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MEMORANDUM

August 12, 2022

To: Keith Hamas
Organization: North Jersey Transportation Planning Authority
From: Theja Putta and Michael Blau
Project: North Jersey Transportation Planning Authority Regional Active Transportation Plan

Re: Barrier Analysis – FINAL REVISED (6/16/23)

Introduction

A barrier analysis identified street segments that are high-stress for bicyclists and detrimental to active transportation network connectivity, as well as low-stress street segments that would lead to better connectivity if nearby high-stress streets were converted to low-stress instead, with treatments such as separated bike lanes or neighborhood greenways . While bicyclists are legally allowed to use most of the street network (except for freeways and other access-controlled segments), bicyclists experience a high level of stress on many of those road segments due to high vehicle volumes, high speeds, multiple lanes, and other roadway characteristics. Most adults are not willing to ride in high-stress areas, resulting in those roads creating significant barriers to connectivity on a regional active transportation network.

There are different ways to identify barriers to connectivity. The connectivity islands proposed by Furth et al[1] and an algorithm to abstract barriers proposed by Putta et al[2] are useful ways to visualize gaps in the networks, but the results of these methods do not quantify specific links in the network that form barriers. For this analysis, the project team discussed different methods of identifying barriers with NJTPA staff and decided that the analysis must evaluate specific segments in the network so that network improvements may be targeted along those segments to maximize connectivity.

[1] Furth, P. G., M. C. Mekuria, and H. Nixon. Network Connectivity for Low-Stress Bicycling. Transportation Research Record: Journal of the Transportation Research Board, 2016. 2587: 41–49.

[2] Putta T, Furth PG. Method to Identify and Visualize Barriers in a Low-Stress Bike Network. Transportation Research Record. 2019;2673(9):452-460. doi:10.1177/0361198119847617

Summary

Evaluating individual street segments helped identify potential improvements along specific segments to maximize bicycle connectivity. The barrier analysis scored street segments based on population data, connectivity, and level of stress (or comfort level for biking). The technical analysis involved assigning each street segment a score using the following steps:

- Calculating the population weight for each intersection using census data and the overlap with the intersection's "area of influence," where any point inside each area is closer to the intersection than any other intersection.
- A connectivity analysis using the shortest paths between all intersections within five miles. Selection of the shortest path was based on length as well as level of stress for bicyclists (segments with higher levels of stress incurred a penalty of a 20 percent longer length, since research has shown that people are willing to go 15-30 percent out of their way for a low-stress path).[3] [4] Level of stress was derived from the NJTPA's Level of Bicycle Compatibility (LBC) analysis.
- Assigning each street segment a value based on population weight of adjacent intersections.

Through this method, street segments received higher scores based on higher connectivity as well as being in more densely populated areas. A segment could get a higher score if it is part of multiple shortest paths between intersections, and/or if there is a larger population around the segment that may use it.

The analysis also incorporated an equity-focused weight (using data from the NJTPA's Equity Analysis Tool, which helps gauge where underserved populations are within the region based on a composite score of multiple factors including race, income, limited English proficiency, disability, age, foreign-born status, female population, zero-vehicle households, and educational attainment. The equity-focused weight was calculated by multiplying the population weight of each segment with an equity index value. The barrier analysis created four different outputs:

- Raw Centrality Score – Population Weighted
- Raw Centrality Score – Equity Focus Weighted
- County Percentile Score – Population Weighted
- County Percentile Score – Equity Focus Weighted

The raw centrality scores may be used to compare street segments across the region while county percentile scores are used to compare street segments only within a county (and should not be used to compare across multiple counties). The county percentile scores can differ significantly from the raw scores, and this difference is especially pronounced for segments in rural counties, which do not have high raw centrality scores compared to segments in more urbanized counties.

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[3] Broach, Joseph & Dill, Jennifer & Gliebe, John. (2012). Where do cyclists ride? A route choice model developed with revealed preference GPS data. Transportation Research Part A: Policy and Practice. 46. 1730-1740. 10.1016/j.tra.2012.07.005.

[4] Furth, P. G., Putta, T. V., & Moser, P. (2018). Measuring low-stress connectivity in terms of bike-accessible jobs and potential bike-to-work trips: A case study evaluating alternative bike route alignments in northern Delaware. Journal of Transport and Land Use, 11(1). https://doi.org/10.5198/jtlu.2018.1159

Detailed Methodology

This analysis uses the concept of a road link's centrality in the network as a measure of its importance to the network. This concept has been applied to identify key links in bicycle networks in other studies successfully.[5,6] The Delaware Valley Regional Planning Commission (DVRPC) conducted an analysis using a similar method.[7] The methodology can be divided into three key steps, discussed in more detail below:

1. Process routable network
2. Select weights for routing
3. Measure weighted centrality of links

Process Routable Network

The analysis needs a routable network of intersections and segments classified by stress. NJTPA staff provided a polyline layer consisting of the streets and bike trails in the network. This layer has an attribute identifying the stress level by segment. Stress level was derived from the NTJPA Level of Bicycle Compatibility analysis, which was completed as part of Plan 2050.[8] The stress value has four levels with 1 and 2 being low-stress and 3 and 4 being high-stress. There are also segments with a stress value of 5 which denotes limited-access highways. Some segments were missing the stress information in the routable layer. The project team filled this information in by spatially joining these segments to nearby segments with stress information. After this step, a small fraction of segments (< 0.1%) in the region were still missing data – these segments were flagged, shared with the NJTPA, and excluded from the analysis. Limited access highways were also excluded from the analysis, as bicyclists are not allowed to use them.

The project team created an intersections layer from the segment layers based on the start and end points of the segments. These intersection points were then joined to the streets to build a graph on which shortest path analysis was completed as described in subsequent sections. The links in the routing graph are given a cost based on their length and stress level. The cost of low-stress links is equal to their length while the cost of high-stress links is 1.2 times the length. This is to account for the fact that people might choose lower stress links even if they are slightly longer than a parallel high-stress route. The 20 percent penalty applied is consistent with findings and usage in other studies that compared low-stress routes to high stress connectivity.[9,10]

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[5] Lowry, M., & Loh, T. H. (2017). Quantifying bicycle network connectivity. Preventive medicine, 95 Suppl, S134–S140. https://doi.org/10.1016/j.ypmed.2016.12.007

[6] Putta T, Furth PG. Impact of One-Way Streets and Contraflow on Low-Stress Bicycle Network Connectivity. Transportation Research Record. 2021;2675(10):1174-1183. doi:10.1177/03611981211014893

[7] Bicycle LTS and Connectivity Analysis. https://www.dvrpc.org/webmaps/bike-lts/

[8] Plan 2050 Background Paper: Active Transportation in the NJTPA Region. (2020). https://www.njtpa.org/NJTPA/media/Documents/Planning/Plans-Guidance/Planning%20for%202050/draft%20final/njtpa_activetransportation.pdf

[9] Broach, Joseph & Dill, Jennifer & Gliebe, John. (2012). Where do cyclists ride? A route choice model developed with revealed preference GPS data. Transportation Research Part A: Policy and Practice. 46. 1730-1740. 10.1016/j.tra.2012.07.005.

[10] Furth, P. G., Putta, T. V., & Moser, P. (2018). Measuring low-stress connectivity in terms of bike-accessible jobs and potential bike-to-work trips: A case study evaluating alternative bike route alignments in northern Delaware. Journal of Transport and Land Use, 11(1). https://doi.org/10.5198/jtlu.2018.1159

Select Weights for Routing

In connectivity analysis, not all routes are equal – some provide connections to more destinations or improve access for certain types of trips. For example, a path connecting a dense population center to a large retail or employment center is more important than a path that connects smaller activity centers. In this analysis, all the routing uses intersections as starting and ending points. Each intersection is weighted by the population within its area of influence. An intersection's area of influence is calculated using Thiessen polygons which are created by partitioning the region into polygons, in which every point in a polygon is closer to one intersection than any other intersection. An intersection's weight is calculated by overlapping its corresponding Thiessen polygon with census blocks and is described by Equation 1.

$$W_i = \sum_j \left(\frac{A_{ij} * P_j}{A_j} \right) \tag{1}$$

Where

W_i = Weight of intersection i

A_{ij} = Area of overlap between intersection i and census block j

A_j = Area of census block j

P_j = Population of census block j (from Census 2020 data)

In addition to the population weight described, we also calculated an equity-focused weight by incorporating data from the NJTPA's Equity Analysis Tool.[11] We calculated the equity-focused weight by multiplying the weight W_i with the composite equity score of the census tract in which the intersection is located.

Measure Weighted Centrality of Links

The importance of a link in the network is measured using the weighted centrality of the link which is described in Equation 2.

$$WC_e = \sum_i \sum_j W_i * W_j * e_{ij} \tag{2}$$

Where

WC_e = weighted centrality of link e

W_i = weight of intersection i

W_j = weight of intersection j

e_{ij} = 1 if edge e is on the shortest path between i and j; 0 otherwise

The weighted centrality measure of a segment can be high if it is part of many shortest paths or if it is part of paths that connect intersections with large weights. Shortest paths that are longer than five miles are

[11] Equity Analysis. https://njtpa.maps.arcgis.com/apps/webappviewer/index.html?id=1ccbe954ff744697babb57d370cd101c

not included in this calculation as most bicycle trips tend to be shorter than five miles. A similar centrality measure is calculated using the equity-focused intersection weights. Since the region has a varied density of populations, weighted centrality of segments in the more densely populated regions can make it seem like segments in other regions are not as important. To counter this phenomenon, a percentile score of links within each county is also calculated so that links may be compared against others within each county rather than the entire region.

Results

The methodology described in the previous section yielded four different outputs for the analysis.

1. Raw Centrality Score – Population Weighted
2. Raw Centrality Score – Equity Focus Weighted
3. County Percentile Score – Population Weighted
4. County Percentile Score – Equity Focus Weighted

The raw centrality scores are useful for comparing a given segment in the network with any other segment in the entire region. County percentile scores are useful in comparing links within a county and should not be used to compare segments across multiple counties. These four scores are illustrated using the results from the Newark area shown in Figure 1. The thicker lines represent links with high centrality and the red lines represent high-stress segments. The thicker red lines represent larger barriers to connectivity while the thicker blue lines show which of the low-stress links would likely become well-travelled if the connecting high-stress barriers were converted to low-stress.

The top left map shows the population weighted raw scores and the top right map shows equity weighted raw scores. These two maps share many segments that have similar centrality scores; the main difference in results occurs between segments that are near census tracts with a large variance in equity scores. While this difference is not noticeable everywhere, it is more apparent in certain areas like Mt Pleasant Avenue in West Orange (northwest corner of the maps) which shows as having a higher importance under population weighted score than under equity weighted scores.

The bottom left and right maps shows the percentile scores within each county for population and equity focused weightings, respectively. These maps display the relative importance of segments within their counties, which can differ significantly from the raw scores. This difference is especially strong for segments in rural counties which do not have a high centrality score compared to segments in more urbanized counties. The county percentile scores are useful to identify barriers which might be disconnecting the network at a county level but may not appear important when looking at the results for the entire region. This can be observed in Union County (southwest corner of the maps) where the county percentile scores highlight the importance of some of the links more effectively than raw centrality scores.

In the Newark region, we can see that certain streets form bigger barriers like Springfield Road, Bloomfield Avenue, and Clay Street approaching the Passaic River. There are some longer connections (Union Avenue, Mount Prospect Avenue, Clifton Avenue, and Norfolk Street) that would benefit from converting short sections of certain barriers to low-stress.

Figure 1: Barrier Analysis Results – Newark Area

Displaying barrier analysis results at the regional scale is difficult. Because this analysis uses street segments as the output measure, areas with highly connected, dense street grids are mostly illegible when viewed from a regional perspective, and do not allow the reader to draw definitive conclusions. To overcome this challenge, we grouped the region into four subregional categories. This approach provides a finer grained look at each area and allows better interpretation of the displayed results. The four regions are:

1. Central Region (Essex, Union, Somerset, Hunterdon) – Figure 3
2. Hudson River Region (Hudson, Bergen) – Figure 4
3. Coastal Region (Middlesex, Monmouth, Ocean) – Figure 5
4. Northern Region (Passaic, Morris, Sussex, Warren) – Figure 6

Results for each region are discussed below. The maps show the five percent highest and lowest stress street segments with equity weighted county percentile scores. The red lines represent high-stress segments while the blue lines represent low-stress segments (taken from the NJTPA's LBC analysis). The thicker red lines represent larger barriers to connectivity while the thicker blue lines show the low-stress links that would likely become well-travelled if the connecting high-stress links were converted to low-stress.

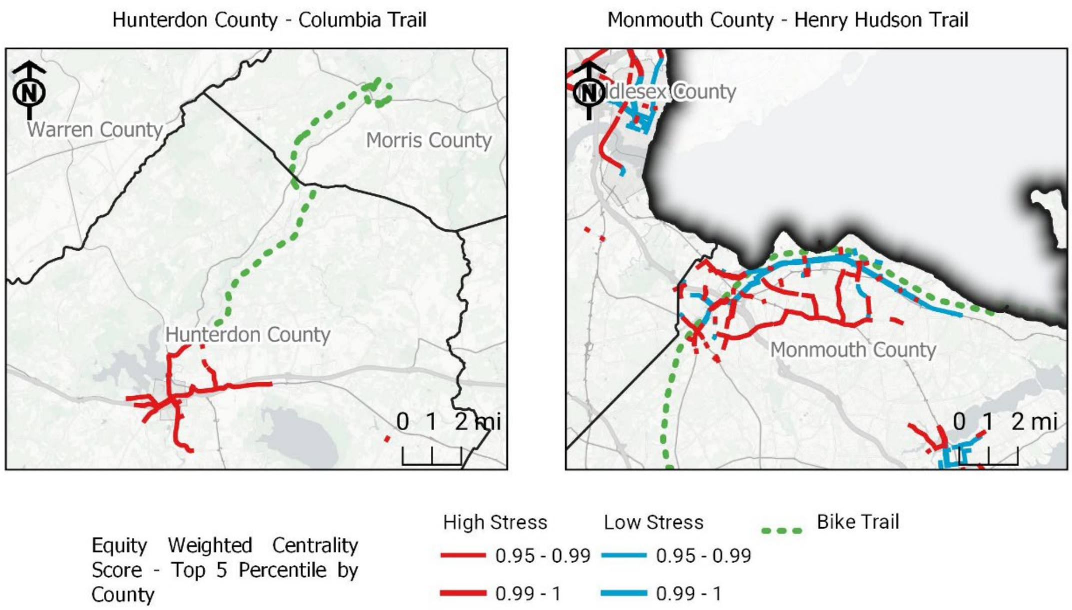
Several conclusions can be drawn from the analysis:

- Top percentile street segments[12] are almost exclusively confined to the most densely populated communities in each county (a function of the population weight). The equity weight likely plays a role as well, since many of the region's larger and more densely populated communities have a high composite equity score based on the NJTPA's Equity Analysis.
- With some exceptions, major roads form the most stressful barriers in the region. There are some smaller collectors and residential streets that are also barriers, but these are likely a function of the county percentile scores, which show the relative importance of segments within their counties. In rural counties without major high-stress roads, the county percentile scores boost smaller but still stressful segments to the top of the list.
- Residential streets have the potential to significantly improve low-stress connectivity if certain barriers were removed. Most larger communities feature a few (or in some cases, many) low-volume residential streets in the top five percent of low-stress links. These low-stress streets have the potential to be important connections within the ATP network and the barrier analysis can help local and subregional jurisdictions identify these locations when doing further planning for and implementation of the network.
- Separated bicycle facilities play an important role in creating continuous low-stress networks. Adding protected bicycle facilities on existing barrier segments or creating new separated trails parallel to major barriers can dramatically improve connectivity. This is clear in Monmouth County

[12] These segments are mostly in densely populated areas because the centrality score is calculated using population density. If the top percentile links also happen to be high-stress, then they form barriers to connectivity.

(the Henry Hudson Bike Trail), although it is less evident in other parts of the region, like Morris and Hunterdon counties (the Columbia Trail). See Figure 2.[13]

Figure 2: Correlation between trails and stress scores.



Central Region (Essex, Union, Somerset, Hunterdon)

In **Essex County**, the highest and lowest stress street segments are concentrated in Newark and East Orange. As discussed above, Springfield Avenue and Bloomfield Avenue pose major barriers in Newark, and Clinton Avenue to a lesser extent. In East Orange, Dr MLK Jr Boulevard and Williams Street are the most prominent barriers. There are many low-stress segments that could be extended and connected if these high-stress roads were improved. These streets include: 18th Avenue, Clifton Avenue, Clinton Street, Dr MLK Jr Boulevard (Newark), Mount Prospect Avenue, Norfolk Street, Sanford Avenue, Springdale Avenue, and Washington Street.

In **Union County**, almost all highest and lowest stress segments are in or around Elizabeth, with some low-stress links (East Elizabeth Avenue and East Linden Avenue) extending into Linden. High-stress barriers include Morris Avenue, Conant Street, and North Broad Street on north side of town (North Broad becomes low-stress south of Hurden Street). Among the top five percent, low-stress street segments outnumber high-stress ones. This finding indicates that several key improvements in Elizabeth's network could dramatically improve low-stress connectivity, even though the city lacks extensive bicycle infrastructure.

Somerset County's highest and lowest stress segments are confined to Somerville and East Franklin. In Somerville, Dukes Parkway East, South Bridge Street, Easton Turnpike, First Avenue, and US 206 form the main high-stress barriers. Low-stress routes are disconnected and include North 13th Avenue, East

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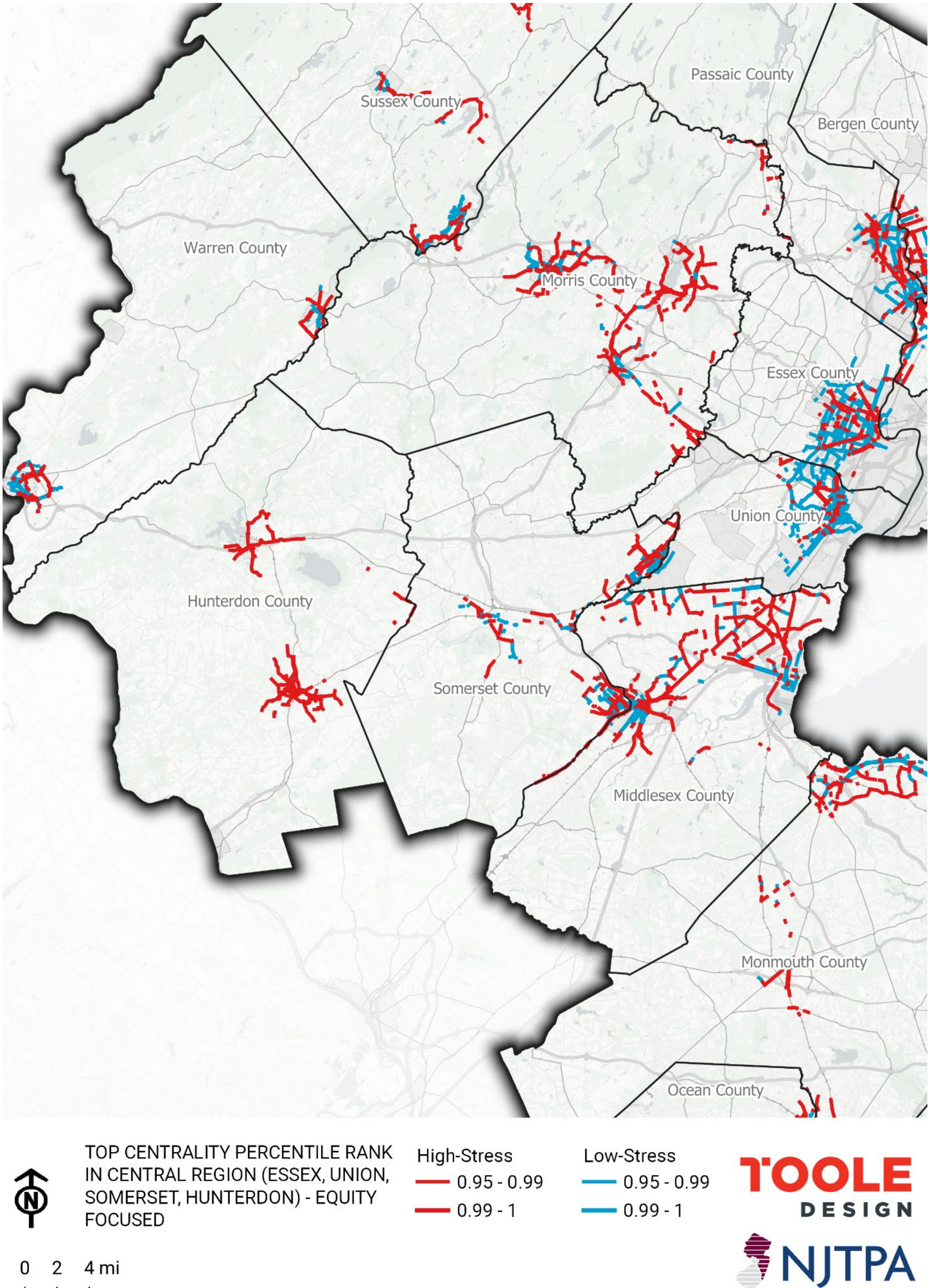
[13] The Columbia Trail may not appear as a key connection because it is either not the most direct route or it only connects areas with smaller populations.

High Street, Altamont Place, and several smaller connections. In East Franklin, high-stress segments include Easton Avenue, Franklin Boulevard, Hamilton Street (west), Somerset Street, and New Brunswick Road; low-stress segments include Hamilton Street (east) and residential streets like Appleman Road, Winston Drive, Abbot Road, Arden Street, Magnolia Road, and others.

Hunterdon County's top scoring segments are almost entirely high-stress, concentrated in Clinton and Flemington. In Clinton these streets include most of the major roads: Hamden Road/Leigh Street, Old Highway 22, Beaver Avenue, Pittstown Road, Halstead Street, and West Main Street (in neighboring High Bridge); Flemington's barriers include Sergeantsville Road, Main Street, US 202, Vorhees Corner Road, Case Boulevard, Church Street, Thatchers Hill Road, and NJ 31. All top scoring low-stress segments are flanked by much longer high-stress segments on both sides and provide little benefit to the network.

Figure 3: Barrier Analysis Results – Central Region (Essex, Union, Somerset, Hunterdon)

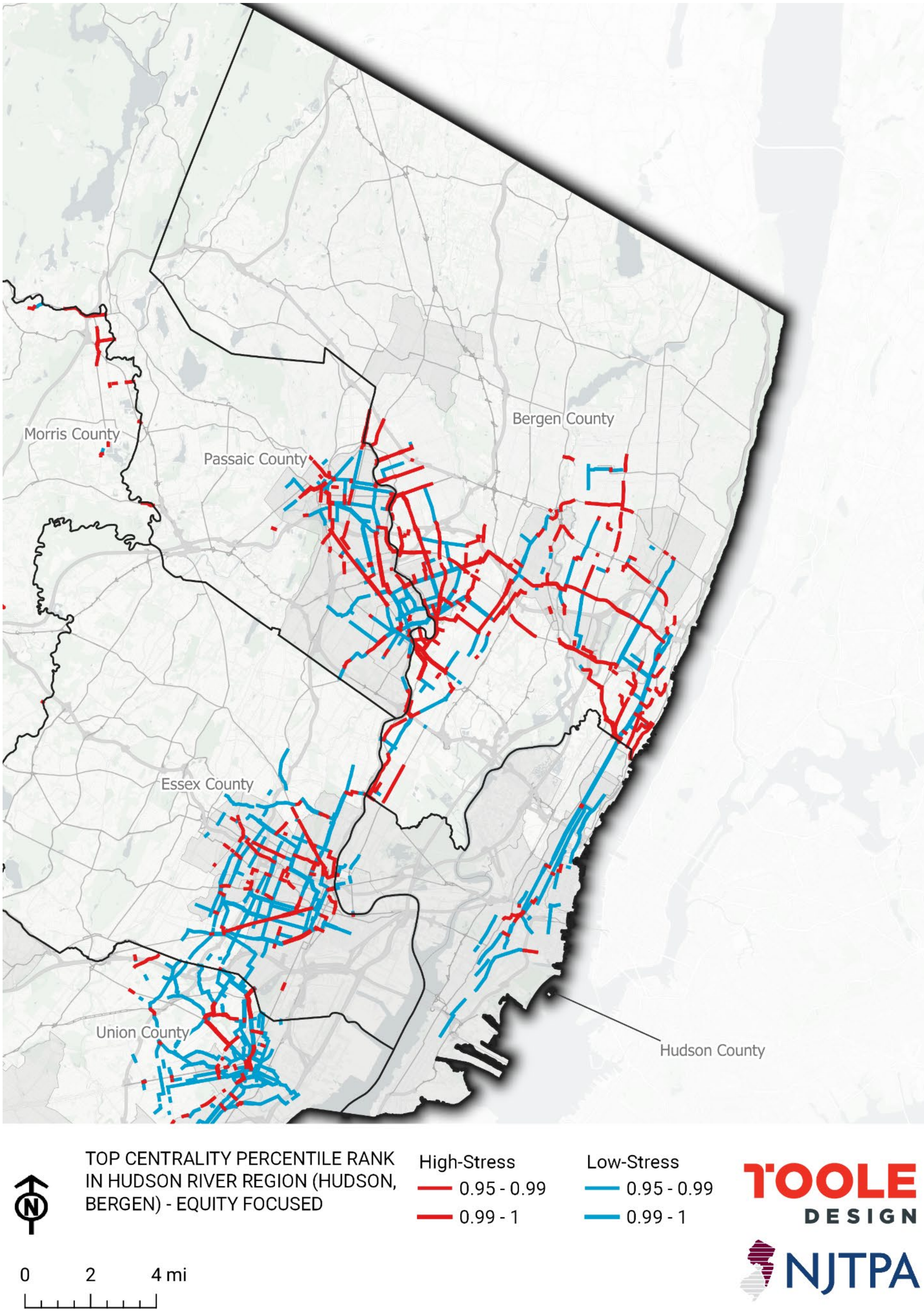


Hudson River Region (Hudson, Bergen)

In **Hudson County**, the five percent highest scoring segments are almost entirely low-stress, with major north-south corridors of low-stress streets connecting Jersey City, Hoboken, Union City, and North Bergen. These corridors include: Central Avenue, Palisade Avenue, Bergenline Avenue, and Park Avenue. None of these streets currently have bicycle facilities, and their low-stress score is likely due to the population and equity weights applied to the results. Secaucus and Kearny feature no highest or lowest stress segments, and Bayonne's low-stress links are disconnected from the rest of the county.

The top highest and lowest stress segments in **Bergen County** are located in larger communities, like Garfield, Hackensack, Edgewater, Ridgefield, and Englewood. Major high-stress barriers include Degraw Avenue/Fort Lee Road/Main Street, Essex Street, Valley Boulevard, Paterson Avenue, Broad Avenue (Ridgefield), Mola Boulevard, Broadway, Morlot Avenue, and Fair Lawn Avenue. The main low-stress links are Anderson Avenue, Broad Avenue (Fort Lee and Englewood), Sussex Road/Garrison Avenue, Prospect Avenue, Harrison Avenue, Passaic Avenue, and Market Street. There are no top-scoring segments in the northern part of the county.

Figure 4: Barrier Analysis Results – Hudson River Region (Hudson, Bergen)



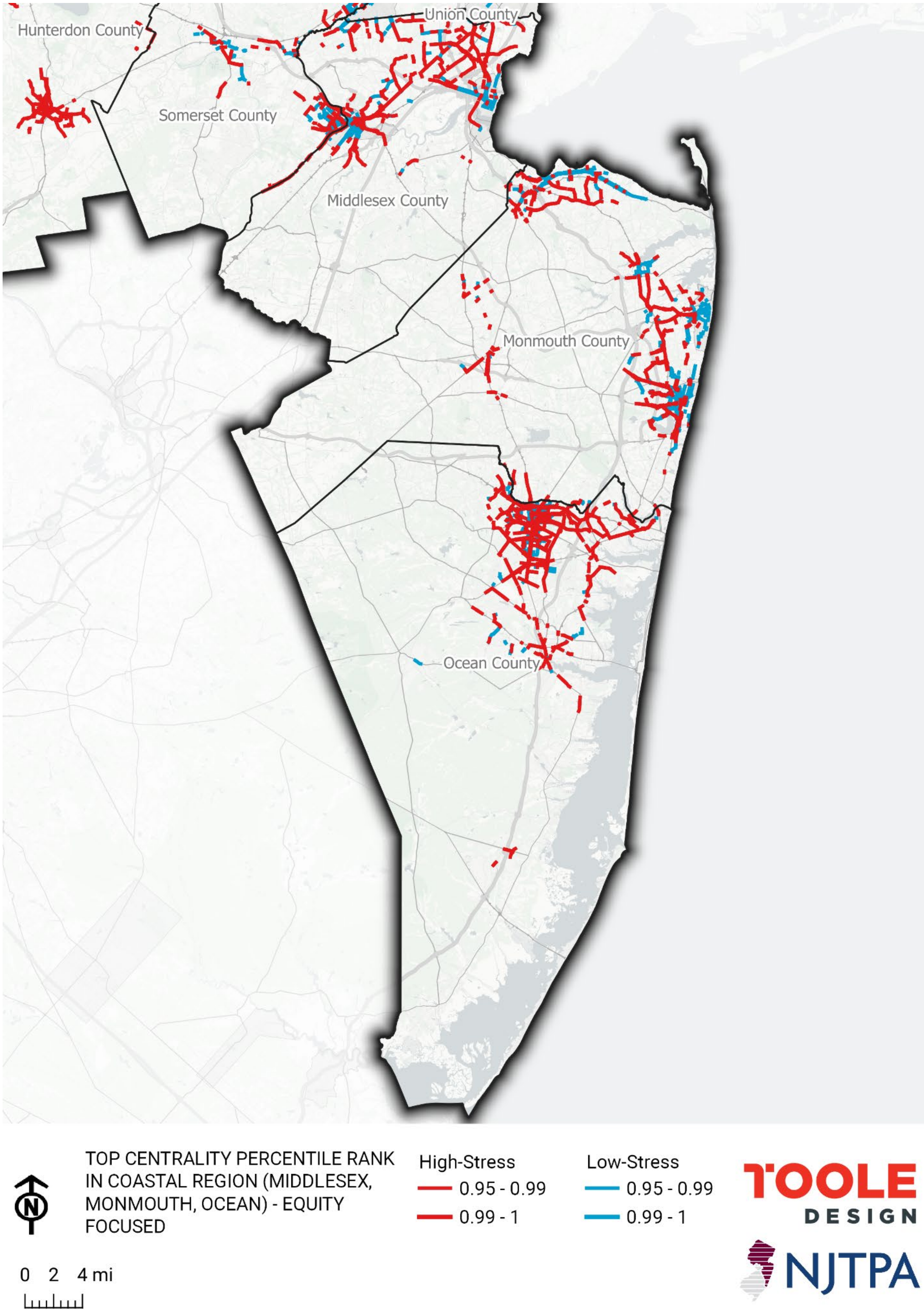
Coastal Region (Middlesex, Monmouth, Ocean)

In **Middlesex County**, the five percent highest and lowest stress street segments are confined to the more populated northern part of the county: New Brunswick, Perth Amboy, South Plainfield, Metuchen, and Woodbridge. The largest high-stress segment is NJ 27/Lincoln Highway, which forms an almost continuous barrier between New Brunswick and Rahway in neighboring Union County. Smaller barriers include Green Street, Rahway Avenue, Talmadge Road, Port Reading Avenue, and NJ 18/Memorial Parkway. Significant low-stress links include Joyce Kilmer Avenue, Hamilton Street and George Street in New Brunswick, and New Brunswick Avenue, Amboy Avenue, and State Street in Perth Amboy.

The top highest and lowest stress segments in **Monmouth County** are located in the Keansburg and Matawan area, Long Branch, and Asbury Park. The Henry Hudson Bike Trail forms a continuous low-stress link from Atlantic Highlands to Matawan (the low-stress link continues down to Freehold along the trail but this segment is not among the top five percent low-stress links in the county). This low-stress corridor is flanked by several high-stress segments, including Bethany Road, NJ 35, Laurel Avenue, and Middle Road. Major high-stress links around Long Branch include Kings Highway, Broad Street, Shrewsberry Avenue, and Main Street (Shrewsberry). Top low-stress links are confined mostly to Long Branch proper. Several high-stress segments extend out from Asbury Park, including Asbury Avenue, Kings Highway, and Corlies Avenue. Also in Asbury Park, Ridge Avenue, West Lake Avenue/Springwood Avenue, Prospect Avenue, Bond Street, Belmont Avenue, and Grand Avenue comprise the primary low-stress segments. In neighboring Bradley Beach and Belmar, Main Street alternates between low- and high-stress extremes several times.

Virtually all of **Ocean County's** highest scoring links are confined to its larger communities in the north of the county: Lakewood, Toms River, and Brick Township. Major high-stress barriers include Lakewood Road, New Hampshire Avenue, Cedar Bridge Avenue, Ocean Avenue, East/West County Line Road, and Cross Street in Lakewood; Hooper Avenue, Herbertsville Road, and Lakewood Road in Brick Township; and Main Street, Lakehurst Road, Cedar Grove Road, and NJ 37 in Toms River. There are many smaller high-stress segments throughout these communities. Low-stress links are mostly in downtown Lakewood, with some isolated pockets of low-stress in other parts of the county.

Figure 5: Barrier Analysis Results – Coastal Region (Middlesex, Monmouth, Ocean)



Northern Region (Passaic, Morris, Sussex, Warren)

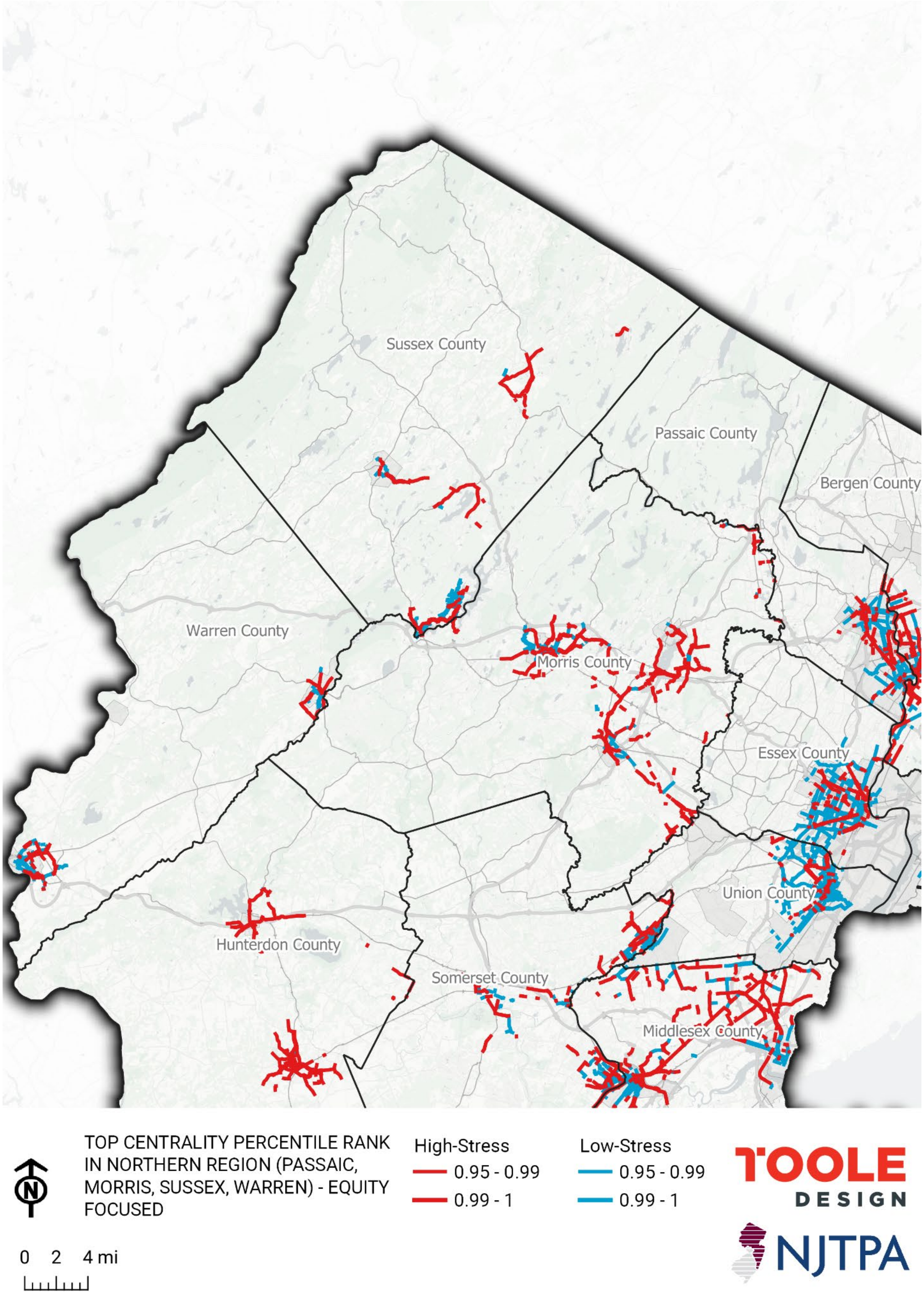
All of **Passaic County's** highest and lowest stress links are in Paterson, Clifton, and Passaic. Many of these segments extend into Garfield and other parts of neighboring Bergen County. Major barriers include Main Avenue and Lakeview Avenue in Clifton (between Paterson and Passaic). River Street, East 18th Street, Market Street, Park Avenue, Trenton Avenue, Vreeland Avenue, East 33rd Street, and Layfette Street/10th Avenue comprise the primary low-stress links in Paterson. In Passaic low-stress streets include Lexington Avenue, Passaic Street/Avenue, Paulison Avenue; and in Clifton they include Van Houten Avenue and Clifton Avenue.

Morris County's top scoring segments are located in Dover, Morristown, and Parsippany. Major barriers leading into Dover include West Clinton Street, Mount Hope Avenue, Main Street, and Reservoir Avenue; Parsippany Boulevard/Road, and North Beverwyck Road, in Parsippany; and Sussex Avenue, Speedwell Avenue, Spring Street, and Morris Street in Morristown. Littleton Road between Morristown and Parsippany is also a major barrier. Low-stress links include Richards Avenue, Perry Street, Prospect Street, Baker Avenue, Penn Avenue, and many smaller segments in Dover, and MLK Avenue and Washington Avenue in Morristown (Washington Avenue becomes high-stress in downtown Morristown); the only significant low-stress segment in Parsippany is on North Beverwyck Road and is flanked by high-stress barriers on both ends.

In **Sussex County**, top-scoring segments are confined to Newton, Sparta, Layfette, and Hopatcong. These are mostly high-stress barriers, including Sparta Avenue/Newton Sparta Road in Newton; Andover Road, Sparta Avenue, and Stanhope Road in Sparta; and North Church Road, Hamburg Turnpike, and Vernon Avenue in and around Layfette. Brooklyn Road/Wills Avenue, and US 206 form major barriers around Hopatcong. There are some significant low-stress links in Hopatcong, such as Flora Avenue, Brooklyn Mountain Road, and Bucknell Trail.

Warren County's highest and lowest stress links are in Phillipsburg and Hackettstown. Barriers include Stryker Road, US 22/NJ 57/Memorial Parkway in Phillipsburg, and Main Street, Willow Grove Street, and High Street in Hackettstown. Significant low-stress links in Warren County include Warren Street, Marshall Street, Hillcrest Boulevard, and several other roads in Phillipsburg, and Arthur Terrace/Mitchell Road in Hackettstown.

Figure 6: Barrier Analysis Results – Northern Region (Passaic, Morris, Sussex, Warren)



Top 10 Ranked Street Names by County

To provide more informative results in preparation for Task 4.1: Regional Priority network Mapping, we conducted additional post-processing analysis of the findings. Appendix A shows the top 10 high-stress barrier links per county by street name. We queried the results by street name rather than individual segments because the highest stress barrier segments in each county would likely all be on the same street corridor. Some barrier segments did not have street name information within the dataset and were omitted from Appendix B. However, they are included in the analysis and are shown in the result maps. While the list of high-stress streets is useful for summarizing important barriers, it is not a substitute for a thorough review of the analysis results on a map.

Data Limitations

A key input to this analysis is a street network with information on Level of Bicycle Compatibility (LBC) for each of the street segments. The LBC information of street segments was derived from NTJPA Level of Bicycle Compatibility analysis, completed as part of Plan 2050. Based on review of the LBC values, it was found that many segments might have a different LBC value than what the data show. This is largely due to the data limitations of performing such an analysis at a large scale. LBC analysis requires inputs such as speed, volume, lanes, bike facilities, and parking presence. These data are not always readily available, especially at a large regional scale, which leads to blanket assumptions for missing data. As a result, LBC calculations may not always be accurate and manually verifying individual segments' stress level is not practical for a large region. Based on past experience conducting LBC analysis on large-scale networks, the project team offered some ideas to effectively review and fix inaccuracies in such analyses.

Leverage Other Data Sources

Some data may be available via other sources. These sources may not follow the same data structure as that of the street network layer. In such cases, there are methods to conflate these datasets to transfer the required inputs to the street network layer. The specific processes involved in conflating these data depends on the structure of the data and the GIS analysis platform being used. Even if regionally specific data sources are not available, datasets such as Open Street Map (OSM) are publicly available. Due to the crowdsourced nature of OSM data, the quality and completeness of the data can vary from location to location.

Missing or Incomplete Data

Many of the analysis accuracy issues can be traced back to missing or incomplete data. This is especially the case for attributes like traffic volume and parking presence. While attributes like speed, lanes, and bike facilities are usually more complete, they can also have significant gaps in the network. Common ways to overcome these limitations include:

Traffic Volume

Traffic volume (AADT) data when present is usually only available for busier roads. In some cases, the volume data can be points or for isolated segments rather than the entire corridor of the street. In such cases, identify streets that share the same name and functional class of the segments with AADT values and apply it those segments if the segments are not too far apart. For those streets without any AADT information, aggregate the AADT (usually an average value) of all the nearby segments with the same functional class that have AADT and use that to fill the data gap. For any segments with that might still be missing AADT information, use default assumptions based on functional class of streets. These assumptions may have to be tailored to the land use context based on local expertise. A relatively simple way of doing this is by dividing the region into urban, suburban, and rural contexts and assigning different assumptions for each context. In some cases, when number of lanes is known, traffic volume estimates can be assumed.

Speed

Stress values are affected by prevailing speed rather than posted speed limits. However, due to the lack of prevailing speed data, speed limit data is often used as a proxy. Local statutory speed limits can be used for locations with missing speed data. Speed data gaps can also be filled in the same way as that of traffic volumes. If appropriate, adjust default assumptions based on local knowledge. For example, if it is well known that a certain town has wider collector streets that are conducive for speeding, add 5-10 mph to the default speed assumptions for those streets.

Parking Presence

Parking lane data are not available everywhere. OSM sometimes has this information available. For many streets, presence or absence of parking lanes may not be necessary to calculate LBC. In typical level of traffic stress calculations, parking lanes are only relevant only when they are next to bike lanes. This automatically reduces the number of segments where accurate parking lane information is needed. Adjust this approach based on local knowledge to identify a default assumption and then override the default only when necessary, which reduces the amount of manual review needed. For example, if all the bike lanes in a given city have parking next to them except for one street, set the default to having a parking lane and only code the one street as an exception.

Bike Facilities

In many cases bike facilities are available as a dataset separate from the underlying street network. This information can be joined using conflation and spatial joins to the street network. Occasionally, there might be a need to add new segments, especially where off-street facilities exist. While there are semi-automated ways of doing this, the processes can vary based on the data structures involved and it is not possible to suggest one specific process.

Lanes

Number of lanes information is usually available from the agency that maintains the dataset. If it is not available, OSM has this information with varying levels of completeness and accuracy. If no other sources exist, the best course of action would be to use the functional class as a proxy and set default assumptions based on local context.

Reviewing Data

The above-mentioned ideas for working around data limitations will need to be implemented with a review process to ensure that the data integrity and accuracy is maintained. Where possible, it is useful to note the source of the data being joined so that the reviewer may have a better understanding on where and why a given attribute has a specific value. In addition, it is useful to map and symbolize the individual attributes in a GIS application to visually inspect any unexpected values and adjust the assumptions or apply manual corrections as necessary. It is recommended that any manual adjustments be kept separate from the automated processes initially and combine them at a later stage to avoid overriding manually adjusted data.

Next Steps

The project team compared the results to the trip potential analysis to find areas with high active transportation potential and low connectivity. We also overlaid results with the New Jersey Department of Transportation's network screening datasets and the New Jersey Department of Environmental Protection's environmental justice datasets to determine where there is overlap between high-stress barriers and regional safety/equity priorities. These areas served as a starting point to develop a conceptual, regional active transportation network.

APPENDIX A: TOP 10 RANKED STREET NAMES BY COUNTY

Street Name	Functional Class	County	Rank in County	Municipality Name	Equity Centrality % in County
Maine Ave	Minor Arterials	Bergen	1	Passaic	99.92%
Broadway	N/A	Bergen	2	Elmwood Park Borough	99.90%
Paterson Ave	Minor Arterials	Bergen	3	Wallington Borough	99.89%
Fairview Ave	Minor Arterials	Bergen	4	Fairview Borough	99.79%
Carlton Ave	Principal Arterial Other	Bergen	5	East Rutherford Borough	99.75%
W Fort Lee Rd	Minor Arterials	Bergen	6	Bogota Borough	99.74%
Jackson Ave	Principal Arterial Other	Bergen	7	Rutherford Borough	99.73%
Cottage Pl	Principal Arterial Other	Bergen	8	East Rutherford Borough	99.71%
US Hwy 46	N/A	Bergen	9	Elmwood Park Borough	99.65%
Outwater Ln	Minor Arterials	Bergen	10	Lodi Borough	99.65%
Clinton Ave	Minor Arterials	Essex	1	Newark	99.99%
Clay St	Major Collector	Essex	2	Newark	99.97%
Bridge St	Local	Essex	3	Newark	99.78%
Clifton Ave	Minor Arterials	Essex	4	Newark	99.74%
Bloomfield Ave	Principal Arterial Other	Essex	5	Newark	99.56%
Park Ave	Principal Arterial Other	Essex	6	Newark	99.55%
Springfield Ave	Principal Arterial Other	Essex	7	Newark	99.49%
Jones St	Minor Arterials	Essex	8	Newark	99.41%
Broad St	Principal Arterial Other	Essex	9	Newark	99.27%
Broadway	Principal Arterial Other	Essex	10	Newark	98.96%
47th St	Minor Arterials	Hudson	1	Union City	99.62%
Cook St	Local	Hudson	2	Jersey City	99.32%
Pavonia Ave	Major Collector	Hudson	3	Jersey City	99.16%
Central Ave	Local	Hudson	4	Jersey City	99.12%
Summit Ave	Minor Arterials	Hudson	5	Jersey City	98.67%
3rd St	Local	Hudson	6	Union City	98.55%
Grand St	Minor Arterials	Hudson	7	Jersey City	98.19%
Webster Ave	Minor Arterials	Hudson	8	Jersey City	97.95%

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Montgomery St	Minor Arterials	Hudson	9	Jersey City	97.91%
Prospect St	Local	Hudson	10	Jersey City	97.71%
Voorhees Corner Rd	Major Collector	Hunterdon	1	Raritan Township	100.00%
Church St	Minor Arterials	Hunterdon	2	Raritan Township	99.92%
Main St	Minor Arterials	Hunterdon	3	Flemington Borough	99.87%
Reaville Ave	Major Collector	Hunterdon	4	Raritan Township	99.71%
Case Blvd	Major Collector	Hunterdon	4	Raritan Township	99.71%
Broad St	Local	Hunterdon	6	Flemington Borough	99.70%
N Main St	Minor Arterials	Hunterdon	7	Flemington Borough	99.68%
Barley Sheaf Rd	Local	Hunterdon	8	Raritan Township	99.61%
William St	Local	Hunterdon	9	Flemington Borough	99.59%
Bonnell St	Local	Hunterdon	10	Flemington Borough	99.56%
Raritan Ave	Principal Arterial Other	Middlesex	1	New Brunswick	99.99%
Albany St	N/A	Middlesex	2	New Brunswick	99.92%
Amboy Ave	Principal Arterial Other	Middlesex	3	Woodbridge Township	99.88%
Easton Ave	Principal Arterial Other	Middlesex	4	New Brunswick	99.76%
Green St	Minor Arterials	Middlesex	5	Woodbridge Township	99.74%
Saint Georges Ave	Principal Arterial Other	Middlesex	6	Woodbridge Township	99.66%
Woodbridge Ave	Principal Arterial Other	Middlesex	7	Highland Park Borough	99.64%
Georges Rd	Minor Arterials	Middlesex	8	North Brunswick Township	99.63%
US Hwy 9	N/A	Middlesex	9	Woodbridge Township	99.61%
Commercial Ave	Minor Arterials	Middlesex	10	New Brunswick	99.46%
Wickapecko Dr	Major Collector	Monmouth	1	Asbury Park	100.00%
Broadway	Minor Arterials	Monmouth	2	Keyport Borough	99.97%

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Lower Main St	Minor Arterials	Monmouth	3	Aberdeen Township	99.85%
W Sylvania Ave	Minor Arterials	Monmouth	4	Neptune City Borough	99.83%
Deal Rd	Minor Arterials	Monmouth	5	Ocean Township	99.83%
W Bangs Ave	Major Collector	Monmouth	6	Neptune Township	99.80%
Lakewood Rd	Major Collector	Monmouth	7	Neptune Township	99.77%
E End Ave	Major Collector	Monmouth	7	Neptune City Borough	99.77%
Main St	Minor Arterials	Monmouth	9	Avon-by-the-Sea Borough	99.75%
Asbury Ave	Minor Arterials	Monmouth	10	Tinton Falls Borough	99.72%
W Blackwell St	Principal Arterial Other	Morris	1	Dover	100.00%
Princeton Ave	Minor Arterials	Morris	2	Dover	99.95%
Speedwell Ave	Principal Arterial Other	Morris	3	Morristown	99.89%
Baldwin Rd	Local	Morris	4	Parsippany-Troy Hills Township	99.89%
Vail Rd	Minor Arterials	Morris	5	Parsippany-Troy Hills Township	99.84%
Watchung Ave	Minor Arterials	Morris	6	Summit	99.82%
Mount Pleasant Ave	Major Collector	Morris	7	Rockaway Township	99.72%
Art St	Local	Morris	8	Rockaway Township	99.66%
Spring St	Principal Arterial Other	Morris	9	Morristown	99.66%
US Hwy 46	Principal Arterial Other	Morris	10	Rockaway Township	99.65%
S Clifton Ave	Major Collector	Ocean	1	Lakewood Township	100.00%
Madison Ave	Principal Arterial Other	Ocean	2	Lakewood Township	100.00%
River Ave	Principal Arterial Other	Ocean	3	Lakewood Township	99.99%
Hurley Ave	Principal Arterial Other	Ocean	4	Lakewood Township	99.97%
Prospect St	Major Collector	Ocean	5	Lakewood Township	99.88%

Street Name	Functional Class	County	Rank in County	Municipality Name	Equity Centrality % in County
Steckler St	Local	Ocean	6	Lakewood Township	99.84%
2nd St	Local	Ocean	7	Lakewood Township	99.84%
Central Ave	N/A	Ocean	8	Lakewood Township	99.82%
Pine St	Minor Collector	Ocean	9	Lakewood Township	99.82%
Lakewood Rd	Principal Arterial Other	Ocean	10	Lakewood Township	99.78%
Presidential Blvd	Principal Arterial Other	Passaic	1	Paterson	99.97%
Lexington Ave	Minor Arterials	Passaic	2	Clifton	99.96%
Main Ave	Principal Arterial Other	Passaic	3	Clifton	99.92%
Lakeview Ave	Minor Arterials	Passaic	4	Clifton	99.85%
Memorial Dr	Principal Arterial Other	Passaic	5	Paterson	99.81%
Ackerman Ave	Major Collector	Passaic	6	Clifton	99.68%
Totowa Ave	Minor Arterials	Passaic	7	Paterson	99.66%
Ryle Ave	Minor Arterials	Passaic	8	Paterson	99.56%
Broadway	N/A	Passaic	9	Elmwood Park Borough	99.28%
Straight St	Minor Arterials	Passaic	10	Paterson	99.24%
Somerset St	Principal Arterial Other	Somerset	1	New Brunswick	99.92%
Landing Ln	Minor Arterials	Somerset	2	Franklin Township	99.85%
Greenbrook Rd	Minor Arterials	Somerset	3	North Plainfield Borough	99.84%
US Hwy 22	N/A	Somerset	4	North Plainfield Borough	99.78%
Easton Ave	Principal Arterial Other	Somerset	5	Franklin Township	99.78%
State Hwy 27	Principal Arterial Other	Somerset	6	North Brunswick Township	99.57%
Norwood Ave	Minor Arterials	Somerset	7	North Plainfield Borough	99.55%
W End Ave	Major Collector	Somerset	8	North Plainfield Borough	99.53%
Lincoln Hwy	Principal Arterial Other	Somerset	9	North Brunswick Township	99.52%

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New Providence Rd	Minor Arterials	Somerset	10	Watchung Borough	99.49%
Lakeside Blvd	Minor Arterials	Sussex	1	Hopatcong Borough	100.00%
Ledgewood Ave	Principal Arterial Other	Sussex	2	Stanhope Borough	99.92%
Brooklyn Ave	Minor Arterials	Sussex	3	Stanhope Borough	99.89%
Durban Ave	Minor Arterials	Sussex	4	Hopatcong Borough	99.72%
Willis Ave	Minor Arterials	Sussex	5	Hopatcong Borough	99.70%
Wills Ave	Minor Arterials	Sussex	5	Hopatcong Borough	99.70%
Newton Sparta Ave	Minor Arterials	Sussex	7	Newton	99.36%
Hicks Ave	Major Collector	Sussex	8	Newton	99.34%
Brooklyn Stanhope Rd	Minor Arterials	Sussex	9	Hopatcong Borough	99.29%
State Hwy 23	Principal Arterial Other	Sussex	10	Franklin Borough	99.13%
Hardysonville Rd	Principal Arterial Other	Sussex	10	Franklin Borough	99.13%
N Broad St	Minor Arterials	Union	1	Hillside Township	100.00%
Liberty Ave	Minor Arterials	Union	2	Hillside Township	99.82%
Elmora Ave	Principal Arterial Other	Union	3	Elizabeth	99.70%
Morris Ave	Principal Arterial Other	Union	4	Union Township	99.67%
Broad St	Principal Arterial Other	Union	5	Elizabeth	99.57%
Rahway Ave	Principal Arterial Other	Union	6	Elizabeth	99.39%
Westfield Ave	Principal Arterial Other	Union	7	Elizabeth	99.33%
Conant St	Minor Arterials	Union	8	Hillside Township	99.24%
Salem Rd	Minor Arterials	Union	9	Union Township	99.22%
Union St	Major Collector	Union	10	Elizabeth	99.20%
Maple Ave	Minor Arterials	Warren	1	Pohatcong Township	99.98%
Chestnut St	Minor Arterials	Warren	1	Pohatcong Township	99.98%
Memorial Pkwy	Principal Arterial Other	Warren	3	Lopatcong Township	99.97%
Lock St	Minor Arterials	Warren	4	Pohatcong Township	99.95%

Street Name	Functional Class	County	Rank in County	Municipality Name	Equity Centrality % in County
Uniontown Rd	Minor Arterials	Warren	5	Greenwich Township	99.85%
Mill St	Principal Arterial Other	Warren	6	Hackettstown	99.79%
Roseberry St	Minor Arterials	Warren	7	Phillipsburg	99.74%
S Main St	Principal Arterial Other	Warren	8	Phillipsburg	99.72%
Main St	Principal Arterial Other	Warren	9	Hackettstown	99.70%
Logan St	Minor Arterials	Warren	10	Phillipsburg	99.67%