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Methods for Investigating and Advancing Active Transportation in New Hampshire

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Laura E. Getts
For the degree of
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METHODS FOR INVESTIGATING AND ADVANCING ACTIVE TRANSPORTATION IN NEW HAMPSHIRE

Abstract approved:

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Amy M. Villamagna, Thesis Advisor

Access to and use of active transportation opportunities are central to the creation of sustainable communities in the state of New Hampshire (NH). To further active transportation participation in the state, Plymouth State University partnered with NH's Department of Transportation and regional planning commissions to better understand barriers to bicycling throughout NH. Participatory GIS mapping (PPGIS) surveys in two case study regions of NH captured perceived barriers to bicycling, which validated Level of Traffic Stress (LTS) roads models. Additional community and regional accessibility assessments utilized a Level of Traffic Stress model to identify gaps in the state's bicycling network and prioritize roadways for improvement. The results of the PPGIS survey revealed few distinctions between regional perceptions of barriers to bikeability, supporting the application of bicycle prescriptions statewide. The survey also suggested that LTS-measured variables are among the most prominent barriers to bicycling engagement in NH. Planners can thus justify funding and prioritizing pro-bicycle roadway improvements informed by LTS model results, and, by extension, the accessibility analysis. This research provides planners, government officials, citizens, and advocacy groups with recommendations regarding the most effective processes for developing and implementing active transportation improvements throughout their communities.

METHODS FOR INVESTIGATING AND ADVANCING ACTIVE TRANSPORTATION IN NEW HAMPSHIRE

BY

Laura E. Getts

A THESIS

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degree of

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I understand that my thesis will become part of the permanent collection at Plymouth State University, Lamson Library. My signature below authorizes release of my thesis to any reader upon request.

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Laura E. Getts, Author

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LIST OF ABBREVIATIONS

GIS = Geographical Information Systems

LTS = Level of Traffic Stress

NH = New Hampshire

NHDOT = New Hampshire Department of Transportation

PPGIS = Public Participatory Geographical Information Systems

Chapter 1: Introduction

Transportation matters, and prevailing transportation choices impact public health, the local environment, and societal prosperity. Active transportation—any human-powered mode of transit, such as walking or bicycling—are modes that provide the widest array of benefits to communities, states, and regions. In addition to reducing vehicle congestion, vehicle noise, and the state's pollution burden, increased numbers of residents engaging in active transportation may boost a locality's social equity and capital, and result in a population that is physically healthier, more environmentally conscious, and financially liberated by mobility alternatives (Legrain et al., 2015; Garrett-Peltier, 2011; Smart Growth America, 2015; Clifton et al., 2013; Lankford, J. et al, 2011; Heath et al., 2006).

Data Gaps

Sufficient knowledge about active transportation trends and deficits can empower planners to allocate time and funding to pro-active transportation programs and infrastructure developments that encourage public participation. The Bureau of Transportation Statistics (BTS) identified comprehensive and systematic data on usage, including potential usage, as perhaps the highest priority for bicycle data needs (Dill and Carr, 2003). BTS also identified "data on user preferences, attitudes, and expressed needs of existing and potential bicyclists and pedestrians" as an important priority (Dill and Carr, 2003).

Active transportation-specific models enable engineers and planners to prioritize projects that further facilitate such modes of transport. Tools that quantitatively assess gaps, usage, potential for usage, and preferences/needs of active transportation users can help communities compete for funding that is historically allocated to motorized transportation. According to Landis et al. (1997), "Currently in the United States, the choice between bicycle-facility projects is often made in the absence of an objective supply-side evaluation of the existing roadway facilities. Because competition is fierce among the various transportation modes for project construction funding, a reliable, quantitative supply-side evaluation is needed for bicycle-mode projects".

While existing models and tools assess bicycle infrastructure, roadway-specific bicycle stress, and even where individuals ride, questions about who cycles, motivations for cycling, and barriers to engagement are important considerations that require public outreach and feedback. Answers to all of these questions provide much needed support for interventions that promote bicycling. Additionally, such data can enhance prevailing transportation forecasting models. To both justify and accurately prescribe active transportation interventions, it is beneficial to support actions with high quality information. As a result, communities, states, and regions benefit from the systematic collection and evaluation of both quantitative and qualitative active transportation-specific data.

New Hampshire Sustainable Communities

According to the New Hampshire Sustainable Communities Initiative (NH SCI), both access to and use of active transportation opportunities are central to the development of sustainable communities in the state of New Hampshire (NH). In the list of factors underpinning the need for a New Hampshire sustainable communities initiative, NH planners identify "lack of alternative transportation" as a priority (Nashua Regional Planning Commission (NRPC), 2011). Stated transportation goals include: a decrease in per capita vehicle-miles traveled (VMT) and transportation related emissions for the region, an increase in miles and/or percentage of streets served by bike and pedestrian infrastructure, a decrease in per capita vehicle miles traveled in the region, a shift in the proportion of regional trips performed by automobile, transit, walking and bicycling, reduced disproportionate access of transit alternatives to different populations, decreased age and improved condition of existing transportation infrastructure, and improved status of ozone and or particulate matter (NRPC, 2011).

From 1960 to 2010, NH's population more than doubled from about 600,000 to over 1.3 million people. Much of this growth was low-density residential sprawl (NRPC, 2011). In response, many communities have implemented regulations that further encouraged unsustainable, dispersed settlement patterns. According to the NH Sustainable Communities Initiative project summary, approximately 90% of commuting trips in NH are by automobile (95% in rural counties). Most of the remaining 5% is accounted for by intra-city bus transit in a few urban areas including Manchester, Nashua, Concord, and Hanover-Lebanon, with comprehensive community routes and service to select locations in Portsmouth, Dover, Durham, Newington, Rochester, and Somersworth (11 out of the State's 234 municipalities). In 2009, 82% of all work commutes were by single occupant vehicle (NRPC, 2011). While a direct correlation between land use and transportation choices in NH is not definitive, existing statistics reveal significant room for active transportation growth across the state.

NH has a powerful opportunity to place itself at the forefront of active transportation and lead the region in prioritizing non-motorized transportation pathways. According to a report by The League of American Bicyclists, NH is currently the 27th most bike friendly state in America. With careful planning, outreach, and allocation of resources, NH can revolutionize access to active transportation corridors, redefining itself as a bike and walk friendly state that pioneers functional, healthy, safe, and economically beneficial alternatives to motorized vehicle transport.

Project Goals

This project has the potential to make a significant contribution to the statewide effort to reassess transportation corridors within NH and to redefine transportation policy. Most existing active transportation research reflects the values and needs of large, urban cities and their respective residents. It is unclear to what extent active transportation barriers in a state such as New Hampshire are a product of social, physical, environmental, or infrastructural challenges. As a result of this research, both communities and the state will be able to more efficiently allocate funds to target increased active transportation participation and accessibility. Additionally, public participation in the research process will facilitate productive dialogue about sustainable transportation in our communities and empower all stakeholders to maintain or increase their level of civic engagement.

The following chapters of this thesis discuss both tools for evaluating active transportation conditions in NH and the results of tool application in two unique case study regions of New Hampshire:

- Chapter 2, entitled "Bicycling Network Accessibility in NH: Models to Identify Gaps and Prioritize Improvements", combines traffic stress modelling with GIS-based accessibility analyses to determine the degree to which key destinations are accessible via a low-stress road network, and to identify road segments that are most critical to bicycle accessibility (centrality). This chapter demonstrates to planners how proposed bikeability assessments can cheaply and efficiently prioritizing road segments for improvement.

- Chapter 3, entitled “Public Participatory GIS as an Active Transportation Planning Tool in New Hampshire”, used PPGIS to characterize the current and potential bicyclist populations in two case study communities in NH and prescribe associated recommendations for increasing the bicyclist population and frequency of bicycling in NH. Furthermore, the spatial results from a hazardous road mapping portion of this survey were used to validate the NH-specific traffic stress model introduced in Chapter 2. This chapter demonstrates how the PPGIS approach to public feedback can shape the role of models in active transportation planning in NH and fill data gaps not currently captured by existing models.

- Chapter 4 is a summary and discussion of findings from chapters 2 and 3. This chapter reviews the pros and cons of each method, their respective relevance to planners and stakeholders, recommendations for improved bikeability in NH, and recommendations for future work.

Chapter 2: Bicycling Network Accessibility in New Hampshire: Models to Identify Gaps and Prioritize Improvements

INTRODUCTION

An increase in access to and use of active transportation—any human-powered mode of transportation, such as bicycling and walking—generates countless benefits for a community. Active transportation promotes physical activity and social equity, limits environmental pollution, builds social capital, reduces traffic congestion and costs, bolsters the local economy, and improves community mobility and resilience (Mendoza and Yiu, 2014; Rogers et al., 2013; Legrain et al., 2015; Garrett-Peltier, 2011; Smart Growth America, 2015; Wang et al, 2012; Clifton et al., 2013; Lankford, J. et al, 2011; Heath et al., 2006; New Hampshire Department of Transportation, 2010). In recognition of the benefits of active transportation, the United States Department of Transportation (USDOT) recently voiced its commitment to the improvement of nonmotorized transportation systems. The USDOT 2014-2018 Strategic Plan, *Transportation for a New Generation* (2013), places a top priority on improving bicycle and pedestrian safety and providing equitable access to active transportation opportunities.

Active Transportation in NH

The state of New Hampshire (NH) similarly recognizes that active transportation improvements are central to community development and resilience. The *NH Long Range Transportation Plan 2010 – 2030* (New Hampshire Department of Transportation (NHDOT), 2010) expresses a desire to more effectively integrate bicycle and pedestrian facilities into the planning, design, and construction of roadways throughout the state (NHDOT, 2010). Several local municipalities have also adopted *Complete Streets* policies, which are transportation policies encouraging roadway designs that enable safe access for all users, regardless of age, ability, or mode of transportation (Smart Growth America, 2005).

Despite the rhetoric, active transportation engagement has much room for growth in New Hampshire. With only 0.3% of workers in the state traveling to work by bicycle, NH ranks 5th out of 6 states in New England and in the bottom 25% of states nationwide for both percentage and growth of bicycle commuters over the last decade (United States Census Bureau, 2015). A survey by Getts et al. (see chapter 3) revealed that lack of adequate bicycling infrastructure was a significant barrier to bicycling among NH respondents of all levels of self-reported riding confidence. While NH has successfully transformed more than 500 miles of unused rail lines into trails and corridors for active transportation and recreation, the League of American Bicyclists awarded the state 2 out of 5 possible points for infrastructure and funding on its 2014 Bicycle Friendly State Report Card (2014). Furthermore, despite a quadrupling of protected bike lanes in the United States between 2011 and 2016, New Hampshire does not currently have a single protected bike lane listed on the Green Lane Project's "Protected Bike Lane Inventory" (Alliance for Bicycling and Walking, 2016; Green Lane Project).

Network Accessibility

The Federal Highway Administration's Strategic Agenda set a goal of increasing the number of transportation trips represented by bicycling and walking from 20% to 30% by the year 2025 by promoting safe, accessible, comfortable, and connected multimodal networks throughout the United States (Twaddell et al., 2016). While statewide increases in miles of multimodal networks, which consist of interconnected pedestrian and bicycle facilities, are good publicity, the networks are only successful if they help people get where they need to go within a reasonable distance and level of comfort. A recent study of bicyclist and pedestrian attitudes and behaviors, conducted by National Highway Traffic Safety Administration (NHTSA), found that the most common reason for not using a nearby bike path, bike lane, or sidewalk was that the facility did not go where the traveler needed to go (Schroeder and Wilbur, 2013). While preferred destinations and motivations for bicycling or walking vary, planners must acknowledge the importance of accessible key destinations to active transportation engagement.

Not All Networks Are Created Equal

Equity in accessibility—the ability to reach a destination safely, comfortably, and within a reasonable distance—is a matter of social justice. Limited accessibility to key resources and employment opportunities via active transportation modes can disproportionately impact low-income neighborhoods, which often maintain lower rates of car ownership (Murakami and Young, 1997; Ohls et al., 1999). Additionally, lower income households generally spend a higher percentage of their income on transportation than households with higher incomes (FHWA, Mobility Challenges for Households in Poverty, 2014). In a survey conducted in 2008 by NH's Southwest Regional Planning Commission, the lowest-income households spent over 30% of their income on transportation, which was largely the cost of maintaining an automobile and fuel (NRPC, 2011). Such costs suggest that providing affordable transportation alternatives to the automobile, such as bicycling and walking, with high accessibility to key destinations, could have a substantial impact upon social disparities and resident quality of life in NH.

Exploring Bikeability Metrics: Accessibility

Comprehensive measurements of accessibility capture a range of conditions that impact an individual's decision and/or ability to ride a bicycle from an origin to a destination. Previous work has evaluated accessibility in terms of destination attractiveness and/or various "cost barriers" – e.g. time, distance, comfort (Mekuria, 2012). While the term, "connectivity", simply refers to the extent to which different links or routes physically connect in a network (Marshall, 2004), accessibility metrics measure the ease of reaching important destinations by accounting for cost barriers (Lowry et al., 2016; Handy, 1993; Ewing & Cervero, 2010).

Hansen's (1959) evaluation of accessibility, which divides the intensity (i.e., magnitude of attractiveness) of a destination by the impedance of travel (e.g. distance or travel time) between the origin and destination for a specified origin point, has also been adapted by Handy (1993), Lowry et al. (2012, 2016) and Iacono et al. (2010). Aultman-Hall et al. (1997) used Geographic Information Systems (GIS) to calculate accessibility along a network from multiple origins to multiple destinations by incorporating a walking distance cost barrier. McNeil (2011) scored the accessibility of residential parcels based upon their proximity to weighted destination points. The Walk Score^{R} and Bike Score^{TM} rate locations according to key walkability or bikeability indicators, such as street design and land use, and score accessibility according to the diversity of key destinations within walking or biking distance (Walk Score, 2014a; 2014b).

Accessibility's incorporation of cost barriers more accurately reflects the perceived (and thus, actual) ability of a network to transport people from point A to point B. As a result, cost considerations, such as personal stress thresholds, are critical components of network accessibility assessments.

Exploring Accessibility Cost Barriers: Level of Traffic Stress (LTS)

Bicycle suitability assessments use roadway attributes to generate a score or rating of comfort and safety for road segments. Davis (1987) first introduced the bicycle safety index rating (BSIR) that rates a given roadway on a scale of poor to excellent based on attributes, such as pavement condition or presence of on-street parking. Sorton and Walsh's (1994) bicycle-stress level (BSL) and Turner et al.'s (1997) bicycle-suitability score (BSS) for state roadways attempted to simplify the BSIR by using only three and five roadway attributes, respectively. Harkey et al. (1998) Federal Highway Administration-sponsored bicycle compatibility index (BCI) produced a more complex and comprehensive rating system that incorporated nine roadway variables. The Transportation Research Board's Highway Capacity Manual (HCM) introduced the bicycle level-of-service (BLOS), featuring ten roadway attributes that are combined to generate a letter grade rating from ''A" through ''F" for each section of street (Transportation Research Board, 2011). Most recently, Mekuria et al. (2012) pioneered the Level of Traffic Stress (LTS) roadway rating system, which considers number of vehicle lanes, speed limit, bike lane width, parking, and mid-block crossings. Increases in the number of lanes and/or traffic speeds and traffic volumes generate progressively higher LTS scores (i.e., less suitable). Mekuria et al.'s (2012) 1-4 roadway stress rating scheme corresponds to four distinct classes of the population, as first suggested by Geller in 2006 (Dill and McNeil, 2013). This four-tiered LTS classification scheme gives planners and engineers a better description of whom a roadway serves. Table 1 details the LTS rating system in relation to Geller's (2006) population classifications (all headings are bolded):

LTS Rating	**LTS Rating Description**	**Geller Population Class**	**Geller Population Class Description**
LTS 1	Strong separation from all automobiles, except low speed, low volume traffic. Simple-to-use crossings. Suitable for children.	No Way No How	No interest in riding regardless of bicycle accommodations.

LTS 2	Except in low speed / low volume traffic situations, cyclists have their own place to ride that keeps them from having to interact with traffic. Physical separation from higher speed and multilane traffic. Crossings that are easy for an adult to negotiate. Limits traffic stress to what the mainstream adult population can tolerate.	Interested but Concerned	Uncomfortable negotiating fast, high volume traffic.
LTS 3	Interaction with moderate speed or multilane traffic, or close proximity to higher speed traffic.	Enthused and Confident	Willing to ride with minimal bicycle accommodations.
LTS 4	Forced to mix with moderate speed traffic or close proximity to high speed traffic.	Strong and Fearless	Willing to ride under any conditions.

Table 1. The Levels of Traffic Stress (LTS) four-tier classification scheme and a description of the bicycling population, as defined by Geller (2006), served by each.

Mekuria et al. (2012) applied this four-tiered LTS classification scheme to San Jose, California, where an LTS rating was generated for every segment in their roadway network. When researchers removed high stress-rated segments from the road network in San Jose, CA, the street map revealed a disconnected patchwork of origins and destinations. This incorporation of human stress thresholds enabled the researchers to identify road segments contributing to poor network accessibility in an otherwise connected network.

A recent adaptation of Mekuria et al.'s (2012) LTS assessment by Lowry et al. (2016), classified roadway bicycling stress using marginal rates of substitution. This approach employed empirical behavioral research on bicyclist route choice to approximate roadway stress under different road conditions (speed and number of lanes) and accommodations (e.g. protected bicycle lane, sharrows). Moving beyond Mekuria's et al.'s (2012) LTS model, Lowry et al. (2016) also quantified the stress associated with each road segment's slope, length, and intersection demands. Finally, by weighting origins and destinations in terms of importance and computing routes between all scenario origins and destinations, Lowry et al. (2016) produced a comprehensive model that could evaluate the contribution of each road segment to overall network accessibility.

This understanding of segment importance, or centrality, to the greater network allows the accessibility model to serve as a valuable project prioritization planning tool. When an accessibility analysis utilizes both centrality and cost barriers, the quantification of changes to a network under various scenarios can be realized at a finer and more precise scale.

Filling a Void

The Federal Highway Administration has stressed the need for better infrastructure data to eliminate gaps in the nonmotorized network and to evaluate nonmotorized networks for their quality (Twaddell et al., 2016). As NH communities move to apply Complete Street principles to roadways, planners are seeking tools that help them efficiently prioritize multimodal transportation projects. With limited staff, time, budgets, and data, regional planning commissions (RPCs) are not always equipped to understand the extent of active transportation use and demand in their jurisdiction. Furthermore, RPCs and the NHDOT currently lack clear metrics for evaluating bikeability.

Our research evaluates bikeability by examining the ability, perceived comfort, and convenience of accessing important destinations (Lowry et al., 2012). To better quantify and improve the bikeability of NH's road network, we introduce a series of metrics that combine bicycle-specific stress ratings of road segments with measures of bicycle accessibility (i.e., the ability to travel comfortably and conveniently from origins to key destinations). This research combines traffic stress modelling with GIS-based accessibility analyses to 1) determine the degree to which key destinations are accessible via a low-stress road network, and 2) identify road segments that are most critical to bicycle accessibility (centrality). Two case studies are used to demonstrate the value of these methods at multiple scales, because the NHDOT expressed an interest in improving accessibility at both the locally and regionally (NHDOT, 2010). Through application of the proposed bikeability assessments, planners can enhance their understanding of the impact that high stress road segments have upon overall bicycle network accessibility. Furthermore, planners can use this combined assessment of traffic stress and centrality to cheaply and efficiently prioritize road segments for improvement.

This paper showcases the project prioritization capabilities of such an accessibility model at both the community and regional scale using GIS tools, simplified cost barriers (a NH-adapted LTS model and distance), and weighted origins. By quantifying percentages of origin-destination routes that can be completed along low-stress roadways, the model generates baseline bikeability metrics for the state of NH. To better characterize the current state of bicycle accessibility, we use the model to answer the following questions:

1) What percentage of selected origin-destination routes are accessible along LTS 1 and 2 segments?
2) What percentage of these routes (i.e. network) could become accessible to most of the population with alterations to high stress (LTS 3 and 4) segments?
3) Which road segments are most central to network accessibility? And;
4) what percentage of the top 10% "most central" segments are high stress links?

The answers to these questions not only paint a picture of the current bikeability of the case study community and region, but also help identify the potential for bicycle network improvements. The use of a NH-specific LTS model establishes a set of bikeability criteria for the state and reflects the immediate infrastructure priorities of the public, regional planning commissions, and NHDOT. Bikeability expectations and tools are constantly evolving, and while NH is currently pursuing more bikeable road shoulders, future LTS criteria may limit low-stress ratings to protected bicycle lanes or separated facilities. The following case studies highlight the applicability of the existing model for two unique scenarios in NH.

METHODS

This study evaluated bicycling network accessibility by applying distance and NH-specific LTS score cost barriers to a series of GIS-generated shortest path routes between selected origins and key destinations in the case study communities described below. This series of routes serves as a proxy bicycling network for each of the case study communities in NH.

Case Study Communities

The two case study regions—Manchester and the Lakes Region—were deliberately selected to demonstrate bikeability assessments at both the rural-regional and metropolitan scale. The Lakes Region was included in this analysis in response to ongoing work for the

Lakes Region Planning Commission, who requested assistance exploring and prioritizing accessibility and roadway improvements at the regional scale. Local input from the Lakes Region guided our process, confirming the applicability of our inter-community accessibility analysis to regional planners. As the most populous and densely developed city in NH, Manchester has more potential to serve its population through active transportation improvements than any other city in the state. Given this potential for impact, Manchester was the best city to showcase the value of our tools at the intra-community scale.

NHDOT faces the challenge of catering to large communities, medium-sized towns, and small, remote villages. From the highly-developed cities in southern NH to the rural communities surrounding the White Mountain National Forest, NH is grappling with the desire to attract business and a young, skilled workforce while preserving and promoting its rural New England character (Norton et al., 2015; Nashua Regional Planning Commission, 2011). To showcase the applicability of bicycle accessibility assessments at both the community and regional scale, this research assessed accessibility for both a city and a region in NH. The selected study areas: Manchester, NH and the Lakes Region of NH, maintain similar active transportation planning goals, despite differences in land use and scale.

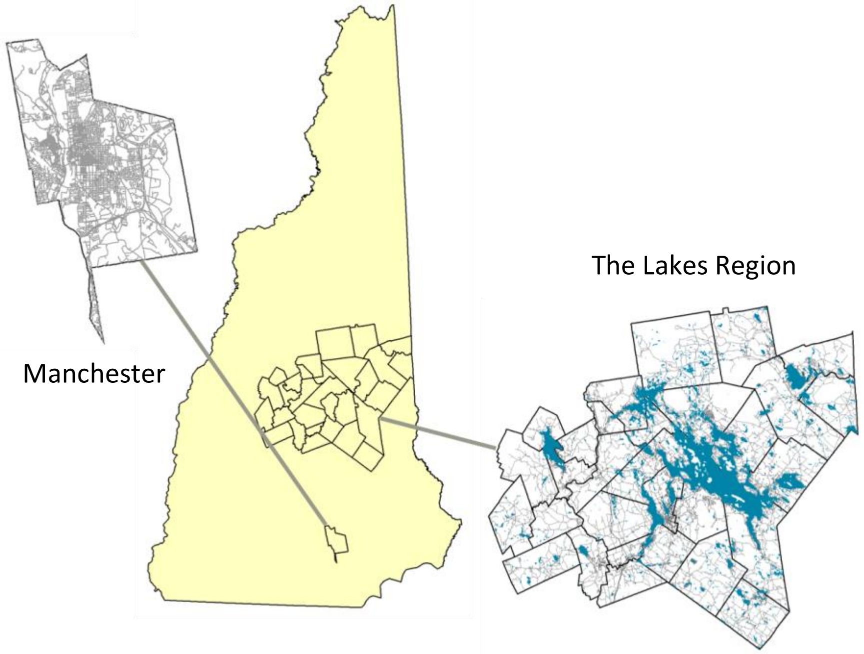


Figure 1. Map of Manchester and Lakes Region case study areas in New Hampshire.

Manchester

With a population of approximately 110,000, Manchester is NH's largest city and one of only 11 NH cities with populations greater than 20,000 individuals (United States Census Bureau, 2016). Geographically, the city's official political boundary spans only 34 sq. miles and boasts a street network whose density is more favorable to multi-modal travel than any other town or city in the state (Environmental Protection Agency (EPA), 2013). On average, Manchester is younger, more diverse, and less affluent than the state as a whole (see Appendix A; ACS survey data). According to the NH Social Vulnerability Index (SVI), 50% of Manchester's census tracts have a vulnerability rating greater than the state average of SVI 2 (out of a possible 12), and approximately 10% of the city's households have no vehicle available (U.S. Census Bureau, 2010). Of the more than 32,000 Manchester residents who live at some level of poverty, over half live within city neighborhoods that qualify as Neighborhood Revitalization Strategy Areas (NRSA), which are United States Department of Housing and Urban Development-designated neighborhoods that require economic development support (City of Manchester, 2014). Given these vulnerable populations, a large percentage of Manchester residents stand to benefit from targeted active transportation improvements.

Despite the decline in percentage of Manchester residents commuting to work by bicycle between 2009 and 2015 (U.S. Census Bureau, 2011), an engaged business and bicycling advocacy community has generated momentum for bicycle infrastructure development. Ongoing improvements to several rail trails, such as the South Manchester Trail and Rockingham Trail, continue to increase low-stress connectivity between Manchester and its surrounding communities. The city also recently approved a pilot bicycle share program that was financed entirely by local businesses (Feely, 2017). Concurrently, the city's Department of Public Works is implementing a new Bicycle Master Plan that promises 40 miles of bike lanes, 83 miles of sharrows, and 543 bike-related road signs (Thomas, 2016a). The plan, which was a collaborative effort between the city, bicycle advocacy organizations, the Manchester Conservation Commission, and the Southern New Hampshire Planning Commission (SNHPC), seeks to improve bicycle safety, increase local and regional multi-modal connectivity, support bicycle facilities (e.g. bicycle racks), and enhance bicycle tourism (2016b).

The Lakes Region

The Lakes Region includes 30, primarily rural, communities that surround Lake Winnipesaukee, Winnisquam Lake, Squam Lake, and Newfound Lake in mid-state NH. The area totals nearly 1,300 sq. miles and collectively, is home to more than 113,000 residents (ACS, 2016), with community populations ranging from 600 – 16,000 residents (U.S. Census Bureau, 2016). Much of the Region consists of densely populated villages and downtowns separated by higher speed corridors with little commercial development, and larger residential, agricultural, and forested parcels. Additionally, many residents live along these rural local roads and state highways, presenting accessibility challenges for the 1.2% of the population that has no vehicle access (LRPC, 2012b).

On average, Lakes Region residents are older, less wealthy, and less educated than the state average, however only 20% of the communities receive an SVI rating above 2, with no single community scoring higher than a 6. Highly forested (85% of the region) and home to more than 40% of the state's water, the Lakes Region is a popular seasonal destination whose economy is firmly grounded in tourism (Lakes Region Planning Commission (LRPC), 2015; LRPC, 2013). With seasonal home ownership at 29%, some communities estimate that their summer population swells to at least three times the year-round population (LRPC, 2015). This dynamic presents both opportunities and challenges for the Lakes Region in terms of affordable housing, bicycle tourism, and alternative transportation solutions to visitation congestion.

Since 2011, the number of Lakes Region residents commuting by bicycle has been stagnant at 0.2% (ACS, 2016). Nevertheless, local and regional efforts have championed several rail trail improvements in recent decades to increase recreational opportunities and improve regional connectivity. Laconia's WOW Trail, the Winnisquam Lake Scenic Trail, the

Winnipesaukee River Trail, the Northern Rail Trail, the Sewall Woods Trail, and the Cotton Valley Trail currently contribute more than 50 miles of dedicated bicycle and pedestrian recreational corridors throughout the Lakes Region. While these trails remain fairly isolated, ongoing fundraising efforts seek to extend several routes to improve regional connectivity.

Adapting Levels of Traffic Stress

In 2013, NH planning commissions began adapting a version of Mekuria et al.'s (2012) Level of Traffic Stress model for the state of NH's roadways. With limited intersection data and a lack of bicycle facilities throughout the state, Mekuria et al.'s (2012) LTS formula was not directly transferrable to NH. To achieve a suitable product for the state, we collaborated with planners in central and southern NH to review an LTS criteria matrix and test model iterations. GIS interns collected and added missing data about road shoulder width, bicycle facility presence, parking presence and width, and speed to the NHDOT road attribute database to provide a more comprehensive assessment of bikeability for each roadway segment. The version of the model that incorporates road shoulder width, bicycle facility presence, parking presence and width, and speed, is hereafter referred to as LTS I. The version of the model that does not include these attributes is called LTS II. LTS II scores are derived solely from the NHDOT Functional Class and Average Annual Daily Traffic (AADT) estimates.

The final LTS I model features several deviations from Mekuria's LTS. As a proxy for stress-reducing bicycle facilities, the final model calculates road shoulders >= 4 ft. as bicycle lanes. Additionally, a residential designation serves as a proxy for traffic volumes along quieter segments of the road network. When speed limit data for a segment was unavailable, the road's functional class became a proxy for speed categorization. Interstates were given a separate designation that omits them from the 1-4 rating. Finally, intersection-specific criteria were omitted due to limited resources. Table 2 provides the final LTS criteria matrix.

A.

	LTS 1	**LTS 1**	**LTS 2**	**LTS 2**	**LTS 2**	**LTS 2**	**LTS 2**	**LTS 2**	**LTS 3**	**LTS 4**
(Parking Lane + Bike Lane) Width	>=15	>=15			>=14			>=14		
LTS Speed	<=2	<=2		1	<=2		1	<=2	<=3	<=4
Number of Lanes	1	<=2	1	1	1	<=2	<=2	1		
Residential			Y			Y				
Direction	One way	Two way	One way	One way	One way	Two way	Two way	Two way		

B

	LTS 1	**LTS 1**	**LTS 2**	**LTS 3**	**LTS 4**
Bike Lane Width	>=6	>=6			
LTS Speed	<=2	<=2	<=2	<=3	<=4
Number of Lanes	1	<=2	<=2		
Direction	One way	Two way			

C.					
	LTS 1	LTS 2	LTS 3	LTS 3	LTS 4
LTS Speed	1	2	3	4	4
Shoulder Width				>=8	

D.							
	LTS 1	LTS 2	LTS 2	LTS 3	LTS 3	LTS 3	LTS 4
LTS Speed	1	<=2	1	<=4	<=2	1	<=4
Number of Lanes	<=2	<=2	<=3	<=2	<=3	<=4	
Residential	Y	Y		Y			

Table 2. Level of Traffic Stress I criteria for roads with A) bike lane and road-side parking, B) bike lane with no road-side parking, C) no bike lane, shoulder >=4' (when parking present, shoulder lane width – parking lane width is >=15), D) no bike lane, shoulder <=4'(When Parking Present, Shoulder Lane Width - Parking Lane Width is < 15)

Functional Class Designation	LTS
Interstate	100
Local or None	1
Minor Collector/Minor Arterial Urban/Collector Urban	2
Major Collector/Minor Arterial Rural (6,7)	3
Principal Arterial (2,12,14)	4

Average Annual Daily Traffic LTS Override			
	LTS 1	LTS 3	LTS 4
AADT	< 500	> 11,500	> 45,000
Functional Class LTS Score	2	2	Any

Table 3. Level of Traffic Stress II criteria

MPH Criteria	Speed Classification
<=25 mph	1
<=30 mph	2
<=35 mph	3
>=40 mph	4

Table 4. LTS speed criteria for all LTS matrices

While the Manchester, NH road attribute database contained enough data to run LTS I, only 10 (New Hampton, Sanbornton, Tuftonboro, Moultonborough, Meredith, Laconia, Center Harbor, Gilford, Wolfeboro, Alton) of the Lakes Region's 30 communities had road shoulder width, bicycle facility presence, parking presence and width, and speed attributes collected to run LTS I. The remaining communities were scored using the LTS II model.

Calculating Accessibility with Network Analyst

We examined accessibility in the case study regions by generating shortest path routes between selected origins and destinations. We then applied distance and high stress (LTS 3 and 4) cost barriers to understand how these barriers interrupt the road network. Road network segments were prioritized by quantifying the centrality, or relative importance, of each link to all routes in the generated bicycle network. Centrality was determined by calculating the frequency a link in a network was used along the path of all shortest paths between origins and destinations; the more frequently included in a path, the more central the road segment was considered.

Building the Network

The bicycle network for this analysis was created by merging a NHDOT polyline shapefile with GIS layers that included updated, paved, bikeable path polylines for each of the case study areas. Origins were centroids generated for each census block group in the region. A census block group is a subdivision of a census tract and is the smallest geographic entity for which the decennial census tabulates and publishes sample data (United States Census Bureau, n.d.). The use of block groups ensured geographic coverage of each study area and facilitated origin weighting by population. To evaluate regional accessibility, centroids were generated for every community center using existing "Community Center Area" polygons, which were delineated by staff at the nine NH Regional Planning Agencies. The delineation of these areas was based upon development characteristics, such as the presence of a higher-density development and/or a mix of different types of uses, such as residential, commercial, and public uses, core main streets areas and historic districts, and recognition by the community as its center (Regional Planning Commissions (RPCs) and New Hampshire Department of Environmental Services (NHDES), 2006).

The New Hampshire Geographically Referenced Analysis and Information Transfer System's (RPCs and NHDES) statewide "Key Destinations" shapefile was the source of potential bicycle trip destination locations. The shapefile's data was developed by NH's nine Regional Planning Agencies based on a common methodology, with input and review from staff at the NH Department of Environmental Services. The database was last revised in September of 2006. Types of destinations identified for all communities included: elementary schools, middle schools, high schools, higher education facilities, municipal offices, libraries (public and private), community facilities, grocery stores, athletic/recreation facilities, post offices, retail/shopping areas, public transportation access points, and hospitals. Additional destinations, such as smaller markets and places of worship, were identified when significant to a community (RPCs & NHDES, 2017).

Origins and destinations remained the same for regional connectivity, as community centers were approximated destinations at the regional scale. When assessing regional accessibility, origins and destinations that began and ended in the same location were removed. With 94 origins and 214 destinations, Manchester had 20,116 possible route combinations. In the Lakes Region, because each segment of roadway was valued equally in the regional network, routes were only generated from each community to its next closest community. For example, when travelling from Tilton to Gilford, the fastest route directs the traveler through Laconia. Because the route between Laconia and Gilford is already accounted for in the network analysis, this duplication is removed. Given this methodology, the Lakes Region had 350 possible route combinations. Centroids were snapped to the nearest road segment that was not an interstate to ensure inclusion in the network analysis.

Running the Analysis

Using the ArcGIS Network Analyst extension, a "New Route" analysis was run to generate the shortest trip path between every origin and every possible destination along a road network. Routes were generated under three different scenarios:

1. Complete network with no stress restrictions (baseline);
2. Network limited to LTS 1, 2, and 3 segments (condition 1);

3. Network limited to LTS 1 and LTS 2 segments (condition 2).

This approach allowed us to measure the "percent trips connected", or proportion of trips that are connected of all possible trips without exceeding a given level of traffic stress and without undue detour (Mekuria et al., 2012). "Undue detour" was flagged whenever a low-stress route (LTS 1 and 2) became >25% longer than the original route, which incorporated segments of all stress levels. Interstates were removed from the road network layer prior to analysis execution as these segments are unsuitable for bicycle travel under all conditions. A distance cost barrier was applied at 5 miles, which met the criteria for a "short" bicycle trip, as defined by the Federal Highway Administration's Strategic Agenda (Twaddell et al., 2016). All generated routes exceeding 5 miles in length were considered "inaccessible". Additionally, all routes < 0.5 mi. in length were removed, as walking is normally the preferred mode of travel up to this distance. There were no distance cost barriers applied to routes in the Lakes Region as regional accessibility conceptualizes travel at the long-distance scale.

Centrality in Manchester

As described above, centrality, or the importance of a segment to a network, was determined by the number of times a road or trail segment participated in a completed route. Segments were dissolved and summed by their Standard Route Identifier (SRI) number and associated LTS score. SRI counts were the basis for centrality rankings. To determine the impact that bikeability improvements may have to the most central, high-stress road segments in Manchester, the top 10 road segments by SRI and LTS score of >2 were added to the "condition 2" analysis and re-assessed for accessibility.

Manchester Weights

Weights were applied to origins to boost importance when determining centrality. Centrality scores were the total number of times a segment was included in a connected route. A weighting factor of 0.1 for every 200 residents in a census block group was added to each segment contributing to a completed route, per its associated route origin. For example, for every route originating in Block Group 3 (population 345), a weight of .1 was added to every segment comprising a completed route that originated in Block Group 3. Weights were subsequently summed by segment SRI number and added to summed SRI counts.

A second weight was applied to all routes originating in tracts with high percentages of residents lacking access to an automobile. A factor of 0.1 for every 10% of residents in block group origins lacking access to a vehicle was applied to associated segments. Data for census block group populations and automobile ownership information was obtained from the American Community Survey (United States Census Bureau, 2016).

Level of Accessibility

To determine the level of accessibility that each block group or community in the Lakes Region currently experiences, we established a low, medium, and high rating scheme. The Level of Accessibility rating was derived from the number of accessible routes that began or ended in a block group or community (as defined per the Lakes Region). Every route that could be completed along road or trail segments rated < LTS 4 and < LTS 3 were counted twice and four times, respectively. This double and quadruple counting effectively weighted routes to boost associated community's Level of Accessibility rating. Accessibility scores for each Lakes Region community were classified relative to other communities in the region using Jenks natural breaks. Centrality was not assessed for the links contributing to regional accessibility in the Lakes Region, as the regional analysis values each route equally.

RESULTS

The analyses revealed a substantial lack of accessibility throughout Manchester and the Lakes Regions' road and trail networks when segments were limited to LTS 1 and LTS 2. These results signal the importance of many high-stress segments to community-wide accessibility, and highlight specific opportunities for infrastructure-specific bikeability improvements.

Manchester

Out of a possible 20,116 origin-destination routes, 16,274 routes were <0.5 mi in length and could be completed within the maximum 5 miles distance. Using this number as a baseline, it was determined that 14,336 routes were accessible (could be completed from start to finish without interruption) along LTS 1, 2, and 3 segments, and 3,247 routes were accessible along LTS 1 and 2 segments. Although only 20% of Manchester's road network consisted of LTS 3 & 4 segments, the removal of these segments from the network reduced accessibility along LTS 1 & 2 road segments by 80%.

A look at the centrality of these LTS 3 and 4 segments revealed that while the majority of these are classed by NHDOT as local roads, the top 25% high-stress segments most crucial to overall accessibility are "principal" and "minor arterials". When we modelled bicycle stress reduction improvements to the top 10 most central segments to the network (per the initial analysis), community accessibility only increased by 3%. When these improvements were modelled in the top 20 most critical streets, accessibility increased by approximately 13%. Such results suggest that while improvements to important roadways will benefit the network, the greatest gains in accessibility may occur when bikeability improvements are approached at the network-wide scale.

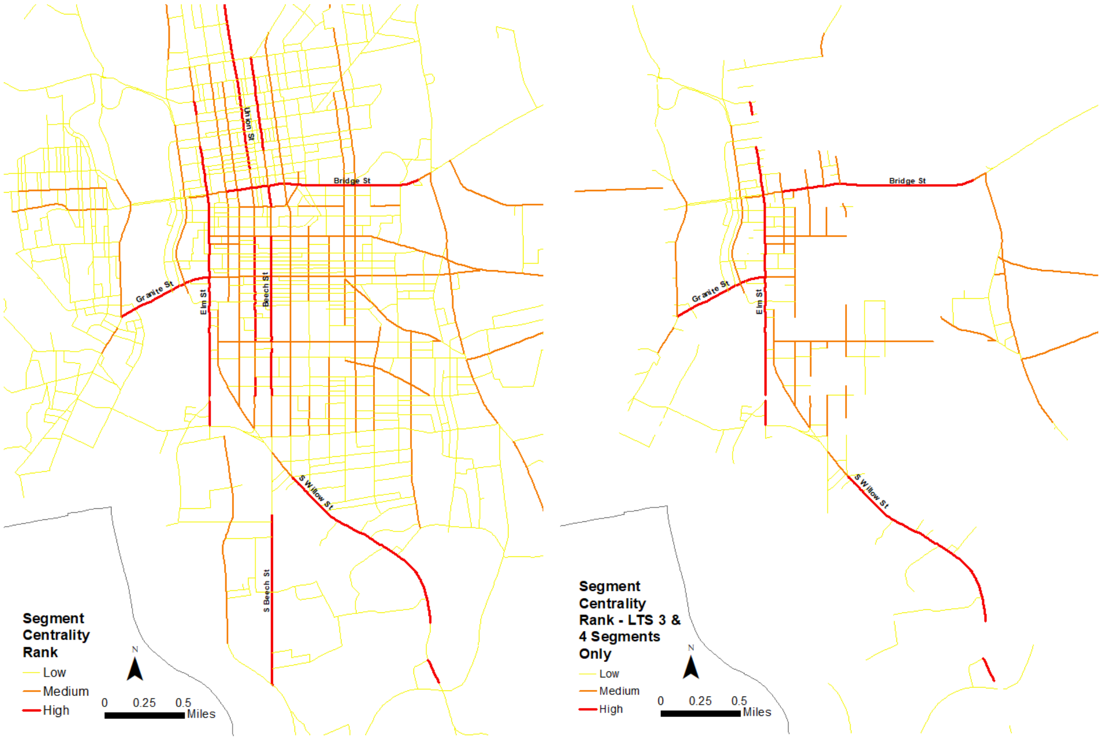


Figure 2. Ranking of centrality, or importance, of each road segment to the overall network. Left: centrality of all segments, regardless of LTS rating. Right: only LTS 3 & 4 road segments.

PRIORITY	SRI	STREET	LTS SCORE
1	U0000003__	Elm St	3
2	U0000003__	Elm St	4
3	S0000028__	S Willow St	4
4	L2850319__	Granite St	4
5	N2850039__	Bridge St	3
6	L2850558__	Willow St	3
7	N2850051__	S Main St	3
8	S0000028A_	Mammoth Rd	3
9	L2850831__	Pine St	3
10	L2850553__	Union St	3

Table 5. Top 10 priority road segments for improvement in Manchester, NH, based upon centrality ranking and LTS score > 2.

An investigation of Manchester's Level of Accessibility along LTS 1 and 2 roadways reveals a disconnect between downtown Manchester and its surrounding neighborhoods. In contrast, a review of populations lacking access to an automobile indicates that most of Manchester's transportation-vulnerable population resides in the city's denser, more walkable block groups. By combining Level of Accessibility ratings with numbers of residents lacking automobile access, we revealed 17 block groups most at risk for restricted accessibility. Although several of these block groups reside in the denser, more walkable portions of downtown Manchester, the analysis penalized them for their inability to access the full extent of destinations scattered throughout the city. Future iterations of the accessibility analysis may restrict specific destinations, such as schools or grocery stores, to a more limited radius from the input origins.

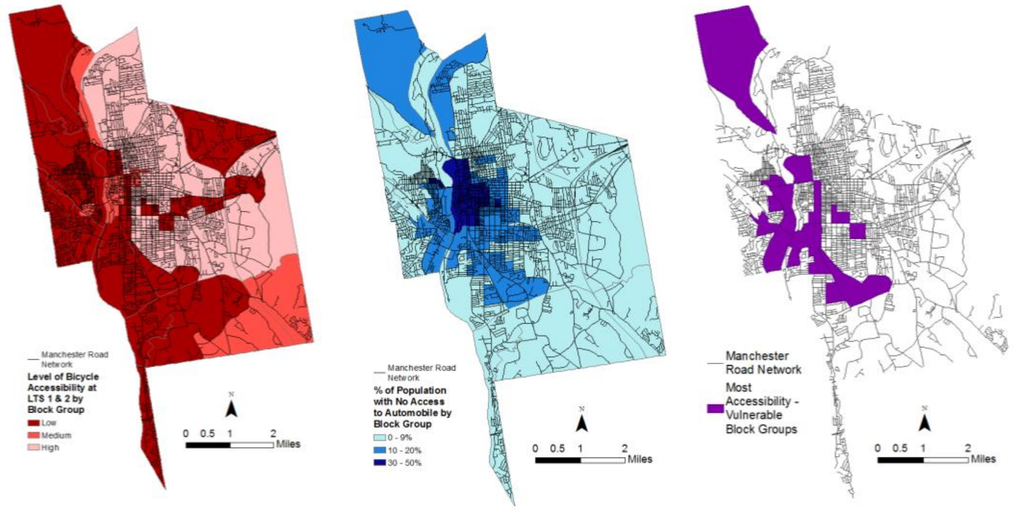


Figure 3. The results of the analysis gauging accessibility vulnerability by block group. The left map ranks block groups by inaccessibility; the middle map displays block groups by percentage of residents lacking an automobile; the third map indicates the block groups with the highest degree of inaccessibility and percentage of population without access to an automobile. The block groups in purple have low accessibility to destinations along LTS 1 & 2 routes and more than 10% of the census block population does not have access to an automobile. Note: In the accessibility vulnerability analysis, accessibility via walking to destinations was accounted for by considering all destinations located 0.5 miles or less from their origin as accessible.

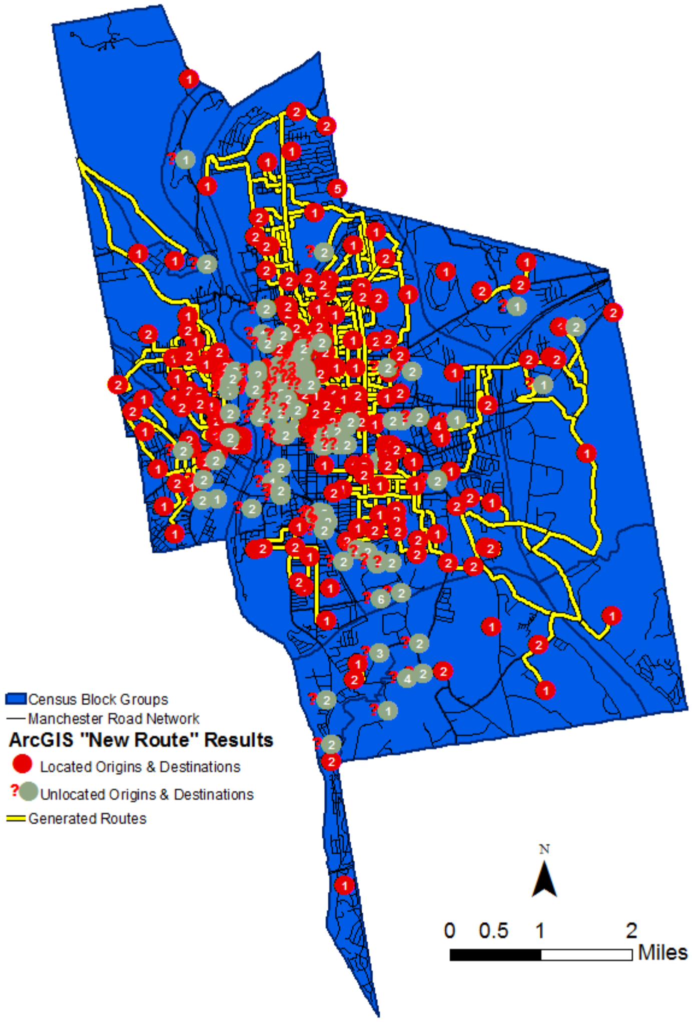


Figure 4. The results of an ArcMap Network Analyst New Route analysis, whereby a route along the road network was attempted from each origin to every possible destination. The number 1s represent input origins and the number 2s are input destinations. Many origin-destination pairs could not be completed as this analysis restricted route-finding to LTS 1 and 2 segments only. These are noted as "Unlocated Origins and Destinations".

The Lakes Region

The longest distance between any two communities in the Lakes Region was 30 miles. Total possible origin-destination route combinations from the center of one community to another totaled 350. These routes, generated without restrictions, represent the network's route potential.

Although only 12% of the Lakes Region's road network consisted of LTS 4 segments, the removal of these segments from the network reduces accessibility via LTS 1, 2, or 3 road segments by 89%. When the network is restricted to LTS 1 and 2 segments only, accessibility drops to a mere 3% of the network's route potential.

Unsurprisingly, the farther a community is from the region's center, the poorer its level of bicycle accessibility. The 11 communities with low accessibility border the outer edge of the region. Eight Lakes Region communities have high accessibility, which is primarily a factor of proximity to multiple neighboring communities rather than an ability to travel from one community to the next another along low-stress roads and trails. The final third of communities, which are situated both centrally and along the outskirts of the region, are primed for inter-community accessibility, but currently suffer from high-stress connection corridors. Many of these communities benefit from immediate lake access and have the potential to develop strong bicycle tourism markets.

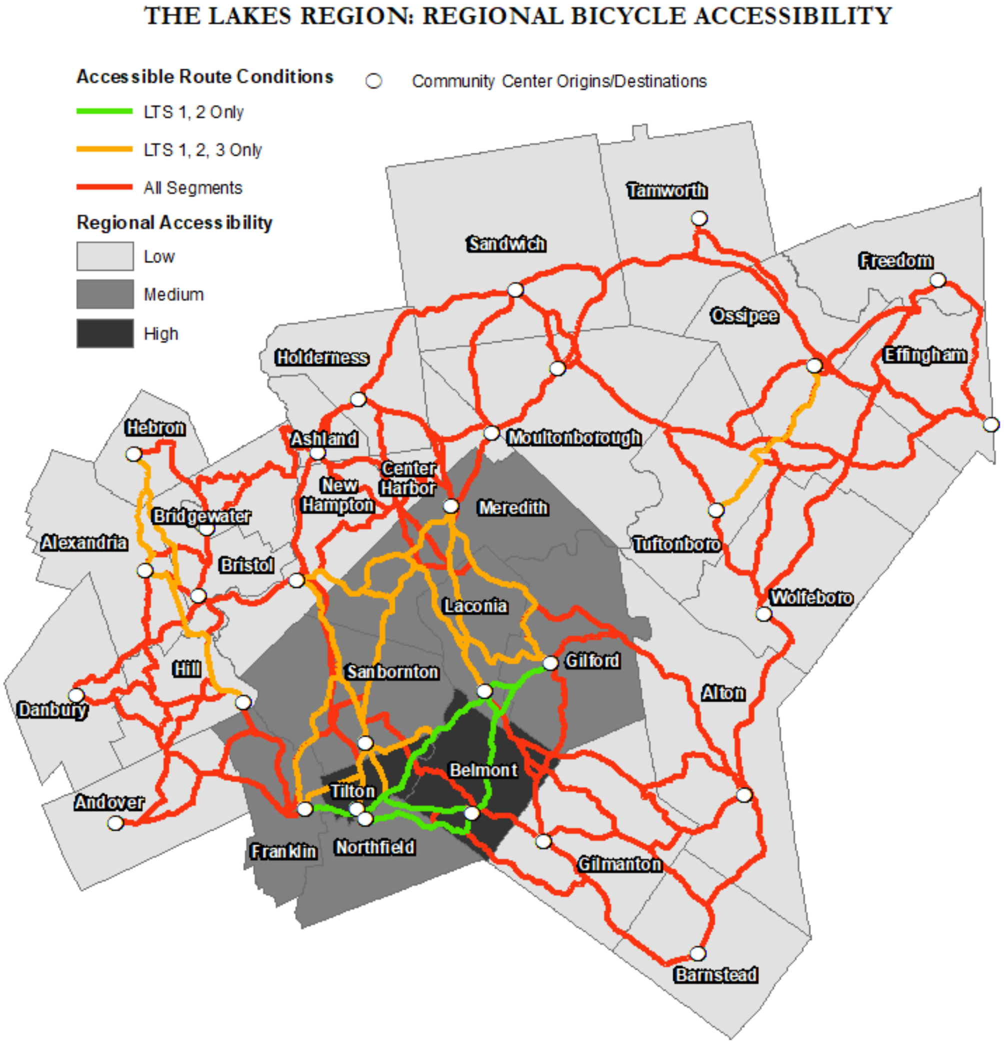


Figure 5. Regional accessibility rank and all regional routes accessible under various Level of Traffic Stress (LTS) conditions in Lakes Region, NH. Approximately 97% of regional routes cannot be completed without travelling along an LTS 3 or 4 segment.

	(Baseline) Total Routes	(Condition 1) % of Total Routes Accessible via LTS 1, 2, or 3-rated Roads or Trails	(Condition 2) % of Total Routes Accessible via LTS 1 or 2-rated Roads or Trails
Lakes Region	350	11%	3%
Manchester	16,274	88%	20%

Note: Routes > 25% longer in distance than baseline route when completed under condition 1 or condition 2 were deemed “inaccessible routes”.

Table 6. Percentage of total origin-destination routes that can be completed given LTS and distance cost barriers.

DISCUSSION

Bikeability metrics are useful tools that can assist planners and policymakers in generating baseline data for their communities, identifying barriers to active transportation participation, and quantifying the impact of investments. The accessibility analysis is one such metric that effectively evaluates infrastructural challenges and successes of a bicycle network. The results of the accessibility analyses indicate a substantial lack of low-stress bicycle networks— both regionally throughout the Lakes Region, and at the community scale in Manchester. More specifically, the analyses reveal the degree of stress impacting the network, and where these higher stress choke points exist. While LTS 4 segments are more crucial to accessibility regionally in the Lakes Region, LTS 3 segments pose the greatest barrier to destination access via bicycle in Manchester.

While centrality identifies specific opportunities for on-road improvement in existing road networks, it does not account for the trails alternative, where a complete circumvention of the high stress road network by rail trail or separated bicycle facility may be the preferred and most impactful option. In the Lakes Region, many of the roadways that currently connect communities may not be capable of obtaining low-stress bikeability ratings under any on-road improvement prescription. Given narrow corridors, high traffic speeds, and high traffic volumes, separated bicycle facilities may be the only realistic option for improving portions of the region’s bikeability.

The Level of Traffic stress model produced for NH is a low-cost adaptation of existing bicycle suitability assessments that attempt to characterize the stress of riding a bicycle under various conditions along a trail, path, or roadway. The version of the model presented in this paper uses few road attributes—most of which are readily available in nationwide Department of Transportation datasets, —which facilitates rapid and generalized rendering of a community, state, or region’s potential or existing bicycle network. While this simplified picture tells an important story, and can either confirm or draw attention to strengths and weaknesses in an existing network, there remains significant room for improvement. Because this paper defines bikeability in NH in terms of the NH-specific LTS model and its inputs, additional considerations, such as terrain, signage, and intersection configurations could make the model a more robust assessment tool. In particular, variables such as intersection lane configuration and signaling are crucial to understanding the accessibility and safety of a bicycle network. Unless these specific network hazards and choke points can be accurately identified, bikeability will suffer from inefficient improvement prioritization.

Accessibility as a Tool

The results from the two case study communities suggest that bicycle-friendly, stress-reducing improvements to central, high-stress road segments will improve bicycling accessibility in Manchester, and regional accessibility in the Lakes Region. The accessibility model excels as a before/after scenario generator, whereby "numbers of communities and/or residents served by a low-stress network" is the measurable impact of alterations to the bicycle network. When these numbers suggest dramatic improvement in accessibility, results may be viewed as justification for active transportation infrastructure spending.

While bicycle-friendly infrastructure improvements may increase the number of individuals with access to low-stress active transportation alternatives, it doesn't necessarily mean that it will increase participation (Nelson and Allen, 1997; Krizek et al., 2009). If the goal is to improve bikeability for most of a population, which includes those intolerant to high-stress routes, then bicycle suitability-informed accessibility models can provide substantial guidance. If the primary goal however, is to engage more of the population in active transportation, then this infrastructure-centric approach may only tackle one piece of what is likely a multi-faceted bicycle advocacy effort.

Social Justice

When combined with population statistics, the accessibility model provides insight into disjunctions in active transportation access. As demonstrated, it is possible to isolate transportation-vulnerable sections of a community by combining low bicycle accessibility ratings with data on lack of access to an automobile. Identification and resolution of such vulnerabilities promotes equity, human health and safety, and community resilience. As a result, population vulnerability is one additional factor that communities may wish to consider when prioritizing active transportation improvements.

Additional Applications

The results of the accessibility analysis reflect the user's origin and destination inputs. Careful consideration must be made when selecting these units of analysis as they drive both the centrality of street segments, as well as the level of accessibility that a community or neighborhood experiences. While this flexibility produces potential for error, it also generates opportunities to tailor the analysis to destination-specific endeavors, such as Safe Routes to School or Food Desert mapping. Furthermore, with implementation of a pedestrian-suitability index, the accessibility assessment could easily be adapted to answer questions about walkability at the community scale. Finally, this analysis could merely serve as the first step in a public validation process that either challenges or confirms its results. Overall, the value of the tool is enhanced by application of localized expertise, which best adapts the process to a community or region's needs.

CONCLUSION

This paper presents two separate tools that, in isolation from each other, provide helpful active transportation assessments, but together provide insight into network service and functionality. The results from two NH case studies demonstrate how the accessibility bikeability metric can be used to establish an active transportation accessibility baseline, highlight network issues and answer questions at both local and regional scales. Because LTS scores of 3 and 4 represent bicycling stress levels that are prohibitive to most of NH's potential ridership (the Willing but Wary), they signal barriers to key destination accessibility, and possibly, to greater active transportation participation. Whether an individual choses to cycle for recreation, necessity, or both, their ability, and subsequent decision to do so has greater impacts upon society. For professions who plan transportation networks with multi-modal users in mind, the LTS-informed accessibility analysis is one more tool to facilitate project prioritization, implementation, and review.

Chapter 3: Public Participatory GIS as an Active Transportation Planning Tool in New Hampshire

INDRODUCTION

In recent decades, the Complete Streets movement—a planning initiative that encourages an integrated transportation system supporting safe travel for people of all ages and abilities—has shifted the vehicle-centric paradigm in America. (Smart Growth America, 2005). Active transportation—any human-powered mode of transportation, such as bicycling and walking— promotes physical activity and social equity, limits environmental pollution, builds social capital, reduces traffic congestion and costs, bolsters the local economy, and improves community mobility and resilience (Mendoza and Yiu, 2014; Rogers et al., 2013; Legrain et al., 2015; Garrett-Peltier, 2011; Smart Growth America, 2015; Wang et al, 2012; Clifton et al., 2013; Lankford, J. et al, 2011; Heath et al., 2006; New Hampshire Department of Transportation, 2010). In recognition of these benefits, many communities and states throughout the United States are simultaneously encouraging engagement in active modes of transportation while attempting to ensure the safety of all users. Despite financial limitations and land use density challenges, New Hampshire is one such state taking steps to boost multi-modal transportation participation.

Active Transportation in New Hampshire

The state of New Hampshire (NH) recognizes that transportation issues are central to community sustainability and resilience. In 2011, the state of NH received a $3.4 million Federal Sustainable Communities Grant to fund the New Hampshire Sustainable Communities Initiative, which is a statewide project that seeks to boost the economic vitality of communities while promoting active living and safeguarding the state's natural resources and rural character. The grant lists the lack of alternative transportation as one of the six major factors contributing to the need for a New Hampshire Sustainable Communities Initiative. Stated goals include: decreasing per capita vehicle-miles traveled (VMT) and transportation related emissions, increasing the miles and/or percentage of streets served by bike and pedestrian infrastructure, reducing disproportionate access of transit alternatives to different populations, improving the condition of existing transportation infrastructure, and improving the status of ozone and or particulate matter in the air (Nashua Regional Planning Commission NRPC, 2011).

While several local NH municipalities have already adopted Complete Streets policies, active transportation engagement has much room for growth in New Hampshire. With only 0.3% of workers in the state traveling to work by bicycle, NH ranks 5th out of 6 states in New England and in the bottom 25% of states nationwide for both percentage and growth of bicycle commuters over the last decade (United States Census Bureau, 2015). According to the League of American Bicyclists, a statewide, bicycle-friendly "Sign of Success" is 1% or more of residents commuting by bicycle (The League of American Bicyclists, 2015).

The *NH Long Range Transportation Plan 2010 – 2030* (New Hampshire Department of Transportation (NHDOT), 2010) states the need to "increase the use and availability of transit, rideshare, bicycle and pedestrian modes". Fulfilling this objective is not necessarily straightforward, and may require that multi-modal infrastructure improvements be coupled with policy changes and programming initiatives. To best understand the specific barriers to engagement in bicycling in the state of New Hampshire, public feedback is essential. While systematic efforts to quantify the scope of the problem, such as traffic stress modelling, are useful, they do not necessarily capture the full story.

Barriers to Bicycling

The ultimate question in active transportation research is why an individual chooses to or not to engage with a specific mode of transportation. While bikeability research reveals that higher percentages of active transportation engagement are never attributable to a single factor, significant relationships between active transportation engagement and certain conditions are informative to planners. Although most studies investigate the relationship between bicycling trends and infrastructure—an important consideration in transportation engagement and safety—, failure to consider additional factors, such as psychological, social, and economic, may overestimate the role of various infrastructural treatments (Légaré et al., 2009).

The Role of Infrastructure

Although communities with greater numbers of cyclists tend to have more bicycle infrastructure, it is generally not known whether it is the infrastructure that influences cyclists or vice versa. In many cases, it may likely be a combination of both. Stated preference studies find that both cyclists and non-cyclists prefer having bike lanes over riding in mixed traffic; however, the addition of bicycle lanes, or facilities in general, is not necessarily linked to statistically significant increases in bicycling (Buehler and Pucher, 2012; Dill and Carr, 2003; Pucher et al., 2010; Landis et al., 1997; Nelson and Allen, 1997). Furthermore, it is not always clear if all populations are served by infrastructural developments. A study by Dill (2009) in Portland, OR revealed that although the largest share of bicycling occurs on streets with bike lanes, a well-connected network of low-traffic streets, including some bicycle boulevards, may be a better way to encourage bicycling among those concerned with safety and avoiding traffic than adding bike lanes on major streets with high volumes of motor vehicle traffic. In many studies, separated bicycle facilities – bikeways that are physically separated from motorized vehicular traffic—are most important to women and non-cyclists that may be persuaded to begin bicycling (Pucher & Buehler, 2008; Dill & Gliebe, 2008; Krizek et al., 2005). While separated bicycle facilities can actually be more dangerous than on-road bicycle lanes due to traffic integration failures (Krizek et al., 2009), the increased perception of safety associated with separated facilities is an important factor in encouraging bicycle use (Nelson and Allen, 1997).

A tangential consideration is the utility of bicycling, and whether it makes sense to use a bicycle as a mode of transportation. In many circumstances, the primary barrier to bicycling is distance and/or time to destination (Iacono et al., 2008; Lee et al., 2008; Ramirez et al., 2006; Williams, C. 2007; Antonakos, 1993). This is arguably a factor of infrastructure, though not necessarily specific to bicycle infrastructure. Dill (2009) and Sonenklar and Hadden-Loh (2013) established relationships between denser built environments and greater levels of bicycling, arguing that well-connected street grids permit shorter distances to destinations.

Nevertheless, while the road network may facilitate trip efficiency, Nelson and Allen (1997) found that bicycle facilities connecting the appropriate origins and destinations were crucial variables impacting the use of bicycling as an alternative commuting mode.

Beyond Infrastructure

It is telling that "infrastructure and funding" comprises only one of five categories on the League of American Bicyclists' Bicycle Friendly State Report Card that contributes to a state's overall Bicycle-Friendly rating (2015). In several cities, programmatic interventions targeting new bicyclists, such as media campaigns, educational events, and bicycle shares, have generated significant and sustaining increases in the number of cyclists. In Victoria, Australia, more than one quarter of first-time cyclists were still bicycling five months after a bike to work event (Rose and Marfurt, 2007). In Lyon, implementation of the Velo'v program increased bicycle counts by 75%, with the number bicycle of trips reaching 2% in 2007 (Velo'v, 2009; Pucher et al., 2010). Nevertheless, although many of these programs were deemed successful, it must be noted that program implementation often accompanies infrastructural upgrades and interventions.

The number of cyclists in an area can often dictate both the safety of and sentiment towards bicyclists. Studies demonstrate that bicycling injury rates fall when the number of bicyclists increases, likely due to a combination of increased visibility and establishment as a road user, and proportion of motorists that are also cyclists (Jacobsen, 2003; Robinson, 2005; Nelson and Allen, 1997). Social responses to increases in bicycling can also manifest in seemingly illogical ways. Goetzke and Rave (2011) demonstrated that, in Germany, social network effects only increased the probability of bicycling for shopping and recreational trip purposes, whereas presence of bicycling infrastructure was only influential for shopping and errand trips. While Gatersleben and Appleton (2007) show that non-cyclists who are surrounded by other cyclists may be more likely to have contemplated cycling, competing research has suggested that prevailing culture and custom may undermine interventions such as programming or infrastructure (de Bruijn et al., 2009).

Overall, combined strategies may generate the greatest desired response. Pucher & Buehler (2008) argue that the most effective initiatives are those that combine pro-bicycle measures (e.g., driver education) with motorized vehicle restrictions (e.g., parking and gas taxes). Pucher et al.'s (2010) review of programs, policies, and developments that increase bicycling likewise determined that integrated packages of pro-bicycle infrastructure measures, programs, and policies generally produced the most significant shifts in bicycling participation. For those communities wishing to cater to bicyclist and potential bicyclist populations alike, there may not be a cost-efficient, one-size-fits-all solution.

PPGIS

Innovative planning approaches to active transportation promotion and development are slowly changing the way communities and their citizens perceive and engage with transportation. One such engagement tool, Public Participation Geographical Information Systems (PPGIS), uses geospatial technology to inform planning processes with public knowledge by inviting participants to provide geospatial information about perceived attributes of place (Sieber, 2006). The concept of PPGIS originated in the United States at the 1996 meetings of the National Center for Geographic Information and Analysis (NCGIA) (Sieber, 2006). Participatory GIS (PGIS) and volunteered geographic information (VGI) are similar terms describing processes for contributing non-expert spatial information (Brown &

Kyttä, 2014). While PGIS is more often associated with collective community opposition of dominant power structures in rural areas of developing countries (Gloeckner et al., 2004; Panek and Vlok, 2013), PPGIS generally involves probability sampling of individuals for survey or research purposes. VGI more often refers to the "crowdsourcing" (Howe, 2006) of spatial information, whereby information is volunteered from a large group of people—especially from an online community (Sui, Elwood, & Goodchild, 2013). Although these three terms refer to the same general concept, PPGIS is most often employed by studies that involve survey design.

Roadway models, which use roadway attributes to gauge roadway levels of stress, have long been employed by planners and engineers to systematically characterize bicycling networks. While this technical approach is useful, it fails to account for the subjective experiences of the facility users (Pánek, J., & Benediktsson, 2017). PPGIS methods permit collection of both quantitative and qualitative data that contribute to the subjective void. Individuals at the local level are generally most attuned to their immediate surroundings and are often eager to recognize and report concerns (Goodchild, 2008). Providing outlets for such information, such as PPGIS, can not only generate valuable data, but also increase stakeholder investment in community or statewide planning initiatives.

Active transportation planning is well suited to benefit from PPGIS, as activities such as bicycling and walking depend on a certain spatial awareness (Kessler, 2011). Although the *NH Long Range Transportation Plan 2010 – 2030*'s (NHDOT, 2010) "Strategic Outcomes" were informed by public and stakeholder input processes, this project was the first use of PPGIS in the state to raise and answer questions about NH transportation systems.

Level of Traffic Stress

A bicyclist's level of bicycling comfort on the roadway—a rating determined using roadway attribute criteria—has been linked to the proportion of residents bicycling for transportation (Xing et al., 2010). Additional bicycle suitability assessments, such as the bicycle safety index rating (BSIR) (Davis, 1987), bicycle-stress level (BSL) (Sorton and Walsh, 1994), bicycle-suitability score (BSS) (Turner et al., 1997), bicycle compatibility index (BCI) (Harkey et al., 1998), and bicycle level-of-service (BLOS) (Transportation Research Board, 2011), all seek to capture the stress of a roadway for bicyclists using various road attributes. Mekuria et al.'s (2012) Level of Traffic Stress (LTS) roadway rating system, which considers number of vehicle lanes, speed limit, bike lane width, parking, and mid-block crossings, uses a 1-4 roadway stress rating scheme that corresponds to four distinct classes of the population. These population classes, first suggested by Geller in 2006 (Dill and McNeil, 2013), attempt to break the population down into confident cyclists, potential cyclists, and those who will never cycle. This classification scheme, coupled with Mekuria et al.'s four-tiered LTS classification scheme, gives planners and engineers a better description of whom a roadway serves. Table 1 details the LTS rating system in relation to Geller's (2006) population classifications.

The most recent bicycle suitability assessment classifies roadway bicycling stress using marginal rates of substitution. Lowry et al. (2016) adapted empirical behavioral research on bicyclist route choice that applies stress reduction values given certain bicycle accommodations (e.g. sharrows or bike lane).

To prescribe appropriate recommendations for increasing the bicyclist population and frequency of bicycling in NH, this research attempted to 1) characterize the current and potential bicyclist populations in two case study communities and 2) understand gender and bicycle population-specific barriers to engagement in bicycling. To this end, we conducted a Public Participatory Geographic Information System (PPGIS) – based survey that captured the stated bikeability preferences and concerns of cyclist and non-cyclist residents in the Lakes Region and Manchester, NH. These case studies provided insight into potential regional variations (or lack thereof) in the active transportation participations rates, preferences, and concerns of NH citizens. The spatial results from this survey were used to validate a NH-specific traffic stress model that uses road attributes to objectively score road segments by degree of bicycling discomfort. Thus, this work demonstrates how the PPGIS approach to public feedback can not only inform NHDOT active transportation policy, but also shapes the role of models in active transportation planning in NH.

METHODOLOGY

Survey Distribution

We conducted a PPGIS intercept survey throughout the two case studies regions over a two-month period. Considering budgetary constraints, the needs of our project partners, and restrictive deadlines, purposive haphazard intercept and snowball sampling was the most appropriate method to use, given our project goal. The intent was to capture a diversity of responses from New Hampshire residents along the attitude spectrum proposed by Geller (2006), as detailed in Table 1. To increase respondent diversity, we deliberately targeted both bicycling and the non-bicycling communities at events such as bicycle races, craft fairs, public meetings, and food pantry dinners. Volunteers were offered a small NH decal and entry into a raffle for a $100 gift card in exchange for taking the survey on a provided laptop, tablet, or paper printout. Additionally, intercepted individuals were given the option of providing their email to receive a link to the survey to complete at will. In total, 16 events were attended by the surveyors – 9 in the Lakes Region and 7 in Manchester. Because the survey could be distributed via a designated web address, a large percentage of additional responses were obtained by means of snowball sampling through social media and email mailing lists.

Using the Finnish PPGIS web platform, Maptionnaire, we issued a questionnaire that addressed bicycling attitudes and habits, motivations for bicycling, barriers to bicycling, access to key destinations, and mapping of hazardous road segments. Survey questions ranged from multiple choice to sliding-bar scale and concluded with a mapping application. In the mapping portion, respondents were asked to place location pins on segments of road or trail that they believed were hazardous and to provide feedback about the perceived hazards for each segment (Figure 6). Points features were selected over lines to minimize confusion with placing features on the map, as was experienced by Pánek and Benediktsson (2017). To facilitate mapping, respondents were given the options of toggling between four different base maps, applying a NH trails layer, and locating specific street addresses using a search bar. Maptionnaire was selected for its user-friendly interface and convenient data delivery packages.

Data Processing

Multiple linear regression was conducted to identify relationships between attitudes towards cycling and selected demographic data and the frequency of cycling and selected demographic data. An analysis of variance (ANOVA) test was conducted on “barriers to bicycling” responses and “motivations for bicycling” responses to determine if variations in response were explained by attitudes toward bicycling or frequency of cycling.

LTS Development

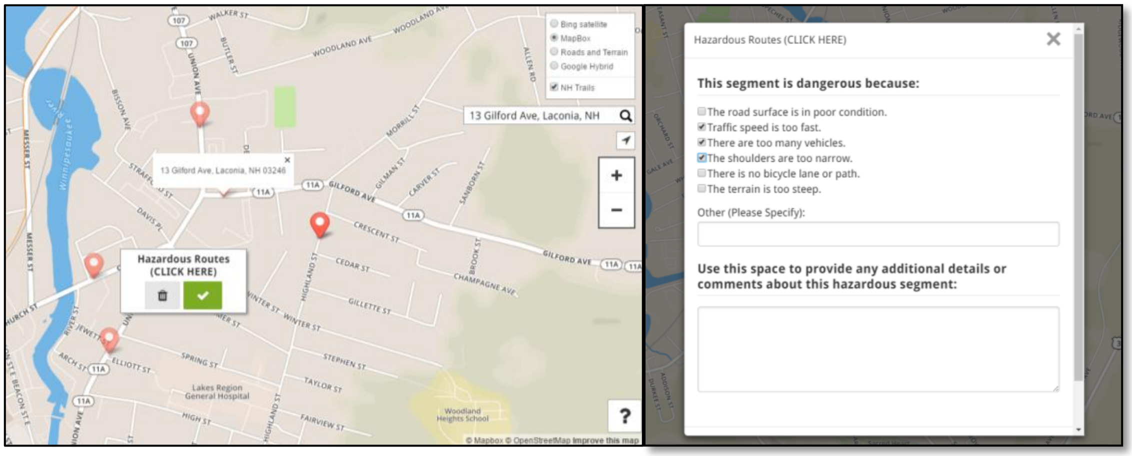
In 2013, NH planning commissions began adapting a version of Mekuria et al.'s (2012) Level of Traffic Stress model for the state of NH's roadways. With limited intersection data and a lack of bicycle facilities throughout the state, Mekuria et al.'s (2012) LTS formula was not directly transferrable to NH. To achieve a suitable product for the state, we collaborated with planners in central and southern NH to review an LTS criteria matrix and test model iterations. GIS interns collected and added missing data about road shoulder width, bicycle facility presence, parking presence and width, and speed to existing attributes in the NHDOT road attribute database to provide a more comprehensive assessment of bikeability for each roadway segment. The version of the model that incorporates road shoulder width, bicycle facility presence, parking presence and width, and speed, is hereafter referred to as LTS I. The version of the model that does not include these attributes is called LTS II. LTS II scores are derived solely from the NHDOT Functional Class and Average Annual Daily Traffic (AADT) estimates. For a more detailed discussion of the LTS models, see (Getts, 2017: Chapter 2)

The final LTS I model features several deviations from Mekuria's LTS. As a proxy for stress-reducing bicycle facilities, the final model calculates road shoulders >= 4 ft. as bicycle lanes. Additionally, a residential designation serves as a proxy for traffic volumes along quieter segments of the road network. When speed limit data for a segment was unavailable, the road's functional class became a proxy for speed categorization. Interstates were given a separate designation that excludes them from the 1-4 rating. Finally, intersection-specific criteria were omitted due to limited resources. The final set of criteria were modelled in ArcMap's ModelBuilder and converted into an ArcTool for use by planners statewide.

LTS-Response Data Comparison

To publicly validate the LTS model, respondents' hazardous road flags were intersected with corresponding LTS segment scores (Figure 7). Because hazardous points were added to the map at various levels of zoom, subjective interpretation was required to correct snapping errors. This potential source of error could be corrected in future PPGIS surveys by asking respondents to specify the name of the segment that they are targeting.

We assumed that respondents would most frequently identify LTS 3 and 4 segments of roadway as hazards. Per the LTS criteria, these pieces of the network are currently stressful to use, but have the potential to become lower stress corridors with strategic improvements. If treatments, such as traffic calming or bicycle lane striping, to segments rated LTS 3 or 4 sufficiently reduce the rating of these segments to an LTS 1 or 2, the low-stress bicycle network would be expanded and a greater bicycle mode share could potentially result.



Hazardous Routes (CLICK HERE)

This segment is dangerous because:

☐ The road surface is in poor condition.
☑ Traffic speed is too fast.
☑ There are too many vehicles.
☑ The shoulders are too narrow.
☐ There is no bicycle lane or path.
☐ The terrain is too steep.

Other (Please Specify):

Use this space to provide any additional details or comments about this hazardous segment:

Figure 6. Maptionnaire "Hazardous Route" mapping screen and hazard explanation dialog box. The dialog box would appear after a respondent placed a point on the map.

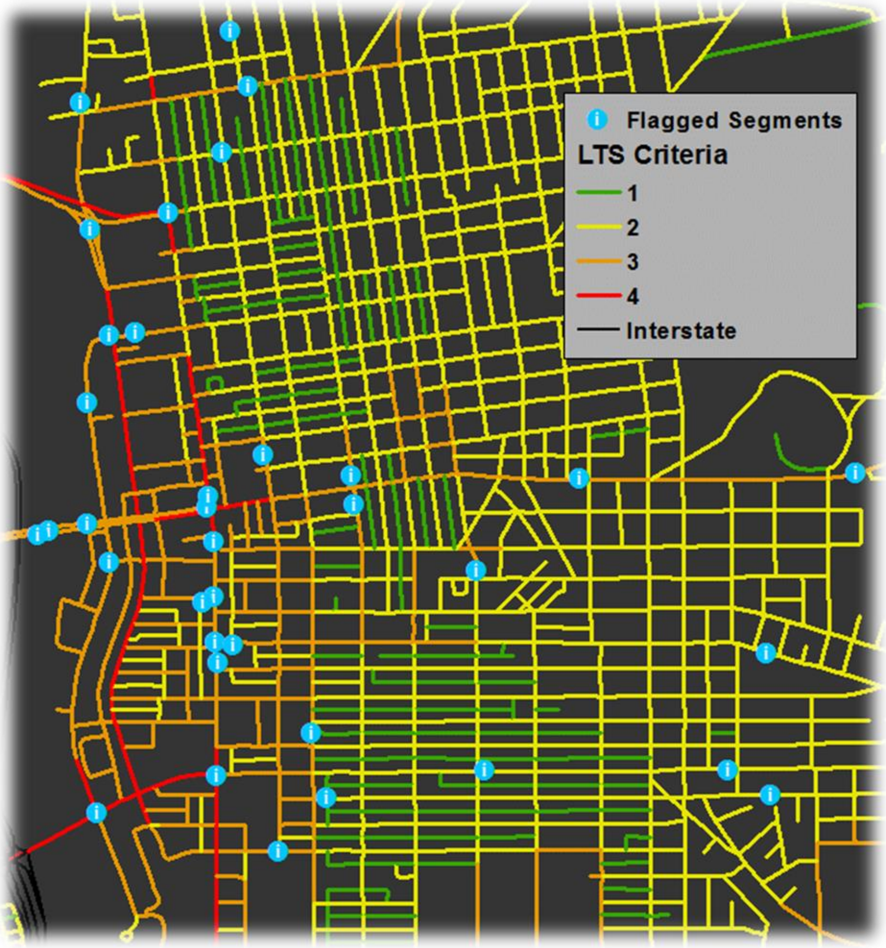


Figure 7. Survey respondents' hazardous road flags intersected with Manchester NH's road network, whose segments are scored by Level of Traffic Stress 1-4.

Case Study Regions

The two case study regions—Manchester and the Lakes Region—were deliberately selected to identify regional variations in resident participation in and perceptions of bikeability in NH. The Lakes Region was included in this analysis in response to ongoing work for the Lakes Region Planning Commission, who was poised to immediately engage with PPGIS feedback. To best capture variations between regions in NH, it was important to select a community that provided appropriate contrast to the Lakes Region. As the most populous and densely developed city in NH, Manchester is the best foil to the Lakes Region, with more potential to serve its population through active transportation improvements than any other city in the state.

Most studies that examine factors contributing to bicycle use occur in metropolitan communities with greater than 50,000 residents. With only 1.3 million residents scattered throughout the predominately rural state of NH, the state's low density community composition presents unique challenges for planners hoping to engage more residents in active transportation. In NH, the average commute time is 27 minutes, with over 90% of the population commuting by automobile (U.S. Census, 2015). Nevertheless, both Manchester and the Lakes Region have much to gain from active transportation improvements. With a robust tourist season and stark natural beauty, the Lakes Region of NH is well positioned to benefit from a bicycle tourism economy. The Economic Impact Analysis of the WOW Trail (2012) found that upon completion, a bicycle trail that connects several communities in The Lakes Region of NH is expected to provide approximately $778,400 in annual economic benefits to local communities. In southern NH, higher road and population densities are strong prerequisites for bicycle networks with high accessibility. The state's only U.S. Census-designated Metropolitan Statistical Area (Manchester-Nashua) hosts approximately one-third of the state's population (United State Census Bureau, 2016), offering potential for significant impact from localized pro-bike and walk measures in this region.

To better understand the potential regional differences between population engagement in and perceptions of barriers to bikeability in NH, we conducted a comparative assessment of two distinct regions. The selected study areas: Manchester, NH and the Lakes Region of NH, maintain similar active transportation planning goals, despite differences in land use and scale.

Manchester

With a population of approximately 110,000, Manchester is NH's largest city and one of only 11 NH cities with populations greater than 20,000 individuals (United States Census Bureau, 2016). Geographically, the city's official political boundary spans only 34 sq. miles and boasts a street network whose density is more favorable to multi-modal travel than any other town or city in the state (Environmental Protection Agency (EPA), 2013). On average, Manchester is younger, more diverse, and less affluent than the state as a whole (see appendix; ACS survey data). According to the NH Social Vulnerability Index (SVI), 50% of Manchester's census tracts have a vulnerability rating greater than the state average of SVI 2, and approximately 10% of the city's households have no vehicle available (U.S. Census Bureau, 2010). Of the more than 32,000 Manchester residents who live at some level of poverty, over half live within city neighborhoods that qualify as Neighborhood Revitalization Strategy Areas (NRSA), which are United States Department of Housing and Urban Development-designated neighborhoods that require economic development support (City of

Manchester, 2014). Given these vulnerable populations, a large percentage of Manchester residents stand to benefit from targeted active transportation improvements.

The Lakes Region

The Lakes Region includes 30, primarily rural, communities that surround Lake Winnipesaukee, Winnisquam Lake, Squam Lake, and Newfound Lake in mid-state NH. The area totals nearly 1,300 sq. miles and collectively, is home to more than 113,000 residents (ACS, 2016), with community populations ranging from 600 – 16,000 residents (U.S. Census Bureau, 2016). Much of the Region consists of densely populated villages and downtowns separated by higher speed corridors with little commercial development, and larger residential, agricultural, and forested parcels. Additionally, many residents live along these rural local roads and state highways, presenting accessibility challenges for the 1.2% of the population that has no vehicle access (LRPC, 2012b). With seasonal home ownership at 29%, some communities estimate that their summer population swells to at least three times the year-round population (LRPC, 2015). This dynamic presents both opportunities and challenges for the Lakes Region in terms of affordable housing, bicycle tourism, and alternative transportation solutions to visitation congestion.

RESULTS

Demographic Response Data

We received 529 survey responses; 121 respondents were from the Lakes Region of NH, 88 were from Manchester, and 320 did not claim residency in either focal region. Although the majority of responses were from outside of the case study regions, only data from respondents residing in the Lakes Region and Manchester was analyzed. In the Lakes Region, 45% of respondents were male, while in Manchester, 57% of respondents were male. The greatest frequency of respondents from both regions fell into the 55-64-year age bracket. Additional demographic information collected included: ethnicity, state of employment, income, number of children in household, and seasonality of residence in NH. The average respondent from both communities was likely to be white, employed, hold a college degree, and have no children living at home. Income varied widely among all respondents in both regions. Overall, survey respondents were slightly older and more educated than the NH state average (U.S. Census Bureau, 2016).

While the majority of respondents in the Lakes Region heard about the survey through social channels (e.g., Facebook, Twitter, word of mouth, or a mailing list and/or organization) most respondents from Manchester were informed about the survey through face-to-face interactions with the researchers.

We found significant relationships between demographic characteristics of our respondents and their perceptions of bicycling, frequency of bicycling for any purpose, and frequency of bicycling to commute. Multiple linear regression with demographic variables revealed that in both communities, more reticent attitudes about bicycling were significantly related to being female. In the Lakes Region, being retired was also a significant factor corresponding with decreased confidence and willingness to bicycle. How often one rode a bicycle was significantly related to a combination of gender, ethnicity, and education, with being male and having received more education associated with more frequent bicycling. In Manchester, gender and ethnicity were significantly associated with how often a respondent cycled, with women and those of white ethnicity bicycling less frequently. In the Lakes Region, a higher tendency to commute was significantly related to being male and having a lower income, while in Manchester, a higher tendency to commute was significantly related to being male and being non-white. Interestingly, age and income were not significant in most regressions. The following table details the significant regression combinations.

Community	Dependent Variables	Independent Variables	Adj. R Square	Std. Error	P Value
Lakes Region	Attitude towards bicycling	Gender, Retirement	0.140	0.782	0.000
Manchester	Attitude towards bicycling	Gender	0.204	0.723	0.000
Lakes Region	How often ride a bicycle	Education, Ethnicity, Gender	0.073	0.649	0.013
Manchester	How often ride a bicycle	Ethnicity, Gender	0.129	0.658	0.002
Lakes Region	How often commute by bicycle	Income, Gender	0.057	0.591	0.020
Manchester	How often commute by bicycle	Ethnicity, Gender	0.078	0.631	0.015

Table 7. Demographic variables impacting survey respondent attitudes toward bicycling, how often respondents rode a bicycle, and how often respondents commuted by bicycle.

Types of Cyclists

In both the Lakes Region and in Manchester, approximately 50% of respondents reportedly ride a bicycle occasionally (several times a month or year) and approximately 30% ride regularly (several times a week or every day). 8% of respondents in the Lakes Region and 9% in Manchester were self-described as regular commuters (several times a week or every day).

Attitudes towards bicycling among respondents in both communities tended to fall in the Comfortably Confident and Willing but Wary categories. The Willing but Wary portion of the population is of greatest interest to NH planners and NHDOT, as this is the largest potential pool of individuals that could shift transportation modes and increase the prevalence of bicycling the state. As shown in Figure 8, individuals identifying as Willing but Wary made up more than one quarter of all respondents in both regions, with the Lakes Region's proportion totaling nearly 50%.

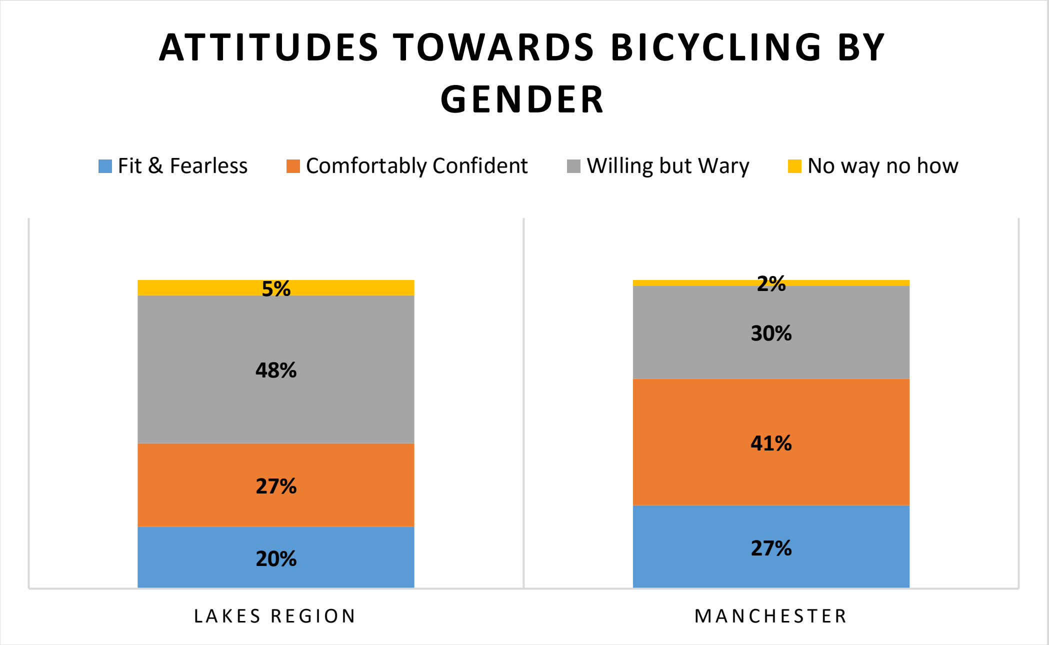


Figure 8. Attitudes toward bicycling among survey respondents in the Lakes Region and Manchester, NH.

Motivations for Riding

The three most frequently stated motivations for riding a bicycle—both in Manchester and the Lakes Region—were exercise, stress relief, and environmental concerns. These results agree with the U.S. Data from the Bureau of Transportation Statistics (BTS) Omnibus Survey for 2002 (Dill and Carr, 2003), which found that only 4.9 percent of adult respondents bicycled primarily for commuting to work or school and 7.5 percent for personal errands.

Barriers to Bicycling

Among respondents in both regions, the three most frequently stated barriers to bicycling in NH were Narrow Shoulders, Fear of Driver's Awareness of Cyclists, and a Fear of Traffic. The ten most frequently cited barriers in the Lakes Region and Manchester included all potential infrastructural barriers included in the survey: Road shoulder is too narrow, Lack of striped bicycle lanes, Lack of dedicated bicycle paths at least 20 ft. from vehicle traffic, Lack of bicycle lanes separated from traffic by barriers (e.g. curb), and Road surface conditions are poor (Figure 9). Interestingly, Narrow road shoulders and Lack of striped bicycle lanes were, overall, considered greater barriers to bicycle than separated bicycle facilities or bicycle boulevards. Respondents in both communities expressed a substantial fear of drivers and traffic volumes. Given that previous research has deemed time and/or distance to destination a major barrier to bicycling for many individuals, it is surprising that Time to Destination was not considered one of the highest-ranked barriers to bicycling among respondents from both the Lakes Region and Manchester. Furthermore, it is interesting to note that Time to Destination is considered a greater barrier in Manchester than the Lakes Region, where communities and road densities are far less compact.

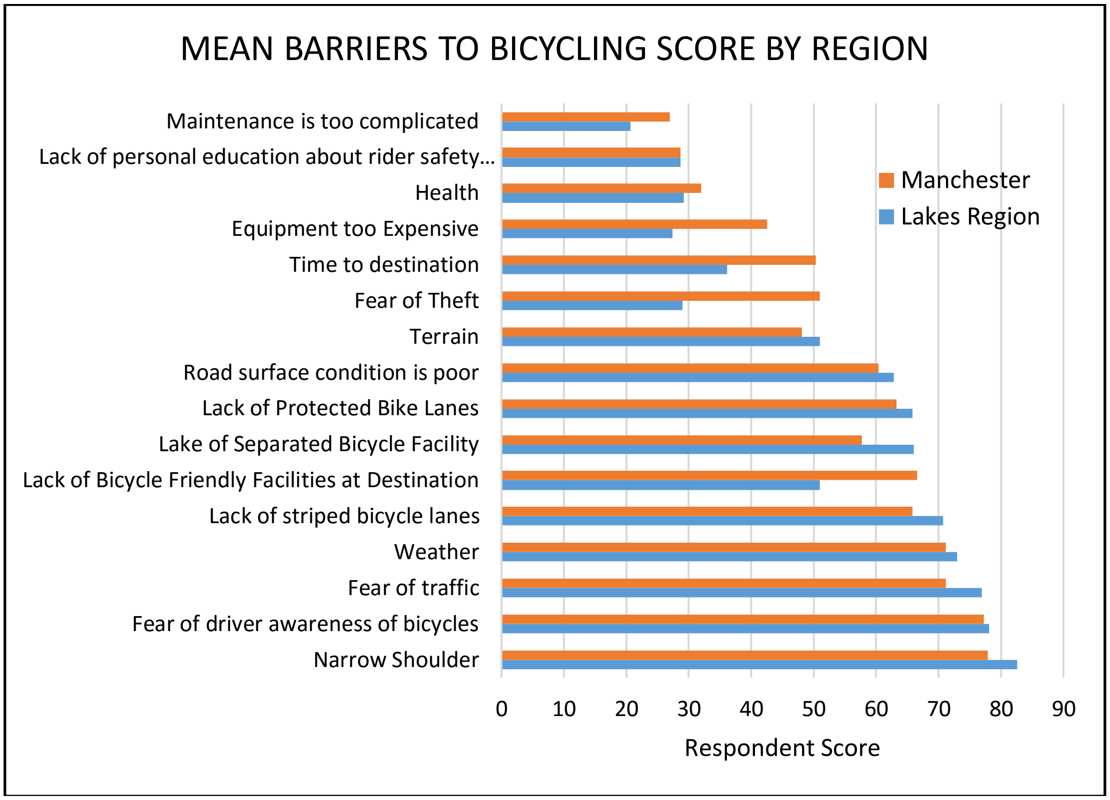


Figure 9. Stated barriers to bicycling by intercept survey respondents in two communities in New Hampshire. Respondents scored each variable between 0 and 100 using a sliding scale bar.

Attitude Towards Bicycling

While both respondents with a confident attitude towards bicycling (Comfortably Confident and Fit and Fearless) and Willing but Wary respondents were almost equally concerned about weather, equipment expense, bicycle facilities at their destination, knowledge of rider safety, bicycle maintenance, and poor road surface conditions, Willing but Wary respondents were significantly more concerned than confident rider respondents about traffic, drivers, and all other infrastructural barriers, as detailed in Table 8. In Manchester, Willing but Wary bicyclists only deviated from confident riders in their concern about terrain and driver awareness of bicyclists. In Manchester, there was no statistically significant difference between Willing but Wary and confident cyclists' concerns for all other potential barriers.

Dependent Variables	Factor		Std. Error	P-Value	95% Confidence Interval		Region
					Lower Bound	Upper Bound	
Terrain	Willing but Wary	Comfortably Confident	8.630	0.007	6.34	51.71	Lakes Region
		Fit & Fearless	9.944	0.000	24.93	77.21	
	Willing but Wary	Comfortably Confident	9.825	0.000	18.33	70.36	Manchester
		Fit & Fearless	10.826	0.000	36.24	93.58	
Fear of Driver Awareness of Bicyclists	Willing but Wary	Comfortably Confident	6.582	0.014	3.18	37.68	Lakes Region
	Willing but Wary	Fit & Fearless	9.674	0.018	3.88	55.09	Manchester
Fear of Traffic	Willing but Wary	Comfortably Confident	6.572	0.002	7.16	41.57	Lakes Region
		Fit & Fearless	7.360	0.012	3.83	42.36	
The road shoulder is too narrow	Willing but Wary	Fit & Fearless	6.955	0.029	1.47	37.85	Lakes Region
Lack of striped bicycle lanes	Willing but Wary	Fit & Fearless	8.734	0.045	0.35	46.19	Lakes Region
Lack of bicycle lanes separated from traffic by barriers	Willing but Wary	Comfortably Confident	8.321	0.001	10.13	53.81	Lakes Region
		Fit & Fearless	9.659	0.029	2.09	52.79	
Lack of dedicated bicycle paths at least 20ft. from vehicle traffic	Willing but Wary	Comfortably Confident	8.429	0.010	4.97	49.18	Lakes Region
		Fit & Fearless	8.581	0.004	7.70	52.71	
Equipment too expensive	Willing but Wary	Fit & Fearless					Manchester
Inclement Weather	Willing but Wary	Comfortably Confident	11.591	0.011	6.62	68.18	Manchester

Table 8. Significant ANOVA Tukey HSD post-hoc test results for bikeability survey results in the Lakes Region and Manchester. Test compares the differences between attitudes towards bicycling for various barriers to bicycling variables. Willing but Wary respondents consistently scored barriers higher than both Comfortably Confident and Fit and Fearless respondents.

Gender

Women comprised more than half of all Willing but Wary-identified respondents (Figure 10).

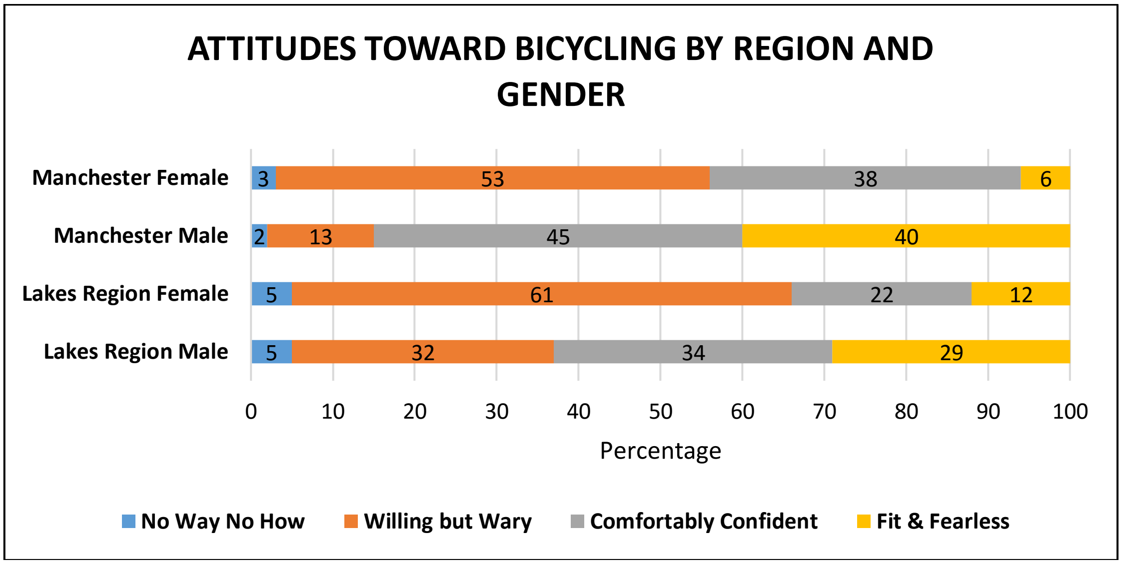


Figure 10. Attitudes toward bicycling by gender among survey respondents in the Lakes Region and Manchester, NH.

Evaluations of barriers to bicycling were more largely driven by gender in the Lakes Region than in Manchester. In the Lakes Region, females’ score of terrain, a fear of drivers and traffic, a lack of striped bicycle lanes, a lack of bicycle lanes separated from traffic by barriers, a lack of bicycle paths at least 20 ft. from vehicle traffic, time to destination, and a lack of bicycle-friendly facilities at one’s destination was significantly higher than that of males (Table 9). It is noteworthy that the highest rated barrier in the Lakes Region, The road shoulder is too narrow, did not experience a statistically significant score difference between males and females. In Manchester, terrain and a fear or traffic were the only barriers that exhibited a gender bias in score. Interestingly, with the exception of Fear of bicycle theft in Manchester, female score means were higher than male score means for all barriers in both regions.

Variable	t	df	P-Value	Region
Terrain	-4.545	84	0.000	Lakes Region
	-3.367	58.316	0.001	Manchester
Fear of traffic	-2.950	76.009	0.004	Lakes Region
	-2.538	62.990	0.014	Manchester
Inclement weather	-2.020	59.617	0.048	Lakes Region
Fear of driver awareness of bicycles	-2.010	62.574	0.049	Lakes Region
Time to destination	-2.998	64.357	0.004	Lakes Region
Lack of bicycle friendly facilities at destination	-3.701	85	0.000	Lakes Region
Equipment is too expensive	-2.024	74	0.047	Lakes Region
Maintenance is too complicated	-3.693	64.255	0.000	Lakes Region
Lack of striped bicycle lanes	-2.424	66.386	0.018	Lakes Region
Lack of bicycle lanes separated from traffic by barriers	-2.418	64.674	0.018	Lakes Region
Lack of dedicated bicycle paths at least 20ft. from vehicle traffic	-3.306	61.511	0.002	Lakes Region

Table 9. Independent t-test for Equality of Means test results for bikeability survey results in the Lakes Region and Manchester. Test compares the differences between genders for various barriers to bicycling variables. Barriers were scored on a sliding scale of 0-100. Female mean scores were significantly higher than male mean scores for all variables.

Hazardous Road Flags and Level of Traffic Stress

In the Lakes Region, 59 unique respondents flagged 138 routes. Of the 138 routes flagged, approximately 62% were rated LTS 4, 20% were rated LTS 3, 14% were rated LTS 2, and 4% were rated LTS 1 (Figure 11), with 1 flag along the interstate (removed from total percentage). Streets with more than four hazardous flags included: Lake Shore Rd, NH Rte. 175, US Rte. 3, Central St., Laconia Rd, Main St., NH Rte. 25, and Whittier Hwy. Each of these streets ranged from an LTS 2 to an LTS 4. These hazardous road flags were dispersed throughout Holderness, Moultonborough, Gilford, Belmont, Tilton, Northfield, Sanbornton, and Franklin (North-South through middle of region). In the Lakes Region, the most frequently cited reasons for flagging these roads were narrow road shoulders, followed by a lack of bicycle lane or path and heavy traffic speeds. High traffic volumes were also listed as a concern for approximately 15% of the flagged segments (Figure 12).

In Manchester, 21 different respondents flagged a total of 69 road segments as hazardous. Of these segments, approximately 57% were rated LTS 3, 27% were rated LTS 2, 16% were rated LTS 2 (Figure 11), and 2 flags were placed along the interstate (removed from total percentage). Streets with more than three hazardous flags included: Elm St., Union St., Bridge St., Brown Ave., Hanover St., and W Bridge St. Each of these street segments ranged from an LTS 2 to an LTS 4. In Manchester, the top rationales for flagging these roads were a lack of bikeable infrastructure and traffic volumes, followed closely by high traffic speeds (Figure 12).

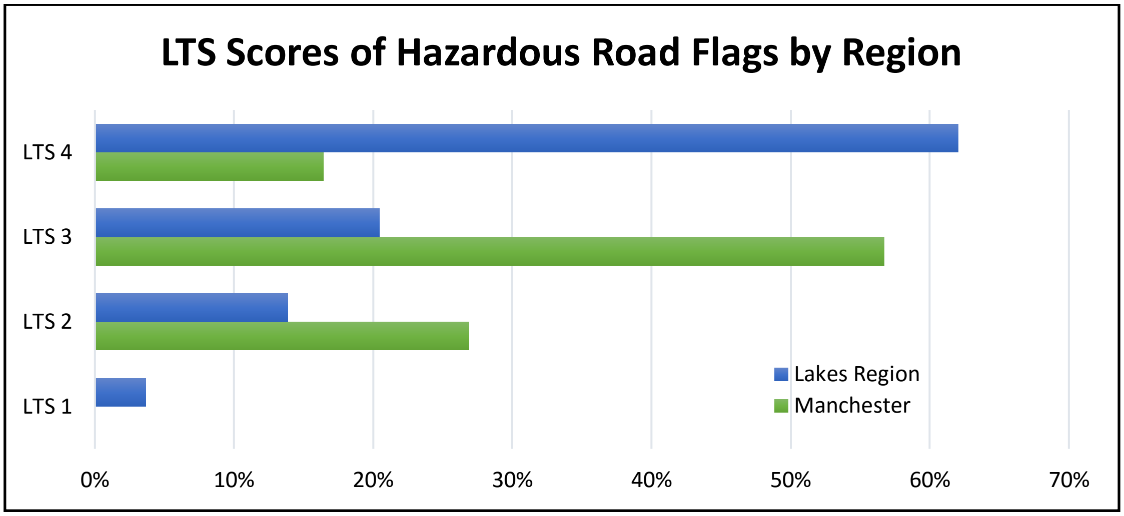


Figure 11. Percentage hazardous road flagged-segments by Level of Traffic Stress score 1-4 and region.

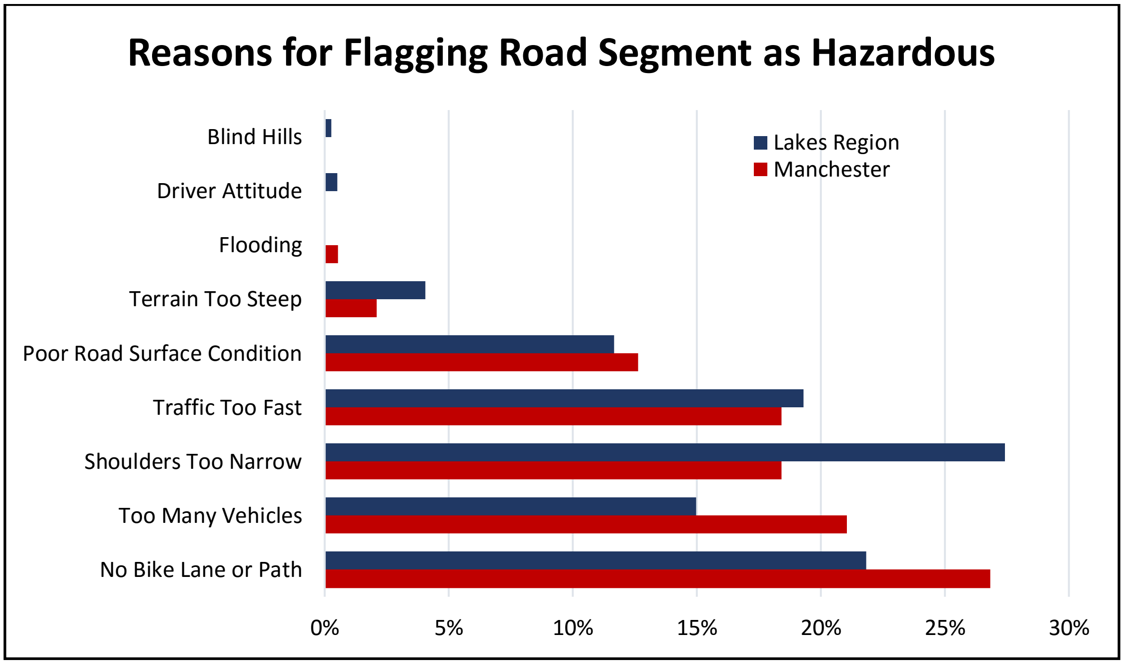


Figure 12. Rationales for flagging a road segment as hazardous by region and percentage of overall segments flagged.

DISCUSSION

While models have become highly efficient transportation planning tools, their effectiveness cannot be confirmed without public feedback and validation. In harnessing the knowledge of community members, the planning process evolves and is strengthened. The advent of PPGIS platforms, such as Maptionnaire, have streamlined the process of collecting and manipulating public response data. Our NH Bikeability Questionnaire showcased the advantages and disadvantages of this approach by collecting both spatial and non-spatial data from a diversity of individuals across the state. The following discussion draws upon our results to introduce active transportation planning considerations and recommendations for NH.

Gender

In both regions, gender was the most consistent variable impacting a respondent's attitude towards bicycling, how often one rode a bicycle, and how often one commuted by bicycle. For each of these variables, females were less likely to be engaged in bicycling, which may suggest the need for gender-specific bicycle initiatives. Encouragingly, in both regions, most female respondents fall into the Willing but Wary category, which implies that women may be an untapped pool of potential bicyclists in NH.

While female respondents had a significantly higher fear of traffic than males, and in the Lakes Region, a significantly greater desire than males for designated and/or separated bicycle facilities, they prioritized barriers similarly to men. Males and females in both regions were most concerned about narrow road shoulders and traffic, followed closely by a desire for more striped bicycle lanes. While research has suggested the importance of dedicated bicycle facilities and lower levels of traffic stress to women (Dill and Gliebe, 2008; Emond et al., 2009; Garrard et al., 2008), NH females respondents did not consider the lack of separated bicycle facilities a greater barrier to bicycling than the lack of striped bicycle lanes. Given these results, NHDOT can be confident that cost-effective roadway improvements, such as lane restriping, will not necessarily isolate both existing and potential female cyclist populations. Rather, these groups would be best served by a combination of strategies supporting bicycle lane striping, traffic calming, and increased visibility.

Characterizing NH's Bicyclists

The New Hampshire bikeability survey reached a diverse audience through purposive haphazard intercept and social media snowball sampling efforts. While this survey was not necessarily representative of New Hampshire bicycling populations, response data demonstrates that demographically, the sampled population strongly reflects NH demographics statewide, as shown in Appendix A. Furthermore, this approach successfully captured the perspective of both cyclists and non-cyclists, lending a voice to all user groups of interest. While survey results cannot be definitively extrapolated beyond this pool of respondents, such findings suggest that planners, advocacy groups, and NHDOT would benefit from targeting residents of all ages, incomes, and regions alike with pro-bike policies and programming. Likewise, these stakeholders may have greater confidence that adjustments to roadway levels of traffic stress are serving a diverse populous.

Making Investments Count

An investigation of significant variations in mean barrier scores by attitude towards bicycling provides potential insight into the active transportation mindset of NH's Willing but Wary population. Among respondents, this population possessed a stronger fear of drivers than confident bicyclists. In the Lakes Region, a lack of bicycle-specific infrastructure was also a far greater concern for the Willing but Wary than confident bicyclists, with a lack of striped bicycle lanes receiving the highest mean score. In Manchester, the Willing but Wary prioritized narrow road shoulder concerns, followed closely by a lack of separated bicycle facilities and a lack of striped bicycle lanes. These high scores were consistent with the high scores given by confident cyclist respondents in Manchester, confirming that the road network is a primary barrier to active transportation engagement statewide.

Such results suggest opportunities for physical and programmatic interventions by planners and engineers that may encourage members of NH's Willing but Wary population to engage in bicycling, and incentivize confident bicyclists to ride more often and for different purposes. Chief among these are alterations to the road network that lower the level of traffic stress. Interventions that increase the visibility of bicyclists, limit direct bicyclist integration into high automobile volume roadways, and improve the physical comfort of the bicyclist, may have the greatest impact upon bicyclist safety and engagement. The NH Long Range Transportation Plan 2010 – 2030 (New Hampshire Department of Transportation (NHDOT), 2010) expresses a desire to more effectively integrate bicycle and pedestrian facilities into the planning, design, and construction of roadways throughout the state (NHDOT, 2010). Given the results of the PPGIS survey, this goal is a productive step towards increasing the use and availability bicycle modes in NH.

Level of Traffic Stress Model Validation

The results of the hazardous road mapping portion of the bikeability survey provide useful feedback for the NH-specific Level of Traffic Stress model. That the majority of flagged segments in Manchester were LTS 3-rated, suggests that respondents view these roadways as unsafe or uncomfortable for bicycling, yet crucial to the network (Getts, 2017: Chapter 2) and potentially improvable. This may reflect adequate, or nearly adequate, scoring criteria by the LTS model in Manchester. In the Lakes Region, most flagged segments had received a score of LTS 4, confirming that respondents view these roadways as unsafe or uncomfortable for bicycling. That the majority of flagged segments were LTS 4 suggests that the LTS model has overestimated the stress of the roadways, or that LTS 4 links are pervasive in the Lakes Region, or perhaps a combination of both. In both regions, enough segments with ratings of LTS 2, and in particular, the LTS 1 flag in the Lakes Region, were flagged as hazardous to prompt additional review of the LTS model. The "reasons for flagging" data provides a useful means of comparison between perceived roadway hazards and modeled roadway stress. While PPGIS model feedback is currently limited to two regions of NH, replications of this feedback process throughout the state may provide a robust and highly useful set of data that can shape the LTS model and facilitate specific planning goals.

The majority of respondents that engaged in the mapping portion of the survey were active cyclists (see Appendix B). Their feedback demonstrates that residents—particularly those who know the road from the perspective of a bicyclist—are an excellent source of local knowledge and have an important role to play in the planning process. This PPGIS platform demonstrates the ease with which members of the public can participate in important transportation planning decisions.

Importance of the Network

While bicycle trip distances are a known barrier to active transportation engagement, NH's road network does not currently permit the completion of origin-key destination trips at any distance along low-stress networks (Getts, 2017: Chapter 2). Most of the top barrier to bicycling factors are accounted for in the Level of Traffic Stress model, which indicates that the LTS model is a good approximation of disruptions in bicycle origin-destination accessibility. Lack of accessibility becomes a secondary barrier that further removes the incentive, or even ability, to use a bicycle for transportation.

Interestingly, distance to destination was not an important barrier, relative to all other barriers, in either region. This may reflect a recreational motivation for bicycling in NH, rather than a utilitarian one. Although alterations to the road network that significantly decrease bicycle Levels of Traffic Stress may encourage bicycle use for additional purposes (i.e. shopping, commuting, visiting family and friends), results from the survey that asked whether respondents would consider bicycling to a series of key destinations if the route had more bicycle friendly road conditions revealed that, with the exception of a park or trailhead, less than 25% of respondents in Manchester and 20% of respondents in the Lakes Region would be willing to do so (see Appendix C).

Caveats and Future Work

The use of a technology-heavy survey platform presented challenges to several respondents who either did not have access to internet, or were unfamiliar with mapping mediums. In such cases, paper copies were useful, however they limited the respondent's ability to provide spatial feedback. An additional concern associated with the spatial portion of the PPGIS survey was respondent mapping precision. For those who were unfamiliar with standard map scale adjustments, spatial points were often positioned at a small scale. For these cases, researchers needed to verify intended point location using the respondent's qualitative comment data.

Moving forward, it would be interesting to collect information about respondents' participating in VGI platforms, such as Strava or MapMyRide. Future surveys may benefit from additional barrier prompts, such as, lack of knowledge about where to ride, or the importance of aesthetics vs. safety when selecting a route. Additional survey work could aim to capture psychological influences and benefits that emerge from various policy and programmatic initiatives. At the end of the day, maintaining the conversation about active transportation is an important step in normalizing automobile alternatives, which produces safer and healthier outcomes for all.

Conclusion

The New Hampshire Department of Transportation is currently pursuing its goal of increasing the use and availability bicycle modes in NH (NHDOT, 2010). The "safety in numbers" mantra holds true for bicycling and underlines the importance of increasing bicycle use in communities and regions throughout the state. To best increase the number of bicyclists in NH, it is crucial to understand barriers to bicycling by targeting portions of the population that both currently cycle, and will consider bicycling specific certain conditions. This PPGIS public intercept survey of New Hampshire state residents in two unique regions revealed that, among respondents, stated barriers to engagement in bicycling were road quality-specific (e.g. shoulder width, traffic volumes, presence/absence of bicycle lanes). Furthermore, the spatial dataset collected from regional respondents was a valuable LTS model validation tool that emphasizes the utility of implementing state-wide, public, spatial active transportation feedback platforms. The results of this survey provide insight into the possible active transportation concerns of residents, and the potential differences between those who currently bicycle and those who may be willing to engage in bicycling. Such information provides planners and engineers with feedback that is not readily captured by models, and, moving forward, may better inform prioritization of active transportation-specific projects.

Chapter 4: Conclusion

Applications for Planners

The accessibility analysis introduced in Chapter 2 and the PPGIS survey in Chapter 3 are complementary bikeability planning and assessment tools for NH. The accessibility analysis generates road stress improvement recommendations, or infrastructure-specific recommendations, and the results of the PPGIS survey reveal that these variables are the most prominent barriers to bicycling engagement in NH. As a result, planners can justify funding and prioritizing pro-bicycle roadway improvements on the basis of LTS, and by extension, the accessibility analysis. Likewise, planners can flexibly quantify communities or populations served or isolated by the active transportation network. These tools systematically identify network gaps that may complement or challenge community planners' understanding of local transportation challenges and priorities. They also provide a communication framework around which planners and the public can constructively discuss the validity or inadequacies of such dispassionate improvement recommendations. Such conversations will ultimately reveal the degree to which these tools can and should be employed on behalf on the public's welfare.

Recommendations

Infrastructure

Given the results of the PPGIS survey, it is recommended that NHDOT prioritize road shoulder widening prescriptions, such as lane restriping. For among wary and confident riders in both case study regions, narrow road shoulder widths were the dominant barrier to bicycling more often, or at all. Fortunately, such measures are often cheaper than other bicycle comfort installations, such as off-street paths, or separated bicycle facilities. According to the National Association of City Transportation Officials' Urban Bikeway Design Guide, a bike lane may be as small as 3 ft. wide, however lanes of 5 ft. + are desirable, particularly when adjacent to a parking lane (National Association of City Transportation Officials, n.d.). In NH, planners prefer a 4 ft. minimum bicycle lane, and NHDOT should strive to meet this criteria for all potentially bikeable roadway shoulders.

While respondents' prioritization of road shoulders may reflect a general desire to remain integrated with traffic on the roadway while cycling, it may also be an acknowledgement of the limits of NHDOT funding for active transportation, and an expression of hope that road shoulders--a proxy for a bicycle lane-- will, at minimum, receive treatments. Finally, the high rating for road shoulders may also reflect the perception that increasing road shoulder widths will be the most efficient way to expand and increase the safety of NH's bicycle network. In the event of the latter, studies suggest that this is a relatively accurate assumption, particularly when expanding the shoulder width resultantly narrows the driving lane (a form of traffic calming).

Studies have shown that striped bicycle lanes significantly increase a cyclist's comfort and perception of safety (Landis et al., 1997; Dill et al., 2003). These perceptions are warranted, as additional studies have shown that streets with bicycle lanes have significantly lower crash rates than streets without bicycle facilities (Mortiz, 1998). Additionally, in the presence of a striped bicycle lane, both cyclists and drivers position themselves such that the bicyclist has more room to maneuver (Howard et al., 2001). Striped bicycle lanes also offer a compromise for both experienced and inexperienced riders, as they keep experienced riders in the flow of traffic, yet increase the wary riders' sense of separation and visibility (Dill et al., 2008). Where road shoulder width is paved, in good condition, and a minimum of 4 ft., NHDOT should consider official bicycle lane designation and marking.

Studies have shown that cycling infrastructure, such as separated bicycle facilities (SBF), are often perceived as safer than non-separated facilities, particularly among those that are female, younger, less experienced, and/or physically impaired (Krizek et al. 2005; Pucher et al., 2008). Interestingly, female respondents in the NH bikeability survey did not consider the lack of SBFs a greater barrier to bicycling than the lack of striped bicycle lanes. While lack of separated bicycle facilities scored higher than lack of striped bicycle lanes among women in Manchester, the mean score between the two roadway conditions was less than 1 point out of 100. Among wary riders in both regions, the difference in mean barrier score between striped bicycle lanes and separated facilities was less than 4 points out of 100. These results suggest that while lack of infrastructure represents an important barrier to potential riders, they will not necessarily discriminate between bicycle treatments. This is encouraging data for NHDOT, who may not be financially equipped to install SBFs for many years.

Nevertheless, in the event that the state pursues infrastructure developments or modifications, prescriptions should be issued with caution and on a case by case basis. According to Kriezek, Forsyth, and Baum (2009), while separated bicycle facilities and related treatments lead to the perception of increased safety by many cyclists, these facilities can be particularly troublesome in intersections involving automobile traffic and are not necessarily safer. Intersections, in particular, are critical pinch points for cyclists and bicycle-minded engineering may be necessarily to increase navigational comfort.

Awareness

Among both males and females and wary and confident rider groups, a fear of traffic and of driver awareness of bicycles also emerged as a top barrier to bicycling in both case study communities. Depending upon the circumstance, high traffic volume roads may be addressed by applying traffic calming measures, such as advisory lanes or lane narrowing, by directing cyclists to ride on alternative roadways, or by installing separated bicycle facilities. Increased bicycle signage is another, relatively inexpensive way to increase drivers' awareness of bicyclists. In particular, NHDOT should consider designing and posting a "State Law" sign that reminds drivers they must maintain a 3 ft. minimum when passing bicyclists and pedestrians.

Such visibility can also increase the social acceptability of bicycling, particularly among the Willing but Wary populations. Some research suggests that differences in attitudes and preferences may be more important in explaining travel behaviour than differences in the built environment (Handy et al., 2006; Cao et al., 2006). Increased numbers of bicyclists on the roadway will not only increase driver awareness of bicyclist presence, but potentially normalize the activity and encourage participation among populations that are traditionally unengaged in active transportation.

Programs and Policies

Infrastructural prescriptions are most effective when coupled with programs and policies that educate, enforce, and encourage use of active transportation modes. To encourage competition among mode shares, NH planners and policymakers should consider implementing motor vehicle use disincentives, such as increased parking fees and gas taxes. Additionally, efforts to improve traffic education of both motorists and non-motorists, and the enforcement of traffic regulations protecting cyclists could be paired with new performance measures to decrease bicycle fatalities. Publicizing roadway improvements, bicycle-friendly routes, and bicycle safety information could be a powerful way to support new bike share facilities, such as Zagster in Manchester (Zagster, 2017). Furthermore, communities could support programs incentivizing active transportation participation and incorporate Complete Streets policies into all transportation and land use policy and project decisions. Ultimately, coordinated implementation of such diverse and mutually reinforcing policies and programs will best support active transportation environments and engagers.

Completing the Network

Network accessibility should be central to the conversation about transportation funding priorities. Network choke points should be evaluated using all available tools and feedback, as a single high-stress link in the network can be the definitive factor preventing an individual from engaging in active transportation. Targeted efforts will likely yield the greatest return on investment as not all links are created equal. Improvement efforts should focus on those segments serving (or potentially serving) the largest and most vulnerable populations. Nevertheless, opportunistic improvement opportunities should be seized. As NHDOT continues to repave and restripe roadways, road shoulder expansion should be evaluated and completed if cost is minimal.

Data

It is recommended that NHDOT include additional attributes in their state roadway database, such as bicycle lane presence/absence and bicycle lane width, to facilitate the use of the LTS model for planning. It is also recommended that NHDOT systematically record and update shoulder width data in their state roadway database. Such information would greatly improve the accuracy and efficiency of LTS model application throughout the state.

Final Considerations

Because the survey results did not reveal important distinctions between regional perceptions of barriers to bikeability, our recommendations may be applicable statewide. Such findings encourage promotion of NH-wide initiatives that support and streamline efforts to make active transportation safe and accessible for all users.

Additional Applications

The Level of Traffic Stress model’s inputs may be adjusted to serve additional active transportation populations, such as pedestrians. Nashua, NH has already piloted a pedestrian-specific LTS and generated a map of high-stress roadway segments for pedestrians. As with the bicycle-specific LTS, these results can help prioritize infrastructure improvements, be validated through public feedback processes and be used to identify interruptions in community accessibility.

The flexibility inherent in the accessibility analysis makes it ideal for scenario-specific adaptation. For example, given that origin-destination inputs and cost barriers are user-defined, Safe Routes to School advocates could run an analysis that limited origins and key destinations to schools and residential populations served, while applying the strictest available cost barriers. Furthermore, there is potential for origins and/or destinations to be ranked by priority, population, vulnerability, etc. Finally, this application could easily be expanded to address multiple forms of active transportation, such as walking.

Next Steps

The Level of Traffic Stress model may be validated or improved by integrating public feedback, facilitated through online mapping application that displays the current LTS model results. An interactive feedback platform would permit the public to either confirm or challenge the existing model, generating opportunities for expansion or simplification of the

LTS criteria matrix. Furthermore, such public outreach approaches would strengthen the public's sense of inclusion in the community planning process, potentially increasing resident satisfaction and civic engagement.

Efficacy of the accessibility tool will likewise be improved by an interactive public feedback process. As with LTS, a combination of printed map results and an online mapping application would permit valuable public feedback concerning important road segments and relevant key destinations. Given a diverse set of respondents, the key destinations, and thus, ranked list of priority segments, may change significantly. Furthermore, if implemented on a finer scale, the inclusion of all residential units into the model as origins could likewise substantially shift model outcomes. As a result, the most reliable applications of the accessibility model will likely be those applied by users with intimate knowledge of the target geographical region's needs.

Conclusion

Ultimately, adaptive management should prevail in the transportation planning sectors of NH. As pro-bicycle infrastructure and programming are implemented, stakeholder feedback and impact analyses should be continuous, or at the very least, intermittent. Actual behavior does not always reflect stated preferences or desired choices. Continued active transportation funding and prioritization is contingent upon the quantification of successes, while efficient allocation of resources requires rejection of ineffective strategies. These tools and recommendations provide a starting point for the NHDOT and community planners. Active implementation and validation of these approaches will yield the most valuable feedback to the state, and serve as a model for other states or communities--particularly those with similar land use challenges. NH has both the tools and the public will to improve active transportation throughout the state and set the national standard for bikeability. Upon implementation of the appropriate combination of strategies, New Hampshire will reap the social, financial, environmental, and public health improvement rewards.

Works Cited

Advocacy Advance. (2014). Lifting the Veil on Bicycle & Pedestrian Spending: An Analysis of Problems & Priorities in Transportation Planning and What to Do About It. http://www.advocacyadvance.org/docs/LiftingTheVeil_Report.pdf

Alliance for Biking and Walking. (2016). Bicycling and Walking in the United States 2016 Benchmarking Report. Retrieved from http://www.bikewalkalliance.org/storage/documents/reports/2016benchmarkingreport_web.pdf

American Association of State Highway and Transportation Officials (AASHTO). (2012). *Guide for the development of bicycle facilities* (4th ed.).

Antonakos, C. L. (1993). *Environmental and travel preferences of cyclists* (Doctoral dissertation).

Aultman-Hall, L., Roorda, M., & Baetz, B. W. (1997). Using GIS for evaluation of neighborhood pedestrian accessibility. *Journal of Urban Planning and Development, 123*(1), 10-17.

Belknap County Economic Development Council. (2012, January). Economic Impact Analysis of the WOW Trail. Retrieved from http://www.bing.com/cr?IG=A551375EC04B46C991BBFC649D083964&CID=23C6474B0121604D3E8F4DF200276136&rd=1&h=W0QfqML3QMIiE1OUKDIhCU6-8lOLHM5XHf6u3sG6-BI&v=1&r=http%3a%2f%2fwww.wowtrail.org%2fwp-content%2fuploads%2fsites%2f10%2f2013%2f03%2ffinal-wow-trail-impact-study.pdf&p=DevEx,5060.1

Berrigan, D., Pickle, L. W., & Dill, J. (2010). Associations between street connectivity and active transportation. *International journal of health geographics*, *9*(1), 20.

Boarnet, M., & Crane, R. (2001). The influence of land use on travel behavior: specification and estimation strategies. *Transportation Research Part A: Policy and Practice, 35*(9), 823-845.

Brabham, D. C. (2009). Crowdsourcing the public participation process for planning projects. *Planning Theory*, *8*(3), 242-262.

Brown, G., & Kyttä, M. (2014). Key issues and research priorities for public participation GIS (PPGIS): A synthesis based on empirical research. *Applied Geography*, *46*, 122-136.

Brown, G., Kelly, M., & Whitall, D. (2014). Which ‘public'? Sampling effects in public participation GIS (PPGIS) and volunteered geographic information (VGI) systems for public lands management. *Journal of Environmental Planning and Management*, *57*(2), 190-214.

Buehler, R., & Pucher, J. (2012). Cycling to work in 90 large American cities: new evidence on the role of bike paths and lanes. *Transportation*, *39*(2), 409-432.

Bureau of Transportation Statistics. (2002) Omnibus Survey - Household Survey. http://www.bts.gov/omnibus/household/2002/. Data analysis performed by Jennifer Dill and Theresa Carr.

Cao, X., Mokhtarian, P. L., & Handy, S. L. (2006). Impacts of the Built Environment and Residential Self-Selection on Nonwork Travel: Seemingly Unrelated Regression Approach. In *Transportation Research Board 85th Annual Meeting* (No. 06-1595).
Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: density, diversity, and design. *Transportation Research Part D: Transport and Environment*, *2*(3), 199-219.

Cervero, R., & Radisch, C. (1996). Travel choices in pedestrian versus automobile oriented neighborhoods. *Transport Policy*, *3*(3), 127-141.

City of Manchester. (2014). 2014 Manchester Neighborhood Health Improvement Strategy. Retrieved from http://www.manchesternh.gov/health/NeighborhoodHealthImprovementStrategy.pdf

Clifton, K., Muhs, C., Morrissey, S., Morrissey, T., Currans, K., & Ritter, C. (2013). Examining Consumer Behavior and Travel Choices. *Oregon Transportation Research and Education Consortium, OTREC-RR-12-15*. Retrieved from http://ppms.otrec.us/media/project_ files/OTREC-RR-12-15%20Final.pdf.

Daly, A. J. (1997). Improved methods for trip generation. In *Transportation planning methods Volume 11. Proceedings of seminar F held at PTRC European Transport Forum, Brunel University, England, 1-5 September 1997. Volume P415*.

Davies, P. W. K., & Townshend, P. I. J. (2015). New Urbanisms: From Neo-Traditional Neighbourhoods to New Regionalism. In *Theme Cities: Solutions for Urban Problems* (pp. 17-61). Springer Netherlands.

Davis, W. J. (1987). *Bicycle safety evaluation* (Doctoral dissertation, Auburn University).

de Bruijn, G. J., Kremers, S. P., Singh, A., Van den Putte, B., & Van Mechelen, W. (2009). Adult active transportation: adding habit strength to the theory of planned behavior. *American journal of preventive medicine*, *36*(3), 189-194.

Dill, J. (2004, January). Measuring network connectivity for bicycling and walking. In *83rd Annual Meeting of the Transportation Research Board, Washington, DC* (pp. 11-15).

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

Dill, J., & Carr, T. (2003). Bicycle commuting and facilities in major US cities: if you build them, commuters will use them. *Transportation Research Record: Journal of the Transportation Research Board*, (1828), 116-123.

Dill, J., & Gliebe, J. (2008). Understanding and Measuring Bicycling Behavior: A Focus on Travel Time and Route Choice. *Oregon Transportation Research and Education Consortium, OTREC-RR-08-03*.

Dill, J., & McNeil, N. (2013). Four types of cyclists? Examination of typology for better understanding of bicycling behavior and potential. *Transportation Research Record: Journal of the Transportation Research Board*, (2387), 129-138.

Emond, C., Tang, W., & Handy, S. (2009). Explaining gender difference in bicycling behavior. *Transportation Research Record: Journal of the Transportation Research Board*, (2125), 16-25.
Ewing, R., & Cervero, R. (2010). Travel and the built environment: a meta-analysis. *Journal of the American planning association*, *76*(3), 265-294.

Frumkin, H., Frank, L., & Jackson, R. (2004). Urban Sprawl and Public Health: Designing. *Planning, and Building for Healthy Communities*.

Garrard, J., Rose, G., & Lo, S. K. (2008). Promoting transportation cycling for women: the role of bicycle infrastructure. *Preventive medicine*, *46*(1), 55-59.

Garrett-Peltier, H. (2011). Pedestrian and bicycle infrastructure: A national study of employment impacts. *Amherst, MA: Political Economy Research Institute*. Retrieved from http:// www.peri.umass.edu/fileadmin/pdf/published_study/PERI_ABikes_ October2011.pdf.

Geller, R. (2009). *Four types of cyclists*. PortlandOnline. Retrieved from http://www.portlandonline.com/transportation/ index.cfm?&a=237507&c=44597.

Gloeckner, H., Mkanga, M., & Ndezi, T. (2004). Local empowerment through community mapping for water and sanitation in Dar es Salaam. *Environment and Urbanization, 16*(1), 185-198.

Goetzke, F., & Rave, T. (2011). Bicycle use in Germany: explaining differences between municipalities with social network effects. *Urban studies, 48*(2), 427-437.

Goodchild, M. F. (2008). Commentary: whither VGI?. *GeoJournal*, *72*(3-4), 239-244.

Gotschi, T. & Mills, K. (2008). Active Transportation for America: The Case for Increased Federal Investment in Bicycling and Walking. *Rails-to-Trails Conservancy*. http://www.railstotrails.org/resourcelibrary/resources/active-transportation-for-america/.

Green Lane Project. (n.d.). Inventory of Protected Bike Lanes. http://www.peopleforbikes.org/green-lane-project/pages/inventory-of-protected-bike-lanes

Greenwald, M., & Boarnet, M. (2001). Built environment as determinant of walking behavior: Analyzing nonwork pedestrian travel in Portland, Oregon. *Transportation Research Record: Journal of the Transportation Research Board*, (1780), 33-41.

Handy, S. (1996). Urban form and pedestrian choices: study of Austin neighborhoods. *Transportation Research Record: Journal of the Transportation Research Board*, (1552), 135-144.

Handy, S. (2005). Critical assessment of the literature on the relationships among transportation, land use, and physical activity. *Transportation Research Board and the Institute of Medicine Committee on Physical Activity, Health, Transportation, and Land Use. Resource paper for TRB Special Report*, *282*.

Handy, S. (1993). Regional versus local accessibility: Implications for nonwork travel. *University of California Transportation Center*.

Handy, S., Cao, X., & Mokhtarian, P. L. (2006). Self-selection in the relationship between the built environment and walking: Empirical evidence from Northern California. *Journal of the American Planning Association*, *72*(1), 55-74.

Handy, S. L., & Clifton, K. J. (2001). Evaluating neighborhood accessibility: Possibilities and practicalities. *Journal of transportation and statistics*, *4*(2/3), 67-78.

Hansen, W. G. (1959). How accessibility shapes land use. *Journal of the American Institute of planners*, *25*(2), 73-76.

Hanson, S., & Schwab, M. (1987). Accessibility and intraurban travel. *Environment and Planning A*, *19*(6), 735-748.

Harkey, D., Reinfurt, D., & Knuiman, M. (1998). Development of the bicycle compatibility index. *Transportation Research Record: Journal of the Transportation Research Board*, (1636), 13-20.

Healthy Eating Active Living (HEAL) NH. (2016, January). HEAL NH ACTIVE TRANSPORTATION PROGRAM CASE STUDIES. Retrieved from http://www.healnh.org/images/pdffiles/ActiveTransportation/HEAL_AT_Case_Study_Jan_2016.pdf

Heath, G. W., Brownson, R. C., Kruger, J., Miles, R., Powell, K. E., & Ramsey, L. T. (2006). The effectiveness of urban design and land use and transport policies and practices to increase physical activity: a systematic review. *Journal of Physical Activity and Health*, *3*(s1), S55-S76.

Hess, P. M. (1997). Measures of connectivity [Streets: Old paradigm, new investment]. *Places*, *11*(2).

Howard, C., & Burns, E. (2001). Cycling to work in Phoenix: route choice, travel behavior, and commuter characteristics. *Transportation Research Record: Journal of the Transportation Research Board*, (1773), 39-46.

Howe, J. (2006). The rise of crowdsourcing. *Wired magazine*, *14*(6), 1-4.

Hunt, J. D., & Abraham, J. E. (2007). Influences on bicycle use. *Transportation*, *34*(4), 453-470.

Iacono, M., K. J. Krizek, and A. El-Geneidy. (2007). Incorporating distance decay functions into measures of accessibility. *Final Report. Active Communities/Transportation (ACT) Research Group*, University of Minnesota, Minneapolis, MN.

Iacono, M., Krizek, K. J., & El-Geneidy, A. (2010). Measuring non-motorized accessibility: issues, alternatives, and execution. *Journal of Transport Geography*, *18*(1), 133-140.

Jacobsen, P. L. (2003). Safety in numbers: more walkers and bicyclists, safer walking and bicycling. *Injury prevention*, *9*(3), 205-209.

Kessler, F. (2011). Volunteered geographic information: A bicycling enthusiast perspective. *Cartography and Geographic Information Science*, *38*(3), 258-268. http://www.tandfonline.com/doi/pdf/10.1559/15230406382258

Krizek, K. J., Johnson, P. J., & Tilahun, N. (2005). Gender differences in bicycling behavior and facility preferences. *Research on Women's Issues in Transportation*, *2*, 31-40.

Krizek, K., Forsyth, A., & Baum, L. (2009). Walking and cycling international literature review. *Victoria Department of Transport, Melbourne, Australia*.

Krygsman, S., Dijst, M., & Arentze, T. (2004). Multimodal public transport: an analysis of travel time elements and the interconnectivity ratio. *Transport Policy*, *11*(3), 265-275.

Ramirez, L. K. B., Hoehner, C. M., Brownson, R. C., Cook, R., Orleans, C. T., Hollander, M., ... & Petersmarck, K. (2006). Indicators of activity-friendly communities: an evidence-based consensus process. *American journal of preventive medicine*, *31*(6), 515-524.

Landis, B., Vattikuti, V., & Brannick, M. (1997). Real-time human perceptions: toward a bicycle level of service. *Transportation Research Record: Journal of the Transportation Research Board*, (1578), 119-126.

Lankford, J., Lankford, S., Grybovych, O., Bowles, B., Fleming, K., Fuller, K., & Printz, J. (2011). Economic and health benefits of bicycling in Iowa. *Prepared for the Iowa Bicycle Coalition. Sustainable Tourism and Environmental Program, University of Northern Iowa, Cedar Falls, Iowa. Available: http://www. uni. edu/step/reports/economic_health_benefits_of_bicycling. pdf [15 June 2014]*.

Lee, V., Mikkelsen, L., Srikantharajah, J. & Cohen, L. (2008). Strategies for Enhancing the Built Environment to Support Healthy Eating and Active Living. *Prevention Institute*.

Legrain, A., Eluru, N., & El-Geneidy, A. M. (2015). Am stressed, must travel: the relationship between mode choice and commuting stress. *Transportation research part F: traffic psychology and behaviour, 34*, 141-151.

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.
Lowry, M., Callister, D., Gresham, M., & Moore, B. (2012). Assessment of communitywide bikeability with bicycle level of service. *Transportation Research Record: Journal of the Transportation Research Board*, (2314), 41-48.

Marshall, S. (2004). *Streets and patterns*. Routledge.

Mately, M., Goldman, L. M. and Fineman, B. J. (2001) Pedestrian Travel Potential in Northern New Jersey. Transportation Research Record, 1705, 1-8.

McDaniel, S., Lowry, M., & Dixon, M. (2014). Using origin-destination centrality to estimate directional bicycle volumes. *Transportation Research Record: Journal of the Transportation Research Board*, (2430), 12-19.

McNeil, N. (2011). Bikeability and the 20-min neighborhood: How infrastructure and destinations influence bicycle accessibility. *Transportation Research Record: Journal of the Transportation Research Board*, (2247), 53-63.

Mekuria, M. C. (2014). Bicycle Connectivity and Safety Model. In *Transportation Research Board 93rd Annual Meeting* (No. 14-0971).

Mekuria, M. C., Furth, P. G., & Nixon, H. (2012). Low-stress bicycling and network connectivity. *Mineta Transportation Institute*, Report No. 11-19. NACTO, National Association of City Transportation Officials, 2014. Urban Bikeway Design Guide. Island Press.

Mendoza, J. A., & Liu, Y. (2014). Active commuting to elementary school and adiposity: an observational study. *Childhood Obesity*, *10*(1), 34-41.

Moritz, W. (1998). Adult bicyclists in the United States: characteristics and riding experience in 1996. *Transportation Research Record: Journal of the Transportation Research Board*, (1636), 1-7.

Murakami, E., & Young, J. (1997). *Daily travel by persons with low income*. Washington, DC: US Federal Highway Administration.

Nashua Regional Planning Commission (NRPC). (2011). New Hampshire Sustainable Communities Initiative. Retrieved May 04, 2017, from https://www.scribd.com/document/106642535/New-Hampshire-Sustainable-Communities-Initiative

National Association of City Transportation Officials. (n.d.). Conventional Bike Lanes. https://nacto.org/publication/urban-bikeway-design-guide/bike-lanes/conventional-bike-lanes/

Nelson, A., & Allen, D. (1997). If you build them, commuters will use them: association between bicycle facilities and bicycle commuting. *Transportation Research Record: Journal of the Transportation Research Board*, (1578), 79-83.

New Hampshire Department of Transportation (NHDOT). (2010). NH Long Range Transportation Plan 2010 – 2030. Retrieved from https://www.nh.gov/dot/org/projectdevelopment/planning/documents/CompleteLRTP083110.pdf

New Hampshire Department of Health and Human Services. (n.d.). Social Vulnerability Index: An Emergency Response Tool. Retrieved March 30, 2017, from https://www.nh.gov/epht/highlights/documents/social-vulnerability-index.pdf

"New Hampshire Receives $3.4 Million Federal Sustainable Communities Grant - Heal NH." Healthy Eating Active Living NH, 2011. <http://www.healnh.org/index.php/newsroom/news/191-new-hampshire-receives-34-million-federal-sustainable-communities-grant>.

Norton, S., Delay, D., & Stoff, T. (2015, September). What is New Hampshire?. *New Hampshire Center for Public Policy Studies*. Retrieved from http://www.nhpolicy.org/UploadedFiles/Reports/What_is_NH_2015.pdf.

Page, M., 2005. Non-motorized transportation policy. In: Button, K.J., Hensher, D.A. (Eds.), Handbook of Transport Strategy, Policy and Institutions Amsterdam. Elsevier, The Netherlands, pp. 581–596.

Pánek, J., & Benediktsson, K. (2017). Emotional mapping and its participatory potential: Opinions about cycling conditions in Reykjavík, Iceland. *Cities*, *61*, 65-73.

Pánek, J., & Vlok, C. (2013). Participatory mapping as a tool for community empowerment–a case study of community engagement in Koffiekraal, South Africa. In *26th International cartographic conference* (p. 26). Dresden.

Pollard, T. (2003). Policy prescriptions for healthier communities. *American Journal of Health Promotion*, *18*(1), 109-113.

Porter, C., Suhrbier, J., & Schwartz, W. (1999). Forecasting bicycle and pedestrian travel: State of the practice and research needs. *Transportation Research Record: Journal of the Transportation Research Board*, (1674), 94-101.

Prevention Institute. (2008). Strategies for Enhancing the Built Environment to Support Healthy Eating and Active Living. *Healthy Eating Active Living Convergence Partnership: Oakland, CA*. 1-24. Retrieved from http:// www.parventioninstitute.org. Accessed July 22, 2009.

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

Pucher, J., Dill, J., & Handy, S. (2010). Infrastructure, programs, and policies to increase bicycling: an international review. *Preventive medicine*, *50*, S106-S125.

Ramirez, L. K. B., Hoehner, C. M., Brownson, R. C., Cook, R., Orleans, C. T., Hollander, M., ... & Petersmarck, K. (2006). Indicators of activity-friendly communities: an evidence-based consensus process. *American journal of preventive medicine*, *31*(6), 515-524.

Randall, T. A., & Baetz, B. W. (2001). Evaluating pedestrian connectivity for suburban sustainability. *Journal of Urban Planning and Development*, *127*(1), 1-15.

Regional Planning Commissions & New Hampshire Department of Environmental Services. (2006). Key Destinations. Retrieved January 4, 2017, from http://www.granit.unh.edu/data/datacat/pages/keydestinations.pdf

Reilly, M., & Landis, J. (2003). The influence of built-form and land use on mode choice. *University of California Transportation Center*.
Robert Wood Johnson Foundation, "The Synthesis Project. The Built Environment and Physical Activity: What is the Relationship?" (April 2007). retrieved from http://www.rwjf.org/pr/synthesis/reports_and_briefs/pdf/no11_policybrief.pdf.

Robinson, D. L. (2005). Safety in numbers in Australia: more walkers and bicyclists, safer walking and bicycling. *Health promotion journal of Australia*, *16*(1), 47-51.

Rogers, S. H., Gardner, K. H., & Carlson, C. H. (2013). Social capital and walkability as social aspects of sustainability. *Sustainability*, *5*(8), 3473-3483.

Rose, G., & Marfurt, H. (2007). Travel behaviour change impacts of a major ride to work day event. *Transportation Research Part A: Policy and Practice*, *41*(4), 351-364.

Schlossberg, M., & Brehm, C. (2009). Participatory geographic information systems and active transportation: collecting data and creating change. *Transportation Research Record: Journal of the Transportation Research Board*, (2105), 83-91.

Schroeder, P., & Wilbur, M. (2013). *2012 National Survey of Bicyclist and Pedestrian Attitudes and Behavior. Volume 1: Summary Report* (No. DOT HS 811 841 A).

Sieber, R. (2006). Public participation geographic information systems: a literature review and framework. Annals of the Association of American Geographers, 96(3), 491e507.

Smart Growth America. (2003). What is smart growth? Retrieved May 06, 2017, from https://smartgrowthamerica.org/our-vision/what-is-smart-growth/

Smart Growth America. (2005). What are Complete Streets? https://smartgrowthamerica.org/program/national-complete-streets-coalition/what-are-complete-streets/

Smart Growth America. (2015, March). "Safer Streets, Stronger Economies: Complete Streets project outcomes from around the country." http://www.smartgrowthamerica.org/documents/saferstreets-stronger-economies.pdf.

Sonenklar, D., & Hadden-Loh, T. (2013). Active Transportation Beyond Urban Centers. In *Transportation Research Board 92nd Annual Meeting* (No. 13-2951).

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

Sui, D., Elwood, S., & Goodchild, M. (Eds.). (2013). Crowdsourcing geographic knowledge. Springer.

The League of American Bicyclists. (2015). Bicycle Friendly State Report Card: New Hampshire. Retrieved from http://bikeleague.org/sites/default/files/BFS2015_NewHampshire.pdf

Tilahun, N. Y., Levinson, D. M., & Krizek, K. J. (2007). Trails, lanes, or traffic: Valuing bicycle facilities with an adaptive stated preference survey. *Transportation Research Part A: Policy and Practice*, *41*(4), 287-301.

Transport NH. (2015). Executive Summary. Retrieved from

Transportation Research Board (TRB). (2011b). 2010 highway capacity manual, Transportation Research Board, Washington, DC.

Turner, S., Shafer, C. S., & Stewart, W. P. (1997). *Bicycle suitability criteria: literature review and state-of-the-practice survey* (No. TX-97/3988-1,). Texas Transportation Institute, Texas A & M University System.

Twaddell, H., Martin, L., Dill, J., McNeil, N., Petritsch, T., McLeod, P., Dickman, D. & Gilpin, J. (2016). *Strategic Agenda for Pedestrian and Bicycle Transportation* (No. FHWA-HEP-16-086). U.S. Department of Transportation. September 2016 https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/strategic_agenda/fhwahep16086.pdf

U.S. Department of Transportation. (2013). TRANSPORTATION FOR A NEW GENERATION. Retrieved from https://www.transportation.gov/sites/dot.gov/files/docs/2014-2018-strategic-plan_0.pdf

United State Census Bureau. (n.d.). Census Blocks and Block Groups. Retrieved from https://www2.census.gov/geo/pdfs/reference/GARM/Ch11GARM.pdf

United States Census Bureau (2016). ACS Demographic and Housing Estimates, *2011-2015 American Community Survey 5-year estimates*. Retrieved from https://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t#.

United States Census Bureau (2016). Annual Estimates of the Resident Population, *2016 Population Estimates*. Retrieved from https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=PEP_2016_PEPANNRES&prodType=table

United States Census Bureau (2016). Educational Attainment, *2011-2015 American Community Survey 5-year estimates*. Retrieved from https://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t#.

United States Census Bureau (2016). Total Population, *2011-2015 American Community Survey 5-year estimates*. Retrieved from https://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t#.

United States Census Bureau / American FactFinder (2016). Commuting Characteristics, *2005 – 2015 American Community Survey*. U.S. Census Bureau's American Community Survey Office, 2015. <http://factfinder2.census.gov>.

United States Census Bureau/ American FactFinder (2016). Tenure by Vehicles Available, *2011-2015 American Community Survey 5-year estimates*. Retrieved from https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_15_5YR_B25044&prodType=table.
Ohls, J. C., Ponza, M., Moreno, L., Zambrowski, A., & Cohen, R. (1999). Food stamp participants' access to food retailers. *USDA Final Report. MPR*, (8243-140), 64.

Velo'v. (2009). Velo'v information website. Accessible at: http://www.velov.grandlyon.com/Archives-Velo-V.63.0.html.

Vision Zero Network. (n.d.). What is Vision Zero? Retrieved from http://visionzeronetwork.org/about/what-is-vision-zero/

Walk Score. (2014a). Bike Score Methodology. *Walk Score*. <https://www.walkscore.com/bike-score-methodology.shtml>.

Walk Score. (2014b). About Walk Score. *Walk Score*. <https://www.walkscore.com/about.shtml>.

Wang, X., Lindsey, G., Schoner, J. E., & Harrison, A. (2015). Modeling bike share station activity: effects of nearby businesses and jobs on trips to and from stations. *Journal of Urban Planning and Development*, *142*(1), 04015001.

Wendel- Vos, W. M. S. J. F., Droomers, M., Kremers, S., Brug, J., & Van Lenthe, F. (2007). Potential environmental determinants of physical activity in adults: a systematic review. *Obesity reviews*, *8*(5), 425-440.

Williams, C. (2007). The built environment and physical activity: What is the relationship? The Synthesis Project. *Robert Wood Johnson Foundation*. http://www.rwjf.org/content/dam/farm/reports/issue_briefs/2007/rwjf17960/subassets/rwjf17960_1

Winters, M., Teschke, K., Grant, M., Setton, E., & 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: Journal of the Transportation Research Board*, (2190), 1-10.

Xing, Y., Handy, S. L., & Mokhtarian, P. L. (2010). Factors associated with proportions and miles of bicycling for transportation and recreation in six small US cities. *Transportation research part D: Transport and Environment*, *15*(2), 73-81.

Zagster. (2017). Bike Share for The City of Manchester, NH. Retrieved from http://bike.zagster.com/manchester/

Appendices

A. Manchester and Lakes Region American Community Survey estimates compared to bikeability survey results.

	Population	Median Age	% Male/Female	% White	% Hispanic or Latino	% All Other Races
State of NH (ACS Survey)	1,316,470	42	49/51	94	3	3
All Respondents (Bikeability Survey)	529	52	51/48	96	2	2
Manchester (ACS Survey)	110,139	37	50/50	86	9	5
Manchester (Bikeability Survey)	88	48	58/42	88	5	7
Lakes Region (ACS Survey)	113,451	47	49/51	97	1	2
Lakes Region (Bikeability Survey)	121	52	47/53	98	1	1

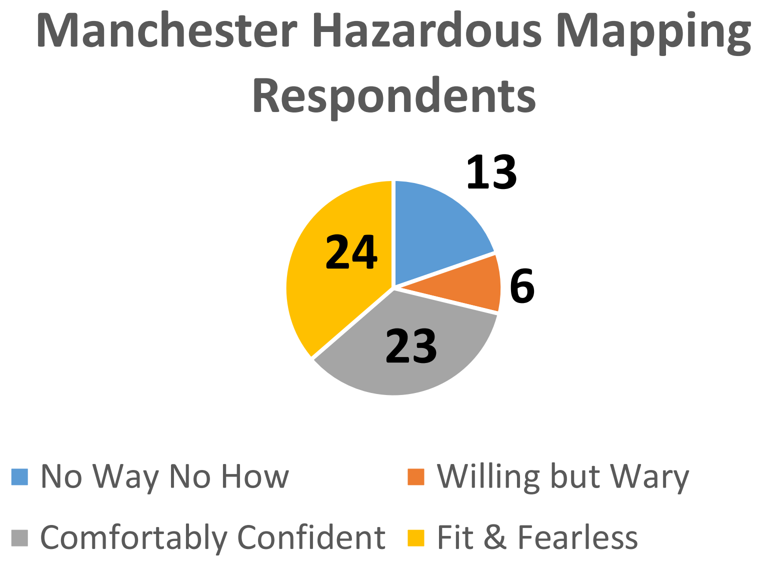
	% No Diploma	% High School Graduate	% Some college credit, trade/technical/vocational training/Associate degree	% Bachelor's Degree	% Graduate or professional degree
State of NH (ACS Survey)	7	29	29	22	13
All Respondents (Bikeability Survey)	1	9	21	31	38
Manchester (ACS Survey)	12	32	28	19	9
Manchester (Bikeability Survey)	2	14	24	31	30
Lakes Region (ACS Survey)	7	32	30	20	11
Lakes Region (Bikeability Survey)	1	14	21	26	38

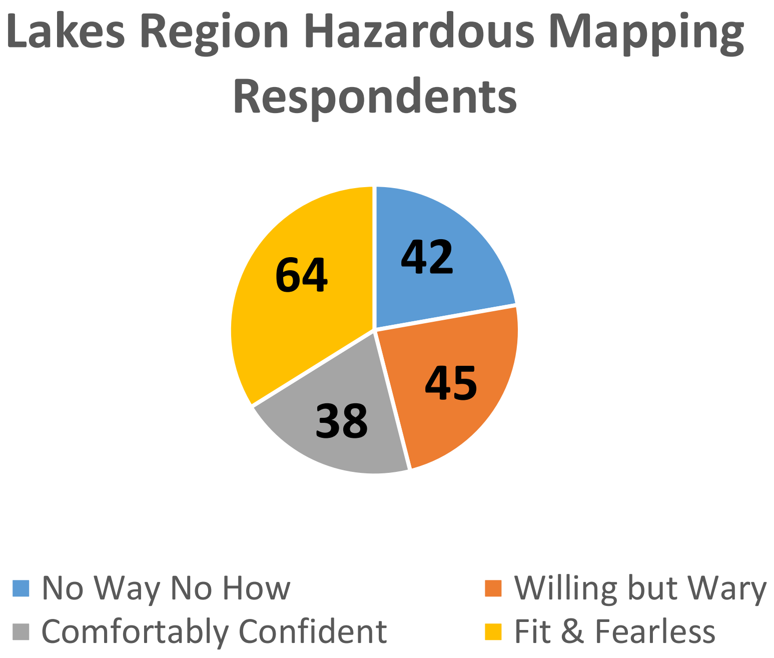
	% Income <$25,000	% Income $25,000 to $34,999	% Income $35,000 to $49,999	% Income $50,000 to $74,999	% Income $75,000 to $99,999	% Income $100,000 to $149,999	% Income >= $150,000	Mean/ Median Income
State of NH (ACS Survey)	17	8	12	19	14	17	13	$85,727/ $66,779
All Respondents (Bikeability Survey)	15	7	14	19	16	20	10	X
Manchester (ACS Survey)	22	10	13	21	13	14	7	$67,009/$54,282
Manchester (Bikeability Survey)	26	7	8	13	8	27	11	X
Lakes Region (ACS Survey)	18	11	14	20	15	14	8	$73,580/$66,823
Lakes Region (Bikeability Survey)	14	10	20	18	17	16	5	X

	% Commute to Work by Car, Truck, or Van - Drove Alone (All)	% Commute to Work by Bicycle (All)	% Commute to Work by Walking (All)	% Commute to Work by Public Transport (All)	% No Vehicle Available 16 yrs. and over	Mean Travel Time to Work (min.)
State of NH (ACS Survey)	81	0.2	2.9	0.8	1.8	27
All Respondents (Bikeability Survey)	X	12	X	X	X	X
Manchester (ACS Survey)	80	0.2	3	1.3	3.2	23
Manchester (Bikeability Survey)	X	9	X	X	X	X

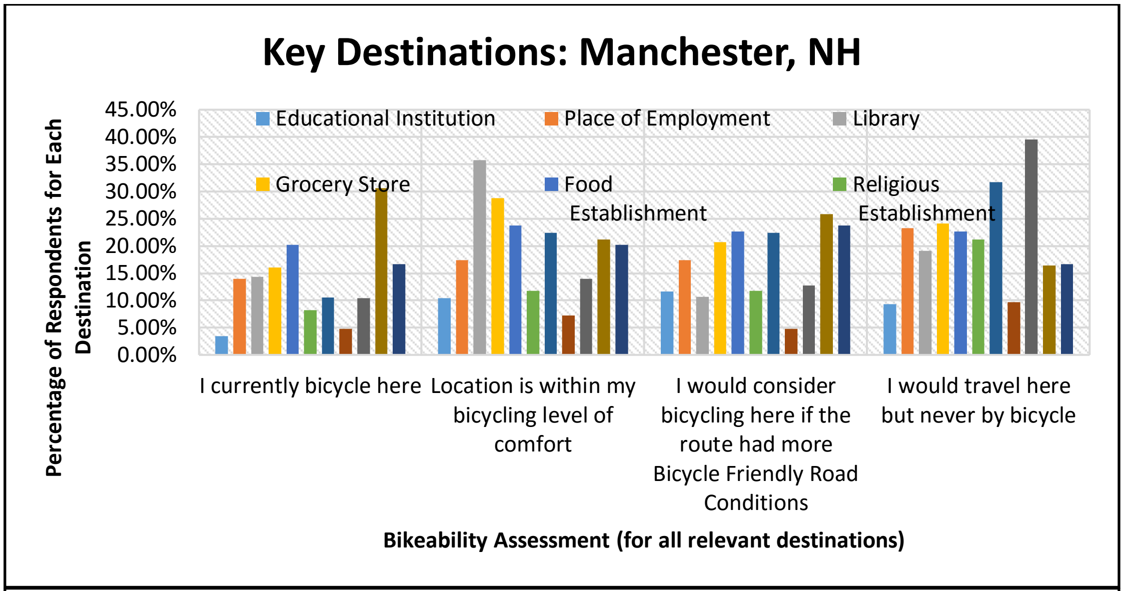
Lakes Region (ACS Survey)	82	0.2	1.9	0.3	1.2	30
Lakes Region (Bikeability Survey)	X	8	X	X	X	X

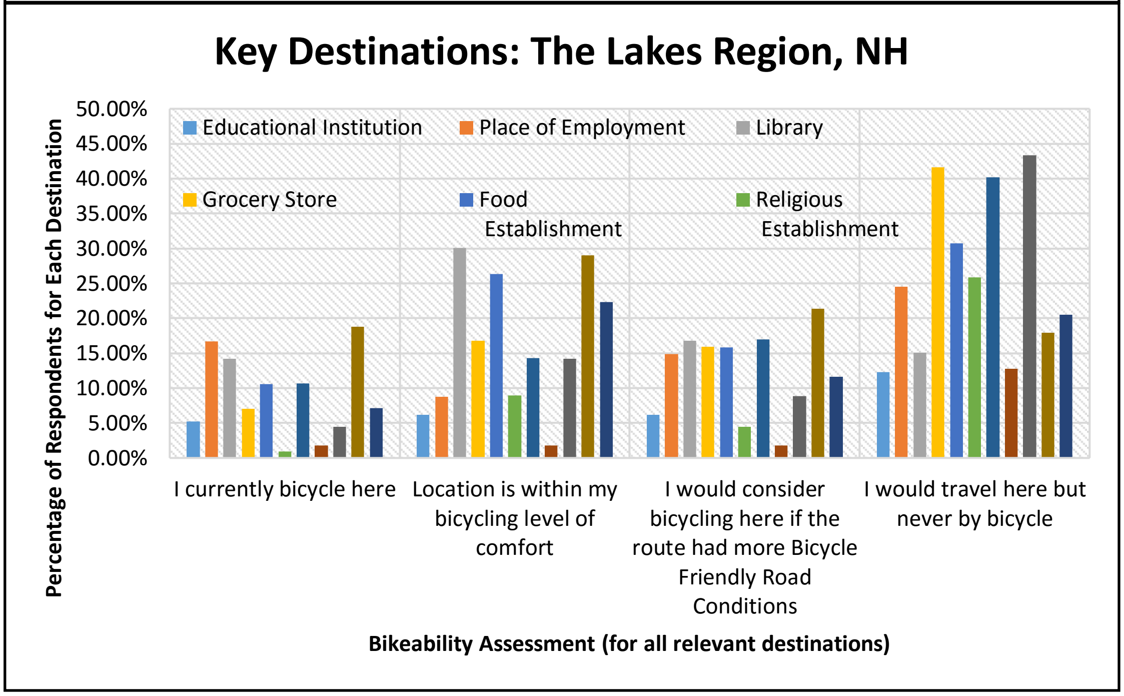
B. Manchester and Lakes Region Hazardous Mapping Respondents by Attitude towards bicycling.





C. Summary of Manchester and Lakes Region resident survey respondents’ willingness to bicycle to a variety of key destinations.





D. Mean score ranking of barriers to bicycling by region and gender.

Barrier Rank	Manchester Females	Manchester Males	Lakes Region Females	Lakes Region Males
1	Fear of traffic (84.21)	The road shoulder is too narrow (76.93)	The road shoulder is too narrow (87.76)	The road shoulder is too narrow (80.95)
2	The road shoulder is too narrow (82.8)	Fear of driver awareness of bicycles (73.13)	Fear of traffic (85.84)	Fear of driver awareness of bicycles (74.33)
3	Fear of driver awareness of bicycles (82.57)	Inclement weather (69.66)	Fear of driver awareness of bicycles (84.84)	Fear of traffic (70.13)
4	Inclement weather (74.24)	Fear of traffic (64.88)	Inclement weather (78.37)	Inclement weather (69.52)
5	Lack of bicycle lanes separated from traffic by barriers (e.g. curb) (72.12)	Lack of striped bicycle lanes (63.20)	Lack of striped bicycle lanes (78.36)	Lack of striped bicycle lanes (61.75)
6	Lack of striped bicycle lanes (71.47)	Lack of bicycle-friendly facilities at destination (bike racks, shower, etc.) (62.38)	Lack of dedicated bicycle paths at least 20 ft. from vehicle traffic (74.16)	Road surface condition is poor (58.41)
7	Road surface condition is poor (69.32)	Lack of bicycle lanes separated from traffic by barriers (e.g. curb) (56.26)	Lack of bicycle lanes separated from traffic by barriers (e.g. curb) (69.39)	Lack of bicycle lanes separated from traffic by barriers (e.g. curb) (52.77)
8	Lack of dedicated bicycle paths at least 20 ft. from vehicle traffic (68.18)	Fear of bicycle theft (56.18)	Road surface condition is poor (67.95)	Lack of dedicated bicycle paths at least 20 ft. from vehicle traffic (50.98)
9	Lack of bicycle-friendly facilities at destination (bike racks, shower, etc.) (64.32)	Road surface condition is poor (53.98)	Lack of bicycle-friendly facilities at destination (bike racks, shower, etc.) (66.22)	Lack of bicycle-friendly facilities at destination (bike racks, shower, etc.) (40.02)
10	Terrain (62.71)	Lack of dedicated bicycle paths at least 20 ft. from vehicle traffic (51.56)	Terrain (63.20)	Terrain (39.6)
11	Time to destination (50.96)	Time to destination (48.19)	Time to destination (47.56)	Fear of bicycle theft (28.57)
12	Fear of bicycle theft (50.72)	Equipment is too expensive (36.95)	Fear of bicycle theft (33.59)	Lack of personal education about rider safety (e.g. signaling) (25.98)
13	Equipment is too expensive (43.10)	Terrain (36.11)	Health (30.81)	Health (25.42)
14	Lack of personal education about rider safety (e.g. signaling) (34.83)	Health (27.38)	Lack of personal education about rider safety (e.g. signaling) (29.63)	Time to destination (24.28)

15	Health (33.78)	Lack of personal education about rider safety (e.g. signaling) (24.49)	Equipment is too expensive (29.35)	Equipment is too expensive (20.24)
16	Maintenance is too complicated (28.75)	Maintenance is too complicated (23.82)	Maintenance is too complicated (26.20)	Maintenance is too complicated (12.17)

E. Mean score ranking of barriers to bicycling by region and attitude towards bicycling.

Barrier Rank	Manchester Wary	Manchester Confident	Lakes Region Wary	Lakes Region Confident
1	Fear of driver awareness of bicycles (93.90)	The road shoulder is too narrow (81.02)	The road shoulder is too narrow (91.98)	The road shoulder is too narrow (79.41)
2	Inclement weather (84.80)	Fear of driver awareness of bicycles (72.25)	Fear of traffic (89.46)	Fear of driver awareness of bicycles (74.60)
3	Terrain (83.80)	Inclement weather (69.37)	Fear of driver awareness of bicycles (86.13)	Inclement weather (73.68)
4	Fear of traffic (83.20)	Fear of traffic (67.81)	Lack of striped bicycle lanes (81.70)	Fear of traffic (68.30)
5	The road shoulder is too narrow (80.40)	Lack of striped bicycle lanes (65.73)	Inclement weather (80.02)	Lack of striped bicycle lanes (64.80)
6	Lack of dedicated bicycle paths at least 20 ft. from vehicle traffic (73.30)	Lack of bicycle-friendly facilities at destination (bike racks, shower, etc.) (64.57)	Lack of dedicated bicycle paths at least 20 ft. from vehicle traffic (79.00)	Road surface condition is poor (63.48)
7	Lack of bicycle lanes separated from traffic by barriers (e.g. curb) (72.20)	Road surface condition is poor (59.82)	Lack of bicycle lanes separated from traffic by barriers (e.g. curb) (78.37)	Lack of dedicated bicycle paths at least 20 ft. from vehicle traffic (50.79)
8	Lack of striped bicycle lanes (70.10)	Lack of bicycle lanes separated from traffic by barriers (e.g. curb) (58.52)	Road surface condition is poor (67.44)	Lack of bicycle lanes separated from traffic by barriers (e.g. curb) (49.69)
9	Lack of bicycle-friendly facilities at destination (bike racks, shower, etc.) (66.90)	Fear of bicycle theft (55.96)	Terrain (64.66)	Lack of bicycle-friendly facilities at destination (bike racks, shower, etc.) (48.93)
10	Road surface condition is poor (63.60)	Time to destination (53.04)	Lack of bicycle-friendly facilities at destination (bike racks, shower, etc.) (61.44)	Terrain (41.95)

11	Equipment is too expensive (62.70)	Lack of dedicated bicycle paths at least 20 ft. from vehicle traffic (50.80)	Time to destination (43.87)	Fear of bicycle theft (28.96)
12	Fear of bicycle theft (54.70)	Terrain (33.69)	Fear of bicycle theft (34.02)	Time to destination (26.33)
13	Time to destination (51.20)	Equipment is too expensive (28.71)	Equipment is too expensive (33.55)	Lack of personal education about rider safety (e.g. signaling) (24.62)
14	Health (46.60)	Lack of personal education about rider safety (e.g. signaling) (24.24)	Lack of personal education about rider safety (e.g. signaling) (31.78)	Health (20.08)
15	Lack of personal education about rider safety (e.g. signaling) (43.30)	Health (23.02)	Health (29.78)	Equipment is too expensive (17.00)
16	Maintenance is too complicated (37.80)	Maintenance is too complicated (20.11)	Maintenance is too complicated (24.60)	Maintenance is too complicated (13.08)

F. Summary of significant and non-significant score means of barriers to bicycling between respondents self-identified as Willing but Wary bicyclists and those identified as Comfortably Confident or Fit and Fearless cyclists in the Lakes Region and Manchester. Willing but Wary respondents consistently scored significant barriers higher than both Comfortably Confident and Fit and Fearless respondents. Barriers were scored on a sliding scale of 0-100.

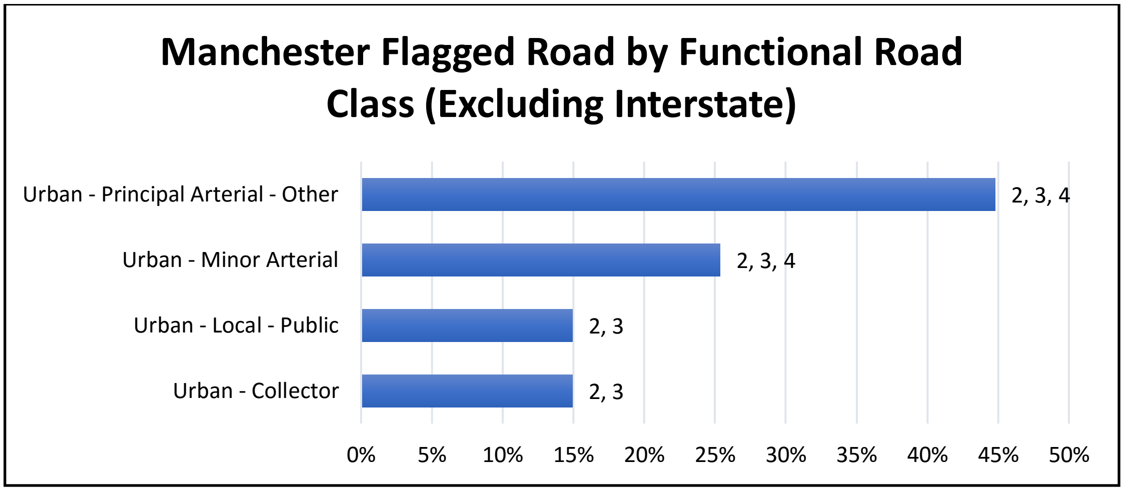
Comparing responses between Willing but Wary and Comfortably Confident or Fit and Fearless Respondents			
Lakes Region		**Manchester**	
Significant Difference	**No Significant Difference**	**Significant Difference**	**No Significant Difference**
◦ Terrain ◦ Fear of driver awareness of bicycles ◦ Fear of traffic ◦ The road shoulder is too narrow ◦ Lack of striped bicycle lanes ◦ Lack of bicycle lanes separated from traffic by barriers ◦ Lack of bicycle paths at least 20 ft. from vehicle traffic	◦ Time to destination ◦ Lack of bicycle-friendly facilities at destination ◦ Road surface condition is poor ◦ Maintenance is too complicated ◦ Inclement weather ◦ Lack of education about rider safety ◦ Equipment is too expensive ◦ Health ◦ Fear of bicycle theft	◦ Terrain ◦ Fear of driver awareness of bicycles ◦ Equipment is too expensive ◦ Inclement weather	◦ Lack of education about rider safety ◦ Time to destination ◦ Lack of bicycle-friendly facilities at destination ◦ Road surface condition is poor ◦ Maintenance is too complicated ◦ The road shoulder is too narrow ◦ Lack of striped bicycle lanes ◦ Lack of bicycle lanes separated from traffic by barriers ◦ Lack of bicycle paths at least 20 ft. from vehicle traffic

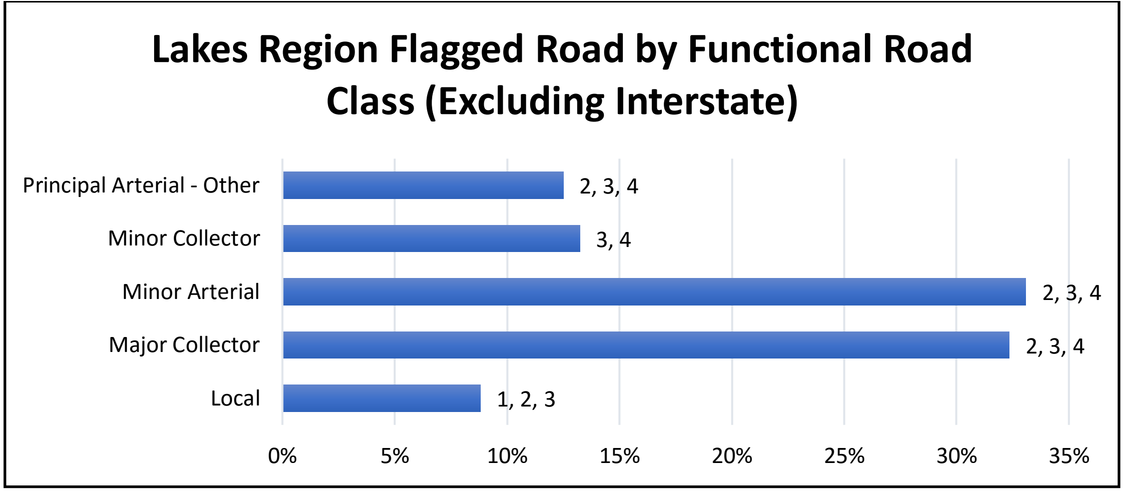
			◦ Health ◦ Fear of bicycle theft ◦ Fear of traffic

G. Summary of significant and non-significant score means of barriers to bicycling between genders in the Lakes Region and Manchester. Female mean scores were higher than male mean scores for all variables (see Appendix D).

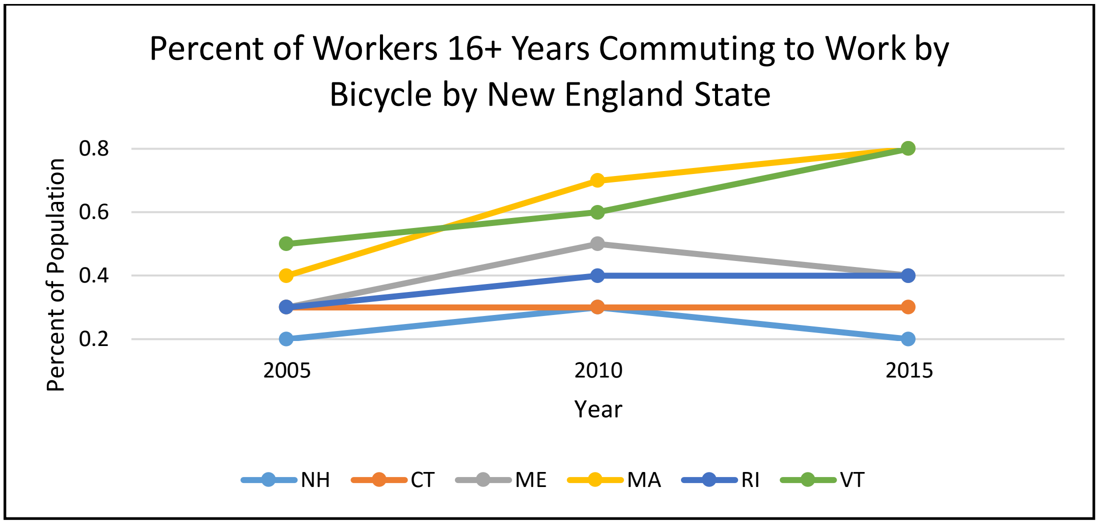
Comparing responses between Male and Female Respondents			
Lakes Region		**Manchester**	
Significant Difference	**No Significant Difference**	**Significant Difference**	**No Significant Difference**
◦ Terrain ◦ Fear of driver awareness of bicycles ◦ Fear of traffic ◦ Lack of striped bicycle lanes ◦ Lack of bicycle lanes separated from traffic by barriers ◦ Lack of bicycle paths at least 20 ft. from vehicle traffic ◦ Time to destination ◦ Lack of bicycle-friendly facilities at destination ◦ Maintenance is too complicated ◦ Inclement weather ◦ Equipment is too expensive	◦ The road shoulder is too narrow ◦ Road surface condition is poor ◦ Lack of education about rider safety ◦ Health ◦ Fear of bicycle theft	◦ Terrain ◦ Fear of traffic	◦ Lack of education about rider safety ◦ Time to destination ◦ Lack of bicycle-friendly facilities at destination ◦ Road surface condition is poor ◦ Maintenance is too complicated ◦ The road shoulder is too narrow ◦ Lack of striped bicycle lanes ◦ Lack of bicycle lanes separated from traffic by barriers ◦ Lack of bicycle paths at least 20 ft. from vehicle traffic ◦ Health ◦ Fear of bicycle theft ◦ Fear of driver awareness of bicycles ◦ Equipment is too expensive ◦ Inclement weather

H. Manchester and Lakes Region roads flagged as hazardous in PPGIS survey by NHDOT-designated functional road class.

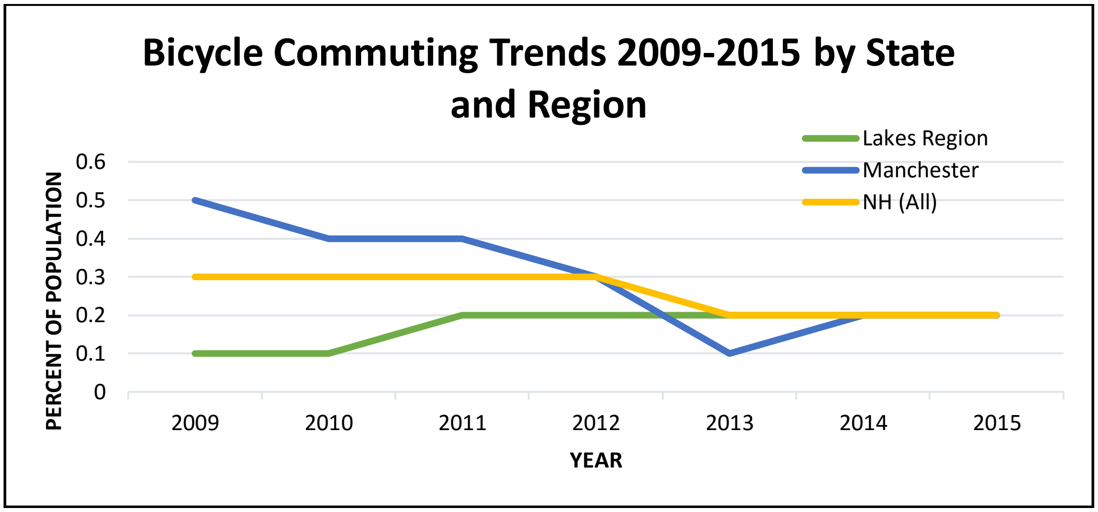




I. Percent of Workers 16+ Years Commuting to Work by Bicycle by New England State from 2005-2015. Data from American Community Survey 2005-2015.



J. Bicycle commuting trends by state and region from 2009-2015. Data from American Community Survey 2009-2015.



K. Percent of population commuting by bicycle by Lakes Region community from 2009-2015. Data from American Community Survey 2009-2015.