among all bicyclists. State and local transportation officials further stated that they are actively engaged in strategies to encourage voluntary bicycle helmet use, such as distributing print materials and promoting web-based resources that typically feature bicycle helmets. State and local transportation officials also reported coordinating with bicycle advocates to host public engagement events, such as bicycle rodeos, to promote helmet use among bicyclists of all ages and to distribute free bicycle helmets.

The links between education and outreach events that encourage voluntary helmet use and improvements in bicyclist safety are not as well established as the research showing that helmet laws are associated with increases in helmet use. However, there is some research showing that nonlegislative interventions can increase helmet use among young bicyclists (Lee, Mann, and Takriti 2000; Royal, Kendrick, and Coleman 2007). For example, a meta-analysis of 11 studies examining education campaigns alone and those paired with helmet distribution programs found that a combination of education paired with free helmet distribution programs resulted in the largest increases in children's helmet use (Royal, Kendrick, and Coleman 2007). Consequently, such efforts should be considered as part of an overall strategy to increase bicycle helmet use.

NHTSA's current Bicycle Safety webpage encourages bicyclists to wear helmets and provides suggestions for finding a helmet that fits correctly, but it does not mention helmet laws.[96] In fact, nearly every NHTSA publication concerning bicycle safety currently linked to the NHTSA Bicycle Safety webpage focuses on education and awareness raising, particularly for young bicyclists, rather than providing information about the known value of helmet laws for improving bicyclist safety. This focus on education rather than laws is inconsistent with the NHTSA publication, *Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices*, which identifies bicycle helmet laws for both children and adults as more effective countermeasures than bicycle safety education or bicycle helmet use education (Richard and others 2018). Because of its mission to prevent injuries due to road traffic crashes and its clear support of helmet laws as an effective countermeasure, NHTSA can play an important role by working with its stakeholder community to provide guidance to states and communities that would like to undertake efforts to enact bicycle helmet legislation. The NTSB concludes that a comprehensive strategy that includes both helmet legislation and complementary nonlegislative interventions is most likely to increase overall helmet use among bicyclists of all ages.

[96] See the NHTSA Bicycle Safety webpage.

Therefore, the NTSB recommends that NHTSA (1) convene a bicycle safety coalition of stakeholders to develop a comprehensive national strategy to increase bicycle helmet use among bicyclists of all ages that would include, at a minimum, a model all-ages bicycle helmet law; (2) disseminate the strategy to all states and make it available on NHTSA's website. Such a coalition might include federal, state, and local government transportation officials; law enforcement and public safety officials; prehospital and hospital emergency medicine professionals; bicycle and safety advocacy groups; and bicycle and helmet industry representatives. NHTSA publishes *Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices* biennially, and it can benefit from the inclusion of the model all-ages bicycle helmet law. Therefore, the NTSB further recommends that NHTSA, after Safety Recommendation H-19-38 is completed, include the model all-ages bicycle helmet law in *Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices*. In addition, the NTSB recommends that the 50 states, the District of Columbia, and the Commonwealth of Puerto Rico require that all persons shall wear an age-appropriate bicycle helmet while riding a bicycle.

4.4 Exploring Emerging Issues Relevant to Bicycling Safety

The final goal of this research was to explore emerging issues that may be relevant to bicycle safety. In addition to the safety issues discussed earlier in this report, multiple stakeholders frequently mentioned the following emerging issues: (1) shared-use micromobility devices and (2) the need for a comprehensive approach to bicyclist safety.

4.4.1 Shared-Use Micromobility Devices

Many stakeholders mentioned the growing use of shared-use micromobility devices as an emerging safety issue. Although stakeholders did not share a common definition of a micromobility device, in general, they used the term "micro" when referring to (1) the size of the device and (2) the use of the device for short-distance travel, often known as "last mile" travel. Micromobility devices may be owned by individuals; however, they are more commonly used in urban areas as part of a shared-use network. Stakeholders were concerned about battery-powered electric scooters and bicycles—often referred to as e-scooters and e-bikes—and nonmotorized bicycles organized specifically for shared-use operations.

The main problem stakeholders mentioned most often was the lack of commonly understood definitions for the various shared-use micromobility devices. They also stressed how little is known about these devices and the potential safety issues they present. According to NACTO, 84 million trips were completed using these shared-use micromobility devices in 2018, an increase of 140% from 35 million trips in 2017 (NACTO 2018). The rapidly expanding shared-use mobility industry underscores the need to understand these issues and to develop new evidence-based countermeasures for preventing crashes and mitigating injuries involving these devices.

4.4.2 Acknowledging the Need for a Comprehensive Approach

In this safety research report, the NTSB examined the prevalence and risk factors of bicycle crashes involving motor vehicles and assessed the most applicable countermeasures. The safety issues identified, the recommendations made, and the themes repeatedly stated by stakeholders suggest the need for a comprehensive approach to bicyclist safety that—

- Improves roadway infrastructure for bicyclists, enhances bicycle conspicuity, and mitigates bicyclist head injuries.
- Demands a commitment to safety from all stakeholders, including policy makers, transportation planners, engineers, educators, law enforcement officials, bicycle safety advocates, and bicyclists.
- Adequately captures bicycle activities, crashes, and injuries.
- Effectively monitors safety issues emerging from the rapid growth of the shared-use micromobility device industry.
- Continues research on the indirect effects of changes in bicycle ridership, such as the concept of safety in numbers.

This safety research report and the recommendations it contains complement and reinforce many recommendations put forth in previous NTSB safety reports that have addressed vulnerable road users and improving the traffic safety environment for them (NTSB 2013a, 2017b, 2018a, 2018b). Still, much work needs to be done to comprehensively assess and improve the safety of bicyclists and all vulnerable road users on US roadways.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

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Member

BRUCE LANDSBERG
Vice Chairman

Report Date: November 5, 2019

Appendixes

Appendix A: Countermeasures Identified by the FHWA, NHTSA, the CDC, and the GHSA

The NTSB began researching safety countermeasures by reviewing lists prepared by the FHWA, NHTSA, the CDC, and the GHSA. The FHWA's list focused on roadway infrastructure or engineering treatments. NHTSA's list focused on behavioral countermeasures. The CDC's list primarily focused on countermeasures aimed at improving public health. The GHSA's list highlighted actions to be taken by state and local agencies and organizations.

FHWA's Bicycle Safety Guide and Countermeasure Selection System (BIKESAFE) http://www.pedbikesafe.org/bikesafe/.

The FHWA BIKESAFE online tool includes 46 engineering, education, and enforcement countermeasures. According to the FHWA, the countermeasures listed have been implemented for some time and/or have proven effective. Information about their effectiveness is provided in the report, titled *Evaluation of Bicycle-Related Roadway Measures: A Summary of Available Research* (Mead and others 2014). All 46 countermeasures are listed below.

1. On-Road Bike Facilities:
    a. Bike Lanes
    b. Wide Curb Lanes
    c. Paved Shoulders
    d. Shared Bus-Bike Lanes
    e. Contraflow Bike Lanes
    f. Separated Bike Lanes
2. Intersection Treatments:
    a. Curb Radius Reduction
    b. Roundabouts
    c. Intersection Markings
    d. Sight Distance Improvements
    e. Turning Restrictions
    f. Merge and Weave Area Redesign
3. Markings, Signs, and Signals:
    a. Optimizing Signal Timing for Bicyclists
    b. Bike-activated Signal Detection
    c. Sign Improvements for Bicyclists
    d. Pavement Marking Improvements
    e. School-zone Improvements
    f. Rectangular Rapid Flashing Beacons (RRFB)
    g. Pedestrian Hybrid Beacon
    h. Bicycle Signal Heads
4. Traffic Calming:
    a. Mini-circles
    b. Chicanes

   c. Speed Tables/Humps/Cushions
   d. Traffic Diversion
   e. Visual Narrowing
5. Shared Roadway:
   a. Roadway Surface Improvements
   b. Bridge and Overpass Access
   c. Tunnel and Underpass Access
   d. Lighting Improvements
   e. Parking Treatments
   f. Median/Crossing Island
   g. Driveway Improvements
   h. Lane Reduction (road diet)
   i. Lane Narrowing
   j. Streetcar Track Treatments
6. Trails and Shared-Use Paths:
   a. Separate Shared-Use Paths
   b. Path Intersection Treatments
   c. Share the Path Treatments
7. Maintenance:
   a. Repetitive/Short-term Maintenance
   b. Major Maintenance
   c. Hazard Identification Program
8. Others:
   a. Law Enforcement
   b. Bicyclist/Motorist Education
   c. Transit Access
   d. Wayfinding
   e. Landscaping/Aesthetics

NHTSA's *Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices, Ninth Edition, 2017*, Chapter 9: Bicycle Safety (Richard and others 2018).

NHTSA assessed the effectiveness of each countermeasure and assigned up to 5 stars to each. In the following list, countermeasures receiving 4 or 5 stars are considered effective and 3 stars are promising and likely effective. States, communities, and other organizations are encouraged to use countermeasures with 3- to 5- star ratings. The description of how NHTSA established effectiveness follows.

"What the effectiveness data mean: The effectiveness of any countermeasure can vary immensely from State to State or community to community. What is done is often less important than how it is done. The best countermeasure may have little effect if it is not implemented vigorously, publicized extensively, and funded satisfactorily. Evaluation studies generally examine and report on high-quality implementation because there is little interest in evaluating poor implementation. Also, the fact that a countermeasure is being evaluated usually gets the attention of those implementing it, so that it is likely to be done well. The countermeasure effectiveness data presented in this guide probably shows the maximum effect that can be realized with high-quality implementation. Many countermeasures have not been evaluated well, or at all, as noted in the effectiveness data. ***Effectiveness ratings are based primarily on demonstrated reductions in crashes; however, changes in behavior and knowledge are taken into account in the ratings when crash information is not available****"* (Richard and others 2018, page 2).

1. Targeting children
    a. Bicycle helmet laws for children, 5 stars
    b. Safe routes to school, 3 stars
    c. Bicycle safety education for children 2 stars
    d. Cycling skills clinics, bike fairs, bike rodeos 1 star
2. Targeting adults
    a. Bicycle helmet laws for adults, 4 stars
    b. Bicycle safety education for adult cyclists, 1 star
3. Targeting all bicyclists
    a. Active lighting and rider conspicuity, 3 stars
    b. Promote bicycle helmet use with education, 2 stars
    c. Enforcement strategies, 1 star
    d. Motorist passing bicyclists laws, 1 star
4. Targeting all drivers and bicyclists
    a. Driver training, 1 star
    b. Share the road awareness programs, 2 stars

CDC's Bicycle Safety Interventions https://www.cdc.gov/motorvehiclesafety/bicycle/index.html.

The CDC conducted systematic reviews of interventions in public health topics, such as bicyclist safety. The CDC used specialists in systematic review methods and subject matter experts to formally identify interventions supported by studies with strong or sufficient evidence (CDC 2019d).

1. Effective Interventions: Effective interventions to reduce injuries and fatalities to bicyclists include the following:
    a. Bicycle helmets: Bicycle helmets reduce the risk of head and brain injuries in the event of a crash. All bicyclists, regardless of age, can help protect themselves by wearing properly fitted bicycle helmets every time they ride.
    b. Bicycle helmet laws: Bicycle helmet laws are effective for increasing helmet use and reducing crash-related injuries and deaths among children and adults.
2. Promising Interventions: Interventions that have shown promise for reducing injuries and fatalities to bicyclists include the following:
    a. Active lighting and rider visibility: Fluorescent clothing can make bicyclists visible from further away than regular clothing during the daytime; Retro-reflective clothing can make bicyclists more visible at night; Active lighting can include front white lights, rear red lights, or other lighting on the bicycle or bicyclist. This lighting may improve the visibility of bicyclists.
    b. Roadway engineering measures.

GHSA's Action Steps included in its *A Right to the Road: Understanding and Addressing Safety* (GHSA 2017).

The GHSA identified 30 action steps to foster discussion among state highway safety offices, advocates, educators, elected officials, and planning and transportation officials to improve bicyclist safety using an integrative approach that involves engineering, education, and enforcement.

1. Refine crash reports so they capture critical data elements for bicycle-motor vehicle crashes and provide tools and training to help law enforcement capture this data.
2. Carefully review crash data to fully understand the extent of your state's bicycle-motor vehicle crash problem, including who is crashing and why, and develop and implement appropriate and proven countermeasures using the 3 E's delivered through the most cost-effective channels.
3. Partner with businesses and bicyclist, community and civic groups to promote the importance of rider conspicuity and drivers to looking for and giving adequate space to bicyclists.
4. Educate the public and the hospitality industry about the dangers of impaired cycling and promote alternatives for getting home safely.
5. Poll bicyclists to gauge their education and training needs.
6. Leverage NHTSA's bicycle safety training and assessment tools.
7. Apply for Section 405(h) and 403 grants, if eligible.
8. Coordinate efforts to maximize resources and minimize duplication of efforts to grow Safe Routes to School activities.
9. Establish a dedicated funding source for bicyclist safety initiatives.
10. Partner with bicycling and community-based organizations to deliver safety programs.
11. Promote law enforcement's use of proven technology to enforce safe passing laws.
12. Follow design standards that offer a model for designing safe, attractive, and sustainable streets that accommodate and encourage bicycling.
13. Educate all bicyclists about the proven benefits of helmets with a focus on proper fit and the role parents play in modeling their use.
14. Clarify state laws to address bicycling while impaired.
15. Allow communities to reduce speed limits or establish slow zones in areas with a history of bicyclist-motor vehicle crashes and in neighborhoods with schools, parks, and day care and senior centers.
16. Allow the use of automated enforcement to deter speeding and red light running.
17. Expand distraction initiatives to include bicyclists who may be riding inattentive as well as the danger distracted drivers pose to non-motorist road users.
18. Develop and enforce an electric powered bicycle policy.
19. Couple new or improved infrastructure with educational and enforcement strategies that convey why and how the roadway improvement works.
20. Educate bicyclists and motorists about intersection safety.
21. Educate policy makers about Complete Streets policies.
22. Develop and deliver bicyclist safety training to law enforcement officials on traffic safety laws applicable to bicycle safety, to include why bicycle-motor vehicle crashes occur and the importance of serving the most vulnerable roadway users.
23. Partner with bicycling and community groups prior to conducting enforcement.

24. Conduct high visibility enforcement coupled with public outreach on high bicycle-motor vehicle crash corridors.
25. Offer ticket diversion programs for bicyclists and motorists.
26. Review driver licensing exams for bicyclist safety information and call for inclusion of the Dutch Reach in driver manuals.
27. Provide bicyclist safety training, resources, and information to driver education professionals.
28. Incorporate on-bike and on-road training components into bicycle education programs for all riders and develop more widespread and compelling promotion.
29. Humanize traffic crashes and transportation mode nomenclature.
30. Use bicycling ambassadors to foster street-level engagement and education with all roadway users.

Appendix B: Descriptions of Person Types in NHTSA FARS and NASS GES/CRSS Data

Bicyclists, including other cyclists, were identified using the person-level variable, Person Type (PER_TYP). See the Fatality Analysis Reporting System (FARS): Analytical User's Manual 1975–2016 and the FARS/CRSS Coding and Validation Manual (NHTSA 2016a; NHTSA 2017).

1. PER_TYP = 6 → Bicyclist
    - 06 (Bicyclist) is used for a two-wheel, non-motorized cycle. This includes all persons (operator and passengers) on a bicycle and a person being pulled by a bicycle (for example, in a wagon or bike trailer).
2. PER_TYP = 7 → Other Cyclist
    - 07 (Other Cyclist) is used for unicycles and tricycles.
3. Note: PER_TYP = 8 → Person on Personal Conveyances
    - 08 (Person on Personal Conveyances): This attribute should be used for pedestrians using personal conveyances. A personal conveyance is a device, other than a transport device, used by a pedestrian for personal mobility assistance or recreation. These devices can be motorized or human powered, but not propelled by pedaling.

      Inclusions:
        1. Rideable toys
            a. Roller skates, in-line skates
            b. Skateboards
            c. Skates
            d. Baby carriage
            e. Scooters
            f. Toy wagons
        2. Motorized rideable toys
            a. Motorized skateboard
            b. Motorized toy car
        3. Devices for personal mobility assistance
            a. Segway-style devices
            b. Motorized and non-motorized wheelchairs
            c. Handicapped scooters

      Exclusions (that is, excluded from being counted as cyclist):
        1. Golf cart
        2. Low speed vehicles (LSVs)
        3. Go-carts
        4. Minibike
        5. "Pocket" motorcycles
        6. Motor scooters
        7. Moped

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