Investigating Tools for Evaluating Service and Improvement Opportunities on Bicycle Routes in Ohio

Prepared by:
Gulsah Akar
Kailai Wang
Kevin Lee
Meredyth Sanders

Prepared for:
Ohio's Research Initiative for Locals
The Ohio Department of Transportation,
Office of Statewide Planning & Research

State Job Number 135807

August 2019

Final Report

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/OH-2019-20		
4. Title and Subtitle		5. Report Date
Investigating Tools for Evaluating Service and Improvement Opportunities on Bicycle Routes in Ohio		**August 2019**
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No.
Gulsah Akar, Kailai Wang, Kevin Lee, Meredyth Sanders,		
9. Performing Organization Name and Address		10. Work Unit No. (TRAIS)
City and Regional Planning, Knowlton School The Ohio State University 275 West Woodruff Avenue, Columbus, OH 43210 Kittelson & Associates, Inc. 11 Garfield Place Cincinnati, OH 45202		
		11. Contract or Grant No.
		Project ID Number 135807
12. Sponsoring Agency Name and Address		13. Type of Report and Period Covered
Ohio Department of Transportation 1980 West Broad Street Columbus, Ohio 43223		**Final Report**
		14. Sponsoring Agency Code
15. Supplementary Notes		
16. Abstract		

Over the past two decades, transportation engineers and urban planners have become increasingly interested in using performance measures to capture roadway infrastructure effects on bicyclists' comfort levels. This study develops a useful tool to evaluate current service levels and identify improvement opportunities on Ohio's local roadway network. The research team begins by assessing the available data sources required to develop a customized model for Ohio. Stakeholder interviews and data assessment outcomes indicate that most local jurisdictions do not have access to all relevant data for a complete bicycle LTS analysis. Therefore, the team extends the original bicycle LTS framework by formulating effective methods to deal with missing data. The designed methods are based on Ohio's functional classification system, and existing data on speed limits, traffic volumes, and bicycle facility widths. Although this approach enables agencies to conduct bicycle LTS analysis when critical data elements are missing (such as posted speed limits, traffic volumes, and bicycle facility widths), it may produce partially incorrect assignments. For instance, analyses based on Mid-Ohio region data show that in cases where road traffic volumes are missing, the research team's approach replicates the results with an 18.6% mismatch in bicycle LTS score assignments overall. The mismatch percentage breaks down to 10.0% in urban areas and 27.5% in rural areas. Given this outcome, the research team recommends that local communities collect all necessary data before conducting a bicycle LTS analysis. The team's approach to handling missing data can help when collecting accurate data is not feasible due to time and cost considerations, and in cases where interim and temporary results may prove useful while acquiring these data.

17. Keywords	18. Distribution Statement
Bicycle LTS, Missing Data, Functional Classification, Local Ohio	**No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161**

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**112**	

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

Investigating Tools for Evaluating Service and Improvement Opportunities on Bicycle Routes on Ohio's Local System

Prepared by:
Principal Investigator:
Gulsah Akar, PhD, Associate Professor
City and Regional Planning, Knowlton School
The Ohio State University
275 West Woodruff Ave.
Columbus, OH 43210
(614) 292-6426
akar.3@osu.edu

Graduate Research Associate:
Kailai Wang, PhD
City and Regional Planning, Knowlton School
The Ohio State University
275 West Woodruff Ave.
Columbus, OH 43210
(480) 414-3171
wang.7684@osu.edu

Co-Principal Investigator:
Kevin Lee, Associate Engineer
Kittelson & Associates, Inc.
11 Garfield Place
Cincinnati, OH 45202
(513) 294-8408
klee@kittelson.com

Planner:
Meredyth Sanders
Kittelson & Associates, Inc.
11480 Commerce Park Drive, Suite 450
Reston, VA 20191
(571) 384-2946
msanders@kittelson.com

August 2019

Prepared in cooperation with the Ohio Department of Transportation, Ohio's Research Initiative for Locals, and the US Department of Transportation, Federal Highway Administration

Acknowledgments

We are very grateful to Technical Advisory Committee members Kevin Buettner, Greg Butcher, Andrew Cross, Kjirsten Frank Hoppe, Caraline Griffith, Caitlin Harley, Darryl Kleinhenz, Matthew Lindsay, Nicholas Popa, Katie Moss Sieb, Allison Thomas, Scott Ulrich, James Young, Jordan Whisler, Andrew Shepler, and Bethaney Krzys, who have provided very valuable input and data throughout the project. We also would like to extend our thanks to Vicky Fout for her help in managing this project.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

BCI	Bicycle Compatibility Index
BEQI	Bicycle Environmental Quality Index
BISI	Bicyclist Intersection Safety Indices
BLOS	Bicycle Level of Service
BSL	Bicycle Stress Level
HCM	Highway Capacity Manual
LTS	Level of Traffic Stress
MMLOS	Multimodal Level of Service
MORPC	Mid-Ohio Regional Planning Commission
NHTS	National Household Travel Survey
NOACA	Northeast Ohio Areawide Coordinating Agency
OSM	Open Street Map
PBIS	Perceived Bicycling Intersection Safety
TAC	Technical Advisory Committee

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Over the past two decades, transportation engineers and urban planners have become increasingly interested in using performance measures to capture roadway infrastructure effects on bicyclists' comfort levels. The goal of this study is to develop a useful tool to evaluate current service levels and identify improvement opportunities on Ohio's local roadway network.

The research team reviewed a variety of existing models at the national and local levels. The literature offers ample evidence on the correlation between environment and comfort for bicyclists. Although there is no consensus on how agencies should measure bicycle comfort, bicycle level of traffic stress (LTS) is the approach most widely used by transportation professionals in recent years. After reviewing the existing academic literature and state-of-the-art practice, conducting interviews with various Ohio agencies regarding their needs and ability to access required model-specific data and use cases, the research team recommends bicycle LTS analysis as the measurement tool for the State of Ohio.

The purpose of this study was to develop a tool to assess roadway facilities for bicycle use leveraging Ohio's data sources. The research team began by assessing the available data sources required to develop a customized model for Ohio. Stakeholder interviews and data assessment outcomes indicate that most local jurisdictions do not have access to all relevant data for a complete bicycle LTS analysis. Therefore, the team extended the original bicycle LTS framework by formulating effective methods to deal with missing data. They designed these methods based on Ohio's functional classification system and existing data on speed limits, traffic volumes, and bicycle facility widths.

Although this approach enables agencies to conduct bicycle LTS analysis when critical data elements are missing (such as posted speed limits, traffic volumes, and bicycle facility widths), it may produce partially incorrect assignments. For instance, analyses based on Mid-Ohio region data show that in cases where road traffic volumes are missing, the research team's approach replicates the results with an 18.6% mismatch in bicycle LTS score assignments overall. The mismatch percentage breaks down to 10.0% in urban areas and 27.5% in rural areas. Given this outcome, the research team recommends that local communities collect all necessary data before conducting a bicycle LTS analysis. The team's approach to handling missing data can help when collecting accurate data is not feasible due to time and cost considerations, and in cases where interim and temporary results may prove useful while acquiring these data.

This report presents three case studies where the research team applied its bicycle LTS framework. These case studies cover (i) the Mid-Ohio Region, (ii) Lorain and Medina Counties, and (iii) Ohio's state roadway network within Ohio's Transportation Information Mapping System (TIMS). The results suggest that this bicycle LTS framework can provide promising results when it comes to dealing with missing data. Specifically, this approach can be useful as an interim approach, when data on speed limits and AADT are not readily available, and acquiring accurate data is not possible due to time and cost considerations. We note that most of the case study datasets did not cover local road segments. Filling these data gaps is crucial for comprehensive applications of the bicycle LTS framework.

The outputs of a bicycle LTS analysis may have additional planning implications. The research team discusses some of these in this report and introduces future directions, such as exploring low-stress bicycle access to jobs for disadvantaged populations, and access to schools and activity centers. These will require a routable network. Assignment of bicycle LTS scores to routes with links (street segments) that have different LTS scores is discussed briefly in the Applications in Practice section in Appendix B.

1. PROJECT BACKGROUND

Bicycling has the potential to mitigate the negative environmental and health outcomes of dependence on motorized modes and enhance urban vitality (Pucher et al., 2010; Dill, 2009; Buehler & Handy, 2008; Akar & Clifton, 2009). There have been local and national efforts to promote bicycling for both recreation and daily transportation.

As an active mode of transportation, bicycling is susceptible to the influence of external environments which may either foster pleasant rides or lead to detours to avoid potential nuisances or risks (Broach et al., 2012; Broach & Bigazzi, 2017; Park & Akar, 2019). Urban and rural areas have preexisting street networks that may or may not be able to accommodate additional bicycling infrastructure. These networks are heterogeneous and vary in the suitability of roadways for bicycling (Evans-Cowley and Akar 2014).

Bicyclists face choices of links to travel from their origins to destinations. These choices include various combinations of bicycle infrastructure, such as dedicated multiuse paths, bicycle boulevards, roads with sharrows, and bicycle lanes combined with routes where there is no bicycle infrastructure. Misra and Watkins (2017) argue that bicycle trips are different from vehicular trips because they are likely to be on routes that are optimal in safety and comfort, rather than on the shortest routes in travel time and/or distance. It is important to understand the effects of street characteristics that contribute to bicyclist comfort and stress in order to make informed investment decisions and design streets that are preferred by bicyclists (Evans-Cowley & Akar, 2014).

There have been several efforts to develop methodologies and tools designed to assess bicycle routes in terms of their safety, comfort, and stress levels (Landis et al., 1997; Harkey et al., 1998; Landis et al., 2003; Mekuria et al., 2012; Foster et al., 2015; Wang et al., 2016). However, application of these tools consistently across agencies is still a challenge for the following reasons:

- Existing models need to be customized for local conditions, as they may not be directly applicable for different types of bicyclists (e.g., commuter cyclists vs. recreational cyclists) and facilities,
- Incorporating local parameters may be challenging and lead to caveats in model assessments, and
- Data availability or lack thereof, may hamper developed model implementation, and can prevent agencies from creating reliable and consistent performance measures for bicycling.

This study developed a bicycle LTS assessment framework for local Ohio agencies. The proposed framework provides opportunities for streamlined, data-supported prioritization and decision-making. The research team built upon existing national and local research, adopting and extending the bicycle LTS model to help local agencies assess the performance of road segments in their jurisdictions. The results of this study can help Ohio planners make informed decisions about street features. Even though the parameters in this framework may not apply directly outside Ohio, the analysis methods can be adapted and applied elsewhere.

2. RESEARCH CONTEXT

2.1 Objectives

The primary objective of this study was to develop a model to evaluate the bicycling comfort of road segments and the overall bikeway network in Ohio. The study began with a comprehensive review of existing academic literature and the state of the art in practice. The research team collaborated with Ohio's Research Initiative for Locals (ORIL) Technical Advisory Committee (TAC) to identify useful datasets and propose and develop an evaluation framework applicable to Ohio. The proposed framework accounts for factors such as road widths, posted speed limits, road traffic volumes, and existence and characteristics of bicycle facilities. The framework can be used to assess the needs of various types of bicyclists.

2.2 Project Tasks

To achieve these objectives, the research team completed the following tasks.

Task 1: Review of Existing National and Local Models

The team conducted a comprehensive literature review and identified several unique case studies relevant to the subject. The detailed review is presented in Appendix B.

Task 2: Agency Engagement and Data Inventory

Working closely with the ORIL TAC, the team identified agency needs and model application opportunities. In October 2018, the team conducted interviews with TAC members representing regional planning and local agencies across the state. These interviews identified agency goals and objectives, and current practices for measuring bicycling comfort and BLOS in Ohio. The interviews highlighted challenges associated with existing planning practices, analysis models as well as data availability. The team also conducted a comprehensive data inventory to explore the datasets that are readily available statewide and easily accessible, reliable, and usable for local agencies. The data inventory highlighted key data gaps and informed subsequent tasks to develop a data-driven bicycle evaluation framework for local agencies that can support their strategic goals and objectives.

Task 3: Development of Model Recommendations for Ohio

Based on the literature review, agency engagement interview outcomes, and data inventory, the team assessed existing models in terms of their advantages, limitations, scale, and applicability to Ohio. Based on these assessments, they proposed a bicycle LTS model application for Ohio.

Task 4: Customization of the Recommended Model for Ohio

The research team applied the existing bicycle LTS framework to select Ohio datasets to identify potential challenges. As anticipated during the data inventory process, the team found that most challenges stemmed from missing data relevant to critical model assessment characteristics. The team then extended the state-of-the-art model to accommodate Ohio-specific considerations, such as the features of different types of functional classifications, and the differences between urban and rural areas.

Task 5: Model Application

As part of this final technical task, the research team applied its bicycle LTS framework to three case areas: (*i*) Mid-Ohio region (data mostly available through Mid-Ohio Regional Planning Commission (MORPC)), (*ii*) Lorain and Medina Counties (data available through the Northeast Ohio Areawide Coordinating Agency (NOACA)) and (*iii*) Ohio bikeway network (with data from the Ohio Department of Transportation's (ODOT) Transportation Information Mapping System (TIMS)). The outcome of this task is an overall assessment of the road segments in these select areas as well as an assessment of our approaches in handling missing data.

Task 6: Reporting
The research team documented the main steps and final results of the above tasks as a comprehensive report.

2.3 Literature Review Highlights

The research team conducted a comprehensive review of the existing literature as presented in Appendix B. The highlights are summarized below.

Researchers have developed several bicycle level of service (BLOS) or safety index tools to assess bicyclist safety perceptions and comfort. The state-of-the-art models typically weigh the following factors: roadway attributes (e.g., roadway width, number of lanes, pavement condition, etc.), bicycle and vehicular volumes, adjacent land uses, bicycle infrastructure existence and quality, and traffic calming measures.

The connection between route attributes, safety, safety perception, and bicyclist choice lies at the center of efforts to improve bicycling environments (Landis et al., 1997; Carter et al., 2006). Empirical studies show that bicyclists often choose longer routes in search of better riding conditions, experiencing varying degrees of excess travel (Aultman-Hall et al., 1997; Winters et al., 2010; Krenn et al., 2014; Park & Akar, 2019). Studies on bicycle routing behavior suggest that bicyclists consider efficiency, safety, and leisure jointly when choosing a route (Casello & Usyukov, 2014; Broach et al., 2012; Chen et al., 2018; Zimmermann et al., 2017; Sener et al., 2009).

Several mathematical models have been developed to study bicycling safety. Most of these models examine the determinants of BLOS or comfort level, focusing on whether the bicycling activities are compatible with physical environments (Carter et al., 2006; Landis et al., 1997; Harkey et al., 1998; Landis et al., 2003). These studies focus on developing models by quantifying the bicyclist's perception of hazard or safety when riding along different street segments and through intersections.

Two of the earlier well-established models were developed by Landis et al. (1997) and Harkey et al. (1998). Landis et al. (1997) developed the first statistically calibrated BLOS model for roadway segments based on real-time perceptions from 145 bicyclists nationwide. They modeled bicycle safety as a function of traffic volume, number of through lanes, posted speed limits, percentage of heavy vehicle traffic, nearby land use, width of outside lane, and pavement surface. Their comfort and safety ratings on various road segments were scaled from A to F. For instance, BLOS A indicates a very comfortable ride for an average bicyclist. This model is based on the level of service criteria for vehicles (*Highway Capacity Manual (HCM)* 1994) but focuses on bicycling activities.

Harkey et al. (1998) developed a bicycle compatibility index (BCI) for urban and rural roadway segments. The sites selected for the study were in five cities representing a range of geographic conditions present in the US. Study participants watched a videotape of different roadway segments and rated how comfortable they would feel riding on each segment.

Both the BLOS model and BCI address bicycle comfort along the roadway. The BCI model covers some additional factors that may affect bicyclists' perceived levels of comfort and safety, such as curb lane width, traffic speed, and type of roadside development. Harkey et al. (1998) transformed the estimated BCI values into BLOS classifications.

The *HCM* was expanded in 2010 to include multimodal level of service (MMLOS). This expansion provides bicycle and pedestrian LOS measurements in addition to traditional vehicle LOS. The *HCM*'s BLOS refers to the bicycle component of the MMLOS (*HCM* 2010; Zuniga-Garcia et al., 2018). Consistent with many BLOS studies (e.g., Dowling et al., 2008; Hallett et al., 2006; Harkey et al., 1998;

Landis et al., 1997; Petritsch et al., 2007), the developers of *HCM*'s BLOS models adopted a linear regression approach. The participants of BLOS studies provide their safety or satisfaction on an ordinal Likert scale.

Some researchers adopt an ordinal regression approach to estimate the weights of the independent variables. For example, Jensen (2007) develops a BLOS model in Danish conditions. The Danish BLOS employs a cumulative-logit model that predicts what percentage of users fall into each of the six BLOS grades from "very satisfied" to "very dissatisfied." The Danish BLOS model is more comprehensive than *HCM*'s BLOS and BCI.

One of the highlights of the Danish BLOS model is that it weights the effects of on-road bike lanes and cycle tracks differently. Recent research efforts in the US also consider the varying effects of different bicycle facility types. Foster et al. (2015) appear to develop the first BLOS model accounting for protected bike lanes explicitly. This model can be used to complement the *HCM* 2010 level of service methods in the US context by offering an analysis procedure for protected bike lanes that are currently not included in the manual.

Use of bicycle LTS as a tool to assess bicycle compatibility on urban and suburban roadways was first introduced in the early 1990s (Sorton & Walsh, 1994). Later, Mekuria et al. (2012) revisited the idea and introduced a new system that classified roadways into four different LTS categories based on riding conditions. Bicycle LTS analysis uses data such as number of through auto lanes, posted speed limits, road traffic volumes, presence and width of bikeways, and proximity to motor vehicle parking to determine roadway category (Furth, 2017). Corridors with an LTS score of 1 experience lowest stress while corridors with a score of 4 would indicate highest stress. Instead of statistical modeling, bicycle routes are categorized into these four levels based on roadway attributes.

In recent years, bicycle LTS has become the most popular approach among transportation agencies, surpassing the BLOS models (Zuniga-Garcia et al., 2018; LaMondia & Moore, 2015; Park et al., 2013). Bicycle LTS analysis acknowledges the preferences of different bicyclists instead of assuming all bicyclist types fall along an ordinal scale of comfort or stress. Bicycle LTS criteria are based on the Dutch bicycle facility design guidelines, and use a weakest link approach, which simplifies application but restricts the combinations of attributes that can achieve a good rating (Mekuria et al., 2012).

In addition to measuring the corridors, the perception of bicycling safety or comfort at intersections has also been widely studied in literature (Landis et al., 2003; Carter et al., 2006; *HCM* 2010; Foster et al., 2015; Mekuria et al., 2012; Wang & Akar, 2018a). There is no consensus on how bicycle comfort should be measured for road segments or intersections, what factors (roadway and land use characteristics) should be taken into account, or the relative importance of these factors in determining the final comfort level. Appendix B presents a detailed review of the existing studies. Table 21 and Figure 8 in Appendix B summarize the differences between these approaches.

3. RESEARCH APPROACH

3.1 Agency Engagement: Needs & Opportunities

The research team conducted interviews with representatives from various agencies to assess their needs related to a bicycle safety and comfort analysis tool. These agencies include Akron Metropolitan Area Transportation Study (AMATS), City of Cleveland, City of Columbus, Eastgate Regional Council of Governments (Eastgate), Miami Valley Regional Planning Commission (MVRPC), Northeast Ohio Areawide Coordinating Agency (NOACA), Ohio Mid-Eastern Governments Association (OMEGA), and ODOT. The agency engagement questionnaire included questions on:

(i) the history and background of bicycle-related work (work to date related to bicycle facilities, data availability, challenges related to data access and analysis),
(ii) process and methods (ways the agency will use a bicycle network),
(iii) goals and objectives (goals for defining a bicycle network and target audiences), and
(iv) applications (opportunities and barriers to implementing bicycle facilities, additional information required).

The agency responses revealed a common interest in a user-friendly method that can help agencies identify bicycling comfort in their jurisdictions. Most agencies pointed to data access, collection and maintenance as important ongoing issues that they are working to quantify and address through ongoing and planned projects.

Below is a summary of what the research team learned from the agency responses. The survey questionnaire is enclosed in Appendix C.

One of the main challenges faced in evaluating improvement opportunities on Ohio's local system is the lack of a standard approach for maintaining bicycle facility data statewide. Ohio's local and regional agencies use different rules to define existing bicycle facilities. For example, MVRPC uses a simple 'path,' 'lane,' and 'route' description; NOACA categorizes bicycle facilities as 'signed route,' 'sharrowed route,' 'conventional bike lane,' 'buffered lane,' 'separated lane,' and 'trail.' Some agencies are in the midst of their efforts to construct datasets for existing bicycle facilities. The issues discussed above raised the need to formulate methods of improving data consistency and deal with missing data at local and regional agencies in Ohio.

Some agencies have used different bicycle performance models to map their bicycle networks. For instance, Eastgate applied BLOS models but did not reach a satisfactory result. NOACA developed bicycle LTS maps for two counties (Medina and Lorain Counties). Almost all of the interviewed project TAC members mentioned that a consistent assessment tool could guide potential improvements. Although bicycle LTS may not be detailed enough for this type of assessment, it can serve as a first step to help prioritize locations for more detailed and rigorous analysis.

Some of the use cases for defining and assessing bicycle networks included providing data for local and regional planning efforts, general information sharing with the public, creating bicycle user maps, providing route guidance and leveraging funding opportunities.

The agency responses also reflected that the assessment tool needed to cater to a broad range of targeted audiences, such as local governments and planners, internal staff members, bicycle groups, various age groups, and data mappers (OSM, Google, etc.).

3.2 Data Assessment

Robust bicycle comfort assessments require access to accurate, detailed, comprehensive, and mappable data. The research team needed a sound understanding of existing data gaps and opportunities to develop a bicycle comfort model that could be implemented in the short term and refined over the long term. During the data assessment task, the research team documented existing geographic information system (GIS) data maintained by jurisdictions across Ohio. This effort helped the research team and ORIL TAC understand the accuracy, coverage, and detail of statewide GIS data and informed the model selection process.

The research team worked with the ORIL TAC to assemble publicly available multimodal data that could inform a bicycle comfort model. The data assessment process first focused on jurisdictions involved in the ORIL TAC:

- MVRPC
- MORPC
- NOACA
- ODOT

Based on feedback from the ORIL TAC, the research team also investigated GIS data provided by other organizations or private entities that could inform a bicycle comfort metric for Ohio:

- Ohio Department of Natural Resources (ODNR)
- Open Street Map (OSM)
- Strava

The research team developed a GIS data dictionary that lists relevant spatial layers from each jurisdiction, organization, or private entity (Appendix D*)*. The data dictionary describes each spatial layer, highlights known data issues, and indicates data relevance to bicycle comfort calculations. The data dictionary also details attributes from each spatial layer that could be used to inform a statewide bicycle comfort calculation.

The data assessment process revealed key insights about GIS data availability, accuracy, and applicability to different bicycle comfort assessments. Details on these assessments are provided in Figure 8 in Appendix B.

Miami Valley Regional Planning Commission (MVRPC)

MVRPC maintains some pertinent regional datasets (e.g., regional bikeways), but primarily serves as a clearinghouse for its member jurisdictions' GIS datasets. Key data gaps include a regional road centerlines dataset containing all streets regardless of road type, and roadway speed data. Key existing data sources include a regional bikeways dataset containing existing and proposed regional bikeways, routes, and trails.

Mid-Ohio Regional Planning Commission (MORPC)

MORPC maintains several pertinent regional datasets, including one for regional street centerlines and one for regional bikeways. MORPC has used its regional datasets to conduct a bicycle level of comfort assessment. MORPC's regional street centerlines dataset includes many data elements needed to conduct a bicycle comfort assessment (e.g., posted speed, number of lanes in roadway cross-section, and roadway functional classification) but has some accuracy challenges. The file is a compilation of data by county for the MORPC 15 region. Due to schema issues, not all fields from each county file were carried over during the data merge process.

Northeast Ohio Areawide Coordinating Agency (NOACA)
NOACA maintains several pertinent regional datasets, including a regional street centerlines dataset providing functional classification and other pertinent roadway attributes; a regional bikeways dataset; and AADT, bicycle, and pedestrian count datasets. NOACA is in the process of building on its regional datasets by conducting bicycle LTS for its counties. At the time of this study, Lorain and Medina county LTS data was available. Through this bicycle LTS process, NOACA has incorporated 2,512 additional lane miles of roadways into its LTS network for Lorain and Medina county.

Ohio Department of Transportation (ODOT)
ODOT maintains a wide range of statewide datasets, including linear referencing system (LRS) routes, a statewide street centerlines dataset providing functional classification and other pertinent roadway attributes, a statewide AADT dataset, and a pavement condition rating dataset. ODOT is in the process of updating its statewide bicycle routes dataset. ODOT's datasets have varying accuracy challenges depending on the ODOT department in charge of compiling and updating each dataset. ODOT does not maintain local road data.

In addition to its statewide datasets, ODOT is working with local partners to develop a Location Based Response System (LBRS). The LBRS will include spatially accurate street centerlines with address ranges and field verified site-specific address locations for all roads in Ohio, including local county roads. This statewide dataset will provide Ohio jurisdictions with a key data opportunity by creating a common baseline roadway centerline dataset for bicycle comfort analyses.

Ohio Department of Natural Resources (ODNR)
ODNR maintains trail name and type data for off-road trails throughout Ohio. The key data opportunity and challenge associated with ODNR data involves effectively merging off-road trail data with on-road datasets to understand the network benefits provided by off-road trails.

Open Street Map (OSM)
OSM data is a publicly accessible, open source data set that may contain information about the presence of relevant features such as roadway locations and attributes. When fully populated with roadway attribute data, OSM can serve as a valuable tool for supplementing missing local, regional, and statewide data and conducting bicycle comfort assessments. However, OSM data frequently contains data gaps that limit their long-term usefulness compared to existing Ohio datasets.

Strava
Strava data are privately compiled bike ridership data captured from bicyclists using the Strava app. While Strava data are useful for comparing specific street corridors and determining which corridors might have higher bicycle use, they are not useful for establishing bicycle volume numbers (comparatively in a given geography). Because it is recreational users who typically use the Strava app, the usefulness of these data is usually limited to determining recreational ride patterns throughout a network.

The data assessment confirmed that many Ohio jurisdictions have begun to maintain the foundational dataset needed to conduct bicycle comfort analyses (i.e., roadway centerline data). However, the research team also found differences in the number of supplemental datasets maintained by individual jurisdictions (i.e., speed, volume, and bicycle facility data). Findings from the data assessment confirmed that a common bicycle comfort assessment and associated datasets could provide Ohio jurisdictions with the necessary guidance and structure to apply a preliminary bicycle comfort model.

3.3 Model Selection – Bicycle LTS

Previous studies indicate that the leading deterrent to riding a bicycle in North American cities is the subjects' perceptions of danger or stress from road traffic (e.g., Pucher & Buehler, 2008; Akar & Clifton, 2009; Winter et al., 2011). The literature offers ample evidence on the environmental correlates of bicyclists' perceived comfort or safety (e.g., Landis et al., 1997; Harkey et al., 1998; Jensen, 2007; Mekuria et al., 2012; Foster et al., 2015; Wang & Akar 2018a). Though there is no consensus on how bicycle comfort should be measured, bicycle LTS is the approach most widely used by transportation professionals in recent years.

As discussed in Section 3.1, the agency engagement interview outcomes revealed a common interest in a user-friendly method to help agencies measure bicycle comfort levels in their jurisdictions. Most agencies identified data access, collection, and maintenance as significant challenges.

The study team integrated the agency engagement interview outcomes with the overall assessments of various BLOS, traffic stress, and compatibility analysis tools. Figure 8 in Appendix B provides a multidimensional comparison of these methods. Given the data requirements and ease of application, the research team concluded that the bicycle LTS approach has advantages over other methods in terms of manageability, data analysis, and customizability for Ohio-specific applications.

Following the well-known and accepted bicyclist type classification by Geller (2006), the developers of bicycle LTS assigned four levels of traffic stress to measure bicycle networks (Furth, 2017):

- LTS 1 – most children can tolerate;
- LTS 2 – will be tolerated by the mainstream adult population;
- LTS 3 – can be tolerated by American cyclists who are 'enthused and confident' but still prefer having their own dedicated space for riding;
- LTS 4 – can be tolerated only by those characterized as 'strong and fearless.'

Bicycle LTS analysis requires fewer data compared to other bicycle performance measures. Bicycle LTS follows a 'weakest link' logic, which means the lowest performing attribute can determine the stress level. For example, even if a segment has mostly low-stress characteristics, the occurrence of one high-stress attribute dictates the stress level for the link. Consequently, it is not always necessary to collect data on every characteristic to perform an analysis.

Unlike other quality of service methods, the bicycle LTS categorizes road environments based on the preferences of the entire population who currently bicycle or would consider bicycling (Geller, 2006; Mekuria et al., 2012). The outputs of a bicycle LTS analysis can provide guidance to planning practices and a macroscopic-level assessment of roadway networks. Some studies have conducted low-stress network connectivity analyses between origin and destination pairs to measure bicycle access to jobs (Furth et al., 2018; Semler et al., 2018). Also, bicycle LTS analysis has been conducted to measure the stress levels of the shortest paths between public bike share stations (Prabhakar & Rixey, 2017). Other applications and future work may include mapping and analyzing bicycle access to schools, restaurants and other retail activities, recreational spaces, parks, universities, and libraries.

3.4 Bicycle LTS Framework Development for Ohio

The bicycle LTS criteria were first formalized by Mekuria, Furth and Nixon in 2012 (Mekuria et al., 2012). They then refined the criteria in 2017 by adding average daily traffic as an important input (Furth et al., 2018). Consistent with the updated bicycle LTS criteria, the research team adopted the influential factors in the bicycle LTS framework as follows:

- Road width: number of through lanes
- Posted speed limits: miles per hour (mph)
- Road volume: annual average daily traffic (AADT)
- Bicycle facility type: off-road trail, cycle track, shared-use lane, or on-road bike lane
- Bicycle facility width: reported in feet (only for on-road bike lanes)
- Presence of a parking lane: only for on-road parking lanes alongside on-road bike lanes
- On-road parking lane width: reported in feet (only for on-road parking lanes alongside bike lanes)
- Presence of a marked centerline

The effects of these factors on individuals' bicycling safety perceptions have been well documented in the literature (Jensen, 2007; Park et al., 2013; Foster et al., 2015; Wang & Akar, 2018a). What makes these factors important determinants of bicycling safety and comfort is outlined below. The research team used the same bicycle LTS criteria as Furth (2017) with some effective methods for handling missing data using Ohio-specific input values. Below are the details on the correlates of bicycle LTS scores.

Road Traffic

The number of through traffic lanes, posted speed limits, and traffic volumes are critical determinants of bicyclist comfort, and are crucial for a bicycle LTS analysis (Providelo & Sanches, 2011; Kang & Lee, 2012). These three factors can serve as surrogates for real-time road traffic. Two of the earlier and well-established BLOS models suggest that increases in the number of through lanes, posted speed limits, and vehicular traffic are associated with lower bicycling safety ratings (Landis et al., 1997; Harkey et al., 1998). The marginal effects of explanatory variables in BLOS models based on the *Highway Capacity Manual* 2010 reveal that a bicyclist's safety perception depends largely on factors related to road traffic.

Measuring the number of lanes captures the effects of street width. The developers of the bicycle LTS noted that higher numbers of lanes are linked to higher travel speeds. In addition, increasing the number of through lanes can lead to a decrease in the visibility of bicyclists for left-turning and crossing motor vehicle traffic (Mekuria et al., 2012). In the bicycle LTS framework, posted speed limits are designed to correspond with actual traffic speeds since observed speed measurements are generally not available (Mekuria et al., 2012). Regarding the effects of road traffic volumes, bicyclists may rarely encounter more than one motor vehicle at a time when bicycling on streets with low average daily traffic volumes. Higher volumes mean cyclists will more frequently encounter multiple vehicles driving in a platoon. In such cases, bicyclists are more likely to be constrained and threatened (Furth et al., 2018).

The presence of a marked centerline influences bicyclists' stress levels significantly when there are fewer than three lanes present. The developers of the bicycle LTS scheme, Furth et al. (2018), state that motorists tend to drive down the middle when on roads without a marked centerline, leaving larger spaces for other road users. When there is a marked centerline, motorists tend to stay on their half, reducing the space on the right side of the road where bicyclists generally ride.

Bicycle facilities

Research has shown both regular and potential bicyclists prefer physically separated bicycle infrastructure such as trails and paths, over on-road unprotected bicycle lanes that do not exhibit physical separation (e.g., Akar & Clifton, 2009; Winter et al, 2011; Foster et al., 2015; Wang & Akar, 2018b). In the bicycle

LTS framework, road segments with paths that are physically separated from vehicle traffic are classified as LTS 1. These paths include off-road trails, roads with cycle tracks, and shared-use paths. The bicycle LTS levels on roads with on-road bike lanes are assigned based on the number of through lanes, posted speed limits, and widths of bicycle and parking facilities. This is due to the potential interactions of motor vehicles and bicycles on the roadways (Mekuria et al., 2012).

Empirical evidence also suggests that bicyclists prefer riding on streets without on-street parking to those with on-street parking (Sener et al., 2009; Winter et al., 2011). When riding in bike lanes alongside a parking lane, bicyclists have to contend with parked vehicles and door zones on their right and moving traffic on their left. Bicycle LTS framework applies different criteria for bike lanes not adjacent to a parking lane and those alongside a parking lane (Mekuria et al., 2012; Furth, 2017). In general, increases in the combined width of the bike and parking lanes are associated with lower bicycle LTS scores, indicating better comfort perceptions.

Missing data

This research project extended the updated bicycle LTS framework (Furth, 2017) by formulating interim approaches for dealing with missing data. Approaches were developed for different functional classifications for roadways and urban typologies.

Roadways are designed and constructed for their expected functions (US Department of Transportation Federal Highway Administration 2013; Watkins et al., 2016). For example, arterials are designed to deliver traffic from collector roads to freeways or expressways, and therefore likely have higher posted speed limits than collectors or local roads. Functional classification is also associated with traffic volumes (Eom et al., 2006; Selby & Kockelman, 2013). Observing these considerations, the research team proposed methods for inputting missing speed limit and AADT data based on functional classifications and Ohio-specific data, accounting for the differences between urban and rural contexts.

Details of the research team's methods of imputing missing data are discussed in Appendix A. The team proposed slightly different approaches for urban and rural typologies. They finalized these methods by testing multiple criteria on Ohio datasets. They consulted the *Ohio Revised Code (ORC)*, the *National Association of City Transportation Officials (NACTO) Urban Street Design Guide*, *Methods and Practices for Setting Speed Limits: An Informational Report*, and data-driven approaches while developing their methods.

The first step was formulating criteria based on roadway functional classifications and the documents mentioned above. Next, the team tested the accuracy of these criteria by comparing the outputs with actual complete data. Assuming missing road traffic volumes for all street segments, they assigned road traffic volumes using the formulated criteria. The results of the bicycle LTS analysis with assumed road traffic volumes were compared to those with complete data in order to validate the accuracy of the research team's methods in dealing with missing data. The same approach was applied assuming missing speed limit data.

After testing multiple criteria on various local datasets, the research team found that applying the same criteria for imputing missing data in urban and rural contexts was the primary cause of mismatch. They took a closer look at the outcomes in the Mid-Ohio region and Lorain and Medina Counties. Comparing the recommendations of the *Methods and Practices for Setting Speed Limits: An Informational Report* with actual posted speed limits, they found that posted speed limits were significantly higher across all types of roadway functional classifications in rural areas as compared to urban regions.

For traffic volumes (AADT), the team analyzed ODOT TIMS AADT data and found that not surprisingly, the volumes on minor collectors and local roads in rural areas were much lower than those in urban areas. Therefore, they developed separate criteria for imputing missing data for urban and rural contexts based on a combination of sources (*ORC*, *NACTO Urban Street Design Guide*, and *Methods and Practices for Setting Speed Limits: An Informational Report*) and data-driven approaches (using Ohio-specific posted speed limits and AADT averages for different functional classifications in urban and rural contexts). As noted, the team categorized block groups with a population density of at least 1,000 people per square mile as urban[1]. Applications of the proposed bicycle LTS framework are introduced in the following section.

3.5 Model Applications

The research team applied the bicycle LTS framework to three case areas: (*i*) Mid-Ohio region (with data mostly available through MORPC), (*ii*) Lorain and Medina Counties (with data available through NOACA) and (*iii*) Ohio bikeway network (with data from ODOT TIMS). The outcome of this task is an assessment of the analyzed road segments in these select areas as well as an assessment of the team's approaches to handling missing data. The team compared the accuracy of the estimated bicycle LTS scores with assumed data to those the team assigned based on actual data. The interim approach provides an 83.6% match in Mid-Ohio's urban areas when using assumed speed limits. This percentage reaches 90.0% when using assumed road volumes.

3.5.1 Mid-Ohio Region

Introduction & Goals

MORPC has a complete and more comprehensive dataset to support a bicycle LTS analysis compared to many local Ohio communities. The team therefore began by testing the bicycle LTS framework in the Mid-Ohio region.

The goals of this application were two-fold. First, the team made a network-level assessment of road segments based on their bicycle LTS framework. Second, the team assessed their approaches to handling missing data by comparing the accuracy of the estimated bicycle LTS scores that were missing data to those the team assigned based on actual data.

Data Sources & Coverage

The research team created the baseline road network using data from MORPC's Greater Franklin County LBRS Centerlines. Table 1 summarizes the data sources for the bicycle LTS model inputs in the MORPC region. The data the team gathered from MORPC's datasets[2] provided a network with all the variables needed for conducting a bicycle LTS analysis, except for information on AADT and widths of on-street bicycle facilities and parking lanes.

The team extracted AADT information from ODOT TIMS datasets. They estimated the widths of bicycle and parking facilities based on the bicycle and parking facility types reported in the *NACTO Urban Street Design Guide*[3]. In order to assess the accuracy of their approach to missing bicycle facility and parking lane width data, they randomly selected a portion of their estimates and compared it with accurate data using Google Earth. The results confirmed that the estimates were highly accurate. For instance, the mean value of the width of the team's selected on-road bike lanes equaled approximately 5 feet, which is consistent with the value in Table 18 in Appendix A.

[1] Link: https://www2.census.gov/geo/pdfs/reference/GARM/Ch12GARM.pdf
[2] Link: https://public-morpc.opendata.arcgis.com/datasets?q=GIS&sort_by=name&sort_order=asc
[3] Link: https://nacto.org/publication/urban-bikeway-design-guide/

Table 1 – Model Inputs and Sources in the Mid-Ohio Region

Model Inputs	Data Sources	Notes
Road Networks	**MORPC/ODOT TIMS**	All segments in the analysis sample are included in both MORPC's and ODOT TIMS's datasets.
Posted Speed Limits	**MORPC**	
Number of Lanes	**MORPC**	
Annual Average Daily Traffic (AADT)	**ODOT TIMS**	
Bicycle Facilities (presence/types)	**MORPC**	
Parking Facilities (presence/types)	**MORPC**	
Presence of Centerline	**MORPC**	All segments in the analysis sample have centerlines.
Functional Classification	**MORPC**	

The road network in MORPC's LBRS data extends beyond the boundary of Franklin County. This enabled the research team to explore the differences between urban and rural typologies pertinent to bicycle LTS applications and test the accuracy of their methods for handling missing data. Figure 1 illustrates the spatial distribution of road networks and urban typologies.

Data Processing

The team joined the AADT information from ODOT TIMS's layer with MORPC's layer. The road networks on two layers do not match exactly. The team found that approximately 65% of the road segments in MORPC's datasets were not covered by TIMS (as shown in Table 2) and therefore ended up with missing AADT data. The team removed these road segments from their analysis sample. As shown in Table 1, all other model inputs related to bicycle LTS analysis came from MORPC's datasets. After removing the road segments with missing data, the total length of the road segments in the team's analysis sample became 2,986.6 miles. This consisted of 35.7% of all road segments in MORPC's LBRS data, as presented in Table 2.

Summary Statistics

Table 2 compares the team's analysis sample with its respective population in terms of roadway classification (all segments included in MORPC's LBRS dataset). Approximately 80% of the local roads are not included in the analysis sample. Of the other roadway functional types, the analysis sample covers more than half of all segments in MORPC's datasets. For example, the combined length of minor arterial roads is 668.07 miles in MORPC's LBRS data, and 457.71 miles in the research team's analysis sample. Main features of the analysis sample are summarized in Table 3.

Bicycle LTS Score Assignment Process

The research team assigned bicycle LTS scores to its analysis sample following the framework in Appendix A. The team followed four main steps:

- Remove non-bikeable roads (such as freeways or expressways) and score physically separated bicycle facilities
- Score road segments without bicycle facilities
- Score road segments with bicycle facilities not adjacent to a parking lane
- Score road segments with bicycle facilities adjacent to a parking lane

Table 2 – Functional Classification of the Analysis Sample in the Mid-Ohio Region

Road Classification	All segments in the analysis sample		All Segments covered by MORPC datasets		% of the analysis sample in all segments covered by MOPRC
	Length (Miles)	% in Total	Length (Miles)	% in Total	
Interstates	249.1	8.3	312.0	3.7	79.8%
Other Freeways or Expressways	95.2	3.2	123.1	1.5	77.3%
Other Principal Arterial Roads	366.6	12.3	434.0	5.2	84.5%
Minor Arterial Roads	457.7	15.3	668.1	8.0	68.5%
Major Collector Roads	466.0	15.6	678.9	8.1	68.6%
Minor Collector Roads	162.7	5.5	290.5	3.5	56.0%
Local Roads	1,189.3	39.8	5,855.3	70.0	20.3%
Total Length	2,986.6		8,361.9		35.7%

Table 3 – Main Features of the Analysis Sample in the Mid-Ohio Region

	Urban Areas		**Rural Area**	
Speed Limits	Length (Miles)	% in Total	Length (Miles)	% in Total
≤ 20 mph	17.4	1.1%	10.8	0.7%
25 mph	568.8	37.3%	153.5	10.5%
30 mph	4.3	0.3%	0.0	0.0%
35 mph	355.5	23.3%	77.4	5.3%
40 mph	28.2	1.8%	30.9	2.1%
45 mph	241.2	15.8%	352.5	24.1%
≥ 50 mph	309.4	20.3%	836.6	57.2%
Number of Lanes	Length (Miles)	% in Total	Length (Miles)	% in Total
1 – Lane	24.8	1.6%	10.0	0.7%
2 – Lane	1137.1	74.6%	1398.7	95.7%
3 – Lane	157.4	10.3%	18.7	1.3%
4 – Lane	190.0	12.5%	33.2	2.3%
5 – Lane	7.0	0.5%	0.4	0.0%
6 – Lane	8.5	0.6%	0.8	0.1%
Types of Bicycle Facilities	Length (Miles)	% in Total	Length (Miles)	% in Total
Separated Path	146.4	9.6%	35.9	2.5%
Separated Bike Lane	2.9	0.2%	0.0	0.0%
On-road Bike Lane	84.0	5.5%	5.8	0.4%
Paved Shoulder	33.6	2.2%	21.6	1.5%
Bike Lanes Alongside a Parking Lane*	5.4	0.4%	0.0	0.0%

*'Bike Lanes Alongside a Parking Lane' may refer to separated bike lanes, on-road bike lanes, or paved shoulders.

Results with available data

Figures 16 through 18 in Appendix E illustrate the outputs of the research team's bicycle LTS score assignments for the Mid-Ohio region. Using the bicycle LTS framework, the majority of the road segments in the analysis sample were assigned LTS 3 (48.8%) and LTS 4 (34.8%). This outcome does not, as it might appear, indicate that over 80% of the roadway segments in Mid-Ohio are in higher-stress categories. As presented in Table 2, the team's analysis sample does not include 80% of local roads due to missing data. In general, local roads are more likely to receive lower bicycle LTS score assignments.

Results with missing data

This section discusses the performance of the research team's bicycle LTS framework with missing data. Although the data were not actually missing, these analyses were conducted to test the performance of the team's approach. The bicycle LTS framework proposed an interim pathway to fill data gaps when data are not available and acquiring accurate data is not possible due to time and cost considerations. As speed limits and AADT are two of the most influential factors likely to be not available, the team focused on them, assessing the variations in estimated bicycle LTS assignments with *assumed speed limits* and *assumed AADT* as compared to the assignments with full data.

The team first assumed missing speed limit data for all street segments and assigned speed limits to all segments based on the bicycle LTS framework. These assignments were based on functional classification and urban/rural designation. Table 4 compares the results of the team's analysis with assumed speed limit data to those with full data. The team found that using assumed speed limits in urban areas caused more than 93.5% of street segments to receive a bicycle LTS score equal to or higher than those assigned using complete data. In rural areas, 67.8% of street segments ranked as such. The team concluded that although their criteria for missing speed limits would lead to higher (worse) LTS scores in general, particularly in urban areas, using assumed speed limits may be risky in rural areas, where about 1/3 of the roads result in lower LTS scores as compared to the results with actual data.

The team then assumed missing AADT for all street segments and replicated the steps for missing speed data as discussed above. They assigned AADT to all segments based on functional classification, and urban/rural designation. Table 5 compares the results of the team's analysis with assumed AADT data to those with full data. Consistent with the team's findings with assumed speed limits, with assumed AADT, the approach provided higher percentage matches in urban areas.

Discussion

The research team's applications using data from the Mid-Ohio region revealed that the bicycle LTS framework provided promising results when dealing with missing data. This approach can be useful when data on speed limits and AADT are not readily available and acquiring accurate data is not feasible. The team proved that their assumptions followed the weakest link principle at most times, resulting in higher (worse) LTS score assignments. This indicates the assignments err on the safe side. With this, for most cases our approach would not promise more comfortable rides as compared to the outputs of the actual data. As noted, the team's assumptions yielded more accurate predictions in urban areas than in rural ones.

Though these methods for handling missing data are promising and can prove vital to help fill unavoidable data gaps, the research team still recommends collecting all necessary data before conducting a bicycle LTS analysis. This is particularly important to note, as most local agencies in Ohio lack data one way or the other to conduct a complete bicycle LTS analysis. Although the mismatch percentages in estimated LTS score assignments are not large, they exist nevertheless. Agencies should only implement these approaches if accurate data cannot be collected and should treat them as an interim step while accurate data are collected.

Table 4 – Accuracy of Assumed Speed Limits in the Mid-Ohio Region

Urban Areas	LTS 1 using assumed speed limits	LTS 2 using assumed speed limits	LTS 3 using assumed speed limits	LTS 4 using assumed speed limits	LTS 5 using assumed speed limits	Total Length (miles)
Actual LTS 1	165.6	1.0				166.6
Actual LTS 2	1.0	95.3	33.6	0.0		129.9
Actual LTS 3	5.7	6.7	507.1	116.3		635.8
Actual LTS 4		6.2	79.1	284.9		370.2
Actual LTS 5					222.4	222.4
Rural Areas	LTS 1 using assumed speed limits	LTS 2 using assumed speed limits	LTS 3 using assumed speed limits	LTS 4 using assumed speed limits	LTS 5 using assumed speed limits	Total Length (miles)
Actual LTS 1	32.3	38.3	1.0			71.7
Actual LTS 2		8.3	22.1	2.5		32.8
Actual LTS 3		247.5	224.3	70.9		542.6
Actual LTS 4		1.7	220.5	470.5		692.7
Actual LTS 5					121.9	121.9

Matched Percentage: 83.6% in urban areas; 58.6% in rural areas

. **Table 5 – Accuracy of Assumed AADT in the Mid-Ohio Region**

Urban Areas	LTS 1 using assumed AADT	LTS 2 using assumed AADT	LTS 2 using assumed AADT	LTS 4 using assumed AADT	LTS 5 using assumed AADT	Total Length (miles)
Actual LTS 1	118.9	0.7	47.1			166.6
Actual LTS 2		70.3	59.6			129.9
Actual LTS 3		13.3	594.3	28.1		635.8
Actual LTS 4			3.8	366.3		370.2
Actual LTS 5					222.4	222.4
Rural Areas	LTS 1 using assumed AADT	LTS 2 using assumed AADT	LTS 2 using assumed AADT	LTS 4 using assumed AADT	LTS 5 using assumed AADT	Total Length (miles)
Actual LTS 1	32.3	38.3	1.0			71.7
Actual LTS 2		25.2	7.7			32.8
Actual LTS 3		71.8	259.8	211.1		542.6
Actual LTS 4			71.8	620.9		692.7
Actual LTS 5					121.9	121.9

Matched Percentage: 90.0% in urban areas: 72.5% in rural areas.

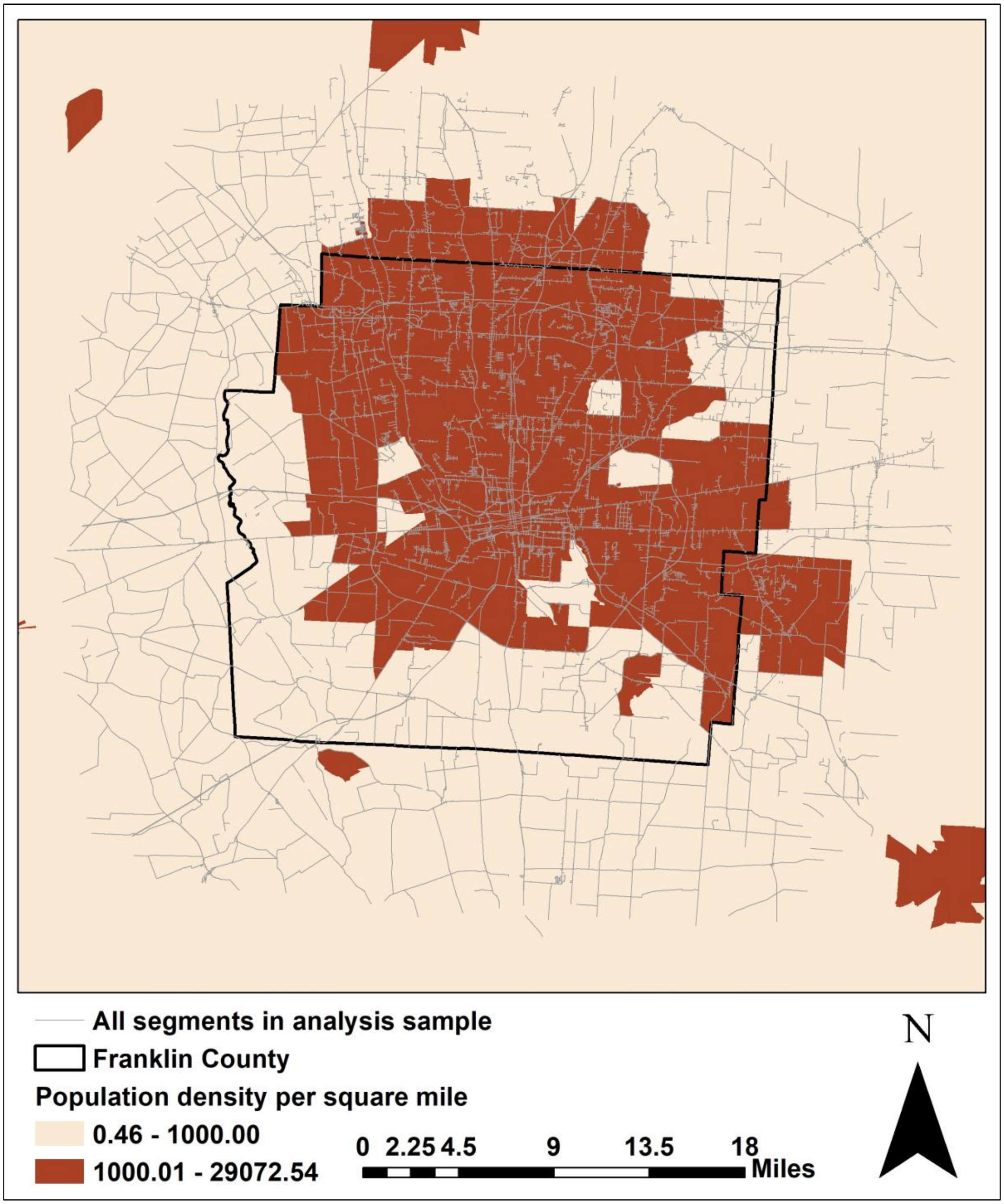

Figure 1 – Road Networks and Urban Typologies in Mid-Ohio Region

3.5.2 Lorain and Medina Counties

Introduction & Goals

NOACA completed its first application of a bicycle LTS analysis in 2017, building on the refined bicycle LTS criteria developed by Furth and his colleagues in 2017. NOACA modified Furth's criteria in several key ways, including the removal of an "Effective ADT multiplier" applied to one-way roads and the development of a set of assumptions to score roadways that were missing AADT Data. The criteria used in this study's bicycle LTS framework align closely with NOACA's criteria. The analysis focused on two of NOACA's member jurisdictions, Lorain and Medina Counties, and produced countywide bicycle LTS maps for both jurisdictions. After creating bicycle LTS maps using Furth's criteria, NOACA staff solicited public input on the map outputs to further refine their final product. The final versions of the LTS maps that NOACA developed for Lorain and Medina Counties incorporate public feedback and include a different LTS classification category: LTS 5. Roads that received an LTS 5 classification were identified by the public as 'roads to avoid,' which generally had one or more of the following characteristics: more than five lanes in either direction, very steep hills or tight curves, or a history of crashes involving cyclists.

NOACA's work allowed the research team to compare results produced by its bicycle LTS framework to results produced through another LTS analysis. The team's goals for this assessment included developing LTS maps of road segments in Lorain and Medina Counties based on the bicycle LTS framework and assessing the differences between the research team's LTS outputs (with and without missing data) and NOACA's (with and without public input). The research team's bicycle LTS framework (Appendix A) recommends that local and regional jurisdictions work with members of the public to verify bicycle LTS scores produced using full datasets. When implemented, this step should provide a more nuanced reflection of bicycle comfort on local and regional roadways. This step was not implemented during the team's research efforts, but the team's comparison of their LTS outputs with NOACA's outputs (with and without public input) underscores how the inclusion of public input can change LTS scores on roadways.

Data Sources and Coverage

The team used GIS data from NOACA's *Functional Class Dataset* layer to create the baseline road network for the analysis. Since the goal of the NOACA assessment was to gauge the differences between the research team's LTS outputs (with and without missing data) and NOACA's 2017 LTS analysis (with and without public input), the team created their own baseline road network. Since NOACA gathered additional data as part of the 2017 LTS analysis (such as the presence/absence of road centerlines and posted speed limits), these data were incorporated into the baseline road network to allow a like-for-like comparison. Table 6 summarizes the data sources for the bicycle LTS model inputs in the NOACA region.

NOACA's data inputs provided the team with a baseline road network containing most of the variables needed to conduct a bicycle LTS analysis. Of the roadway lane miles in the NOACA dataset, 3% did not include AADT data, and 23% did not include posted speed data. These data gaps were filled using the bicycle LTS framework.

NOACA's data inputs also did not include the widths of on-street bicycle facilities or the presence and width of on-street parking lanes. Assumed bicycle facility widths were assigned to roadways with bicycle facilities based on their corresponding classification as reported by the *NACTO Urban Street Design Guide*. Since data on the presence of on-street parking lanes was unavailable, the analysis assumed all on-road bicycle facilities were not located adjacent to an on-street parking lane.

Table 6 – Model Inputs and Sources in Lorain and Medina Counties

Model Inputs	Data Sources	Notes
Road Networks	**NOACA**	
Posted Speed Limits	**NOACA**	Missing speed data assumed per bicycle LTS framework
Number of Lanes	**NOACA**	
Annual Average Daily Traffic (AADT)	**NOACA**	Missing AADT data assumed per bicycle LTS framework
Bicycle Facilities (presence/types)	**NOACA**	Missing bicycle facility widths assumed per bicycle LTS framework
Parking Facilities (presence/types)	**N/A**	
Presence of Centerline	**NOACA**	
Functional Classification	**NOACA**	

The baseline road network contains data for roadways within two of NOACA's member counties: Lorain County and Medina County. This geographic distribution enabled the research team to further explore differences between urban and rural typologies and test the accuracy of the bicycle LTS framework for filling data gaps. Using the US Census Bureau's definitions for urbanized and rural areas, the team categorized block groups with a population density of at least 1,000 people per square mile as 'urban.' 311 lane miles of roadway in Lorain and Medina County fall within the 'urban' category (26%) and the remaining 897 lane miles of roadway fall within the 'rural' category (74%). Figure 2 illustrates the spatial distribution of road networks and urban typologies.

Data Processing

Data from NOACA's 2017 LTS analysis was joined to the baseline road network. The total length of the road segments in the NOACA analysis amounted to 1,204.4 miles (Table 7). Since the goal of the NOACA assessment was to gauge the differences between the research team's LTS outputs (with and without missing data) and NOACA's 2017 LTS analysis (with and without public input), the team created two additional copies of the baseline road network. The first (original) baseline road network included all data inputs, the second used assumed AADT data, and the third used assumed posted speed limit data.

Summary Statistics

Table 7 compares the roadway functional classification of the baseline roadway network with its respective population (all lane miles included in NOACA's 2017 LTS analysis). NOACA added 2,512 additional lane miles of roadway to its 2017 LTS analysis layer. Most (77%) of these new roads were local roads that did not include speed, volume, or roadway width data, and many were classified as neighborhood streets based on NOACA-specific criteria (54%). Since most of the 2,512 lane miles of new roadway were not specifically classified based on Furth's 2017 criteria, the research team did not include them in their analysis. Approximately 96% of local roads are not included in the team's analysis sample. Of the other roadway functional classification types, the segments in the analysis sample cover more than half of all lane miles in NOACA's datasets (95%). For example, the total length of minor arterial roads is 264 miles in NOACA's 2017 LTS analysis layer, and 258 miles in the baseline roadway network sample. The main features of the baseline roadway network sample are summarized in Table 8.

Table 7 – Functional Classification of the Analysis Sample in Lorain and Medina Counties

Road Classification	All Segments in the Analysis Sample		All Segments Covered by NOACA 2017 Dataset		% of the analysis sample in all segments covered by NOACA 2017
	Length (Miles)	% in Total	Length (Miles)	% in Total	
Interstates	153.8	12.8%	157.1	4.2%	97.9%
Other Freeways or Expressways	21.8	1.8%	21.8	0.6%	100.0%
Other Principal Arterial Roads	101.3	8.4%	103.7	2.8%	97.7%
Minor Arterial Roads	258.5	21.5%	264.4	7.1%	97.8%
Major Collector Roads	401.1	33.3%	413.7	11.1%	97.0%
Minor Collector Roads	78.1	6.5%	78.4	2.1%	99.6%
Local Roads	102.1	8.5%	2,563.1	68.9%	4.0%
No Classification	87.6	7.3%	119.7	3.2%	73.2%
Total Length	1,204.4		3,721.8		32.4%

Table 8 – Main Features of the Analysis Sample in Lorain and Medina Counties

	Urban Areas		**Rural Area**	
Speed Limits	Length (Miles)	% in Total	Length (Miles)	% in Total
≤ 20 mph	0.5	0.2%	0.2	0.0%
25 mph	54.5	20.0%	6.5	0.8%
30 mph	0.0	0.0%	0.0	0.0%
35 mph	164.7	60.4%	97.4	11.4%
40 mph	11.4	4.2%	12.9	1.5%
45 mph	28.1	10.3%	128.8	15.1%
≥ 50 mph	13.5	4.9%	410.6	48.2%
Unknown	0.0	0.0%	195.2	22.9%
Number of Lanes	Length (Miles)	% in Total	Length (Miles)	% in Total
1 – Lane	0.1	0.0%	0.2	0.0%
2 – Lane	220.6	61.9%	627.7	73.7%
3 – Lane	1.9	0.5%	2.7	0.3%
4 – Lane	49.7	13.9%	19.8	2.3%
5 – Lane	0.0	0.0%	0.2	0.0%
6 – Lane	0.5	0.1%	4.9	0.6%
6+ – Lane	0.1	0.0%	0.3	0.0%
Unknown	83.3	23.4%	195.7	23.0%
Types of Bicycle Facilities	Length (Miles)	% in Total	Length (Miles)	% in Total
Separated Path	3.0	0.8%	3.3	0.4%
Separated Bike Lane	0.0	0.0%	0.0	0.0%
On-road Bike Lane	14.1	4.0%	1.9	0.2%
Paved Shoulder	17.8	5.0%	75.7	8.9%

Bicycle LTS Score Assignment Process

The research team assigned bicycle LTS scores to their baseline roadway network sample in accordance with the bicycle LTS framework in Appendix A. They followed four main steps:

1. Remove non-bikeable roads (such as freeways or expressways), and score bicycle facilities that are physically separated from motor traffic (e.g. shared-use path, side path, trail, or cycle track)
    a. 363.78 lane miles (30%) of the baseline roadway network were classified during this step
2. Score segments without bicycle facilities
    a. 754.94 lane miles (63%) of the baseline roadway network were classified during this step
3. Score road segments with bicycle facilities not adjacent to a parking lane (all on-road bicycle facilities in the NOACA assessment)
    a. 85.72 lane miles (7%) of the baseline roadway network were classified during this step
4. Score road segments with bicycle facilities adjacent to a parking lane

Results with actual data

Figure 19 in Appendix E illustrates the bicycle LTS scores assigned to the baseline roadway network by the bicycle LTS framework. Based on the team's application of the bicycle LTS framework, 1.0% of roadways scored LTS 1, 3.3% scored LTS 2, 25.2% scored LTS 3, and 40.8% scored LTS 4. An additional 29.7% of roadways received a score of LTS 5 (non-bikeable roads such as freeways, expressways, and other principal arterial roads). As noted in Table 7, the team's analysis sample did not include 96% of local roads, which are more likely to score LTS 1 or LTS 2.

Table 9 compares the results of the team's analysis with the results of NOACA's 2017 LTS analysis, first with public input, and then without public input. NOACA used different assumptions to fill data gaps, so these two approaches do not produce perfect matches. The results from NOACA's 2017 LTS analysis that incorporated public feedback have a slightly lower percentage match with the research team's baseline roadway network analysis than results that did not incorporate public feedback.

Table 9 – Comparison of Bicycle LTS Framework Analysis to NOACA Analysis

NOACA's assignments with Public Input	Team's LTS score assignments with actual data (miles)					Total Length (miles)
	LTS 1	LTS 2	LTS 3	LTS 4	LTS 5	
LTS 1	11.9	1.1				13.0
LTS 2	1.2	37.9	2.1			41.2
LTS 3	2.5	2.6	281.2	7.9		294.1
LTS 4			31.5	463.5		495.0
LTS 5			12.3	80.1	0.2	92.6
NOACA's assignments without Public Input	Team's LTS score assignments with actual data (miles)					Total Length (miles)
	LTS 1	LTS 2	LTS 3	LTS 4	LTS 5	
LTS 1	4.0					4.0
LTS 2	1.1	1.2				2.3
LTS 3	4.5	14.5	296.2			315.2
LTS 4	2.6	25.4	31.8	479.96		60.2
LTS 5		0.4		7.37	60.07	547.5

Matched Percentage: 84.9% with public input; 90.6% without public input.

Results with assumed data

In addition to comparing its LTS outputs and NOACA's (without public input), the research team compared its LTS outputs with missing data with NOACA's. The bicycle LTS framework proposes an interim pathway to fill data gaps when acquiring accurate data may not be feasible due to time and cost considerations. The following analyses focused on variations in assumed bicycle LTS scores with assumed speed limits and assumed AADT as compared to NOACA's 2017 LTS analysis.

The first test assumed missing speed limit data for all street segments and assigned speed limits to all segments based on the research team's bicycle LTS framework. The assignments were informed by functional classification and each roadway's urban/rural designation. Table 10 compares the results of the team's analysis with assumed speed limit data to the results of the NOACA 2017 LTS analysis with full data and without public input. The team's analysis showed that using assumed speed limits produced a 65% match with NOACA's 2017 LTS analysis. A remaining 20% of scores underestimate roadway comfort (higher scores than NOACA's 2017 LTS analysis), and 15% overestimate roadway comfort (lower scores than NOACA's 2017 LTS analysis).

The second test assumed missing AADT data for all street segments and assigned AADT data to all segments based on the bicycle LTS framework. The assignments were informed by functional classification and each roadway's urban/rural designation. Table 11 compares the results of the team's analysis with assumed speed limit data to the results of the NOACA 2017 LTS analysis with full data and without public input. The team's analysis showed that using assumed AADT produces an 81% match with NOACA's 2017 LTS analysis; 12% of scores underestimate roadway comfort (higher scores than NOACA's 2017 LTS analysis), and 7% overestimate roadway comfort (lower scores than NOACA's 2017 LTS analysis).

Discussion

The research team's application using data from NOACA on a subset of NOACA's roadway network (32.4%) showed that the bicycle LTS framework provides similar results to NOACA's 2017 LTS approach. It supports findings from the team's MORPC assessment that this proposed approach to filling data gaps can be useful when data on speed limits and AADT are not readily available. We note that the MORPC and NOACA samples were not similar. Scores produced using assumed AADT tend to match scores produced using full data more than scores produced using assumed speed limits. Scores produced using either assumed AADT or speed limit data tend to underestimate roadway comfort (higher LTS score assignments), providing a conservative estimate when specific data are not available. However, it should be noted that some LTS scores overestimated roadway comfort (lower LTS score assignments) on roadways that fall within the LTS 4 category when using full data. The stress level on high stress roadways should not be underreported to the public. In any scenario where assumed AADT or speed limit scores are used to estimate bicycle LTS scores, these scores should be reported as assumed. As recommended in preceding sections, agencies should prioritize filling data gaps when possible before applying the bicycle LTS framework.

Table 10 – Accuracy of Assumed Speed in the NOACA Region (without public inputs)

	LTS 1 using assumed speed limits	LTS 2 using assumed speed limits	LTS 3 using assumed speed limits	LTS 4 using assumed speed limits	LTS 5 using assumed speed limits	Total Length (miles)
Actual LTS 1	9.6	0.5	2.8			13.0
Actual LTS 2	5.5	4.1	28.1	3.5		41.2
Actual LTS 3	0.4	9.6	135.8	148.4		294.1
Actual LTS 4	0.0	1.0	136.3	357.7		495.0
Actual LTS 5			23.4	69.0	0.2	92.6

Matched Percentage: 54.2%

Table 11 – Accuracy of Assumed AADT in the NOACA Region (without public inputs)

	LTS 1 using assumed AADT	LTS 2 using assumed AADT	LTS 2 using assumed AADT	LTS 4 using assumed AADT	LTS 5 using assumed AADT	Total Length (miles)
Actual LTS 1	9.6	1.3	2.0			13.0
Actual LTS 2	1.5	24.8	14.9			41.2
Actual LTS 3	0.0	0.6	244.9	48.7		294.1
Actual LTS 4	0.0	0.1	48.4	446.5		495.0
Actual LTS 5			18.5	73.9	0.2	92.6

Matched Percentage: 77.6%

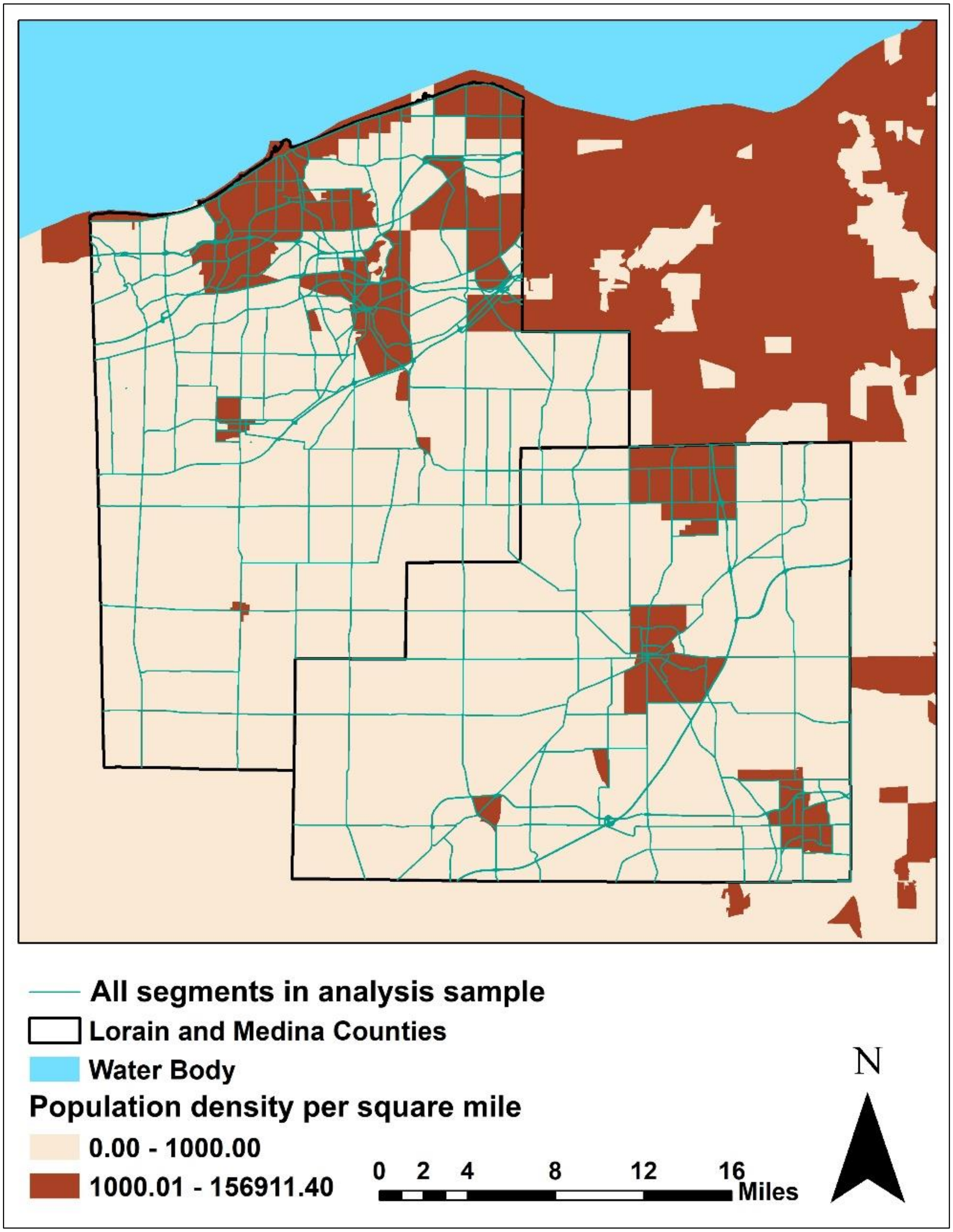

Figure 2 – Road Networks and Urban/Rural Typologies in Lorain and Medina Counties

3.5.3 Ohio Statewide Roadway Network

Introduction & Goals

ODOT maintains statewide GIS data through TIMS. TIMS contains much of the data needed to conduct a bicycle LTS analysis on U.S. routes and State routes, so many localities may look to this dataset as a springboard for developing their own bicycle LTS maps. Some principal arterial roads with full access control or partial access (i.e., interstates, and other freeways and expressways) in the ODOT data are labelled as non-bikeable roads. The research team's goals for this assessment included developing LTS maps of state roads in all ODOT districts using the bicycle LTS framework.

Data Sources and Coverage

The research team used GIS data from the *WGIS Road Inventory – Functional Class, WGIS AADT Segments*, and *Active Bike Routes* layers to create the baseline road network for the analysis. Table 12 summarizes the data sources for the bicycle LTS model inputs using ODOT data. ODOT TIMS data supplied a baseline road network containing most of the variables needed to conduct a bicycle LTS analysis. 0.2% of lane miles in the ODOT data did not include AADT data, and 0.2% of roadway lane miles did not include posted speed data. The team filled these data gaps using the bicycle LTS framework. It should be noted that ODOT recognizes reliability issues of ODOT TIMS posted speed data can vary by ODOT District.

Of the lane miles in the ODOT data, 0.2% did not include lane width data. However, 87.8% of lane miles of missing lane data fell along roadways that could be classified without lane width, AADT, or speed data (i.e., interstates, other freeways or expressways, and other principal arterial roads). The remaining 12.2% of lane miles without lane width data could not be immediately classified using the bicycle LTS framework (0.03% of total lane miles in the ODOT data).

ODOT's data inputs did not include the widths of on-street bicycle facilities, the presence and widths of on-street parking lanes, or the presence or absence of centerlines. Assumed bicycle facility widths were assigned to roadways with bicycle facilities based on their corresponding classification as reported by the *NACTO Urban Street Design Guide*. Since data on the presence of on-street parking lanes was unavailable, the analysis assumed all on-road bicycle facilities were not located adjacent to an on-street parking lane. To produce conservative outputs (i.e., overestimate bicycle LTS), the research team assumed that all roads in the baseline road network have a centerline.

Table 12 – Model Inputs and Sources for ODOT District Maps

Model Inputs	Data Sources	Notes
Road Networks	**TIMS**	
Posted Speed Limits	**TIMS**	Missing speed data assumed per bicycle LTS framework
Number of Lanes	**TIMS**	Missing lane width data assumed using pavement width data
AADT	**TIMS**	Missing AADT data assumed per bicycle LTS framework
Bicycle Facilities (presence/types)	**TIMS**	Missing bicycle facility widths assumed per bicycle LTS framework
Parking Facilities (presence/types)	**N/A**	
Presence of Centerline	**N/A**	Assumed that all roads have a centerline
Functional Classification	**TIMS**	

The baseline road network contains data for roadways across Ohio. This geographic distribution enabled the research team to apply the bicycle LTS framework approach to fill data gaps based on urban and rural typologies. Using the US Census Bureau's definitions for urbanized and rural areas, the team categorized block groups with a population density of at least 1,000 people per square mile as 'urban.' Figure 3 illustrates the spatial distribution of road networks and urban typologies. 3,338 lane miles of roadway in the analysis sample fall within the 'urban' category (13%) and the remaining 22,285 lane miles of roadway fall within the ‘rural’ category (87%). Figure 2 illustrates the spatial distribution of road networks and urban typologies.

Data Processing
ODOT roads with the following route types were included in the analysis: interstate route, state route, US route. The research team joined TIMS AADT, bike route, and road inventory data to create the baseline roadway network. The combined length of the road segments in the ODOT analysis totaled 25,623.2 miles (Table 13).

Summary Statistics
Table 13 outlines the functional classification of the baseline roadway network. The main features of the baseline roadway network sample are summarized in Table 14.

Bicycle LTS Score Assignment Process
The research team assigned bicycle LTS scores to its baseline roadway network sample in accordance with the bicycle LTS framework in Appendix A. They followed four main steps:

1. Remove non-bikeable roads, such as freeways or expressways, and score bicycle facilities that are physically separated from motor traffic (e.g. shared use path, side path, trail, or cycle track)
    a. 8,039 lane miles (31.4%) of the baseline roadway network were classified during this step
2. Score segments without bicycle facilities
    a. 17,576 lane miles (68.6%) of the baseline roadway network were classified during this step
3. Score road segments with bicycle facilities not adjacent to a parking lane (all on-road bicycle facilities in the NOACA assessment)
4. Score road segments with bicycle facilities adjacent to a parking lane

7.8 lane miles (0.03%) of the baseline roadway network remained unclassified following the bicycle LTS score assignment process.

Results
Figure 20 Appendix E illustrates the bicycle LTS scores assigned to the baseline roadway network within Ohio by the bicycle LTS framework. Based on the research team’s application of the framework, 0.4% of roadways scored LTS 1, 0.6% scored LTS 2, 16.1% scored LTS 3, and 51.8% scored LTS 4. An additional 21.0% of roadways received a score of LTS 5 (these were non-bikeable roads such as freeways, expressways, and other principal arterial roads), and 0.03% of roads remained unclassified due to missing lane width data. As noted previously, the baseline roadway network comprised interstate routes, state routes, and US routes, which are more likely to score LTS 3, LTS 4, or LTS 5.

Discussion
The research team’s application using data from ODOT’s TIMS dataset shows that the bicycle LTS framework may be efficiently applied at a statewide level. When ODOT has completed ongoing updates to the State Bike Route System data, this bicycle LTS analysis could be specifically applied to state bike routes that fall within the TIMS dataset. The LTS framework leverages the ODOT dataset to assess the large area. This preliminary analysis highlights a diverse network across Ohio with major routes and facilities scoring as high-stress. There are some challenges with broad generalizations on this analysis as bicycle trips are shorter in distance and the analysis should reflect user characteristics. A microscopic level analysis may be better suited for bicycle planning purposes.

Ongoing ODOT efforts for continued data gathering and validation are being conducted through other projects and it is anticipated that the bicycle LTS analysis can be refined as additional data is incorporated into ODOT's datasets.

Table 13 – Functional Classification of the ODOT Analysis Sample

Road Classification	All Segments in the Analysis Sample	
	Length (Miles)	% in Total
Interstates	2,073.5	8.1%
Other Freeways or Expressways	1,001.5	3.9%
Other Principal Arterial Roads	4,873.9	19.0%
Minor Arterial Roads	5,746.4	22.4%
Major Collector Roads	10,467.0	40.8%
Minor Collector Roads	1,454.5	5.7%
Local Roads	6.3	0.02%
No Classification	0.0	0.0%
Total Length	25,623.2	

Table 14 – Main Features of the ODOT Analysis Sample

	Urban Areas		**Rural Area**	
Speed Limits	Length (Miles)	% in Total	Length (Miles)	% in Total
≤ 20 mph	4.6	0.1%	6.6	0.0%
25 mph	355.3	10.6%	193.4	0.9%
30 mph	15.5	0.5%	6.1	0.0%
35 mph	1286.7	38.5%	1658.3	7.4%
40 mph	155.4	4.7%	375.5	1.7%
45 mph	273.6	8.2%	1366.5	6.1%
≥ 50 mph	1239.1	37.1%	18623.0	83.6%
Unknown	8.0	0.2%	55.6	0.2%
Number of Lanes	Length (Miles)	% in Total	Length (Miles)	% in Total
1 – Lane	1.5	0.0%	3.6	0.0%
2 – Lane	1171.2	35.1%	18033.3	80.9%
3 – Lane	56.2	1.7%	61.6	0.3%
4 – Lane	1462.5	43.8%	3450.6	15.5%
5 – Lane	45.8	1.4%	33.6	0.2%
6 – Lane	431.0	12.9%	574.7	2.6%
6+ – Lane	162.0	4.9%	72.0	0.3%
Unknown	8.0	0.2%	55.6	0.2%
Types of Bicycle Facilities	Length (Miles)	% in Total	Length (Miles)	% in Total
Separated Path	25.4	0.8%	40.5	0.2%
Separated Bike Lane	3.1	0.1%	65.0	0.3%
On-road Bike Lane	0.0	0.0%	0.0	0.0%
Paved Shoulder	0.0	0.0%	0.0	0.0%

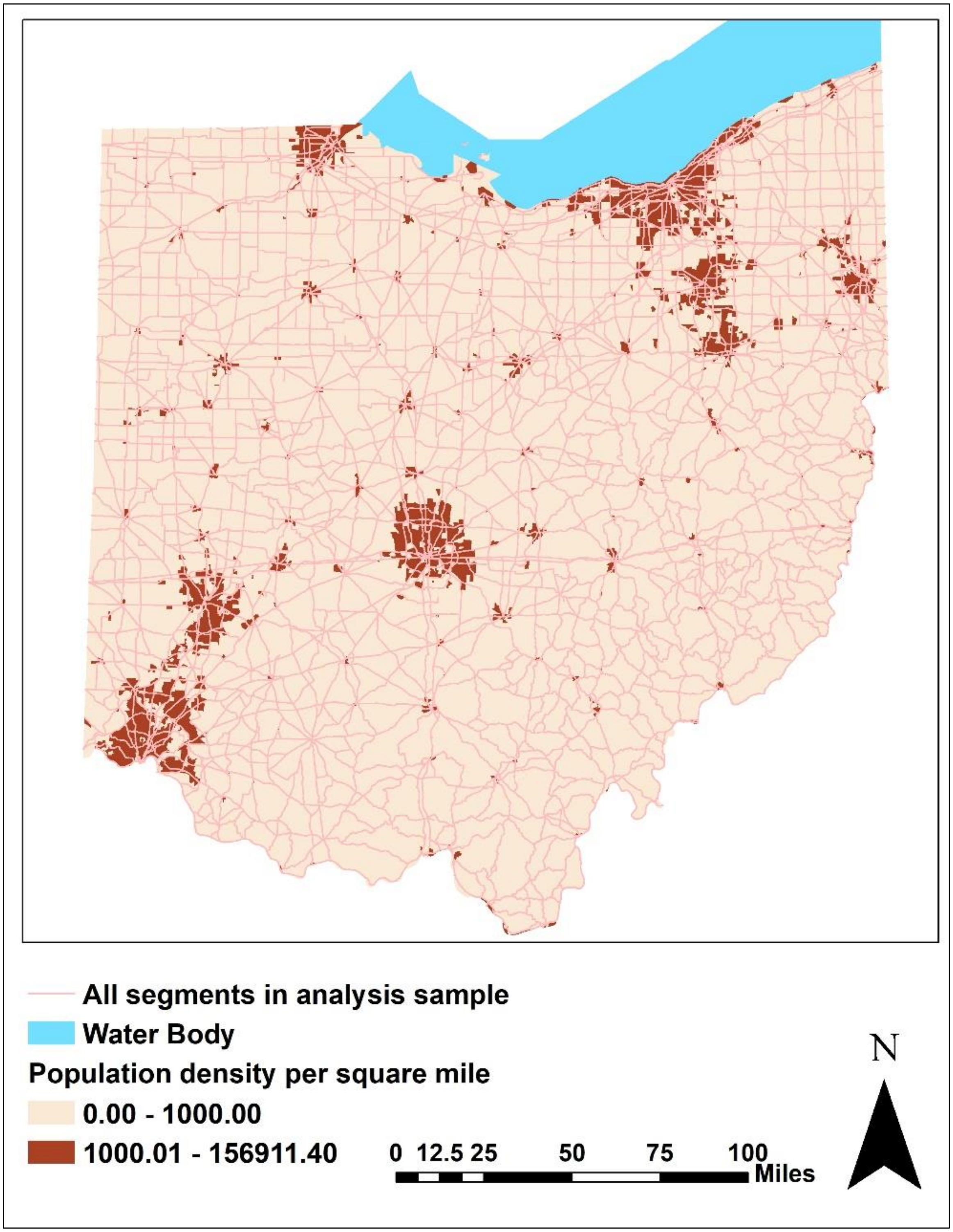

Figure 3 – Road Networks and Urban/Rural Typologies in Ohio

4. CONCUSIONS AND FUTURE DIRECTIONS

This study developed a bicycle LTS framework based on Ohio's data sources. Although there is no consensus on how bicyclist comfort should be measured, bicycle LTS is the approach most widely used by transportation professionals in recent years. After reviewing existing academic literature and state-of-the-art practices and conducting interviews with various Ohio agencies in terms of their needs and ability to access to required model-specific data and use cases, the research team recommends the use of bicycle LTS analysis as the measurement tool for the State of Ohio.

Stakeholder interviews and data assessment outcomes indicate that most local jurisdictions in Ohio do not have access to all relevant data for a complete bicycle LTS analysis. Therefore, this study extended the original bicycle LTS framework by formulating effective methods of dealing with missing data based on Ohio's functional classification system and existing data on speed limits, traffic volumes and bicycle facility widths.

Although this approach enables agencies to conduct bicycle LTS analysis when critical data elements are missing (such as posted speed limits, traffic volumes, and bicycle facility widths), it may produce partially incorrect assignments. For instance, analyses based on Mid-Ohio region data show that in cases where road traffic volumes are missing, the research team's approach replicates the results with an 18.6% mismatch in bicycle LTS score assignments overall. The mismatch percentage breaks down to a 10.0% in urban areas and a 27.1% in rural areas. Given this outcome, the research team recommends that local communities collect all necessary data before conducting a bicycle LTS analysis. The team's approach to handling missing data can help when collecting accurate data is not feasible due to time and cost considerations, and in cases where interim and temporary results may prove useful while acquiring these data. We note that most of the case study datasets did not cover local road segments. Filling these data gaps is crucial for comprehensive applications of the bicycle LTS framework.

Opportunities to expand upon this research include further refinement of the urban/rural dichotomy for developing assumed LTS scores and assessing LTS processes for intersection approaches. The team recommends collecting data about rural facilities and bicyclists who ride on rural roadways to refine the bicycle LTS framework. Efforts within this project identified gaps in the bicycle LTS analysis for rural areas however the bicycle LTS framework can be refined to integrate a wider range of facility and rider characteristics.

Additional opportunities for refining the bicycle LTS framework include assessing intersections and expanding the analysis of urban roadway conditions to include driveways and various curb-side activity. The current bicycle LTS framework integrates roadway characteristics that can be utilized for most Ohio agencies. The framework can be expanded to provide a more detailed assessment for agencies that have a more robust data set that may include curb-side activity such as bus stops and loading zones. Additionally, the bicycle LTS framework focuses on segment-level characteristics but can integrate analysis for intersections, signalized and unsignalized. Expanding the bicycle LTS framework can provide a more robust tool for all agencies across Ohio.

The team also recommends testing how the outputs of a bicycle LTS analysis can be used to inform planning efforts within Ohio. A preliminary effort for leveraging bicycle LTS analysis is to identify performance measures that could assist with agency efforts for bicycle facility planning. Communities that incorporate their LTS analysis results into a routable network can conduct connectivity analyses to provide a network-descriptive depiction of bicycle accessibility. These analyses can be used to explore bicycle access to jobs, schools, activity centers, healthcare destinations, and other key destinations. They can inform health impact assessments (HIA), premium transit station planning, and bicycle facility planning. For example, communities can conduct sensitivity analyses where groups of planned or proposed bicycle projects are incorporated into the LTS network to calculate the effects of overall network connectivity. Such analyses can help communities identify the most effective projects and quantify the benefits offered by each one to stakeholders and the public at large.

5. BIBLIOGRAPHY

Akar, G., & Clifton, K. J. (2009). Influence of individual perceptions and bicycle infrastructure on decision to bike. *Transportation Research Record, 2140*(1), 165-172.

Aultman-Hall, L., Hall, F. L., & Baetz, B. B. (1997). Analysis of bicycle commuter routes using geographic information systems: implications for bicycle planning. *Transportation Research Record, 1578*(1), 102-110.

Berkeley City Council (2017). Berkeley Bicycle Plan. Retrieved from: https://www.cityofberkeley.info/berkeleybikeplan

Broach, J., & Bigazzi, A. Y. (2017). Existence and use of low-pollution route options for observed bicycling trips. *Transportation Research Record, 2662*(1), 152-159.

Broach, J., Dill, J., & Gliebe, J. (2012). Where do cyclists ride? A route choice model developed with revealed preference GPS data. *Transportation Research Part A: Policy and Practice, 46*(10), 1730-1740.

Buehler, T., & Handy, S. (2008). Fifty years of bicycle policy in Davis, California. *Transportation Research Record, 2074*(1), 52-57.

Carter, D. L., Hunter, W. W., Zegeer, C. V., Stewart, J. R., & Huang, H. F. (2006). *Pedestrian and bicyclist intersection safety indices* (No. FHWA-HRT-06-125). United States. Federal Highway Administration. Office of Research, Development, and Technology.

Casello, J. M., & Usyukov, V. (2014). Modeling cyclists' route choice based on GPS data. *Transportation Research Record, 2430*(1), 155-161.

Chen, P., Shen, Q., & Childress, S. (2018). A GPS data-based analysis of built environment influences on bicyclist route preferences. *International Journal of Sustainable Transportation, 12*(3), 218-231.

Dill, J. (2009). Bicycling for transportation and health: the role of infrastructure. *Journal of public health policy, 30*(1), S95-S110.

Dock, S., Westrom, R., Lee, K., Cesme, B., Sanders, M., Pochowski, A., Kittelson & Associates, Inc, Miller, D. & Recchia, A. (2017). *District Mobility Project.* Retrieved from: https://www.districtmobility.org/documents/district-mobility-project-summary-report.pdf

Dowling, R., Flannery, A., Landis, B., Petritsch, T., Rouphail, N., & Ryus, P. (2008). Multimodal level of service for urban streets. *Transportation Research Record, 2071*(1), 1-7.

Eom, J. K., Park, M. S., Heo, T. Y., & Huntsinger, L. F. (2006). Improving the prediction of annual average daily traffic for nonfreeway facilities by applying a spatial statistical method. *Transportation Research Record, 1968*(1), 20-29.

Evans-Cowley, J. S., & Akar, G. (2014). StreetSeen visual survey tool for determining factors that make a street attractive for bicycling. *Transportation Research Record, 2468*(1), 19-27.

Félix, R., Moura, F., & Clifton, K. J. (2017). Typologies of urban cyclists: review of market segmentation methods for planning practice. *Transportation Research Record, 2662*(1), 125-133.

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

Furth (2017). Level of Traffic Stress Criteria for Road Segments, version 2.0, June 2017. Retrieved from: http://www.northeastern.edu/peter.furth/wp-content/uploads/2014/05/LTS-Tables-v2-June-1.pdf

Furth, P. G., Putta, T. V., & Moser, P. (2018). Measuring low-stress connectivity in terms of bike-accessible jobs and potential bike-to-work trips: A case study evaluating alternative bike route alignments in northern Delaware. *Journal of Transport and Land Use, 11*(1).

Geller, R. (2012). Four Types of Cyclists. Portland Bureau of Transportation, Portland, Ore., 2006.

Goodno, M., McNeil, N., Parks, J., & Dock, S. (2013). Evaluation of Innovative Bicycle Facilities in Washington, DC: Pennsylvania Avenue Median Lanes and 15th Street Cycle Track. *Transportation Research Record, 2387*(1), 139-148.

Gordon, E., & Semler, C. (2016). Building a Bike Network That Works: Level of Traffic Stress Methodology and Separated Facility Network Recommendations. *Baltimore, MD.*

Griswold, J. B., Yu, M., Filingeri, V., Grembek, O., & Walker, J. L. (2018). A behavioral modeling approach to bicycle level of service. *Transportation Research Part A: Policy and Practice, 116*, 166-177.
Hallett, I., Luskin, D., & Machemehl, R. B. (2006). *Evaluation of on-street bicycle facilities added to existing roadways.* Center for Transportation Research, The University of Texas at Austin.
Harkey, D. L., Reinfurt, D. W., & Knuiman, M. (1998). Development of the bicycle compatibility index. *Transportation Research Record, 1636*(1), 13-20.
Highway Capacity Manual, Update of the Third Edition (1994). Transportation Research Board of the National Academies, Washington, DC.
Highway Capacity Manual, Fifth Edition (2010). Transportation Research Board of the National Academies, Washington, DC.
Federal Highway Administration. (2013). Highway functional classification concepts, criteria and procedures. Retrieved from: https://www.fhwa.dot.gov/planning/processes/statewide/related/highway_functional_classifications/fcauab.pdf
Jensen, S. U. (2013, January). Pedestrian and bicycle level of service at intersections, roundabouts and other crossings. In 92nd Annual Meeting of the Transportation Research Board, Washington, DC.
Jensen, S. U. (2007). Pedestrian and bicyclist level of service on roadway segments. *Transportation Research Record, 2031*(1), 43-51.
Kang, K., & Lee, K. (2012). Development of a bicycle level of service model from the user's perspective. *KSCE Journal of Civil Engineering, 16*(6), 1032-1039.
Kent, M., & Karner, A. (2019). Prioritizing low-stress and equitable bicycle networks using neighborhood-based accessibility measures. *International Journal of Sustainable Transportation, 13*(2), 1-11.
Krenn, P. J., Oja, P., & Titze, S. (2014). Route choices of transport bicyclists: a comparison of actually used and shortest routes. *International journal of behavioral nutrition and physical activity, 11*(1), 31.
LaMondia, J. J., & Moore, N. (2015). Using bicycle level of service for decision making comparison of common bicycle level-of-service measures, roadway characteristics, and perceived bike route suitability. *Transportation Research Record, 2520*, 123-131.
Landis, B. W., Vattikuti, V. R., & Brannick, M. T. (1997). Real-time human perceptions: toward a bicycle level of service. *Transportation Research Record, 1578*(1), 119-126.
Landis, B. W., Vattikuti, V. R., Ottenberg, R. M., Petritsch, T. A., Guttenplan, M., & Crider, L. B. (2003). Intersection level of service for the bicycle through movement. *Transportation Research Record, 1828*(1), 101-106.
Lowry, M. B., Furth, P., & Hadden-Loh, T. (2016). Prioritizing new bicycle facilities to improve low-stress network connectivity. *Transportation Research Part A: Policy and Practice, 86*, 124-140.
Majumdar, B. B., & Mitra, S. (2018). Development of Level of Service Criteria for Evaluation of Bicycle Suitability. *Journal of Urban Planning and Development, 144*(2), 04018012.
McNeil, N. (2011). Bikeability and the 20-min neighborhood: How infrastructure and destinations influence bicycle accessibility. *Transportation Research Record, 2247*(1), 53-63.
Methods and Practices for Setting Speed Limits: An Informational Report - Safety | Federal Highway Administration. (n.d.). Retrieved from: https://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa12004/
Mekuria, M. C., Furth, P. G., & Nixon, H. (2012). Low-stress bicycling and network connectivity. Retrieved from: https://scholarworks.sjsu.edu/mti_publications/74/
Misra, A., & Watkins, K. (2017). Modeling Cyclists' Willingness to Deviate from Shortest Path Using Revealed Preference Data (No. 17-03556).
Montgomery County Bicycle Planning Guidance (2014). Montgomery County Planning Department, Silver Spring, MD, and the Metropolitan Washington Council of Governments, Washington, DC. Retrieved from:

http://www.montgomeryplanning.org/transportation/bikeways/documents/FINALBicyclePlanningGuidance.pdf.

National Association of City Transportation Officials (NACTO) Urban Street Design Guide (2017, November 13). Retrieved from https://nacto.org/publication/urban-street-design-guide/

Ohio Revised Code. Chapter 4511: TRAFFIC LAWS - OPERATION OF MOTOR VEHICLES. (n.d.). Retrieved from http://codes.ohio.gov/orc/4511

Park, Y., & Akar, G. (2019). Why do bicyclists take detours? A multilevel regression model using smartphone GPS data. *Journal of Transport Geography, 74,* 191-200.

Parks, J., Tanaka, A., Ryus, P., Monsere, C. M., McNeil, N., & Goodno, M. (2013). Assessment of three alternative bicycle infrastructure quality-of-service metrics. *Transportation Research Record, 2387*(1), 56-65.

Petritsch, T. A., Landis, B. W., Huang, H. F., McLeod, P. S., Lamb, D., Farah, W., & Guttenplan, M. (2007). Bicycle level of service for arterials. *Transportation Research Record, 2031*(1), 34-42.

Prabhakar, R., & Rixey, R. A. (2017). Impacts of level of traffic stress on bikeshare ridership in the case of Capital Bikeshare in Montgomery County, Maryland. *Transportation Research Record, 2662*(1), 168-178.

Providelo, J. K., & da Penha Sanches, S. (2011). Roadway and traffic characteristics for bicycling. *Transportation, 38*(5), 765.

Pucher, J., & Buehler, R. (2008). Making cycling irresistible: lessons from the Netherlands, Denmark and Germany. *Transport reviews, 28*(4), 495-528.

Pucher, J., Buehler, R., Bassett, D. R., & Dannenberg, A. L. (2010). Walking and cycling to health: a comparative analysis of city, state, and international data. *American journal of public health, 100*(10), 1986-1992.

Rybarczyk, G., & Wu, C. (2010). Bicycle facility planning using GIS and multi-criteria decision analysis. *Applied Geography, 30*(2), 282-293.

San Francisco Department of Public Health, 2009. Bicycle Environmental Quality Index (BEQI). *Draft Report*. SFDPH, 2009.

Scrivener, A (2015). *Transportation Equity in San Diego Bicycle Networks: Using Traffic Stress Levels to Evaluate Bicycle Facilities* (Doctoral dissertation, San José State University).

Selby, B., & Kockelman, K. M. (2013). Spatial prediction of traffic levels in unmeasured locations: applications of universal kriging and geographically weighted regression. *Journal of Transport Geography, 29*, 24-32.

Semler, C., Sanders, M., Buck, D., Dock, S., Cesme, B., & Wang, S. (2018). The Keys to Connectivity: The District of Columbia's Innovative Approach to Unlocking Low-Stress Bicycle Networks. *Transportation Research Record, 2672*(36), 63-72.

Sener, I. N., Eluru, N., & Bhat, C. R. (2009). An analysis of bicycle route choice preferences in Texas, US. *Transportation, 36*(5), 511-539.

Sorton, A., & Walsh, T. (1994). Bicycle stress level as a tool to evaluate urban and suburban bicycle compatibility. *Transportation Research Record, 1438*, 17-24.

Wang, H., Palm, M., Chen, C., Vogt, R., & Wang, Y. (2016). Does bicycle network level of traffic stress (LTS) explain bicycle travel behavior? Mixed results from an Oregon case study. *Journal of Transport Geography, 57*, 8-18.

Wang, K., & Akar, G. (2018a). Street intersection characteristics and their impacts on perceived bicycling safety. *Transportation Research Record, 2672* (46), 41-54.

Wang, K., & Akar, G. (2019). Gender gap generators for bike share ridership: Evidence from Citi Bike system in New York City. *Journal of Transport Geography, 76,* 1-9.

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

Wang, K., Akar, G., & Chen, Y. J. (2018). Bike sharing differences among millennials, Gen Xers, and baby boomers: Lessons learnt from New York City's bike share. *Transportation Research Part A: Policy and Practice, 116*, 1-14.

Watkins, K. E., LeDantec, C., Misra, A., Asad, M., Mingus, C., Bearn, C., Poznanski, A., Guo, A., Ammanamanchi, R., Gentry, V., & Gooze, A. (2016). *Using crowdsourcing to prioritize bicycle network improvements* (No. FHWA-GA-16-1439). Georgia. Dept. of Transportation. Office of Materials & Research.

Winters, M. L. (2011). *Improving public health through active transportation: Understanding the influence of the built environment on decisions to travel by bicycle* (Doctoral dissertation, University of British Columbia).

Winters, M., Teschke, K., Grant, M., Setton, E. M., & Brauer, M. (2010). How far out of the way will we travel? Built environment influences on route selection for bicycle and car travel. *Transportation Research Record*, *2190*(1), 1-10.

Zimmermann, M., Mai, T., & Frejinger, E. (2017). Bike route choice modeling using GPS data without choice sets of paths. *Transportation Research Part C: Emerging Technologies*, *75*, 183-196.

Zuniga-Garcia, N., Ross, H. W., & Machemehl, R. B. (2018). Multimodal Level of Service Methodologies: Evaluation of the Multimodal Performance of Arterial Corridors. *Transportation Research Record*, *2672*(15), 142-154.

APPENDIX A: Bicycle LTS Framework for Ohio

Introduction

Bicycle level of traffic stress (LTS) rating serves communities by characterizing roadway facilities relative to bicycling stress levels. People can use bicycle LTS to understand how roadways match their individual bicycling levels and plan bicycle trips to access residences, places of work, businesses, community centers, and more that match their individual bicycling levels. A bicycle LTS framework can serve Ohio by providing a standardized way for communities across the state to characterize, assign, and communicate bicycle LTS scores to their roadway networks at a macroscopic planning level. Other factors, such as topography and land use (i.e., freight-generating land uses), bicycle facility designs, and intersection treatments also influence bicycle LTS. The intent of bicycle LTS analysis is to serve as a starting point of bicycle facility planning and network assessment and should be used in conjunction with project development process for implementations. While a bicycle LTS analysis is most powerful when conducted with a complete roadway data set, many communities across the US are still working to compile comprehensive roadway data. This framework provides an interim pathway to filling data gaps and completing a baseline bicycle LTS analysis. Continued refinement of regional and local datasets will be required to achieve higher levels of accuracy in bicycle LTS mapping. Segment level bicycle LTS does not provide a final or complete picture of cyclist comfort on any given roadway. Bicycle LTS may be used as one planning tool among a range of planning tools to identify and prioritize roadways for further detailed alternatives assessments (preliminary engineering and feasibility assessments).

What is LTS?

Bicycle LTS is a four-point scoring system that indicates how comfortable a road is for different types of cyclists:

Comfortable for **most** cyclists	Comfortable for **many** cyclists	Comfortable for **some** cyclists	Comfortable for **few** cyclists

Figure 4 – Four different types of cyclists

The broad definitions for each bicycle LTS category may be fine-tuned by different communities to use messaging that resonates with the public.

Why is bicycle LTS helpful?

Bicycle LTS is a simple communication tool that can help the public understand which roads are most comfortable for bicycle travel. It is also a useful planning tool to help communities plan for and connect comfortable bicycle networks.

***Weakest Link Principle**: Each roadway segment is assigned a bicycle LTS score based on its worst-performing metric.*

Figure 5 shows how bicycle LTS can be used to visualize bicyclist comfort on Ohio roadways. It also provides an example of a critical gap in the bicycle network. Cyclists west of East Avenue in Elyria, Ohio are currently separated from cyclists east of River Road by bicycle LTS 3 roadway segments. If comfortable bicycle facilities are constructed on 4th Street between East Avenue and River Road, and on the segments of East Avenue that intersect with 4th Street, then cyclists can access new neighborhoods. This is a prime example of how a small bicycle project can increase access to a much larger network.

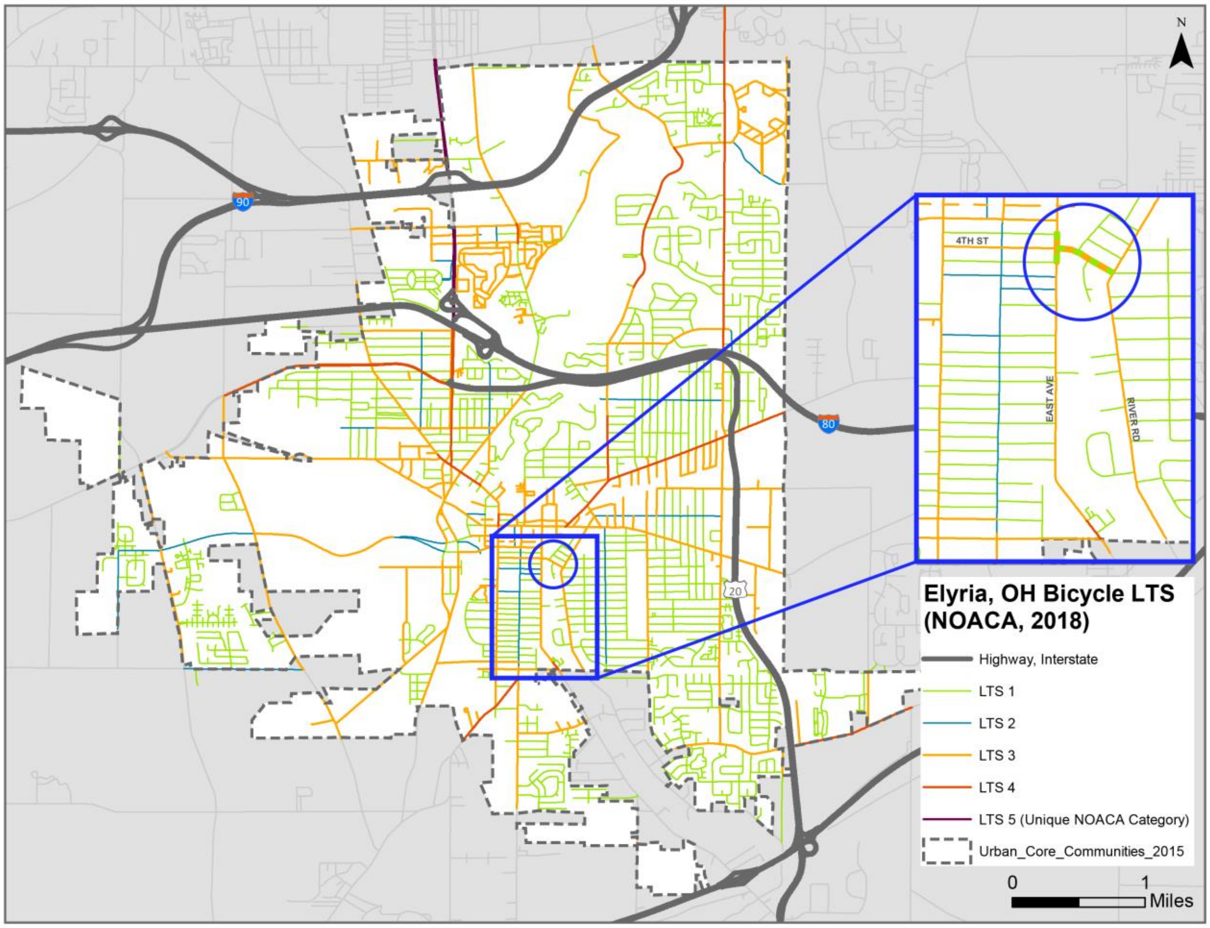

Figure 5 – Bicycle LTS

How is bicycle LTS applied?

Communities typically use roadway characteristic data and geographic information systems (GIS) to assess and assign bicycle LTS scores to roadway facilities.

Why is a statewide framework needed?

This framework shows how any Ohio community could develop a bicycle LTS network. The rules build on the original bicycle LTS criteria[4, 5] and provide guidance for filling data gaps based on Ohio's transportation and land use characteristics. They provide a simple, four-step process that makes the most of existing data to reduce data collection costs for bicycle LTS analysis. The goal of the framework is to

---

[4] Link: http://www.northeastern.edu/peter.furth/wp-content/uploads/2014/05/LTS-Tables-v2-June-1.pdf

[5] Link: http://transweb.sjsu.edu/sites/default/files/1005-low-stress-bicycling-network-connectivity.pdf

make a bicycle LTS analysis accessible and consistent for any Ohio community that wants to create its own bicycle LTS map.

Data Requirements

The following data components are used to conduct a complete bicycle LTS analysis:

Road network

Serves as the foundation layer for the bicycle LTS analysis.

Road functional classification

Informs the Ohio-specific process for filling data gaps (see Appendix A for further details).

Road width

Per the original bicycle LTS criteria, the number of lanes influences traffic speed and roadway comfort. Roads with a wider roadway cross-section are characterized by less confined and predictable traffic and decrease cyclist visibility to left-turning and cross traffic at driveways and intersections. This data component is reported in lanes.

Posted road speed

Posted roadway speed influences roadway comfort for cyclists, per the original bicycle LTS criteria. This data component is reported in miles per hour (mph).

Road volume

According to the original bicycle LTS criteria, influences roadway comfort for cyclists. This data component is reported in annual average daily traffic (AADT).

Bicycle facility type

Per the original bicycle LTS criteria, bicycle facilities can offer cyclists low- or high-stress riding environments based on their width and location. This data component is reported as separated bicycle facility, standard bicycle facility, or no bicycle facility (mixed traffic).

Bicycle facility width

This data component is reported in feet.

On-street parking lane location

As noted in the original bicycle LTS criteria, the comfort of bicycle facilities located adjacent to parking lane locations can vary based on the widths of the bicycle facility and parking lane. This data component is only needed for on-street parking lanes adjoining bicycle facilities.

On-street parking lane width, including any striped door zone buffer

This data component is reported in feet.

Road centerline

The original bicycle LTS criteria indicate that roads with marked centerlines give each directional stream of traffic a designated lane, guiding motorists to stay on their half of the road. Roads without marked centerlines direct motorists to share space, reducing conflicts with bicycles. Road centerline data is only needed for 25 mph road segments with an ADT between 751 and 3,000, 20 mph road segments with an ADT between 751 and 1,500, and 20 mph road segments with an ADT greater than or equal to 3,000.

One-/two-way street designation

The stress to a cyclist on a one-way street matches the stress to a cyclist on a two-way street with double the number of lanes and a median, according to the original bicycle LTS criteria. Since one-way roads lack a conflicting roadway direction and corresponding friction, they are characterized by less confined and predictable traffic than two-way roads with the same lane width.

Data gaps

Most communities need to conduct additional data collection to fill data gaps before completing a bicycle LTS analysis. Only some of the data components need to be complete at the start of the bicycle LTS analysis. Table 15 outlines these data component requirements: Ohio Department of Transportation's (ODOT) Transportation Information Mapping System (TIMS) provides most of the data components needed to conduct a bicycle LTS analysis for interstates, US routes, and state routes in Ohio. Local communities can use ODOT TIMS data as a starting point for conducting their own bicycle LTS analyses but will need to fill gaps for the other roads in their jurisdictions that may not be captured within TIMS.

Table 15 – Bicycle LTS Data Requirements

Complete Data Required	Partial/Missing Data Acceptable
Road network	Posted road speed (mph)
Road functional classification	Road volume (AADT)
Road width (lanes)	Bicycle facility width
Bicycle facility location and type	On-street parking facility width
On-street parking facility location[1, 2]	Presence/absence of road centerline
One-/two-way street designation	

[1]This information is only needed for bicycle facilities adjoining on-street parking facilities. If the location of bicycle facilities in a community is already known, then a desktop scan of each bicycle facility in the roadway network and an aerial base map can quickly provide necessary on-street parking facility location information. This approach was applied to fill on-street parking facility location gaps in Washington, DC.

[2] Bicycle facility shapefiles and feature classes should include an on-street parking field to indicate whether or not each bicycle facility is adjacent to a parking facility. By making it standard practice to document the presence or absence of on-street parking adjoining bicycle facilities, communities can reduce data collection requirements for future bicycle LTS mapping efforts

Weakest link principle

Some partial or missing data components are acceptable because the bicycle LTS method is based on a 'weakest link' principle. This approach can reduce data collection needs for roadway segments where the worst-performing metric is already known. For instance, all mixed-traffic roads that are three or more lanes wide are automatically assigned a bicycle LTS score of 4 if they have a posted speed limit of 40 mph or higher (Figure 6). If roadway speed and lane width are known, there is no need to gather additional data for these roads.

To understand how many existing data gaps need to be filled, it is important to walk through the four steps outlined in the following section using existing data. This way some roads can be assigned bicycle LTS scores with existing data, and a minimum viable data collection plan can be developed to classify the remaining roads.

Attachment A outlines a recommended, low-cost approach to fill data gaps.

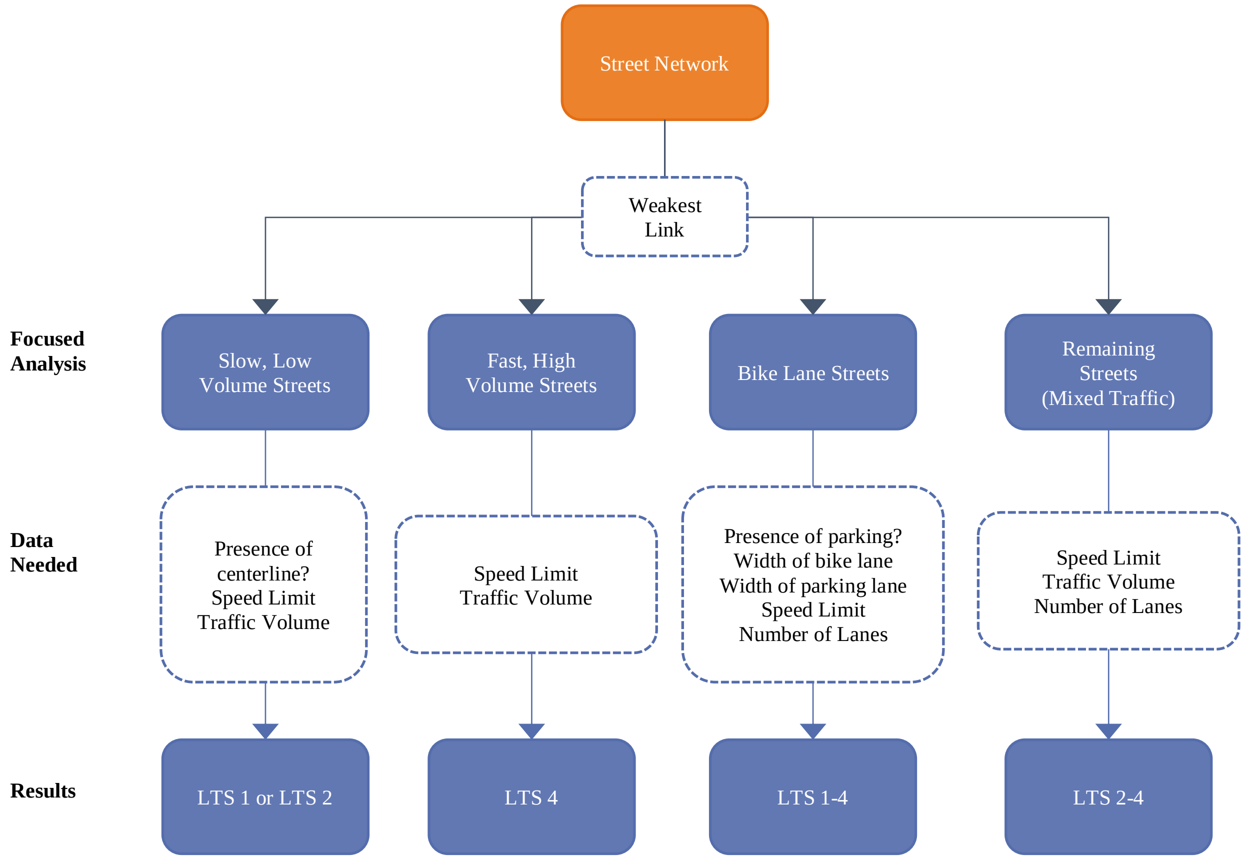

Figure 6 – Weakest Link Principle

Assigning Bicycle Level of Traffic Stress Scores

Five main steps are used to assign bicycle level of traffic stress scores:

1. Score non-bikeable roads and physically-separated bicycle facilities
2. Score road segments without bicycle facilities
3. Score road segments with bicycle facilities not adjacent to a parking lane
4. Score road segments with bicycle facilities adjacent to a parking lane
5. Verify and refine bicycle LTS scores

The following steps reflect the original bicycle LTS criteria and arrange them in a way that allows communities to take full advantage of the weakest link approach.[2] Based on that approach, the following steps do classify roadway segments in increasing order from bicycle LTS 1 to bicycle LTS 5. In many cases, bicycle LTS 1, bicycle LTS 2, and bicycle LTS 4 roadway segments are classified prior to classifying bicycle LTS 3 roadway segments.

Step 1

1. Bicycle LTS Score 5: Some principal arterial roads with full access control or partial access (i.e., interstates, and other freeways and expressways)[6,7]
2. Bicycle LTS Score 1: All roads with bicycle facilities that are physically separated from motor traffic (e.g., shared-use path, side path, trail, or cycle track)

Step 2

For mixed-traffic roadway segments without on-road bicycle facilities, the following instructions must be followed in sequence to correctly assign bicycle LTS scores.

Identify two-way roads *without* the presence of a road centerline (one lane per direction)

1. Bicycle LTS Score 1
    a. Roads with an AADT of 1,500 or less and a posted speed limit of 25 mph or lower
2. Bicycle LTS Score 2
    a. Roads with an AADT of 3,000 or less and a posted speed limit of 30 mph or lower
    b. Roads with an AADT of 750 or less and a posted speed limit of 35 mph or lower
    c. Roads with a posted speed limit of 20 mph or lower
3. Bicycle LTS 4
    a. Roads with an AADT of 1,501 or more and a posted speed limit of 40 mph or higher
    b. Roads with an AADT of between 751 and 1,500 and a posted speed limit of 50 mph or higher
4. Bicycle LTS Score 3
    a. All other roads

Identify one-way, one-lane roads or two-way roads with a road centerline (one lane per direction).

1. Bicycle LTS Score 1
    a. Roads with an AADT of 750 or less and a posted speed limit of 25 mph or lower
2. Bicycle LTS Score 2
    a. Roads with an AADT of 1,500 or less and a posted speed limit of 30 mph or lower
    b. Roads with an AADT of 750 or less and a posted speed limit of 35 mph or lower
    c. Roads with an AADT of 3,000 or less and a posted speed limit of 20 mph or lower
3. Bicycle LTS Score 4
    a. Roads with an AADT of 1,501 or more and a posted speed limit of 40 mph or higher
    b. Roads with an AADT between 751 and 1,500 and a posted speed limit of 50 mph or higher
4. Bicycle LTS Score 3
    a. All other roads

Identify streets with two through lanes per direction.[8]

1. Bicycle LTS Score 3
    a. Roads with an AADT 0f 8,000 or less and a posted speed limit of 35 mph or lower
    b. Roads with an AADT greater than 8,000 and a posted speed of 25 mph or lower
2. Bicycle LTS Score 4
    a. All other roads

Identify streets with three or more through lanes per direction.[9]

1. Bicycle LTS Score 3
    a. Roads with a posted speed of 25 mph or lower

---

[6] A Bicycle LTS score of 5 is used to identify non-bikeable roads.

[7] Link: http://www.dot.state.oh.us/Divisions/Planning/ProgramManagement/MajorPrograms/Documents/FunctionalClassificationProcedures.pdf

[8] If direction information is incomplete, identify streets with three or four lanes in total width.

[9] If direction information is incomplete, identify streets with five or more lanes in total width.

2. Bicycle LTS Score 4
    a. All other roads

Step 3

For roadway segments with on-road bicycle facilities not adjacent to a parking lane, the following instructions must be executed in sequence to correctly assign bicycle LTS scores.

1. Bicycle LTS Score 1
    a. Roads with a maximum of one through lane per direction, a posted speed limit of 25 mph or lower, and a bike lane with a width of 6 feet or wider
2. Bicycle LTS Score 2
    a. Roads with a maximum of two through lanes per direction and a posted speed limit of 35 mph or lower
3. Bicycle LTS Score 4
    a. Roads with a maximum of one through lane per direction and a posted speed limit of 50 mph or higher
    b. Roads with a maximum of two through lanes per direction, a posted speed limit of 50 mph or higher, and a bike lane with a width of 5 feet or narrower
    c. Roads with more than two through lanes per direction and a posted speed limit of 40 mph or higher
4. Bicycle LTS Score 3
    a. All other roads

Step 4

For roadway segments with on-road bicycle facilities adjacent to a parking lane, the following instructions must be executed in sequence to correctly assign bicycle LTS scores.

1. Bicycle LTS Score 1
    a. Roads with a maximum of one through lane per direction, a posted speed limit of 25 mph or lower, and a combined bike lane and parking lane width of 15 feet or wider
2. Bicycle LTS Score 2
    a. Roads with a maximum of one through lane per direction and a posted speed limit of 30 mph or lower
    b. Roads with a maximum of two through lanes per direction (two-way) or two to three through lanes per direction (one-way) and a posted speed limit of 25 mph or lower
3. Bicycle LTS Score 3
    a. All other roads

Step 5

Once a completed bicycle LTS map is produced (using full data), work with cyclists of all experience levels to verify the bicycle LTS scores and make changes as needed.

Attachment A– Filling Data Gaps
Bicycle LTS data needs may be met through two main approaches:

1) Higher accuracy approach: Conduct surveys in the field or use Google Street View or a similar program to gather missing speed limit and lane data. Although this approach results in higher-accuracy data, it could be prohibitively time and labor intensive.
2) Lower accuracy approach: Assign average or typical values to missing roadway segments based on Ohio-specific characteristics. While this approach can result in lower-accuracy data, it requires less time and labor.

The lower accuracy approach may be used for developing a temporary, *assumed bicycle LTS* map, that communities may reference while accurate, necessary data is being collected. This attachment outlines the lower-accuracy approach for all data components that may be partial or missing at the start of a bicycle LTS analysis. Much of the lower-accuracy approach builds off of Ohio's functional classification system. The lower accuracy approach should only be used for assigning *assumed bicycle LTS* scores to roadway segments. The concept of functional classification defines the role that a particular roadway segment plays in serving traffic flows. Roadways in Ohio are all categorized within one of the seven classifications, as follows:[4]

Principal arterial roads:
- Interstates: The highest classification of arterials, designed and constructed with mobility and long-distance travel in mind.
- Other freeways or expressways: Like interstates, these roads are designed and constructed to maximize mobility.
- Other principal arterial roads: Typically serving cities and metropolitan areas, these roads provide a high degree of mobility and can directly service abutting land uses via driveways and intersections.

Minor arterial roads: These roads provide service for trips of moderate length and offer connectivity to the higher principal arterial system.

Collector roads
- Major collector roads: These roads gather and channel traffic from local roads to the arterial network. Typically, major collector roads are higher speed, lower access, higher volume, and wider than minor collector roads.
- Minor collector roads: These roads gather and channel traffic from local roads to the arterial network. Typically, minor collector roads are lower speed, higher access, lower volume, and narrower than minor collector roads.

Local roads: These provide direct access to adjoining land and are often designed to discourage through traffic.

Posted Road Speed (mph)

Table 16 summarizes recommended typical posted road speed based on roadway functional classification and urban/rural classification. Speed limits were set based on *Methods and Practices for Setting Speed Limits: An Informational Report.*[10] Urban roadways are located in any US census block or block group with a population density of at least 1,000 people per square mile. Rural roadways are located in any census block or block group having a population less than 1,000 people per square mile. The urban/rural

[10] Link: https://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa12004/fhwasa12004.pdf

classification was set based on US Census Bureau thresholds.[11] The values reported in Table 16 may be adjusted as necessary to suit local agencies.

Table 16 – Posted Road Speed Assumptions for Road Segment Functional Class

Functional Classification	Speed Limit (mph)	
	Urban	Rural
Principal Arterial Road	40	50
Minor Arterial Road	40	50
Major Collector Road	35	45
Minor Collector Road	30	45
Local Road	25	35

Road Volume (AADT)

Table 17 summarizes recommended typical AADT based on roadway functional classification and urban/rural classification. Average AADT values were calculated based on roadway functional classification using Ohio's Transportation Information Mapping System (TIMS)[12]. The urban/rural classification was set based on U.S. Census Bureau thresholds[7]. The values reported in Table 17 may be adjusted as necessary to suit local agencies.

Table 17 – Recommended Road Volume Assumptions for Road Segment Functional Class

Functional Classification	Annual Average Daily Traffic (AADT)	
	Urban	Rural
Principal Arterial Road	20,000	15,000
Minor Arterial Road	8,200	8,200
Major Collector Road	3,500	3,500
Minor Collector Road	1,600	1,000
Local Road	1,600	1,000

Bicycle Facility Width

Table 18 summarizes how bike facility widths may be estimated based on bike facility type. Recommended widths were developed for three main bicycle facility types based on the National Association of City Transportation Officials (NACTO) *Urban Bikeway Design Guide.*[13] The values reported in Table 18 may be adjusted as necessary to suit local agencies.

Table 18 – Maximum Width Assumptions for Bicycle Facility Types

Bicycle Facility Type	Width
Separated bike lane (striped buffer)	6 ft
Standard bike lane	5 ft
Paved shoulder	4 ft

[11] Link: https://www.nal.usda.gov/ric/what-is-rural
[12] Link: https://gis.dot.state.oh.us/tims/Data/Download
[13] Link: https://nacto.org/publication/urban-bikeway-design-guide/

Parking Facility Width

Table 19 summarizes how on-street parking facility widths may be estimated based on parking facility type. Recommended widths were developed for two main parking facility types based on the NACTO *Urban Street Design Guide.*[14]

Table 19 – Maximum Parking Width Assumptions for On-Street Parking Adjoining Bicycle Facilities

Parking Facility Type	Width
Standard On-Street Parking Lane	8 ft
Loading and Double Parking	15 ft

Presence/Absence of Road Centerline

If roadway centerline data is incomplete, land use data may be used to estimate whether or not a road centerline is present on certain roadways. This exercise is only necessary for mixed-traffic roads with a maximum of one through lane per direction. By using geoprocessing tools to assign adjoining land use data to these roadway segments, it is possible to identify segments adjoining residential land uses.

Table 20 shows how roadway segments may be classified based on land use:

Table 20 – Road Centerline Classification Assumptions

Land Use	Centerline/No Centerline
Residential	No Centerline
All other land uses	Centerline

[14] Link: https://nacto.org/publication/urban-street-design-guide/street-design-elements/lane-width/

APPENDIX B: Literature Review

Overview

There are several BLOS or safety index tools that are proposed to assess bicyclist safety perceptions and comfort. The research team reviewed existing literature with the purpose of formulating a model that can be customized to specific applications in Ohio. State-of-the-art models typically take into account factors such as roadway attributes (e.g., width of the roadway, number of lanes, pavement condition), bicycle and vehicular volumes, adjacent land uses, and existence of bicycle infrastructure and/or traffic calming measures. A review of the models appears below.

Bicycle LTS

Use of bicycle LTS as a tool to assess bicycle compatibility on urban and suburban roadways was first introduced in the early 1990s (Sorton & Walsh, 1994). Later, Mekuria et al. (2012) revisited the idea and introduced a relatively new system that classified roadways into four different LTS categories based on their riding conditions:

- LTS 1 – most children can tolerate;
- LTS 2 – will be tolerated by the mainstream adult population;
- LTS 3 – can be tolerated by American cyclists who are 'enthused and confident' but still prefer having their own dedicated space for riding;
- LTS 4 – can be tolerated only by those characterized as 'strong and fearless.'

As bicycle LTS provides easy-to-understand criteria for road segments and intersections and does not require intensive datasets, this approach has been widely used by transportation practitioners in recent years. Bicycle LTS allows professionals to categorize road conditions for people who are likely to bicycle (Geller, 2006). Figure 7 displays how bicycle LTS categories are determined under different road conditions.

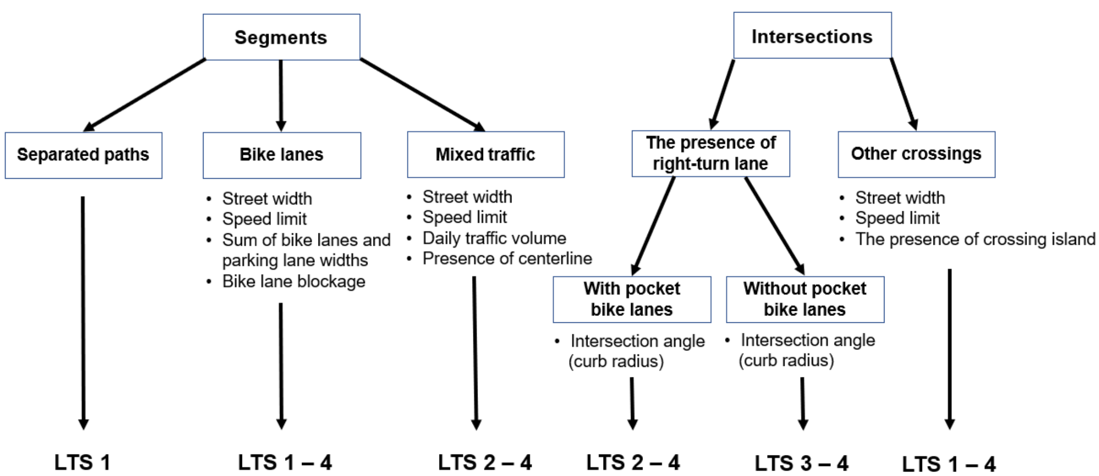

Figure 7 – Flow Chart of Bicycle LTS

(LTS Criteria for Road Segments, version 2.0, June 2017;
Source: http://www.northeastern.edu/peter.furth/wp-content/uploads/2014/05/LTS-Tables-v2-June-1.pdf)

Street segments with paths that are physically separated from vehicular traffic, such as off-road trails, roads with cycle tracks, and shared-use paths, are assigned a bicycle LTS score of 1. The developers do not regard stress related to sharing paths with pedestrians as a deterrent to bicycling. As expected, sidewalks are not assigned a bicycle LTS score of 1 unless they have been designated for bicycling or as shared-use paths. In the presence of on-road bike lanes, the developers assigned bicycle LTS scores based on the following factors:

- Number of through lanes per direction,
- Speed limit,
- The sum of bike lanes and parking lane widths, and
- Bike lane blockage frequency.

Mixed traffic, where bicyclists ride with vehicular traffic, is the most common road condition. Factors influencing bicycle LTS scores for mixed traffic segments include:

- Number of through lanes per direction,
- Speed limit,
- Effective average daily traffic volume, and
- Presence of centerline.

For intersections, the developers assigned bicycle LTS scores based on the presence of a pocket bike lane (i.e., a bike lane positioned between a right-turn lane and a through lane), presence of right-turn lanes, intersection angle, and curb radius. Bicycle LTS scores of unsignalized crossings are determined by the number of through lanes of the crossing streets, speed limits of these crossing streets, and the presence of a median refuge.

Linear-regression-based Model – the *Highway Capacity Manual*'s BLOS

Two of the earlier and well-established models were developed by Landis et al. (1997) and Harkey et al. (1998). Landis et al. (1997) developed the first statistically calibrated BLOS model for roadway segments based on real-time perceptions from 145 bicyclists nationwide. They estimated a regression model to relate the following roadway and land use characteristics to real time safety perceptions.

- Traffic volume
- Number of through lanes
- Posted speed limits
- Percentage of heavy vehicle traffic
- Nearby land use
- Width of outside lane
- Pavement surface

They scaled comfort and safety ratings on various road segments from A to F, A presenting a very comfortable ride for an average bicyclist. This transformation is based on the LOS criteria for vehicles (*Highway Capacity Manual* 1994), but focuses on bicycling activities.

Harkey et al. (1998) developed a bicycle compatibility index (BCI) for urban and rural roadway segments. The sites selected for the study were located in five cities representing a range of geographic conditions present in the US. The participants watched a videotape of different roadway segments and rated how comfortable they would feel riding on each segment. Both BLOS and BCI address bicycle comfort along the roadway. The BCI model covers some additional factors that may affect bicyclists' perceived levels of comfort and safety, such as curb lane width, traffic speed and type of roadside development. Harkey et al. (1998) transformed the estimated BCI values into BLOS classifications.

The *Highway Capacity Manual (HCM)* was expanded to include multimodal level of service (MMLOS) in 2010. This expansion included bicycle and pedestrian LOS measurements in addition to traditional vehicle LOS. *HCM*'s BLOS refers to the bicycle component of the MMLOS (*HCM* 2010; Zuniga-Garcia et al., 2018). Consistent with many BLOS studies (e.g., Dowling et al., 2008; Hallett et al., 2006; Harkey et al., 1998; Landis et al., 1997; Petritsch et al., 2007), the developers of *HCM*'s BLOS models adopted a linear regression approach. They estimated separate linear LOS functions for intersections and links. *HCM*'s BLOS application covers a broader range of roadway and intersection characteristics than the bicycle LTS. These characteristics include (*HCM* 2010):

- Width of outside lane,
- Width of bike lane,
- Width of shoulder,
- Proportion of occupied on-street parking,
- Number of through lanes,
- Vehicle traffic volume and speeds,
- Percentage of heavy vehicles,
- Pavement conditions, and
- Presence of curbs.

A BLOS grade represents an average quality-of-service experienced for all bicyclists. It ranges from LOS F (worst riding conditions) to LOS A (best operating conditions) (*HCM* 2010).

Discrete Choice-based Models – Danish BLOS and LOS for Protected Bike Lanes
Existing studies that model bicyclist comfort usually collect data through field surveys or visual surveys. The participants relate their perceptions of bicycling safety or satisfaction on an ordinal Likert scale. Some researchers adopted an ordinal regression approach to estimating the weights of independent variables. For example, Jensen (2007) developed a bicycle LOS model in Danish conditions. The Danish BLOS employs a cumulative logit model that predicts the percentage of users that fall into each of the six LOS grades from 'very satisfied' to 'very dissatisfied.' The developer estimated separate models for roadway links and intersections (Jensen, 2013). Danish BLOS models are more comprehensive than the bicycle LTS, BLOS and BCI. The Danish BLOS model for roadway links covers:

- Neighborhood types (residential/shopping/mixed/rural fields/rural forest),
- Motor vehicles per hour in both directions,
- Width of buffer area between the bicycle facility and driving lane on the nearest roadside,
- Average motor vehicle speed,
- Passed pedestrians per hour on nearest roadside at 20 km/h riding speed,
- Parked motor vehicle on nearest roadside per 100 m,
- Width of bicycle path/track on nearest roadside,
- Width of bicycle lane/paved shoulder on nearest roadside in urban/rural areas,
- Width of nearest drive lane,
- Width of buffer area between sidewalk and bicycle facility/drive lane,
- Sidewalk dummy (sidewalk on nearest roadside/ no sidewalk),
- Bus stop dummy (bus stop on roadway/ no bus stop),
- Drive lane dummy (four or more drive lanes/ one to three lanes).

It is worth noting that the Danish BLOS method differentiates between bike lanes and cycle tracks based on empirical data. The estimated parameters suggest that bicyclists are most sensitive to the width of the buffer area between the bicycle facility and the nearest auto lane, the width of the bicycle facility, and the presence of a sidewalk.

Recent research efforts in the US consider the effects of different bicycle facility types. Foster et al. (2015) appear to have developed the first BLOS model accounting for protected bike lanes explicitly. They collected data through in-person video surveys in Portland, Oregon, then estimated a series of cumulative logit models to predict bicyclists' comfort levels in protected bike lanes under different traffic conditions. The significant predictors in their models are:

- Types of buffers (planter/parked car/raised-parking/posts/buffers),
- Direction of travel (two-way/one-way facility),
- Adjacent motor vehicle speed limit, and
- Average daily motor vehicle volumes

This model can be used to complement the *HCM* 2010 level-of-service methods by providing an analysis procedure for protected bike lanes that are not currently included in the manual.

Expert Opinion Scores – Bicycle Environmental Quality Index (BEQI)

Bicycle environmental quality index (BEQI) offers another way of measuring bicyclist comfort. BEQI was created by The San Francisco Department of Public Health (SFDPH). Transportation professionals and members of the local bicycling community were invited to weigh the most important variables affecting their bicycle facility quality perceptions. There is a total of 22 inputs to the BEQI model. Based on the responses, the factors are combined into an index that ranges from zero to 100. The factors with the highest weights in the BEQI tool are:

- Bicycle facility type,
- Bicycle facility width,
- Pavement type,
- Pavement condition,
- Slope,
- Pavement markings,
- Connectivity of bike lanes,
- Driveway cuts, and
- Presence of trees.

The logic of the BEQI tool is straightforward and easy to understand. It is written in Microsoft Access based on San Francisco's spatial information. The tool can evaluate some locations in that city effectively, but is harder to use when applied outside of San Francisco. A moderate amount of time is needed to learn the software (given its use of Microsoft Access). Besides, the BEQI tool uses expert opinions rather than user surveys to develop weighted scores for various roadway characteristics. The results may be primarily determined by the evaluation process and the invited experts. For example, the experts did not rate the factors related to roadway traffic (i.e., number of vehicle lanes, vehicle speed, and traffic volume) as important factors, which contradicts the existing literature as well as the bicycle LTS and BLOS methods. Using expert opinions allows the BEQI to incorporate some street-level critical design factors but may lead to less reliable assessments.

Bicycling Intersection Safety Measurements

Bicyclist perceptions of safety at intersections have also been widely studied in literature. The general results indicate bicyclists feel safer when separated from motor vehicles and pedestrians (Landis et al., 2003; Carter et al., 2007; Wang & Akar 2018a). Landis et al. (2003) proposed the intersection BLOS model for bicycle through movements. This is the first model that focused on complex intersection features through the lens of the whole transportation system. This model provides insight on intersection design characteristics that could more safely accommodate cyclists. Data were collected from cyclists who rode through 18 selected signalized intersections and recorded their comfort and safety ratings on a scale of A through F. Roadway traffic volume, total width of the outside through lane, and intersection crossing distance were found to be the primary factors affecting bicyclist safety perceptions at the intersection level. It is of interest that the presence of a bicycle lane or a paved shoulder was not found to be statistically significant.

The Bicyclist Intersection Safety Index (Bike ISI) developed by Carter et al. (2007) is a more comprehensive safety rating model for intersections compared to the other models. This model involves both subjective user ratings and objective data, such as evasive actions taken by cyclists to avoid collisions. The authors selected 67 intersections in four different cities. The study received 97 safety ratings from bicycling experts using a six-point Likert scale. The Bike ISI models were estimated for three possible bicycle movements at intersections: through movement, right turn, and left turn. Traffic volumes, number of lanes, speed limits, and presence of bicycle lanes, parking, and traffic control devices were found to affect Bike ISI values.

The literature offers ample evidence on the environmental correlates of bicyclist comfort. Recent studies reflect a growing interest in analyzing the differences in the environmental correlates for bicyclists from different demographic groups (e.g., Griswold et al., 2018; Wang et al., 2018; Wang & Akar, 2019). Still, there is no consensus on how bicyclist comfort should be measured. Table 21 provides a summary of some representative studies. In addition to variations in measurement approaches, there is no consensus on what factors (roadway and land use characteristics) to take into account, and the relative importance of these factors in determining the final comfort level. Indeed, data limitations may always hamper the implementation of the state-of-the-art models for local transportation officials and planners.

Table 21 – Roadway Characteristics used by various BLOS and Traffic Stress Models

		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
	Types of Measurements	BSL	BLTS	BLTS	BCI	BLOS	BLOS	BLOS	BLOS	BLOS	BLOS	BISI	PBIS
Road traffic	Motor vehicle speed	√		√	√	√	√	√		√			
	Posted speed limit/Traffic calming		√	√					√			√	
	Street width (number of lanes)		√	√		√			√	√		√	√
	Right-turn lane		√	√								√	√
	Presence of median refuge												√
	Motor vehicle volume			√	√	√	√	√	√	√	√	√	√
	Curb lane volume	√			√	√							
	Curb lane width	√			√	√			√		√		
	Presence of physical barrier and buffers					√			√				
Bicycle facilities	Presence of bike lane		√	√	√	√	√		√			√	√
	Width of bike lane		√	√	√		√		√	√			√
	Presence of bike lane blockage		√	√									
	Presence of sidewalk						√						√
	Pedestrians volume					√						√	
	Bus stop dummy						√						
Surroundings	Presence of parking		√	√	√							√	
	Width of parking lane		√	√					√	√			
	Number of parked vehicles						√	√	√				
	Neighborhood types (e.g., residential)				√		√	√					√
	Pavement surface condition					√		√	√				
Intersection treatments	Intersection crossing distance								√		√		
	Intersection crossing markings												√
	Traffic signals								√			√	√
	Presence of crosswalk												√
	Marked bicycle crossings												√
	Bicycle box												√

Notes: 1 – Sorton and Walsh 1994. Bicycle stress level as a tool to evaluate urban and suburban bicycle compatibility; 2 – Mekuria et al. 2012. Low-stress bicycling and network connectivity; 3 – Watkins et al. 2016. Using crowdsourcing to prioritize bicycle network improvements; 4 – Harkey et al. 1998. Development of the bicycle compatibility index; 5 – Landis et al. 1997. Real-time human perceptions: toward a bicycle level of service; 6 – Jensen 2007. Pedestrian and bicyclist level of service on roadway segments; 7 – Majumdar and Mitra 2018. Development of Level of Service Criteria for Evaluation of Bicycle Suitability; 8 – *Highway Capacity Manual* 2010; 9 – Foster et al. 2015. Level-of-Service Model for Protected Bike Lanes; 10 – Landis et al. 2003. Intersection level of service for the bicycle through movement; 11 – Carter et al. 2007. Bicyclist intersection safety index; 12 – Wang 2018 and Akar. Street Intersection Characteristics and Their Impacts on Perceived Bicycling Safety.

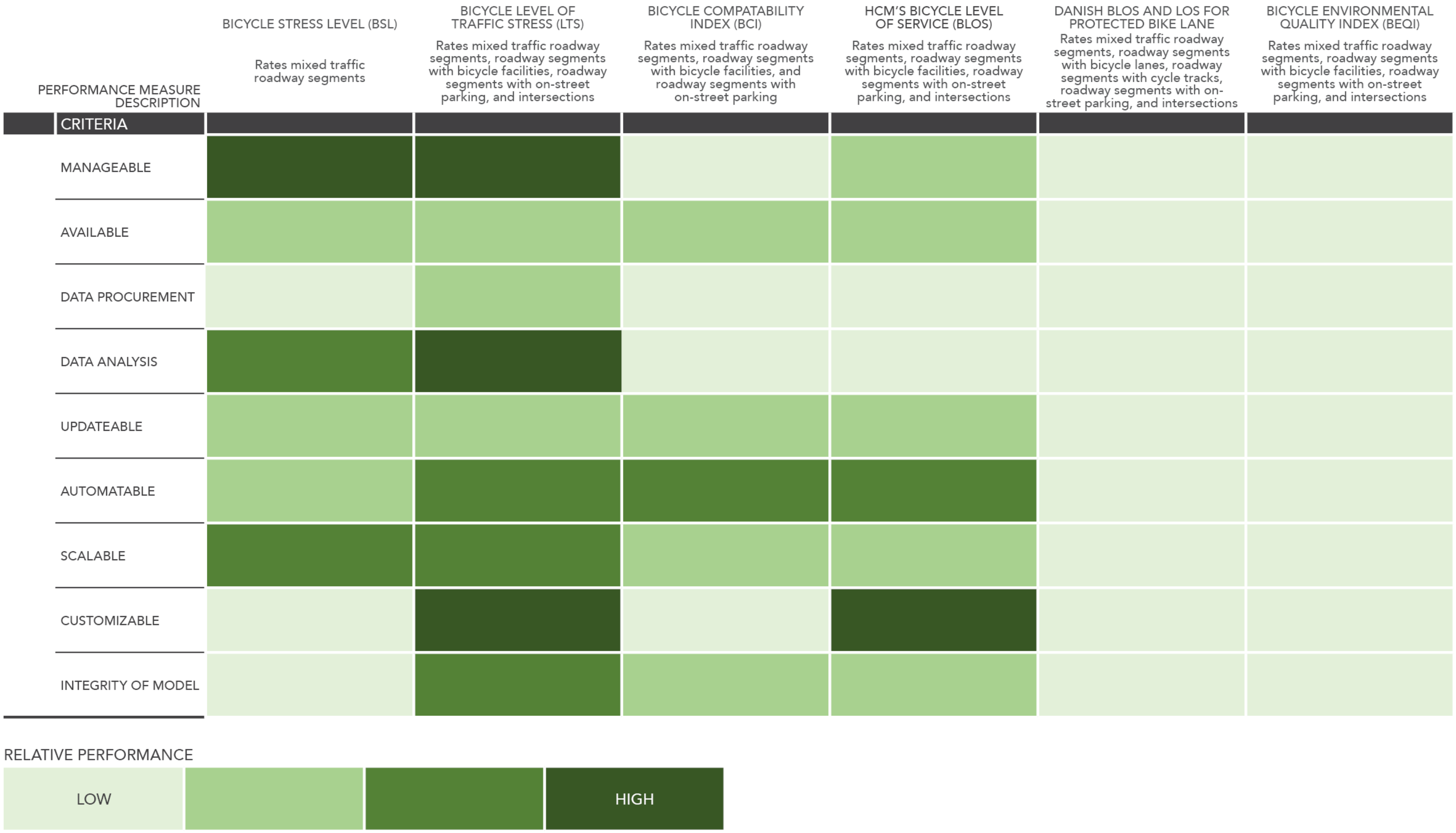

Figure 8 – A Comparison between Several State-of-the-art Methods on Measuring BLOS and Traffic Stress

Applications in Practice
Bicycle LTS
In recent years, bicycle LTS has become the most popular approach among transportation agencies, surpassing the BLOS models (Zuniga-Garcia et al., 2018; LaMondia & Moore, 2015; Park et al., 2013). One of the main advantages of using bicycle LTS is that it follows 'weakest link' logic, thus requiring fewer data compared to other bicycle performance measures. A roadway segment's stress level is assigned on the basis of its lowest-performing attribute. For example, even if a segment mostly has low-stress characteristics, the occurrence of one high-stress attribute dictates the stress level for the link. Consequently, it is not always necessary to collect all the data on each street to perform an analysis.

San Jose, CA
Bicycle LTS was first employed to measure the bicycle stress map for the city of San Jose, California by the original developers (Mekuria et al., 2012). In their study, they also made a comparison between bicycle demand and traffic stress levels. They found a slate of 67 locations that needed improvements, and 40 of those locations were intersections (as shown in Figure 9).

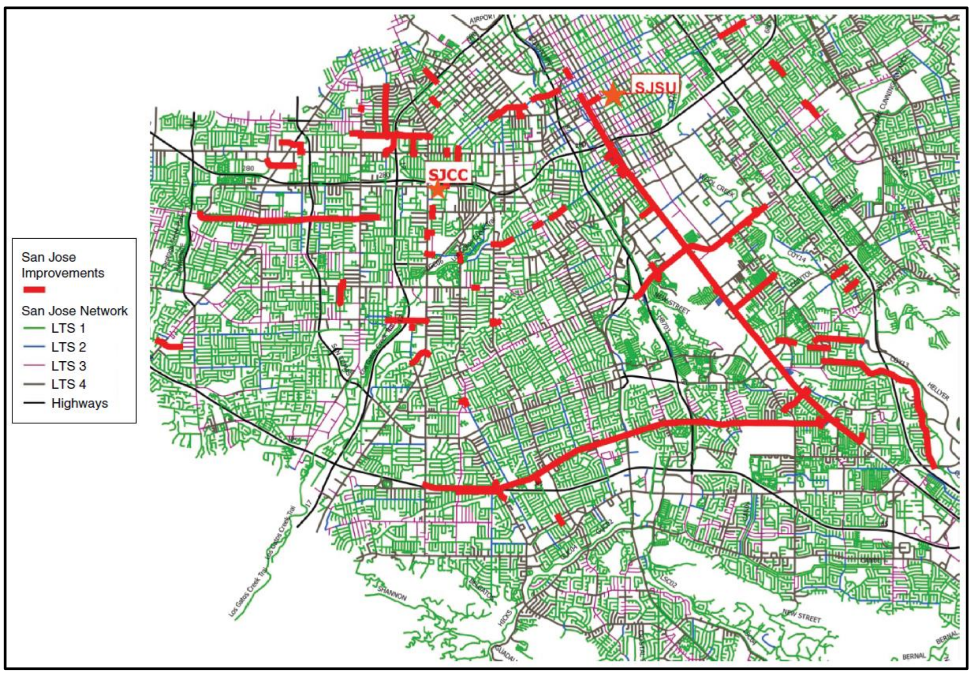

Figure 9 – Locations of Proposed Improvements in San Jose, California (Mekuria et al., 2012)

The finding highlights the idea that intersection features play an important role in bicycling decisions. The authors acknowledged that future research needs to extend the existing criteria to other specific traffic conditions, such as one-way streets, roundabouts, and local streets (e.g., bicycle boulevards).

San Diego, CA
Scrivener (2015) categorized road segments in San Diego County using the bicycle LTS approach. The results showed that a high percentage of the total road network was categorized as LTS 1 in San Diego County; however, the connections between LTS 1 segments were deficient. The authors developed visual tools to identify problem areas that required improvements. For example, Figure 10 shows the spatial distribution of road segments labelled as LTS 1 in La Jolla, San Diego, California. One limitation of this

study was that the authors treated all bicycle infrastructure as equal due to lack of sufficient data, such as data on widths of these bicycle facilities.

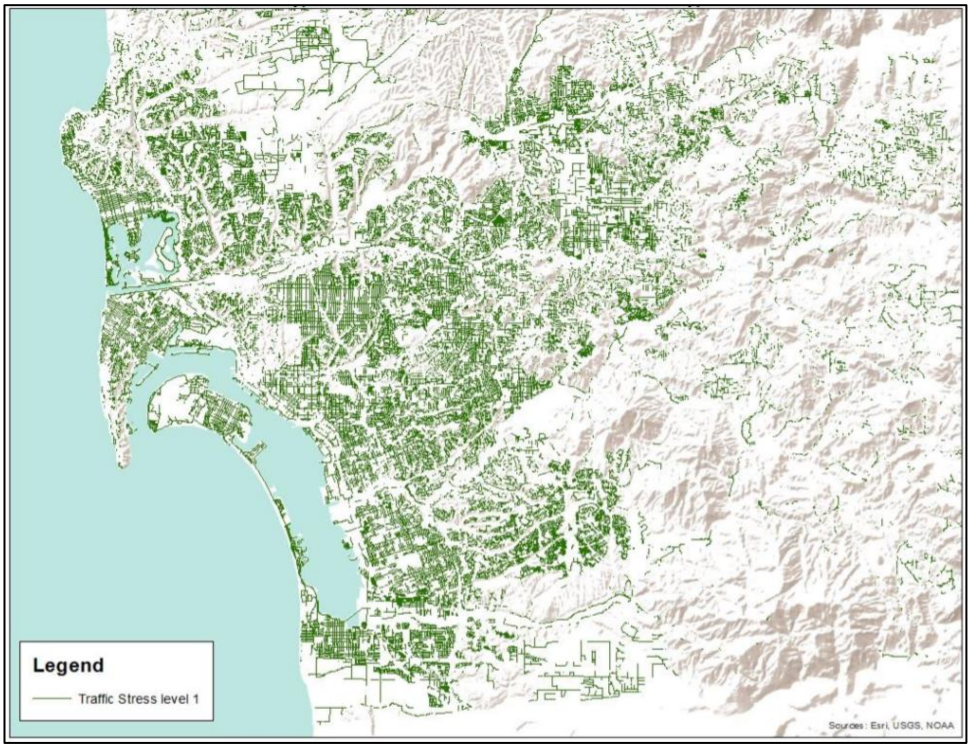

Figure 10 – LTS 1 Road segments in La Jolla, San Diego, California (Scrivener, 2015)

Atlanta, Georgia
In a study conducted in Atlanta, Georgia, Waltkins et al. (2016) modified the original bicycle LTS by updating the bicyclist typologies, and refining the required data to more easily accessible data while maintaining the strength of analysis. Based on the modified LTS approach, they investigated the improvement opportunities on bicycle routes in West End, Oakland City, and Lakewood/Ft. McPherson in Atlanta. Figure 11 visualizes the potential key improvement locations in their study area.

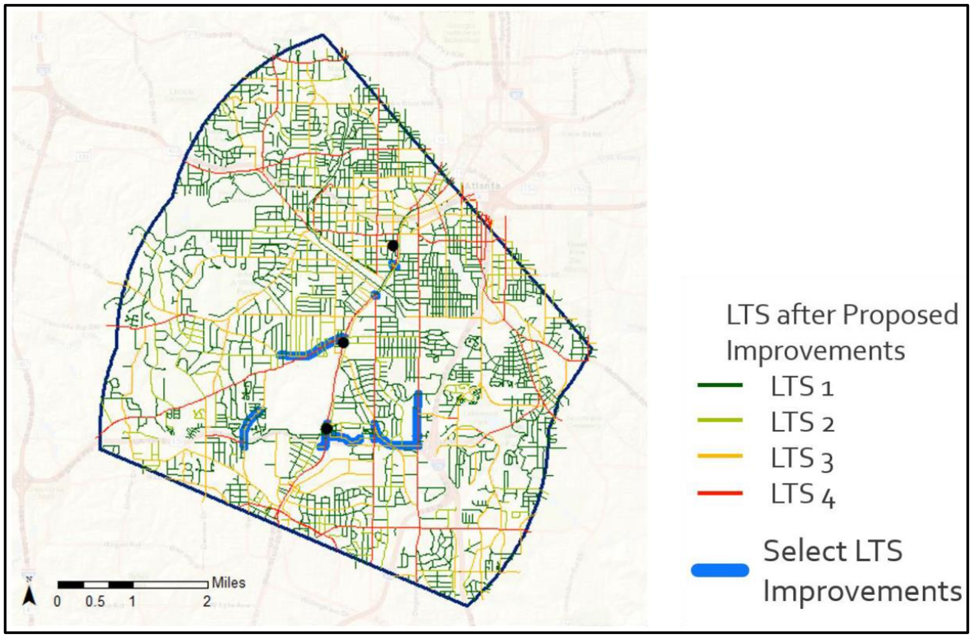

Figure 11 – LTS Scores of the Existing Network with Possible Key Improvements in the Areas of West End, Oakland City, and Lakewood/Ft. McPherson, Atlanta, Georgia (Waltkins et al., 2016)

Berkeley, California
The Berkeley City Council (Berkeley Bicycle Plan 2017) proposed another calibrated bicycle LTS method to analyze potential improvements that could encourage more people to bicycle. Their calibrated LTS method treats average daily traffic as an alternative to the posted speed limit used in the original LTS method. Figure 12 shows the LTS assignment results of the major roadways and bicycle network in Berkeley.

Berkeley City Council also generated separate maps to show low-stress streets and intersections with LTS scores of 1 or 2; high-stress streets and intersections along the existing bikeway network; and low-stress streets and with high stress (LTS 4) intersections. The results reveal the exact locations that likely dissuade 87% of Berkeley residents who identify as ‘enthusiastic and confident’ and ‘interested but concerned’ from riding bicycles.

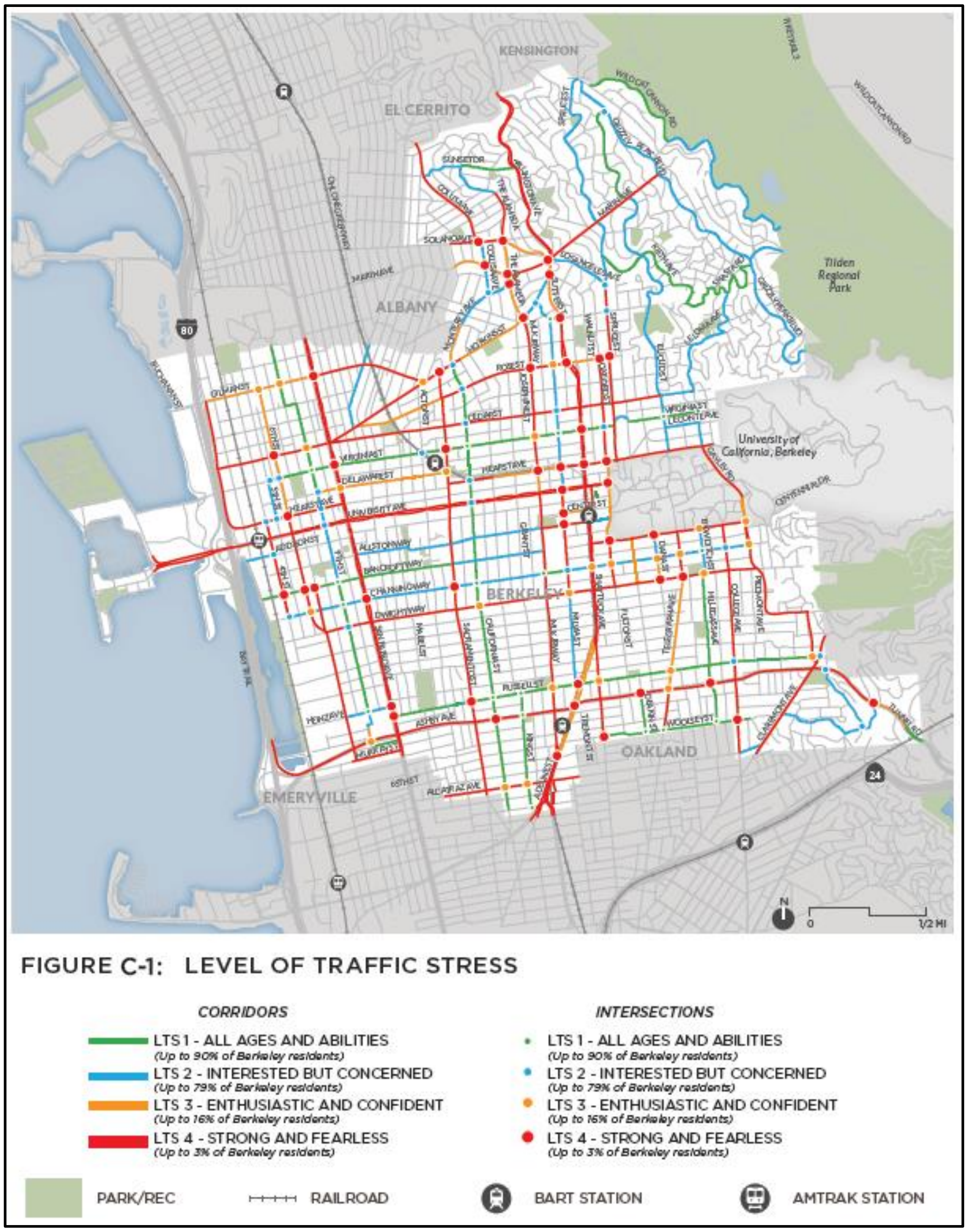

Figure 12 – LTS Map of Berkeley City, California by (Berkeley Bicycle Plan 2017)

Projects by Kittelson & Associates, Inc.

Kittelson has worked with several agencies using the bicycle LTS approach to measure bicycle networks. For example, Kittelson developed a Bikeway Guidance Tool in Downtown Bethesda, Maryland, for the Montgomery County Planning Department. They found the bicycle network for bicyclists who are interested but concerned (i.e., LTS 1 and LTS 2) are highly disconnected. In another case, Gordon and Semler (2016) of Kittelson updated the bicycle master plan for the City of Baltimore, Maryland. The results suggested that, although there exist low stress facilities that provide connectivity for 'interested but concerned' riders, many of Baltimore City's bike lanes are suitable only for experienced riders. The updated plan also provided recommendations for future planning efforts regarding Baltimore's existing bike lanes.

More recently, Kittelson completed the District Mobility Project for the District Department of Transportation (DDOT) (Dock et al., 2017; Semler et al., 2018). Figure 13 depicts the results of their LTS analysis for the District. The project provided a network-level assessment of bicycle facility availability. Specifically, the map shows that roadways for river crossings in Washington, DC lack low-stress bike facilities (unless bicyclists use the sidewalk), which would be a barrier for most bicyclists. The results also show that most major arterials (e.g., 16th Street NW or Connecticut Avenue NW) are assigned an LTS score of 4. Within the condensed project period, the project team calculated the LTS scores for the roadway segments only, not the intersections.

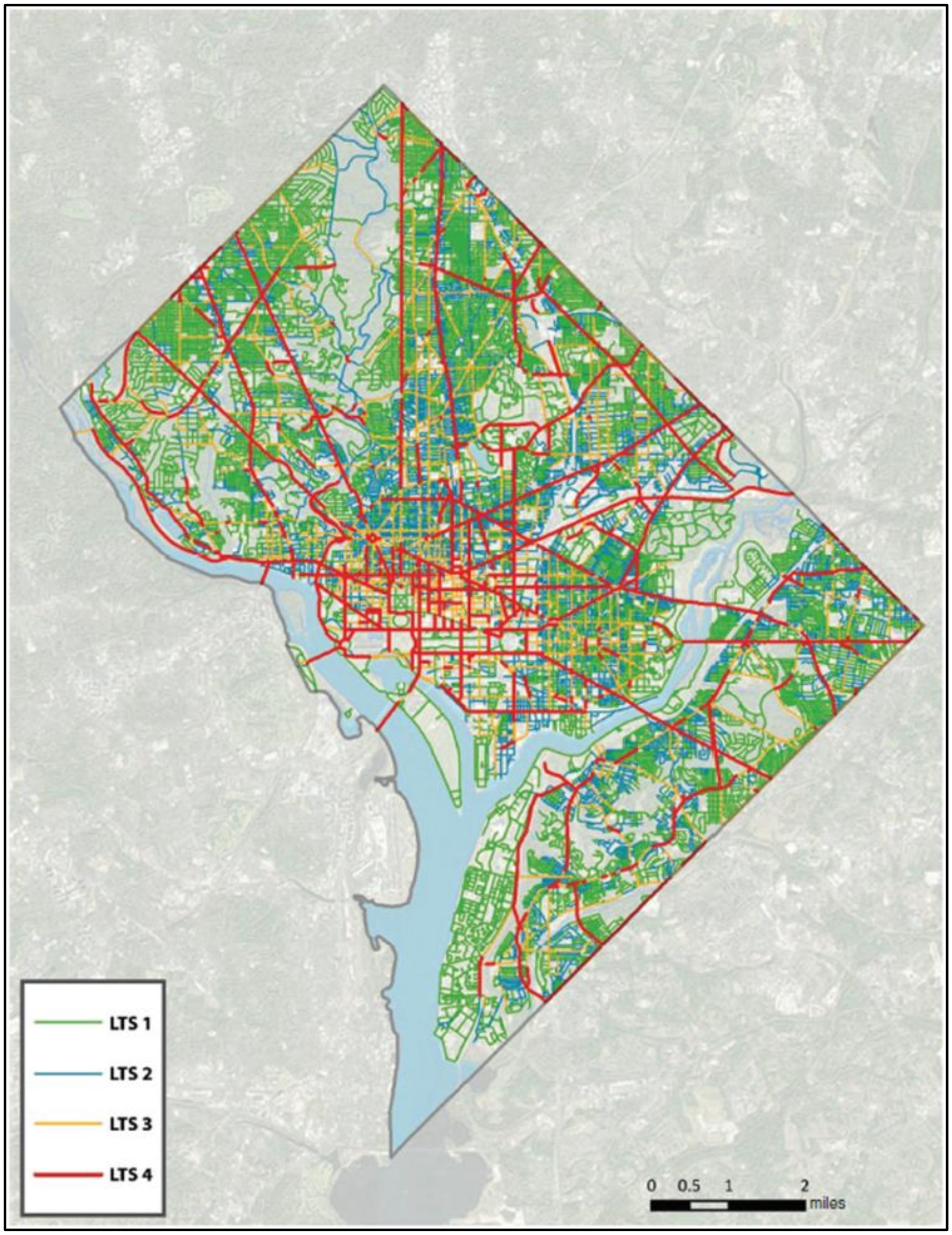

Figure 13 – LTS Map of Washington, DC (Kittelson and Associates, Inc.)

Bicycle Level of Service (BLOS)
Using the BLOS models of *HCM* 2010, Lowry et al. (2016) calculated BLOS for all bikeways across the entire community of Moscow, Idaho. The results showed that collector roads exhibit the most variation in BLOS, based on the associated vehicle volumes, bike lanes, and widths of outside shoulders. Notably, most local streets report a BLOS grade of A or a B. There exists a potential issue regarding the application of BLOS. *HCM* advises caution when applying the calculation to local streets because the method is developed primarily for higher vehicle volumes, like those expected on arterials and collectors.

Many urban planning agencies and state highway departments have used this established method to evaluate their roadway network, such as Richmond and the Northern Virginia region through Virginia Department of Transportation (VDOT); The Cities of Anchorage, Alaska; Baltimore Maryland; Birmingham, Alabama; Buffalo, New York; Gainesville Florida; Greensboro North Carolina; Houston, Texas; Lexington, Kentucky; Philadelphia, Pennsylvania; Sacramento, California; Springfield Massachusetts; Tampa, Florida; Washington, DC; and Winston-Salem, North Carolina; and by the Delaware Department of Transportation (DelDOT); Florida Department of Transportation (FDOT); New York State Department of Transportation (NYDOT); Maryland Department of Transportation (MDOT); and many others.

BLOS is a single parameter approach, assuming the relationships between the environmental factors and perceived level-of-service are fixed. This assumption does not always hold true in real-world cases. There is a vast amount of literature on measuring the bicyclist's perception of comfort or safety using data collected from different study areas. These studies follow methodologies similar to the *HCM*'s BLOS models (e.g., Landis et al., 1997; Harkey et al., 1998; Foster et al., 2015). These studies collect data through field surveys or visual surveys, and then conduct multivariate regression analysis to identify the influences of their variables of interest. The factors included, and parameter estimates associated with these factors vary across these studies.

To supplement the BLOS models developed by Landis et al. (1997), Rybarczyk and Wu (2010) estimated facility supply and bicycle demand models using data from Milwaukee, Wisconsin. They considered the factors that influence bicycle trip productions and attractions in their demand models, such as population, businesses, schools, recreational areas, parks, and criminal activities. In their case study, they found that some roadway segments with good BLOS grades had low bicycling demand, and some with low BLOS grades were associated with higher demands. The results implied the importance of integrating supply and demand while planning for future facilities and prioritizing investments.

Other Tools
Many state-of-the-art approaches have not been widely used by transportation agencies due to extensive data requirements and application challenges. However, each assessment tool has its own strengths. For instance, Danish BLOS can capture the effects of different types of bicycle facilities and road infrastructure. Goodno et al. (2013) employed the Danish BLOS method to examine the impacts of two innovative bicycle facilities installed in Washington, DC during 2010, the first being the buffered center median bicycle lanes on Pennsylvania Avenue, NW, and the second a two-way cycle track on 15th Street, NW. Both facilities have dedicated road space with buffers between bicyclists and motor vehicles, signal control, and signs and pavement markings. Due to the complex formulation, the Danish BLOS model has only attracted the attention of academic researchers so far (Park et al., 2013; Foster et al., 2015).

The BEQI tool covers some street-level critical design factors that have not been considered by other measurements, such as the presence of trees and driveway cuts. The logic of the BEQI tool is easy to follow. It develops weighted scores for various roadway characteristics based on expert opinions instead of user surveys. There are two potential issues with the application of the BEQI tool. First, the evaluates may be biased due to invited experts' experiences. In the BEQI tool, the factors related to road traffic (i.e., number of vehicle lanes, vehicle speed, and traffic volume) are not considered to be as important as they are in bicycle LTS and BLOS methods. Second, the BEQI tool is written in Microsoft Access based on San Francisco’s spatial information. The tool can assess some locations in that city effectively, but is not directly transferable when applied outside of San Francisco. A moderate amount of time is needed to learn the software program, given its use of Microsoft Access.

Detour Criteria and Point-to-Point Connectivity

Connectivity at an acceptable bicycle LTS without excessive detours is considered a possible determinant of how well a bicycle network serves an area (Park & Akar, 2019). Mekuria et al. (2012) propose a method for measuring the connectivity of origin-destination (OD) pairs based on the associated road segments’ bicycle LTS scores. Based on their description, two points are connected at bicycle LTS *k* if a route connecting them avoids links with LTS > *k*, and its length, L_k, satisfies the following detour criterion:

$$\frac{L_k}{L_4} \leq 1.25 \text{ (in general)}$$

or

$$L_k - L_4 \leq 0.33 \text{ mi (for short trips)}$$

L_4 is the shortest path with links of any level of stress on which bicycling is permitted. In other words, the low-stress route must be no more than 25% longer (or, for short trips, no more than 0.33 miles longer) than the shortest route. Researchers use different cutoff points for short trips. Kent and Karner (2019) use two miles as the threshold. This is because based on the 2009 National Household Travel Survey (NHTS) data, the average bicycle trip length is 2.3 miles, with non-work trips such as shopping and personal business trips averaging 1.3 and 1.4 miles, respectively. Other studies have used 1, 2, 2.5, or 3 miles as cut-off points (Waltkins et al., 2016; Lowry et al., 2016; McNeil, 2011).

Some studies have conducted connectivity analyses between origin and destination pairs to examine planning and policy implications. Figure 14 presents bicycle access to jobs in Washington, DC using bicycle routes with different stress levels (Semler et al., 2018). Figure 15 shows the bicycle LTS score assignments for the shortest paths between Capital Bikeshare bike stations in Montgomery County, Maryland (Prabhakar & Rixey, 2017). Other applications and future work may include mapping and analyzing bicycle access to schools, restaurants and other retail activities, disadvantaged populations, recreational space, parks, universities, and libraries.

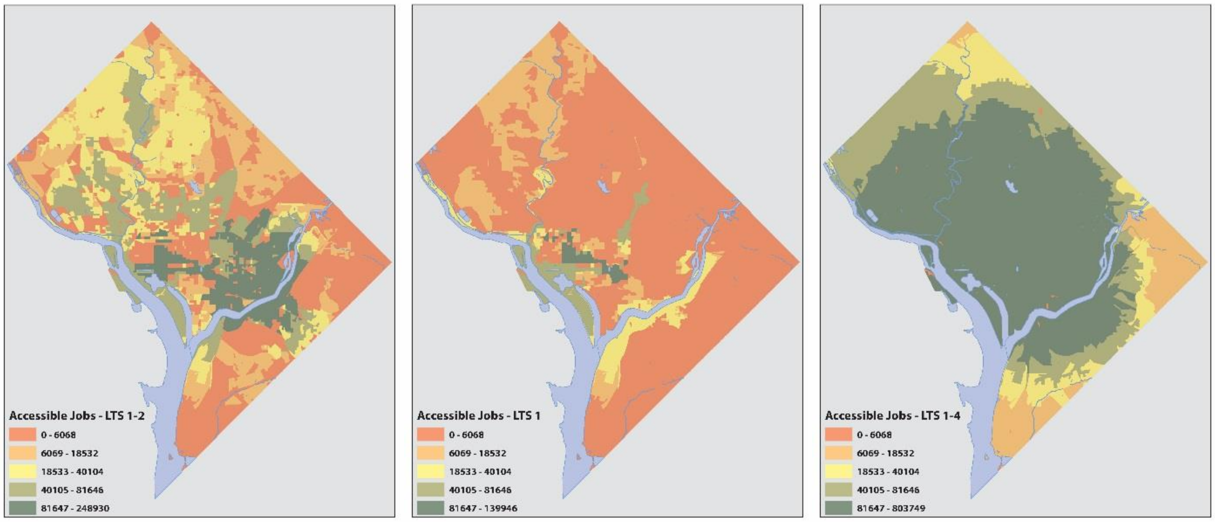

Figure 14 – Comparison of Bicycle Access to Jobs in Washington, DC on the Low Stress Networks (LTS 1 and LTS 1-2) and Full Network (LTS 1-4) (Semler et al., 2018)

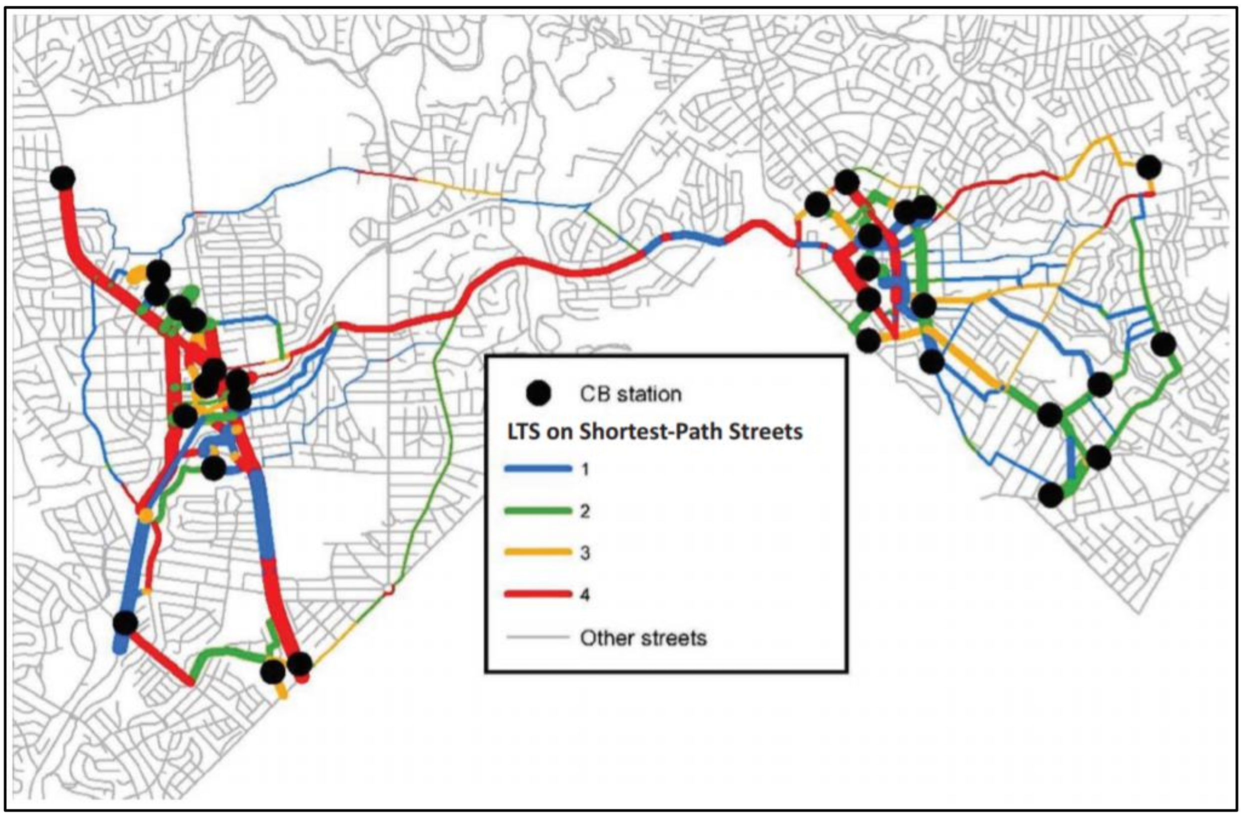

Figure 15 – LTS Scores for Shortest Paths between Bike Share Stations (Prabhakar & Rixey, 2017)

Limitations of State-of-art Measurements and Future Directions

Among all bicycling performance measures, bicycle LTS is the most widely used approach. This approach can still be improved in several aspects. First, both Geller's (2006) theory and LTS criteria assume that bicycle facilities and road infrastructure may only influence those who currently bicycle, at least those who may consider bicycling. Road environments should also be designed to encourage more non-bicyclists to bicycle (Felix et al. 2017; Wang & Akar, 2018b). Second, in most situations, manual data collection is required to measure bicycle lane and parking lane widths, since most jurisdictions do not collect this data. Manual data collection can be time consuming, and therefore may not be feasible. Third, bicycle LTS criteria are proposed without rigorous statistical validations. The thresholds of the determinants in the criteria should be considered with caution for the applications at different spatial contexts (Watkin et al., 2016; Furth et al., 2018).

The BLOS models are useful tools to assess detailed road environments, and guide improvement scenarios. Admittedly, most BLOS models developed in the US context share two common weaknesses. First, these models are developed based on empirical data from arterials and collectors. The characteristics of local roads are different. Existing research suggests bicyclists may prefer to ride on local roads over arterials and collectors, even if the distance is up to 10% longer (Winters, 2011). By focusing only on BLOS for arterials and collectors, there is a potential to bias the spatial allocation of new infrastructure investments. BLOS models should measure the impacts of on-road bike lanes and separate facilities differently (Park et al., 2013). Danish BLOS models (Jensen, 2007; 2013) and BLOS model for protected bike lanes (Foster et al., 2015) may fit some applications better.

When it comes to using the state-of-the-art approaches to assess bicycle networks, planners and practitioners need to integrate various road environments, such as arterials, collectors, local streets, and intersections, into a complete framework. The determinants and criteria may vary in different conditions. For example, some infrastructure facilities (e.g., cycle tracks, shared-use lanes) may disappear at intersections, making bicyclists feel less comfortable when riding through intersections. Using multiple criteria under various road conditions may provide more realistic and accurate guidance for improving the bicyclist comfort of a bicycle network.

APPENDIX C: Agency Engagement Questions

History and Background

- What work has been conducted to date related to bicycle facilities? - Identification and designation
- How were bicycle facilities identified/designated/characterized?
- How much of your streets network is covered/assessed?
- What data is currently available for the streets network?
- What are your successes and challenges for identifying/characterizing bicycle facilities?
- What changes in the effort have you considered?

Process and Methodology

- What is the process for identifying and designating bicycle facilities?
- How will your agency use a bicycle network?
- What departments (inter and intra) are you collaborating with on the bicycle facility planning?

Goals and Objective

- What are the goals for defining a bicycle network?
- What wishes do you have for defining a bicycle network (related to the prior work)
- In a perfect world, what would be perfect (or what would be different from initial efforts)?
- Who is your target audience for the work completed to date?

Application and Implementation

- What are your plans (near and long term) for the bicycle network?
- What is the process for expanding the bicycle network?
- What opportunities and barriers are present for planning and expanding the bicycle network?
- What successes and challenges have you experienced with implementing bicycle facilities?
- What treatments is your agency utilizing/implementing?
- What additional information would be desired to assist with planning and implementation efforts?

APPENDIX D: Data Dictionary

The ORIL: Bike Routes on Local Ohio System (ORIL) project aims to identify a viable model for measuring the comfort of statewide roadway facilities for bicycle users. As part of this effort, the project team documented existing GIS data maintained by jurisdictions across Ohio. By understanding data accuracy, coverage, and detail, the project team can develop a feasible bicycle comfort model that can be implemented in the short term and refined in the long term.

Summary

This memorandum outlines data Kittelson & Associates, Inc. (Kittelson) has obtained and organized for multimodal assessment as part of the ORIL project. The data is stored in a database for analysis and mapping purposes. Upon request, Kittelson can provide ORIL TAC members with the spatial database.

Multimodal Database

Kittelson assembled publicly available multimodal data that could inform a bicycle comfort model from jurisdictions across Ohio. The project team focused first on jurisdictions directly involved in the ORIL project with publicly available GIS data:

- Miami Valley Regional Planning Commission (MVRPC)
    - Counties located within MVRPC's jurisdiction with relevant, publicly available GIS data
- Mid-Ohio Regional Planning Commission (MORPC)
- Northeast Ohio Areawide Coordinating Agency (NOACA)
- Ohio Department of Transportation (ODOT)

Based on feedback from TAC members, Kittelson also investigated GIS data provided by other organizations or private entities that could inform a bicycle comfort metric for Ohio:

- Ohio Department of Natural Resources (ODNR)
- Open Street Map (OSM)
- Strava

The GIS data dictionary will be updated as the project team expands its spatial geodatabase of multimodal data for Ohio. It could be updated to include GIS data from Ohio jurisdictions that is not public-facing, data provided by other organizations, and other relevant datasets.

The following sections contain the current data dictionary for the ORIL project. It is arranged by jurisdiction or organization that the project team has obtained spatial data from, and includes two tables for each jurisdiction:

- Files in Geodatabase: this table lists all relevant spatial layers provided by the jurisdiction/ organization in question. It describes each spatial layer and highlights known issues with the data. Each layer is color coded to indicate how relevant it is to a bicycle comfort calculation.
- Pertinent Field Names and Descriptions: this table details all attributes from each spatial layer that could be used to inform a statewide bicycle comfort calculation.

Mid-Ohio Regional Planning Commission (MORPC) Regional Data Catalog

Files in Geodatabase

File name	Description	Source
Greenway Trails	This service is for the Central Ohio Greenways map application. It shows existing and proposed trails that are part of the recognized greenway trails system. Geography: 12 county Central Ohio region: Delaware, Fairfield, Fayette, Franklin, Knox, Licking, Madison, Marion, Morrow, Pickaway, Ross, and Union Counties. **This shapefile is duplicative of the Central Ohio Bikeways shapefile, and includes less data**	Mid-Ohio Regional Planning Commission Regional Data Catalog
Regional Street Centerline	This file is a compilation of LBRS data by County for the MORPC 15 region. The files were merged together by MORPC, but **due to schema issues, not all fields from each county file were carried over**. This layer was created for general display purposes only and is only updated quarterly at most.	Mid-Ohio Regional Planning Commission Regional Data Catalog
Parking Inventory	This file geodatabase contains the following parking items: On-Street Meters (provided by City of Columbus), On-Street Non-Metered, a Traffic Analysis Zone Boundary (provided by MORPC), and Parking Facilities. **Data only for City of Columbus.**	Mid-Ohio Regional Planning Commission Regional Data Catalog
Central Ohio Bikeways	Regional file showing existing, committed, proposed, and under construction bikeway facilities and multi-use trails in Central Ohio. Recognized bikeways include Lanes, Sharrows, Bike Boulevards, Routes and multi-use paths 8 ft or wider. Paved shoulders are currently included but are under review.	Mid-Ohio Regional Planning Commission Regional Data Catalog
Bike Level Of Comfort	**Major roads** are color-coded based on non-rush hour travel conditions, along with feedback from Columbus area residents, in order to indicate suitability for cyclists.	Mid-Ohio Regional Planning Commission Regional Data Catalog
Greater Franklin County Location Based Response System (LBRS) Centerlines	Road centerline file for Franklin County, Ohio, including a 7 mile buffer. It is maintained by multiple local agencies and part of the ODOT/OGRIP statewide LBRS program. The file is a constant work in progress and to be used for	Mid-Ohio Regional Planning Commission Regional Data Catalog

File name	Description	Source
	reference only. New data is being added or edited weekly.	
Traffic Count Database System (from MORPC Web Maps)	MORPC's Traffic Count Database System allows agencies to share traffic count data with the public instantaneously. **This data is not available to the public as a downloadable GIS shapefile or feature class and would have to be digitized.**	Mid-Ohio Regional Planning Commission Regional Data Catalog - http://morpc.ms2soft.com/tcds/tsearch.asp?loc=Morpc&mod=
Very helpful		
Moderately helpful		
A little helpful		
Not very helpful		

Pertinent Field Names and Descriptions

File name	Field Name	Field Description	Data Type	Notes
Greenway Trails	Bikeway Status	Bike Facility Construction Status (existing, proposed, committed / funded)	Text	Informs bike facility component of bicycle comfort calc for Central Ohio
Greenway Trails	Bikeway Type	Bike Facility Type, ranging from multi-use path to bicycle lane.	Text	Informs bike facility component of bicycle comfort calc for Central Ohio
Regional Street Centerline	Surface Type	Paved vs. Unpaved	String	Informs roadway screening component of bicycle comfort calc for Central Ohio **37,522 of 144,806 records are NULL, 53 are ` `**
Regional Street Centerline	Lanes	Number of lanes in roadway cross-section	String	Informs roadway width component of bicycle comfort calc for Central Ohio **12,773 of 144,806 records are NULL, 665 are ` `**
Regional Street Centerline	Speed	Posted speed limit	String	Informs roadway speed component of bicycle comfort calc for Central Ohio **6,441 of 144,806 records are NULL, 753 are ` `**
Regional Street Centerline	ODOT Functional Class	Functional Classification	String	Informs roadway screening component of bicycle comfort calc for Central Ohio **57,477 of 144,806 records are NULL, 37 are ` `**
Parking Inventory	Onstreet_metered	Metered on-street parking locations within Columbus, OH	Point	Informs parking location component of bicycle comfort calc for Columbus Ohio (**data type adds to complexity of GIS work**)

File name	Field Name	Field Description	Data Type	Notes
Parking Inventory	Onstreet_nonmetered	Non-metered on-street parking locations within Columbus, OH	Polyline	Informs parking location component of bicycle comfort calc for Columbus Ohio
Central Ohio Bikeways	Bike Facility Name	Bike Facility Name	Text	
Central Ohio Bikeways	Bikeway Status	Bike Facility Construction Status (existing, proposed, committed / funded)	Text	Informs bike facility component of bicycle comfort calc for Central Ohio
Central Ohio Bikeways	Bikeway Type	Bike Facility Type, ranging from multi-use path to bicycle lane.	Text	Informs bike facility component of bicycle comfort calc for Central Ohio
Bike Level Of Comfort	Lanes	Number of lanes in roadway cross-section	String	Informs roadway width component of bicycle comfort calc for Columbus Area
Bike Level Of Comfort	Speed	Posted speed limit	String	Informs roadway speed component of comfort calc for Columbus Area
Bike Level Of Comfort	BikeLOS201	Bicycle level of comfort scores (1-4)	String	Bicycle level of comfort scores for Columbus Area
Greater Franklin County Location Based Response System (LBRS) Centerlines	Surface Type	Paved vs. Unpaved	String	Informs roadway screening component of comfort calc for Franklin County
Greater Franklin County Location Based Response System	Lanes	Number of lanes in roadway cross-section	String	Informs roadway width component of comfort calc for Franklin County

File name	Field Name	Field Description	Data Type	Notes
(LBRS) Centerlines				
Greater Franklin County Location Based Response System (LBRS) Centerlines	Speed	Posted speed limit	String	Informs roadway speed component of comfort calc for Franklin County
Greater Franklin County Location Based Response System (LBRS) Centerlines	ODOT Functional Class	Functional Classification	String	Informs roadway screening component of comfort calc for Franklin County
Greater Franklin County Location Based Response System (LBRS) Centerlines	Bikeway	Type of Bike Facility located on the roadway	String	Informs bike facility component of comfort calc for Franklin County

ODOT Transportation Information Mapping System (TIMS) Data

Files in Geodatabase

File name	Description	Source
AADT Segments	Annual Average Daily Traffic Along Roadway Segments (updated 10/17)	ODOT TIMS Dataset
Active Bike Routes	Active bike routes maintained by the Office of Program Management (updated 9/18)	ODOT TIMS Dataset
LRS Routes	Linear Referencing System segments that are the basis for identifying unique roadway segments in ODOT's graphic roadway network. Very useful for standardizing bicycle comfort assessments statewide. (updated 10/17)	ODOT TIMS Dataset
Functional Classification	The organization of roadways into a hierarchy based on the character of service provided. Typical classifications include arterial, local, and collector roadways. (updated 5/18)	ODOT TIMS Dataset
Speed Zones	Inventory of Speed Zones (ODOT approved speed zones are needed for roads and streets that are to have a speed limit lower than the statutory prima-facie speed limits given in the Ohio Revised Code regardless of jurisdiction. This includes, rural state highways, county and township roads and streets in both cities and villages.) (updated 9/18)	ODOT TIMS Dataset
CMS (Car Growth Rate)	Car Annual Growth Rate as determined by Traffic Congestion Model produced by ODOT's Office of Statewide Planning and Research (updated 10/17)	ODOT TIMS Dataset
CMS (Volume Capacity Ratio)	Capacity of a segment by the hour as determined by Traffic Congestion Model produced by ODOT's Office of Statewide Planning and Research (updated 10/17)	ODOT TIMS Dataset
Destape	Roadway description point file contains physical features along the roadway such as intersections, corporation lines, brides, and mileposts (updated 10/17)	ODOT TIMS Dataset
Federal Truck Routes	Federal truck routes through the state of Ohio	ODOT TIMS Dataset
Ownership	Entity that has legal ownership of the roadway section (updated 3/18)	ODOT TIMS Dataset
PCR – Local	The latest pavement condition rating (PCR) sections for ODOT roads with a local functional classification	ODOT TIMS Dataset

File name	Description	Source
PCR	The latest pavement condition rating (PCR) for ODOT roads	ODOT TIMS Dataset
Road Inventory	Inventory of roadway characteristics (updated 3/18)	ODOT TIMS Dataset
School Zone Extensions	Inventory of school zone extensions (places where traditional school zone boundaries have been extended based on special circumstances)	ODOT TIMS Dataset
Very helpful		
Moderately helpful		
A little helpful		
Not very helpful		

Pertinent Field Names and Descriptions

File name	Field Name	Field Description	Data Type	Notes
AADT Segments	FAC_AADT_TOTAL_NBR	Total Annual Average Daily Traffic	Long	Informs roadway volume component of bicycle comfort calc for Ohio **72,194 miles of data**
AADT Segments	FAC_AADT_YR	Year AADT number corresponds to. Number may not represent year of collection since data is not collected every year.	Long	**All data updated 2016**
AADT Segments	NLF_ID	Primary key field that is the basis for identifying unique roadway segments in ODOT's graphic roadway network – aligns with LRS file	String	Connects to statewide LRS network. Helpful standardizing bicycle comfort assessments statewide.
Active Bike Routes	DESIGNATION	Identifies if the route is proposed or designated and by which jurisdiction	Text	Informs bicycle facility type component of bicycle comfort calc for ODOT roads.

File name	Field Name	Field Description	Data Type	Notes
				5,861 miles of data
Active Bike Routes	TYPE	Defines the type of bicycle facility	Text	Informs bicycle facility type component of bicycle comfort calc for ODOT roads – **missing facility width info 5,861 miles of data**
Active Bike Routes	NLF_ID	Primary key field that is the basis for identifying unique roadway segments in ODOT's graphic roadway network – aligns with LRS file	String	Connects to statewide LRS network. Helpful standardizing bicycle comfort assessments statewide.
Functional Classification	ROUTE_TYPE	Functional Classification of the Roadway Segment	String	Informs roadway screening component of the bicycle comfort calc for ODOT roads.
Functional Classification	NLF_ID	Primary key field that is the basis for identifying unique roadway segments in ODOT's graphic roadway network – aligns with LRS file	String	Connects to statewide LRS network. Helpful standardizing bicycle comfort assessments statewide.
Speed Zones	APPROVED_SPEED	Designated speed limit for speed zone	Double	Informs roadway speed component of bicycle comfort calc for ODOT roads.
Speed Zones	EXISTING_SPEED	Existing speed limit on the road	Text	Informs roadway speed component of bicycle comfort calc for ODOT roads.

File name	Field Name	Field Description	Data Type	Notes
Speed Zones	NLF_ID	Primary key field that is the basis for identifying unique roadway segments in ODOT's graphic roadway network – aligns with LRS file	String	Connects to statewide LRS network. Helpful standardizing bicycle comfort assessments statewide.
CMS (Car Growth Rate)	CAR_GROWTH_NBR	Car Annual Growth Rate	Double	Informs decision-making processes about bicycle mode share for ODOT modes.
CMS (Car Growth Rate)	NLF_ID	Primary key field that is the basis for identifying unique roadway segments in ODOT's graphic roadway network – aligns with LRS file	String	Connects to statewide LRS network. Helpful standardizing bicycle comfort assessments statewide.
CMS (Volume Capacity Ratio)	CAPACITY_NBR	Capacity of a segment by the hour	Long	Informs decision-making processes about bicycle mode share for ODOT modes.
CMS (Volume Capacity Ratio)	NLF_ID	Primary key field that is the basis for identifying unique roadway segments in ODOT's graphic roadway network – aligns with LRS file	String	Connects to statewide LRS network. Helpful standardizing bicycle comfort assessments statewide.
Destape	RECORD_TYPE_INDICATOR	Type of record. A - Route beginning, B - Split Jurisdiction, C - Corp Limit, E - Station Equation, F - Misc, G - Bridge, I - Intersection, J - Begin Gap, K - End Gap, M - Milepost, N - Railroad Underpass, O - Overpass, P - Blue	Text	Informs any intersection-related bicycle comfort assessment for ODOT roads.

File name	Field Name	Field Description	Data Type	Notes
		reference marker milepost,		
Federal Truck Routes	TRUCK_ROUTE	Yes/No field identifying whether the roadway is a federal truck route	String	Informs decision-making processes about bicycle mode share for ODOT modes.
Federal Truck Routes	NLF_ID	Primary key field that is the basis for identifying unique roadway segments in ODOT's graphic roadway network – aligns with LRS file	String	Connects to statewide LRS network. Helpful standardizing bicycle comfort assessments statewide.
Ownership	ODOT_DISTR	ODOT District Number for roadway segments	String	Assists in identifying responsible parties for projects identified through a bicycle comfort calc.
Ownership	JURISDICTION	Jurisdiction Code for roadway segments	String	Assists in identifying responsible parties for projects identified through a bicycle comfort calc.
Ownership	URBAN_AREA	Code identifying roadways located within urban areas	String	
Ownership	NLF_ID	Primary key field that is the basis for identifying unique roadway segments in ODOT's graphic roadway network – aligns with LRS file	String	Connects to statewide LRS network. Helpful standardizing bicycle comfort assessments statewide.

File name	Field Name	Field Description	Data Type	Notes
PCR – Local	PCR_NBR	Pavement Condition Rating for Roadway Segment	Long	Informs roadway condition component of bicycle comfort calc for ODOT roads.
PCR – Local	NLF_ID	Primary key field that is the basis for identifying unique roadway segments in ODOT's graphic roadway network – aligns with LRS file	String	Connects to statewide LRS network. Helpful standardizing bicycle comfort assessments statewide.
PCR	PCR_NBR	Pavement Condition Rating for Roadway Segment	Long	Informs roadway condition component of bicycle comfort calc for ODOT roads.
PCR	NLF_ID	Primary key field that is the basis for identifying unique roadway segments in ODOT's graphic roadway network – aligns with LRS file	String	Connects to statewide LRS network. Helpful standardizing bicycle comfort assessments statewide.
Road Inventory	LANES	Number of lanes in both directions carrying through traffic	Long	Informs roadway width component of bicycle comfort calc for ODOT roads. 37,452 out of 580,059 attributes have **0 values. 165,740 Miles of data.**
Road Inventory	SHLD_LT_TOTAL_WIDTH	Width of left (outside) shoulder, including both paved and unpaved parts measured from the center of the edge line outward	Long	Assists in identifying extra roadway width for striping bicycle facilities for ODOT roads. **165,740 Miles of data.**

File name	Field Name	Field Description	Data Type	Notes
Road Inventory	SHLD_RT_TOTAL_WIDTH	Width of the paved portion of the right (outside) shoulder measured from the center of the edge line outward	Long	Assists in identifying extra roadway width for striping bicycle facilities for ODOT roads. **165,740 Miles of data.**
Road Inventory	SPEED_LIMIT_NBR	Speed limit associated with the section of roadway	Long	Informs roadway speed component of bicycle comfort calc for ODOT roads. **165,740 Miles of data.**
Road Inventory	SURFACE_LT_WIDTH	Surface width on the left side of the roadway	Long	Assists in identifying extra roadway width for striping bicycle facilities for ODOT roads. **165,740 Miles of data.**
Road Inventory	SURFACE_RT_WIDTH	Surface width on the right side of the roadway	Long	Assists in identifying extra roadway width for striping bicycle facilities for ODOT roads. **165,740 Miles of data.**
Road Inventory	NLF_ID	Primary key field that is the basis for identifying unique roadway segments in ODOT's graphic roadway network – aligns with LRS file	String	Connects to statewide LRS network. Helpful standardizing bicycle comfort assessments statewide.
School Zone Extensions	NLF_ID	Primary key field that is the basis for identifying unique roadway segments in ODOT's graphic	String	Connects to statewide LRS network. Helpful standardizing bicycle comfort

File name	Field Name	Field Description	Data Type	Notes
		roadway network – aligns with LRS file		assessments statewide.

Northeast Ohio Areawide Coordinating Agency (NOACA) Data

Files in Geodatabase

File name	Description	Source
Bike_Pedestrian_Counts_2011_2016	Point file with bicycle and pedestrian count locations and corresponding count data conducted between 2011 and 2016.	NOACA GIS Data Portal
Bike_Pedestrian_Crashes_2010_2014_All_Crashes	Point file with bicycle and pedestrian crash locations and corresponding data for crashes occurring between 2010 and 2014	NOACA GIS Data Portal
Bike_Suitability	Polyline file detailing suitability of roadways based on bicyclists' varying levels of experience.	NOACA GIS Data Portal
Bikeway_Network	Polyline file detailing existing and planned bicycle facilities in the NOACA region.	NOACA GIS Data Portal
Functional_Class_2016	Polyline file providing functional classification and other roadway attributes for roadways in the NOACA region.	NOACA GIS Data Portal
Intermodal_Connectors	Polyline file with roadways that provide access between major intermodal facilities (roads that link different modes of transportation).	NOACA GIS Data Portal
NOACA_Freight_Network	Polyline file with all roadways in the NOACA region's freight network.	NOACA GIS Data Portal
NOACA_Traffic_Counts_2012, 2013, 2014, 2015	Polyline file with traffic count locations and associated data collected in 2012, 2013, 2014, and 2015 through NOACA's count program.	NOACA GIS Data Portal
Potential_Bike_Demand	Polygon file reporting potential bike demand across the NOACA region based on an analysis conducted by NOACA.	NOACA GIS Data Portal
Priority_Bikeway_Network	Polyline file representing a smaller subset of the NOACA region's bikeway network – the prioritized subset.	NOACA GIS Data Portal
Railroads_Lines	Polyline file representing the location of railroad lines in the NOACA region.	NOACA GIS Data Portal
Transit_2016	Polyline file representing light rail and heavy rail transit lines in Cuyahoga County and Cleveland, OH.	NOACA GIS Data Portal
2018 Level of Traffic Stress Analysis	Polyline file representing LTS scores for Lorain and Medina County (**this file has not yet been uploaded to NOACA's GIS Portal)**	NOACA
Very helpful		

File name	Description	Source
Moderately helpful		
A little helpful		
Not very helpful		

Pertinent Field Names and Descriptions

File name	Field Name	Field Description	Data Type	Notes
Bike_Pedestrian_Counts_2011_2016	Count Year	Year that bicycle and pedestrian count was conducted	String	Could inform volume component of bicycle comfort calc for NOACA region. **246 count locations**
Bike_Pedestrian_Counts_2011_2016	Bike – Total	Number of bicyclists observed at time of count	Long	Could inform volume component of bicycle comfort calc for NOACA region. **246 count locations**
Bike_Pedestrian_Counts_2011_2016	Pedestrian – Total	Number of pedestrians observed at time of count	Long	Could inform volume component of bicycle comfort calc for NOACA region. **246 count locations**
Bike_Pedestrian_Crashes_ 2010_ 2014_ All_ Crashes	Crash_Date	Month, date and year that the crash occurred	String	Could inform safety component of bicycle comfort calc or project prioritization for NOACA region.
Bike_Pedestrian_Crashes_ 2010_ 2014_ All_ Crashes	Crash_Severity	Crash Severity	String	Could inform safety component of bicycle comfort calc or project prioritization for NOACA region.

File name	Field Name	Field Description	Data Type	Notes
Bike_Pedestrian_Crashes_ 2010_ 2014_ All_ Crashes	Location_T	Approximate location of crash (intersection, segment, ramp, driveway, etc.)	String	Could inform safety component of bicycle comfort calc or project prioritization for NOACA region.
Bike_Pedestrian_Crashes_ 2010_ 2014_ All_ Crashes	Contribu	Contributing factors to crash	String	Could inform safety component of bicycle comfort calc or project prioritization for NOACA region.
Bike_Pedestrian_Crashes_ 2010_ 2014_ All_ Crashes	Road_Condi	Pavement condition (wet, ice, dry, etc.)	String	Could inform safety component of bicycle comfort calc or project prioritization for NOACA region.
Bike_Suitability	Skill Level	Assessed suitability of each roadway segment	String	Bike suitability score for NOACA region.
Bikeway_Network	Phase	Facility status (existing, planned, etc.)	String	Informs bicycle facility type component of bicycle comfort calc for NOACA region.
Bikeway_Network	Facility	Facility location (off-road vs. on-road)	String	Informs bicycle facility type component of bicycle comfort calc for NOACA region.
Bikeway_Network	Type	Facility type (trail, route, lane)	String	Informs bicycle facility type component of bicycle comfort calc for NOACA region.
Bikeway_Network	Width	Facility width, if available	String	Informs bicycle facility type

File name	Field Name	Field Description	Data Type	Notes
				component of bicycle comfort calc for NOACA region.
Functional_Class_2016	Type	Functional classification of roadway segment	String	Informs roadway width, speed, and screening components of bicycle comfort calc for NOACA region.
Functional_Class_2016	Lanes	Number of lanes in roadway cross-section	String	Informs roadway width, speed, and screening components of bicycle comfort calc for NOACA region.
Functional_Class_2016	Swdth	Roadway width (ft)	String	Informs roadway width, speed, and screening components of bicycle comfort calc for NOACA region.
Functional_Class_2016	Speed	Posted speed limit of roadway segment	String	Informs roadway width, speed, and screening components of bicycle comfort calc for NOACA region.
NOACA_Freight_Network	Truck_ADT	Truck ADT observed on each segment of the NOACA freight network	Double	Informs decision-making processes about bicycle mode share for NOACA modes.
NOACA_Freight_Network	Percent_Truck	Percent of ADT comprised of Truck traffic for each	Double	Informs decision-making processes about bicycle mode share for NOACA modes.

File name	Field Name	Field Description	Data Type	Notes
		segment of the NOACA freight network		
NOACA_Traffic_Counts_2012, 2013, 2014, 2015	Date	Year that traffic count was conducted	Date	Informs roadway volume component of the bicycle comfort calc for NOACA region.
NOACA_Traffic_Counts_2012, 2013, 2014, 2015	Total_AADT	AADT observed at the time of count	Long	Informs roadway volume component of the bicycle comfort calc for NOACA region.
Potential_Bike_Demand	TotScore	Bike demand score assigned to NOACA jurisdictions.	Short	Bike demand score for NOACA region.
Priority_Bikeway_Network	Status	Facility status (existing, planned, etc.)	String	Informs bicycle facility type component of bicycle comfort calc for NOACA region.
2018 Level of Traffic Stress Analysis	Road_Class	Road classifications used in NOACA's 2018 LTS study, including special categories like access streets, neighborhood streets, and highways	?	Informs the roadway screening components of bicycle comfort calc for Lorain and Medina Counties.
2018 Level of Traffic Stress Analysis	SpeedFinal	Speed limit used in the LTS analysis; NOACA gathered the	?	Informs the roadway speed components of bicycle comfort

File name	Field Name	Field Description	Data Type	Notes
		speed limit for every road in the counties by checking street imagery from Google Maps. In areas where no speed limit is posted, the default speed according to the Ohio Revised Code was used (typically 55 MPH)		calc for Lorain and Medina Counties.
2018 Level of Traffic Stress Analysis	LTS_Lanes	Number of directional through lanes used in the LTS analysis; the number of travel lanes came from ODOT when available. Where this data is not available, staff counted the number of lanes visible on recent aerial imagery.	?	Informs the roadway width components of bicycle comfort calc for Lorain and Medina Counties.
2018 Level of Traffic Stress Analysis	LTS_Countinput	Traffic count uses as average daily traffic in the LTS analysis; NOACA relied on traffic counts taken	?	Informs the roadway volume components of bicycle comfort calc for Lorain and Medina Counties.

File name	Field Name	Field Description	Data Type	Notes
		by ODOT and NOACA.		
2018 Level of Traffic Stress Analysis	Centerline	1: centerline is present, 0: centerline is not present, <Null>: centerline information was not needed to assign an LTS score (NOACA relied on recent aerial imagery to determine the presence or absence of a centerline)	?	Informs the roadway centerline components of bicycle comfort calc for Lorain and Medina Counties.
2018 Level of Traffic Stress Analysis	Final_LTS	LTS score used in the final 2018 Lorain and Medina County Bicycle Transportation Map	?	Bicycle LTS score for Lorain and Medina Counties.

Miami Valley Regional Planning Commission (MVRPC) Regional Data Catalog

FILES IN GEODATABASE

File name	Description	Source
Vehicle Traffic and Trail Counts	MVRPC maintains a regional traffic count program database with the assistance of participating jurisdictions and the Ohio Department of Transportation (ODOT). **This data is available via an online map and needs to be acquired from MVRPC for further investigation.**	Miami Valley Regional Planning Commission (MVRPC) Open GIS
Regional Bikeways	Existing regional bike ways and trails for the Miami Valley Region, as well as proposed routes and trails as detailed in the 2040 Long Range Transportation Plan (published in 2012 by MVRPC). **This data is available via an online map and needs to be acquired from MVRPC for further investigation.**	Miami Valley Regional Planning Commission (MVRPC) Open GIS
Functionally Classified Streets	Grouping of roads, streets, and highways in hierarchy based on the type of highway service they provide. This set give a complete listing of all public streets, roads, and highways in Ohio classified above local.	Miami Valley Regional Planning Commission (MVRPC) Open GIS
Transit Routes	GDRTA Fixed Route and GreeneCATS Flex Routes. **This data is available via an online map and needs to be acquired from MVRPC for further investigation.**	Miami Valley Regional Planning Commission (MVRPC) Open GIS
Very helpful		
Moderately helpful		
A little helpful		
Not very helpful		

Pertinent Field Names and Descriptions

File name	Field Name	Field Description	Data Type	Notes
Vehicle Traffic and Trail Counts	~TBD~	~TBD~	~TBD~	Informs roadway volume component of bicycle comfort calc for Miami Valley Regional Planning Commission
Regional Bikeways	~TBD~	~TBD~	~TBD~	Informs bike facility component of bicycle comfort calc for Miami Valley Regional Planning Commission
Functionally Classified Streets	FUNCCLS	Functional classification of major roadways: Interstate (01, 11), Freeway and Expressway (12), Major Arterial (02, 14), Minor Arterial (06, 16), Collector – Urban and Major (07, 17), and Collector – Minor Rural (08)	String	Informs roadway screening component of bicycle comfort calc for Miami Valley Regional Planning Commission

Butler, Clark, Darke, Greene, Miami, Montgomery, Preble, and Warren Data Catalog

FILES IN GEODATABASE

File name	Description	Source
~N/A~	*Unclear from online resources whether Butler County maintains transportation-related GIS data.*	Butler County
RoadCenterline	Roadway centerline for streets in Clark County. **This data is available via an online map and needs to be acquired from Clark County for further investigation.**	Clark County GIS
Trails	Trail polyline for Clark County. **This data is available via an online map and needs to be acquired from Clark County for further investigation.**	Clark County GIS
~N/A~	*Unclear from online resources whether Darke County maintains transportation-related GIS data.*	Darke County
Centerlines	The Road Centerlines layer contains all streets regardless of road type. This layer is designed for both map display and for network routing. Address ranges for each segment may also be used for geocoding. For **Greene County**.	Greene County Open GIS
Edge of Pavement	This is a polygon layer which shows the approximate edges of paved roads in **Greene County**, Ohio. The data set does not include street names, it only shows the edges of the pavement and whether the road is paved.	Greene County Open GIS
~N/A~	*Unclear from online resources whether Miami County maintains transportation-related GIS data.*	Miami County
Street_CL	This data set contains streets for **Montgomery County**.	Montgomery County Open GIS
Road Centerlines	This data set contains streets for **Preble County**.	Preble County Open GIS
LBRS_Centerlines (within ParcelsandRoads Geodatabase)	This database contains parcels, **centerlines**, boundaries and **right of way** for Warren County.	Warren County Open GIS
Very helpful		

File name	Description	Source
Moderately helpful		
A little helpful		
Not very helpful		

Pertinent Field Names and Descriptions

File name	Field Name	Field Description	Data Type	Notes
RoadCenterline (Clark County)	~TBD~	~TBD~	~TBD~	Could inform roadway screening component of bicycle comfort calc for Clark County
Trails (Clark County)	~TBD~	~TBD~	~TBD~	Could inform bicycle facility component of bicycle comfort calc for Clark County
Centerlines (Greene County)	SpeedLimit	Speed limit for road segments.	Double	Informs roadway screening component of bicycle comfort calc for Greene County
Edge of Pavement (Greene County)	Type	Indicates whether roadway segment is paved or unpaved.	String	Informs roadway screening component of bicycle comfort calc for Greene County
Street_CL (Montgomery County)	NLFID	Primary key field that is the basis for identifying unique roadway segments in ODOT's graphic roadway network – *probably* aligns with ODOT LRS file.	String	*Probably* connects to statewide LRS network. Helpful standardizing bicycle comfort assessments statewide.
Road Centerlines (Preble County)	SPEEDLIMIT	Speed limit for road segments.	Long	Informs roadway screening component of bicycle comfort calc for Preble County.
Road Centerlines (Preble County)	LANES	Number of lanes in roadway cross-section.	Short	Informs roadway screening component of bicycle comfort calc for Preble County.
Road Centerlines (Preble County)	NFLIDNEW	Primary key field that is the basis for identifying unique roadway segments in ODOT's graphic roadway network – *probably* aligns with ODOT LRS file.	String	*Probably* connects to statewide LRS network. Helpful standardizing bicycle comfort assessments statewide.

File name	Field Name	Field Description	Data Type	Notes
LBRS_Centerlines (within Warren County ParcelsandRoads Geodatabase)	ROUTECLASS	Functional classification of streets in Warren County.	String	Informs roadway screening component of bicycle comfort calc for Warren County.
LBRS_Centerlines (within Warren County ParcelsandRoads Geodatabase)	NLFID	Primary key field that is the basis for identifying unique roadway segments in ODOT's graphic roadway network – *probably* aligns with ODOT LRS file.	String	*Probably* connects to statewide LRS network. Helpful standardizing bicycle comfort assessments statewide.
LBRS_Centerlines (within Warren County ParcelsandRoads Geodatabase)	LANES	Number of lanes per street in Warren County.	String	Informs roadway screening component of bicycle comfort calc for Warren County.
LBRS_Centerlines (within Warren County ParcelsandRoads Geodatabase)	SPEED	Speed limit for streets in Warren County.		Informs roadway screening component of bicycle comfort calc for Warren County.

Strava[15]

FILES IN GEODATABASE

File name	Description	Source
FL_Edges_2016_RIDE_JantoJun	This database contains polylines for bike ride data for the state of Florida via STRAVA data collection from January 2016 to June 2016.	Florida Department of Transportation (FDOT)
Very helpful		
Moderately helpful		
A little helpful		
Not very helpful		

Pertinent Field Names and Descriptions

File name	Field Name	Field Description	Data Type	Notes
FL_Edges_2016_RIDE_JantoJun	ATHCNT	Count of unique cyclists on the piece of street for the rolled-up date frame. This number represents the number of cyclists going the direction the street was digitized.	Double	Informs counts of cyclists for use considerations.
FL_Edges_2016_RIDE_JantoJun	RACTCNT	Count of unique cyclists on the piece of street for the rolled-up date frame. This number represents the number of cyclists going against direction the street was digitized.	Double	Informs counts of cyclists for use considerations.

[15] Kittelson conducted a review of statewide STRAVA data for Florida, available through FDOT.

File name	Field Name	Field Description	Data Type	Notes
FL_Edges_2016_RIDE_JantoJun	ACTCNT	Count of bike trips (regardless of unique riders) on the piece of street for the rolled-up date frame. This number represents the number of cyclists going the direction the street was digitized.	Double	Informs counts of cyclists for use considerations.
FL_Edges_2016_RIDE_JantoJun	RACTCNT	Count of bike trips (regardless of unique riders) on the piece of street for the rolled-up date frame. This number represents the number of cyclists going against the direction the street was digitized	Double	Informs counts of cyclists for use considerations.
FL_Edges_2016_RIDE_JantoJun	TATHCNT	Total number of unique cyclists on the piece of street regardless of direction of travel for the rolled-up date frame	Double	Informs counts of cyclists for use considerations.
FL_Edges_2016_RIDE_JantoJun	TACTCNT	Total number of bike trips on the piece of street regardless of direction of travel	Double	Informs counts of cyclists for use considerations.

File name	Field Name	Field Description	Data Type	Notes
		for the rolled-up date frame.		
FL_Edges_2016_RIDE_JantoJun	ACTTIME	Median time in seconds of bike trips on the piece ofstreet for the rolledup date frame. This number represents the time of cyclists going the direction the street was digitized.	Double	Informs time data for length of ride considerations.
FL_Edges_2016_RIDE_JantoJun	RACTTIME	Median time in seconds of bike trips on the piece of street for the rolledup date frame. This number represents the time of cyclists going against direction the street was digitized.	Double	Informs time data for length of ride considerations.
FL_Edges_2016_RIDE_JantoJun	CMTCNT	Total number of commute bike trips on the piece of street regardless of direction of travel for the rolled-up date frame.	Double	Informs commute cycle data.
FL_Edges_2016_RIDE_JantoJun	RCMTCNT	Total number of commute bike trips on the piece of street for the rolledup date frame. This number	Double	Informs commute cycle data.

File name	Field Name	Field Description	Data Type	Notes
		represents the count of commute trips going against the direction the street was digitized.		
FL_Edges_2016_RIDE_JantoJun	TCMTCNT	Total number of commute bike trips on the piece of street for the rolledup date frame.	Double	Informs commute cycle data.
FL_Edges_2016_RIDE_JantoJun	ATHCNT_X	Count of unique cyclists on the piece of street for the rolled-up date frame between the predefined time frames as noted above (where X=the numbered time frame). This number represents the numberof cyclists going the direction the street was digitized.	Double	Counts individuals that use a segment verses regular riders.
FL_Edges_2016_RIDE_JantoJun	RATHCNT_X	Count of unique cyclists on the piece of street for the rolled-up date time frame between the predefined time frames as noted above (where X=the numbered time frame). This	Double	Counts individuals that use a segment verses regular riders.

File name	Field Name	Field Description	Data Type	Notes
		number represents the number of cyclists going against direction the street was digitized.		
FL_Edges_2016_RIDE_JantoJun	ACTCNT_X	Count of bike trips (regardless of unique riders) on the piece of street for the rolled-up time frame between the predefined time frames as noted above (where X=the numbered time frame). This number represents the number of cyclists going the direction the street was digitized.	Double	Total counts for ridership of a location.
FL_Edges_2016_RIDE_JantoJun	RACTCNT_X	Count of bike trips (regardlessof unique riders) on the piece of street for the rolled-up time frame between the predefined time frames as noted above (where X=the numbered time frame).	Double	Total counts for ridership of a location.

File name	Field Name	Field Description	Data Type	Notes
		This number represents the numberof cyclists going against the direction the street as digitized.		
FL_Edges_2016_RIDE_JantoJun	TATHCNT_X	Total number of unique athletes on the piece of street regardless of direction of travel for rolled-up time frame between the predefined time frames as noted above (where X=the numbered time frame).	Double	Counts for number of athletes on a specific segment.
FL_Edges_2016_RIDE_JantoJun	TATHCNT_X	Total number of bike trips on the piece of street regardless of direction of travel for rolled-up time frame between the predefined time frames as noted above (where X=the numbere d time frame).	Double	Total counts for ridership of a location.
FL_Edges_2016_RIDE_JantoJun	ACTTIME_X	Median time in seconds for bike trips on the piece of street during the rolled-up time frame between	Double	Time can help determine speed, traffic, etc.

File name	Field Name	Field Description	Data Type	Notes
		the predefined time frames as noted above (where X=the numbered time frame). This number represents the time of cyclists going the direction the street was digitized.		
FL_Edges_2016_RIDE_JantoJun	RACTTIME_X	Median time in seconds for bike trips on the piece of street during the rolled-up time frame between the predefined time frames as noted above (where X=the numbered time frame). This number represents the time of cyclists going against direction the street was digitized.	Double	Time can help determine speed, traffic, etc.
FL_Edges_2016_RIDE_JantoJun	CMTCNT_X	Total number of commute bike trips on the piece of street for the rolled-up time frame between the predefined time frames as noted above	Double	Informs commute cycle data.

File name	Field Name	Field Description	Data Type	Notes
		(where X=the numbered time frame). This number represents the time of cyclists going against direction the street was digitized.		
FL_Edges_2016_RIDE_JantoJun	RCMTCNT_X	Total number of commute bike trips on the piece of for the rolled-up time frame between the predefined time frames as noted above (where X=the numbered time frame). This number represents the time of cyclists going against direction the street was digitized.	Double	Informs commute cycle data.

Kittelson Concerns/Questions About Strava Data

- It is useful to compare street corridors against each other. It would be reasonable to conclude which routes bicyclists prefer or which routes might have higher bicycle use (comparatively in a given geography). It's not a good proxy to establish bicycle volume numbers.
- The data is only captured by those using the Strava app. As I understand it, not only do you have to have the app, you must actively use it to be counted. For all the other non-recreational riders, folks without cars who use their bike as primary transportation, they may not be using Strava (and would not be counted). Because of that, jurisdictions have somewhat backed off evaluating Strava for counts.
- Its usefulness might really be limited to determining recreational ride patterns throughout a network

Open Street Map Data Catalog

FILES IN GEODATABASE

File name	Description	Source
osm_pt	Point file containing information about the presence of the following relevant map features: barriers, railways, highways, and more.	Open Street Map (October 2018)
osm_ln	Polyline file containing information about the presence of the following relevant map features: barriers, routes, railways, highways, and more.	Open Street Map (October 2018)
osm_ply	Polygon file containing information about the presence of the following relevant map features: barriers, highways, railways, and more.	Open Street Map (October 2018)
Very helpful		
Moderately helpful		
A little helpful		
Not very helpful		

Pertinent Field Names and Descriptions

File name	Field Name	Field Description	Data Type	Notes
osm_pt	OSMID	Unique ID used to identify the OSM point.	String	Connects osm point to OSM database to incorporate updates to osm network into analyses.
osm_pt	Highway	The point location of roadway elements including, but not limited to: crosswalks, yield signs, mini-roundabouts, highway exits, passing places, stop signs, traffic signals, and cul de sacs.	String	Could inform crossing component of statewide bicycle comfort calc.
osm_pt	Railway	The point location of railway elements including, but not limited to: pedestrian crossing locations and roadway crossing locations.	String	Could inform crossing component of statewide bicycle comfort calc.
osm_pt	Barrier	The point location of barrier elements including, but not limited to: curbs.	String	Could inform crossing component of statewide bicycle comfort calc.

File name	Field Name	Field Description	Data Type	Notes
osm_ln	OSMID	Unique ID used to identify the OSM line.	String	Connects osm line to OSM database to incorporate updates to osm network into analyses.
osm_ln	Highway	The line location of roadway types including, but not limited to: motorway, trunk, primary, secondary, tertiary, unclassified, residential, service, bus only lanes, footways, cycleways, and paths.	String	Could inform roadway screening component of statewide bicycle comfort calc.
osm_ln	Lanes (tag value)	The number of lanes in an osm roadway cross-section.	String	Could inform roadway screening component of statewide bicycle comfort calc.
osm_ln	Maxspeed (tag value)	The posted speed for an osm roadway .	String	Could inform roadway screening component of statewide bicycle comfort calc.
osm_ln	Railway	The line location of railway types including, but not limited to: rail, subway, tram, and light rail.	String	Could inform crossing component of statewide bicycle comfort calc.
osm_ln	Barrier	The line location of barrier types including, but not limited to cable barriers, guard rails, fences, curbs, and retaining walls.	String	Could inform crossing component of statewide bicycle comfort calc.

Ohio Department of Natural Resources (ODNR) Data

FILES IN GEODATABASE

File name	Description	Source
ODNR_Trails	This database contains 2464 polylines for trail data for the state of Ohio.	Ohio Department of Natural Resources (ODNR) Metadata
Very helpful		
Moderately helpful		
A little helpful		
Not very helpful		

Pertinent Field Names and Descriptions

File name	Field Name	Field Description	Data Type	Notes
ODNR_Trails	TRAIL_NAME	Names of trails throughout Ohio.	String	Trail locations to incorporate off-road facilities into ODOT's statewide bicycle comfort network.
ODNR_Trails	USE_CODE	Use code of trails including ATV, Equestrian, Hike, Mountain Bike, On-Street Bike, Park Trail, Shared Use, and Snowmobile.	String	Trail type to incorporate off-road facilities into ODOT's statewide bicycle comfort network.

APPENDIX E: Application Outcomes

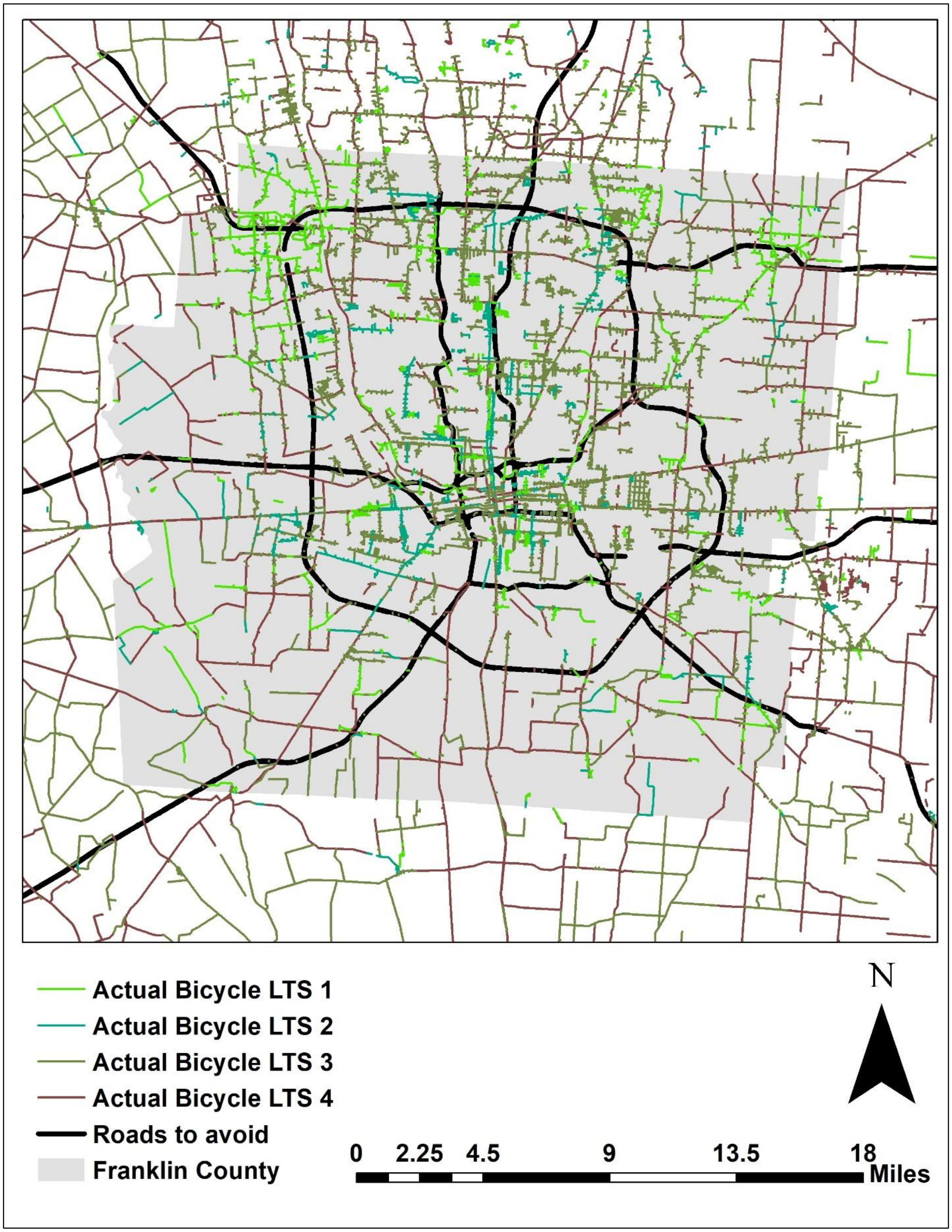

Figure 16 – Bicycle LTS score Assignments for the Mid-Ohio Region with Actual Data

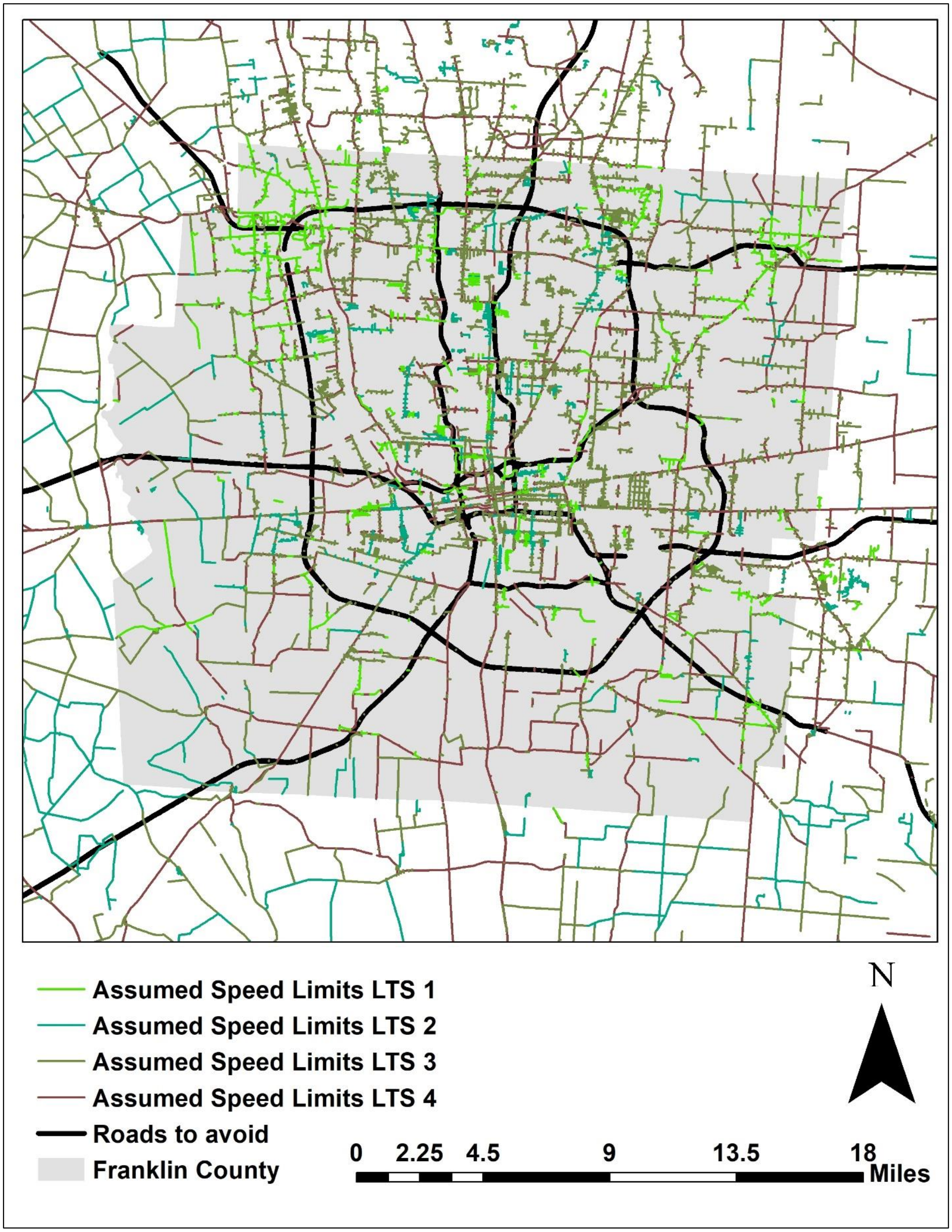

Figure 17 – Bicycle LTS score Assignments for the Mid-Ohio Region with Assumed Speed Limits

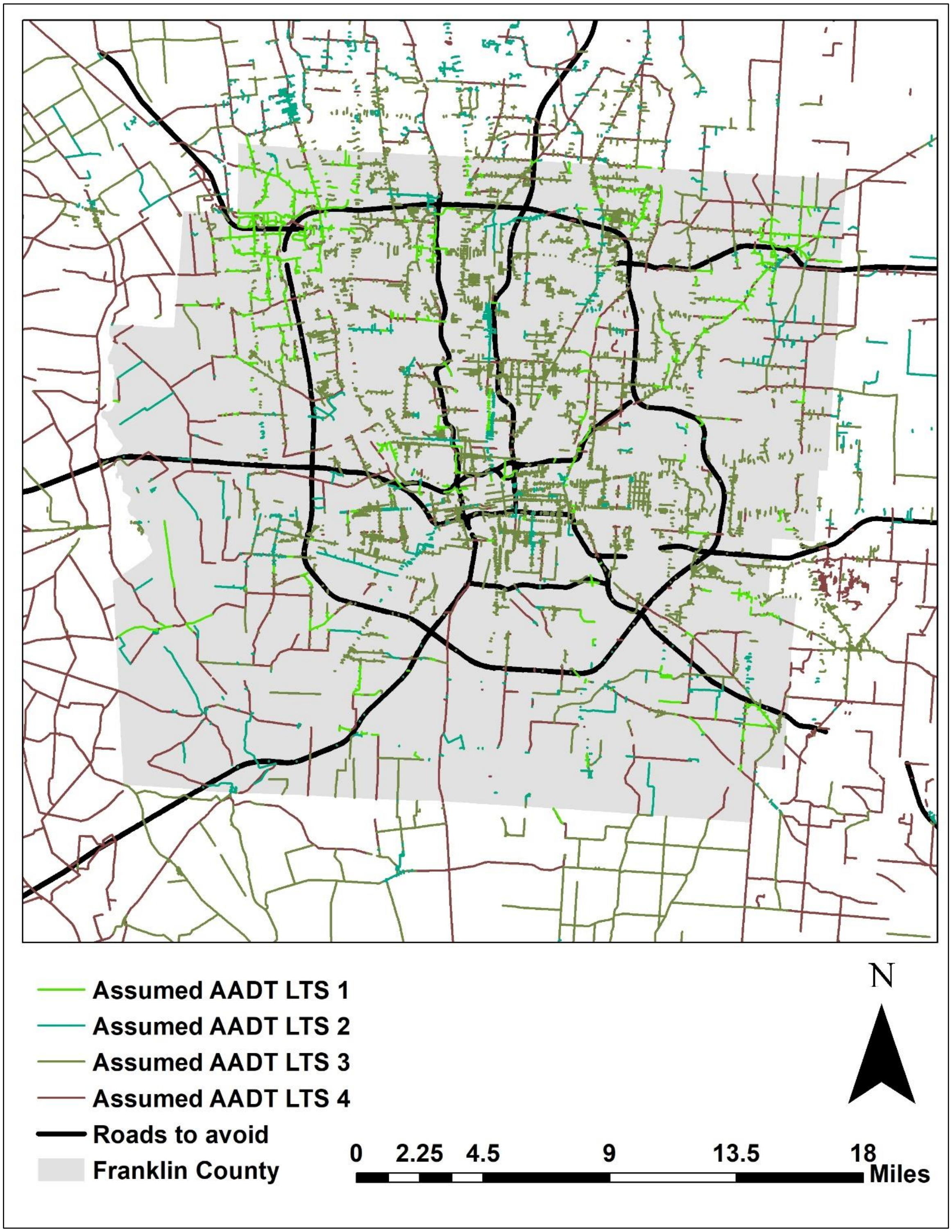

Figure 18 – Bicycle LTS score Assignments for the Mid-Ohio Region with Assumed AADT

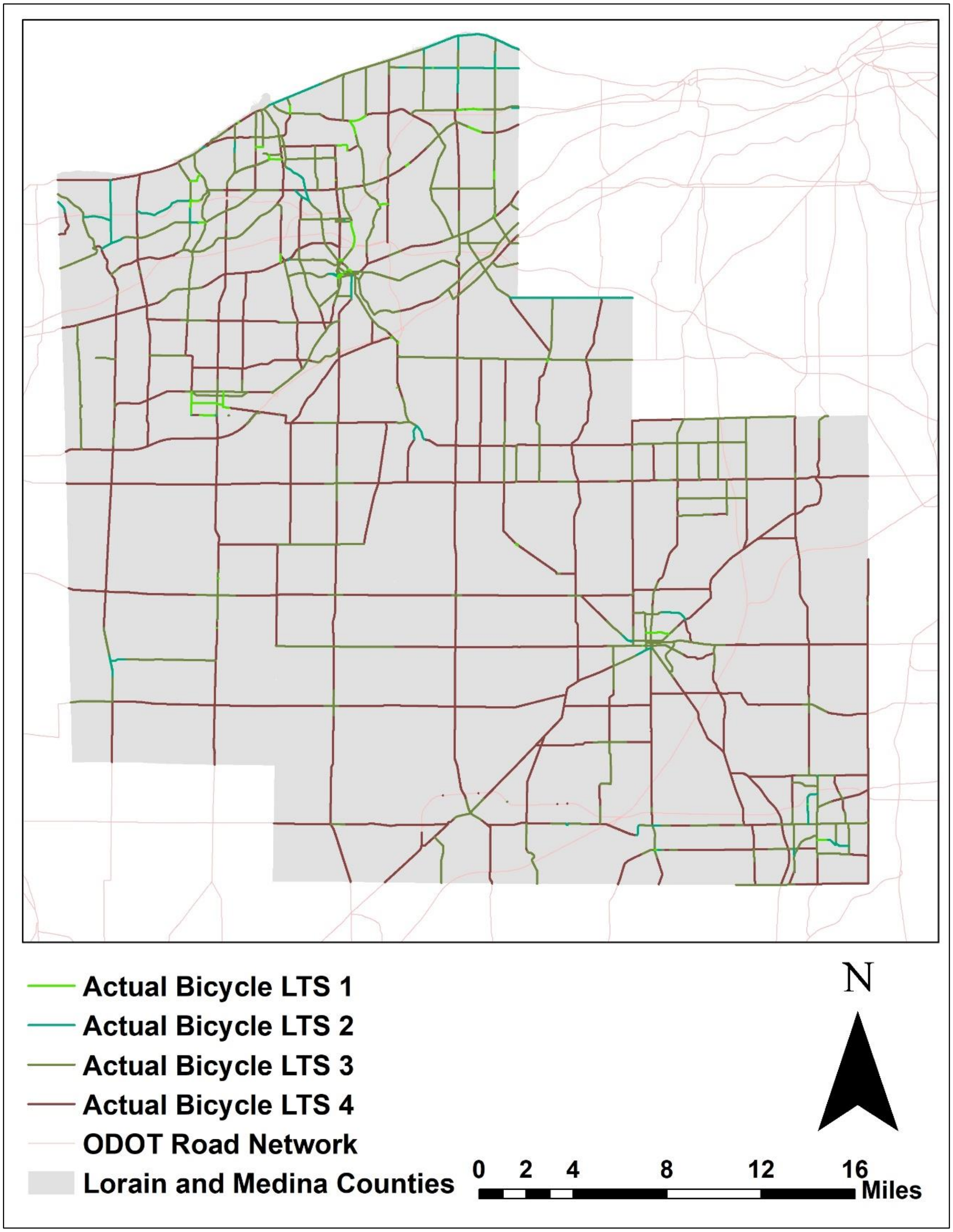

Figure 19 – Bicycle LTS score Assignments for NOACA Area Using LTS Framework

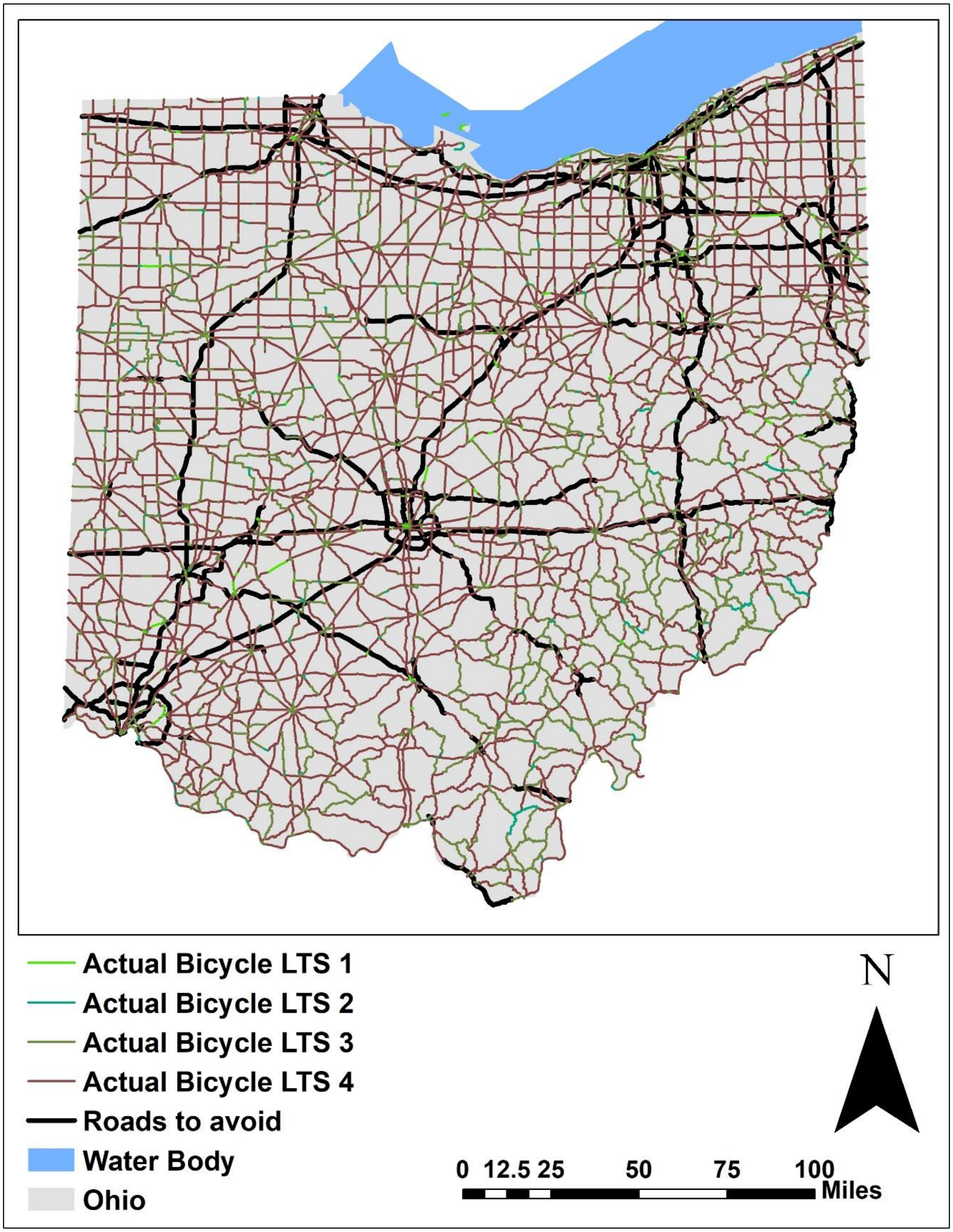

Figure 20 – Bicycle LTS score Assignments for the Ohio State Routes