Incorporating Bicycle Level of Traffic Stress into MPO Performance Based Planning

FHWA Measuring Multimodal Connectivity Pilot Grant Program

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New Hampshire Regional Planning Commissions & Plymouth State University

Rockingham Planning Commission
Central New Hampshire Planning Commission
Nashua Regional Planning Commission
Southern New Hampshire Planning Commission
Strafford Regional Planning Commission
Plymouth State University

Foreword

Transportation planners with smaller MPOs and rural regional planning agencies often lack the rich datasets used by their larger urban counterparts to assess quality and connectivity of bicycle facilities. The vision of this pilot project has been to improve bicycle network planning for New Hampshire's Metropolitan Planning Organizations (MPOs) and rural regional planning commissions through further development and refinement of a shared model for evaluating Bicycle Level of Traffic Stress (BLTS) and application of that model for both regional and municipal bicycle planning. Beyond consistent multi-region data collection and model refinement, a key project objective has been incorporating BLTS analysis into performance-based planning as part of project identification and prioritization and tracking progress toward a more extensive network of low stress bicycle facilities.

This report will be of interest to transportation planning staff with Metropolitan Planning Organizations, rural planning commissions and municipalities, as well as a broader audience of advocates working to improve bicycle safety.

Scott Bogle, Senior Transportation Planner
Rockingham Planning Commission

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LIST OF ABBREVIATIONS

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway Transportation Officers
BLOS	Bicycle Level of Service
BLTS	Bicycle Level of Traffic Stress
CDC	Center for Disease Control
CMAQ	Congestion Mitigation/Air Quality Program
CNHRPC	Central NH Planning Commission
DEM	Digital Elevation Model
FAST Act	Fixing America's Surface Transportation Act of 2015
FHWA	Federal Highway Administration
GIS	Geographic Information Systems
LODES	Census LEHD Origin-Destination Employment Statistics dataset
LOS	Highway Level of Service
LTS	Bicycle Level of Traffic Stress
MPO	Metropolitan Planning Organization
MTI	Mineta Transportation Institute
MTP	Metropolitan Transportation Plan
MUTCD	Manual of Uniform Traffic Control Devices
NHDOT	New Hampshire Department of Transportation
NPMRDS	National Performance Management Road Data Set
NRPC	Nashua Regional Planning Commission
OSM	Open Street Map
PPGIS	Public Participatory Geographic Information System
PSU	Plymouth State University
RPC	Regional Planning Commission
RPC	Rockingham Planning Commission
SHRP2	Strategic Highway Research Program
SNHPC	Southern NH Planning Commission
SRPC	Strafford Regional Planning Commission
STBG	Surface Transportation Block Grant
SVI	Social Vulnerability Index
TAP	Transportation Alternatives Program\
TAZ	Transportation Analysis Zone

INCORPORATING BICYCLE LEVEL OF TRAFFIC STRESS INTO PERFORMANCE BASED PLANNING FOR SMALL MPOs

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1.0 INTRODUCTION

Similar to other regions of the country, interest in improving safe accommodation for bicycle travel has grown in New Hampshire in the past decade, particularly in the state's urbanized areas and college campus communities. Multiple communities in each of New Hampshire's four Metropolitan Planning Commission (MPO) regions have initiated local bicycle planning efforts on a city-wide basis or focused more narrowly on specific school zones through the Safe Routes to School program. While the four MPOs and the state's five rural regional planning commissions (RPCs) have adopted goals and policies related to improving bicycle networks, to date no standard tools have been agreed upon across agencies to assess bicycle network quality and connectivity, and no performance measures have been defined to spur and track implementation.

The vision of this pilot project has been to improve bicycle network planning for New Hampshire's Metropolitan Planning Organizations (MPOs) and rural regional planning commissions through further development and refinement of a shared model for evaluating Bicycle Level of Traffic Stress (BLTS) and application of that model across multiple planning regions. The state's four MPOs include the Nashua Regional Planning Commission, Rockingham Planning Commission, Southern New Hampshire Planning Commission, and Strafford Regional Planning Commission. Also participating in the pilot was the Central New Hampshire Planning Commission (CNHRPC). While CNHRPC is one of the state's five rural regional planning commissions, it is centered on Concord, the state capitol and third largest city. The sixth partner in this project, and the leader on Bicycle Level of Traffic Stress model development and bicycle network analysis in New Hampshire, is Plymouth State University (PSU).

Beyond consistent multi-region data collection and model refinement, a key project objective has been to incorporate BLTS analysis into MPO performance-based planning as part of project identification, project prioritization and tracking progress toward a more extensive network of low stress bicycle facilities. The scope of work for the study included the following tasks introduced below and detailed in the following pages.

1.1 Regional Data Collection & BLTS Model Refinement

Bicycle Level of Traffic Stress is a measure of the suitability of a given stretch of roadway for bicycling, recognizing that people have differing levels of tolerance for riding a bicycle in proximity to automobile traffic. The original BLTS model, developed at the Mineta Transportation Center in 2012 by Mekuria et al., considered road attributes including the number of traffic lanes in each direction, posted and prevailing speed, type and width of bicycle infrastructure, presence and width of on-street parking, frequency of bike lane blockage, presence and characteristics of turning lanes, and presence and characteristics of unsignalized crossings. Some of these data inputs are readily available in the New Hampshire Department of Transportation's public GIS road layer. Some however are not, including on-street parking, bicycle lane presence and blockage frequency, and intersection characteristics. Beginning in 2016 faculty and graduate students at Plymouth State University (PSU) have worked to develop a more streamlined version of the MTI model that can work with the more limited dataset of road attributes available in more rural areas.

This first task was the most time intensive of the project. It started with review and refinement of data already available in the NHDOT Road Layer followed by collection of data parameters not available in the road layer. The PSU model was then run to establish a baseline set of BLTS ratings for all public roads in the study area. These baseline BLTS ratings were then brought out for public feedback through a series of public forums and an interactive online map. Public feedback was then considered in making refinements to input data and in some cases model code. These steps are described in greater detail in the following pages.

1.2 Performance Measure Definition

This task began with a review of other statewide, regional and municipal planning agencies that have incorporated BLTS analysis in local or regional bicycle and pedestrian planning or broader long range planning processes; and the extent to which use of BLTS has gone beyond static mapping to formal inclusion in project development or prioritization processes. A range of potential BLTS-based performance measures was defined based on this outreach as well as practices described in the *FHWA Guidebook for Measuring Multimodal Network Connectivity.* Of the five core aspects of multimodal network connectivity described in the *FHWA Guidebook* (Network Completeness, Network Density, Route Directness, Access To Destinations And Network Quality), emphasis was placed on *Access to Destinations* (what key destinations can be reached via a low stress network), and *Network Quality* (how does the network support users of varying levels of experience and comfort with bicycling).

1.3 Network Analysis by Region & Target Community

A series of network analyses were completed assessing the potential for bicycle travel between residential areas and a series of destination types via low stress routes. Destination types included educational institutions, employment centers, community facilities and a combined category aggregating all three initial destination groups. Analyses were completed for each of the five MPO/RPC regions, and for two sample municipalities in each region. Measures for each geography included the percentage of trips completable by low-stress route, origin and destination scores, and centrality for each road segment.

1.4 Visualization Development

A series of sample visualizations were developed to convey the results of the various network connectivity analyses for use by planners and policy-makers. At their simplest these included network maps depicting road segment BLTS rating by color and basic pie charts showing the percentage of school or employment trips for a given geography achievable by bicycle on a low stress route. Origin and destination score maps aid planners in identifying underserved neighborhoods or destinations with limited access. Maps combining segment centrality with stress level are particularly useful tools for identifying and prioritizing network gaps. Data from regional Title VI Civil Rights plans and the Social Vulnerability Index were also overlaid on origin score maps to assist in Environmental Justice analysis.

1.5 Performance Measure Implementation

The analysis yielded results of clear value for project identification at the local as well as regional level. Taking this a next step and incorporating BLTS into project prioritization has also been a central goal of this project. This proved to be a greater challenge than initially envisioned, particularly identifying a consistent approach acceptable to all the participating planning agencies. Ultimately each agency developed separate approaches to incorporating LTS data into project prioritization. These reflect differences among planning regions including overall development densities, differences between regions with a single primary urban center vs. multiple centers, and varying priorities placed on regional inter-town recreational and commuting routes vs. in-town connections. Similar regional differences were apparent in efforts to define shared LTS-based performance measures tracking long term improvements in low stress network connectivity.

The report concludes with a series of recommendations for future iterative improvements to the PSU model, institutionalizing and automating data collection for key road attributes, and analysis updates on a regular cycle as part of Metropolitan Transportation Plan revisions.

2.0 BACKGROUND

2.1. Bicycle Level of Traffic Stress in National Use

The original Bicycle Level of Traffic Stress (BLTS) model was developed at the Mineta Transportation Center in 2012 by Maaza Mekuria, Peter Furth and Hilary Nixon (Mekuria et al. 2012) as an easily understood measure of the suitability of a given segment of roadway for bicyclists with differing levels of tolerance for riding with automobile traffic. The measure was in turn designed to facilitate analysis of connectivity between origin and destination points for utilitarian trips short enough to be taken by bicycle where traffic stress conditions permitted.

The measure was developed in part as an alternative to the traditional Highway Capacity Manual Level of Service (LOS) measurement, which categorizes facilities largely based on capacity and traffic flow. While LOS analysis has been adapted to address people walking and bicycling (PLOS and BLOS), those methodologies treat all pedestrians and bicyclists as having the same skill level and sensitivity to automobile traffic. The LTS classification system characterizes traffic stress on a given road segment based on how comfortable bicycle riders of varying abilities would feel riding that segment. The traffic stress scale of one to four corresponds roughly to four categories of would-be transportation cyclists identified through survey work by Roger Geller and others for the City of Portland, Oregon (Geller 2006; Dill and McNeil 2013).

Gellar's four groups included: 1) "Strong and Fearless" riders (~1% of the Portland population) who will travel by bicycle in virtually any conditions and on any roadway; 2) "Enthused and Confident" riders (~7% of the population) with advanced skills who will travel on most roadways but avoid high volume and speed conditions; 3) "Interested but Concerned" would-be riders (~59% of the population) who would ride if they see conditions on certain roadways as safe enough; and 4) "No Way No How" individuals (~33% of the population) who will not ride under any circumstance. While the percent of population in each group will vary somewhat by city or region, the basic groupings are transferable. They point to a large pool of would be cyclists - the "Interested But Concerned" - who could be induced to bicycle rather than drive for certain trip more frequently if roadways can be adapted to improve perceived safety. The BLTS methodology drops the "No Way No How" group and essentially divides the "Interested but Concerned" category into

Figure 1. Chart. Description of Bicycle Level of Traffic Stress (BLTS) Ratings

groupings of children and adults, defining the following four levels of traffic stress shown in Figure 1.

While the Mekuria BLTS model is less data intensive than BLOS, it still depends on range of data inputs that are often not available at a regional or statewide level. In all the Mekuria model included 18 input variables, some of which, like length of right turn lanes, frequency of bike lane blockage, or even prevailing speed, tend not to be available as part of statewide GIS road layers.

Since 2012 multiple other variations of the BLTS concept have been developed, some designed to achieve greater precision with additional data input, and some designed to strip down the analysis for geographies with less available data. Examples of streamlined models include the Conveyal LTS model (Conveyal 2015) based largely on OpenStreetMap (OSM) and highway classification; the LTS 2.0 model developed by Peter Furth which dropped the variable count to nine and omitted intersection configuration (Furth 2017); and a binary low/high stress classification system developed by People for Bikes also using OSM data.

Moving in the opposite direction several researchers and planning agencies have sought to further refine the Mekuria model by adding data attributes. These have typically been developed for, or in cooperation with, municipalities with robust geographic information system (GIS) road databases facilitating the analysis. Examples of this include a model developed by Montgomery County, Maryland, for their Bicycle Master Plan that distinguishes among several designs of separated bikeways, includes an input for frequency of driveway cuts, and splits out a fifth classification for moderate levels of stress (LTS 2.5).

Another example is the alternative BLTS methodology Michael Lowry, Peter Furth and Tracy Hadden-Loh developed in collaboration with the City of Seattle that included attributes for road slope and assumptions regarding marginal rates of substitution by bicyclists (i.e. how far from a shortest path will a rider divert in order to use a low-stress route) (Lowry et. al. 2016). Lowry et. al. also sought to classify the importance of individual segments on the road network. They modeled all possible routes of any stress level connecting defined baskets of trip origin and destination points. Road segments were assigned a centrality score based on how many of the possible routes include that segment. This measure of segment centrality has significant potential benefit in helping prioritize gaps in the low stress bicycle network and is used in the analysis here.

2.2. Work on BLTS in New Hampshire

Efforts to model bicycling level of traffic stress (BLTS) in New Hampshire have been underway since 2014 when a sample of four population centers in New Hampshire became the focus of a collaborative pilot project. This pilot project attempted to adapt the Mekuria BLTS framework (Mekuria et al. 2012) for application in NH. This early effort stalled when the project champion changed jobs and was unable to continue the work. As a result, the original partners attempted to calculate their own BLTS scores, with little standardization of data collection or calculation process across geographies. The focus remained on population centers such as Nashua, Concord, and Keene. In 2015, a new collaborative effort emerged with Plymouth State University (PSU) who contributed to data collection in the Lakes Region, Concord, and Manchester to compliment data collected earlier and began to develop a standardized ArcGIS model to automate (and standardize) BLTS calculation. These efforts were conducted by PSU as part of faculty and graduate student research on improving quantitative analysis of bicycle networks and bicycle usage with funding from NH Dept of Transportation (NHDOT). Elements of this research included:

- Analysis of Strava Metro data purchased by NHDOT in comparison to actual bicycle volume count data to assess current biking patterns through the state;
- Network connectivity assessments using BLTS ratings for the Lakes Region and Manchester;
- A broad reaching public survey to assess perceived barriers to bicycling in NH, identifying perceived hazards, and to identify valued biking routes.

The NHDOT funded project also resulted in the development of a series of BLTS tools for ArcGIS. The results of the BLTS model were vetted using a public participatory GIS survey to identify errors in calculation and additional parameters that should be included. The models resulting from the 2016-2018 PSU-NHDOT project became the starting point for this FHWA-funded pilot project.

3.0 PLANNING & PROJECT DEVELOPMENT CONTEXT

This study also builds on a collaborative effort of New Hampshire's four Metropolitan Planning Organizations (MPOs) to begin implementing performance-based planning requirements initially set out in the Moving Ahead for Progress in the 21st Century Act (MAP-21) and continued in the Fixing America's Surface Transportation (FAST) Act of 2015. This collaborative process was initiated by the Strafford Regional Planning Commission and supported with grant funding from the FHWA Strategic Highway Research Program (SHRP2) Implementation Assistance Program. The initial SHRP2 grant project featured participation by the following agencies:

- Nashua Regional Planning Commission MPO
- Rockingham Planning Commission MPO
- Southern New Hampshire Planning Commission MPO
- Strafford Regional Planning Commission MPO
- Southwest Regional Planning Commission (one of 5 rural planning commissions)
- NHDOT Bureau of Planning and Community Assistance
- NH Department of Environmental Services (NHDES)
- Federal Transit Administration (FTA) Region I
- Federal Highway Administration (FHWA) New Hampshire Field Office.

The planning process included an extensive series of stakeholder interviews and focus group meetings with over 80 individuals to identify perceived strengths of the existing transportation system, unmet needs, goals for system modernization and improvement, and ideas for measures to track improvement. The interviews and research by MPO staff led to an initial list of over 650 potential supplemental performance measures to supplement the seventeen core measures mandated by FHWA and four measures mandated by FTA.

This initial list was vetted against a series of evaluation criteria addressing data availability, difficulty of new data collection, scalability to multiple geographies, consistency with MPO goals, relevance to stakeholder priorities, ease of comprehension, and other factors. This vetting process narrowed the list of potential supplemental measures to 24, for which draft methodologies were developed for data collection and measure calculation. Based on barriers encountered with data collection the short list was further narrowed to seven supplemental shared performance measures for which the MPOs have developed baseline conditions, historic trend data, draft targets and implementation strategies. These seven supplemental measures, addressing several aspects of transit access, transportation related Greenhouse Gas emissions, transit asset management and motorcycle fatalities, represent issues specific to New Hampshire and will be tracked jointly by the four MPOs.

While each of the MPOs and the state's five rural regional planning commissions have adopted goals and policies related to improving bicycle networks, to date no performance measures have been defined to spur and track implementation. Multiple measures for bicycle network safety and accessibility were evaluated as part of the SHRP2 research process, including miles of dedicated bicycle route, Highway Capacity Manual Bicycle Level of Service (BLOS), and Bicycle Level of Traffic Stress (BLTS). However, the lack of consistent data across MPO regions was identified at the time as a barrier to defining shared performance measures in this area. Building on the SHRP2 process and filling this data gap was a key impetus for this project.

Having a quantitative tool to identify gaps in bicycle networks and effectively portray those to policy makers will be helpful in both regional and municipal efforts to build out safe, low-stress bicycle connections. At the MPO level this BLTS analysis will be incorporated into updates to regional pedestrian and bicycle plans, corridor studies, and Metropolitan Transportation Plans. Gap identification has to date been based more on a combination of shoulder width, crash history, qualitative input on hazard areas, and proximity to destinations like schools or community facilities. The MPOs will also share the tool with member communities for developing Safe Routes to School travel plans or local bicycle and pedestrian plans. Beyond project identification the BLTS tool will facilitate a more systematic process for project prioritization described in Section 8.

4. ANALYSIS METHOD

4.1. Challenge of adapting BLTS to New Hampshire

Plymouth State University created ArcGIS python-based tools to automate the calculation of BLTS throughout NH. Adopting a single method for evaluating BLTS statewide has been challenging. PSU adapted frameworks developed by leaders in the field (e.g. Mekuria and Furth). However, these frameworks have largely been designed for metropolitan areas with extensive data available on roadway attributes. Much of this challenge lies in the paucity of centralized data on our roadways and, more inherent to the framework itself, the importance of different roadway attributes in urban versus rural regions. For example, bike lanes are rare in rural areas, yet many cyclists of NH agree that rural roads with wide shoulders are excellent cycling corridors. In response, the PSU BLTS model treats any paved shoulder greater than 4 feet as a bike lane, consistent with the minimum standard for shoulder bicycle routes defined by the American Association of State Highway and Transportation Officials (AASHTO 2012).

The basic data available in the NHDOT road layer include only a subset of road attribute inputs for the original Mekuria et al. model. BLTS is largely driven by speed limit and/or traffic volume. Speed limit sign locations were available as a point data layer, but not included as a field in the primary state GIS road layer. Similarly, a field exists in the road layer for Annual Average Daily Traffic (AADT), but the data populating this field are often rough estimates. Unless a road segment is immediately adjacent to a permanent traffic count site the AADT data tend to be place holder figures with a low confidence interval. Perhaps most challenging, shoulder width data for lower tier state highways in the road layer are often placeholder figures.

Collecting additional roadway attribute data to fill gaps such as those described is very time intensive. This has led to piecemeal efforts at data collection to date. As a result, the comprehensive dataset needed to calculate BLTS with reasonable accuracy is patchy with large areas lacking additional data inputs. It also results in time lags during which road networks may have changed or attributes may have been updated in the NHDOT road data layer which is revised and released to the public annually. Finally, maintaining an up-to-date dataset for the entire state is a challenge since project funding for BLTS work has to date been limited to one- or two-year grant cycles, usually focused on novel applications rather than data maintenance.

4.2. New Hampshire BLTS Variable Data Adaptive Model

To better accommodate the stark contrast in roadways and bicycling stress experience in urban versus rural regions of the state, we developed an adaptive model that includes three sub-frameworks (i.e., processes) for quantifying expected BLTS. This model is embedded in an ArcGIS tool in which the user can identify the fields that match the required and optional data inputs. The model selects the most data intensive sub-framework possible for each roadway segment. Given the lack of speed limit data in the NH roadways dataset and its importance in calculating BLTS, the PSU model classifies speed on a scale of 1-5 based on posted speed limit or functional class where posted or prevailing speed data are unavailable. Appendix A provides two tables describing the parameters used for the speed tool and for each BLTS sub-model.

The most data-intensive model (Version 3) includes the following parameters reflecting existing data from NHDOT and supplemental data collected by the project team: *speed class (derived from posted speed or functional class), number of lanes, traffic direction, bike lane width, parking lane width, shoulder type,* and *shoulder width*. The least data-intensive model (Version 1) calculated BLTS using only the data available in the statewide road data layer: *speed class (derived from posted speed or functional class), number of lanes, traffic direction, shoulder type, shoulder width, and AADT*. For roadways where data are available on the width of designated bike lanes or parking lanes, the model will process BLTS using all data. For roadways where these attributes are not provided or equal zero (for bike or parking lane width), BLTS will be calculated using speed limit, number of lanes and direction, shoulder type, and shoulder width.

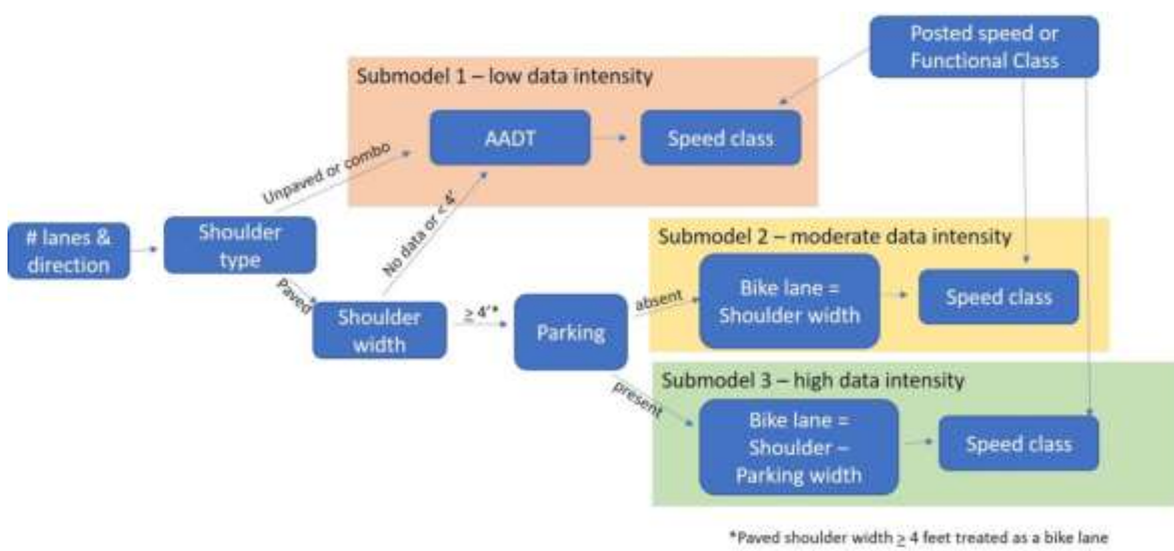


Figure 2. Chart. Conceptual model illustrating the decision framework for calculating BLTS based on the presence and values of roadway attributes.

4.3. Supplemental Data Collection

The five regional planning commissions collected and/or updated supplemental data for roadways in their respective regions using a combination of aerial imagery (Google Maps and Google Street View), a point file of speed signposts and locally or regionally collected speed and volume data. These additional attributes included: bike and parking lane widths, posted/prevailing speed, residential area designations, and presence of midblock crossing (not used in current model). To ensure these data were collected similarly across regions, PSU developed and shared a data collection guide providing an orientation to the process with supportive imagery and tips for users.

4.4. Model Refinement

Following the collection of road attribute data described above, an initial model run was completed and results reviewed by each planning commission. Road segments where the initial BLTS rating seemed anomalously high or low were flagged for review. In most cases a review of the underlying input data revealed an inaccurate cell entry for AADT or shoulder width, or a speed limit entry that didn't accurately reflect prevailing speed. Updates to these data inputs in turn yielded more accurate BLTS ratings. Other broader issues were identified that necessitated modifications to the model framework (in comparison to Mekuria et al. 2012 and recent updates by Firth). Modifications to the models included:

- Treating road segments with unpaved or combination paved/unpaved road shoulders as if the shoulder width was zero;
- Treating a road segment with paved shoulder wider than 4 feet as a functional bike lane, which prompts the use of the more data intensive sub-model;
- Increasing speed classification on "Minor Collectors" from 2 to 3, and on "Major Collectors" from 3 to 4 to account for prevailing speeds;
- All Interstate and Tier 1 (limited access) roadways were given speed classifications of 5 that automatically result in BLTS of 5 and exclusion from bicycle network analyses;
- Road segments that were deemed "residential" or on cul-de-sacs were coded with a speed class of 20 to reflect low prevailing speeds, enabling a BLTS score of 1. Otherwise default speed limits in some towns of 30-35 MPH would produce a BLTS of 2 or 3.

4.5 Public Review & Feedback

Once all attribute data were collected and the initial model run subjected to the first cut staff evaluation described above, a new base map with updated draft BLTS classifications was developed and put out for public review. The goal was to gather "ground-truthing" input from local bicyclists and other road users as to whether the model output was consistent with their personal experience of the roads in their communities. Input was gathered through a combination of an online survey with an interactive map and a series of public meetings in each region where participants could either mark-up paper maps or comment online using web-connected iPads. The link to the online survey was circulated via email through planning commission websites, newsletters and email lists. Local, regional and statewide bicycling organizations and area bike shops also circulated the request for input to members and customers. In person events included tables at farmers markets, a bicycle race and discussions with MPO Technical Advisory Committee (TAC) meetings and bike/ped or trail committee meetings. In total 12 outreach events were held involving an estimated 240 people.

The online survey used the ArcOnline Web Application platform. Following a brief project explanation, it invited respondents to place comment pins on road segments where they thought the initial BLTS rating was either too high or too low. For each pin placed, a respondent was asked to indicate what BLTS rating they thought was appropriate for that road segment, select reasons for that evaluation based on a series of response options in dropdown menus, and include a brief explanation in a comment box. For each pin respondents were also asked their personal traffic tolerance based on a variant of Geller's (2006) four categories of bicyclists. The revised categories for self-identification included: 1) Kids & Beginners (corresponding to comfort on BLTS1 roadways), 2) Willing but Wary (comfort on BLTS2 roadways), 3) Comfortably Confident (BLTS3), and 4) Exposure-Experienced (BLTS4). This self-categorization provided useful context in reviewing comments. A total of 172 comments were received on the online survey. The public feedback identified several scenarios where model outputs tended to diverge from road user evaluation:

Figure 3. Chart. Sample Public Comment from Interactive Online Map

- The model tended to under-rate stress on corridors with frequent intersections and consequent turning movements. This is in part a consequence of the model not incorporating intersection information.
- The model similarly tended to under-rate stress on corridors with wide shoulders, even shoulders of >8', but with high traffic volumes and speeds.
- The model doesn't currently account for stress impacts of factors like blind corners, steepness of road grade or lighting issues.

To refine model results for the next stage of the project, manual adjustments were incorporated for several corridors and noted in a comment field for later reference on future model runs. Addressing these scenarios will be a priority for the next update to the PSU model script.

5.0 PERFORMANCE MEASURES & NETWORK ANALYSIS APPROACH

With an updated base map refined through the public comment process, the project team shifted focus to network connectivity analysis and BLTS-based network performance measures. In selecting performance measures, the project team drew on the *FHWA Guidebook for Measuring Multimodal Network Connectivity (2018)*, as well as a scan of BLTS-based performance measures used by other public agencies nationally.

To identify BLTS-based network performance measures in use by other public agencies the project team started with agencies highlighted in the *FHWA Guidebook for Measuring Multimodal Network Connectivity*. An online scan of other agencies that had incorporated BLTS analysis into bicycle and pedestrian plans or regional master plans rounded out a list of twenty agencies. This including four state departments of transportation, three MPOs and thirteen municipal and county governments. Phone interviews and/or email were used to gather information on how each agency had used BLTS in their multimodal planning processes. Of the twenty agencies contacted nineteen responded. All nineteen of the agencies had completed initial data collection and developed BLTS mapping, either through a consultant or with their own staff.

Thirteen of the agencies (three states, two MPOs, eight municipalities) had used BLTS analysis for project identification, helping to pinpoint gaps in the low stress bicycling network and identify which improvements would most significantly expand the connected low stress network. The same 13 agencies indicated they had incorporated BLTS analysis into project prioritization. Typically this meant incorporating BLTS into safety factors in project selection criteria, often combined with separate factors for connectivity, demand, and in some cases equity.

While several agencies indicated an intention to develop long term performance measures incorporating BLTS data, few had defined the metrics to operationalize such measures. Arlington County, VA was one municipality that has. Their performance targets included completing 75% of a planned Low Stress network by 2025 (90% by 2030) and providing a low stress route within 0.25 mile of at least 80% of households by 2025 (95% by 2030). Another agency that did this is Montgomery County, MD. Montgomery County has established a suite of performance measures that draw on BLTS analysis. These addressed the overall percentage of potential bicycle trips that can be made by low-stress route, and the percentage of dwelling units within specified distances of transit stops, K-12 schools, public libraries, recreation centers and parks that are connected to those facilities by low stress bicycle route. The specified trip distance varied by destination, with 2 miles used for most destinations, but one mile used for elementary schools and 1.5 miles used for middle schools. Montgomery County has also developed an environmental justice-based performance measure looking at the relative accessibility via low-stress route of bicycle trips in lower income census tracts vs. all census tracts in the county.

The information from the interviews with peer agencies shaped the selection of the performance measures tested for use in New Hampshire. The *FHWA Guidebook for Measuring Multimodal Network Connectivity* references a range of network connectivity metrics encompassing categories of *network completeness, network density, route directness, access to destinations,* and *network quality*. Metrics from each of these categories were explored and considered. Ultimately, five metrics were defined related to *Network Quality* (i.e., how much of the transportation network is below threshold of BLTS, measured in street-miles) and *Access to Destinations* (ie., assessing destinations that can be reached by bike on low-stress roadways. The low-stress bicycling network was defined to include roads with a BLTS rating of 1 or 2, as well as a small number of known bikeways and trails separated from the road network. In addition to the road data associated with the five planning commission regions, a 5-mile buffer area was added around the analysis region to include routes that cross town and regional planning commission boundaries.

Substantial time went into operationalizing the datasets to be used for trip origins and destinations. While Mekuria et al. analyzed the percent of total trips connected by low-stress bicycle route using trip tables from regional travel demand models, this level of modeling was not an option for this project given time, cost and the relatively large size of Transportation Analysis Zones (TAZs) in the travel demand models used by three of the four MPOs. A series of destination themes were developed to categorize groups of likely destinations for utilitarian bicycle trips. After review of the available place data from the OpenStreetMap database, these themes were narrowed to include schools and community centers. Lastly, to capture commute trips possible by bicycle via low stress route, employment center destinations were created by extracting centroids of census blocks with greater than 100 employees, available through the census distributed LEHD Origin-Destination Employment Statistics (LODES). A fourth analysis was completed using a combined “All Destinations” dataset including schools, employment centers and community facilities. Census block centroids with a population greater than zero were used to represent trip origins in every analysis theme.

6.0 COMPUTING CONNECTIVITY ANALYSES

<u>6.1. Access to Destination Analysis</u>

The access to destinations analysis includes the identification of spatially explicit origins and destinations. This analysis is essentially a comparison between the shortest path distance between an origin and destination pair compared to the distance required to complete the same trip on a low-stress network. The ESRI ArcMap Network Analyst extension was used to generate shortest-path routes between destinations and origins within the region. Two separate analyses must be run for every destination theme, one to find routes on the full available network (BLTS 1-4) and one on the low-stress network more suitable for riders (BLTS 1-2). Using "Closest Facility", an individual shortest-path route is generated between every possible origin and destination pair, with real geometry. Some destination theme analyses had slightly different parameters to accommodate the target audience associated, most notably, the route distance limit as shown in Table 1. Origins were considered connected to network if they were within 0.1 mile of a network segment, while destinations were connected within 0.5 miles from the network. From here, each metric seeks to compare the routes possible on the low-stress network to those possible if the entire network was suitable for riders.

Table 1. Destination Theme Definitions

Destination Theme	Destination Type Details	Route Distance Limit
Schools	Included OpenStreetMap places labeled as K-12 schools, childcare facilities, and college campuses	2 Miles
Community Centers	Included OpenStreetMap places labeled as libraries, community centers, senior centers, parks and playgrounds	2 Miles
Employment Centers	Census Block centroids of blocks with greater than 100 employees	5 Miles
All Destinations	All three other destinations themes combined into one dataset	2 Miles

6.2 Computing Metrics

The full technical analysis was completed using a combination of custom tools and manual data manipulation. Custom tools were created in an ArcGIS Model Builder environment to automate and standard metric computation. Figure 4, at the end of the section, provides an overview of the complete workflow associated with each Destination theme, with steps including custom tools highlighted. To simplify processing, the Network Analyst portion of route creation was run on a network which combined all five regional planning commission areas. To provide results specific to each region, the routes were separated out after the Network Analyst runs. BLTS 1-2 routes were only considered viable if the trip was completed without undue detour, represented here as 0.5 miles longer than the shortest corresponding BLTS 1-4 route. A measure of network completeness, percent street-miles of

BLTS 1 through 4, was included in the analysis to serve as a descriptive statistic of the BLTs model outputs (Table 2) and is independent of the route analysis.

6.2.1. Computing Metrics: Percent Routes Accessible

"Percent Routes Accessible" is a basic measure of the percent of possible routes accessible on an ideal BLTS 1-4 full network that can still be completed on the low-stress BLTS 1-2 network. This metric can give planners an understanding of the overall suitability of the region for cyclists interested in the specific destination theme.

A custom tool was created to automate the computing of this metric, which calculates the total number of routes in the region that are accessible on the BLTS 1-2 network, and divides that by the total number of routes in the region accessible on the BLTS 1-4 network. The results are converted into an excel sheet where charts and graphs were created manually.

6.2.2. Computing Metrics: Origin and Destination Scores

To get an understanding of what neighborhoods and communities are best served by low-stress networks, the percent of possible destinations accessible in the BLTS 1-2 network was calculated for each origin Census block in every destination theme, known here as *Origin Scores*. An origin-specific metric was developed counting the number of unique destinations each origin is able to access on the BLTS 1-2 network and comparing it to the total unique destinations accessed in the full BLTS 1-4 network. This can also be aggregated at the municipal or regional level. This provides planners a clear picture of neighborhoods or communities in their region where lack of safe accommodation inhibits potential bicycle travel to schools, workplaces or community centers. PSU also calculated the converse measure, *Destinations Scores*, representing the percent of possible origins connected to any given destination in the BLTS 1-2 network. This provides an understanding of what types of destinations have the best low-stress bicycle access, facilitating project identification and prioritization.

Two custom tools were created to calculate the origin and destination scores within the five planning regions. Through the planning process we identified several metric calculation challenges (e.g., including origins and/or destinations that don't connect to network in calculations). These challenges are described and solutions provided in the guidebook provided to partners and in Appendix X of this report. Calculating accurate origin and destination scores required a series of joins and field calculations, and ultimately updated tables were exported from the spatial data to Excel to create charts and tables. The data can be used to compute an overarching score, as well as a score of just origins or destinations which are connected to the network in the first place.

6.2.3. Computing Metrics: Centrality

Lastly, and perhaps most importantly, the routes generated in the BLTS 1-4 network represent the ideal shortest path for any given origin-destination pair and can therefore be used to prioritize areas for improvement. Centrality, here defined as a count of routes which cross a given segment in the BLTS 1-4 network, can be used to identify segments likely to have high utility to bicycle travelers. Segments with high centrality scores that are currently high stress (BLTS 3-4) are likely to offer the greatest return on investment from projects that improve bicycle accommodation and decrease traffic stress. In addition, the average BLTS rating of the most central segments within a specified area of interest (town, RPC/MPO) can help planners further assess connectivity.

Workflow Overview (for each destination theme and focus region)

0) Preprocessing
   a. Merge all regional roadway shapefiles, trails, and patch in statewide data
   b. Delete Class VI roads
   c. Create LTS 1-2 Network Dataset
   d. Create LTS 1-4 Network Dataset

1) Calculate Network Completeness
   a. ***(Network Completeness Tool)***

2) Run Network Analysis "Closest Facility"
   a. Run ***(Closest Facility Tool)*** twice, once for each network
   b. Calculate undue detour for LTS 1-3 Routes
   c. If computing metrics for more than one study region, select all routes which intersect the planning region and export as individual sets of routes.

3) Calculate Percent Routes Accessible
   a. ***(Percents Routes Accessible Tool)***

4) Calculate Origin Scores
   a. ***(Origin Scores Tool)***
   b. Join output table to original origin data
   c. Export table of origin dataset with joined OS scores
   d. Manually calculate Average Origin Score for planning region and focus towns

5) Calculate Destination Scores
   a. ***(Destination Scores Tool)***
   b. Join output table to original destinations data
   c. Export table of destination dataset with joined DS scores
   d. Manually calculate Average Destination Score for planning region and focus towns

6) Calculate Centrality and Average LTS of Most Central Segments
   a. ***(Centrality tool)***
   b. Manually calculate average LTS for top 50 most central segments in planning region, and focus towns from output table

Figure 4. Chart. A workflow overview delineating automated and manual steps for each destination theme and focus region (RPC/MPO).

A series of processes are needed to calculate centrality for each road segment, including a split line function available only with an ArcGIS standard license. PSU developed a custom tool to automate these processes to provide a centrality count for each road segment and to export an excel table to manually calculate the average BLTS of the top 50 most central segments.

7.0 VISUALIZATIONS

7.1. Sample Network Analyses

PSU compiled results by region, including shapefiles, tables and charts. Each metric was calculated on the regional scale, as well as for two municipalities in each region. These typically included one rural and one urban example. Table 2 and Figure 5 depict the percent of total road miles in the Strafford planning region by BLTS rating. As is commonly the case, over 70% of the road network for the region is rated as low-stress (BLTS 1-2). This figure was 61% for Durham, home to the University of New Hampshire campus, and 78% for the rural community of Farmington.

Table 2. Percent of Road Miles by BLTS SPRC Region & Sample Towns

BLTS	Miles by BLTS Rating	Total Network Miles	Percent
1	417.5	1266	32.9
2	476.6	1266	37.6
3	205.1	1266	16.2
4	166.8	1266	13.2
Durham, NH			
1	33.8	77	43.9
2	13.3	77	17.2
3	17.5	77	22.7
4	11.9	77	15.6
Farmington, NH			
1	13.4	65	20.7
2	37.3	65	57.3
3	9.3	65	14.4
4	5.0	65	7.7

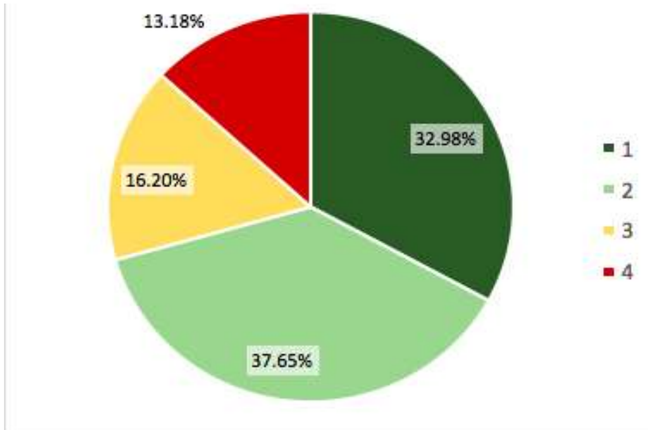


Figure 5. Graph. Percent of Road Miles by BLTS for SRPC Region

7.2 Percent Routes Accessible

In addition to providing numerical scores that summarize the percent of routes available on a low stress network, visualizing the routes accessible on the BLTS 1-2 and the full BLTS 1-4 network side-by-side enables planners to see the distribution of connectivity.

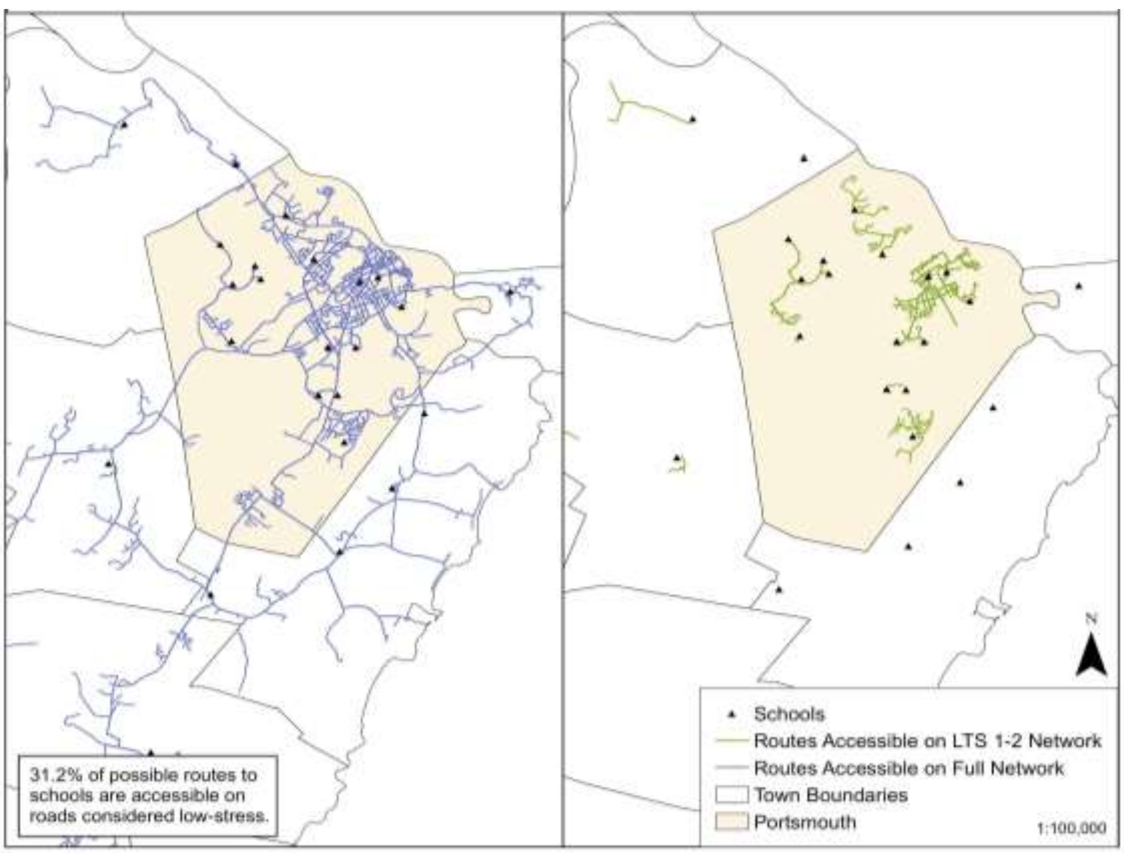


Figure 6. Map. Percent of Routes Accessible for Portsmouth Area Schools

Table 3. Percent Routes Accessible: Schools in RPC Region

Region	Total Routes: Low-Stress	Total Routes: Full Network	Percent Routes Accessible
RPC	1338	6603	20.30%
Portsmouth	675	2166	31.20%
Stratham	24	144	16.70%

7.3 Origin and Destination Scores

Origin scores enable planners to better understand destination access based on where one lives. To better understand the Environmental Justice implications of bicycle traffic stress, variations of the origin score maps were produced with an overlay showing the Center for Disease Control (CDC) Social Vulnerability Index (SVI) calculated at the Census tract level. In lieu of the SVI some of the planning commissions used overlays of Census tracts identified through Title VI Civil Rights plans with relatively high concentrations of poverty or minority populations. Figure 7 shows origin scores for the City of Nashua, while Figure 8 shows those scores overlaid with the CDC Social Vulnerability index. While origin scores vary across the city and not all neighborhoods with low access score high on the SVI, no tract with an SVI greater than 5 on a scale of 1-12 has an origin scores reflecting low-stress access to greater than 25% of destinations.

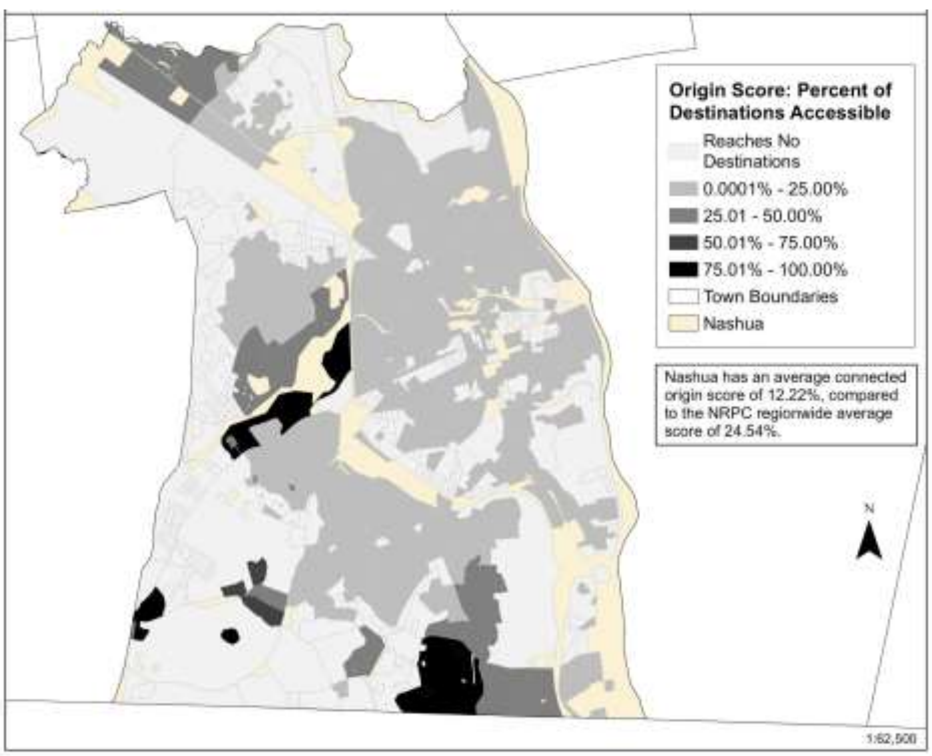
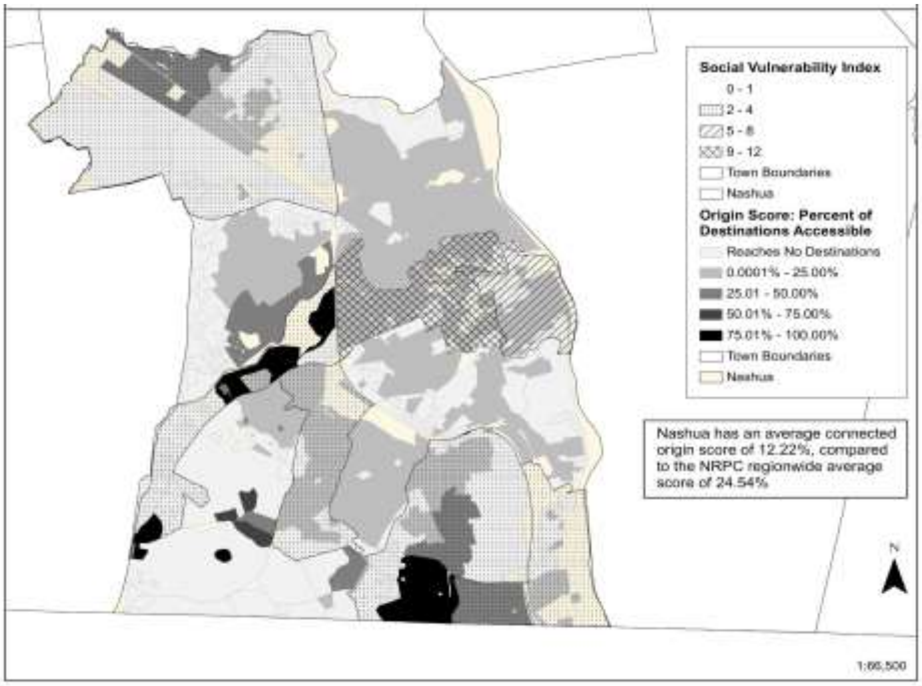


Figure 7. Map. Origin Scores for Nashua, NH Census Blocks



Origin scores of Nashua, NH visualized as census blocks, compared to the CDC Social Vulnerability Index (SVI). SVI considers factors such as poverty, racial/ethnic makeup and transportation access.

Figure 8. Map. Origin Scores for Nashua Overlaid with Social Vulnerability Index

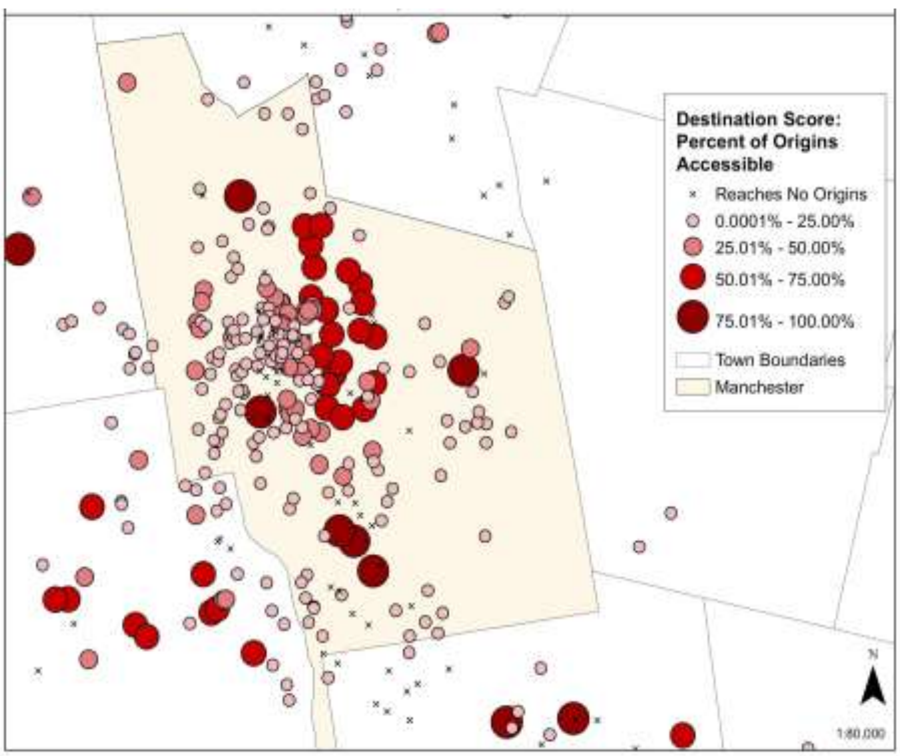


Figure 9. Map. Destination Scores for Manchester, NH

Figure 9 depicts destination scores for the City of Manchester, NH. Without a street grid once can identify neighborhoods just east of the city center with concentrations of destinations (appearing as middle-sized red circles) accessible by low stress route for 50%-75% of residential blocks within two miles. Closer to the city center most destinations are marked by small pink circles denoting their accessibility via low-stress route to fewer than 25% of nearby residential blocks.

7.4 Centrality

The centrality metric was adopted to synthesize the results of the origin destination pair analysis. This measure developed by Furth (2017) enables planners to identify specific road segments that are most essential in connecting the greatest number of specified origin-destination pairs. For example identifying which city streets are most likely to be traveled for trips between a community's residential areas and schools. Figure 10 shows segment centrality in the City of Concord, NH as a heatmap with more central segments appearing as darker purple lines.

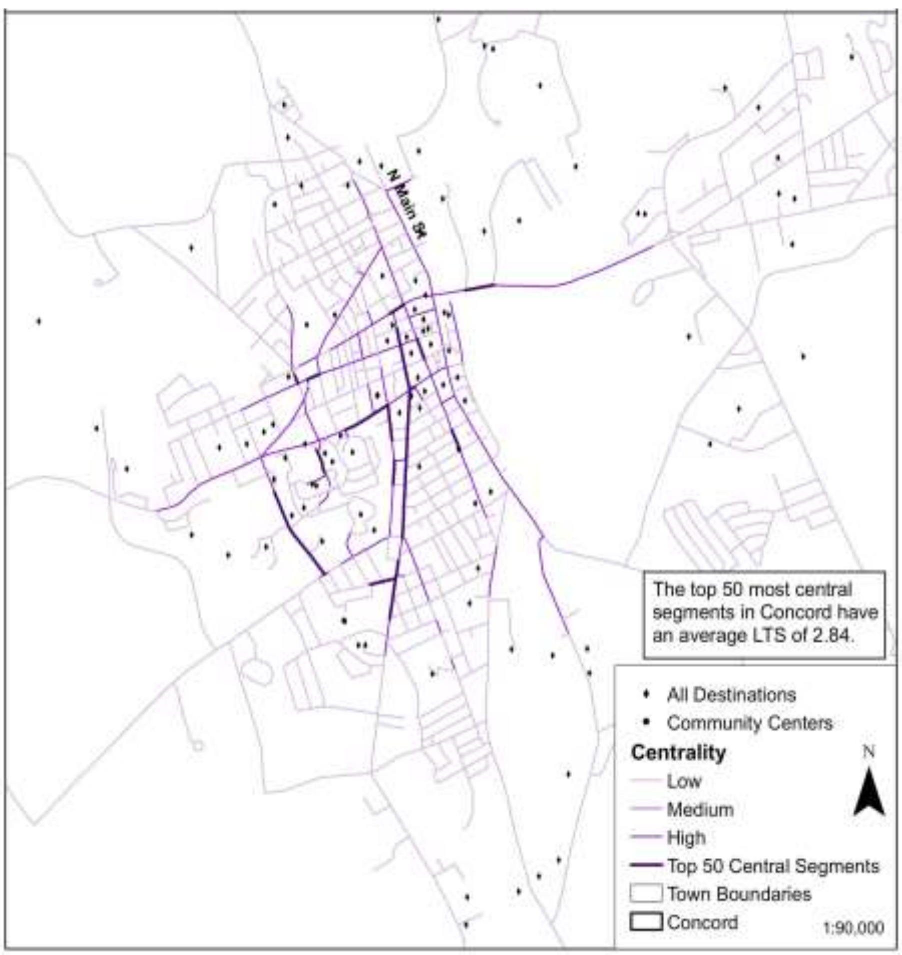


Figure 10. Map. Centrality for All Destinations in Concord, NH

Figure 11 offers another visualization of centrality combined with BLTS rating for the City of Portsmouth, NH. Centrality is depicted by line weight while low stress road segments (BLTS 1-2) are shown in green and high stress segments (BLTS 3-4) in brown. Wide brown lines thus correspond to gaps in the low stress network likely to see high use if facility improvements are made to reduce rider stress.

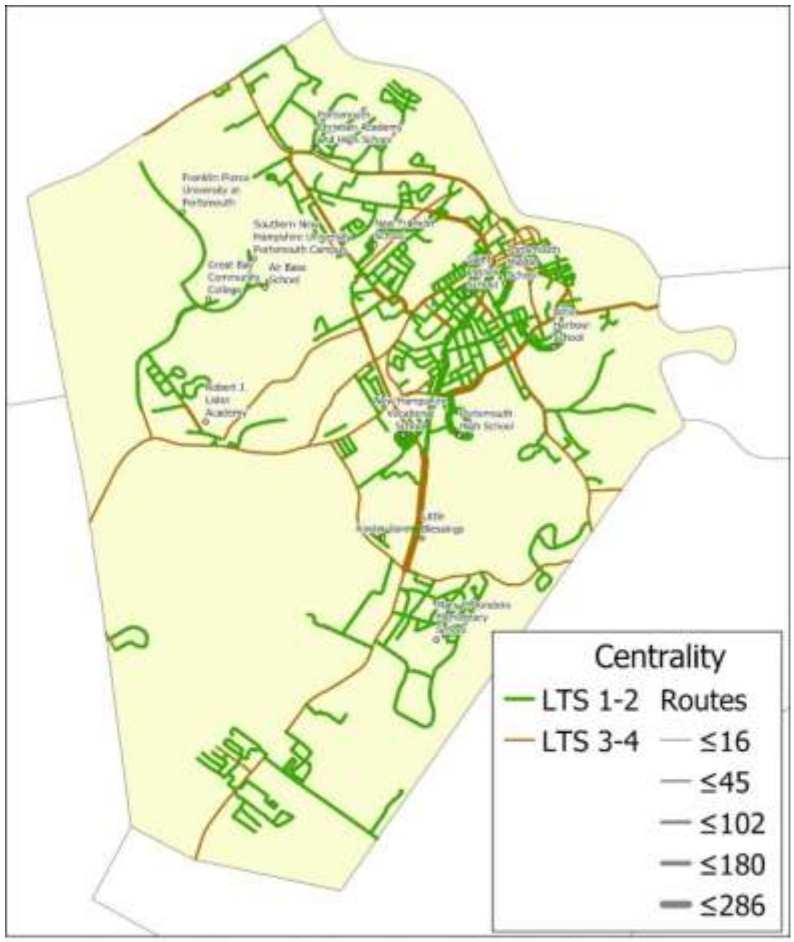


Figure 11. Map. Centrality with BLTS Rating for School Access in Portsmouth, NH

8. APPLICATION TO PERFORMANCE BASED PLANNING FOR NEW HAMPSHIRE

8.1 Incorporation in Project Prioritization

Beginning in 2012 New Hampshire's four MPOs and the NH Department of Transportation have developed a shared set of project scoring criteria that the MPOs use in prioritizing projects for inclusion in Metropolitan Transportation Plans (MTPs) as well as prioritizing projects to put forward for the State Ten Year Transportation Plan. These criteria as originally defined included *Mobility, Alternative Modes, Safety, Network Significance, State of Good Repair* and *Support*. They are revisited and modified every two years by the MPOs. The list was modified in 2019 to add *Resiliency* as a new criterion reflecting the inclusion of transportation system resiliency to the Federal Transportation Planning Factors under the FAST Act. Specific weights applied to the criteria are set regionally by each MPO's technical and policy committees using a pairwise comparison process.

A central goal of this pilot project is identifying an effective approach to incorporating BLTS data into this set of criteria. There was agreement among the MPOs that the most appropriate places to incorporate BLTS analysis would be under the existing criteria for *Alternative Modes* and *Network Significance*, specifically the subcategory of *Facility Importance* within *Network Significance*. At the outset of the pilot project the intention was to develop a single shared methodology to be used by all of the MPOs and eventually NHDOT. For several reasons though each of the four MPOs has developed slightly different approaches to this. These approaches reflect differences among planning regions including overall development densities, differences between regions with a single primary urban center vs. multiple centers, and varying priorities placed on regional inter-town recreational and commuting routes vs. in-town connections.

Southern NH Planning Commission MPO (SNHPC) started by scaling scores for segment centrality for each of their municipalities. This local scaling is critical as otherwise link centrality numbers in Manchester, SNHPC's central city, dwarf those in outlying communities. For on-road improvement projects BLTS is then incorporated into the *Alternative Modes* criterion using two scales: one reflecting the degree to which a project will improve BLTS on a corridor-wide basis, and one reflecting the degree to which a project addresses an identified high stress gap in the regional bicycle network. In each case the minimum threshold for assigning points is that project must improve traffic stress from a level of BLTS 3-4 to at least BLTS 2. For off-road improvements projects that create new low-stress corridors or fill gaps in existing low stress corridors (e.g. rail trails, separated multi-use paths), maximum points are awarded. For the *Network Significance* criterion points are assigned based on the centrality of a segment within the municipality where it is located.

Strafford Regional Planning Commission MPO (SRPC) focused on adjustments to the *Alternative Modes* criterion and defined four sub-criteria for bicycle projects. These include: 1) the level of traffic stress reduction achieved, 2) segment centrality within the project municipality, 3) percentage of municipal population served and 4) increase in total mileage of connected low-stress bicycle route. Additional bonus points are awarded for bicycle projects in municipalities that have not proposed bicycle facilities previously, and for elements of larger multi-phase projects.

Nashua Regional Planning Commission MPO (NRPC) adjusted the overall weight for the *Alternative Modes* criterion, increasing this from 9.2% of total project score to 15.4%, though a project would only be able to receive the full points if it included improvements to bicycle, pedestrian and transit access. Scoring for bicycle facility projects is based on ranking on a regional top 20 list of prioritized projects developed using BLTS analysis.

Central NH Regional Planning Commission (CNHRPC) used three criteria to score projects, including centrality, village/land use context, and regional network. Projects are scored High, Medium, Low, or Zero for the "alternative modes" category in TIP projects, and/or to inform planning commission rankings of TAP projects. With urban areas having much higher centrality scores than rural villages, rural villages and other land use contexts are assigned lower centrality thresholds than urban areas. Longer distance regional networks, such as region-wide rail trails were also given separate considerations to account for projects with important regional connectivity that are not conducive to the short trips (two miles) used in the centrality analysis. These criteria were created to find a balance between raw connectivity values and equity between urban and village land use types common to the region, while also incorporating regional connectivity and the rail trail network. The High, Medium, and Low thresholds were considered more appropriate than a numerical value for the small number of projects typically being evaluated in the region, and a preference by the Technical Advisory Committee to leave room for some qualitative judgements.

Rockingham Planning Commission MPO (RPC) incorporated BLTS data in point assignment for the *Network Significance* criterion. The weight given to this criterion and how points are assigned varies across three categories of project scale used in RPC's scoring rubric. These types include Local projects (typically SRTS or town center improvements); Regional projects connecting two or more municipalities (typically major regional commuting or recreational routes); and Inter-Regional projects (interstate connections such as the East Coast Greenway or US Bicycle Routes). The three buckets based on project scale were originally developed to ensure that major interstate highway improvement projects didn't consume all available funding, and resources would be set aside also for smaller local and regional needs. The scale categories adapt effectively for bicycle facilities as well.

For the Local project category, the *Network Significance* criterion counts for 12% of total points; for Regional projects this increases to 14%, and for Inter-Regional projects it increases again to 17%. Weighting for the *Alternative Modes* criterion has a reverse pattern, representing 17% of point value for Local projects, 14% for Regional and 12% for Inter-Regional projects. This reflects an assumption that pedestrian and bicycle connectivity is most important at the local level to support short trips that replace automobile travel.

For Local scale projects, points for bicycle projects under the *Network Significance* criterion are assigned with 50% based on locally calculated centrality and 50% based on low stress network enlargement. Because segment centrality is most relevant for in-town locations with an abundance of trip origins and destinations, centrality is dropped as a factor for ranking Regional scale projects. When a centrality-based scoring scheme was initially tested for Regional scale projects, existing project priorities such as inter-town commuting or recreational routes scored poorly. Instead for Regional scale projects scoring under the *Network Significance* criterion is based 50% on known or anticipated volume of bicycle usage (either actual counts or Strava data); and 50% on enlargement of the low stress network, defined at this level as specific MPO-prioritized regional routes.

At the Inter-Regional level LTS prioritization is based 100% on whether a project closes a gap on a multi-state designated route prioritized by the MPO. In practice these include US Bike Route 1 and the East Coast Greenway.

For all three scale buckets a threshold criterion is applied that projects must improve stress level on the road segments they address from BLTS3/BLTS4 to at least BLTS2 to be counted as an improvement to the regional low stress bicycle network.

The grant period for this pilot project has not corresponded to an update cycle for any of the participating MPOs' Metropolitan Transportation Plan or Bicycle/Pedestrian Plans, so these revised scoring approaches have not yet been used for formal project selection. This said, each agency ran a test analysis of the criteria using a subset of the long-range project lists in their current Metro Plans. Also included in this were a list of additional projects identified using the BLTS tools tested here, adapted from other agencies.

8.2 Performance Measurement

As described in Section 6, the regional planning commissions identified a series of bicycle network performance measures for evaluation under this project. These were drawn from the *FHWA Guidebook for Measuring Multimodal Network Connectivity* (2019) and other municipal and regional transportation planning agencies around the country interviewed early in the project. PSU calculated baseline values for each of these measures for each of the five RPC regions and for two sample municipalities in each region. The measures included:

- Total mileage of roadway by each traffic stress level (LTS1, LTS2, LTS3, LTS4)
- Total mileage of low stress network (LTS1+LTS2)
- Percent of employment trips of ≤2 miles completable by bicycle on a low stress route
- Percent of school trips of ≤2 miles completable by bicycle on a low stress route
- Percent of community facility trips of ≤2 miles completable by bicycle on a low stress route
- Percent of all trips of ≤2 miles completable by bicycle on a low stress route (this category combined employment, school and community facility trips)

Each of these measures has strengths and drawbacks for application at the MPO level. The first two measures are easily calculated and highlight the availability of significant mileage of low stress routes in islands in most communities. This said, they do not address network connectivity. Numbers 3-6 measuring connectivity for utilitarian bicycle trips, specifically address connectivity; and variants of them have been adopted by at least one other regional agency interviewed (Montgomery County MD). These are well suited to an individual municipality, where a local commitment is made to implementation and measurement, and resources can be marshalled to complete projects, close gaps and expand the low stress bicycling network in a significant way in a relatively short (10-15 year) timeframe.

These connectivity measures can also in theory also be applied to a large multi-jurisdictional region with wide variations in population density and municipal commitment to bicycle network development. A challenge with regional application identified here is the difficulty of achieving meaningful movement of the needle for this measure on the 20-year time horizon of a regional MTP given funding constraints and the sheer number and dispersal of destinations. Significant investment by a relatively dense urban community that greatly improved connectivity locally would have limited impact in moving the needle on a regional measure also influenced by many rural communities with less well-connected networks, fewer resources and/or priority placed on trails or other recreational routes vs. connectivity for utilitarian trips.

We anticipate that these measures and the results of this research will be referenced in future updates to each of the MPOs Metropolitan Transportation Plans. For the reasons described above, though, the participating agencies' current plan for measuring progress on low-stress bicycle network expansion is to each define simple regional lists of top 20-25 network connectivity projects using the LTS data developed here. Performance will be measured based on progress getting these projects programmed and constructed.

9. CONCLUSIONS & NEXT STEPS

The Bicycle Level of Traffic Stress (BLTS) tool, as adapted for New Hampshire by Plymouth State University (PSU), offers a highly useful quantitative approach for regional planning agencies to characterize the quality of bicycle accommodation on the region's road networks and identify connectivity gaps to be prioritized for improvement.

The PSU version of the BLTS framework was developed starting in 2016 based on a desire to apply the work of Mekuria et. al. in New Hampshire combined with a recognition that available data were not adequate to run the original BLTS model from MTI and a simplified version was needed. Even with the simplified model, data development required a substantial commitment of resources and a number of challenges were identified which will need to be addressed with future updates to the analysis. While the PSU BLTS tool had previously been used in several of the state's larger cities, it was further refined through this project and used to characterize all state highways and local roads throughout the five planning commission regions.

The same methodology was also used in parallel by Alta Planning & Design to characterize all state highways in New Hampshire's other four rural planning commission regions as part of an update to the State Pedestrian and Bicycle Plan. Any effort to incorporate BLTS as a criterion for statewide project prioritization, whether for the Transportation Alternatives Program (TAP), Congestion Mitigation/Air Quality (CMAQ) program or flexible Surface Transportation Block Grant (STBG) funding, will require an expansion of the BLTS analysis for the rural RPCs to include municipal roads so there is comprehensive coverage for all roads in the state.

A key element of the project was taking initial BLTS rating results from the PSU model and posting them for public review to determine how model results matched public perception of stress levels. In total 12 outreach events were held across the five planning regions, and 172 comments were received through the Public Participatory GIS (PPGIS) interactive map set up for online comment. Critiques included the tendency of the model to underestimate LTS on routes with frequent turning movements and on road segments with substantial slope and limited sight lines. This was addressed through manual adjustments for specific segments as part of this project and can be addressed more systematically as part of future model updates. While intersection analysis is not planned due to data limitations, a factor for intersection frequency will be considered to address stress induced by auto turning movements. Future iterations will also assess use of digital elevation model (DEM) data to incorporate slope.

There were also data challenges encountered in the development of performance measures, particularly the origin-destination connectivity analyses. Census block centroids were used as origin points for route analysis and Open Street Map (OSM) data were used for locations of community facilities and education institutions. While these are common approaches, quality and completeness of OSM data varied substantially across communities, with smaller towns less likely to have complete data. Consistency of OSM data across communities will be a focus for anticipated future updates, as will identifying high quality point data for employment centers. The analysis here used centroids of census blocks with greater than 100 employees as destination points. For future updates the planning commissions will seek clearance to use employer point data collected by the NH Department of Employment Security, anonymized and grouped into clusters. While these data are used by the MPOs for travel demand modeling this separate use could not be negotiated in time for application here. This will provide better location specific destination data for assessing low-stress employment access.

The MPOs currently envision updating the LTS analysis piloted here on a four to five-year cycle as resources allow, corresponding to major updates to their respective Metropolitan Transportation Plans. This will allow tracking of LTS-based performance measures at both the regional and municipal levels. A number of changes to current practice in road and traffic data collection will greatly facilitate these updates and ensure BLTS analysis remains a useful tool on an ongoing basis. The first of these changes is incorporating shoulder width, parking and bicycle lane data as part of routine statewide road inventory work. Using Google Street View to estimate this information was viable but very time-consuming making routine update a challenge. These are critical data for bicycle and pedestrian planning and should be collected by default. A second improvement with uses far beyond bicycle network planning is a joint multi-region or statewide purchase of cell phone-based data on prevailing speed and AADT. These data are already available for state highways as part of the National Performance Road Management Data Set (NPRMDS), but not currently available to the regional planning commissions for local roads. Access to reliable data on prevailing speed for all roads would improve the reliability of LTS model output as well as general regional traffic modeling. A third need will be access to ESRI Network Analyst for all RPC regions, several of which do not currently have access to that ArcGIS extension.

This study has been intended to help transportation planners with smaller MPOs and rural regional planning agencies to integrate Bicycle Level of Traffic Stress (BLTS) analysis in performance-based planning, including project identification and prioritization. These tools are of equal or perhaps even greater value at the municipal level and will be used by planning commission staff for local technical assistance on municipal master plan transportation chapters and local bicycle and pedestrian plans as much as for regional analysis. While the PSU model was specifically designed for use by smaller New Hampshire agencies lacking extensive, reliable data on the range of road attributes included in the original Mekuria model, it would be equally useable for other states and regions. Python scripts for a range of other streamlined BLTS models are now available to agencies nationally as well (Harvey et. al., 2019). The data collection, analysis and review processes and visualizations presented here provide new opportunities to improve regional and local bicycle network planning in New Hampshire. Hopefully these examples, including discussion of challenges encountered, solutions applied and planned future refinements, can help facilitate similar opportunities in other regions.

REFERENCES

AASHTO Task Force on Geometric Design. (2012) "AASHTO Guide for the Development of Bicycle Facilities." American Association of State Highway and Transportation Officials, Washington, DC.

Conveyal. (2016) "Better Measures of Bike Accessibility," Conveyal, December 15, 2016. http://conveyal.com/blog/2015/12/15/bike-accessibility

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.

Twadell, H., Dill, J., Varas, K. (2018). FHWA Guidebook for Measuring Multimodal Network Connectivity. Federal Highway Administration Report FHWA-HEP-18-032.

Furth, P. (2017). Level of Traffic Stress Criteria for Road Segments, Version 2.0. Northeastern University College of Engineering

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

Getts, L. (2017). Methods for Investigating and Advancing Active Transportation in New Hampshire. Plymouth State University. Masters Thesis.

Harvey, C., Fang, K. Rodriguez, D.A. (2019). Evaluating Alternative Measures of Bicycling Level of Traffic Stress Using Crowdsourced Route Satisfaction Data. *Mineta Transportation Institute*, Project 1711. San Jose State University.

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.

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.

Montgomery County Maryland. (2017). Montgomery County Bicycle Master Appendix D: Level of Traffic Stress Methodology.

New Hampshire Department of Health and Human Services. (n.d.). Social Vulnerability Index: An Emergency Response Tool.

People for Bikes. (2017). Bike Network Analysis Methodology. People for Bikes. https://bna.peopleforbikes.org/#/methodology.

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, *2013-2017* United States Census Bureau – LODES Data.

Villamagna, A. (2019). Active Transportation Accounting: A three-pronged approach to developing metrics for project prioritization, monitoring, safety assessment, and evaluation. Research Report to NHDOT.