RESEARCH & DEVELOPMENT

Assessment of Separated Bike Lane Applications in North Carolina

Sarah Worth O'Brien
Dan Gelinne
Taha Saleem
Highway Safety Research Center
University of North Carolina

Chris Vaughan
James Poslusny
Institute of Transportation Research and Education
North Carolina State University

Jared Draper
Toole Design

William Hunter, Consultant

NCDOT Project 2020-24

FHWA/NC/2020-24

April 2023

Technical Report Documentation Page

1. Report No. FHWA/NC/2020-24	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Assessment of Separated Bike Lane Applications in North Carolina		5. Report Date April 30, 2023
7. Author(s) Sarah Worth O'Brien, Dan Gelinne, Chris Vaughan, James Poslusny, Taha Saleem, Jared Draper, William Hunter		6. Performing Organization Code 8. Performing Organization Report No.
9. Performing Organization Name and Address University of North Carolina Highway Safety Research Center 130 Mason Farm Road, CB # 3430 Chapel Hill, NC 275140		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address North Carolina Department of Transportation Research and Development Unit 1020 Birch Ridge Drive Raleigh, North Carolina 27610		13. Type of Report and Period Covered Final Report: August 2019 – April 2023 14. Sponsoring Agency Code NCDOT Project #2020-24
15. Supplementary Notes:		

16. Abstract

This project documents the experience of separated bike lane (SBL) planning and design in North Carolina. Separated bike lanes are a relatively new phenomenon in the state, and there are few examples of in-the-ground projects to serve as reference points. The research team sought to summarize existing research and guidance on these bicycle facilities both within and outside the state, assess the current state of practice in NC communities, and conduct safety evaluations of ongoing SBL projects to understand their impact on road users. The study monitored bicyclist-motorist interactions, avoidance maneuvers, conflicts, bicycle volume, and other cyclist behaviors via video data collected at 10 sites along four SBLs in Charlotte and Raleigh to better understand the safety and operational outcomes of SBL applications in North Carolina. Generally, results found that bicycling volume per day increased, the percentages of avoidance and conflict maneuvers decreased, percentages of helmet use increased, and the percentage of cyclists or scooter riders using a bikeshare or scooter share micromobility device increased after SBLs were installed, though there were some nuances in specific measures at the site level. Findings can be used to shape discussions around SBL planning and implementation in NC and offer guidance for agencies considering these bicycle facilities in their roadway improvements.

17. Key Words Separated bike lane, conflict analysis, field observations	18. Distribution Statement		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages …80…	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Disclaimer

The contents of this report reflect the views of the author(s) and not necessarily the views of the University. The author(s) are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of either the North Carolina Department of Transportation or the Federal Highway Administration at the time of publication. This report does not constitute a standard, specification, or regulation.

Acknowledgements

The authors acknowledge staff from the City of Raleigh and City of Charlotte for coordinating with us on study sites and allowing us to collect data within their jurisdictions before and after they installed separated bike lanes. Without funding provided through NCDOT, guidance and support from the steering and implementation committee (StIC), and responses from NCDOT Divisions 5, 6, 10, and 13 (as well as several other local and regional agencies) on the state of practice across the state, this research would not have been possible. We also appreciate the contributions of other members of the project team, who helped pave the way to the development of this report across a variety of activities: Sarah Brown and Ethan Sleeman who scanned and summarized relevant literature, Sarah Searcy who devised the data collection process, and Chris Carnes who developed, tested, and applied the video reduction process to extract the before data, and to the many students who assisted in the data extraction.

Executive Summary

As bicycling gains in popularity across North Carolina, communities are seeking ways to incorporate separated bike lane (SBL) facilities into the transportation network to provide safe and comfortable places for a broader range of experience levels of cyclists. For the purpose of this report and the broader research project, a SBL is defined as a facility for the exclusive use of bicyclists that is separated from motor vehicle traffic by a horizontal buffer and vertical element. They are sometimes referred to by other names, including cycle tracks and protected bicycle lanes.

Design guidance and research produced at the national level over recent years have helped planners and engineers understand how to incorporate SBLs into their road systems; however, questions remain about how SBLs are being deployed by agencies within North Carolina. There is a need to better understand the state of practice of SBLs within the state, which some local agencies have begun to deploy through quick-build trials or permanent installation. There are no design standards or typical cross-sections provided by NCDOT or local agencies for SBLs, which means there is not yet a consistent approach to how they are incorporated into roadway design. Lessons learned about planning, design, and implementation of SBLs from agencies who are trying them will be valuable for NCDOT and others considering future SBL installations.

This project documents the experience of SBL planning and design in North Carolina while summarizing existing research and guidance on these bicycle facilities both within and outside the state. Separated bike lanes are a relatively new phenomenon in North Carolina, and there are few examples of on-the-ground projects to serve as reference points. However, a number of municipalities have specifically included recommendations for separated bicycle facilities in their bicycle plans. A scan of bicycle plans from North Carolina communities revealed that 17 of them called for SBLs or mentioned them as a facility type. A separate scan of existing SBLs in North Carolina (as of May 2020) identified seven SBLs in operation across the State, a number that has likely grown since that scan was conducted. Interviews held with agencies across the State revealed several common themes related to SBL planning, design, and implementation:

- Few SBL projects are on the ground, but they are in the conversation for future projects.
- Advocacy for separated facilities frequently drives implementation.
- Absence of in-house or state design guidelines leads to reliance on FHWA/AASHTO/NACTO guides; NC guidelines would be a valuable tool for both municipalities and NCDOT officials.
- Retrofitting buffered bike lanes by adding some type of vertical element is a commonly used methodology that enables stepwise implementation.
- There is value in temporary and demonstration projects.
- Agencies have concerns around additional maintenance costs of separated facilities.
- There has been mixed experience when working with NCDOT regarding approval and support for SBLs.

Agency interviews helped our team identify SBLs that were planned for implementation around the State. Specifically, our conversations with the City of Charlotte and City of Raleigh revealed sites that would be suitable for us to study in terms of their design features and timeline for implementation. This report also describes the new research conducted through this project that evaluated SBLs through a before-after observational study to understand how their installation impacted certain safety and

performance measures. The study monitored bicyclist-motorist interactions, avoidance maneuvers, conflicts, bicycle volume, and other cyclist behaviors via video data collected at 10 sites along four SBLs in Charlotte and Raleigh to better understand the safety and operational outcomes of SBL applications in North Carolina. Generally, results found that bicycling volume per day increased, the percentages of avoidance and conflict maneuvers decreased, percentages of helmet use increased, and the percentage of cyclists or scooter riders using a bikeshare or scooter share micromobility device increased after SBLs were installed, though there were some nuances in specific measures at the site level. For example, avoidance maneuvers increased at four of the 10 sites, and conflict maneuvers increased at 2 sites. These sites were either similar in the type of vertical and horizontal barrier used (e.g., painted buffer with flex-post delineators), or were at driveways or T-intersections.

Table of Contents

List of Tables

List of Figures

1 Introduction

Across the United States, there is a push toward the development of low-stress bicycle facilities to provide opportunities for streets to better serve individuals of all ages and abilities. Portland State University's research that established a typology of bicyclists found that the largest group (51 to 60%) are interested in riding a bicycle but concerned about their safety and the risks associated with riding in traffic.[1] Agencies seeking to provide places for this group to ride is resulting in a movement toward providing dedicated bicycle facilities that separate cyclists from motor vehicle traffic, particularly on roads with higher posted speed limits and motor vehicle traffic. This separation may be simply a few extra feet of marked pavement offered by a buffered bicycle lane or the addition of vertical elements like curbed medians, parked cars, or flexible delineator posts to create a separated bike lane (SBL). These facilities are increasingly used to improve safety and comfort, and agencies in North Carolina also are beginning to experiment with trial deployments of SBLs.

Since SBLs are not explicitly called out in typical cross-sections used by NCDOT or most local agencies in North Carolina, there is not yet a consistent approach to how they are incorporated into roadway design. The objectives of this project are to summarize national SBL research and design guidance, survey local and state practitioners considering SBL projects to understand their experiences and concerns, and to conduct a pre-post observational study of SBL applications in North Carolina to better understand their safety and operational outcomes.

This report is organized into eight sections. Following this introduction, Section 2 provides an overview of relevant literature from peer-reviewed studies, as well as existing national and other key guidelines regarding the use of SBLs. Section 3 explains the methods used in this study from site selection to before and after data collection through a video reduction technique. Section 4 lays out the results and findings based on analyses conducted to understand different measures of effectiveness of the SBLs installed. Conclusions based on these findings are summarized and recommendations for consideration of next steps are suggested in Section 5. Finally, the body of the report wraps up with Section 6, where the authors propose plans for future implementation and technology transfer to move from the research into practice. Sections 7 and 8 round out the report by supplying references cited throughout, as well as appendices for further background and documentation of the full literature review and guidance related to SBLs, example survey/interview questions to collect information on current practices in North Carolina, and completed interviews.

2 Review of the Literature and State of Practice

A literature review was conducted to provide a foundation of current knowledge and guidance around separated bicycle lanes (SBLs). This phase of information gathering supported subsequent interviews of practitioners around the State and informed original research conducted on these types of bicycle facilities as part of this project. Our goal was to compile the latest information about SBLs to NCDOT to help inform the planning and development of bicycle facilities around the State. For the purpose of this review and the broader research project, a SBL was defined as a facility for the exclusive use of bicyclists that is separated from motor vehicle traffic by a horizontal buffer and vertical element. They are sometimes referred to by other names, including cycle tracks and protected bicycle lanes.

The research team uncovered 81 studies examining SBLs and the safety of bicyclists and supplemented these with the studies compiled in the *FHWA Resource Guide for Separating Bicyclists from Traffic.*[2] The search was targeted to specifically identify studies examining the safety and operational performance of SBLs and their associated design treatments along segments and at intersection locations. A total of 31 studies focused on intersections, while another 50 studies were focused on either segments or SBLs more generally. Some of these studies were published since the FHWA literature review was conducted, while others were not reported in depth by that source. After scanning the studies for relevance and quality, 28 were chosen for more detailed review and interpretation. Findings are compiled below based on common themes revealed during the literature scan. The full literature findings report can be found in Appendix 8.1.

2.1 General Safety Performance

Studies examined in this section reinforce findings from the earlier FHWA literature review that SBLs reduce the risk of bicyclist crashes and injuries, though numerous factors related to the SBL itself can influence that risk. Factors that may increase the risk of crashes involving bicyclists on SBL corridors include the presence of driveways and other intersections. Few studies have examined the impact of SBL presence on motorist operating speed, though one did demonstrate lower speeds when SBLs were present.

2.2 Safety at Intersections

Clear benefits have been demonstrated for fully or partially protected intersection maneuvers featuring through bike lanes and elements of protected intersection designs. Mixing zone treatments can be effective in providing safer intersection maneuvers where SBLs meet intersections, though these treatment packages can vary widely in their implementation. More work can be done to examine the safety performance of protected intersection designs, which are relatively new in the U.S.

2.3 Operations

Few studies directly examined the relationship between SBL presence with operational performance for motor vehicles. Some studies evaluated different signal configurations and timing strategies in terms of their impact on motor vehicle delay, but these were not necessarily linked to the presence of SBLs themselves. This is a potential area for future research.

2.4 User Preferences and Safety Perception

SBLs tend to be the preferred bicycle facility by both bicyclists and motorists when compared to other types, though the specific facility type preference and safety perception of those facilities can vary between different types of bicyclists. Bicyclists tend to feel more comfortable using intersection treatments that offer more protection and separation (e.g., protected intersection designs, fully separated signal phases), but the particulars of mixing zone treatment packages and the type of bicyclist being considered can reveal a range of preferences and comfort levels.

2.5 Planning and Design Guidance

Our review also sought to capture the landscape of SBL planning and design guidelines available from Federal, State, and other sources. At the time of this writing, the forthcoming edition of the AASHTO *Guide for the Development of Bicycle Facilities* is under development but not yet published. We identified six references that cover SBLs at the Federal (or national) level, and several others produced by States and international agencies.

Federal Guidelines and Resources

- Bikeway Selection Guide (2018, Federal Highway Administration)
- Separated Bike Lane Planning and Design Guide (2015, Federal Highway Administration)
- Bicycle Facilities and the Manual on Uniform Traffic Control Devices (2009, Federal Highway Administration)

Other National Guidelines and Resources

- Protected Bikeways Practitioner Guide (2017, Institute of Transportation Engineers)
- Urban Bikeway Design Guide (2011, National Association of City Transportation Officials)
- Don’t Give Up at the Intersection (2019, National Association of City Transportation Officials)

Other Agency Guidance

- Separated Bike Lane Planning and Design Guide (2015, Massachusetts Department of Transportation)
- Design Manual for Bicycle Traffic (2017, CROW)
- Cycle Network and Route Planning Guide (2004, New Zealand Land Transport Safety Authority)
- Geometric Design Guide for Canadian Roads (2017, Transportation Association of Canada)

2.6 North Carolina State of Practice

This project assessed the state of practice with respect to SBL planning and design in North Carolina to understand how they are being incorporated into plans and projects across the state. We conducted this assessment by surveying practitioners in local agencies, NCDOT Division stakeholders, and others who have been part of discussions around SBL projects in North Carolina. The survey was designed to collect information on:

- Barriers and challenges to planning, designing, and constructing SBLs
- Successes
- Missed opportunities
- Future plans for planning and constructing SBLs

The outreach email to request an interview and the question set is provided in Appendix 8.2.3. In the course of our interview phase, we reached out to a number of municipalities and DOT representatives across North Carolina. A scan of bicycle plans revealed a number of agencies that either recommended SBLs or discussed them generally as a preferred bicycle facility type. From those cities and other discussions with NCDOT and regional agencies, we identified 38 potential agencies to interview. This list was prioritized into 19 agencies, with a goal of conducting between 10-15 interviews. We reached out to the following agencies to conduct interviews: municipalities of Asheville, Raleigh, Charlotte, Cary, Winston-Salem, Durham, Wilmington, and Fayetteville; NCDOT Divisions 5, 6, 10, and 13; and regional agencies such as Fayetteville MPO and Wilmington MPO. Of these agencies, we completed interviews with the following ten:

- City of Raleigh
- City of Charlotte
- Town of Cary

- City of Winston-Salem
- City of Wilmington and Wilmington MPO (same interview)
- City of Fayetteville
- Fayetteville MPO
- NCDOT Division 5
- NCDOT Division 6
- NCDOT Division 10

Interviews were held during one-hour phone calls with agency representatives. The structured interviews were built around set questions related to SBL planning and design experience. The questions allowed the team the opportunity to shift course during the interviews depending upon whether the agency did or did not have much experience with these projects. If they did, we asked questions about the specifics of the design, the motivation for the projects, and other details about implementation. Most agencies, however, did not have past experience with these types of facilities, so during those interviews we broadened the focus to bicycle facilities in general and how SBLs may fit into their future plans.

Following the interviews, notes were compiled and scanned for common themes that emerged during the discussion. These common themes are presented below. A detailed report summarizing North Carolina's experience with SBLs along with the completed interviews are in Appendix 8.2.

Few SBL projects are on the ground, but SBLs are in the conversation for future efforts.

As noted in our review, there are few examples of SBLs on the ground across the state. However, from our interviews it is clear that the SBL is being considered by many municipalities as a possible intervention in future roadway projects. Cary, Fayetteville, and other municipalities noted that they have adopted formal plans that make specific recommendations for SBL projects. However, there is concern about funding and approval for the projects in instances where NCDOT is involved. There is also often a lack of specific design recommendations, stemming from a lack of local guidance to draw upon (see below). NCDOT representatives suggested that it is important for municipalities to begin implementing these projects to demonstrate the potential to NCDOT.

Advocacy for separated facilities frequently drives implementation.

Representatives of several municipalities including Wilmington, Winston-Salem, and Cary emphasized the importance of advocacy from cycling groups in prioritizing separated facilities. Having a pro-cycling City Council (or other decision-making bodies) was also a key element. Several municipalities felt that the cycling public did not know or understand enough about separated on-road facilities, and, as a result, the advocacy was focused on off-road multi-use paths. There seemed to be a sense that if there was greater awareness of the potential of SBLs among cycling groups, there might be more pressure to install these facilities.

Absence of in-house or state design guidelines leads to reliance on FHWA/AASHTO/NACTO guides; NC guidelines would be a valuable tool for both municipalities and NCDOT officials.

Cary and Charlotte were the only communities we interviewed that were developing their own guidance for SBL designs. The rest were largely relying upon FHWA, AASHTO, and NACTO guides for direction on cross-sections, etc. It was noted that many of the existing examples are from larger municipalities (New

York, Portland, etc.) and having more context-sensitive examples to draw on would be a valuable tool. Many felt that having more specific guidance (such as the forthcoming update to the AASHTO Guide for the Development of Bicycle Facilities) would also be a valuable tool, both from a design standpoint and a legitimization of the concept. They also expressed interest in planning tools and selection criteria that would help them determine the most appropriate locations for SBLs, compared to other bicycle facilities. Both NCDOT officials and municipalities universally agreed that North Carolina-specific guidance would be a valuable resource.

Retrofitting buffered bike lanes by adding some type of vertical element is a commonly used methodology that enables stepwise implementation.

Many municipalities currently have buffered bike facilities on the ground or in the planning stages. These municipalities have floated the idea of retrofitting buffered bike lanes with some type of vertical separation (typically bollards or flexible delineators). Durham has successfully implemented vertical separation on East Main Street, and other municipalities have positioned vertical separation as a way to begin testing the waters for SBL installation without sinking significant development costs.

Value of temporary and demonstration projects.

Charlotte and Winston-Salem specifically pointed to temporary or demonstration SBL installations as a major source of inspiration and guidance for their SBL projects looking forward. These temporary projects provide an opportunity for municipalities to test installation and maintenance processes and allow the public to gain confidence and comfort with the configurations. The temporary projects also provide proof of concept for city officials and the NCDOT that these projects can be successful, though the examples we encountered had only been done on locally owned roadways. Roadway construction and pedestrian/greenway detours provide municipalities with opportunities to attempt innovative temporary installations. Many interviewees referenced the value of temporary projects as a “dry run,” the results of which can be instructive for other municipalities as well.

Concerns around additional maintenance costs of separated facilities.

NCDOT’s Division 5, Winston-Salem, and Cary all noted concerns over whether the responsible parties would be able to maintain separated facilities. Specifically, there are concerns about whether their existing maintenance fleets can operate in the narrower widths of single-direction SBL facilities. In fact, Winston-Salem seemed to prioritize considerations of 2-way SBL designs over 1-way pairs given their ability to maintain the wider paths more easily. There were also concerns about their public works departments lack of equipment to maintain green paint (a common marking tool at conflict points along bicycle facilities) and/or the additional costs to do so. In our interview with Fayetteville, it was suggested that maintenance of bicycle facilities is not always considered in the bicycle planning process but is a real concern when moving to the implementation phase. NCDOT officials from Division 10 also noted concerns about vertical separation during street resurfacing, and the added cost of removing and replacing vertical elements.

Interactions with NCDOT regarding approval and support.

The general perception among municipal agencies is that NCDOT is receptive to pedestrian and bicycle facility installations when the state is not responsible for the road and/or when the installation does not affect travel lanes when intersecting with state roads (hence a preference for multi-use paths, wide outside lanes, etc.). Speaking with the Division Office representatives, their concerns related more to the maintenance of these facilities and how that arrangement would be worked out with local agencies, not necessarily a reluctance to provide these facilities. One representative of Division 5 noted that the NCDOT seemed to be on the cusp of a change in its historic reticence to bike lane projects, observing that upper management seemed on board with SBL projects and that the new Complete Streets guidance created a cost-sharing system that mitigates the maintenance concerns that had been a limiting factor in the adoption of SBLs. On the other hand, Fayetteville noted that even when sharing costs with NCDOT, smaller municipalities and/or municipalities with smaller budgets may be unable to support the costs of installing and maintaining SBL facilities.

One local agency representative (from Rocky Mount) also pointed out that the release of the upcoming AASHTO guidelines on SBLs would be a significant step, as the DOT regularly relies on the AASHTO guides, and the inclusion of SBL guidelines in such an oft-cited document would lend legitimacy to the proposition. One recurring refrain was that having a prominent North Carolina example of an SBL would help illustrate the feasibility of SBLs for other municipalities. Fayetteville representatives expanded on that need, suggesting that beyond design guidance, some best practice recommendations on the types of neighborhoods and local street networks (i.e., land use and context factors) that are appropriate for SBL facilities would also be a useful resource.

The interviews also provided an opportunity for the team to identify possible study sites for the evaluation phase of the project. The site selection process is discussed in more detail below.

3 Methodology

As found in the literature review, there are a variety of measures used to determine the effectiveness of SBLs. Key to our objectives of conducting a pre-post observational study to better understand their impact on safety and operations, we measured types of interactions between vulnerable road users and motor vehicles (e.g., conflict or avoidance maneuvers), bicyclist counts, and characteristics of the bicyclists such as use of helmet, choice of clothing, and whether riders were using some sort of shared mobility vehicle such as a bicycle or e-scooter available through a local system. We selected a variety of sites where SBLs were installed within the project study period and used video cameras to collect observation data on these measures before the SBL was constructed and after it was in place and compared the changes.

3.1 Site Selection

Sites were limited for this research project, as the evaluation design required data both before and after a separated bike lane was installed. As such, the research team relied on the NCDOT and NC cities to provide guidance on which roadways were planned for upcoming SBLs construction. Much of the information gathered on potential sites was collected during our structured interviews with NCDOT and local agency staff. During these interviews, we asked if agencies had any SBL projects planned for construction within the timeframe of our project. We asked a similar question in a survey that was distributed to all of the NCDOT Division Offices. During this process we learned about eight forthcoming potential SBL installations - all in Raleigh and Charlotte. After continued discussions with City staff, we ultimately chose three SBLs in Raleigh and one SBL in Charlotte based on the expected timing of the installations of these four SBLs that best fit within the research project’s timeline.

Along these four SBLs, we subsequently selected 10 specific sites for data collection: four Raleigh sites, and six Charlotte sites. The Raleigh and Charlotte sites were different in that the Raleigh sites were generally standalone SBLs that were not part of the same corridor or path (the exception being the two West Morgan Street locations), whereas the Charlotte sites were all part of the same SBL, the Uptown CycleLink. Given that the installation of an SBL should, by design, mitigate any bicyclist-motorist interactions along a segment with no driveways or intersections, we focused on selecting sites at intersections or segments with driveways. Given the complexity of two of the Charlotte intersections (West 6th Street at North Graham Street and West 5th Street at North Cedar Street) two camera sites were in the same general location to examine different views of each intersection. All site locations are listed in Table 1 with coordinates. This table also includes information for each site regarding the type and presence of a physical barrier throughout the entire observed location and/or green pavement markings in the after period.

While this research project attempted to evaluate the effectiveness of SBL applications on bicyclist safety, the types of SBLs varied across sites. More detailed descriptions of each site follow, along with a map of each area showing the geographic location for each site.

Table 1 SBL Study Locations

Site	Intersection/Location of Interest	Coordinates	SBL Physical Barrier Installed	Use of Green Pavement Markings
Raleigh Site 1 – Crabtree Boulevard	At stop-controlled T-intersection with Timber Drive	35.805331, -78.612067	Painted buffer with flex post delineators	Through intersection
Raleigh Site 2 – Lineberry Drive	At stop-controlled T-intersection with Trailwood Hills Drive	35.750124, -78.685395	Painted buffer with flex post delineators	Through intersection
Raleigh Site 3 – West Morgan Street	At signalized intersection with Salisbury Street; right-turn only lane shared with bike lane; left-turning cyclist movements from Salisbury St.	35.779640, -78.640106	Painted buffer with flex post delineators (dropped on approach to intersection)	In Salisbury St. bike lane on approach to intersection; none on Morgan St.
Raleigh Site 4 – West Morgan Street	At parking deck entrance near South McDowell Street	35.779706, -78.642005	Painted buffer with flex post delineators	none
Charlotte Site 1 – North McDowell Street	At signalized intersection with East 7th Street	35.222701, -80.831722	Raised concrete median (drops before intersection due to driveway)	On approach and through intersection;

				through driveway
Charlotte Site 2- West 6th Street	At signalized intersection with North Graham Street and adjacent CVS driveway	35.232211, -80.844957	Raised concrete median (drops at driveway)	On approach and through intersection; through driveway
Charlotte Site 3 – West 6th Street	At signalized intersection with North Graham Street and repurposed channelized right turn lane	35.232097, -80.844720	Raised concrete median	On approach and through intersection
Charlotte Site 4 – West 5th Street	At signalized intersection with North Cedar Street	35.233999, -80.849092	Raised concrete median	On approach and through intersection
Charlotte Site 5 – West 5th Street	At Parking garage driveway opposite SBL near signalized intersection with North Cedar Street	35.234157, -80.849304	Raised concrete median	On approach and through intersection
Charlotte Site 6 – West 5th Street	At I-77 On-Ramp and repurposed channelized right turn lane	35.237354, -80.853576	Raised concrete median	On approach and through intersection

3.1.1 Raleigh Sites

Raleigh Sites 1 and 4 had buffered bike lanes as their before conditions, with Site 3 having a buffered bike lane upstream of the intersection and a simple marked bike lane downstream of the intersection, while Site 2 did not have a dedicated bicycle facility. The separated bike lanes installed at Raleigh Sites 1, 2, and 4 used vertical delineator posts spaced within buffered lane markings as the separating elements with breaks at driveways and intersections and marked the bike lane with the standard Helmeted Bicyclist Symbol (see Figure 9C-3 (B) of the MUTCD[3]) pavement markings. The SBLs installed along Crabtree Blvd. (Raleigh Site 1) and Lineberry Dr. (Raleigh Site 2) were installed on both sides of the street and use green pavement markings across the stop-controlled T-intersections with Timber Dr. and Trailwood Hills Dr., respectively, for added visibility to turning motorists. The SBL along West Morgan St. (Raleigh Sites 3 and 4) is only on the right side of the one-way street. At Site 4, the SBL is maintained via skip lines for the buffered lane width across a right-turn driveway entrance into a public parking deck but does not utilize green pavement markings. Raleigh Site 3 is at the convergence of Salisbury Street, which includes a bike lane with no vertical or horizontal separation, and West Morgan Street, along which the separated bike lane was installed. On approach to the intersection, the SBL on West Morgan drops to become a shared lane with a right-turn only lane and picks back up on the other side of the intersection as a standard bike lane with no separation (which remained unchanged in the after condition). This means that motor vehicles turning right onto Salisbury St. can enter the space also serving the bike lane on Morgan St. (which is marked with the Helmeted Bicyclist Symbol pavement marking rather than the shared lane marking). The bike lane along Salisbury Street includes green pavement markings on approach to the intersection but not through it. The map in Figure 1 shows the location of each site in Raleigh, denoted by stars within a circle. Google Street View images of each Raleigh site showing after conditions follow in Figure 2.

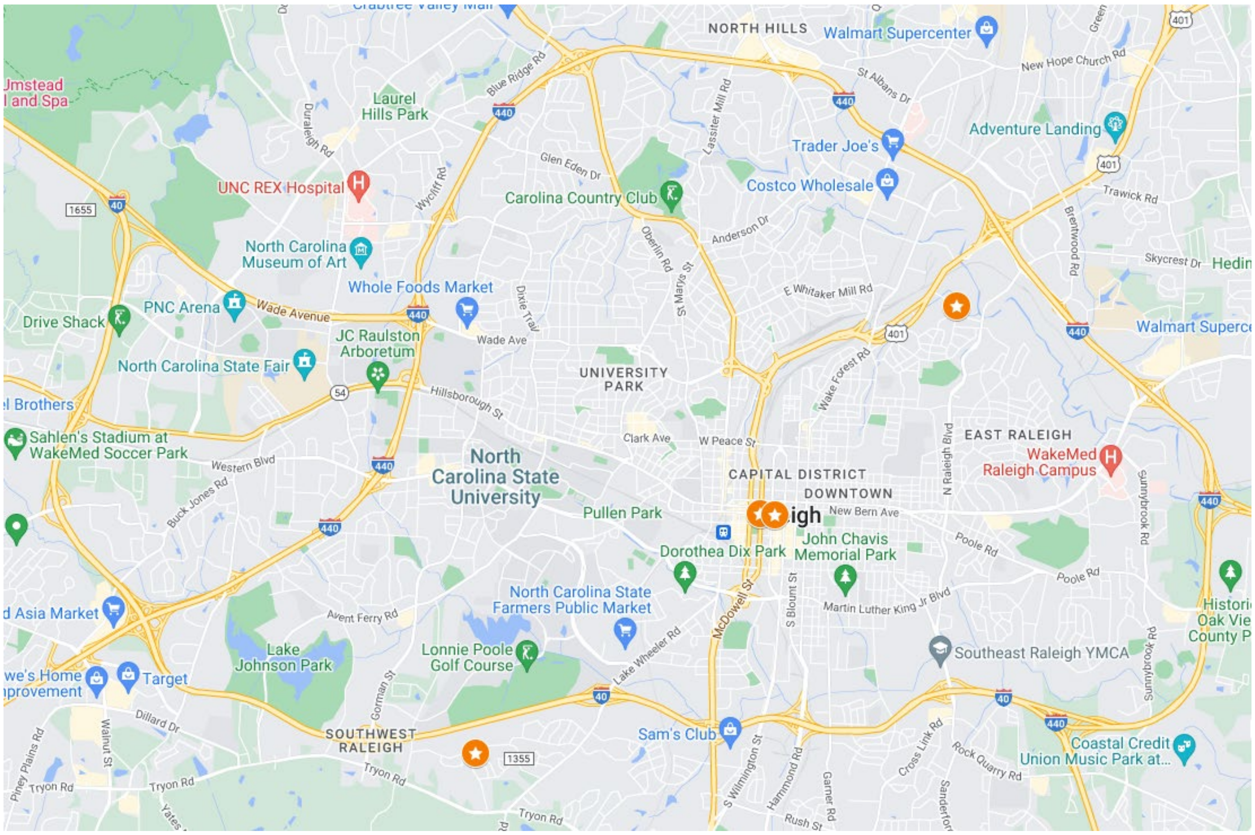


Figure 1 Map of Raleigh sites

a) Raleigh Site 1 –Crabtree Boulevard at Timber Drive (before)

b) Raleigh Site 1 –Crabtree Boulevard at Timber Drive (after)

c) Raleigh Site 2 – Lineberry Drive at Trailwood Hills Drive (before)

d) Raleigh Site 2 – Lineberry Drive at Trailwood Hills Drive (after)

e) Raleigh Site 3 – West Morgan Street and South Salisbury Street (before)

f) Raleigh Site 3 – West Morgan Street and South Salisbury Street (after)

g) Raleigh Site 4 –West Morgan Street at McDowell Parking Deck entrance (before)

h) Raleigh Site 4 –West Morgan Street At McDowell Parking Deck entrance (after)

Figure 2 Google street view images of Raleigh sites showing before and after conditions

3.1.2 Charlotte Sites

The Charlotte sites were generally consistent in terms of design given they are all part of the Uptown CycleLink, a two-way separated bike lane facility located on the north side of McDowell Street and east side of 6th and 5th Streets. Generally, the Uptown CycleLink uses a raised concrete median, typically 3 to 4 feet wide, as the vertical and horizontal separating element from the other travel lanes. Each of the six Charlotte sites contained Helmeted Bicyclist Symbol pavement markings on either side of the observed intersections, as well as green pavement markings leading up to and across the observed intersections. All six Charlotte sites also contained vertical delineators on each end of any opening in the median for driveways and intersections. Charlotte Sites 1, 2, 3, 4, and 5 contained a median on both sides of the observed location, while Charlotte Site 6 had a median on one end of the observed area, but no median or other physical barrier on the other end. Site 6 was also the only site that previously had a standard bike lane that was converted to an SBL, while the other Charlotte sites had no dedicated bicycle facility in the before period. The map in Figure 3 shows the location of each site in Charlotte, denoted by stars within a circle. Google Street View images of each Charlotte site showing after conditions follow in Figure 4.

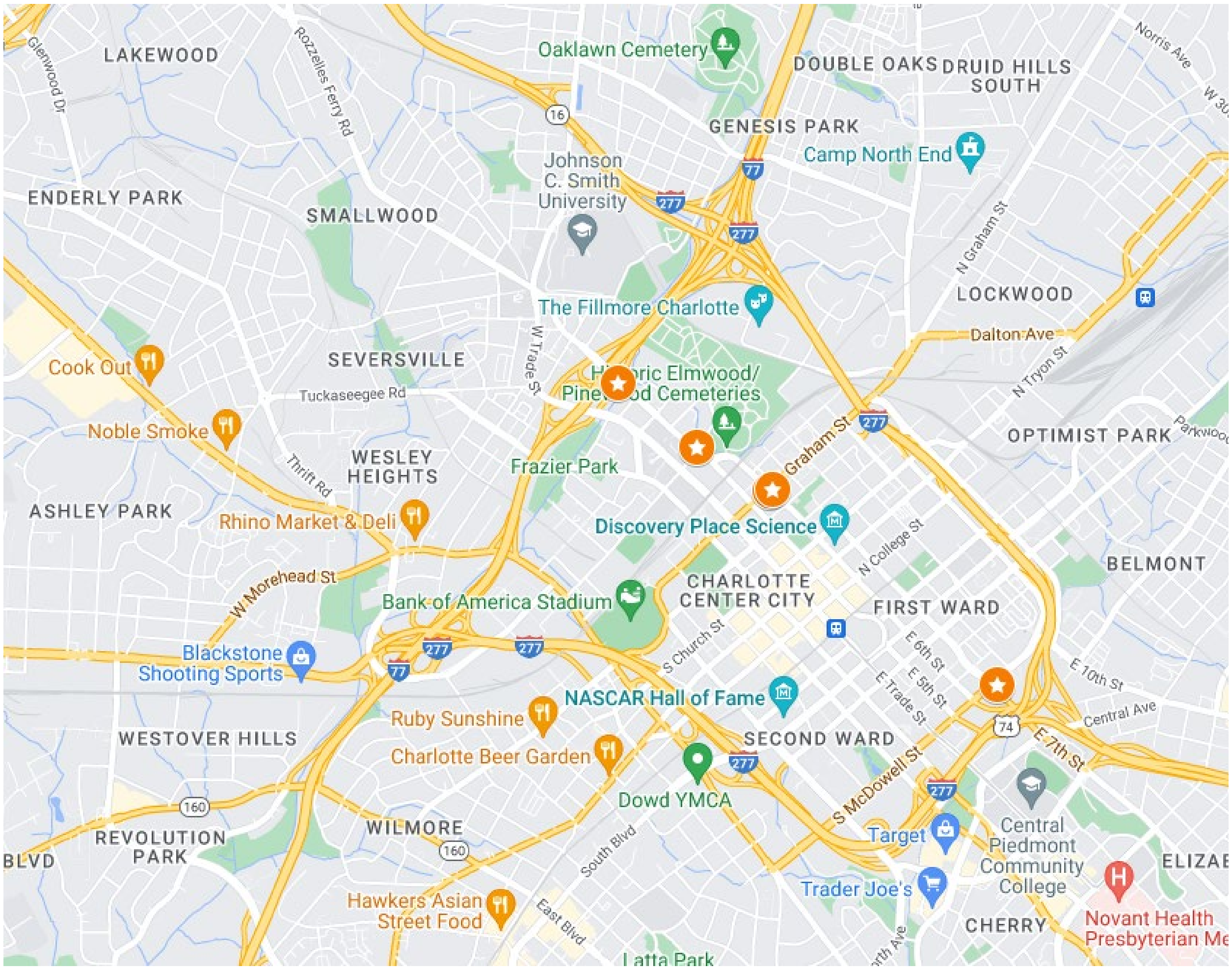
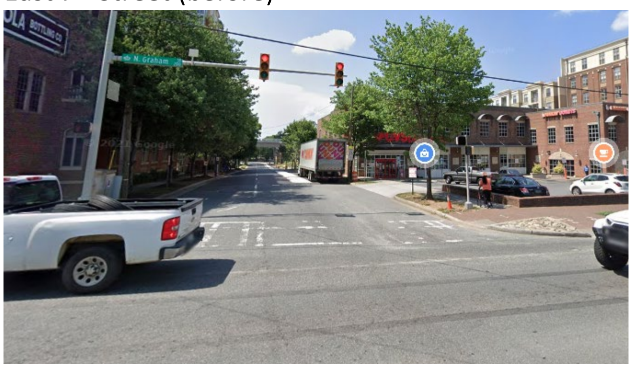


Figure 3 Map of Charlotte sites

a) Charlotte Site 1 – North McDowell Street and East 7th Street (before)

b) Charlotte Site 1 – North McDowell Street and East 7th Street (after)

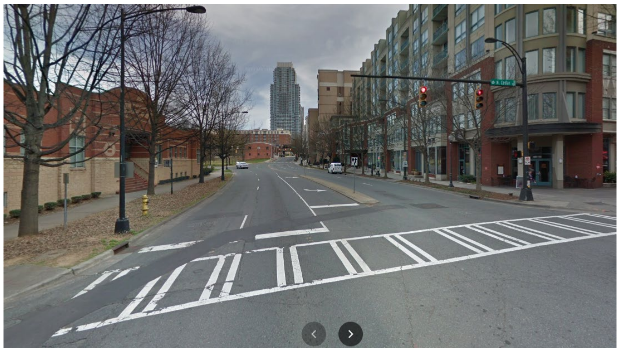


c) Charlotte Site 2 – West 6th Street and North Graham Street 1 (before)

d) Charlotte Site 2 – West 6th Street and North Graham Street 1 (after)

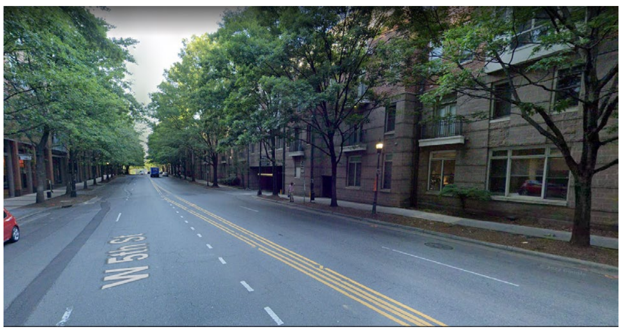
e) Charlotte Site 3 – West 6th Street and North Graham Street 2 (before)

f) Charlotte Site 3 – West 6th Street and North Graham Street 2 (after)

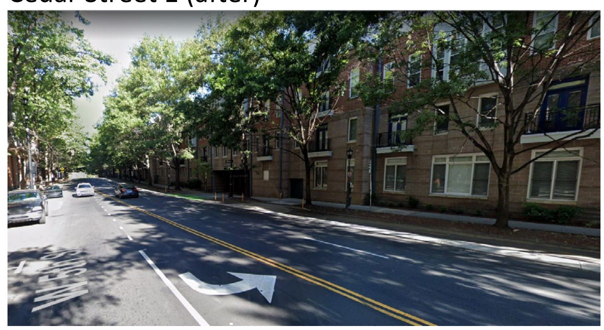


g) Charlotte Site 4 – West 5th Street and North Cedar Street 1 (before)

h) Charlotte Site 4 – West 5th Street and North Cedar Street 1 (after)

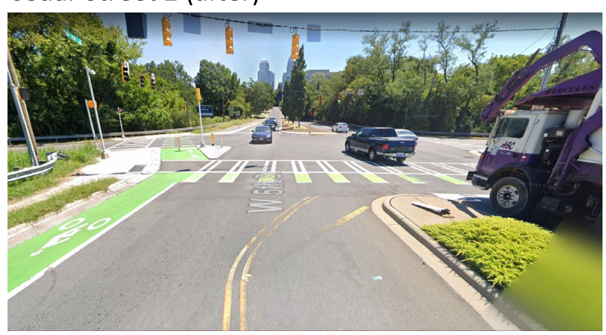


i) Charlotte Site 5 – West 5th Street and North Cedar Street 2 (before)



j) Charlotte Site 5 – West 5th Street and North Cedar Street 2 (after)

k)Charlotte Site 6 – West 5th Street and I-77 On-Ramp (before)



l) Charlotte Site 6 – West 5th Street and I-77 On-Ramp (after)

Figure 4 Street view images of Charlotte sites showing before and after conditions

3.2 Data Collection

Discreet mini-video cameras were mounted in positions approximately 8 ft high to allow for the area where the SBL would be installed (before) or was installed (after) to be within the field of view such that both bicyclist and motorist travel through an intersection and/or near a driveway could be observed. Cameras were installed on existing traffic control devices such as a typical signpost or traffic signal mast/pole, as is shown in Figure 5. To the extent possible, the camera angle was adjusted to avoid capturing license plates and the resolution was such that pedestrians, cyclists, and motorists could be classified as such but not identified individually.

Figure 5. Example camera installation at Raleigh Site 2 with camera mounted to back of STOP sign to capture activity along Lineberry Dr. at the intersection with Trailwood Hills Dr.

Cameras were originally intended to be left out to collect up to three weeks of video at each site, although some sites had video recorded for fewer or more days, as outlined in Table 2. Video was recorded and reduced for the entirety of a camera's installation (i.e., 24 hours for full days). For Raleigh sites 1, 3 and 4, more than three weeks of data were captured because of cameras being left in place for longer than expected. This was due to one of two reasons: 1) the field data collection team was simply having to juggle other projects and could not retrieve the cameras within the three week time frame, or 2) one or more cameras needed to be left in place beyond the three week mark because of equipment failure, in which case the other cameras which had not failed were left out for the duration of the cameras that had failed – this was simply to reduce the amount of time spent picking up cameras. Those at the Charlotte sites were installed with solar panels to ensure longevity of the batteries during the 3-week period, while team members replaced batteries weekly at the Raleigh sites due to their local proximity. Pre-implementation video was collected in August/September 2020 in Raleigh and September/October 2020 in Charlotte. After video was collected in April 2021 in Raleigh and in May 2022 in Charlotte after the SBLs had been open for at least one month in an attempt to capture typical usage. Every attempt was made to set up the cameras at the exact same placement to ensure the same fields of view for both before and after time periods. In total across the 10 sites, the minimum number of usable days captured by camera was nine days and the maximum was 34 days.

3.2.1 Video Reduction

Video footage was processed through a data reduction technique that consisted of staff and students viewing the footage and transcribing or coding key events and other variables of interest into a spreadsheet. Anywhere from 9 to 34 days of video was reduced by site based on the available useable footage at that site in either the before or after period, as shown in Table 2.

Table 2. Number of Days of Video Reduced Per Site

Site ID	Site Name	Before Period # of Days	After Period # of Days
Raleigh Site 1	Crabtree Blvd.	21	24
Raleigh Site 2	Lineberry	12	20
Raleigh Site 3	Morgan & Salisbury	21	26
Raleigh Site 4	Morgan St Parking Deck	20	34
Charlotte Site 1	McDowell & 7th	21	17
Charlotte Site 2	6th & Graham - 1	10	14
Charlotte Site 3	6th & Graham- 2	12	17
Charlotte Site 4	5th & Cedar - 1	18	12
Charlotte Site 5	5th & Cedar -2	21	18
Charlotte Site 6	5th & I-77	9	18

For the purpose of this study, the research team coded an event for each person, generally referred to as a vulnerable road user (VRU), who could reasonably use a SBL. This primarily included bicyclists on any form of bicycle (e-bike, recumbent, cargo bike, with trailer, etc.) and scooter users, including those using e-scooters or manually propelled scooters; however, we also documented people using skateboards, hoverboards, wheelchairs, mopeds, strollers, and dirt bikes if a portion of their trip through the camera's field of view was in the street and not only at a crosswalk. Pedestrian activity was not counted or coded unless they use a wheeled device such as a wheelchair or stroller in the street and not at a crosswalk.

For each event, several other factors were extracted:

- Interaction Type
    - *No Interaction* – the VRU traveled alone with no motor vehicles sharing the same space in time.
    - *Coexist* – The VRU coexisted safely in the same space as one or more motor vehicles; neither the VRU nor the motorist altered their direction of travel or speed to maintain safety.
    - *Avoidance Maneuver*– A VRU and one or more motor vehicles share the same space, but one of them altered their direction of travel or speed to avoid the other. Maneuvers where a traveler slowed or stopped based on compliance with a traffic control device such as a STOP sign, traffic signal, or pedestrian signal head, were not coded as avoidance maneuvers. Maneuvers where a traveler slowed, stopped or changed direction against the traffic control device assigning their movement based on another traveler's movement were coded as an avoidance maneuver.
    - *Conflict* – This was a more severe and dangerous avoidance maneuver: at least one traveler (VRU or motorist) exhibited a *sudden* change in speed or direction (e.g.,

observed swerving or hard braking) to prevent a crash with another traveler. (Note: no crashes were observed in the video collected.)

- *Helmet Usage* – Was the VRU wearing a bike helmet? This was coded for bicyclists and riders using scooters, skateboards, roller skates or rollerblades, or hoverboards.
- *Cycling Kit/Jersey* – Was the bicyclist wearing a cycling kit or jersey, bike shorts, or other clothing more typically associated with exercise?
- *Rideshare Usage* – Was the VRU riding a scooter or bicycle branded as part of a shared micromobility system (e.g., BCycle, Bird, Lime, LEAP, Spin, Citrix Cycle, Cardinal, etc.)?
- *Who Yielded* – for avoidance or conflict maneuvers only, the traveler who yielded was coded (e.g., bike, car, skateboard, etc.)
- *Was Yielded To* - for avoidance or conflict maneuvers only, the traveler who was yielded to was coded (e.g., bike, car, skateboard, etc.)

See Appendix 8.3 for a more complete list of the data fields and codes used as well as an archive of the camera views at each site.

When observing traveler activity in the before period, the research team only coded events along the corridor and/or side of the road where the SBL would eventually be installed (e.g., the primary street). At intersections, this meant that vehicles turning onto or off of the primary street or travelers passing along the primary street were coded. Vehicles traveling along the secondary street through an intersection with the primary street were not coded unless they interacted with the traveler on the primary street.

a) Turning vehicle yielding to bicyclist

b) Adjacent vehicle traveling beside bicyclist

c) Vehicle on cross street yielding to bicyclist running red light

d) Turning vehicle yielding to bicyclist

Figure 6. Items (a) through (d)show examples of events coded from Before period. Yellow lines indicate where the SBL would be once installed; red ovals indicate where difficult-to-see bicyclist is present.

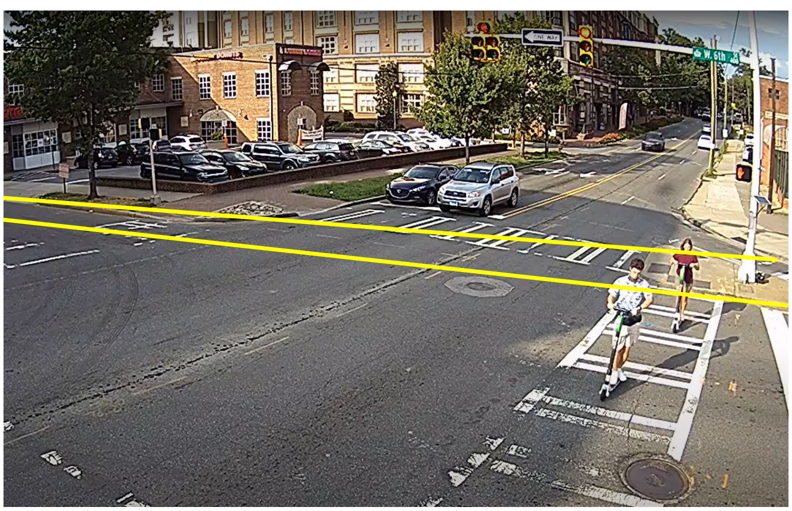


Figure 7. Example of observations not coded because they occurred only on the secondary street. Yellow lines indicate where SBL will go once installed.

At two Raleigh sites and two Charlotte sites, the camera field of view also allowed for capturing and coding events related to travelers turning into or out of driveways with access to the primary street.

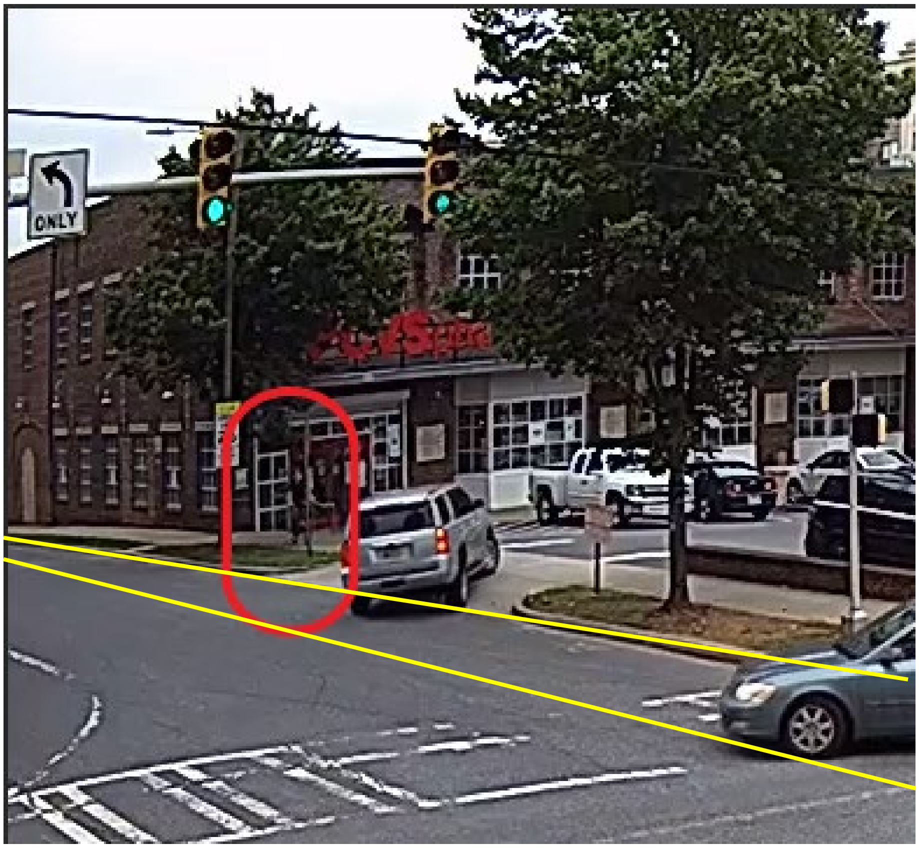


Figure 8 Coexist interaction between bicyclist and motorist turning into driveway. Bicyclist is indicated within the red oval; yellow lines indicate where the SBL will be installed.

3.3 Hypotheses and Assumptions

Several different measures of effectiveness were considered when preparing the data to compare before and after results. These are listed here in the form of hypotheses or assumptions we hoped to test to determine if safety and operations improved after the SBLs were in place.

1) Bicyclists traveling along the street will increase. This assumes that an increase in bicycling activity after the SBL is installed suggests that more people feel safer bicycling because of the SBL.
2) VRUs will travel along the street in the appropriate location. In other words, if we see a percent decrease in bicyclists and scooter users riding on the sidewalk and a higher percentage of them using the SBL in the after period, this would be considered an improvement. Likewise, we expect to see fewer people using wheelchairs, strollers, dirt bikes, or mopeds in the location of the SBL (e.g., using the SBL) once it is installed.
3) The percentage of avoidance and conflict interactions will decrease after the SBL is installed. The percentage of “no interaction” types will increase after the SBL is installed with an increase in the number of VRUs.

4) Helmet usage for bicyclists, scooter users, skateboarders, roller skaters and other VRUs that typically wear helmets will increase. This assumption may not be directly related to the installation of the SBL, but it is a general indicator of safe riding and rolling behavior.
5) The percentage of bicyclists wearing a cycling kit or bike jersey will decrease. The type of clothing observed on bicyclists serves as a proxy for the typology of the rider, and those wearing cycling kits are assumed to represent the “strong and fearless” type of cyclist. If we see fewer riders wearing exercise gear, the assumption is that the SBL appeals to a broader “interested but concerned” type of cyclist and is viewed as a facility that feels safe and comfortable to use.
6) The number of VRUs using a bikeshare or scooter share vehicle will increase while the percentage of VRUs using a shared system vehicle stays the same or also increases. Often, people using a micromobility rideshare service are casual riders who are making short trips, who do not otherwise have access to a bicycle or scooter, or who are tourists. They are more likely to represent the “enthused and confident” or the “interested but concerned” type of cyclist, so observing an increase in this ridership may suggest that people feel safer bicycling in a SBL.
7) The percentage of motorists observed as yielding to VRUs will increase. While we did not code which party had the legal right of way, an increase in motorists yielding should result in a safety improvement. Although road safety is a shared responsibility between all travelers, motorists assume a greater share simply by operating a vehicle that is of greater weight, affords a higher level of protection, and that travels at a higher speed than those on foot or bicycle.

4 Results and Findings

All results presented here proceeded in two steps:

1. Normalizing the before and after data to the greatest number of days for which video was collected for any specific site. This resulted in data for Charlotte sites being normalized to 21 days, and data for Raleigh sites being normalized to 34 days. As an example, this would mean for the site in Raleigh with 34 days of data collected, the normalization factor would be 1.00; however, for a different site in Raleigh with 20 days of data collected, the normalization factor would be 1.700 (i.e., 34 / 20).
2. Calculating likelihood ratio chi-square tests to assess associations between before and after data for Charlotte and Raleigh pertaining to interactions, helmet use, ride share use (i.e., use of shared bikes and scooters), and cycling kit use.

4.1 Change in Bicyclist Volume

To provide context to the analysis presented in the following sections, pre-normalized before and after data was used to derive the bicyclist rate (i.e., volume/day). Table 3 presents the before and after period bicyclist rate for all Raleigh and Charlotte sites. Data for VRUs other than bicyclists were also collected and analyzed. Table 4 presents the before and after period all VRU rate for all Raleigh and Charlotte sites for comparison purposes. While the differences were not tested for statistical significance, bicycling rates specifically and overall VRU rates increased from before to after periods, with the exception of the Morgan St. Parking Deck site.

Table 3. Bicyclist Rate (i.e., Volume/Day in the before and after periods)

Raleigh Sites			
Site	**Period**	**# of Days**	**Bicyclists/Day**
Crabtree & Timber	Before	21	19.43
	After	25	24.72
Lineberry	Before	12	11.00
	After	20	14.80
Morgan & Salisbury	Before	21	92.81
	After	26	133.65
Morgan St Parking Deck	Before	20	28.90
	After	34	25.29
Charlotte Sites			
Site	**Period**	**# of Days**	**Bicyclists/Day**
McDowell & 7th	Before	21	77.86
	After	17	145.65
6th & Graham - 1	Before	10	17.30
	After	14	89.93
6th & Graham - 2	Before	12	39.83
	After	17	81.06
5th & Cedar - 1	Before	18	49.17
	After	12	70.75
5th & Cedar - 2	Before	21	19.10
	After	18	54.72
5th & I-77	Before	9	20.78
	After	18	24.67

Table 4. VRU Rate (i.e., Volume/Day in the before and after periods)

Site	Period	# of Days	VRUs/Day
Raleigh Sites			
Site	**Period**	**# of Days**	**VRUs/Day**
Crabtree & Timber	Before	21	20.24
	After	25	27.24
Lineberry	Before	12	14.25
	After	20	18.15
Morgan & Salisbury	Before	21	110.05
	After	26	149.46
Morgan St Parking Deck	Before	20	33.05
	After	34	27.06
Charlotte Sites			
Site	**Period**	**# of Days**	**VRUs/Day**
McDowell & 7th	Before	21	86.95
	After	17	193.35
6th & Graham - 1	Before	10	43.60
	After	14	192.93
6th & Graham - 2	Before	12	67.58
	After	17	148.24
5th & Cedar - 1	Before	18	75.11
	After	12	127.50
5th & Cedar - 2	Before	21	26.81
	After	18	101.72
5th & I-77	Before	9	28.11
	After	18	36.83

4.2 VRU Interactions with Motor Vehicles

Aggregate interaction data across all sites in Charlotte and Raleigh show that the majority of VRUs had no interaction with motor vehicles (both before and after SBL installations) – approximately 62% in Charlotte and 53% in Raleigh. The data shows slight increases – 0.22% to 0.34% – in no interactions post SBL installations. The number of VRU's increased by 20% at the Raleigh sites and more than doubled at the Charlotte sites.

The coexist interactions (i.e., VRUs coexisted with motor vehicles) increased from 30.70% to 36.18% at Charlotte sites and from 42.70% to 44.19% at Raleigh sites post SBL installation. This is expected as SBLs would not only encourage bicycle and scooter usage but also provide separation between bicyclists and scooter users and motorists, though it should be noted that 4 of the 10 of the sites experienced decreased rates of coexist interactions when examining disaggregated data. Other interactions leading to an avoidance maneuver and/or conflict represented a small sample both before and after SBL installation. However, both avoidance maneuvers and conflicts decreased significantly post SBL installations with conflicts almost being non-existent.

Likelihood ratio chi-square tests revealed statistically significant differences between before and after periods for interaction data for both Charlotte ($\chi2$ (3, N = 23703) = 562.185, p = < 0.005) and Raleigh ($\chi2$ (3, N = 13582) = 65.990, p = < 0.005) as shown in Table 5.

Table 5. Associations between aggregated before and after interaction data (Raleigh and Charlotte – All sites combined)

Raleigh* - All Sites*						
Period	**Avoidance**	**Conflict**	**Coexist**	**No Interaction**	**n**	***p***
Before	3.61%	0.73%	42.70%	52.96%	6037	<0.005
After	2.09%	0.09%	44.19%	53.62%	7545	
Charlotte* - All Sites*						
Period	**Avoidance**	**Conflict**	**Coexist**	**No Interaction**	**n**	***p***
Before	5.22%	1.99%	30.70%	62.09%	6892	<0.005
After	1.30%	0.21%	36.18%	62.31%	16811	

***indicates statistically significant differences between before and after periods at $p < 0.05$*

In general, across all sites, safety as measured through interaction types appeared to improve after SBLs were installed given that percentages of avoidance maneuvers and conflict maneuvers decreased while no interactions increased. Reviewing the same analysis by site offers a bit more nuance, though. Table 6 and Table 7 present disaggregated site level interaction type analysis for both Charlotte and Raleigh. At the site level, each Charlotte site mostly aligns with the aggregate trend above (except for 5th & Cedar - 2 reflecting an increase in avoidance maneuvers); however, Raleigh's Crabtree Blvd, Lineberry Dr, and Morgan Street Parking Deck sites each reflect an increase in avoidance maneuvers. In fact, the Morgan Street Parking Deck also showed an increase in percentage of conflict maneuvers after the SBL was installed – the only site where this was found. This site was also the only site that saw a reduction in the adjusted number of VRUs counted in the after period.

Table 6. Associations between disaggregated before and after interaction data (Raleigh)

Raleigh* - Crabtree & Timber*						
Period	**Avoidance**	**Conflict**	**Coexist**	**No Interaction**	**n**	***p***
Before	1.89%	0.73%	37.65%	59.74%	688	<0.005
After	4.00%	0.00%	57.67%	38.34%	926	
Raleigh* - Lineberry*						
Period	**Avoidance**	**Conflict**	**Coexist**	**No Interaction**	**n**	***p***
Before	2.89%	0.00%	33.40%	63.71%	485	<0.005
After	5.83%	0.00%	24.27%	69.90%	618	
Raleigh* - Morgan & Salisbury*						
Period	**Avoidance**	**Conflict**	**Coexist**	**No Interaction**	**n**	***p***
Before	4.94%	0.96%	42.48%	51.62%	3743	<0.005
After	1.20%	0.08%	45.47%	53.25%	5082	
Raleigh* - Morgan St Parking Deck*						
Period	**Avoidance**	**Conflict**	**Coexist**	**No Interaction**	**n**	***p***
Before	0.62%	0.27%	50.53%	48.58%	1124	<0.005
After	2.61%	0.33%	36.85%	60.22%	920	

***indicates statistically significant differences between before and after periods at $p < 0.05$*

Table 7. Associations between disaggregated before and after interaction data (Charlotte)

Charlotte* - McDowell & 7th**						
Period	**Avoidance**	**Conflict**	**Coexist**	**No Interaction**	**n**	***p***
Before	6.46%	2.46%	31.87%	59.20%	1826	<0.005
After	1.06%	0.05%	16.80%	82.09%	4060	
Charlotte* - *6th* & Graham - *1**						
Period	**Avoidance**	**Conflict**	**Coexist**	**No Interaction**	**n**	***p***
Before	4.59%	2.51%	12.66%	80.24%	916	<0.005
After	0.30%	0.05%	39.31%	60.34%	4052	
Charlotte* - *6th* & Graham - *2**						
Period	**Avoidance**	**Conflict**	**Coexist**	**No Interaction**	**n**	***p***
Before	6.55%	3.10%	21.83%	68.52%	1420	<0.005
After	0.19%	0.00%	66.68%	33.13%	3112	
Charlotte* - 5th & Cedar - *1**						
Period	**Avoidance**	**Conflict**	**Coexist**	**No Interaction**	**n**	***p***
Before	3.80%	0.06%	46.64%	49.49%	1578	<0.005
After	0.60%	0.34%	25.35%	73.71%	2678	
Charlotte* - 5th & Cedar - *2**						
Period	**Avoidance**	**Conflict**	**Coexist**	**No Interaction**	**n**	***p***
Before	2.31%	3.02%	23.45%	71.23%	563	<0.005
After	5.76%	0.70%	31.73%	61.82%	2137	
Charlotte* - 5th & I-77**						
Period	**Avoidance**	**Conflict**	**Coexist**	**No Interaction**	**n**	***p***
Before	5.93%	1.19%	40.68%	52.20%	590	<0.005
After	2.45%	1.03%	48.58%	47.93%	774	

***indicates statistically significant differences between before and after periods at p < 0.05*

Likelihood ratio chi-square tests revealed statistically significant differences at $p<0.05$ between before and after periods at all sites in Charlotte and Raleigh. The percentages of avoidance maneuvers and conflicts decreased from before to after at all Charlotte sites. There was some variability in the Raleigh sites.

A few other notable differences observed at site level include:

- Raleigh – *Crabtree & Timber*
  - No interactions decreased from 59.74% to 38.34% post SBL installation.
  - Coexist interactions increased from 37.65% to 57.67% post SBL installation.
- Raleigh – *Morgan Street Parking Deck*
  - No interactions increased from 48.58% to 60.22% post SBL installation.
  - Coexist interactions decreased from 50.53% to 36.85% post SBL installation.
- Charlotte – *McDowell & 7th*
  - No interactions increased from 59.20% to 82.09% post SBL installation.
  - Coexist interactions decreased from 31.87% to 16.80% post SBL installation.
- Charlotte – *6th & Graham* – 1
  - No interactions decreased from 80.24% to 60.34% post SBL installation.
  - Coexist interactions increased from 12.66% to 39.31% post SBL installation.

- Charlotte – *6th & Graham* – 2
    - No interactions decreased from 68.52% to 33.13% post SBL installation.
    - Coexist interactions increased from 21.83% to 66.68% post SBL installation.
- Charlotte – *5th & Cedar* - 1
    - No interactions increased from 49.49% to 73.71% post SBL installation.
    - Coexist interactions decreased from 46.64% to 25.35% post SBL installation.

4.3 Helmet Use

Aggregate helmet use data across all sites in Charlotte and Raleigh show an increase in helmet use post SBL installations – 5.95% in Charlotte and 12.1% in Raleigh.

Likelihood ratio chi-square tests revealed statistically significant differences between before and after periods for helmet use for both Charlotte – $\chi 2$ (1, N = 23427) = 77.065, p = < 0.005 – and Raleigh – $\chi 2$ (1, N = 13476) = 196.355, p = < 0.005 – as shown in Table 8.

Table 8. Associations between aggregated before and after helmet use data (Charlotte and Raleigh – All sites combined)

Raleigh* - All Sites*				
Period	**No**	**Yes**	**n**	***p***
Before	61.12%	38.88%	5962	<0.005
After	49.02%	50.98%	7514	
Charlotte* - All Sites*				
Period	**No**	**Yes**	**n**	***p***
Before	71.80%	28.20%	6678	<0.005
After	65.85%	34.15%	16749	

***indicates statistically significant differences between before and after periods at p < 0.05*

Table 9 and Table 10 present disaggregated site level helmet use analysis for both Raleigh and Charlotte. The increase in helmet usage at the site level was consistent with what was found at the aggregated level.

Table 9. Associations between disaggregated before and after helmet use data (Raleigh)

Raleigh* - Crabtree & Timber*				
Period	**No**	**Yes**	**n**	***p***
Before	74.42%	25.58%	688	<0.005
After	47.89%	52.11%	923	
Raleigh* - Lineberry*				
Period	**No**	**Yes**	**n**	***p***
Before	57.05%	42.95%	482	<0.005
After	43.16%	56.84%	614	
Raleigh* - Morgan & Salisbury*				
Period	**No**	**Yes**	**n**	***p***
Before	57.63%	42.37%	3672	<0.005
After	51.20%	48.80%	5061	
Raleigh* - Morgan St Parking Deck*				
Period	**No**	**Yes**	**n**	***p***
Before	66.16%	33.84%	1120	<0.005
After	42.03%	57.97%	916	

***indicates statistically significant differences between before and after periods at $p < 0.05$*

Table 10. Associations between disaggregated before and after helmet use data (Charlotte)

Charlotte* - McDowell & 7th*				
Period	**No**	**Yes**	**n**	***p***
Before	62.77%	37.23%	1821	<0.005
After	50.87%	49.13%	4036	
Charlotte* - 6th & Graham - *1**				
Period	**No**	**Yes**	**n**	***p***
Before	90.00%	10.00%	880	<0.005
After	76.96%	23.04%	4046	
Charlotte* - 6th & Graham - *2**				
Period	**No**	**Yes**	**n**	***p***
Before	73.70%	26.30%	1403	<0.005
After	68.79%	31.21%	3111	
Charlotte* - 5th & Cedar - *1**				
Period	**No**	**Yes**	**n**	***p***
Before	73.37%	26.63%	1517	<0.005
After	67.61%	32.39%	2658	
Charlotte* - 5th & Cedar - *2				
Period	**No**	**Yes**	**n**	***p***
Before	64.93%	35.07%	556	0.120
After	68.39%	31.61%	2126	
Charlotte* - 5th & I-77*				
Period	**No**	**Yes**	**n**	***p***
Before	70.26%	29.74%	501	<0.005
After	61.01%	38.99%	772	

***indicates statistically significant differences between before and after periods at p < 0.05*

Likelihood ratio chi-square tests revealed statistically significant differences at p<0.05 between before and after periods at all sites in Charlotte and Raleigh (except for 5th and Cedar-2 in Charlotte). A few notable differences observed at site level include:

- Raleigh – *Crabtree & Timber*
  - Helmet Use increased from 25.58% to 52.11% post SBL installation.
- Raleigh – *Morgan Street Parking Deck*
  - Helmet Use increased from 33.84% to 57.97% post SBL installation.
- Charlotte – *McDowell & 7th*
  - Helmet Use increased from 37.23% to 49.13% post SBL installation.
- Charlotte – *6th & Graham* – 1
  - Helmet Use increased from 10.00% to 23.04% post SBL installation.

4.4 Cycling Kit Use

Aggregate cycling kit use data across all sites in Raleigh and Charlotte show a minor decrease of 0.13% in Charlotte and an increase of 1.42% in Raleigh.

Likelihood ratio chi-square tests revealed statistically insignificant differences between before and after periods for cycling kit use for Charlotte – $\chi2$ (1, N = 14504) = 0.052, p = 0.819 – and statistically significant differences for cycling kit use for Raleigh – $\chi2$ (1, N = 11722) = 4.944, p = 0.026 – as shown in Table 11.

Table 11. Associations between aggregated before and after cycling kit use data (Raleigh and Charlotte – All sites combined)

Raleigh* - All Sites*				
Period	**No**	**Yes**	**n**	***p***
Before	87.00%	13.00%	5163	0.026
After	85.58%	14.42%	6559	
***Charlotte* - All Sites**				
Period	**No**	**Yes**	**n**	***p***
Before	88.61%	11.39%	4705	0.819
After	88.48%	11.52%	9799	

***indicates statistically significant differences between before and after periods at p < 0.05*

Table 12 and Table 13 present disaggregated site level cycling kit analysis for both Charlotte and Raleigh. In Charlotte, four sites showed an increase in riders wearing cycling-specific clothing aligned with the overall trend for the area (McDowell & 7th, 6th and Graham – 1, 5th and Cedar - 2, and 5th & I-77), while the other two sites showed a decrease in riders wearing cycling-specific clothing. In Raleigh, three of the sites aligned with the area's overall trend, while lower percent of riders at the Morgan St. Parking Deck site were observed in cycling-specific clothing after the SBL installation.

Table 12. Associations between disaggregated before and after cycling kit use data (Raleigh)

Raleigh* - Crabtree & Timber*				
Period	**No**	**Yes**	**n**	***p***
Before	96.52%	3.48%	661	<0.005
After	83.69%	16.31%	840	
***Raleigh* - Lineberry**				
Period	**No**	**Yes**	**n**	***p***
Before	76.47%	23.53%	374	0.089
After	21.86%	78.14%	1098	
***Raleigh* - Morgan & Salisbury**				
Period	**No**	**Yes**	**n**	***p***
Before	83.70%	16.30%	3147	0.312
After	84.55%	15.45%	4532	
Raleigh* - Morgan St Parking Deck*				
Period	**No**	**Yes**	**n**	***p***
Before	95.11%	4.89%	981	0.006
After	97.56%	2.44%	860	

***indicates statistically significant differences between before and after periods at p < 0.05*

Table 13. Associations between disaggregated before and after cycling kit use data (Charlotte)

Charlotte* - McDowell & 7th*				
Period	**No**	**Yes**	**n**	***p***
Before	88.93%	11.07%	1635	0.013
After	86.40%	13.60%	3058	
Charlotte* - 6th & Graham - *1**				
Period	**No**	**Yes**	**n**	***p***
Before	98.90%	1.10%	363	<0.005
After	89.57%	10.43%	1888	
Charlotte* - 6th & Graham - *2**				
Period	**No**	**Yes**	**n**	***p***
Before	82.99%	17.01%	835	<0.005
After	93.18%	6.82%	1702	
Charlotte* - 5th & Cedar - *1**				
Period	**No**	**Yes**	**n**	***p***
Before	85.96%	14.04%	1033	<0.005
After	91.04%	8.96%	1484	
Charlotte* - 5th & Cedar - *2				
Period	**No**	**Yes**	**n**	***p***
Before	92.02%	7.98%	401	0.421
After	90.69%	9.31%	1149	
Charlotte* - 5th & I-77*				
Period	**No**	**Yes**	**n**	***p***
Before	92.48%	7.52%	439	<0.005
After	69.11%	30.89%	518	

***indicates statistically significant differences between before and after periods at p < 0.05*

Likelihood ratio chi-square tests revealed statistically significant differences at p<0.05 between before and after periods at all sites in Charlotte and Raleigh (with the exclusion of Lineberry and Morgan & Salisbury in Raleigh and 5th & Cedar – 2 in Charlotte). A few notable differences observed at site level include:

- Raleigh – *Crabtree & Timber*
  - Cycling kit use increased from 3.48% to 16.31% post SBL installation.
- Raleigh – *Lineberry*
  - Cycling kit use increased from 23.53% to 78.14% post SBL installation.
- Charlotte – *McDowell & 7th*
  - Cycling kit use increased from 11.07% to 13.60% post SBL installation.
- Charlotte – *6th and Graham – 1*
  - Cycling kit use increased from 1.10% to 10.43% post SBL installation
- Charlotte – *5th and Cedar -2*
  - Cycling kit use increased from 7.98% to 9.31% post SBL installation

- Charlotte – *5th & I-77*
    - Cycling kit use increased from 7.52% to 30.89% post SBL installation.

4.5 Usage of Bikeshare or Scooter Share Micromobility

Aggregate ride share data (whether the person was using a bikeshare or scooter share micromobility device (e.g., Lime, B-cycle, Spin, etc.)) across all sites in Raleigh and Charlotte show an increase in ride share use post SBL installations – 4.94% in Charlotte and 4.70% in Raleigh.

Likelihood ratio chi-square tests revealed statistically significant differences between before and after periods for ride share use for both Charlotte – $\chi 2$ (1, N = 22582) = 153.548, p = < 0.005 – and Raleigh – $\chi 2$ (1, N = 12571) = 97.122, p = < 0.005 – as shown in Table 14.

Table 14. Associations between aggregated before and after ride share use data (Raleigh and Charlotte – All sites combined)

Raleigh* - All Sites*				
Period	**No**	**Yes**	**n**	***p***
Before	94.98%	5.02%	5557	<0.005
After	90.28%	9.72%	7014	
Charlotte* - All Sites*				
Period	**No**	**Yes**	**n**	***p***
Before	95.54%	4.46%	6500	<0.005
After	90.60%	9.40%	16082	

***indicates statistically significant differences between before and after periods at p < 0.05*

Table 15 and Table 16 present disaggregated site level ride share use analysis for both Raleigh and Charlotte, which showed consistent trends in increases in ride share use at each site with the exception of 6th and Graham in Charlotte and the Morgan Street Parking Deck in Raleigh.

Likelihood ratio chi-square tests revealed statistically significant differences at p<0.05 between before and after periods at all sites in Charlotte and Raleigh (with the exclusion of Lineberry in Raleigh). A few notable differences observed at site level include:

- Raleigh – *Morgan & Salisbury*
    - Ride share use decreased from 11.49% to 0.11% post SBL installation.
- Raleigh – *Morgan Street Parking Deck*
    - Ride share use increased from 4.54% to 13.66% post SBL installation.
- Charlotte – *6th & Graham – 1*
    - Ride share use decreased from 14.5% to 0.90% post SBL installations
- Charlotte – *5th & Cedar - 2*
    - Ride share use increased from 4.18% to 25.21% post SBL installation.
- Charlotte – *5th & I-77*
    - Ride share use increased from 6.67% to 15.55% post SBL installation.

Table 15. Associations between disaggregated before and after ride share use data (Raleigh)

Raleigh* - Crabtree & Timber*				
Period	**No**	**Yes**	**n**	***p***
Before	99.70%	0.30%	669	<0.005
After	96.96%	3.04%	854	
***Raleigh* - Lineberry**				
Period	**No**	**Yes**	**n**	***p***
Before	100.00%	0.00%	380	0.140
After	98.66%	1.34%	524	
Raleigh* - Morgan & Salisbury*				
Period	**No**	**Yes**	**n**	***p***
Before	88.51%	11.49%	1053	<0.005
After	99.89%	0.11%	887	
Raleigh* - Morgan St Parking Deck*				
Period	**No**	**Yes**	**n**	***p***
Before	95.46%	4.54%	3457	<0.005
After	86.34%	13.66%	4750	

***indicates statistically significant differences between before and after periods at $p < 0.05$*

Table 16. Associations between disaggregated before and after ride share use data (Charlotte)

Charlotte* - McDowell & 7^{th}*				
Period	**No**	**Yes**	**n**	***p***
Before	98.67%	1.33%	1809	<0.005
After	89.17%	10.83%	3934	
Charlotte* - 6th & Graham – *1**				
Period	**No**	**Yes**	**n**	***p***
Before	85.50%	14.50%	855	<0.005
After	99.10%	0.90%	3887	
Charlotte* – 6^{th} & Graham – *2**				
Period	**No**	**Yes**	**n**	***p***
Before	98.40%	1.60%	1316	<0.005
After	93.68%	6.32%	2992	
Charlotte* – 5^{th} & Cedar – *1**				
Period	**No**	**Yes**	**n**	***p***
Before	95.60%	4.40%	1476	<0.005
After	90.39%	9.61%	2529	
Charlotte* – 5^{th} & Cedar – *2**				
Period	**No**	**Yes**	**n**	***p***
Before	95.82%	4.18%	550	<0.005
After	74.79%	25.21%	1995	
Charlotte* - 5th & I-77*				
Period	**No**	**Yes**	**n**	***p***
Before	93.33%	6.67%	495	<0.005
After	84.45%	15.55%	746	

***indicates statistically significant differences between before and after periods at $p < 0.05$*

5 Conclusions

After normalizing the count data, we saw a significant increase in the aggregated number of VRUs traveling through both study areas with almost 10,000 more VRUs observed in Charlotte alone after the SBLs were installed. Without analyzing volume data across the network in each city, it is unclear whether these increases are due to network-wide increases in walking and bicycling activity, or whether they represent an increase primarily on these corridors which now have SBLs. If it is the latter, are these people new VRUs – the "interested but concerned," who now feel comfortable bicycling - or are they people who already were riding elsewhere and modified their routes from the before period to take advantage of the SBLs? Unfortunately, due to impacts from COVID-19, this project was unable to conduct intercept surveys on the SBL users to gain some context and attempt to better understand the changes in volume we observed.

Aggregate interaction data across all sites in Raleigh and Charlotte in both the before and after periods show that the majority of VRUs had no interaction with motorists when traveling through the study sites, or that they successfully negotiated the shared space with other travelers such that avoidance or conflict maneuvers represented a small sample of the observations. Even so, both avoidance and conflict maneuvers significantly decreased post-SBL installation, with the riskier conflict behaviors (e.g., sudden changes in speed or direction such as swerving or hard braking) being almost non-existent in the after period. Similar positive results as measures in safety and operations were found in the aggregated data with helmet usage and prevalence of bikeshare and scooter share usage, which both increased in the after period in both Raleigh and Charlotte. Cycling kit usage showed mixed results with the percentage staying roughly the same in Charlotte but increasing in Raleigh. Again, without being able to conduct the intercept surveys, it is unclear if this increase is due to 'strong and fearless' riders changing their route to use the SBL or if the increase represents new bicyclists and an increase in recreational riders.

Due to insufficient data, two of our hypotheses could not be tested. Attempts to understand changes in motorist yielding could not be analyzed given that very low sample of avoidance and conflict maneuvers observed. Data collected on start and end locations of VRUs as well as descriptions of each maneuver observed also proved difficult to analyze to form any meaningful results on how the SBLs may have impacted VRUs' decisions on where to travel.

At the site-level, some measures stood out that may suggest further investigation is needed for particular sites to determine if the constructed SBL needs further modifications to improve safety performance. The following section summarizes the operational and geometric changes installed with each SBL at each site and how these changes may contribute to the results found through this study.

5.1 Impacts from Raleigh's SBL Designs

Overall, Raleigh's sites gave more nuanced results (see previous Figure 2 for before and after images of the Raleigh sites).

5.1.1 Crabtree Blvd. & Timber Dr.

This bicycle facility was updated from a buffered bike lane to a SBL with green conflict markings in the bicycle crossing and vertical delineators within the buffer of the bike lane. Changes observed in the proportions of different types of interactions between VRUs and drivers after the installation of the SBL at this location included: avoidance maneuvers increasing by 2.1%, conflicts decreasing from 0.73% to zero, and coexist interactions increasing by 20.02%. This may be due to more bicyclists using the facility when vehicle volumes are greater.

Geometric changes that reduced exposure and risk include:

- Installing vertical delineators to enforce the separation of vehicles and bicyclists prior to the intersection; right turning vehicles on Crabtree Boulevard could not merge with the bike lane before turning right onto Timber Street
- Effectively decreasing the turning radius of the right turn, which caused vehicles to decrease speeds during right turning maneuvers
- Adding green conflict markings demarcating the bicycle crossing increased drivers' awareness of bicycle users by improving contrast of the bicycle facility with the surrounding roadway

5.1.2 Lineberry Dr. & Trailwood Hills Dr.

Prior to the installation of the SBL, Lineberry Drive did not have a bicycle facility. The new SBL included horizontal and vertical separation along with green conflict markings for bicycle crossings. Changes observed in the proportions of different types of interactions between VRUs and drivers after the installation of the SBL at this location included avoidance maneuvers increasing by 2.94%, coexist interactions decreasing by 9.13%, and no interactions increasing by 6.19%. No conflict maneuvers were observed in either the before or after period. This was the lowest volume site studied in both the before and after periods, so the increase in avoidance maneuvers may be due to drivers not expecting to see bicyclists due to their infrequent presence.

Geometric changes that reduce exposure and risk include:

- Installing vertical delineators to enforce the separation of vehicles and bicyclists prior to the intersection
- Narrowing the vehicle lane width which can lead to slower vehicle speeds
- Adding green conflict markings demarcating the bicycle crossing increased drivers' awareness of bicycle users by improving contrast of the bicycle facility with the surrounding roadway
- Decreasing the effective turning radius for right turning vehicles so that vehicles travel at slower, safer speeds when they enter the bicycle crossing

Lineberry had the highest proportion of cyclists wearing cycling-specific gear both in the before and after period, with 78.14% of bicyclists observed wearing kit-like clothing after the SBL was installed.

5.1.3 W. Morgan St. & Salisbury St.

The bicycle facility along Morgan Street was updated from a buffered bike lane to a SBL with vertical delineators within the buffer of the bike lane; however, no changes were made just before or after the intersection with Salisbury, where on approach to the intersection the bike lane drops into a shared lane design with a vehicle right-turn-only lane. The bicycle facilities on Salisbury Street already included green conflict markings on the approach to the intersection with W Morgan Street in the before period and no other changes were made to those bicycle lanes. Changes observed in the proportions of different types of interactions between VRUs and drivers after the installation of the SBL at this location included avoidance maneuvers decreasing by 3.74% and conflicts decreasing by 0.88%.

Geometric changes that reduce exposure and risk include:

- Adding green conflict markings demarcating the bicycle crossings, which increased drivers' awareness of bicycle users by improving contrast of the bicycle facility with the surrounding roadway.

5.1.4 Morgan St. & McDowell Parking Deck

Vertical delineators were added to an existing buffer of the buffered bike lane along W Morgan Street to establish an SBL. Changes observed in the proportions of different types of interactions between VRUs and drivers after the installation of the SBL at this location included avoidance maneuvers increasing by 1.99%, conflicts increasing by 0.06%, and no interactions increasing by 11.64%. This site was the only site where fewer VRUs were observed in the after period than the before period, and it was the only site in Raleigh where conflicts increased after the SBL was installed.

Geometric changes that reduce exposure and risk include:

- The implementation of vertical delineators shortened the area where vehicles could execute a right turn into the parking deck which effectively decreased in the turning radius of vehicles crossing the bicycle lane.

This treatment would theoretically prevent more dangerous interactions from occurring; however, since the share of avoidance maneuvers increased (either the VRUs' or drivers' speed or direction changed to avoid encroachment on the other), this likely meant that more drivers were turning right in the parking deck and yielding to VRUs in the bike lane or more VRUs were slowing their speed to avoid a right turning vehicle that failed to yield than during the before period.

The highest percentage of helmet usage was observed at this site in the after period across all the study sites at 57.97% (an increase of 24.13% at this site from the before period).

5.2 Impacts from Charlotte's CycleLink Design

5.2.1 McDowell Street & 7th Street

Prior to the installation of the SBL, no bicycle facilities were present on McDowell Street or 7th Street; bicyclists needed to navigate vehicular traffic without any horizontal separation or vertical protection. (See previous Figure 4 for before and after images of the Charlotte sites.) Bicycle facility improvements studied in the after period included a two-way SBL on McDowell Street and a one-way SBL in the eastbound direction on 7th Street. Changes observed in the proportions of different types of interactions between bicyclists and vehicles after the installation of the SBL at this location included avoidance maneuvers decreasing by 5.4%, conflicts decreasing by 2.41%, coexist interactions also decreasing by 15.07%, and no interactions increasing by 22.89%. This site showed the largest gain in the percentage of no interaction events, which may be due to the unique design features at the southwest corner that was most like a protected intersection.

Geometric changes that reduce exposure and risk include:

- Installing a concrete median between vehicle travel lanes and bicycle lanes which added vertical and horizontal separation between bicyclists and motor vehicles, recessed the bikeway crossing, and increased visibility and awareness of bicyclists for drivers
- Adding a curb island on the southwest corner of the intersection (a corner most like that of a protected intersection) that recesses the bicyclists entering the intersection and effectively decreasing the turning radius for right turning vehicles so that vehicles travel at slower, safer speeds when they enter the bicycle crossing
- Adding green conflict markings demarcating the bicycle crossings, which may increase drivers' awareness of bicycle users by improving contrast of the bicycle facility with the surrounding roadway.

5.2.2 6th Street & Graham Street

No bicycle facilities were present on Graham Street or 6th Street prior to the installation of the SBL; bicyclists needed to navigate vehicular traffic without any horizontal separation or vertical protection.

Geometric changes that reduced exposure and risk include:

- Restructuring the lane configuration to change the previous eastern approach of the intersection from a left turn lane, two through lanes, and a right turn lane to a through and left turn lane, a through lane, and a right turn lane
- Replacing the westbound vehicle right-turn slip lane on the eastern approach of the intersection with a standard right turn lane
- Decreasing the effective turning radius for right turning vehicles so that vehicles travel at slower, safer speeds when they enter the bicycle crossing
- Installing a concrete median between vehicle travel lanes and bicycle lanes, which added vertical and horizontal separation between bicyclists and motor vehicles, recessed the bikeway crossing, and increased visibility and awareness of bicyclists for drivers
- Delineating westbound vehicle lanes within the intersection by dashed lines and bicycle lanes with dashed white and green lines, further separating bicycle from vehicle traffic within the intersection
- Adding green conflict markings demarcating the bicycle crossings at the intersection and through driveways, which increased drivers' awareness of bicycle users by improving contrast of the bicycle facility with the surrounding roadway.

The first site at the intersection (6th and Graham -1) focused on how changes to the east side of the intersection may have impacted safety. Changes observed in the proportions of different types of interactions between VRUs and drivers after the installation of the SBL at this location included avoidance maneuvers decreasing by 4.29 %, conflicts decreasing by 2.46%, and coexist interactions increasing by 26.65%, while no interactions decreased by 19.9%.

The second site, 6th and Graham – 2, focused more on the driveway just west of the intersection proper. Here, changes observed in the proportions of different types of interactions between VRUs and drivers after the installation of the SBL included avoidance maneuvers decreasing by 6.36%, conflicts decreasing by 3.1%, and coexist interactions increasing by 44.85% while no interactions decreased by 35.39%.

The presence of more VRUs at different times of the day and during different levels of vehicular traffic volume after the installation of the bike lanes led to more interactions overall at both sites, but on the whole, these interactions were negotiated more safely by all travelers.

Interestingly, the percentage of riders on bikeshare or scooter share vehicles decreased by 13.67% at the 1st site of 6th Street and Graham Street, which was the only location where this metric decreased after the SBL was installed in Charlotte, while the 2nd site focused more on the driveway saw an increase of this same metric by 4.72%.

5.2.3 5th Street & Cedar Street

Prior to the installation of the SBL, no bicycle facilities were present on Cedar Street or 5th Street; bicyclists needed to navigate vehicular traffic without any horizontal separation or vertical protection.

Major geometric changes to the intersection included:

- Removing the center median on 5th Street on the east approach of the intersection
- Removing an eastbound vehicle through lane

- Installing a concrete median between vehicle travel lanes and bicycle lanes which added vertical and horizontal separation between bicyclists and motor vehicles, recessed the bikeway crossing, and increased visibility and awareness for drivers
- Decreasing the effective turning radius for right-turning vehicles so that vehicles travel at slower, safer speeds when they enter the bicycle crossing.

At the second site of 5th and Cedar street, which focused on the driveway to a parking deck, the major change was the installation of green pavement through the driveway crossing.

Changes observed in the proportions of different types of interactions between VRUs and drivers after the installation of the SBL at the 5th and Cedar -1- site included conflicts increasing by 0.28%, avoidance maneuvers decreasing by 3.2%, and coexist interactions decreasing by 21.29% while No-Interactions increased by 24.22%. This may be due to changes in signal timing that led to bicyclists being in the intersection at different times than motorists and more bicyclists observed during parts of the day when vehicle volumes were lower.

Changes at the 5th and Cedar – 2 site included avoidance maneuvers increasing by 3.45%, conflicts decreasing by 2.32%, and coexist interactions increasing by 8.28% while No-Interactions decreased by 9.41%. This driveway site was the only site in Charlotte where avoidance maneuvers increased. Interestingly, this site also had the highest percentage of ride share users observed across all study sites at 25.21%, which may have an association with the increased percentage of avoidance maneuvers.

5.2.4 5th Street & I-77

Separated bike lanes (SBL) replaced conventional bike lanes—delineated bikeways without vertical or horizontal separation—at the 5th Street crossing of I-77. Changes observed in the proportions of different types of interactions between bicyclists and vehicles after the installation of the SBL at this location included avoidance maneuvers decreasing by 3.48% and conflicts decreasing by 0.16%.

These changes are likely due to several operational and geometric changes implemented in the intersection. Operational changes that formalized and prioritized modal movements included:

- New bicycle signals to separate when bicyclists are moving through the intersection and when left and right turning vehicles are permitted to turn into the bicycle crossing
- A dynamic No Turn on Red sign was added to the westbound approach east of I-77, so drivers are not permitted to enter the bicycle crossing when bicyclists have an exclusive green phase.

Several geometric changes were also implemented in the intersection that reduced exposure and risk for bicyclists. Geometric changes included:

- Adding green conflict markings demarcating the bicycle crossings, which increased drivers' awareness of bicycle users by improving contrast of the bicycle facility with the surrounding roadway
- Installing a concrete median between vehicle travel lanes and bicycle lanes which added vertical and horizontal separation between bicyclists and motorists, recessed the bikeway crossing, and increased visibility and awareness of bicyclists for drivers.

- Removing the right-turn slip lane onto I-77 which decreased the turning radius for right turning vehicles so that motorists are now decelerating and moving at a slower speed when they enter the bicycle crossing.

Three of the four sites where avoidance interactions increased (Crabtree, Lineberry, and Morgan St. Parking Deck in Raleigh) used the same separation style (buffered bike lane with flex post delineators); however, green pavement markings were used across the intersections of Lineberry and Crabtree Blvd. sites but not across the driveway at the Parking Deck, where conflicts also increased. It is unclear why the only other site with similar SBL design in Raleigh, Morgan at Salisbury, performed better, but perhaps it is because of it being a 4-leg intersection with a bike lane also across the secondary street. Travelers may simply be more alert for one another moving through this intersection, or 4-leg intersections in general. The fourth site where avoidance maneuvers increased, 5th and Cedar - 2 in Charlotte, was also a driveway. It is possible that drivers turning into/out of the driveway are not expecting or looking for bicyclists or scooter riders at this location, even with the green pavement used to heighten the visibility of this conflict zone.

6 Implementation & Technology Transfer Plan

Based on the findings from this research, the construction of separated bike lanes appears to improve the safety and operations of streets by potentially increasing bicycling activity, decreasing bicyclist-motorist avoidance maneuvers and conflicts, and potentially attracting a wider population of bicyclists – the “interested but concerned” types to use SBL facilities. The SBLs studied varied in the vertical and horizontal barriers used to separate bicyclists from other travel lanes – some used painted buffers with vertical delineator posts, while others used a raised curb median. Additional design details at intersections or driveways also varied, with some using green pavement markings on approach to a conflict point, through the conflict point, or both, while others used additional features like curb islands to create protected intersection corners. Further research is needed to determine a hierarchy or matrix for when higher-order separating elements would be beneficial when installing a SBL and would likely be based on the motor vehicle volume, bicycle volume, vehicle speeds and frequency of driveways, among other factors. However, in this study, some corridors went from no dedicated bicycle facility at all to an SBL while others converted a standard or buffered bike lane into an SBL, and all conversion types were found to improve safety. The one exception was noted at the Morgan Street site in Raleigh near the McDowell Parking Deck where both avoidance and conflict maneuvers increased after the delineator posts were installed to create a SBL. The study team recommends that green pavement markings be used along the driveway entrance to the parking deck to enhance visibility of this conflict point.

There are several actions that NCDOT could take based on these research findings and within context of the interviews conducted to understand the state of practice with respect to SBLs in North Carolina:

- Support local agencies interested in installing SBLs on state-owned roads through project funding and approvals as a means to build up a series of case studies to continue to demonstrate the potential of SBLs to NCDOT. These can be permanent or quick-build (temporary) types of installations. Per the general guidance found outside of the state, SBLs are more likely to be recommended as a design on roads with higher speeds where bicyclists need physical separation from motorists to mitigate crash risk or severity of injury. Many local jurisdictions are seeking to use this type of bicycle facility as a tool to move toward a complete street specifically on the state-owned roads due to their speed and volume.

- Provide specific design recommendations and direction on typical cross-sections for agencies to use as guidance. At the time of interviews, only two municipalities in North Carolina were developing their own guidance; others are relying on national guides from FHWA or NACTO. NCDOT should consider adopting design information from these national guides and tailoring or customizing them to produce a state-specific guide with more NC-focused examples to display. Both Divisions and municipalities interviewed desire that this guidance include planning-level tools or selection criteria to help determine the most appropriate location for SBLs compared to other bicycle facilities.
- NCDOT should consider developing a maintenance policy related to SBLs on state-owned roads and begin investing in the equipment and supplies needed to maintain them. This may require additional research to investigate life cycle costs related to different types of SBLs (e.g., one-way SBL; two-way cycletrack; type of vertical delineation used; and whether the SBL is at street level, sidewalk level, or somewhere in between) or synthesizing information from other states or agencies for best practices around SBL maintenance and considerations. NCDOT may also need to revisit the cost-sharing structure around its Complete Streets guidance specifically as it pertains to bicycle facilities needed in smaller municipalities or in those with smaller budgets.

Any updates made to NCDOT standards, policies, or practices should be disseminated to others within the Department to ensure uptake in implementation. Local agencies and private consultants who design roadways for proposed projects on state-owned roads should also be notified about any changes in SBL guidance acceptable by NCDOT. The research team recommends that training materials be developed in conjunction with any new guidance published by NCDOT to explain any updates on where SBLs can be installed on state roads; the types of SBLs recommended based on context, roadway characteristics and other factors; and where additional resources may be found.

7 References

[1] Jennifer Dill and Nathan McNeil, "Four Types of Cyclists? Examination of Typology for Better Understanding of Bicycling Behavior and Potential," Transportation Research Record: Journal of the Transportation Research Board, 2387: 129-138, 2013.

[2] Schultheiss, W., Sanders, R., Judelman, B., Boudart, J., Blackburn, L., Brookshire, K., Norback, K., Thomas, L., Van Veen, D., & Embry, M. (2018). Literature Review: Resource Guide for Separating Bicyclists from Traffic. Federal Highway Administration. Report FHWA-SA-18-030. https://safety.fhwa.dot.gov/ped_bike/tools_solve/docs/fhwasa18030.pdf.

[3] FHWA. *Manual on Uniform Traffic Control Devices*. US Department of Transportation, 2009 Edition including revisions through July 2022.

8 Appendices

8.1 Summary of Research and Guidance Related to Separated Bike Lanes

This summary was originally compiled and submitted to NCDOT on December 19, 2019 by Sarah O'Brien, Dan Gelinne, Sarah Brown, and Ethan Sleeman.

8.1.1 Background

This literature review was conducted to provide a foundation of current knowledge and guidance around separated bicycle lanes (SBLs). This phase of information gathering also supports subsequent interviews of practitioners around the State and informs original research to be conducted on these types of bicycle facilities as part of this project. Our goal is to collect and relay the latest information about SBLs to NCDOT to help inform the planning and development of bicycle facilities around the State.

For the purpose of this review and the broader research project, a SBL is defined as a facility for the exclusive use of bicyclists that is separated from motor vehicle traffic by a horizontal buffer and vertical element. They are sometimes referred to by other names, including cycle tracks and protected bicycle lanes.

This review builds upon the FHWA Resource Guide for Separating Bicyclists from Traffic (Schultheiss et al., 2018) which summarizes a wide range of benefits of various bicycle facilities, including SBLs, for road user comfort, operations, safety, and other outcomes based on an extensive review of the literature. With respect to SBLs, specifically, the report documents the following benefits on pages 37-39:

Road User Preferences: Facilities that are physically separated from adjacent travel lanes have the most support among bicyclists (Monsere, McNeil, & Dill, 2012) and some motorists (Sanders, 2014). Mixing zones at intersections are not preferable to dedicated through lanes, according to bicyclist preference (McNeil et al., 2015). Bicyclists tend to also prefer treatments like bike boxes and bicycle signals (Rahimi, Kojima, & Kubota, 2013), which may be commonly used to transition SBLs at intersection locations.

Crash and Injury Risk: Studies show that SBLs reduce the risk of bicyclist crashes and injuries while increasing the number of people bicycling (Goodno, McNeil, Parks and Dock, 2013; Lusk, Morency, Miranda-Moreno, Willett, & Dennerlein, 2013; McNeil, Monsere, & Dill, 2015; Monsere, Foster, McNeil, & Dill, 2015; Monsere et al., 2014; Teschke, et al., 2012).

Safety and Perception at Intersections: Some studies looked at motorist detection of bicyclists at intersections. Bicyclists riding in front of motor vehicles are more readily perceived by drivers than those approaching from the rear, since drivers are focused on multiple other things such as oncoming traffic when approaching intersections (Hurwitz, Jannat, Warner, Monsere, & Razmpa, 2015). Certain intersection treatments, such as deflecting the SBL away from the motor vehicle lane to improve visibility or raising the conflict point (such as a raised crosswalk) to slow turning traffic can reduce the risk of a crash (Reid & Adams, 2010).

SBL Configuration: Studies comparing one-way to two-way SBL configurations showed mixed results, with some finding that one-way SBLs were the safer option (Schepers, Kroeze, Sweers, & Wüst, 2011; Zangenehpour, Strauss, Miranda-Moreno & Saunier, 2016; Thomas & DeRobertis, 2013) while others showed no difference (Harris et al., 2013). On one-way streets, two-way SBLs located to the right of motor vehicle travel lanes were shown to be safer than those located to the left of motor vehicle travel lanes (Jensen, 2008).

The synthesis presented in this report builds upon Schultheiss et al.'s previous work and reflects more current studies assessing the safety and operations of SBLs.

8.1.2 Literature Review Findings

Our research team uncovered 81 studies examining SBLs and the safety of bicyclists that were not included in FHWA's Resource Guide. The search was targeted to specifically identify studies examining the safety and operational performance of SBLs and their associated design treatments along segments and at intersection locations. A total of 31 studies focused on intersections, while another 50 studies were focused on either segments or SBLs more generally. Some of these studies were published since the FHWA literature review was conducted, while others were not reported in depth by that source. After scanning the studies for relevance and quality, 28 were chosen for more detailed review and interpretation. These studies and their findings are summarized below.

General Safety Performance

Summary: **Studies examined in this section reinforce findings from the earlier FHWA literature review that separated bicycle facilities (namely SBLs) reduce the risk of bicyclist crashes and injuries, though numerous factors related to the SBL itself can influence that risk. Factors that may increase the risk of crashes involving bicyclists on SBL corridors include the presence of driveways and other intersections. Few studies have examined the impact of SBL presence on motorist operating speed, though one did demonstrate lower speeds when SBLs were present.**

A research team from the Insurance Institute of Highway Safety (IIHS) examined 604 bicyclist crashes and falls in three cities and explored bicycle facilities and other roadway features at the sites of those events. Researchers identified the location of the collision or fall and used a randomly selected point along the same corridor to serve as a control site. Both were categorized by bicycle facility type and other features, and comparisons were made between the sites of collisions or falls and control sites. Researchers found lower bicyclist crash/fall risk at locations with conventional bike lanes or local streets compared to major roads without bicycle facilities. They found that the bicyclist crash/fall risk on one-way SBLs was not different from major roads without bicycle facilities, though they noted that this risk is dependent on many factors, and one-way SBLs can have reduced risk of crashes or falls if there are less frequent intersections and driveways. Two-way SBLs had a higher risk of a crash or fall compared to major roads when the facility was at street level but a lower risk when the facility was raised from the roadway (Cicchino et al., 2019).

A study using bicyclist injury data from New York City found that physically protected paths reduced injury risk by 23%, whereas shared lane markings (sharrows) were associated with higher moderate, severe, or critical injury risk compared to no bicycle facility. Conventional painted bike lanes were also associated with a reduced risk of injury. Pedestrian exposure was used as a proxy for bicyclist volume in this study (Wall et al., 2016).

Researchers compared the bicyclist injury risk of corridors with and without "cycle track" (or SBL) facilities and found that corridors with separated facilities had a lower injury risk than the comparison sites. They noted that factors influencing the relative risk of a bicycle facility include the configuration (whether it is bidirectional), bicyclist visibility, type of physical separation, and other factors (Nosal & Miranda-Moreno, 2012).

Two studies looked specifically at SBLs and on-street parking. A review of studies related to bicycle-involved crashes with parked motor vehicles (primarily "dooring" crashes) noted that SBL designs that integrate a buffer between the bicyclist position and parked vehicles removes the bicyclist from the zone where an open door can be a collision hazard (Schimek, 2018). Another study examined common conflicts that arise between motor vehicle and bicycle traffic and attributed those conflicts to the volumes of motorist and bicyclist traffic as well as the widths of the bicycle lane. These conflicts were shown to increase delay along corridors, which may influence the design of bicycle lanes and to what degree bicycle facilities should be separated from motor vehicle traffic (Chen, Wang, & Jiang, 2018).

Though speed can be used as a proxy for safety performance, few studies explicitly examined the impact of SBLs on motor vehicle speed. One research team did find that the average speed of motorists along a corridor was reduced by the presence of bicyclists (33.69 mph compared to 35.12 mph) and SBLs (33.9 mph compared to 34.9 mph) (Christofa, Knodler, & Deliali, 2019).

A review of case studies by Utah DOT found that drivers along corridors with SBLs provided more space when passing bicyclists and were less likely to encroach into bicycle lanes when compared with other bicycle facility types (Burbridge & Shea, 2018).

Safety at Intersections

Summary: **Clear benefits have been demonstrated for fully or partially protected intersection maneuvers featuring through bike lanes and elements of protected intersection designs (see Figure 1).** M**ixing zone treatments can be effective in providing safer intersection maneuvers where SBLs meet intersections, though these treatment packages can vary widely in their implementation. More work can be done to examine the safety performance of protected intersection designs, which are relatively new in the U.S.**

Using simulators, one research team sought to understand how right-turning motorists behaved at intersections and how they detected bicyclists in a number of different intersection configurations using both traditional bike lanes and SBLs. They found that bicyclist presence along the corridor resulted in reduced speeds at intersections and a higher likelihood that motorists would glance for bicyclists, no matter which intersection treatment was present (traditional mixing zone or protected intersection). When SBLs were present on the corridor, they found motorists were less likely to glance for bicyclists when approaching the intersection than when conventional bike lanes were present (Christofa, Knodler, & Deliali, 2019). In a related paper, the researchers noted that intersection geometry features such as larger corner islands, curb extensions, and smaller intersection radii led to reduced motorist turning speeds. They also noted that bicyclist presence was a significant factor in reducing the speeds of right-turning motorists (from 16.7 mph to 14.8 mph), while pavement markings reduced approach speeds (from 26.6 mph to 25.9 mph) but not turning speeds (Christofa, Knodler, Deliali, & Campbell, 2019).

Figure 9. Example of a protected intersection design (Chicago Department of Transportation)

A research team from New York City Department of Transportation (NYCDOT) assessed the impact of their bicycle infrastructure changes through an analysis of crash data and a review of coded video data at nine intersections. Overall, they found that application of mixing zone treatments and fully split signal phases reduced bicyclist crash rate at intersections by 30% when installed as part of a SBL project. Mixing zones are combinations of pavement markings and signs that delineate conflict zones and define through movements for both bicyclists and motor vehicles (see Figure 2). The study included pilot designs, such as the delayed turn and off-set crossing (similar to a protected intersection design), but researchers did not find conclusive results about these treatments (Sundstrom et al., 2018).

Figure 10. Mixing zone treatment used by New York City DOT (Sundstrom et al., 2018)

Another paper examining the safety performance of bicycle treatments at New York City intersections demonstrated that mixing zones and fully split phases showed similar benefits where turning volumes were low, while shorter mixing zones performed better at locations with high turning volumes. The fully split phase performed better at locations where the cross-street was wider (Sundstrom, Quinn, & Weld, 2019).

Various signal phasing methods were tested by researchers from Portland State University and Northern Arizona University. They looked at the impacts of concurrent phasing, leading bicycle intervals (LBI), split LBI, and exclusive bicycle phasing and noted their impacts on both operations and conflicts (using post encroachment time). The split LBI was shown to be successful in reducing conflicts during the protected portion of the phase, while results were mixed for the other methods (Kothuri et al., 2018).

When comparing the safety performance of mixing zone treatments to clearly-demarcated turning zones with a through bike lane, researchers from Portland State University found clear benefits to the restricted-entry, semi-protected through bike lane when compared to the mixing zone alternative (Monsere et al., 2015).

A traffic conflict study compared five intersection designs ranging from mixing zones to "recessed bicycle tracks" (see Figure 3), or those that resemble protected intersection crossings where bicyclist crossings are bent outward and track along the pedestrian crosswalk at intersections. After observing maneuvers and conflicts at the various intersection designs, they found that the recessed bicycle track design offered the highest level of safety for bicyclists (Madsen & Lahrmann, 2017).

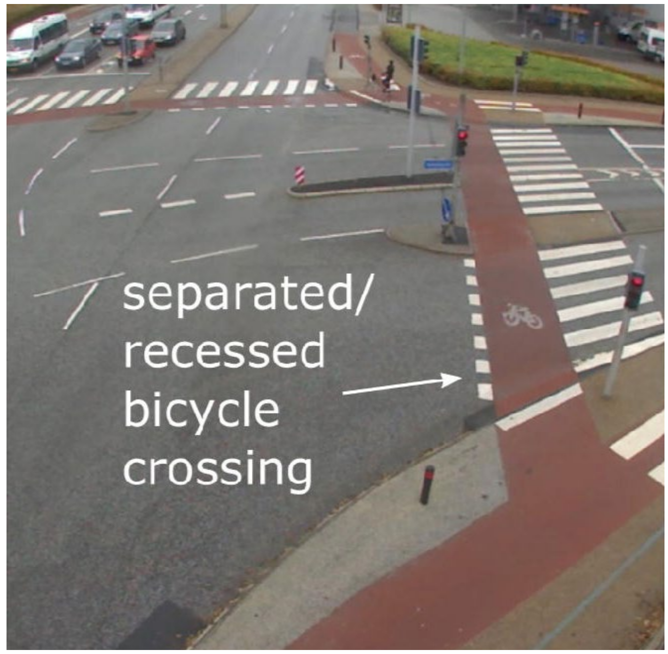


Figure 11. Recessed bicycle crossing (Madsen & Lahrmann, 2017)

One study examined the behavior of bicyclists at intersections featuring bi-directional SBLs. Using the Desire Lines Analysis tool, researchers observed that nearly three quarters of users "followed the prescribed routes of the street design through each intersection." Maneuvers by the remaining bicyclists resulted in observed conflicts that were categorized by the researchers as "counterflow interaction," "priority confusion," and "directional awareness," which describe the context for bicyclists' decisions and offer considerations for these designs (Wexler & El-Geneidy, 2017).

Operations

Summary: **Few studies directly examined the relationship between SBL presence with operational performance for motor vehicles. This is a potential area for future research.**

One study used the Network Robustness Index (NRI) methodology to identify suitable candidates for SBLs on urban streets and measure travel-time impacts of their implementation. They specifically examined the impact of removing a motor vehicle travel lane across the street network of Toronto to identify the most suitable corridors for SBL development. They found that the total estimated travel-time impact of installing a SBL was roughly three to five seconds per motor vehicle trip (using an average trip distance), and this was dependent on a number of factors including SBL configuration (Burke & Scott, 2018).

Another study examined capacity of SBLs for bicycle traffic. Researchers coded video data at one-way SBLs of different widths to assess bicyclist speed, volume and overall capacity of bicycle traffic. One-way SBLs narrower in width and those adjacent to vehicle parking have reduced "effective width" for bicyclist operation. Even in high traffic conditions, which were typically short in duration, observed capacity of the SBL was not reached or exceeded. Increased bicyclist volume did not impact average bicyclist speeds (Greibe & Buch, 2016).

One study did find that a SBL project in Boulder, CO, did increase motorist travel times from an average of 3 minutes and 20 seconds to an average of 5 minutes and 36 seconds. Though it was subsequently removed, the formal evaluation showed a 60% increase in bicyclist volumes and a 40% reduction in collisions, along with daily vehicle speed reductions of 3 miles per hour (Burbridge & Shea, 2018).

A study by Northeastern University compared signal phasing options that allow pedestrians and bicyclists to cross in the same phase while holding right-turning vehicles. This "protected yet concurrent" phasing is intended to reduce conflicts between turning vehicles and the crossing pedestrians and bicyclists. This phasing was shown to result in "modest" delays for motorists but resulted in fewer delays than an alternative all-pedestrian phase option. The phasing does require right-turn lanes, which may influence how the bicycle lane and intersection. treatment for bicyclists can be configured (Furth, Koonce, Miao, Peng, & Littman, 2014).

A study examined operational impacts of various bicycle-oriented signal phasing improvements at intersections, including concurrent phasing, leading bicycle intervals (LBI), split LBI, and exclusive bicycle phasing. The team reported increased delays from all of these except the concurrent phasing, yet (as noted later in this review) the LBI and split LBI led to reductions in conflicts between bicyclists and motor vehicles (Kothuri et al., 2018).

Bicyclist Volumes and "Safety in Numbers"

In addition to studies presented previously and cited in the FHWA literature review, some more recent studies looked broadly at connections between expanding separated bicycle infrastructure, increases in bicycling, and safety outcomes. An assessment of crash data in 12 major U.S. cities found an association between the prevalence of SBLs and positive safety outcomes for all road users, not just bicyclists (Marshall & Ferenchak, 2019). A case study of Seville, Spain, revealed a relationship between SBL network development and the number of bicyclists. The researchers found a "safety in numbers" effect in reducing overall risk by expanding SBL networks and drawing more bicyclists, determining that connecting these networks has a positive effect on the safety of bicyclists (Marqués & Hernández-Herrador, 2017).

User Preferences and Safety Perception

Summary: **SBLs tend to be the preferred bicycle facility by both bicyclists and motorists when compared to other types, though the specific facility type preference and safety perception of those facilities can vary between different types of bicyclists. Bicyclists tend to feel more comfortable using intersection treatments that offer more protection and separation (e.g., protected intersection designs, fully separated signal phases), but the particulars of mixing zone treatment packages and the type of bicyclist being considered can reveal a range of preferences and comfort levels.**

A survey of Michigan residents explored safety perceptions and attitudes toward bicycling, with a focus on roadway design preferences. The research team found strong preference for bicycle facilities that are separated from the roadway by a physical barrier, especially when respondents were asked about bicycling with children. Likewise, respondents were more comfortable driving a motor vehicle with greater separation from bicyclists, suggesting a motorist preference for SBLs (Sanders & Judelman, 2018).

A survey of bicyclists and motorists in the San Francisco Bay area revealed a shared preference for SBLs among both groups, when compared to other types of bicycle facilities. Researchers noted that focus group and survey feedback identified a "desire for greater predictability"). By contrast, shared lanes and other shared spaces were unpopular and seen by potential cyclists as a barrier to riding (Sanders, 2016).

Using bicyclist-mounted video footage and survey responses, researchers from Portland State University assessed factors influencing bicyclist comfort to develop a level-of-service model for SBLs. Bicyclists tended to prefer one-way SBLs over two-way configurations, and there were clear preferences of vertical separator (e.g., planters preferred over parked vehicles). Traffic volume and roadway conditions contributed to the perception of safety and comfort for bicyclists (Foster, Monsere, Dill, & Clifton, 2015).

Building on previous efforts to assess road user perception of bicycle facilities, a research team used surveys to better understand how different roadway design features – including intersection design treatments and bicycle lane types – were perceived by different categories of bicyclists. Their findings were wide-ranging, but in general they found that certain bicycle facilities and related design treatments only affected the perceived safety of regular and potential bicyclists, not the perceived safety of non-bicycling motorists, pedestrians, or transit users (Wang & Akar, 2018).

A research team in London interviewed bicyclists involved in "near miss" incidents, compiling their feedback and the factors influencing the degree of fear felt by the person involved. Among the factors examined, researchers found that separated facilities were less commonly cited in these near-miss incidents, especially those resulting in feelings of pronounced fear by the bicyclist involved. In their conclusions, the researchers cited "good quality separated cycling infrastructure" as a popular intervention for reducing these near-miss events (Aldred, 2016).

Another paper examined the link between safety perception and near-miss incidents, offering insight into particular factors more worrisome to bicyclists than others. These factors, the author noted, impact both regular bicyclists and those who may choose to ride and can be compounded by near-miss events and crash involvement. SBLs were identified in the conclusion as a potential countermeasure for reducing both the real and perceived threat of being struck by a motor vehicle (Sanders, 2015).

The previously mentioned analysis by NYCDOT also included intercept surveys to assess the comfort of bicyclists with respect to various intersection design treatments. They found that their offset crossing (Figure 4), which is similar to the protected intersection design, had the highest levels of user comfort with 93% of bicyclists feeling safe riding through them. By comparison, the more traditional mixing zone treatments were perceived as safe by 65% of bicyclists who took the survey (Sundstrom et al., 2018).

Figure 12. Offset crossing design used by New York City DOT (Sundstrom et al., 2018)

8.1.3 Planning and Design Guidance

Our review also sought to capture the landscape of SBL planning and design guidelines available from Federal, State and other sources. The section below provides a current look at these available tools and provides some detail about the relevance and applicability of each. At the time of this writing, the forthcoming edition of the *AASHTO Guide for the Development of Bicycle Facilities* is under development, but not yet published.

Federal Guidelines and Resources

- Bikeway Selection Guide (Federal Highway Administration)

The prior FHWA literature review laid the groundwork for the FHWA Bikeway Selection Guide, which became one of the most current resources for choosing the most appropriate bikeway type given a number of roadways, traffic, and land use considerations. While not a design guide, it offers planners and engineers a framework for choosing bike facilities based on traffic volume, speed, and other considerations.

- Separated Bike Lane Planning and Design Guide (Federal Highway Administration)

The FHWA Separated Bike Lane Planning and Design guide offered companion guidance to the already-released fourth edition of AASHTO Guide for the Development of Bicycle Facilities. The guide contains design recommendations for both corridors and intersection locations, and helps agencies consider the particulars of these designs with respect to driveway locations, transit stops, and other facilities.

- Bicycle Facilities and the Manual on Uniform Traffic Control Devices

Though not specific to SBLs alone, this page from FHWA catalogs elements of SBLs and mixing zone treatments that are commonly used when these facilities cross at intersections. The intent is to share recommendations for compliant and interim approved devices that may be used in conjunction with other bicycle facilities, as laid out in the MUTCD. (**https://www.fhwa.dot.gov/environment/bicycle_pedestrian/guidance/mutcd/**)

Other National Guidelines and Resources

- Protected Bikeways Practitioner Guide (Institute of Transportation Engineers)

This manual is a compilation of critical design standards and guidelines related to SBL development, applicable to practice in the U.S. and Canada. Like other non-Federal resources, it does not create new design standards but serves as a user-friendly cross-reference for existing design parameters offered by AASHTO, the MUTCD, FHWA, and other authorities. (https://ecommerce.ite.org/IMIS/ItemDetail?iProductCode=IR-144&Category=PUB&WebsiteKey=d5326f96-5db7-43ca-89dc-c6ef0daae20e)

- Urban Bikeway Design Guide (National Association of City Transportation Officials)

The NACTO Urban Bikeway Design Guide offers recommendations for integrating bicycle facilities, including separated facilities, into an urban context. It reflects practices from US cities and includes cross-references to other design manuals and resources available from Federal and other sources. (**https://nacto.org/publication/urban-bikeway-design-guide/**)

- Don’t Give Up at the Intersection (National Association of City Transportation Officials)

A companion resource to their Urban Bikeway Design Guide, this document focuses on how best to handle bicycle facilities at intersections in a way that safely and comfortable manages bicyclist through movements and turns while reducing conflicts. It does not establish new design standards, but outlines packages of treatments and references design sources relating to each one. (**https://nacto.org/wp-content/uploads/2019/05/NACTO_Dont-Give-Up-at-the-Intersection.pdf**)

Other Agency Guidance

- Separated Bike Lane Planning and Design Guide (Massachusetts Department of Transportation)

Massachusetts was the first State to develop and adopt a design manual specifically around SBLs. It was released shortly after FHWA’s guide of the same name was published and contains both planning recommendations and detailed design specifications for separated facilities and intersection treatments. (**https://www.mass.gov/lists/separated-bike-lane-planning-design-guide**)

- Design Manual for Bicycle Traffic (CROW)

This Dutch design manual served as the precursor to many of the subsequent guides for bicycle facility design in other parts of Europe and U.S. cities, including the NACTO manuals. Its update in 2017 reflected changes to designs and newer treatments, many of which can inform U.S. practice. (**http://www.crow.nl/publicaties/design-manual-for-bicycle-traffic**)

- Cycle Network and Route Planning Guide (New Zealand Land Transport Safety Authority)

This manual from New Zealand tracks closely with the framework laid out in the FHWA Bikeway Selection Guide, offering pointers and recommendations for developing bicycle route networks and selecting appropriate facilities. Like the FHWA guide, it serves primarily as a planning tool rather than a detailed design reference. (**https://www.nzta.govt.nz/assets/resources/cycle-network-and-route-planning/docs/cycle-network-and-route-planning.pdf**)

- Geometric Design Guide for Canadian Roads (Transportation Association of Canada)

Chapter 5 of this manual covers Bicycle Integrated Design, and places focus on the less-confident bicyclist. It includes detailed design specifications for bicycle facilities, though it does not offer a framework for selecting bikeways or planning bicycle networks. (**https://www.tac-atc.ca/en/publications-and-resources/geometric-design-guide-canadian-roads**)

8.1.4 References

Abdul Rahmi, A.R., Kojima, A. & Kubota, H. (2013). Experimental research on bicycle safety measures at signalized intersections. *Journal of the Eastern Asia Society for Transportation Studies, 10*, 1426-1445. doi:10.11175/easts.10.1426

Aldred, R. (2016). Cycling near misses: Their frequency, impact, and prevention. *Transportation Research Part A, 90*, 69-83. doi:10.1016/j.tra.2016.04.016

Burbridge, S.K. & Shea, M. S. (2018). Measuring Systemic Impacts of bike Infrastructure Projects [Government Report]. *Utah Department of Transportation Research Division*. Retrieved from https://www.udot.utah.gov/main/uconowner.gf?n=2404180664921364

Burke, C. M., & Scott, D. M. (2018). Identifying "sensible locations" for separated bike lanes on a congested urban road network: A Toronto case study. *The Professional Geographer, 70*(4), 541-551. doi:10.1080/00330124.2018.1455518

Chen, J., Li, Z., Wang, W., & Jiang, H. (2018). Evaluating bicycle–vehicle conflicts and delays on urban streets with bike lane and on-street parking. *Transportation Letters, 10*(1), 1-11. doi:10.1080/19427867.2016.1207365

Christofa, E., Knodler Jr. M., & Deliali, A. (2019). Using Simulation to Assess Conflicts Between Bicyclists and Right-Turning Vehicles. Harvard Dataverse, V1. https://doi.org/10.7910/DVN/9LNBUB

Christofa, Eleni; Knodler Jr., Michael; Deliali, Aikaterini; Campbell, Nicholas. (2019). Dissecting the Safety Benefits of Protected Intersection Design Features. *Harvard Dataverse*. https://doi.org/10.7910/DVN/4CNELH

Cicchino, J.B., M. L. McCarthy, C. D. Newgard, S.P. Wall, C.J. DiMaggio, P.E. Kulie, B.N. Arnold and D. S. Zuby. (2019). Not all protected bike lanes are the same: infrastructure and risk of cyclist collisions and falls leading to emergency department visits in three U.S. cities. *Insurance Institute for Highway Safety.*

Foster, N., Monsere, C. M., Dill, J., & Clifton, K. (2015). Level-of-service model for protected bike lanes. *Transportation Research Record, 2520*(2520), 90-99. doi:10.3141/2520-11

Furth, P. G., Koonce, P. J., Miao, Y., Peng, F., & Littman, M. (2014). Mitigating right-turn conflict with protected yet concurrent phasing for cycle track and pedestrian crossings. *Transportation Research Record: Journal of the Transportation Research Board, 2438*, 81-88. doi:10.3141/2438-09

Greibe, P., & Buch, T. S. (2016). Capacity and behaviour on one-way cycle tracks of different widths. *Transportation Research Procedia, 15*, 122-136. doi:10.1016/j.trpro.2016.06.011

Goodno, M., McNeil, N., Parks, J., & Dock, S. (2013). Evaluation of Innovative Bicycle Facilities in Washington, DC: Pennsylvania Avenue Median Lanes and 15th Street Separated Bike Lane. Transportation Research Record 2387, pp.139-148.

Harris, M. A., Reynolds, C. C. O., Winters, M., Cripton, P. A., Shen, H., Chipman, M. L., Teschke, K. (2013). Comparing the effects of infrastructure on bicycling injury at intersections and non-intersections using a case–crossover design. *Injury Prevention, 19*(5), 303-310. doi:10.1136/injuryprev-2012-040561

Hurwitz, D., Jannat, M., Warner, J., Monsere, C., and Razmpa A. (2015). Towards Effective Design Treatment for Right Turns at Intersections with Bicycle Traffic. FHWA-OR-RD-16-06.

Jensen, S.U. (2008). Bicycle Tracks and Lanes: A Before-and-After Study. *Transportation Research Board 87th Annual Meeting Compendium of Papers DVD.* Retrieved from https://trid.trb.org/view/848364

Kothuri, S., Kading, A., Schrope, A., White, K., Smaglik, E., Aguilar, C., & Gil, W. (2018). Addressing Bicycle-Vehicle Conflicts with Alternate Signal Control Strategies [Research Report]. *Portland, OR: Transportation Research and Education Center (TREC),* NITC-RR-897. https://dx.doi.org/10.15760/trec.194

Lusk, A., Furth, P., Morency, P., Miranda-Moreno, L.F., Willett, W.C., & Dennerlein, J.T. (2011). Risk of Injury for Bicycling on Separated Bike Lanes Versus in the Street. Injury Prevention: 17, pp. 131-135.

Lusk, A.C., Morency, P., Miranda-Moreno, L.F., Willett, W.C., and Dennerlein, J.T. (2013). Bicycle Guidelines and Crash Rates on Separated bike lanes in the United States. American Journal of Public Health, 103 (7), 1240-1248.

Madsen, T. K. O., & Lahrmann, H. (2017). Comparison of five bicycle facility designs in signalized intersections using traffic conflict studies. *Transportation Research Part F: Psychology and Behaviour, 46*, 438-450. doi:10.1016/j.trf.2016.05.008

Marqués, R., & Hernández-Herrador, V. (2017). On the effect of networks of cycle-tracks on the risk of cycling. the case of Seville. *Accident Analysis and Prevention, 102*, 181-190. doi:10.1016/j.aap.2017.03.004

Marshall, W. E., & Ferenchak, N. N. (2019). Why cities with high bicycling rates are safer for all road users. *Journal of Transport & Health, 13*, 100539-301. doi:10.1016/j.jth.2019.03.004

McNeil, N., Monsere, C.M., & Dill, J. (2015). The Influence of Bike Lane Buffer Types on Perceived Comfort and Safety of Bicyclists and Potential Bicyclist. *Portland State University Civil and Environmental Engineering Faculty Publications and Presentations, 221*. Retrieved from https://pdxscholar.library.pdx.edu/cengin_fac/221

Monsere, C., McNeil, N., & Dill, J. (2012). Multiuser Perspectives on Separated, On-street Bicycle Infrastructure. Transportation Research Record 2314, pp .22-30.

Monsere, C., Dill, J., McNeil, N., Clifton, K., Foster, N., Goddard, T., Berkow, M., Gilpin, J., Voros, K., van Hengel, D., & Parks, J. (2014). Lessons from the Green Lanes: Evaluating Protected Bike Lanes in the U.S. National Institute for Transportation and Communities, Portland, OR.

Monsere, C. M., Foster, N., Dill, J., & McNeil, N. (2015). User behavior and perceptions at intersections with turning and mixing zones on protected bike lanes. *Transportation Research Record, 2520*(2520), 112-122. doi:10.3141/2520-13

Nosal, T. & Miranda-Moreno, L. (2012). Cycle-Tracks, Bicycle Lanes, and On-street Cycling in Montreal, Canada: A Preliminary Comparison of the Cyclist Injury Risk.

Rahimi, A., Kojima, A., and Kubota, H. (2013). Experimental Research on Bicycle Safety Measures at Signalized Intersections. Journal of the Eastern Asia Society for Transportation Studies: 10, pp. 1426-1445.

Reid, S. & Adams, S. (2010). Infrastructure and cyclist safety. Published Project Report PPR580. Transport Research Laboratory. https://pdfs.semanticscholar.org/d79a/9652090ea0397bdb5a66dabaf43f6073094f.pdf

Sanders, R. L. (2014). Roadway Design Preferences Among Drivers and Bicyclists in the Bay Area. Paper presented at the 93rd Annual Meeting of the Transportation Research Board, Washington, DC

Sanders, R. L. (2015). Perceived traffic risk for cyclists: The impact of near miss and collision experiences. *Accident Analysis and Prevention, 75*, 26-34. doi:10.1016/j.aap.2014.11.004

Sanders, R. L. (2016). We can all get along: The alignment of driver and bicyclist roadway design preferences in the San Francisco Bay area. *Transportation Research Part A, 91*, 120-133. doi:10.1016/j.tra.2016.06.002

Sanders, R. L., & Judelman, B. (2018). Perceived safety and separated bike lanes in the midwest: Results from a roadway design survey in Michigan. *Transportation Research Record, 2672*(36), 1-11. doi:10.1177/0361198118758395

Schepers, J. P., Kroeze, P. A., Sweers, W., & Wüst, J. C. (2011). Road factors and bicycle–motor vehicle crashes at unsignalized priority intersections. *Accident Analysis and Prevention, 43*(3), 853-861. doi:10.1016/j.aap.2010.11.005

Schimek, P. (2018). Bike lanes next to on-street parallel parking. *Accident Analysis and Prevention, 120*, 74-82. doi:10.1016/j.aap.2018.08.002

Schultheiss, W., Sanders, R., Judelman, B., Boudart, J., Blackburn, L., Brookshire, K., Nordback, K., Thomas, L., Van Veen, D., & Embry, M. (2018). Literature Review: Resource Guide for Separating Bicyclists from Traffic. Federal Highway Administration. Report FHWA-SA-18-030. https://safety.fhwa.dot.gov/ped_bike/tools_solve/docs/fhwasa18030.pdf

Sundstrom, C. A., Quinn, S. M., & Weld, R. (2019). Bicyclist crash comparison of mixing zone and fully split phase signal treatments at intersections with protected bicycle lanes in New York City. *Transportation Research Record: Journal of the Transportation Research Board, 0361*(1981). doi:10.1177/0361198119859301

Sundstrom, C., Quinn, S., Wright, T., Friedman, A., Kennedy, P., Carey, N & Wyche, Z. (2018). Cycling at a Crossroads: The Design Future of New York City Intersections [Government Report]. *New York City Department of Transportation*. Retrieved from http://home.nyc.gov/html/dot/downloads/pdf/cycling-at-a-crossroads-2018.pdf

Teschke, K., Harris, M.A., Reynolds, C.C.O., Winters, M., Babul, S., Chipman, M., Cusimano, M.D., Brubacher, J.R., Hunte, G., Friedman, S.M., Monro, M., Shen, H., Vernich, L., & Cripton, P.A. (2012). Route Infrastructure and the Risk of Injuries to Bicyclists: A Case-Crossover Study. American Journal of Public Health 102, 2336_2343, https://doi.org/10.2105/AJPH.2012.300762

Thomas, B., & DeRobertis, M. (2013). The safety of urban cycle tracks: A review of the literature. *Accident Analysis and Prevention, 52*, 219-227. doi:10.1016/j.aap.2012.12.017

Wachtel, A., & Lewiston, D. (1994). Risk factors for bicycle-motor vehicle collisions at intersections. ITE Journal, 64(9), 30-35.

Wall, S. P., Lee, D. C., Frangos, S. G., Sethi, M., Heyer, J. H., Ayoung-Chee, P., & DiMaggio, C. J. (2016). The effect of sharrows, painted bicycle lanes and physically protected paths on the severity of bicycle injuries caused by motor vehicles. Safety, 2, 26. doi:10.3390/safety2040026

Wang, K., & Akar, G. (2018). The perceptions of bicycling intersection safety by four types of bicyclists. *Transportation Research Part F: Psychology and Behaviour, 59*, 67-80. doi:10.1016/j.trf.2018.08.014

Wexler, M. S., & El-Geneidy, A. (2017). Keep ’Em separated: Desire lines analysis of bidirectional cycle tracks in Montreal, Canada. *Transportation Research Record, 2662*(1), 102-115. doi:10.3141/2662-12

Zangenehpour, S., Strauss, J., Miranda-Moreno, L. F., & Saunier, N. (2016). Are signalized intersections with cycle tracks safer? A case–control study based on automated surrogate safety analysis using video data. *Accident Analysis and Prevention, 86*, 161-172. doi:10.1016/j.aap.2015.10.025

8.2 Summary of North Carolina State of the Practice

The following contents were originally reported to NCDOT on May 1, 2020, by Ethan Sleeman, Dan Gelinne, and Sarah O'Brien as parts of the "North Carolina Experience with Separated Bike Lanes: Interview Summary and Findings" technical brief.

8.2.1 SBLs in NC Bike Plans

Separated bike lanes are a relatively new phenomenon in North Carolina, and there are few examples of in-the-ground projects to serve as reference points. However, a number of municipalities have specifically included recommendations for separated bicycle facilities in their bicycle plans. We reviewed bike plans for local and regional agencies across the state to find instances of SBLs either as a recommended treatment for a specific corridor or a general mention of the facility type. The following communities make explicit recommendations for SBLs in their bike plans: Raleigh, Charlotte, Durham, Lenoir, Hendersonville, Black Mountain, Transylvania County, Rocky Mount, Fayetteville (still in draft form), and Carrboro (still in draft form).

Several other municipalities (including Asheville, Apex, Wilmington, Cramerton, Mount Holly, Cape Fear COG, and Cornelius) discuss SBL facilities in their plans, but for various reasons do not recommend them for near-term implementation. Among the reasons noted is that many smaller communities do not have sufficient right-of-way or excess capacity to install SBLs and also maintain a reasonable level of service for motor vehicle traffic. A number of municipalities and counties are in the process of developing or updating their bike plans, and initial documents from the planning processes suggests that SBLs are a part of the discussion (see Carrboro and Fayetteville as examples).

Finally, a number of municipalities including Chapel Hill, Elizabethtown, and many others (especially those with plans older than five years) frequently conflate the terms "buffered bike lane," "separated bike lane," and "cyclepath." Sometimes these terms are in reference to SBLs as currently understood, but at other times the plans refer to a range of different facility types. The confusion around what constitutes an SBL, especially in older documents, points to the need for unified guidance on these facilities, from both national and more local sources.

8.2.2 Existing SBLs in North Carolina

We asked agencies about whether they had SBLs on the ground and in operation in their communities. There are not many of these projects in North Carolina yet, but we did identify several existing facilities. The following is a list of existing SBL projects that were determined through our interview and preliminary research efforts.[1]

- **East Main Street - Durham**
- **Uptown Cycle Track (5th and 6th Streets) - Charlotte**

[1] It is noteworthy that there are also five SBL projects slated for construction in 2020, nearly doubling the total number of SBL projects.

- **10th/12th/McDowell Connector - Charlotte**
- **The Plaza Street Conversion – Charlotte**
- **North Green Street (NC 181) - Morganton**
- **Atlantic Avenue - Kinston**
- **Eastwood Dr. - Cramerton**

We also encountered a number of projects in various phases of the planning process, from projects that were purely conceptual to projects that are well into the advanced design phase. These SBL projects are predominately located in major cities (Charlotte and Raleigh in particular), but the projects that are proposed vary widely in scale, design, and location. How SBLs are characterized or defined also varies, with some referring to "cycletracks," "cyclepaths," or "separated bike lanes."

8.2.3 Interview Materials

Outreach Email to initiate Interview

Hi __________,

I'm part of a team at the UNC Highway Safety Research Center (HSRC) working with NCDOT on an assessment of Separated Bicycle Lane projects in North Carolina. We're interested in talking with agencies around the State about their experiences planning and developing these types of bicycle facilities, highlighting both success stories and common challenges.

I was hoping to find a time when we can talk on the phone and learn more about ____________'s experience with these types of projects. Can you help us identify the person in your agency to talk with?

Thank you,

(Team Member)

Interview Questions

The following questions would be used to guide our interview. If other topics come up during the interview that are relevant, we would make notes of those and follow up on related threads during or after the calls.

- *Do you have any existing SBLs?*
    - Yes
        - *Project location (street and termini)*
    - No – planned
        - *Project location (street and termini)*
        - *When is construction expected to begin / end?*
        - *What is motivation for project?*
            - *Why bike facility at all?*
            - *Why SBL specifically?*

If agency has more than one SBL existing or planned, answer following questions for each SBL:

- *How did you decide to prioritize an SBL as the chosen bicycle facility? What tradeoffs were considered?*
- *Which design resource(s) did you use to prepare the plans for your project?*
    - List likely sources
    - List "other" to record something else
- *What were some of the most challenging planning and design problems you encountered during this project?*
    - *Could this include public involvement aspects? ROW constraints? Driveway/access management?*
    - *Do we mean engineering-operations-design related aspects only?*
- *Who owns the corridor where the project was implemented (or is being implemented)? Does the corridor include locations where local and State routes intersect?*
- *What resources or tools would have made the project more successful?*

If agency has not been able to develop any SBLs, shift to these questions?

- *Have you tried to plan or develop SBL projects in the past?*
- *If past projects have been unsuccessful, what would you identify as the barriers or challenges to getting those off the ground?*
- *Do you plan to pursue SBLs on other streets in your jurisdiction?*

If we determine the agency has forthcoming or planned SBL project, we will gather the following additional details (to help us determine which projects can be included in our evaluation).

- *Type of separation from road and from sidewalk*
- *Direction of bicyclists – 2-way, same side; 2-way opposite sides; 1-way*
- *Protected intersections?*
- *What type of bicycle facility, if any, does the SBL connect to?*
- *What are the goals for this project (e.g., increase bicycling, improve safety, improve operations)?*

8.2.4 Completed Interviews

Raleigh, January 23, 2020

The interview question format was slightly different for the interview with the municipality of Raleigh, for various reasons. The Raleigh conversation focused in on a number of current and future projects w/ SBL components and the challenges/opportunities Raleigh has found in planning and implementing these types of facilities.

- Question Prompts

Can you help us identify all of the SBL projects Raleigh is working on right now (those that are moving toward implementation, not just everything in their plans)?

Guiding questions for the conversation:

- **For the projects identified, ask them:** Have you run into any coordination issues with other agencies (e.g., NCDOT) on the intersection work?
- Is there any data you've collected already that we could use for our project?
- What's your current timeline for construction?
- Can you tell us more about the overall configuration of the facility along the route, what type of physical separation you're using, etc?
- What are the intersection treatments you are using? Are there different intersection treatments being used along the corridor (2-3 different types of markings/designs we could study)?
- What design resources did you use for your intersection treatments?
- Have you run into any coordination issues with other agencies (e.g., NCDOT) on the intersection work?
- Is there any data you've collected already that we could use for our project?

- Interview Notes

SBL is described as "Heavy lift so far"; emphasis is on getting some examples on the ground that can be used as proof of concept and test sites

- Projects Discussed

Project 1 (North/South Connector)

- Block between Hillsborough and Edenton will be closed for about two years for redevelopment. The current plan is to complete the rest of project, but handle bottleneck later. Ultimately will connect to greenway and connect five points neighborhood to downtown.
- Expectation is for a Council vote by March or April, with construction ranging from June-October.
- Still in early design phases. The two-way SBL idea has been largely abandoned: NCDOT would have required them to put in separate bike signals at their intersections, which made the price go way too high. Probably would use bike boxes (this appears to be the default intersection treatment), possibly no turn on red.
- East side of Harrington street might give us some trouble, particularly at the Johnson St intersection, which functions as an off-ramp for Capital Blvd. Concerns over traffic backup if signals/traffic flow slows. Described as a "Major Hurdle"
- Green skips or green solid bars at the driveways; several parking decks and lots that will create unique challenges.

Project 2 (South State Street)

- Connect walnut creek wetlands center with Biltmore hills (subdivision)
- Cross I-440

Project 3 (Cameron/Oberlin)

- Raleigh representatives seemed unsure what the timeline is on this project; might be around 65% planned. They are additionally trying to get a counter installed for that one.
- Ask about more definitive timeline - website says complete Winter 2022
- This one has a right-only lane. The design team is working from some examples from around the country to use as a reference.
    - Eau Claire, WI, was one of the examples. NACTO for the other. Another is a marked merge/conflict zone. We asked for the links for these examples, the email is going to be forwarded to us.

Project 4 (Morgan Street)

- Retrofit similar to the St. Albans project.
- Buffered bike lane will get bollards/flexible delineators; Raleigh noted that this is the standard retrofit for their buffered lanes

Project 5: Downtown East West Connector (maybe Martin Street)

- Some alignment with BRT; the BRT process is complicating the routing for this project. Still a lot of ideas (Jared knows more about this one)
- Will need to connect with Harrington/West route

Project 6: (Gorman Street)

- Two way-cycle track; routed along west side of street; probably will have some major intersection components where it ties into the greenway. Ultimately transitions from greenway to SBL to bike lane/shared lane? Possibly the SBL is ONLY on the bridge, and the segment facility is more of a shared use path.
- Federal funding through CAMPO
- Close to construction phase

Project 7: (St. Albans Dr.)

- Buffered bike lane, St Albans near north hills,
- Retrofitting a section of buffered bike lane with bollards for vertical separation.
- This will be the first on-street project in Raleigh; will function as a guinea pig project and test case for Raleigh to work on implementation/maintenance.
- No specific evaluation methods/plans currently in place

Project 8: **Blount/Person conversion of one-way to two-way**

- Goes back to 2013 corridor study, calling for tier 1 bicycle facility
- Three phase implementation: Phase 1 done – removed one of three through lanes to replace with continuous conventional bike lane (in some places just wide pavement), some on-street parking. Part of next step is convert to a protected facility, but this took a back seat to the BRT project in and out of the transit center. Blount street will remain one-way from E Edenton St. to MLK Jr. Blvd.
- Kimley Horn is designing this project and is about to kick off public involvement meeting to present different concepts (beginning March 2020). One likely component is a raised curb line. Reuben says the marked bike lanes there currently might as well not be there; lots of competition for curb space with Uber, etc. Overall timeline is 23 months starting from Feb 2020. They may recommend bike signals.
- Reuben says anecdotally there has been an “imperceptible uptick” in cyclist activity but notes a continued preference for riding on sidewalks. Thinks maybe a six-foot bike lane is too wide; seems like cars pull into them a lot
- The current Blount Street bike lane will be removed entirely when BRT comes on-line
- ‘Lots of moving pieces with this one; the impact of the directional change will impact route choice’

- Experience with NCDOT on SBLs

Project 9: **Lumley/Westgate/Ebenezer Church Road**

- Came from older bike plan
- Connected bike facilities from Brier Creek to Umstead Park with connection over to Leesville Road
- Putting SBLs on Lumley involved a traditional road diet; can do a six-foot bike lane and a six-foot buffer. Current NCDOT District Office leadership isn’t a fan of the road diet approach; Previous leadership was alright with road diet, but WAS concerned over placing bike facilities on high-speed roads. Airport authority is also against this approach.
- Fairly far along in design, but not close to advertising it yet. Not too many concerns about intersections, at least not yet. However, NCDOT is concerned about the Lumley/Westgate intersection, does not want to lose approach lanes. SBL would be routed behind the curb for this intersection, functioning similar to an enlarged sidewalk/signalized multi-use path.
- Project would be a mix of mixed-use (ped/bike) trails off the roadway (~30% of the corridor) and on-road SBL (~70%)

- Potential Projects, details on timelines unclear:

Raleigh noted that of all their projects, there is one example where a protected intersection scoped in the design: Blue Ridge Road at Reedy Creek Road. Part of the Blue Ridge Road bicycle/pedestrian project. Two potential projects as part of Six Forks Project; design materials include bike lane and intersection treatments

- Other Notes and Observations

The City is retrofitting a lot of buffered bike lanes by adding flexible delineators to make them SBLs, and using this as an opportunity to informally observe their performance and note any issues that come up.

Raleigh stated that they are not experimenting with any other vertical element other than flex delineators. Some pressure from community and landscape folks to use buffers and other more visually pleasing elements, but they (Raleigh) don't feel they can do that with confidence yet.

Wilmington, February 6, 2020

Wilmington currently has no SBL on the ground, and no SBL projects in the pipeline.

Considered a SBL for a streetscape project for Wooster street (Wooster street is currently 4 lane 1-way, need is for 3 lanes, and are going to cut it down). The city considered protected bike lanes, bus lanes, before ultimately selecting back-in angled parking. Ultimately, they chose not to use a SBL because it (Wooster) was part of a one-way pair, and as the other road was not going to be treated there wouldn't have been a paired lane in other direction. 2-way Cycletrack was not selected.

The Wilmington bike plan = comprehensive greenways plan; this plan includes bike lane recommendations. In design criteria for consideration, the plan includes cross-sections for protected bike lanes (aka SBLs), but doesn't go into detail w/ regard to what conditions lend themselves to PBL vs. Buffered bike lanes, etc.

Don't have a 'standard bike lane design'; Wilmington staff make those decisions in the design phase based on volume of the road in question, vehicle speed, etc.

Local bicycle groups have been pushing for off-road multi-use paths as a first preference, but there has been some push for on-road as well (to a lesser degree).

Experiences with NCDOT:

- Wilmington has recently finished up a project w/ NCDOT including bike/ped facilities. Cost to the municipality is a concern; this project included a standard bike lane. The city feels that NCDOT has been 'receptive to incorporating bike/ped elements'; Wilmington feels that they have a good relationship with the department. Frequently in these NCDOT projects the city is looking for shared use/multi-use paths, but they defer to the greenways plan for installation type.

Wilmington noted two major projects involving new bike lanes, which at one time considered SBL elements:

- Bike Lane installations on newly constructed streets in the Mayfair area, a multi-use, Live/Play community.
- Ann street, a surface road with access to downtown; this project is designed as a bicycle boulevard).

The municipality is interested in updating their policies with a level-of-comfort analysis on major corridors. The current plan does not explicitly use speed/volumes to make installation-type decisions, but it references to common guidelines (AASHTO, NACTO etc.). Block Length, intersections, etc. are considerations.

The Wilmington MPO plan includes a long-term comprehensive network vision plan, which is extended to the county; the city pulls directly from this plan in identifying potential regional projects.

Anecdotally, the increase in visual clutter at intersections may be a concern with installing SBL projects.

Winston-Salem, February 6, 2020

(Note: The City of Winston-Salem uses the term "cycletrack" to refer to SBLs, so we used that term in the notes below).

No SBL on the ground; had a temporary cycletrack installation a few years ago

Details on the W-S Temporary Installation:

- A popular greenway was going to be interrupted due to a road project for about 1.5 years. There was desire for a detour, but available route options were not ideal. The City worked with NCDOT engineering consultants to ID a detour. Ended up choosing a 2-way cycletrack ('right tool for the context') for a number of reasons, including maintaining 2-way traffic. Traffic on the road was fairly high and running the track on one side alleviated concerns over crossing.
- From a design standpoint: W-S made use of green pavement markings, vertical separation and buffered area. No concrete work; used plastic delineators/bollards. Width of the temp Cycletrack was 10-ft plus gutter pan. Issues at signalized intersections, NCDOT wasn't going to do signal modifications. W-S staff noted that changing signal timing was a major limitation to making installation permanent. The installation lasted 18-months.
- W-S saw it as a learning experience, some back and forth/conflict with consultants; City got involved and made their own improvements. This friction may have deterred some in the department from pursuing them further. New bike plan includes recommendations for 2-way cycletracks. Feels the city needs a good, controlled example going forward.

In the Bike Plan:

- Within priority routes, some routes are specifically identified for protected facilities/separated cycletracks. Opportunity drove the selection of cycletrack corridors, due to lack of support for road widening. Where opportunities exist for reallocating right-of-way, cycletracks are recommended.
- One of those corridors is NCDOT owned (Old Salem Road in historic district), but DOT may want to turn maintenance over to city. Currently a partially divided cross section, 'way over-engineered'. W-S is unsure if NCDOT is willing to maintain it with a cycletrack on it, or if they are preparing to hand off Old Salem Road to the municipality. Timeline: nearest term project, interest from councilmember, expect it on the ground within the next couple years.
- W-S does not place major emphasis on separated one-way paths; noted that some buffered paths could be easily retrofitted with vertical separation as well. Maintenance of surface with vertical separation present is a concern at municipal level (not having a machine to clean such a narrow space). Until they solve the maintenance issues for a one-way cycle track, they are hesitant to install them.
- Winston-Salem does not have their own in-house design manuals for SBLs, instead (reference the NACTO guidelines.
- The city is focused on building out a robust bike boulevard network in areas around downtown, centered around good low-stress neighborhood street connectivity. See this as a more substantial opportunity than SBL installations.

With regards to intersection treatments/mixing areas, there are concerns about being able to maintain colored pavement markings (W-S public works not set up to do it, not available in current budget, etc.). Winston-Salem would like to know how other municipalities manage that additional cost/maintenance burden. In absence of green paint, they plan to at least mark the bike lane through intersection in some way (Skip lines, fully-painted, etc.).

Of the projects going in the ground in near-term, all are standard bike lanes.

W-S feels that the push for separated facilities is predominately driven by public interest, along with 'champions' in city knowing about opportunities for installation. Feel that advocacy is not as organized as in other cities, and that limited support from council is reflected in prioritization of improvement projects; emphasis is on pedestrian improvements.

W-S expressed interest in other municipalities' calculus regarding the impact on driving environment when improving bike facilities. Very interested to know about the experience of cutting into driver space, or if other cities are taking unused/underutilized space. Additionally, where does the support for infringing on drivers come from (public, govt, etc.?)

Cary, February 13, 2020

No SBL currently on the ground, but there are several SBL projects in the pipeline:

Private Development – [Fenton. Large mixed use development]along [Cary Town Blvd near I-40.]City Council wanted to prioritize ped/bike network connectivity, and this project seemed like a clear opportunity.

- Protected intersections; connecting greenway and street-side trail. Started with bike boxes but decided to go to protected intersection design because of concerns over whether cyclists would know how to navigate the bike-boxes. No bike signals.

Capital Project (1) – Louis Stephens Drive. Started as a sidewalk project, but Council and administration pushed for bike/ped network connectivity. The project design initially called for a bike lane, but the interviewees indicated that guidance from FHWA (referring to the FHWA Bikeway Selection Guide) called for more than a bike lane on a 45-mph road. Considering this a pilot project to introduce combination of buffered bike lane and vertical element. Testing different vertical elements, paint, etc. The area in question is somewhat rural, but it is expected that development pressure will drive development very soon.

Cary relies heavily on the FHWA Bikeway Selection Guide criteria. The city has a number of greenways and has an attitude of "let's try it" when it comes to new types of facilities. Maintenance is a concern, but not one that has kept them from doing these projects.

Cary currently relies on FHWA guides for their design guidance (specifically mentioned the Bikeway Selection Guide), as well as NACTO and AASHTO. Cary is currently working on developing/rolling out their own design guidance "toolbox". Cary is attempting to develop a context-sensitive approach to facility selection, following a similar tactic as the Portland facility selection guidance. Frequently, it was referred to as a 'toolbox method'.

Emphasized that the FHWA/AASHTO guides help legitimize SBL installation in interactions with engineers, as the recommendations come from widely accepted guidance literature

Cary noted the following when discussing interactions/relationships w/ NCDOT around bike infrastructure:

- Some of the private development projects impact NCDOT roads; in these instances, the primary plan called for multiuse path specifically, but there’s another nine feet of width for two-way bike traffic as well.
- NCDOT has to sign off on changes in the right of way and is reticent to approve any project that reduces travel lanes for motor vehicles. The Cary Town Blvd. project has a massive right of way that will allow for both multi-use and SBL facilities without impact to travel lanes, and NCDOT has signaled it will be fine with them.

Re: advocacy, Cary noted that the cyclist community in many ways doesn’t know enough about protected facilities to advocate for them. Felt that the most-expressed demand from the cyclist community is for more greenway/multi-use trail facilities.

NCDOT Division 6, February 19, 2020

Dedicated bike lane, not separated bike lanes, in Division 6

Also using multiuse paths, but typically require more ROW

Using multiuse paths instead of sidewalks on both sides

Darius interested in sitting on panel

NCDOT Division 10, February 19, 2020

City of Charlotte has been doing a lot of these types of projects

Bike lane on sixth street in Uptown; took a lane of traffic

Had one project, local municipality (Cornelius) requested a raised cycle track. First exposure to this type of idea; hasn't been explored widely in the division. Issues: how to drain it? How to resurface it? Didn't gain a lot of traction. Ultimately it was converted to multiuse path. Cornelius has a lot of biking and walking.

- If something like this moved forward, the consultant would design the project, but NCDOT would review it (integrated mobility). There isn't a good "standard" guidance document.
- Stuart says there would be value in having a standard guidance for how these types of bike lanes would look.
- Complete streets policy change will impact budgets for projects with environmental projects signed after August 30.

Division typically has conversations early on about what the design alternatives will be on any given project. Anything beyond a standard bike lane (buffered bike lane would also be a betterment, and anything above and beyond that).

Need to remove bollards to resurface street, then put them back

Also concerned about intersection movements; especially where there is a right turn lane. He mentioned higher speed roads need something separated from vehicle traffic.

Driveway movements haven't really come up much

NCDOT reps agree that the sixth street project is a good "standard" project

Huntersville also considered a raised cycle track

Town of Matthews is doing a lot of interesting work on bike/ped projects; engineer is an avid cyclist.

NCDOT Division 5, February 20, 2020

For a variety of reasons, the Department has not gotten into this type of facility on State maintained roads (reasons: history, funding structures, "old ways of doing things"), but on the cusp of moving in a new direction with the recent complete streets improvements

- Referenced the Complete Streets updates frequently. Bob felt that this rewrite represents a significant step towards reducing barriers to implementation of SBL via changes in cost-sharing b/w DOT and municipalities among other reasons.
- Bob felt that the incipient AASHTO guide would be a significant step forward as well, echoing comments from other interviewees that having a widely accepted/referenced source lend its weight to this type of project would be a significant boost to legitimizing/normalizing these projects for the DOT

'Raleigh, Cary, Durham are pushing the envelope a bit. Upper management at the Division Office is coming around.'

Mentioned the Raleigh pilot project, but nothing else on the ground yet for Division 5

With complete streets, these were always “add-ons”, but moving forward the Division will help pay

More often than not, one of the prominent stumbling blocks was angst about maintenance that these SBLs haven’t moved forward. Maybe this is why NCDOT hasn’t been too enthusiastic.

Says the Bike/Ped unit at NCDOT is great, but they usually focus more on the planning end and greenway/multiuse path projects. They do less with project development. They usually review and weigh in during scoping; Bob noted that having an example SBL design guidance would be a significant aid to the Bike/Ped unit being more amenable. Not having a reference point is a challenge.

Talked about Person/Blount restriping to add a bike lane, sometimes a buffer. Says the addition of bike lanes was an improvement.

Mentioned the importance of putting a separated bike lane in a plan. Likes the idea of a more specific recommendation in a plan for a particular facility type.

- Noted that if a municipality comes to DOT with a strong “knowledge of what they want” they are more likely to convince DOT to support a non-traditional installation.

Fayetteville, February 27, 2020

Nearing completion of a NCDOT-funded comprehensive bicycle plan; there will be SBLs recommended in the plan which are sited on NDOT roads. NCDOT just made its final review, taking to City Council in late March.

Makes specific recommendations for where the SBL will go. Offers examples for what the ROW will be. Stantec and consultant pulled the designs from NACTO. Would be useful to have design guidelines from NCDOT.

Locally, bike facilities are not a primary focus of NCDOT. Most of the NCDOT projects are sidewalk and/or multi use paths.

Maintenance was not really discussed as part of the bike plan development, but Lee acknowledged that it is a concern for future implementation.

Most challenging aspect seems to be how to navigate/design the intersection movements.

Public input: lots of different bicyclist types, different levels of experience and comfort.

They have criteria to determine the recommendations for where SBLs are used. Selection framework. Three types of treatments: shared, on-street, separated. Speed limit, volume, and walking/cycling volume and transit operations.

“Multiuse lanes” on city-owned residential streets. Edge line 4-5 feet from edge of pavement or gutter pan. People can use it for whatever.

When we evaluate, Lee thinks we should look at compliance (e.g., are people walking in the bike lane instead of allowing bicyclists to use it?). Lee also made note that without substantial enforcement efforts, restricting travel direction on one-way cycletracks may be an ‘exercise in futility’.

How to select the “slam dunk” SBL project location where these would be a huge success?

Cost is huge: if NCDOT requires local agencies to pay for these, cities like Fayetteville won’t be able to pursue them. Notes that even with 80-20 cost sharing, cost is prohibitive for smaller municipalities.

8.3 Video Reduction Fields, Codes, and Camera Views

Table 17. Data Fields, Codes, and Definitions

Field	**Format**	**Description**
Date	Mm/dd/yyyy	Date that the video was recorded
Video Title	Number	File name of video
Reviewer	Text	Name of staff or student who reviewed the video and coded the data
Timestamp	Hr:min:sec PM	Time on the video in which the VRU was observed
VRU	text	Type of vulnerable road user observed moving along the primary street or turning on to/off of the primary street. Includes bicyclists and scooter riders on sidewalk as well as all VRUs traveling in street who are otherwise not in a crosswalk. *Bike* – bicyclist on any type of bicycle or unicycle except an e-bike (e.g., tandem, cargo bike, bike with trailer, etc.) *E-bike* – bicyclist riding a bicycle or unicycle with a battery to propel or assist in propelling rider *Scooter* – VRU riding a manually propelled device with handlebars and a narrow footboard upon which the rider stands *E-scooter* – VRU riding a battery powered scooter *Skateboard* – VRU riding a skateboard, e-skateboard, one-wheel, hoverboard or other micromobility vehicle with a footboard with no handlebars; may be manually or electronically propelled *Moped* – VRU riding a low-powered motorcycle *Wheelchair* – VRU riding in either an electric or manual wheelchair (only coded if user is riding in the street not at a crosswalk) *Other* – stroller, Segway, delivery robot or other “pedestrian” wheeled devices (only coded if user is riding in the street not at a crosswalk)
InteractionType	text	Type of interaction that VRU had with motorist. *No Interaction* – VRU is observed traveling and no motor vehicles are present *Coexist* – VRU and motor vehicles are traveling in vicinity of one another with no issues *Avoidance* – VRU or motorist changed trajectory to avoid the other (e.g., altering speed or alignment) *Conflict* - -VRU or motorist abruptly changed trajectory to avoid the other (e.g., hard braking, swerving)
ManeuverDescription	text	Open comment field to describe where VRU was and how they traveled in relation to motorists
WhoYielded	text	Only coded for Avoidance or Conflict interactions; coded as the VRU type if the VRU yielded or as “Car” if the motorist yielded; all else is “NA”

WasYieldedTo	text	Only coded for Avoidance or Conflict interactions; coded as the VRU type if the VRU was yielded to or as "Car" if the motorist was yielded to; all else is "NA"
Helmet	True/False	If VRU is observed wearing a helmet, then "TRUE"; all else "False"
Rideshare	True/False	If VRU is observed riding a branded bike share or scooter share micromobility device, then "TRUE"; all else "False"
CyclingKit	True/False	Only coded for Bike or E-Bike VRUs; if cyclist is wearing cycling gear or a kit, then "TRUE"; all else "False"
StartLocation	East, West, North, South	Indicates from where the VRU approached the study site
EndLocation	East, West, North, South	Indicates where the VRU left the study site
Maneuver	text	Indicates movement of VRU traveling through study site; may also indicate placement of VRU (e.g., sidewalk, bike lane, crosswalk)
Notes	text	Open comment

a) Crabtree Blvd – before

b) Crabtree Blvd – after

c) Lineberry Dr – before

d) Lineberry Dr – after

e) Morgan St. at Salisbury – before

f) Morgan St. at Salisbury – after

g) Morgan St Parking Deck – before

h) Morgan St Parking Deck - after

Figure 13 Before and after camera views from each Raleigh study site.

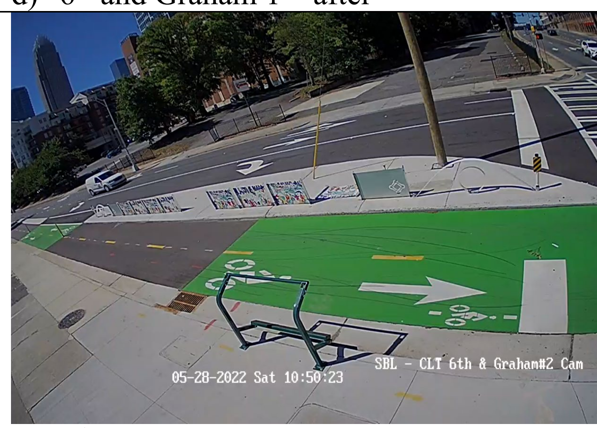
a) McDowell & 7th – before

b) McDowell & 7th – after

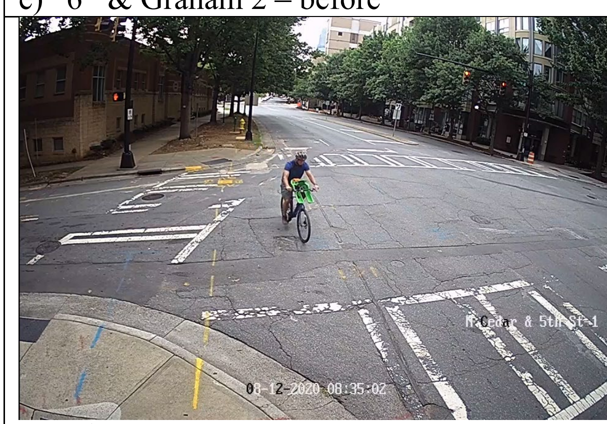
c) 6th & Graham 1 – before

d) 6th and Graham 1 – after

e) 6th & Graham 2 – before



f) 6th and Graham 2 – after



g) 5th & Cedar 1 - before

h) 5th & Cedar 1 - after

i) 5th & Cedar 2 - before

j) 5th & Cedar 2 - after

k) 5th & I-77 - before

l) 5th & I-77 - after

Figure 14. Before and after camera views from each Charlotte study site.