INFO BRIEF

Using Connectivity Measures to Evaluate and Build Connected Bicycle Networks

Pedestrian and Bicycle Information Center

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Introduction

Based on research demonstrating that complete, connected bicycle networks increase ridership and improve safety outcomes for all modes, communities across the U.S. are focusing their efforts on building bicycle networks that provide everyone with seamless access to the places they want to go. Traditional bicycle network measures such as 'miles of bike lanes' focus on infrastructure quantity rather than quality. To build connected, comfortable bicycle networks, communities need to be able to quantify network quality so that they can benchmark the status of the existing bicycle network, set goals, prioritize projects, and measure progress. This brief will provide a short overview of current approaches for measuring bicycle network quality focusing on a case study using the PeopleForBikes Bicycle Network Analysis (BNA) to evaluate the impact of planned projects.

Bicycle Network Connectivity Measures

Bicycle network connectivity measures share features with network connectivity measures for car and pedestrian travel, prioritizing efficiency, safety, and access to key destinations. Adaptations specific to the needs of bicyclists include setting appropriate travel distance expectations, distinguishing between diverse types of bicycle infrastructure, and factoring in the influence of car traffic upon bicyclists' comfort and safety.

Existing measures fall into three categories: road stress rating, connectivity, and route choice modeling. Road stress rating measures classify streets, pathways, and intersections according to their suitability for bicyclists. Factors that make a street, pathway, or intersection suitable for bicyclists include road characteristics such as traffic speed, traffic volume, and the number of travel lanes, as well as the presence and type of bicycle infrastructure. Bicycle Level of Service (BLOS) and Level of Traffic Stress (LTS) are two popular examples of road stress rating measures that have been applied in diverse settings.

Connectivity measures combine road stress ratings with travel origin and destination data to score how well bicyclists can access key destinations. If a bicycle rider can safely and efficiently travel from point A to point B using a route that is highly suitable for bicyclists, the connectivity score improves. If they cannot, the connectivity score is low. Connectivity measures repeat this calculation for numerous origins and destinations across the study area. The resulting data helps identify disparities in bicycle network access across the region and highlight important links in the bicycle network.

Route choice models incorporate aspects of both road stress rating and connectivity measures with an added focus on rider preferences under current conditions. Route choice models explain tradeoffs in route selection as a function of detailed route characteristics including road and bike infrastructure, and as a function of rider characteristics such as their demographics and trip purposes. Route choice models also help explain when and why travelers select other modes of travel over bicycles.

To date, there have been several reviews of best practices in measuring bicycle network connectivity, such as the Federal Highway Administration's (FHWA) **Guidebook for Measuring Multimodal Network Connectivity** released in 2018 (Twadell et al.) (See Sanders et al., In Press; Wei, Zuo, & Chen, 2018; Callister & Lowry, 2013; and Lowry, Callister, Gresham, & Moore, 2012 for other helpful reviews). When selecting a method to apply, practitioners should consider how the measure aligns with the characteristics of the study region, project goals, data availability, computational complexity, and the ease of interpreting results. Bicycle network connectivity measures only represent an improvement over traditional measures if they produce actionable information.

Table 1 summarizes common types of bicycle network connectivity measures, their distinctive features, and useful references for anyone seeking to incorporate these measures into their work.

	Common Measures	Features	Key Citations
Road Stress Rating	**Bicycle Level of Service (BLOS)**	Originally referenced LOS for car travel Well documented and researched over time with many variations and extensions Rates network segments on a six-point scale Early forms of this measure do not evaluate separated bicycle facilities or intersections Typically calculated as a regression analysis, mathematically more complex than LTS	Transportation Research Board, 2016 Foster, Monsere, Dill, & Clifton, 2015 Jensen, 2013 Harkey, Reinfurt, & Sorton, 1998 Landis, Vattikuti, & Brannick, 1997 Dixon, 1996
Road Stress Rating	**Bicycle Level of Traffic Stress (LTS)**	Rates network roads, paths, and intersections on a 1-4 scale Rating scale is based on four distinct bicycle rider types (Geller, 2006) Calculated as a numerical rating method, mathematically simpler than BLOS and route choice models Fewer empirical studies to verify method efficacy and accuracy	Mekuria, Furth, & Nixon, 2012 Sorton & Walsh, 1994
Road Stress Rating	**Rural road stress rating**	Adapts road stress rating framework for rural contexts	Williams, 2006 Jones & Carlson, 2003 Noël, Leclerc, & Lee-Gosselin, 2003
Road Stress Rating	**Multimodal stress rating**	Road stress rating systems for pedestrian and/or car facilities that can be used in conjunction with bicycle road stress rating systems	Zuniga-Garcia, Ross & Machemehl, 2018 Phillips & Guttenplan, 2003 Mozer, 1998
Connectivity	**Bicycle Low-Stress Connectivity**	Combines road stress rating results with destination information to measure connectivity When applied to planned rather than existing networks, can quantify prospective improvement Additional output measure of network centrality can be used to identify the most important links in the network Computationally more complex than road stress rating, but provides more detailed insights	Lowry, Furth, & Hadden-Loh, 2016 Schoner & Levinson, 2014 Lowry, Callister, Gresham, & Moore, 2012
Route Choice	**Route Choice Models**	Highly tailored to local conditions Very data intensive Emphasis on preferences and characteristics of current rather than prospective riders Strong empirical basis for results Outputs can be used to inform or validate road stress ratings	Pritchard, 2018 Broach, Dill, & Gliebe, 2012 Hood, Sall, & Charlton, 2011

Table 1. Common Bicycle Network Connectivity Measures

FHWA network connectivity measure pilots

FHWA is currently funding eight pilots across the country in which State Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) are working to implement network connectivity measures as part of the planning and project evaluation process. The report is planned for release in late 2019.

- **MetroPlan Orlando (Florida)** will identify multimodal connectivity needs for project prioritization in their upcoming long-range transportation plan update by developing multimodal connectivity indices that score access improvements to work and other essential services.
- **Mid-America Regional Council (Missouri, Kansas)** will develop a set of network connectivity measures to assess future investment scenarios and transportation packages to support the development of their upcoming metropolitan transportation plan.
- **New Hampshire MPOs (New Hampshire)** will work collaboratively to incorporate Level of Traffic Stress network analysis into their metropolitan transportation plans, as well as regional pedestrian/bicycle plans and corridor studies.
- **Eastgate Regional Council of Governments (Ohio)** will incorporate multimodal performance measures for pedestrian and bicycle network completeness into their project prioritization process.
- **Corvallis and Albany MPOs (Oregon)** will demonstrate how smaller MPOs can utilize connectivity measures to prioritize regional multimodal improvements across political boundaries.
- **Houston-Galveston Area Council (Texas)** will test connectivity measures on planned and completed projects and select a final set of measures for incorporation in their regional transportation plan, active transportation plan, and future funding opportunity evaluation criteria.
- **Utah DOT (Utah)**, in partnership with the Wasatch Front Regional Council and the Mountainland Association of Governments, will incorporate connectivity analysis into their new corridor/area planning process.
- **Washington State DOT (Washington)** will test and refine a highway corridor permeability rating system to support an update to their active transportation plan.

Using these measures, agencies, non-profits and private firms have developed a range of strategies to estimate bicycle network connectivity. These strategies apply varying levels of customization or automation to the analysis process depending on project goals and available resources. One example of software built to automate connectivity analysis and serve as a free, publicly available tool is PeopleForBikes' Bicycle Network Analysis (BNA), which is detailed in a case study in this Info Brief.

Case Study: The PeopleForBikes Bicycle Network Analysis (BNA)

With the goal of making low-stress bicycle network connectivity analysis available to any community, PeopleForBikes partnered with Toole Design to develop the BNA. The BNA measures how easily bicyclists can get to key destinations on a connected, comfortable network. The BNA results for 510 U.S. cities and methodology details are currently available on the BNA **website** and the source code is available through **GitHub**.

Although the BNA helps cities measure the quality of the bicycle network and track progress over time, the real value lies in its potential to quantify connectivity gains associated with planned improvements to the network. In the following section, we provide a case study of a U.S. city that has used the BNA to prioritize future projects for maximum connectivity.

Case Study: Improving the Bicycle Network in Algiers, New Orleans

New Orleans's streets support an active public life, hosting parades, processions, music, barbeques and bikes – its flat landscape and warm winters are also conducive to bicycling. However New Orleans lacks infrastructure to make bike riding safe and comfortable throughout the city's street network. Recognizing the potential for bikes to offer an equitable mode of transportation, reduce congestion, and improve safety, the City of New Orleans in partnership with Bike Easy, PeopleForBikes, and Toole Design is undertaking a substantial buildout of bicycle infrastructure throughout the city. The neighborhood of Algiers, located on New Orleans' West Bank and separated from the rest of the city by the Mississippi River, is a key target area for those network improvements (Figure 1).

To understand the current state of the bicycle network in Algiers and the potential improvements that proposed infrastructure enhancements will bring, PeopleForBikes ran the BNA for Algiers twice: first using current data and then again incorporating the proposed bicycle network changes[1]. Table 2 contains the results from both analyses.

1 The analysis employed a 400-meter buffer rather than the default 2680-meter buffer since the BNA does not account for ferry access across rivers.

Bicycle Network Analysis details

The BNA measures how well people can access key destinations within a 10-minute bike ride (about one and two-thirds miles) of their home using only low-stress routes. A low-stress route counts towards the accessibility score if it does not require a detour of more than 25 percent of the distance necessary to reach the same destination by car.

In the first stage of the analysis, the BNA uses data from OpenStreetMap to calculate a modified Bicycle Level of Traffic Stress (Mekuria, Furth, & Nixon, 2012) incorporating the following factors:

- Functional class of roadways
- Speed limit
- Direction and number of travel lanes
- Bicycle facilities
- Street parking
- Roadway and bicycle facility width
- Intersection treatments

The BNA also uses OpenStreetMap to obtain the locations of important destinations. Population and employment data are pulled from the U.S. Census Bureau's decennial Census of Population and Housing and annual Longitudinal Employer-Household Dynamics data.

The BNA then calculates accessibility (i.e. Bicycle Low-Stress Connectivity) for every census block in the region across six destination categories: Opportunity, People, Core services, Recreation, Transit, and Retail. Scores range from 0 to 100 where 100 indicates perfect connectivity – meaning bicyclists of all ages and abilities have safe, comfortable routes to all key destinations. Finally, block-level scores are aggregated and a weighted average by population is calculated for the entire region.

Figure 1. Boundary Map of Algiers. The Algiers neighborhood is accessible by bicycle via ferry from downtown New Orleans.

Algiers' current network receives an overall BNA score of 32 out of 100, suggesting substantial room for improvement in network quality and connectivity. Low-stress, primarily residential streets throughout the region are constrained by major high-stress arteries and often lack safe pedestrian crossings (Figure 2a). Despite pockets of good connectivity in northwest Algiers, access to low-stress bicycling isn't equitable across the region. People living in the southern part of Algiers experience poor bicycle access to nearby destinations, as indicated by the maroon regions of the Census Block Access Map (Figure 3a).

Algiers' BNA score improves to 52 when running the BNA including the proposed infrastructure improvements (Figure 4) – a 20-point increase that surpasses the citywide BNA score of 35. Twenty-one miles of high stress streets will be converted to low-stress bikeways, primarily through the addition of protected bike lanes. An additional 16 miles of low-stress bikeways will be added including the extension of the Mississippi River Trail along the waterfront to the southern end of the neighborhood.

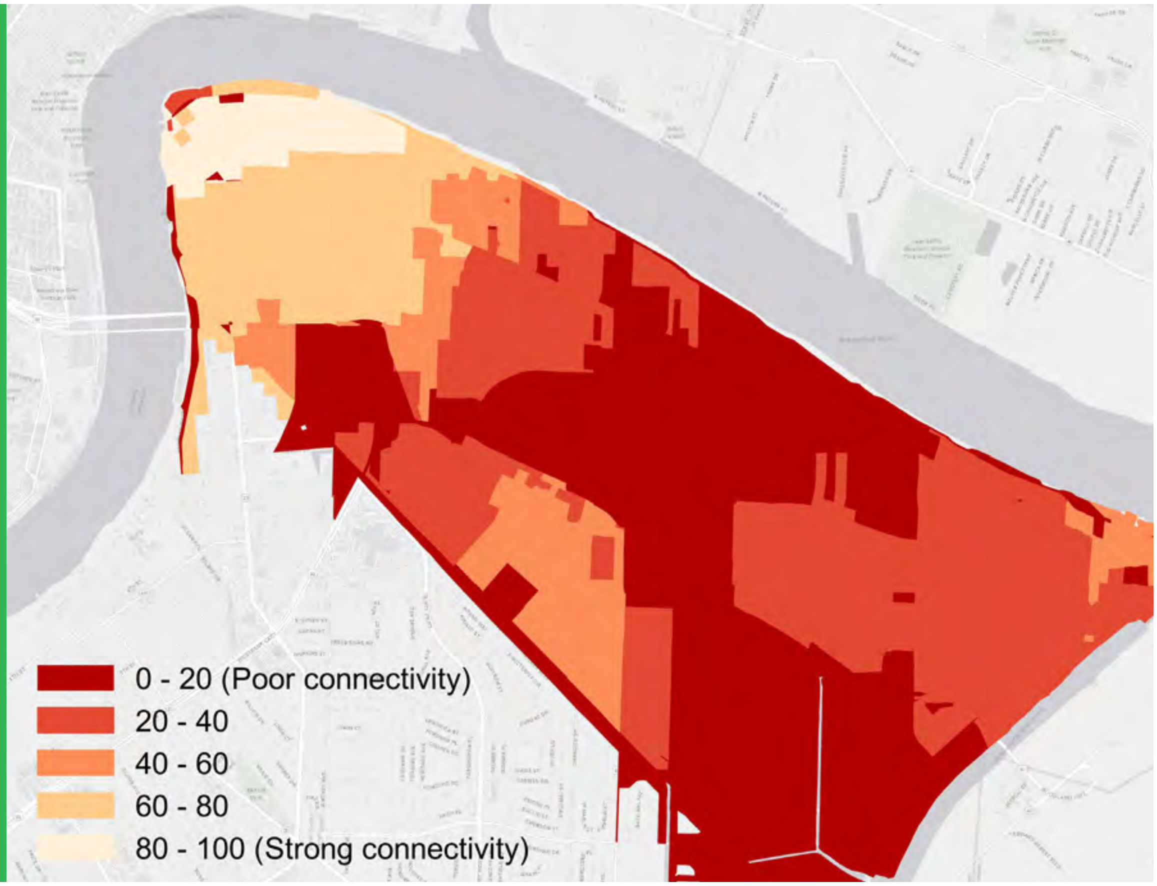
	BNA Score Current	BNA Score Planned	Change
Overall	32	52	+20
People	36	69	+33
Opportunity	32	65	+33
Core Services	45	53	+8
Retail	8	8	0
Recreation	43	66	+23
Transit	N/A	N/A	N/A
Total Miles Low Stress	321	358	+37 miles
Total Miles High Stress	78	58	-20 miles

Table 2. BNA Results. Results of the BNA run under current conditions and with planned infrastructure.

Figure 2a. Stress Network Map: Current.
Low-stress streets for bicyclists are orange and high-stress streets are red.

Figure 2b. Stress Network Map: Planned.
With the planned infrastructure in place, multiple high-stress corridors will become low-stress bikeways.

Figure 3a. Census Block Access Map: Current. Under current conditions, residents of northwest Algiers have good connectivity to nearby destinations by bicycle, while residents of central and southwest Algiers are limited by high-stress barriers.



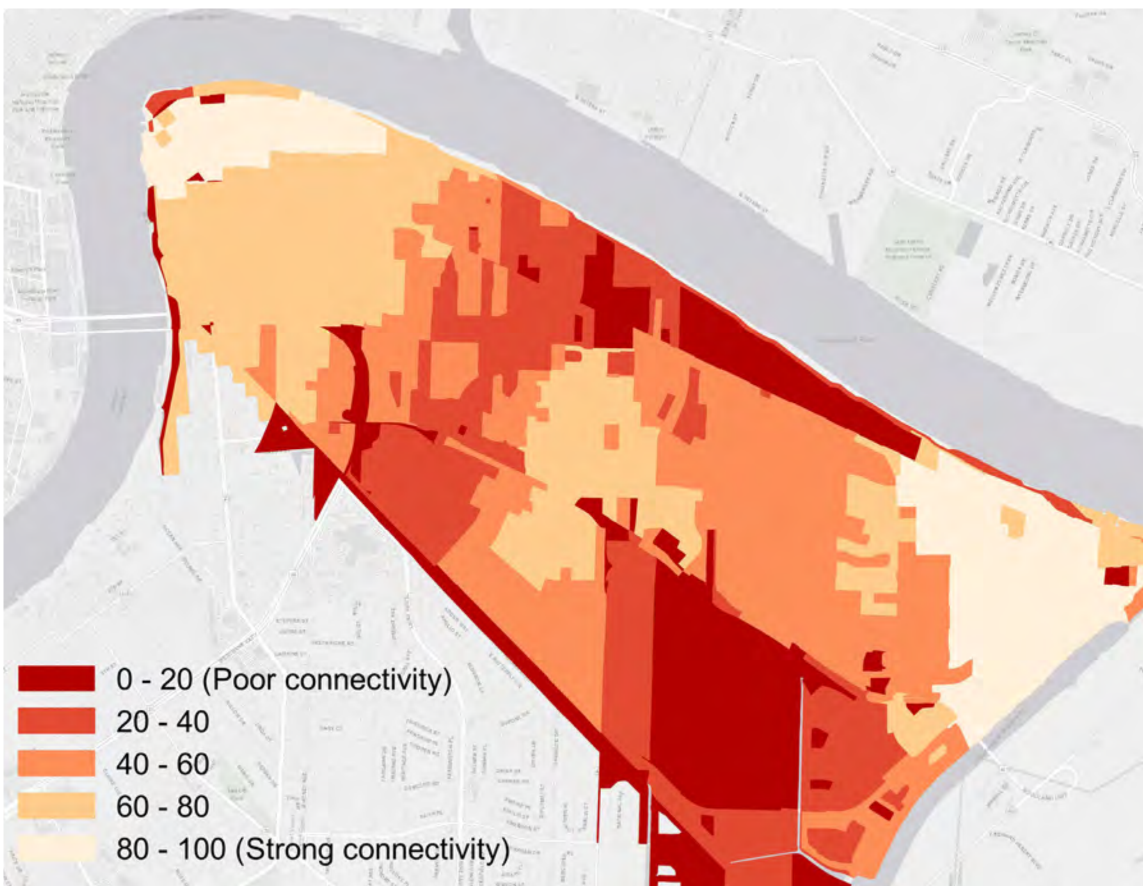


Figure 3b. Census Block Access Map: Planned. With the proposed infrastructure in place, residents of central and southern Algiers will have more destinations within reach using low-stress bicycling routes. However some residents remain isolated in regions of poor connectivity.

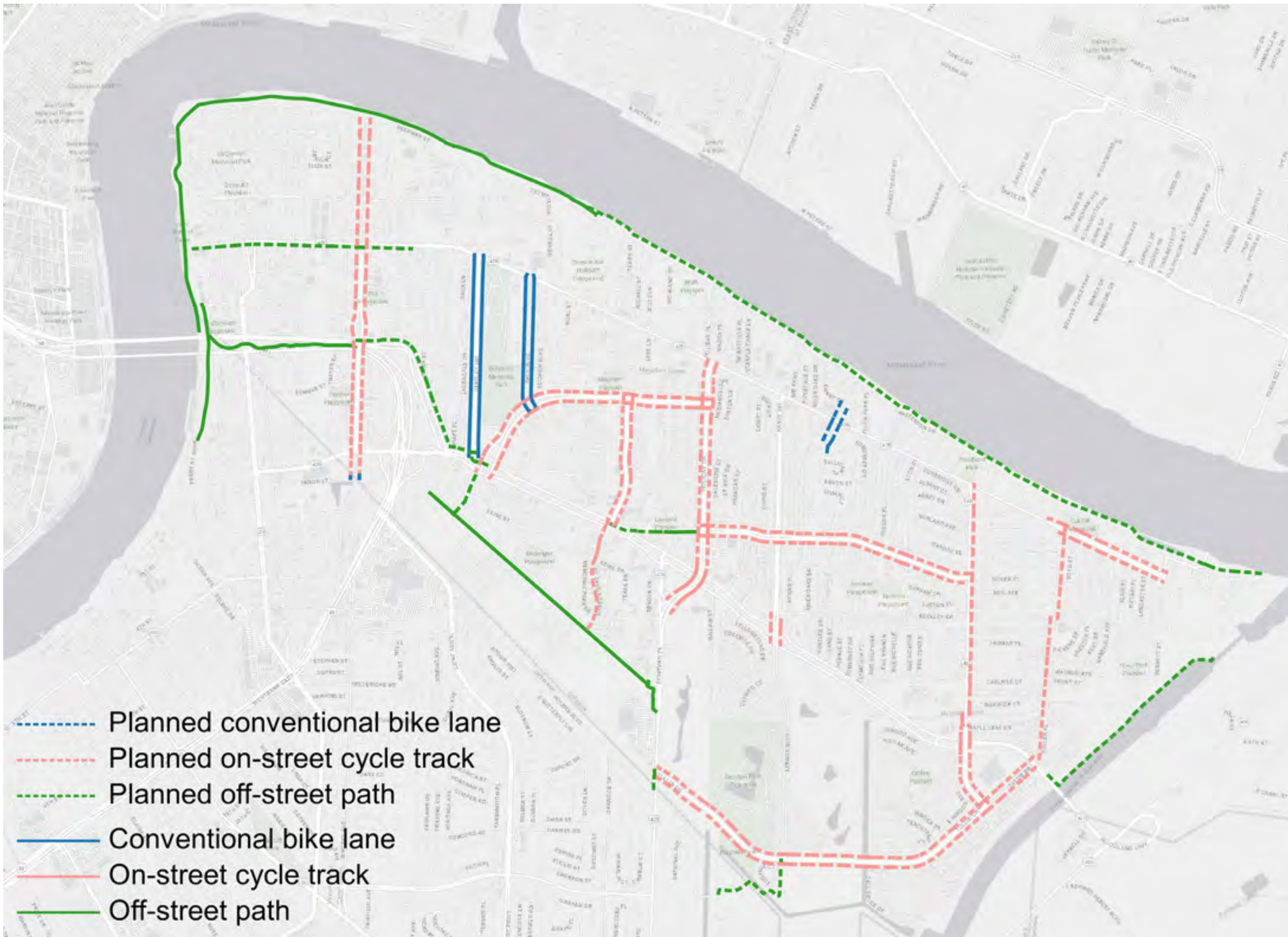


Figure 4. Bicycle Infrastructure Map: Current & Planned. The extension of existing off-street paths and addition of multiple on-street protected lanes will greatly expand bicycle infrastructure in Algiers under the proposed plan.

The benefits of these improvements differ across destination categories. The People category score, which measures how well people can reach other people by bicycle, improves by 33 points to 69 out of 100 while the Core Services score improves only 8 points to 53 out of 100.

Examining the specific locations of these destinations explains why some fare better than others under the new plan. For example, there are two grocery stores in Algiers (Core Services destinations). One of them, Faubourg Fresh Market, is in the northwest region and accessible for 75 percent of nearby residents before the infrastructure enhancements. After the new infrastructure is added, accessibility improves only marginally to 76 percent. The other grocery store, a Walmart located on the southern edge of Algiers, is much less accessible under current conditions (Figure 5a). Only 11 percent of nearby residents can access the store using low-stress routes, although three times as many people live within biking distance of Walmart compared to Faubourg Fresh Market. The addition of a protected bike lane on Tullis Drive under the proposed plan more than doubles access, with 24 percent of nearby residents able to access the store after the enhancements (Figure 5b). For the other 76 percent of residents within biking distance of Walmart, high-stress barriers like General de Gaulle Drive, Lennox Blvd., and Behrman Highway block access, illustrating the importance of upstream connections for destination access.

Figure 5a. Core Destination: Walmart (Current connectivity). Under current conditions, Walmart is only accessible for 11 percent of residents living within a ten-minute bike ride.

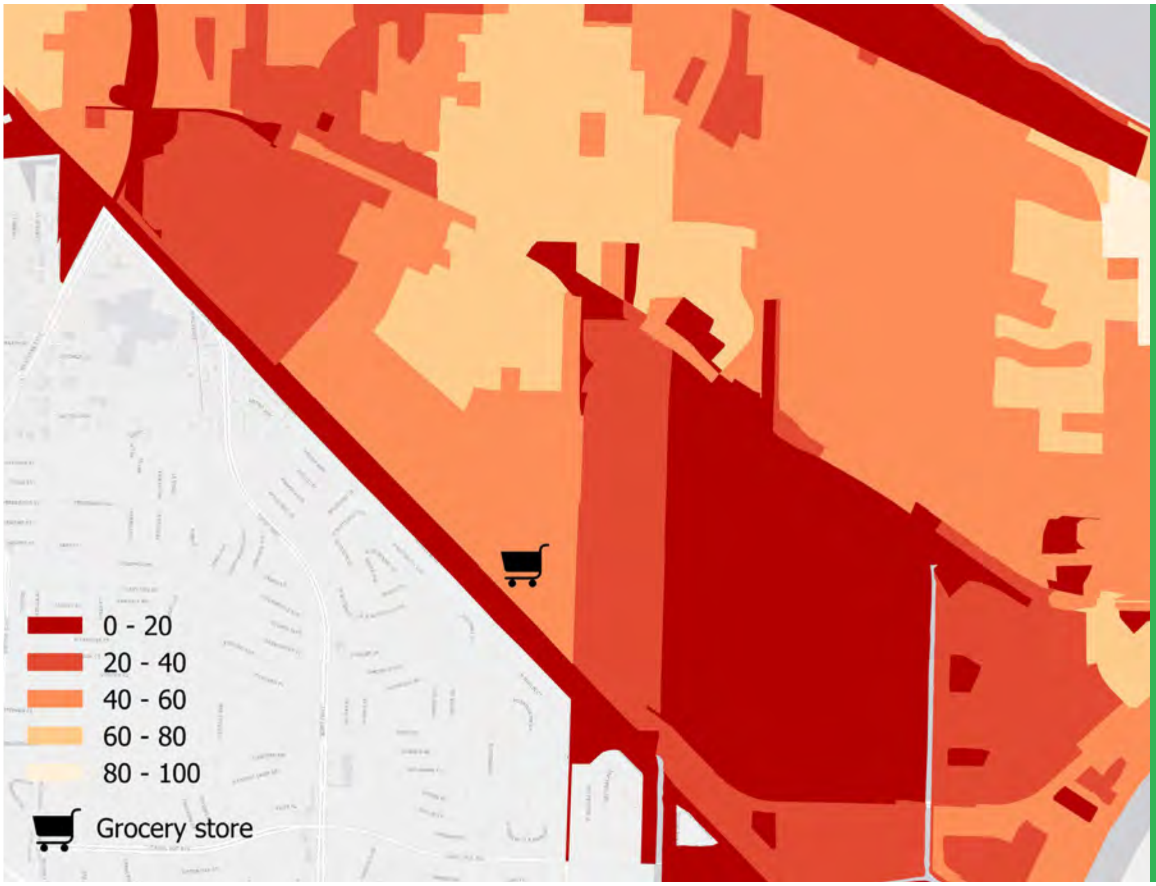


Figure 5b. Core Destination: Walmart (Planned connectivity). Twenty-four percent of nearby residents will be able to access Walmart after planned network improvements are built, an increase of 13 percentage points over current conditions.

In contrast, high growth in the Opportunity category score (a 33-point increase) reflects better access to jobs, K-12 schools, and higher education under the proposed plan. Currently, only 11 percent of people within biking distance of University of the Holy Cross can reach the school using a low-stress route (Figure 6a). With the proposed infrastructure in place, 71 percent of people within biking distance will have access the university using low-stress routes (Figure 6b). The new infrastructure plan's success in connecting people to University of the Holy Cross but not to Walmart illustrates the granular planning insights available using network connectivity measures. Cities can use these measures to prioritize projects that best improve connectivity to important destinations.

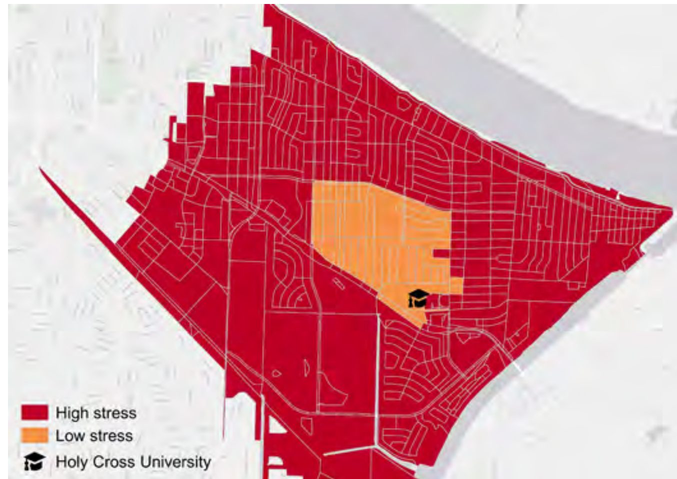


Figure 6a. Bikeshed Access Map: Current.
Residents of census blocks in blue can access Holy Cross University on a low-stress route. Residents of census blocks in orange can access Holy Cross University only via a high-stress route.

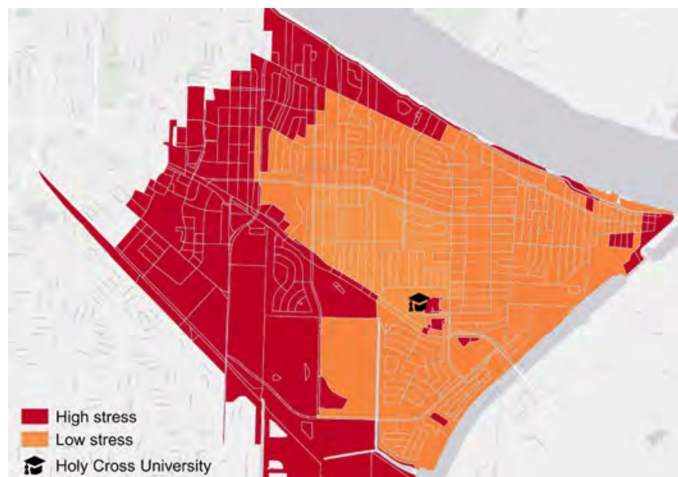


Figure 6b. Bikeshed Access Map: Planned.
Seventy-one percent of people within the bikeshed will be able access Holy Cross University on a low-stress route after the new bicycle infrastructure is built, an improvement of 60 percentage points.

Conclusion

The growing arsenal of innovative bicycle network connectivity measures available to transportation planners, policymakers, and advocates demonstrates increasing interest in growing ridership for bicyclists of all ages and abilities. Bicycle network connectivity measures can check assumptions and reveal disparities in the existing bicycle network. They can also quantify the impact of proposed infrastructure investments, enabling communities to decide how to allocate limited resources for the greatest benefit to current and prospective bicycle riders.

The time, labor, and technical expertise required to produce any of these measures can limit their applicability in practice. Universal frameworks like Bicycle Level of Traffic Stress and tools like PeopleForBikes' BNA help make network analysis accessible to a wider range of practitioners. Transportation planning consultancies also serve as resources for developing and applying these measures through their work with cities, counties, and MPOs. Resource-sharing and technical trainings online, in print, and at conferences are helping further the transportation's sector collective understanding of how to apply and customize these measures.

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SUGGESTED CITATION: Boldry, J. & Davies, R. (August 2019). Using Connectivity Measures to Evaluate and Build Connected Bicycle Networks. Pedestrian and Bicycle Information Center. Chapel Hill, NC.

ACKNOWLEDGMENTS: Reviewed by Krista Nordback and Laura Sandt at the Pedestrian and Bicycle Information Center and FHWA: Christopher Douwes and Darren Buck.

DISCLAIMER: This material is based upon work supported by the Federal Highway Administration and the National Highway Traffic Safety Administration under Cooperative Agreement No. DTFH61-16-H-00029. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the Author(s) and do not necessarily reflect the view of the Federal Highway Administration or the National Highway Traffic Safety Administration.

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