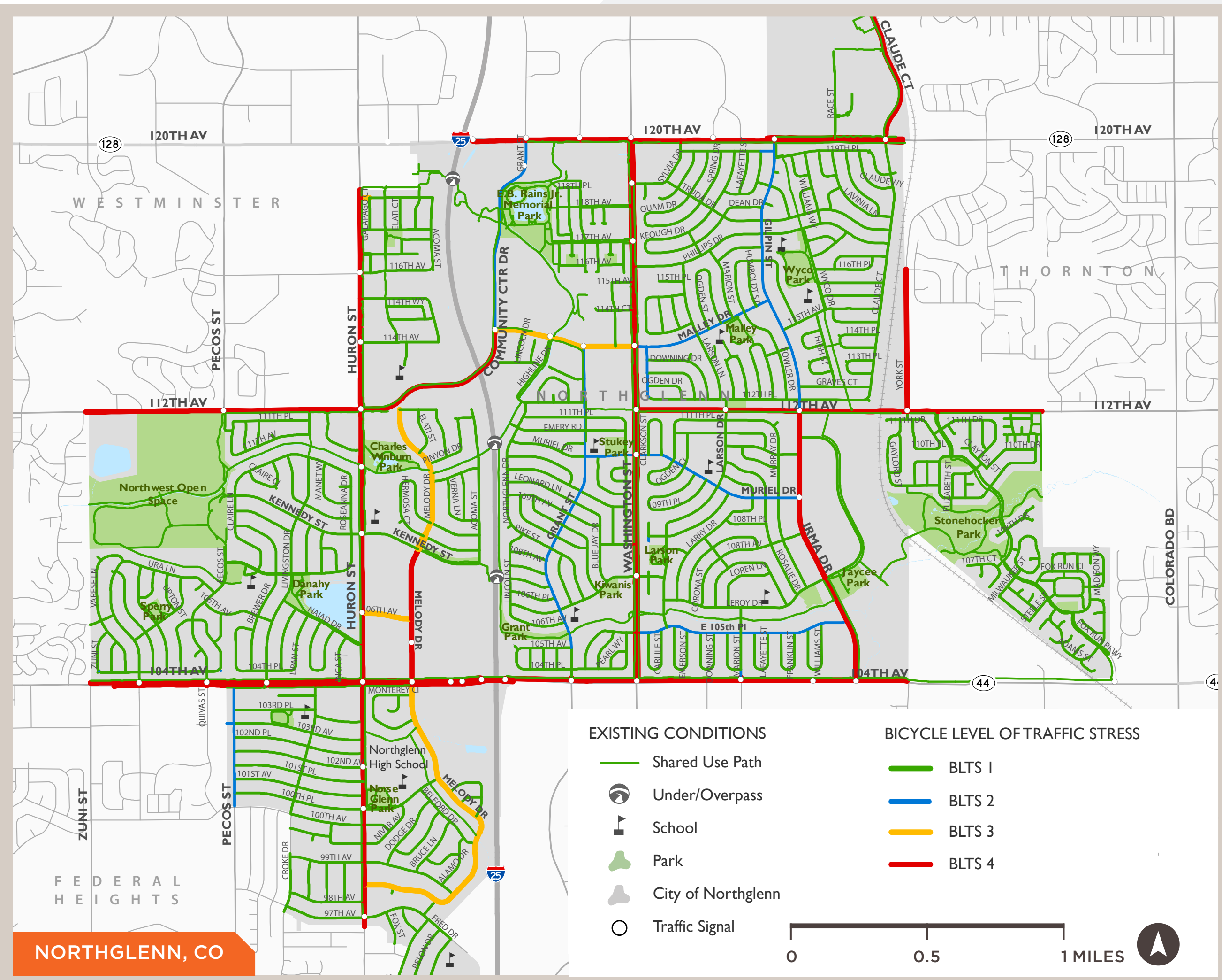


Source: City of Northglenn Department of Transportation. 2017. "Connect Northglenn: Bicycle and Pedestrian Master Plan."

PEER APPLICATION

- In Oregon, the Department of Transportation calls for Bicycle LTS as the preferred measure for Regional Transportation Plans and Transportation System Plans. It can also be used on a screening-level basis for project development and development review. The methodology is outlined in the state's most recent update of its Analysis Procedures Manual, which includes strategies for rural applications that consider shoulder width as well as traffic volumes and speeds.[1]

1 *http://www.oregon.gov/ODOT/Planning/Pages/APM.aspx*

ADVANTAGES

- Specifically considers user (and potential user) differences
- Simple interpretation, making it suitable for use in a variety of contexts
- Captures the quality of a wide range of facilities and crossings, with a strong focus on the extent to which motor vehicle traffic makes cyclists feel unsafe
- For a complex measure, it has been widely applied and the framework is familiar to many practitioners
- Can be applied at route level for broader range of applications

CONSIDERATIONS

- Data-intensive and assumptions can impact the usefulness of the results
- Classification scheme is not strongly supported by preference data
- "All or nothing" classification, sensitive only to "weakest link" improvements
- Methods are not yet validated against behavior/use data

CONNECTIVITY MEASURE

BICYCLE LOW-STRESS CONNECTIVITY

What is the quality of bicycle connections between origins and destinations?

MODE	METHOD	OUTPUTS	CONNECTIVITY ANALYSIS METHODS	ACCESSIBILITY	USE IN PRACTICE	LEVEL OF EFFORT
	Assess routes among types ("basket") of destinations based on link and attribute weighting; aggregate connectivity at range of scale	Centrality by link or project; percent of destinations reached; impedance	Directness, Accessibility, Quality	Explicit consideration of accessibility for people with disabilities: **No**	Emerging	HIGH

DESCRIPTION

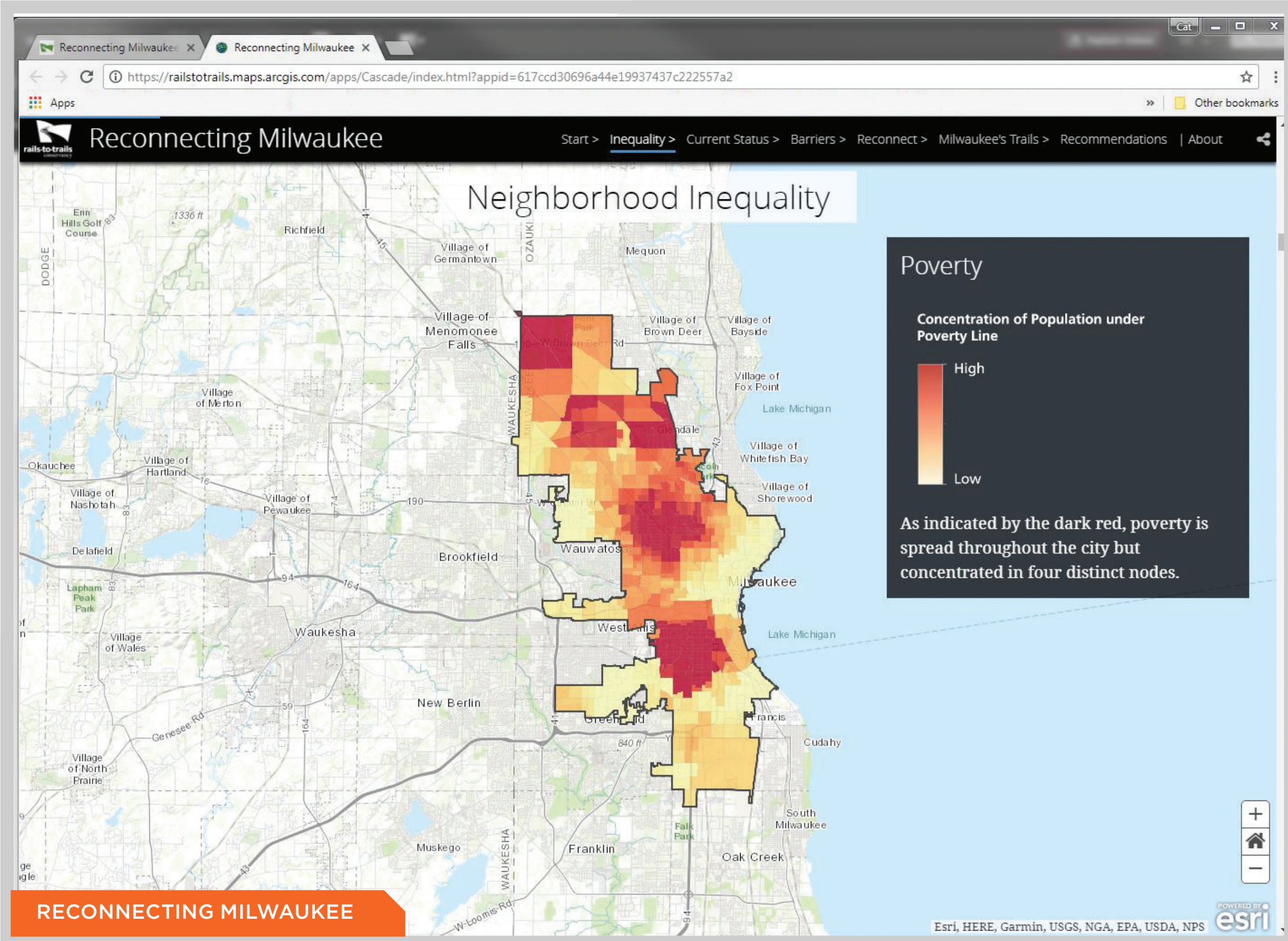
Bicycle low-stress connectivity measures help planners to assess access to key destinations and to identify the importance of specific network links. Low-stress Bicycle Connectivity was designed specifically to prioritize and evaluate bicycle infrastructure projects. The measure combines elements of Level of Traffic Stress (LTS) and Route Quality Index (RQI) in a new way to gauge the quality of routes connecting origins and destinations. A key element is a defined "basket" of destinations. Positive points are awarded if destinations can be reached using routes of acceptable stress levels (accounting for traffic stress and terrain). Outputs include parcel-level accessibility scores and a measure of each planned project's "centrality," a measure of importance related to the expected number of cycling trips that would use links related to the project.

EXAMPLE PLANNING APPLICATION(S)

- To identify segments and routes that are most likely to be utilized by bicyclists
- To consider strategies for improving the quality of connections and/or the range of available destinations that bicyclists can access comfortably and safely
- To compare quality of connectivity within subareas or across regions (not suited to assessments of a single link)

TYPICAL DATA

- Roadway centerline, including number of lanes and posted speed
- Bicycle infrastructure, including type and width
- Intersection attributes (e.g. signals) and bicycle accommodation
- Potential destinations



Source: Rails to Trails Conservancy. 2017. "Reconnecting Milwaukee." https://railstotrails.maps.arcgis.com/apps/Cascade/index.html?appid=617ccd30696a44e19937437c222557a2.

PEER APPLICATION

- Test scenarios have been run by the Rails-to-Trails Conservancy on citywide transportation networks in Seattle, Washington and Milwaukee, Wisconsin using their BikeAble connectivity analysis tool.
- PeopleForBikes Bicycle Network Analysis Tool, described in more detail elsewhere in this document, has been applied to a range of cities and small towns around the U.S.

ADVANTAGES

- The tool is specifically designed to test scenarios
- The tool can produce corridor-level results for a broader range of applications
- A default set of origins and destinations are defined, though these can be modified
- The tool captures the quality of facilities, with a strong focus on the extent to which vehicle traffic makes cyclists feel unsafe
- Intersections and crossings are considered

CONSIDERATIONS

- The tool is data intensive
- Computation of the scores is time- and effort-intensive
- The classification scheme blends existing measures in an ad hoc way
- The results are not yet validated against behavior/use data
- Transferability to rural contexts is not well understood, and rural facilities may not easily fit within the existing urban-oriented scoring framework

CONNECTIVITY MEASURE

BICYCLE ROUTE QUALITY INDEX (RQI)

Where are the best bicycle available routes between given origins and destinations, considering elements such as directness, trip purpose, and supporting infrastructure?

MODE	METHOD	OUTPUTS	CONNECTIVITY ANALYSIS METHODS	ACCESSIBILITY	USE IN PRACTICE	LEVEL OF EFFORT
	Link and intersection attributes are scored by weighted formula; routes are solved between a defined set of destinations. Route scores are indexed and aggregated to origin points/areas.	RQI measure for a route (relative to distance) or facility (for origin/destination areas); ranges from 0 to the best facility possible, with 1.0 reflecting an "adequate" or reference facility	Accessibility to Destinations, Directness, Quality	Explicit consideration of accessibility for people with disabilities: **Not in current forms, but could possibly be added given the complexity of the infrastructure data supporting the measure.**	Emerging	HIGH

DESCRIPTION

Bicycle RQI is an emerging measure that is still largely in the research phase. Portland, OR has been the leader in developing and applying RQI measures. It allows for a more nuanced, complex assessment of quality compared to other measures because it takes into account additional variables such as trip purpose (e.g. commute versus noncommute), roadway slope, and detailed intersection attributes. Several variations of a Route Quality Index (RQI) have been applied, all of them based on route choice models developed at Portland State University (Broach, Dill, and Gliebe 2012) in conjunction with Portland Metro MPO.

The route choice models provide weights for a range of network attributes, including separation from traffic, delay factors, intersection crossing aids and traffic volumes, and terrain. The weights can be used to generate lowest cost or "best" routes to represent the connectivity between a given origin point and some defined set of destination points. Individual routes are typically aggregated and standardized to create an indexed score for use in planning applications. A related technique was developed using a different route choice model developed in San Francisco, CA (Hood et al., 2011).

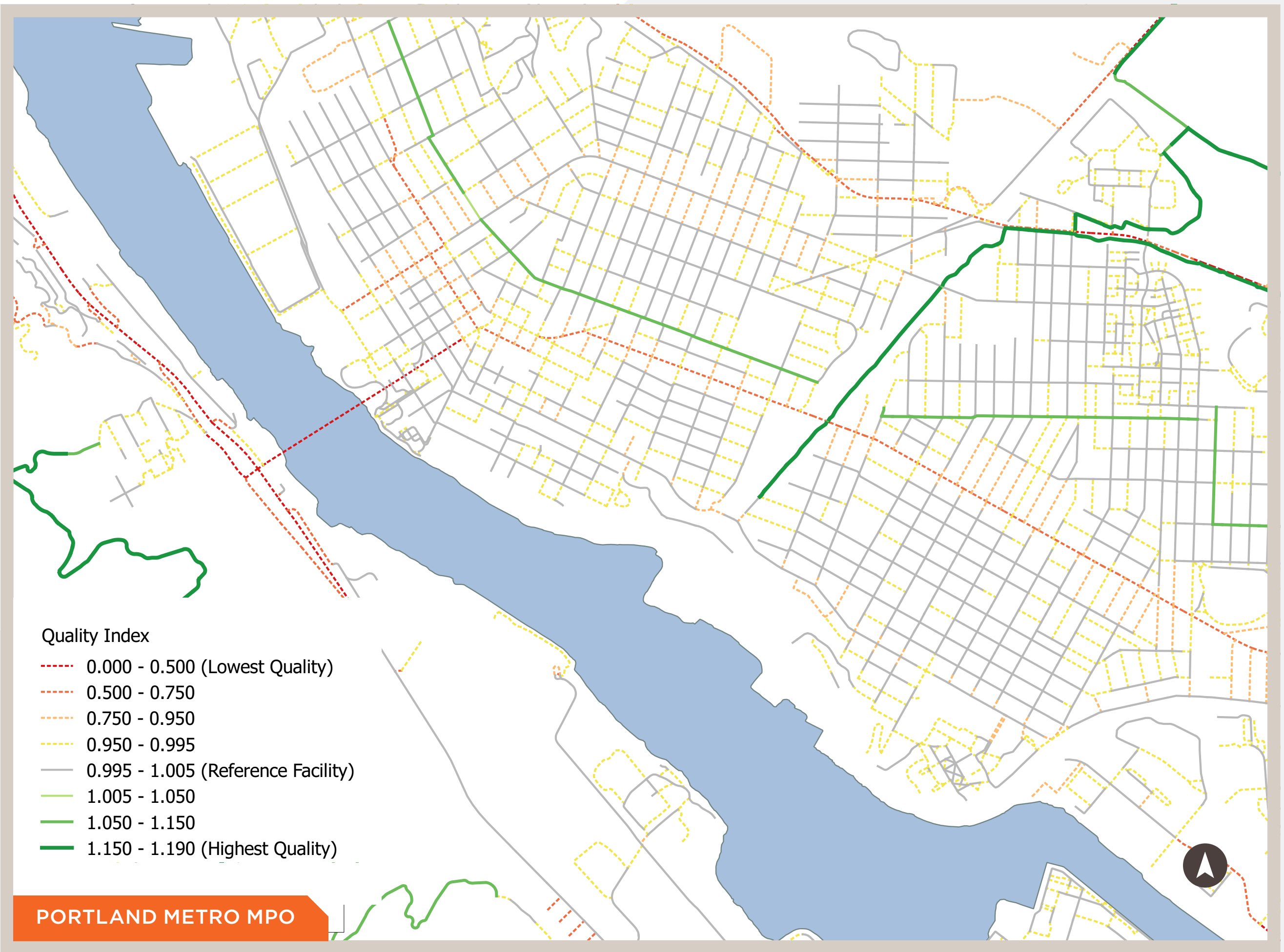
The primary use of RQI-type measures has been in regional bicycle travel demand models. However, recent extensions have applied RQI as a standalone connectivity measure to test scenarios and predict bicycle use.

EXAMPLE PLANNING APPLICATION(S)

- To identify the relative demand for particular routes
- To set priorities for projects that help to support higher demand on key routes and to attract new bicycle trips in corridors that currently score lower on the index
- To select among competing projects based on predicted mode shift

TYPICAL DATA

- Nonmotorized network: Bike lanes, shared-use paths (regional, local use), bicycle boulevards, road slope
- Transportation infrastructure: Traffic signals, stop signs, traffic volume (or functional class), major bridges, one-way streets
- Traveler origins, destinations, and trip purposes (commute/noncommute)



PEER APPLICATION

- Portland Metro MPO uses a version of RQI to measure bicycle connectivity in its regional travel model. Various research applications have been reported as well (Broach and Dill 2016; Broach and Dill 2017).

ADVANTAGES

- Quality weights cover a broad range of factors and are supported by revealed preference route choice data
- Relatively low data requirements for a route-based measure
- Validated against use using both individual trip and aggregate Census commute data
- Acknowledges difference between commute and noncommute connectivity
- Can be used to calculate bike commute shares under future scenarios
- Captures intersection crossing difficulty
- Includes slope of roads in assessing connectivity

CONSIDERATIONS

- Application of the method is complex
- Data on traffic volumes, stop signs, and other key elements are not always available
- No attempt is made to capture quality differences among similar bike facilities (e.g. bike lane widths or pavement quality)
- The measure does not account for some roadway attributes (e.g. parking, speed, width) captured by related quality measures
- The measure has so far been applied exclusively in particularly bike-friendly urban areas; transferability of quality weights is not yet established for use in different types of places

CONNECTIVITY MEASURE

PEDESTRIAN INDEX OF THE ENVIRONMENT (PIE)

Where are the most walkable areas ("zones") of a city?

MODE	METHOD	OUTPUTS	CONNECTIVITY ANALYSIS METHODS	ACCESSIBILITY	USE IN PRACTICE	LEVEL OF EFFORT
	Calculate a series of form-based factors around a given destination. Enter the factors into a weighting equation to calculate PIE	PIE, a standardized score of walkability (20 to 100) at the Pedestrian Analysis Zone (PAZ) scale. Predicted walk share of trips to given destination, based on PIE, is also possible with additional demand data	Directness, Accessibility to Destinations, Quality	Explicit consideration of accessibility for people with disabilities: **No, but could potentially be added**	Experimental	HIGH

DESCRIPTION

PIE measures indicate the quality and attractiveness of the walking environment based on facilities and the presence of pedestrian destinations/amenities (Clifton et al. 2013). PIE is somewhat unusual among walkability indicators in that it starts with locating pedestrian-oriented destinations and works backwards to define walkability. PIE is a composite index of various form-based measures, combined in a weighted equation that was developed and validated against travel survey data. Data needs are relatively low, with the exception of specific business types, and all of the measures can be calculated using simple GIS analysis techniques. PIE was developed as one component of a Regional Pedestrian Travel Model. PIE is not widely used at this time, though it has the potential to effectively describe improvements to pedestrian networks in terms of network use.

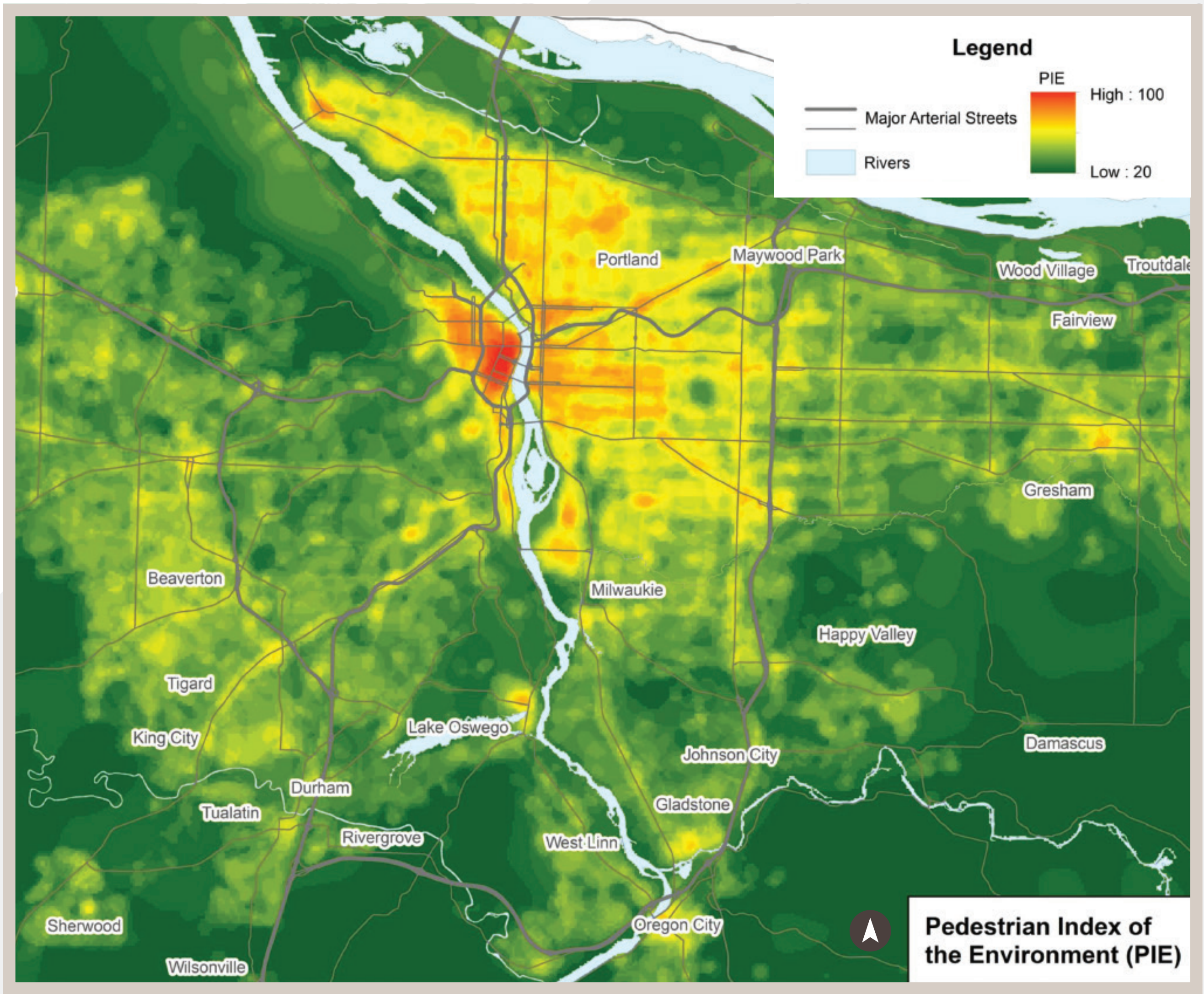
EXAMPLE PLANNING APPLICATION(S)

- To identify areas with high potential pedestrian travel demand
- To set priorities for projects that support high demand areas
- To identify projects that could increase pedestrian attractiveness in designated areas

TYPICAL DATA

- Off street paths or trails, sidewalks
- Block size
- Activity density (population and employment)
- Land use (retail, restaurants, schools, etc.)

Source: FHWA



Source: Clifton, K. J., Singleton, P. A., Muhs, C. D., Schneider, R. J., & Lagerwey, P. (2013). Improving the representation of the pedestrian environment in travel demand models, Phase I. Oregon transportation research and education consortium (OTREC-RR-510). http://ppms.trec.pdx.edu/media/project_files/Clifton_510_final_combined.pdf

PEER APPLICATION

- Portland Metro MPO (Oregon) is in the process of implementing PIE as part of their regional travel demand model. A related project to gauge transferability to other regions is also underway.

ADVANTAGES

- Quality weights are supported by revealed preference travel survey data
- The data and computation needs are modest
- The tool was validated as a predictor of walking using travel survey data
- A simple grid is used to define destinations; no need to define origins and destinations
- With additional data overlays, it can be used to predict walk mode share

CONSIDERATIONS

- Form-based measures are not very sensitive to specific network connectivity or quality improvements
- The tool assesses bicycle facilities to measure pedestrian network quality
- The initial version does not provide summary scores for varying aggregation levels
- The tool has only been used in Portland, though additional applications are currently underway

CONNECTIVITY MEASURE

PEDESTRIAN LEVEL OF SERVICE (PLOS)

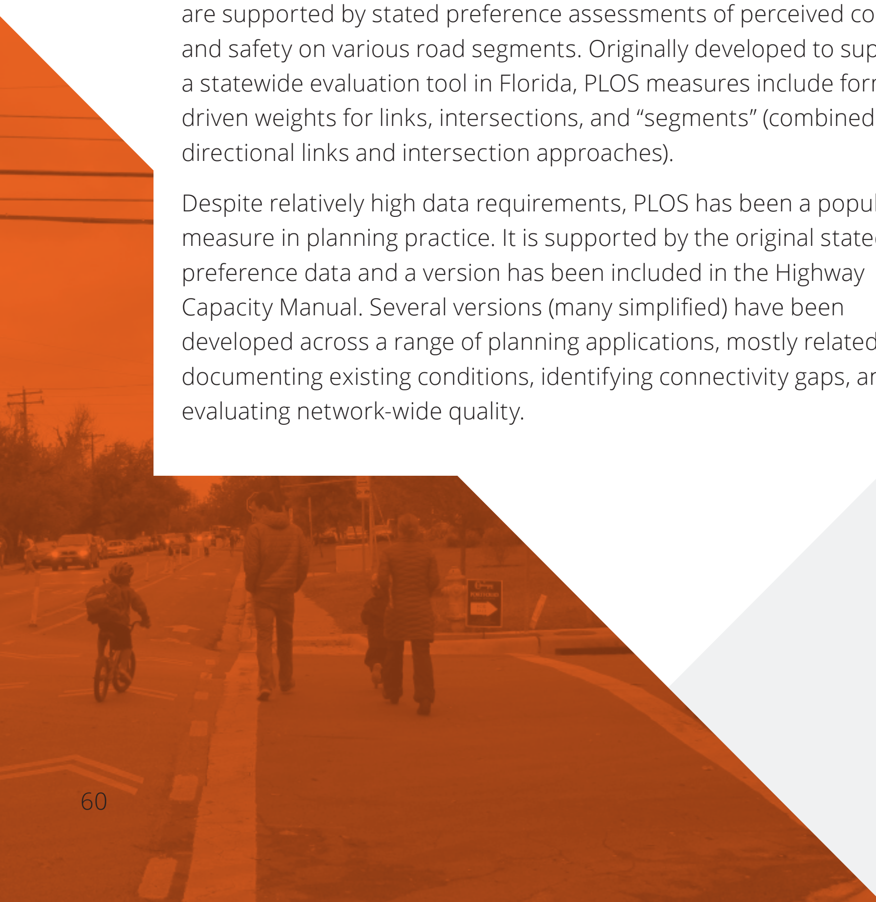
How well does network infrastructure support pedestrian travel, including interaction with other modes, based on perceived pedestrian comfort levels?

MODE	METHOD	OUTPUTS	CONNECTIVITY ANALYSIS METHODS	ACCESSIBILITY	USE IN PRACTICE	LEVEL OF EFFORT
	Inputs entered in a weighted model to calculate link score (*Note: calculations also available for intersections, but these are very complex)*	Numeric scores converted by formula to a six-point scale (A through F)	Quality	Explicit consideration of accessibility for people with disabilities: **No**	Common	LOW

DESCRIPTION

Similar to Bicycle Level of Service (BLOS), PLOS is an attempt to adapt a commonly applied measure of motorized network performance to pedestrian facilities (Landis et al. 2001). PLOS measures indicate the level to which the infrastructure supports pedestrian travel, and how well pedestrian travel interacts with other modes, based on perceived pedestrian comfort levels. PLOS variables and thresholds are supported by stated preference assessments of perceived comfort and safety on various road segments. Originally developed to support a statewide evaluation tool in Florida, PLOS measures include formula-driven weights for links, intersections, and "segments" (combined, directional links and intersection approaches).

Despite relatively high data requirements, PLOS has been a popular measure in planning practice. It is supported by the original stated preference data and a version has been included in the Highway Capacity Manual. Several versions (many simplified) have been developed across a range of planning applications, mostly related to documenting existing conditions, identifying connectivity gaps, and evaluating network-wide quality.

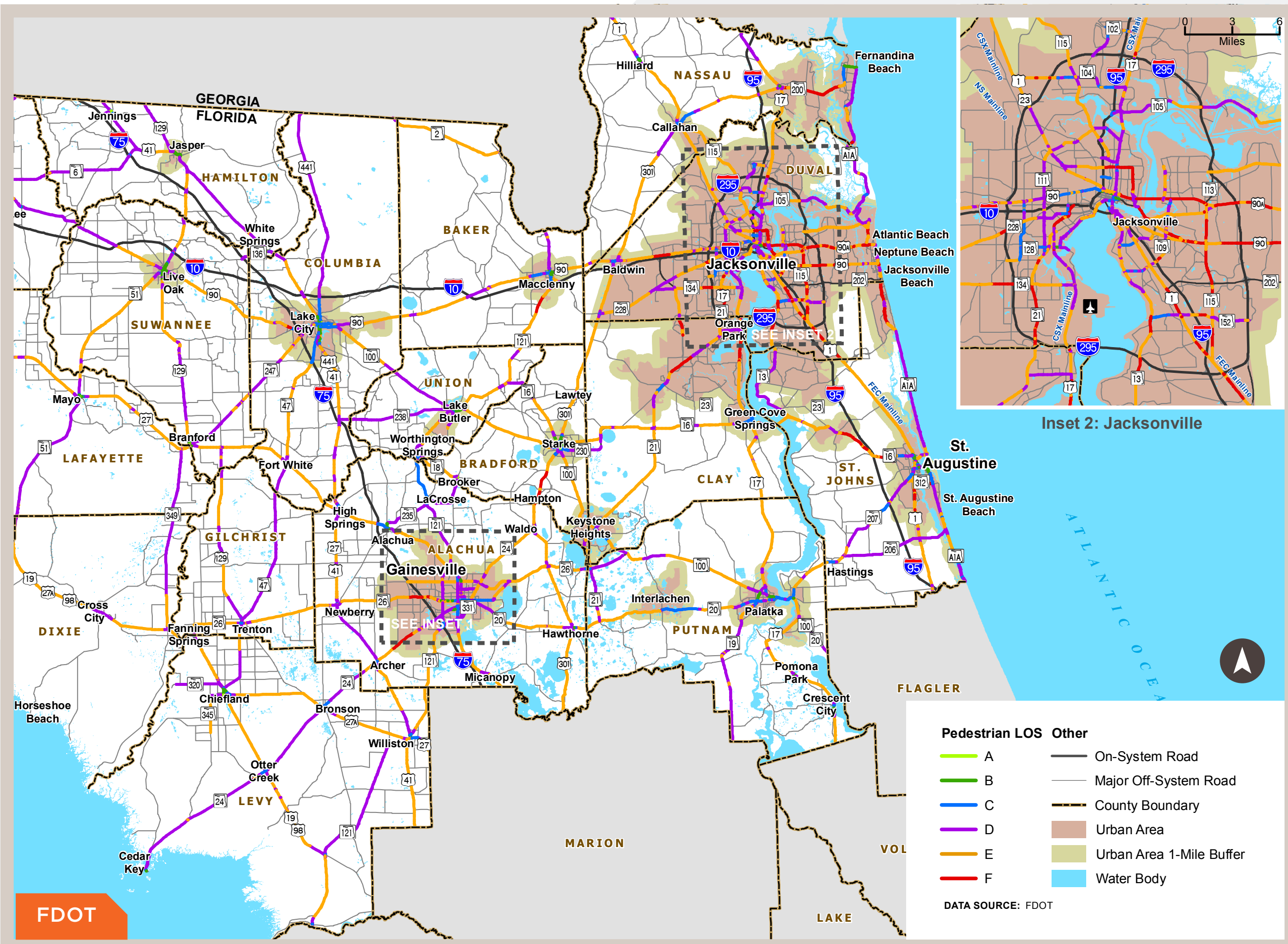


EXAMPLE PLANNING APPLICATION(S)

- To assess the potential impacts of changes such as building or removing a major pedestrian facility on an area-wide network
- To identify the performance of subareas, zones, and corridors within the network
- Not generally useful for subarea analyses of specific links or corridors such as local streets, paths, and trails, nor for individual project development plans

TYPICAL DATA

- Sidewalks (including widths and barrier heights, if any)
- Motorized traffic data: Traffic volumes, traffic speeds, percent heavy vehicles
- Street network data: Number of lanes, outside lane width, bicycle lane width, width of paved shoulder, presence of curbs, on-street parking occupancy, buffer width between road and sidewalk, driveway access frequency and volume
- Defined set of destinations or origin/destination zones and routable network to extend analysis to destination access



Florida Department of Transportation. 2015. "Bicycle and Pedestrian Gap Study." http://www.fdot.gov/planning/systems/programs/sm/los/districts/district2/Bike_Ped/Bicycle_and_Pedestrian_Level_of_Service.pdf.

PEER APPLICATION

- PLOS standards are used by the Florida Department of Transportation in the review of actions that directly impact the State Highway System for all planning and permitting processes. Methods are outlined in the Quality/Level of Service Handbook (2013).

ADVANTAGES

- It is related to vehicle LOS, which is widely used and understood
- An adopted measure included in the Highway Capacity Manual
- It captures the quality of facilities, with a strong focus on the extent to which vehicle traffic and parking make pedestrians feel unsafe or uncomfortable

CONSIDERATIONS

- It is data-intensive, particularly in the adopted HCM version
- The results are not applicable to quiet local streets, paths, or trails
- The measure is not designed for route-level assessment
- The measure has not been validated by use or behavior data
- The measure has a low sensitivity to changes in sidewalk width and buffer presence

CONNECTIVITY MEASURE

PEDESTRIAN LEVEL OF TRAFFIC STRESS (PLTS)

What is the extent to which pedestrians feel safe and comfortable using the network?

MODE	METHOD	OUTPUTS	CONNECTIVITY ANALYSIS METHODS	ACCESSIBILITY	USE IN PRACTICE	LEVEL OF EFFORT
	Classify sidewalk segments by type by highest stress attribute	Pedestrian stress rating of 1 through 4 for sidewalk centerline and intersections	Directness, Accessibility to Destinations, Quality	Explicit consideration of accessibility for people with disabilities: **Yes**	Emerging	HIGH

DESCRIPTION

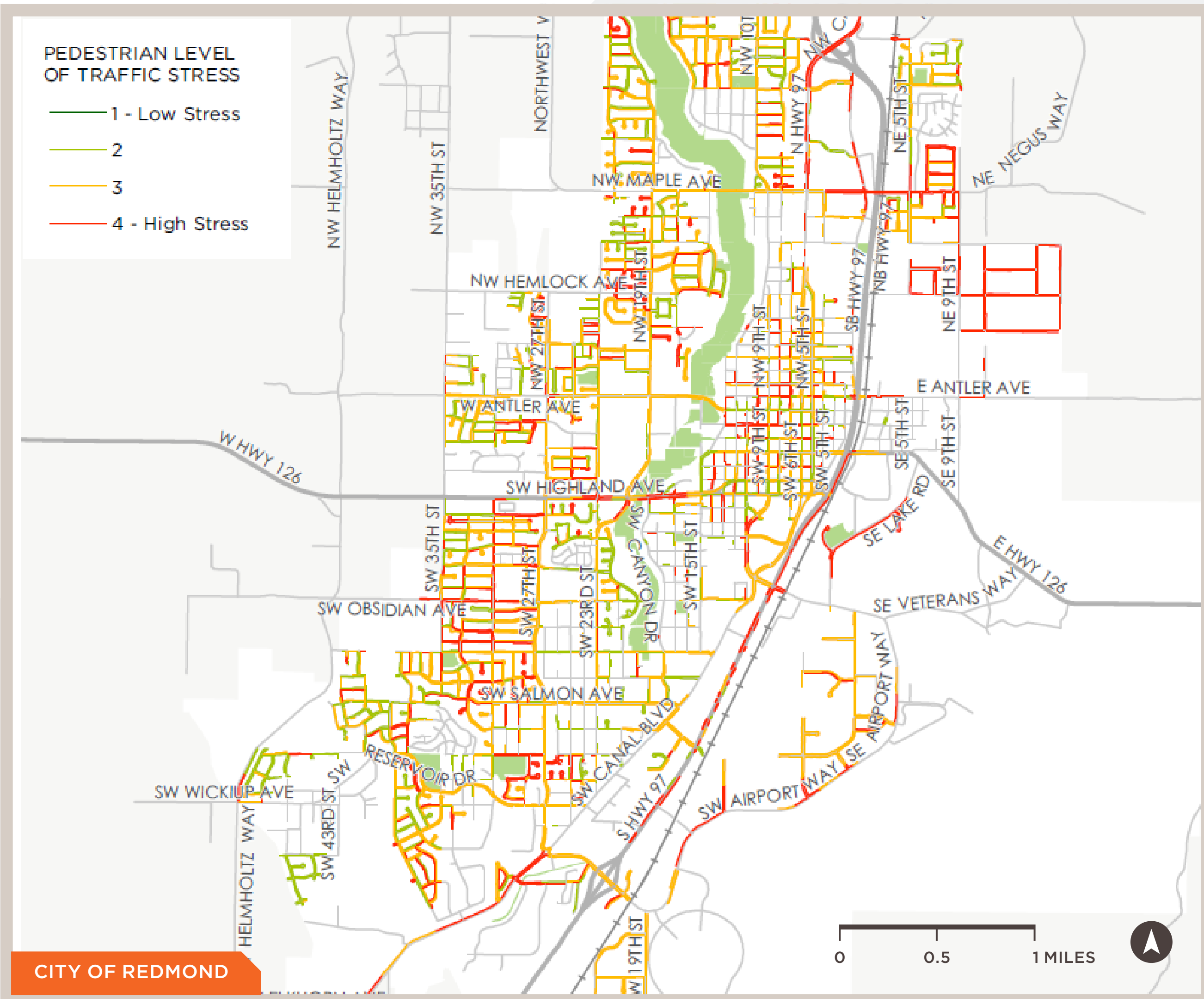
Pedestrian LTS measures indicate the relative level of comfort for pedestrians using a given network, taking into account the variety of abilities and trip purposes among different types of people. The categories of pedestrian traveler characteristics, including user types and trip purposes, are similar to those developed for Bicycle LTS measures. Criteria and thresholds are customized for pedestrians, as described in the Oregon Department of Transportation's Analysis Procedures Manual (2016). Links are classified based on their most stressful feature, including the impact of crossings. Application to measures of connectivity are done best in conjunction with form-based measures.

EXAMPLE PLANNING APPLICATION(S)

- To identify factors that contribute to low- and high-stress corridors and routes
- To set priorities for locations that need specific types of improvements

TYPICAL DATA

- Sidewalk centerlines, widths, surface types, surface quality
- Crossing locations, marking, lighting
- Curb ramps and other infrastructure supporting access for people with disabilities
- Motorized traffic data: Traffic volumes, traffic speeds
- Street network data: Number of lanes, lane width, width of paved shoulder, presence of curbs, on-street parking
- Pedestrian origins and destinations



Steve Faust and Anais Mathez, Cogen Owens Green to Deborah McMahon, City of Redmond. May 22, 2017. Redmond Neighborhood Revitalization Plan: Draft Technical Memorandum #1 Existing and Future Conditions.

PEER APPLICATION

- In Oregon, Pedestrian LTS is the preferred method defined by the DOT for Regional Transportation Plans and Transportation System Plans. It can also be used on a screening-level basis for project development and development review. The recommended PLTS measurement methodology will be outlined in the updated ODOT Analysis Procedures Manual. [1]

1 *http://www.oregon.gov/ODOT/Planning/Pages/APM.aspx*

ADVANTAGES

- Provides a comparable measure to BLTS
- Provides a detailed understanding of individual sidewalk centerline segments and provides visually descriptive picture of physical conditions
- The tool is sensitive to disability access concerns, including ramp quality and surface quality
- It allows adjustments for additional treatments or infrastructure intended to improve the pedestrian environment

CONSIDERATIONS

- The tool is data-intensive
- The data cannot easily be used
- The results are not validated against behavior/use data
- The classification is sensitive only to “weakest link” improvements
- The current methodology precludes improvements in certain areas based on land use types
- In rural areas, the definition of sidewalks and criteria within the measure may need to be adjusted to reflect nonurban characteristics

04

LESSONS LEARNED

This FHWA resource highlights ways that different communities have mapped their existing and proposed bicycle networks. It shows examples of maps at different scales, while also demonstrating a range of mapping strategies, techniques, and approaches.

https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/strategic_agenda/fhwahep16086.pdf.

LESSONS LEARNED

To support the development of this guide, FHWA reached out to numerous transportation planners through webinars, interviews, and focus groups for input and advice about their experiences with analyzing multimodal connectivity. The research team also worked directly with five agencies to conduct assessments that involved the methods and measures described in this guide. The comments in this chapter are a synthesis of reflections and suggestions from both the case study participants and other peer participants in this research. More specific details on the processes conducted and lessons learned by each case study agency are included as an appendix to this guide.

STEP 1: IDENTIFYING THE PLANNING CONTEXT

- Articulate a clearly defined network vision and analysis goal to help analysts determine the right level of detail for the analysis purpose. Networks are complex, and collection of detailed facility data is highly time intensive. The key is to balance the tradeoffs between simplifying data attributes in order to improve the efficiency of network data collection and limiting the questions that can be answered by the analysis.

STEP 2: DEFINING THE ANALYSIS METHOD

- Select a method appropriate for the intended application. Refer to the planning context identified in Step 1 that defines how the analysis will be used in order to help determine the appropriate analysis method and measures. Consider how the measures and analysis results could be used over time and in conjunction with other processes to help fine-tune the decision.
- To enhance accountability, select measures that can be tracked over time. Taking into account the potential availability of data for future analyses, and the possibility that the measures or analysis parameters might need to be changed over time, select measures that are likely to be useful, replicable, and comparable for years to come.
- Select methods and measures appropriate for the study area context. The analysis techniques discussed in this guide provide varying levels of detail about the multimodal network. Not all measures are appropriate for all development contexts. Communities with extensive existing bicycle and pedestrian networks may need to use more sophisticated connectivity measures to capture the full impact of planned projects. Simple methods such as network density analyses capture only the extent to which facilities do or could exist on the ground. More complex approaches such as low-stress indices enable planners to consider the benefits of recent or potential improvements to a mature network. For example, the bicycle and pedestrian network in many areas of the Portland region is largely built out. Metro uses low-stress analyses to help set priorities for filling gaps and improving existing facilities rather than focusing on building new facilities. In rural communities or newly growing suburbs, the network may be too sparse to allow for meaningful analyses of detailed connectivity measures such as stress indices.
- Consider potential implications when modifying existing methods and measures. Agencies commonly adapt connectivity measures to fit available data and technical capacity. This is understandable given the complexity of some measures, but it can make results harder to compare over time, and may require additional research support and validation.
- Stay informed about emerging connectivity analysis methods and measures. Researchers and practitioners are continually refining measures and developing new computation techniques that may be more sensitive to local policies and priorities. Although the implications of applying new methods or measures should be considered carefully, it is important to keep striving for richer, more accurate information to support well-informed decisions.

STEP 3: ASSEMBLING DATA

- Promote consistent standards for local bicycle and pedestrian facility data. Local governments often use different attributes to describe bicycle facilities, and apply different metadata, geographic units, and accuracy standards to GIS datasets. This creates difficulty in merging datasets. Ideally, spatial data for both current facilities and planned projects should use the same attributes and reference networks. Promoting bicycle facility data standards for use by local governments up front can streamline data assembly and analysis for regional agencies and improve the quality of analysis results.
- Establish data storage parameters that are consistent with the selected measure. By storing data in formats that limit the need for extensive processing in order to run the selected analysis, agencies increase their efficiency and their ability to replicate analyses.
- Develop policies and procedures to ensure that the standards for maintaining and updating data with appropriate frequency and levels of accuracy are consistent among various departments and agencies. The quality of an analysis depends on the quality and accuracy of the datasets. These policies can also define important operational elements, such as the lead agencies and staff members responsible for maintaining different datasets.

STEP 4: COMPUTING METRICS

- Be prepared to conduct secondary research and validation exercises to increase the accuracy of the results. All analysis methods and measures have strengths and weaknesses, and could present a distorted picture if not examined carefully. For example, the weakest-link methodology of Level of Traffic Stress analyses is conservative, restricting potential travel to only the lowest-stress facilities. Additional research and validation might be required to understand more fully which representation of user behavior is more accurate, and whether a hybrid behavior profile is the most accurate approach.
- Test connectivity measures before committing to them. One of the case study communities was able to use the technical assistance to test measures that had been agreed with stakeholders but not tested for practical application. The technical assistance process provided a valuable opportunity to refine the methodology, check whether the measures captured what the stakeholders really intended to measure, and think about how to communicate results.

STEP 5: PACKAGING RESULTS

- View the picture from several perspectives. Using several different connectivity analysis tools allows staff, decisionmakers and the public to interpret the network through multiple lenses including safety, equity, and accessibility. This can mitigate the weaknesses of a single technique and lead to a more comprehensive understanding of conditions.
- Overlay the analysis results with a variety of other information. For example, travelshed analyses offer rich visual information that helps to illustrate how well low-stress facilities connect to different parts of each study area. Overlaying quantitative measures with travelshed information makes it much easier to interpret results and compare the benefits of different projects or planning scenarios.
- Consider how subarea or segment analyses can be reflected in a network level. Simply measuring the quality of selected pieces of a multimodal network may not be sufficient to meet many analysis goals. Consider how, for example, the ways in which segments that have been evaluated on a stress index could (or do) connect to form routes that provide access to specific destinations, or how well a combination of routes can provide access to key destinations. The process of layering analyses of nodes, segments, and networks at different scales can inform a broad range of connectivity questions.

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APPENDIX

CASE STUDIES

As part of the development of this guidebook, the following five transportation planning agencies volunteered to test one or more of the connectivity analysis methods and measures described:

- Atlanta Regional Commission
- City of Baltimore
- California Department of Transportation District Four office
- City of Fort Collins
- Portland Metro

Each agency worked with the project team through the five-step process of identifying the planning context, defining the analysis method, assembling data, computing metrics, and packaging the results. Illustrations throughout the guidebook include maps and insights provided by the case study communities, and Chapter 4 summarizes advice to practitioners based on the lessons learned from the case studies. A full description of the case studies is available in the Appendix.[1]

1 *https://www.fhwa.dot.gov/environment/bicycle_pedestrian/*

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