Enhancing the Strategic Prioritization Process with Socioeconomic Geospatial Analysis

NCDOT Research Project 2021-17
FHWA/NC/2021-17

FINAL REPORT
February 2023

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Technical Report Documentation Page

1. Report No. **NCDOT/NC/2021-17**	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle **Enhancing the Strategic Prioritization Process with Socioeconomic Geospatial Analysis**		5. Report Date Febuary15, 2023
		6. Performing Organization Code
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9. Performing Organization Name and Address **Institute for Transportation Research and Education North Carolina State University Centennial Campus Box 8601 Raleigh, NC**		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address **North Carolina Department of Transportation Research and Analysis Group 104 Fayetteville Street Raleigh, North Carolina 27601**		13. Type of Report and Period Covered **Final Report January 2021 - December 2022**
		14. Sponsoring Agency Code **RP2021-17**
Supplementary Notes:		

16. Abstract

This project is designed to provide the North Carolina Department of Transportation (NCDOT) with implementation-ready tools for incorporating data-driven socioeconomic measures into the Strategic Transportation Investments (STI) prioritization process for pedestrian, bicycle, and transit projects. This research will equip NCDOT with the tools needed to incorporate community-level data into the prioritization process that has been historically challenging to integrate. Originally proposed with a focus on incorporating a Raster Suitability Analysis (RSA) methodology, this project has pivoted towards using proximity analysis techniques that more closely align with existing prioritization practices and that are better suited to the relevant data and NCDOT's needs. A core component of this process is a technique that supports the consistent measurement and comparison of transportation disadvantage in communities proximate to projects across the state. Additional deliverables include techniques for augmenting these residential-based community characteristics with workplace characteristics (low and middle-income job centers) and tools for improving and expanding POI analysis with additional data and context-sensitive measurement techniques. These approaches developed through this study can serve as a foundation for other equity-related measures developed for future NCDOT prioritization cycles.

17. Key Words **Prioritization, Measurement, Equity, GIS**	18. Distribution Statement		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 57	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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Acknowledgments

The research team wishes to thank the many individuals of the North Carolina Department of Transportation who contributed to the project. The research team greatly appreciates the tremendous support and efforts received from the SPOT team. Special appreciation is also given to the Steering and Implementation Committee for their valuable support of the study.

Executive Summary

Approximately every two years, the North Carolina Department of Transportation (NCDOT) receives funding requests for transportation projects across the state. Given limited funds, the Department must determine which proposed projects will receive funding. The Strategic Transportation Investments (STI) Law was passed in 2013 to standardize project selection with a process that prioritizes potential investments using quantitative measures. This process, which incorporates data-driven scoring and local input, is regularly updated by a Workgroup of comprised primarily of transportation engineers and planners to help ensure that it incorporates consideration for North Carolina's diverse transportation needs. However, NCDOT continues to be challenged to capture project impacts that are difficult to quantify, such as the potential socioeconomic benefits resulting from a transportation investment.

The purpose of this research is to provide NCDOT with a valid, reliable method and corresponding data recommendations that can be used to incorporate socioeconomic data related to equity into the STI process. This study provides the tools needed to incorporate community-level data, which has been historically challenging to integrate, into the prioritization process. While methods specifically for pedestrian, bicycle, and transit projects were developed, these approaches can be extended to other transportation modes in the future.

Three key methods were developed and are recommended through this study:

1. Transportation Disadvantaged Community Proximity
2. Workplace Characteristics Analysis
3. Context-Sensitive Points of Interest Analysis (POIs)

Originally proposed with a focus on incorporating a Raster Suitability Analysis (RSA) methodology, this project has pivoted towards using proximity analysis techniques that more closely align with existing prioritization practices and that are better suited to the relevant data and NCDOT's needs. A core component of this process is a technique that supports the consistent measurement and comparison of transportation disadvantage in communities proximate to projects across the state. Additional deliverables include a technique for augmenting these residential-based community characteristics with workplace characteristics (low and middle-income job centers) and an approach for improving and expanding POI analysis with additional data and context-sensitive measurement techniques.

Each of these methods support equity-related considerations and can be implemented into the STI process individually or in conjunction with one another. These approaches incorporate data currently collected through the STI process as well as data from reputable sources that are frequently updated and readily available to NCDOT. Ultimately, the results of this study provide the first steps towards measuring the potential community impacts of projects through the STI process and can serve as a foundation for other equity-related measures developed for future NCDOT prioritization cycles.

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Introduction

In 2013, the Strategic Transportation Investments (STI) legislation was signed into North Carolina law. The law was designed to establish a more transparent, systematic, and data-driven process, called strategic project prioritization, for ranking major transportation. In practice, this law guides how the North Carolina Department of Transportation (NCDOT) determines which proposed transportation projects requested across the state will receive funding each year. It regulates the prioritization of projects across projects from modes including highway, public transportation, bicycle & pedestrian, rail, ferry, and aviation (§ 136-189.10, 2013).

NCDOT Project Prioritization

The STI process prioritizes proposed transportation projects using quantitative measures that consider mode and scale, as well as local input. The process is designed to help NCDOT select projects that support a region's goals and objectives, assists NCDOT in distributing funding more efficiently and effectively, and is used to update the State Transportation Improvement Program (STIP). The current cycle to update the STIP for the years 2024-2033 is called Prioritization 7.0 (P7.0).

The STI process, which incorporates data-driven scoring, is routinely updated in collaboration with a Workgroup of transportation comprised primarily of engineers and planners from across the state to help ensure that the process in constantly improving. In recognition of the need to better incorporate consideration for North Carolina's diverse transportation needs, the P5.0 Workgroup recommended adding quantitative measure(s) that represent the needs of vulnerable populations. This project is designed to help address this need.

Project Overview and Objectives

The purpose of this research is to provide NCDOT with a valid, reliable method and corresponding data recommendations that can be used to incorporate socioeconomic data related to equity into the STI process. When evaluating projects and how they will impact surrounding communities, analyzing data that provides insights into socioeconomic and community characteristics is key. Integrating related criteria into the STI process means that NCDOT must capture project considerations that are sometimes more difficult to quantify and compare, such as the scale of transportation disadvantage in the surrounding area.

Currently, NCDOT lacks the data and methods needed to examine socioeconomic and community characteristics and to develop associated measures for the prioritization process. As a result, projects that have the potential to yield higher levels of socioeconomic benefits may not be selected for funding because these factors are not effectively measured through the existing scoring process. Consequently, NCDOT may be missing opportunities to invest in projects that provide greater quality of life benefits for vulnerable and underserved (lower income, mobility-challenged, etc.) North Carolinians.

To enhance NCDOT's ability to include socioeconomic measures in the prioritization process, the research team developed geospatial methods that incorporate data readily available to NCDOT. The approach is designed to be easily incorporated into the existing prioritization process, with consideration for existing measures, scoring methods, and inputs provided by project submitters. The resulting geospatial data can be used to evaluate the socioeconomic implications of proposed pedestrian, bicycle, and transit projects. NCDOT can apply this approach as part of scoring criteria in the prioritization process to better account for how proposed projects may impact vulnerable communities in the state.

Equity and Project Prioritization

Across the United States, state departments of transportation (DOTs) are adopting data-driven prioritization processes to select projects for funding (Haake, 2018). North Carolina is a national leader in this area, with the Strategic Transportation Investments Law ratified in 2013 (§ 136-189.10, 2013). As DOTs and regional agencies have implemented data-driven prioritization processes, there has been a growing need for reliable datasets and defensible data processing methods that support criteria for project scoring.

Measuring Equity

Although transportation agencies have the power to increase or decrease the wellbeing of the communities they serve, especially vulnerable and underserved individuals, few state DOTs currently integrate equity considerations into their quantitative transportation prioritization processes.

Equity is related to the just distribution of resources in communities (Lewis, et al., 2021), including how transportation projects are planned and prioritized (Transit Cooperative Research Program, 2020). Understanding the communities that can be impacted by transportation projects is essential to measuring the equity of potential project impacts. The location and nature of transportation investments can shape how surrounding communities interact with their environment. Projects can either provide benefits or impart burdens on the surrounding communities, with new project burdens often further compounding existing burdens experienced by disadvantaged communities (Litman, 2021).

Analyzing the equity of project options should involve an examination of how a given option will impact a community's access to essential services and places of interest (American Planning Association, 2019; Litman, 2021). Examples include access to education, employment, healthcare, and nutritious food. For many state DOTs, measuring such variables may seem difficult to evaluate because such an analysis requires the incorporation of socioeconomic indicators like income and other demographic information paired with geographic location (Krapp et al., 2021). Quantifying these types of human characteristics and determining what constitutes high and low transportation needs in a community can involve complex decision-making. Furthermore, context such as differences in community need in one region compared to another should be considered when examining equity in project planning across a larger geographic area like a state.

Equity Considerations at NCDOT

The P5.0 Workgroup for the NCDOT prioritization process noted a need to better capture the impact of public transportation projects, for which the process currently emphasizes the number of trips taken without considering the value of those trips or which populations they intend to serve. To address this need, ITRE researchers worked with NCDOT staff to conduct an extensive survey and interviews focused on how these factors are incorporated into funding prioritization algorithms across the U.S. as part of *Research Project 2019-16: Assessing Measures of Transportation Disadvantage for Public Transportation Project Prioritization.* Through this 2019 effort, the research team found that two main types of metrics were typically used: 1) scoresheets (generally staff committees analyze and rate each project using pre-set rubrics), and 2) geographical computations (the proximity of vulnerable populations and/or high-value destinations are identified).

The P6.0 Workgroup considered applying the study recommendations but advised that the findings would need to be incorporated into a format that could be consistently captured and analyzed across the state and more easily quantified to include in the project scoring process. NCDOT and the subsequent Workgroups have expressed a desire for similar metric(s) that can be applied to future prioritization scoring efforts. This interest has grown to include equity-related metric(s) that can extend beyond public transportation to other modes.

In June 2022, NCDOT also established the following definition for transportation equity for long-range planning and project prioritization as part of Research Project 2022-069:

"*Equity is improving quality of life by addressing transportation benefits and burdens in a sustainable way. Equitable planning and investment decisions are made through inclusive collaboration to provide safe, reliable, and attainable transportation options. In order to meet the mobility needs of all North Carolinians, it is essential to recognize and mitigate barriers to access experienced by historically underserved communities."*

This definition further reinforces the agency's growing commitment to developing practices, policies, and measures that consider equity in decision-making.

Common Approaches for Measuring Equity

As of 2019, more than 24 large MPOs across the U.S. considered equity in some way as part of prioritization scoring. Many MPOs measure equity as part of their project prioritization process. The approaches to equity measurement vary greatly, with MPOs across the United States using both different approaches to measuring equity and socioeconomic status, as well as different modeling and analysis approaches.

Types of Measures

There are many types of measures incorporated by MPOs to integrate equity. These measures can be categorized into six different kinds of measurements, according to Krapp et al. (2021)

1. Locations burden-based, where the location of projects that may place a disproportionate burden on certain communities is factored into the criteria;
2. Locations benefits-based, where points are awarded to projects that will enact community benefits
3. Impact-based, where both benefits and burdens are scored;
4. Access to destinations-based, where there are access to points of interest for marginalized communities;
5. User-based, where points are awarded to projects where the users are socioeconomically marginalized; and
6. Community engagement-based, where projects that engaged community participation are awarded points

While many MPOs designate equity-focused areas, the specific measures used to designate socioeconomic disadvantage vary. Examples include the number of people who identify as being part of a minority race, zero-vehicle households, seniors (such as in Houston), the number of jobs to which projects provide minority workers access (such as in Atlanta), or the percentage of riders below the poverty line (such as in Chicago). Whatever the measurement used, projects in designated Environmental Justice (EJ) areas are awarded points for being in (or connected to) EJ areas, an approach in line with most of the surveyed MPO strategic plans (Krapp et al, 2021; Williams et al., 2019).

Application of Measures

There is also great variance in how points are awarded, and how criteria are weighed. Some planning areas and state transportation entities assign values based on externally determined geolocations that designate socioeconomic need. For example, the New Jersey Transportation Planning Authority (NJTPA) uses the Social Vulnerability Index compiled by the Center for Disease Control (CDC) to score communities to fit its Equity dimension, one of four dimensions used to designate promising areas for transportation investment. The approach is similar in Albany, where projects in Environmental Justice areas receive bonus points, and projects avoiding these areas are penalized. In California's San Francisco Bay Area, projects that alleviate transportation expenditures in areas at risk of high displacement (as determined by the council) are scored positively. Projects with adverse effects in these and other criteria receive scoring penalties. In St Louis, the East-West Gateway Planning Committee assigns 15% of its scoring criteria to social equity concerns by awarding four of sixty possible points to projects located in a majority low-income or minority neighborhood, as determined by the US Census (Karner e al, 2013; Krapp et al, 2021; Williams et al, 2019).

Implementation and Considerations for Measures

The variance in approaches highlights a challenge in measuring and weighting equity in project prioritization. MPOs across the country are measuring similar dimensions of equity and/or justice in different ways. Many of these dimensions are related as well. For instance, neighborhoods with high minority populations are most likely to be experiencing poverty and have weaker access to job centers as well as pedestrian and bicycle infrastructure (Braun et al, 2019). This presents a few challenges and considerations for implementing equity-related measures into a project prioritization process.

First, because different measurements are used to capture poverty and marginalization constructs, it can be difficult to understand how scoring or the designation of disadvantaged communities changes with the inclusion of different measures. Robust sensitivity testing is helpful, but it can be unclear how an MPO or state should proceed when different measurements produce different equity scores or major changes in designation. Regardless of the measures used, it is helpful to avoid prioritization based on subjective researcher decisions to maintain consistency and reliability in application (Eboli et al 2011, Karner et al 2013).

Second, sometimes measures of socioeconomic marginalization are correlated. To avoid measuring the same construct more than once, researchers may face a choice related to which metrics to include (Welch et al, 2013). For instance, census tracts with high degrees of income inequality might also have high degrees of housing insecurity. If these two measures are highly (or nearly perfectly) correlated, researchers may choose to remove a measure, even if the MPO explicitly intends for projects to meet the needs of people in both impoverished and housing insecurity demographic groups. Transparency and researcher guidance in these cases is paramount (Xiaohong et al 2020).

Additionally, using data that incorporates different sources can introduce data coordination challenges for MPOs, regardless of whether different measures or data sources introduce challenges of covariance (Blanchard et al, 2017). Also, data sources may undergo external changes that have drastic impacts on the ways that MPOs or states measure socioeconomic status. For instance, the widely used 2020 Decennial Census products underwent major changes to granularity related to security protocols, introducing synthetic data at all levels more granular than census tract, including individual data points and aggregated block groups. MPOs managing major demographic or socioeconomic change will need to consider the synthetic nature of some units of analysis before census data use (Santos-Lozada, 2021).

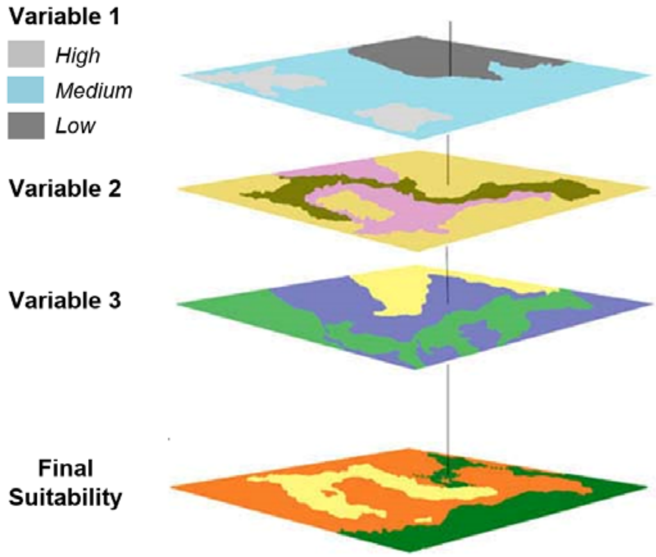
For many of these decisions, researchers can rely on literature reviews for guidance on decisions and their tradeoffs. For this reason, the robust nature of some MPO protocols can be of value to local areas looking to infuse equity into project prioritization. However, the literature at the state level is less robust. As larger and more diverse geographic areas, states face unique challenges compared to MPOs, who plan for smaller regions. For example, states often manage additional modes of transportation, such as ferry and aviation, more comprehensively, and may also need to oversee transportation for large rural populations or large rural spaces. Due to differences in state policies and structures, there may not be procedures consistent enough to be used repeatedly across states (Modlin, 2011). While the federal government has been working on developing more universally helpful approaches for measuring and prioritizing equity in transportation and land use, many of these tools are still in process and may only provide some of the methods states need quantify equity-related considerations. These efforts are discussed in later report sections.

Because of these limitations, transportation and planning agencies may seek sound approaches that allow them to measure equity in a way that can be consistently and reliability integrated into their unique project prioritization processes. One of these approaches is Raster Suitability Analysis (RSA), which involves using weighted geolocated socioeconomic (or other) criteria to score projects as part of existing analysis processes. As such, this project originally focused on developing an RSA-based methodology to create socioeconomic impact factors that NCDOT can utilize in the STI process for non-highway modes.

Initial Method: Raster Suitability Analysis

The RSA approach was proposed by the research team as a way to combine multiple layers of quantitative geospatial datasets into a standardized set of numerical values. Through RSA, these numerical values could be aggregated to produce a single raster layer containing values representing the suitability of each area or project in a geospatial context. RSA allows researchers to create a standardized scale with weights that can also be applied to each evaluation criteria individually. These values can then be compared among projects and integrated into the prioritization scoring measures to inform project comparisons, as shown in Exhibit 1.

Exhibit 1. Raster Suitability Analysis Example



RSA was initially proposed as a promising method because it is widely used for site selection, expansion, and point of entry criteria. The approach has been used to optimize locations for major planning projects investment in vertical urban growth (Koziatek, 2016), placement of waterfront parks in Buffalo (Ilhamdaniah, 2018), and land use optimization in Florida (Turk & Zwick, 2019). General planning projects include identifying optimal locations for wildfire fuel treatment (Thakar, 2017) and the roadside placement of wildflowers (Craig, 2018). Sahu (2018) used the RSA approach for bike lane selection, incorporating socioeconomic criteria. Rodriguez-Espinosa et al (2019) used RSA to optimize selection for green infrastructure development, and Taromi et al (2015) used it to optimize building development in Delaware to maximize transit connectivity. For public agencies that are asked to balance costs and operational efficiency with public values like energy efficiency or conservation (McWilliams et al, 2016), approaches like RSA have become increasingly useful.

Testing for NCDOT Prioritization

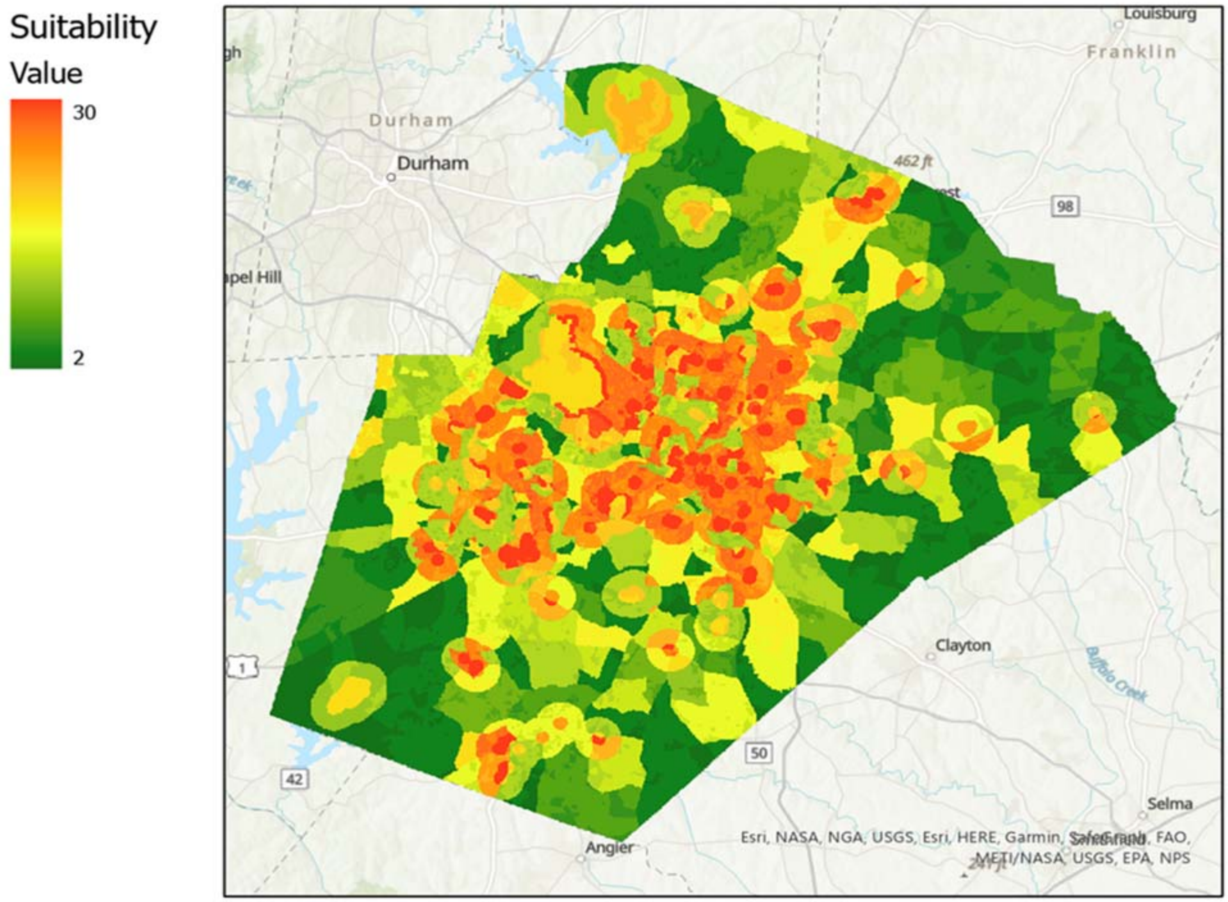
To test the RSA technique for socioeconomic impact analysis in North Carolina, the research team developed small-scale prototype suitability models using demo data. Incorporating data commonly employed in equity analysis, the prototype development provided insights into the methodological requirements and outputs of RSA when applied for the purposes of NCDOT project prioritization.

Particular focus was given to the steps necessary to process datasets from their native format to a raster format suitable for use in RSA. The research team's progress in identifying key data layers suggested demographic and socioeconomic data available from the U.S. Census American Community Survey (ACS) would be fundamental to the analysis. Other noteworthy datasets were identified through the literature review, including equity-related points of interest and workplace characteristics, which are similarly available as discrete geolocated features rather than raster datasets.

With the RSA approach, identifying the correct formulation of the data to rasterize is critical. While raster datasets commonly describe continuously changing surfaces, the feature-based data identified are discrete for each feature. As a result, the rasterization of these datasets must be based on a single summary statistic (sum, rate, or density) for each feature. This preprocessing must also consider how summary statistics would be extracted for each project area.

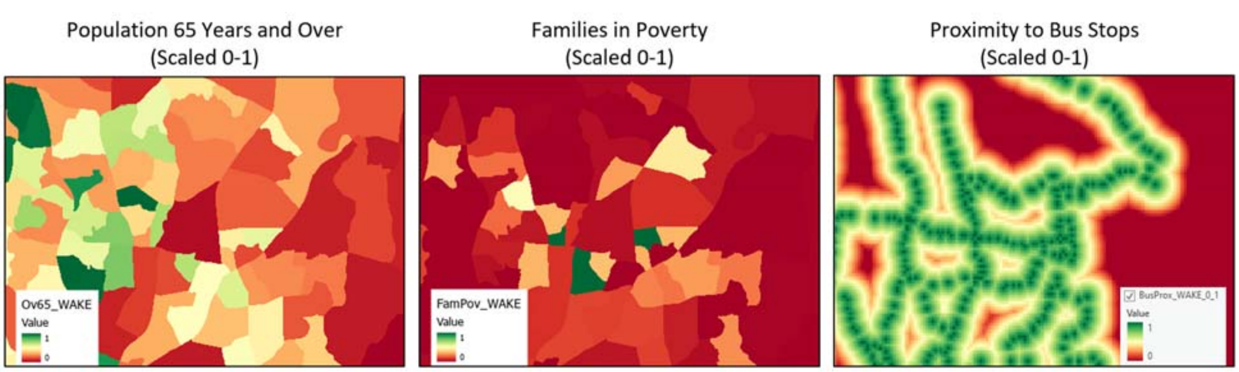
An example of the small-scale prototype models developed for North Carolina is shown in Exhibit 2**.** To create this surface, the research team used feature-base data from the ACS and proximity-based data generated from a set of points of interest. The resulting surface depicts a range of suitability values that show the interaction of representative rasterized feature-based datasets and distance rasters.

Exhibit 2. RSA Model Prototype with Example Socioeconomic and Distance Data



Examples of rasterizing three datasets assessed in the RSA modeling process are provided in Exhibit 3 below. Rasterization of the socioeconomic and demographic data (Population 65 Years and Over and Families in Poverty) results only in the replication of the discrete feature data in a new format. Hard boundaries present in the source data are present in the raster data. The raster format is more suitable for representing Proximity to Bus Stops, as continuous change can be represented in this format.

Exhibit 3. Examples of Rasterized Data used in RSA Modeling



Limitations Identified

Although RSA is a useful approach for overlaying and unifying data, the research team identified several limitations when trying to apply it to socioeconomic data for transportation project periodization. RSA is highly suitable when variables characterized by continuous change across a surface comprise a substantial portion of the input data. Such datasets, especially those that can be reliably obtained at a statewide scale, are more commonly used to analyze environmental phenomena and imagery than socioeconomic factors. As this research focused on integrating key socioeconomic variables, it became apparent that a technique more appropriately tailored to the format of these key datasets should be pursued to minimize the unnecessary manipulation of the data.

While some datasets included in the prototype model were obtained or generated as rasters in their native format, the essential socioeconomic and demographic data identified as being essential to the analysis needed to be converted to a raster format. This technical exercise added processing requirements without commensurate value for the analysis outputs.

Additionally, adaptation of the data to the RSA approach requires numerous non-trivial decisions related to both rasterization and the overlay of variables by scaling and weighting the variables included in the analysis. Weighting and overlay procedures vary, and each comes with different tradeoffs, requiring sometimes subjective decisions related to suitability. This issue is particularly acute when working with socioeconomic data in an RSA context because the data must be heavily processed to yield raster layers suitable for overly. Some of the key questions that must be answered for these datasets include:

- What parameters should be used for the rasterization of the data (e.g., cell size and sampling method)?
- What characteristic of the data should be used for rasterization (e.g., variable count, variable population rate, or variable density per unit of area?)
- How (and at what stage) should the data be adjusted to a common scale for measuring final suitability?
- How should the input datasets be weighted (or not) in the calculation of the final suitability surface?

One feature of the RSA method is the quantification of multiple variables into a single metric that can be situated in a broader scoring process. While developing RSA models, the research team recognized that the expression of many variables as a single metric, such as "suitability", can obscure the individual community characteristics analyzed, making it difficult to communicate the value of summary metrics. This limitation is not unique to the RSA approach. However, it is exacerbated by the other technical challenges inherent to the RSA approach noted here.

Ultimately, the excessive data manipulation and numerous decision-making requirements of RSA obscured the information contained in original data sources, introduced substantial subjectivity, and increased technical burden without increasing benefits at a meaningful level. This lack of transparency is especially problematic when applying the approach to and analysis of community characteristics, as the RSA process would be applied in pursuit of greater equity. As a result, the research team opted to purse alternative methodological approaches that would require less manipulation of the primary socioeconomic datasets by NCDOT, less dependence on researcher judgment, and more overall transparency.

Refined Method: Proximity Analysis with Socioeconomic Index

Given the limitations of RSA, the research team developed a methodology that is better-suited to the relevant socioeconomic data and the measurement of equity-focused factors within the STI process. By pivoting away from the RSA approach and working with data in a more natural format, the research team was able to improve the clarity of the methodology and resulting measures while reducing subjectivity and potential bias in the analysis. After further testing and experimentation, the research team opted to pursue a more conventional proximity-based analysis approach.

In addition to being better suited to the data, a proximity analysis using non-rasterized feature data is also better-aligned with common practices used throughout the country for identifying and measuring disadvantage, as further detailed in the following sections. As part of the methodology development, the research team identified several considerations related to leveraging a proximity analysis that would need to be addressed as part of this research. Exhibit 4 summarizes several of the key implementation consideration addressed when developing the methods recommended through this study.

Exhibit 4. Key Implementation Considerations and Method Development Decisions

Implementation Considerations	Method Development Decisions
Identify factors to be included in equity analysis	Apply "Community of Concern" perspective via the incorporation of NCDOT IMD's Transportation Disadvantage Index (TDI)
Account for regional differences in absolute levels of disadvantage	Assess equity within a regional context by constructing the index at the NCDOT division level
Balance approach for urban and rural contexts	Focus method on population characteristics rather than total population
Define project impact areas using proximity analysis	Apply existing proximity analysis parameters from P6.0

To meet the objectives of this project and to support integration into the prioritization process, the methodological approaches developed must be valid statewide and sensitive to regional differences in land use and population characteristics. Additionally, the approach must be valid across multiple modes considered by the STI process. To these ends, the research team developed a methodology based on the spatial analysis of how population characteristics within a project impact area compare to the characteristics of the NCDOT division in which the project is located. This method leverages data that is publicly-available for the entirety of the state and builds on existing spatial analysis components of the P6.0 prioritization process. Variations of the method are presented here for bicycle, pedestrian, and transit modes as initial test cases.

Method Development

The research team conducted a review of practices for measuring demographic and socioeconomic community characteristics by transportation agencies throughout the country. A national literature and data review revealed that while the specific methods used varied, there are some common practices, including common types of variables, that are used by transportation and planning agencies to define communities with transportation disadvantage for equity analysis.

Many useful models for assessing disadvantaged communities within the domain of transportation can be found in definitions for "Communities of Concern" (COCs) applied by metropolitan planning organizations (MPOs). A 2020 analysis by the Urban Institute found that approximately half of all definitions included just two community characteristics: concentration of populations who are low-income and/or in poverty and concentrations and racial and ethnic minority populations. These factors reflect a minimum level of analysis for addressing *Executive Order 12898 - Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*. For MPOs that include additional community characteristics in their analysis, common factors include concentrations of limited English language proficiency populations, senior/elderly populations, populations with disabilities, and households with no access to a vehicle.

All of the definitions identified rely heavily on public demographic data provided by the U.S. Census, including U.S. American Community Survey (ACS) (Ezike et al., 2020). Definitions for COCs used by MPOs employ a variety of geographies to analyze this data. The Urban Institute review found that 42 MPOs use at least some data at the census tract level. Seventy-two definitions employ data at a smaller geographic level, including 36 definitions using census block group data, 24 using traffic analysis zones, and 12 using census blocks (Ezike et al., 2020).

Likewise, there are a variety of strategies used to compare community characteristics within regions. A common approach used by MPOs for defining COCs is comparing characteristics at a small-scale census geography to the regional mean or median. Others use thresholds set at a multiple of the regional mean or classify communities using standard deviations, natural breaks, or quantiles. Some require the presence of a certain combination of factors above a set value (Ezike et al., 2020). For example, in its definition of Equity Priority Communities, the Metropolitan Transportation Commission of the San Francisco Bay Area requires a concentration of both people of color and low-income households OR a concentration of three other analyzed factors (MTC, 2021).

A useful model of community-level socioeconomic analysis at the national level is the Environmental Protection Agency's (EPA) EJScreen tool, a mapping and screening tool that combines socioeconomic and environmental indicators in a number of indices to assist in environmental justice analysis. The EJ Screen tool includes several socioeconomic community characteristics: people of color, low-income population, unemployed population, limited English proficiency population, population with less than high school education, population under 5 years, and population over 54. Characteristics are enumerated at the block group level using data from the ACS (EPA, 2022).

Other emerging federal tools for assessing the socioeconomic factors underlying disadvantage include the White House Council on Environmental Quality's (CEQ) Climate and Economic Justice Screening Tool (CEJST) (currently in beta version) and U.S. Department of Transportation's (USDOT) interim definition for Transportation Disadvantage Communities (DACs). Both are nationally available at the tract level using a combination of data sources, including the ACS for community characteristics and several sources for health and environmental data. The methodology for the CEJST was designed at the tract level, the smallest unit at which the specific datasets included were available on the national level. Socioeconomic community characteristics common to both tools include low-income and poverty, unemployment, education, and linguistic isolation (CEQ, 2022; USDOT, 2022).

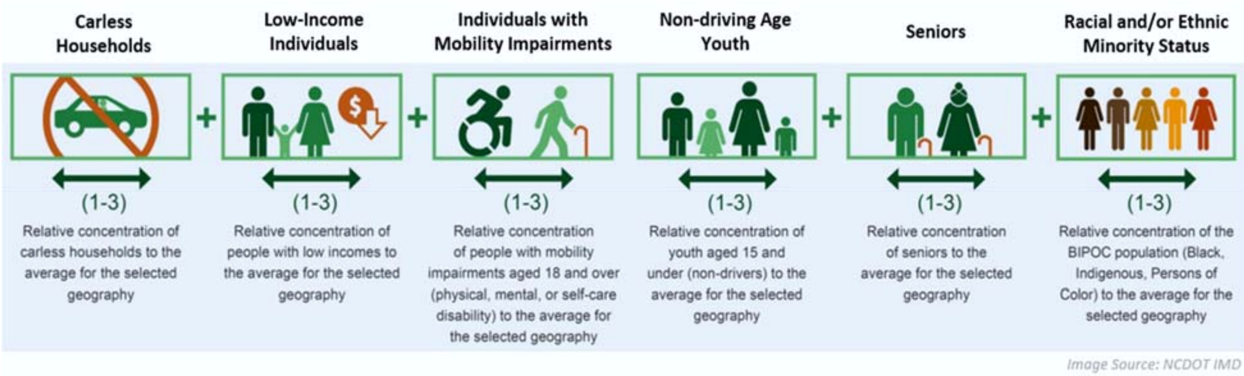
Each of these tools leverages approaches that reinforce the value of the core method recommended through this study, which incorporates a proximity-based analysis and index with socioeconomic data for NCDOT project prioritization.

Analyzing Socioeconomic and Demographic Data

The research team's nationwide review of common methodologies for assessing socioeconomic characteristics for transportation and planning included a definition for transportation disadvantage employed by NCDOT's Integrated Mobility Division (IMD). This definition and associated index have a high degree of alignment with common practices reviewed nationwide and discussed in the previous section.

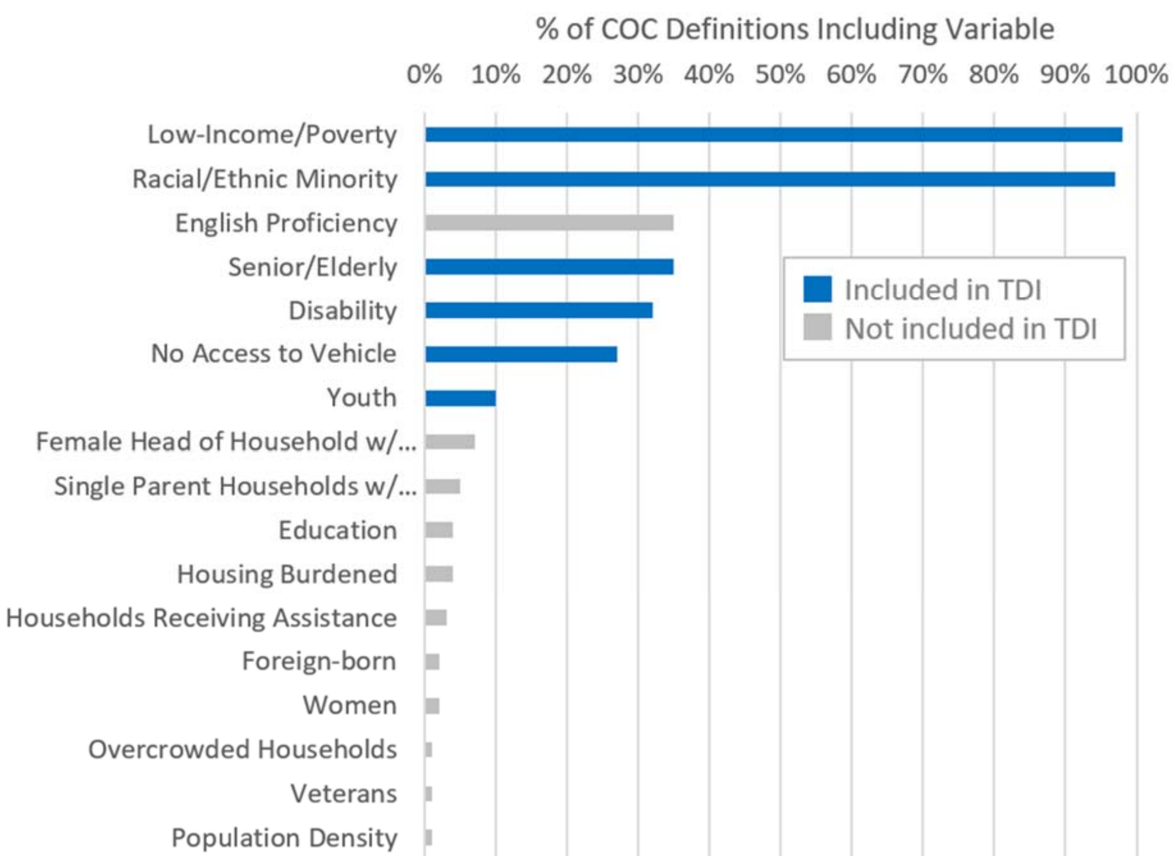
IMD's Transportation Disadvantage Index (TDI) considers six variables related to transportation disadvantage, with each variable representing a unique category for analyzing issues of transportation equity, mobility, and accessibility. These variables are detailed in Exhibit 5.

Exhibit 5. Variables in Transportation Disadvantage Index (TDI) Developed by NCDOT IMD



The variables included in the TDI are among the most commonly analyzed characteristics by MPOs for defining Communities of Concern: poverty/income, racial/ethnic minority status, disability, vehicle access, and age, including both seniors and youth. Exhibit 6 shows the overlap of variables included in the TDI with the most commonly assessed variables in MPO definitions for Communities of Concern. The IMD TDI includes 6 of the top 7 variables used by the 100 largest MPOs in the U.S. and incorporates an approach to analyzing these variables that align well with the previously referenced national literature.

Exhibit 6. Overlap of IMD TDI Variables and Variables in COC Definitions for 100 Largest MPOs



Considering the methodological strength of the IMD TDI, high level of alignment with sound national practices, and current use by NCDOT, the research team decide to use the index as the foundation for the socioeconomic analysis included in the proximity-based methodology.

Data for all variables included in the IMD TDI is available from the ACS at the block group level and is updated annually (NCDOT, 2022). The TDI employs ACS 5-year estimates, a summary of data collected over a 5-year sampling period to increase the sampling reliability for small areas and population subgroups (U. S. Census Bureau, 2022a). Exhibit 7 contains detailed descriptions and data sources notes for the six variables included in the TDI. It is important to note that the ACS-based variables used to construct the TDI describe the residential characteristics of individuals within the census geography analyzed. Consideration of workplace characteristics is described later in this report.

Exhibit 7. Details for Variables Included in the TDI

Variable	Description	Census Table
BIPOC (Black, Indigenous, and people of color)	Percentage of population identifying as Racial and ethnic minorities, defined within the TDI as the total population identifying as non-white population plus the population identifying as white and Hispanic or Latino	B01001_001E - B03002_003E
Poverty	Percentage of population reporting Household Income below 1.5 times the Federal Poverty level	
Disability	Percentage of population reporting one or more disabilities, as defined by the U.S. Census Bureau	C17002_002E + C17002_003E + C17002_004E + C17002_005E
Carless Households	Percentage of Households reporting zero vehicle access	C21007_005E + C21007_008E + C21007_012E + C21007_015E + C21007_020E + C21007_023E + C21007_027E + C21007_030E
Seniors	Percentage of population over 65	B25044_003E + B25044_010E
Youth	Percentage population under 16	B09020_001E

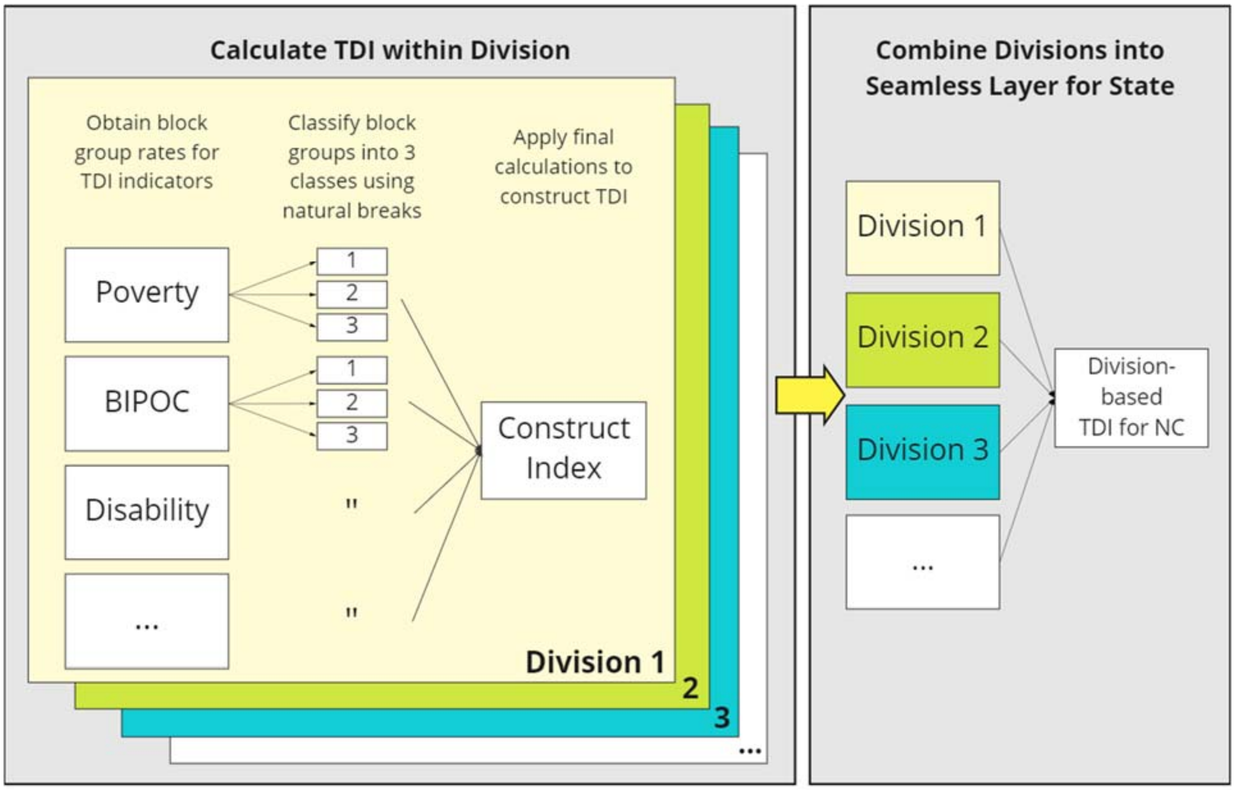
Constructing the Division-Based Approach

The methodology used to construct the IMD TDI can be adapted to a variety of geographies. Final TDI values by block group can be calculated relative to all block groups in the state, region, county, or other geography of choice (NCDOT, 2022). An implementation of the TDI at the level of the NCDOT division is recommended by the research team due to its appropriateness for the context of quantifying community characteristics and impact in the STI process context. By constructing the index at the division level, the disadvantage for each block group is relative to the division, such that every division necessarily includes block groups of highest need, lowest-need, and levels in-between. Through the STI process, projects compete for funding at the statewide, regional, and division levels. As the division is the lowest geography used for comparison, it is an appropriate level at which to classify TDI values.

The division-based construction of TDI acknowledges regional differences within a diverse state and presents a balance-point between a statewide analysis and 100 separate county-level constructions of the index. It also aligns with the shared division-based resources and needs that underpin system planning. Though it is constructed at the division level, the division-based index covers the entirety of the state and allows for the comparison of values across the state.

The steps used to create the division-based TDI for the state are shown in Exhibit 8. Within each division, each of the six variables is classified on a scale from 1 (lowest) to 3 (highest) using a natural breaks algorithm. The natural breaks algorithm classifies values by minimizing value variance within classes and maximizing value variance between classes. Only block groups within the same division are compared. It should be noted that the classification thresholds differ between variables and between divisions. The natural breaks algorithm considers the variance and mean of the data in each case; this is the basis of the division-based approach.

Exhibit 8. Process for Constructing the Division-Based Approach



Prior to summing the classified variables, the TDI is further refined by variable weighting derived from a factor analysis. The factor analysis and weighting account for collinearity among the variables included in the index. Because socioeconomic variables of disadvantage are often correlated, this helps to refine the model and maximize the importance of each variable in the index. Additional notes on the factor analysis used to construct the TDI are provided in the user guide in Appendix I.

Proximity Analysis Application

To measure and compare transportation projects using the equity-related framework defined here, an "area of impact" is first defined based on project mode. Existing proximity analysis practices within P6.0 are the basis for proximity parameters used to define areas of impact in this analysis. Exhibit 9 defines the proximity parameters used for each mode.

Exhibit 9. Recommended Parameters for Proximity Analysis

Mode	Project Feature Type	Proximity	Context
Pedestrian	Point or Line	0.5 Miles	Used for POI analysis for Ped projects in P6.0
Bicycle	Line	1.5 Miles	Used for POI analysis for Transit projects in P6.0
Transit	Point	0.75 Miles	Used for Service Population analysis for Local and Express Routes in P6.0

Using the proximity parameter, a buffer is created around project features. Summary statistics are calculated from the set of block groups intersecting the buffer. Summary statistics are calculated without spatial weighting. This research team recommends the examination of two primary summary statistics for the TDI analysis layer: project area mean and project area maximum. Both summary statistics can be obtained by spatially joining characteristics from block groups in the TDI layer to the projects layer.

The project area mean describes a general picture of the transportation disadvantage within the project impact area. Final TDI values are averaged for block groups intersecting the impact area yielding a value that accounts for the variety of communities within the project impact area and the aggregation of characteristics describing transportation disadvantage. This summary statistic can be understood as being balanced for projects of all sizes through the use of the average value, rather than a count or sum of values. It should be noted that because U.S. Census block groups are designed with balanced populations in mind, projects in areas of greater population concentration are likely to intersect a greater number of block groups than projects in rural areas, all else held equal.

The project area maximum summary statistic presents the greatest magnitude of transportation disadvantage within the project impact area. Unlike the project area mean statistic, the project area maximum is not a blended metric. Instead, it provides the TDI value of the block group with the greatest disadvantage within the project impact area, as measured by the TDI. The project area maximum can be seen as balancing the project area mean because the mean statistic may "wash out" block groups with very high need if surrounding areas are characterized by lower disadvantage and sufficiently numerous to drive the average away from the maximum. This effect may be particularly pronounced where disadvantaged communities are highly concentrated and segregated from surrounding communities with less disadvantage. The project area maximum signals that such highly disadvantaged communities are present and likely to be impacted by the project.

Notably, the research team recommends that demand-response transit projects should receive the highest possible value for any scoring metric implemented. This is because these projects cover a large geographic area which can be challenging to effectively analyze using a proximity analysis but the specific purpose of these projects is to directly serve transportation disadvantaged communities.

Demonstration of the use of the summary statistics for a variety of project modes and geographic contexts is provided through project case studies. As part of the method testing process, the research team conducted case studies based on diverse pedestrian, bicycle, and transit projects from across the state proposed through the P5.0 prioritization cycle. A sample of the case study results is outlined in the following section.

Pedestrian and Bicycle Case Studies

The research team examined P5.0 bicycle, pedestrian, and transit projects from across the state and selected several examples to present as case studies. Data readily available through the STIP was utilized to develop these case studies. Impact areas for bicycle and pedestrian projects were calculated using the parameters described in Exhibit 9. Recommended Parameters for Proximity Analysis. The case studies are not intended to demonstrate all possible permutations, but rather to show how the process itself works. Additional case study examples are shown in Appendix II.

Urban (Raleigh-Durham) Bicycle Projects

Exhibit 10 shows three bicycle projects to the north and east of downtown Raleigh that demonstrate various features of the TDI process. Each of the projects is presented with its TDI Mean (the mean of the census block groups within a 1.5-mile buffer as explained above), and its TDI Max (the highest TDI found within that buffer). The map is color coded with each block's TDI value, ranging from 6 to 18, with each project impact area outlined by a black circle. Exhibit 11 shows the TDI Mean and Max for each of those projects in tabular form. The three projects are:

Project A (SPOT ID B171885) is a project along Atlantic Avenue, crossing over US 401 (Capital Boulevard). It is for expanding the bridge for sidewalks and bike lanes to connect different residential and commercial areas that are blocked by Capital Boulevard. The TDI Mean for the project is 9.85 and the TDI Max is 16. There is a wide variety of TDIs in the zone's block groups, although only three above 13. The four block groups immediately adjacent to the project have high levels of youth, individuals in poverty, and low on carless households.

Project B (SPOT ID B172013) is a project for the Bridges Branch Trail, building a multi-use trail along Raleigh Boulevard to connect Lions Park to the Crabtree Creek Greenway. The TDI Mean for the project is 11.11 and the TDI Max is 16. The three blocks directly adjacent to the project include TDI values that indicate high levels of poverty, an average level of BIPOC representation, and low to average levels of representation for the other TDI measures.

Project C (SPOT ID B17201) is a project that increases access to the WakeMed facilities with a multi-use path along Crabtree Creek to connect WakeMed with the greenway. The TDI Mean for the project is 12.38 and the TDI Max is 15. The project is surrounded by two block groups that have TDI means of 14 and 15. This local population includes high levels of youth, poverty, and BIPOC populations, and an average level of disabled individuals and carless households.

Exhibit 10. Examples of Urban Bicycle Projects: Raleigh-Durham

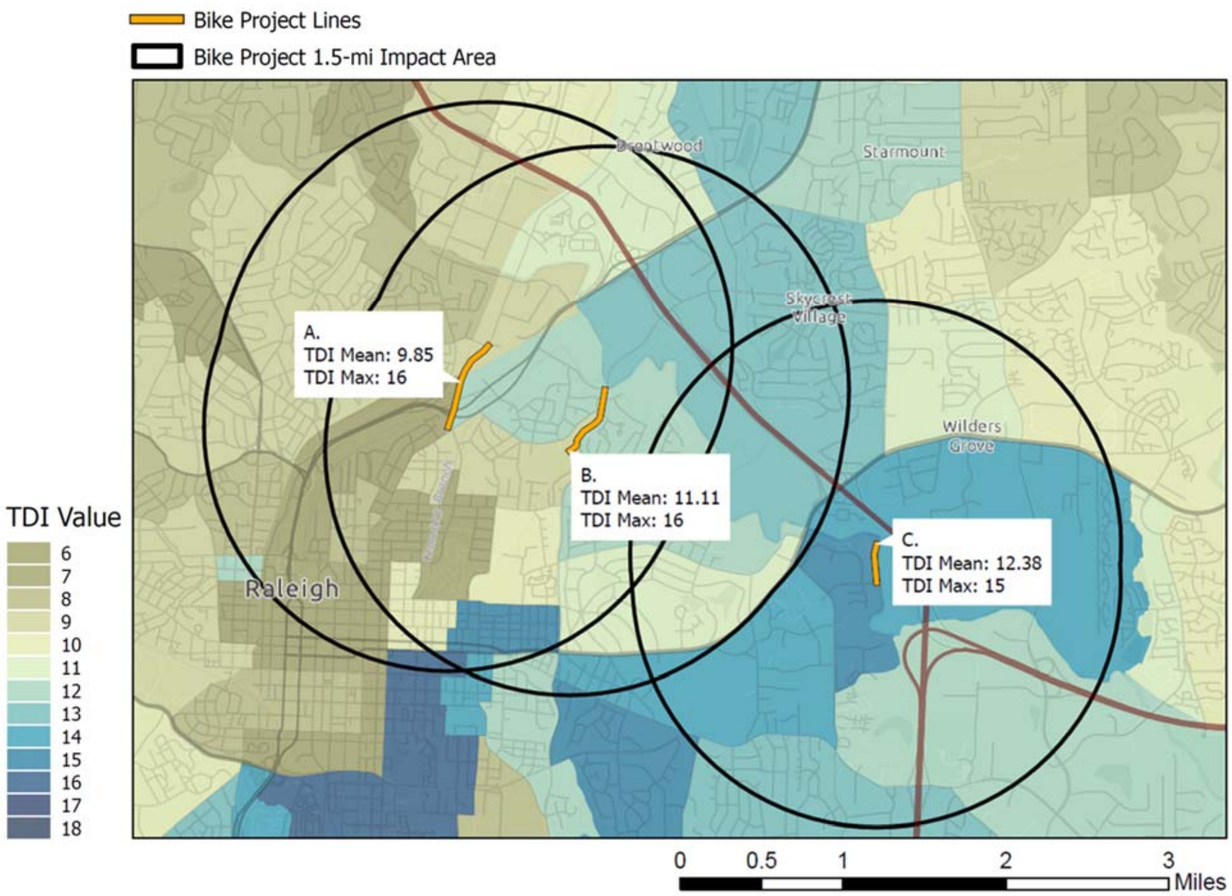


Exhibit 11. TDI Mean and Max for Urban Bicycle Project Examples

Map Label	SPOT ID	*Description*	TDI Mean	TDI Max
A	B171885	*Expand Atlantic Ave. bridge for bike lanes and sidewalks*	9.85	16
B	B172013	*Multi-use trail along Raleigh Blvd., connecting park and greenway*	11.11	16
C	B172011	*Connect Crabtree Greenway Trail to WakeMed*	12.38	15

The 1.5-mile bicycle-project buffer for each of the projects is shown with black circles. With this size of a buffer, each project's TDI depends on a large selection of blocks beyond the ones immediately adjacent. In this map, it can be seen that the TDIs generally increase from the northwest to the southeast corners. Therefore, the TDI means also generally increases as projects move in that direction. Although A and B are only a half mile apart, their means are a substantial 1.26 different, as Project B incorporates more of higher TDI blocks. Likewise, the southeast project (C) has a substantially higher 12.38. This is evident both in how the overall buffers change as well.

Smaller City (Gastonia) Pedestrian Projects

Exhibit 12 shows three pedestrian projects in or near the City of Gastonia, along with a map of each block's TDI score. It is important to note that the buffer for pedestrian projects is only one-half mile. This means that the TDI scores of pedestrian projects are more dominated by adjacent block groups than bicycle projects. Exhibit 13 shows the TDI Mean and Max for each of those projects in tabular form. The three projects are:

Project D (SPOT ID B171729) is a project for sidewalk and intersection improvements along East Hudson Boulevard, running through a low-density neighborhood and connecting to a commercial corridor. The TDI Mean is 13.22 and the TDI Max is 18. The two adjacent block groups that comprise a majority of the impact area have TDI values of 15 and 18 due to average or high levels of need for most types of groups considered in the TDI calculation.

Project E (SPOT ID B171799) is a project focused on constructing missing sidewalk links within a low-density neighborhood along Churchill Drive. The TDI Mean is 12.18 and the TDI Max is 18. The blocks directly adjacent have TDI values of 10, 12, and 14. This immediate area has a high level of seniors and disabled individuals, but low to average levels of representation for other groups considered in the TDI calculation.

Project F (SPOT ID B171899) is a project that constructs sidewalks within a low-density neighborhood along Gardner Park Drive and Pamela Street. The TDI Mean is 10.80 and the TDI Max is 15. The blocks directly adjacent have TDI values of 10, 12, and 14. This area has a high level of seniors and disabled individuals, but lower levels of youth and carless households.

Exhibit 12. Examples of Smaller City Pedestrian Projects: Gastonia

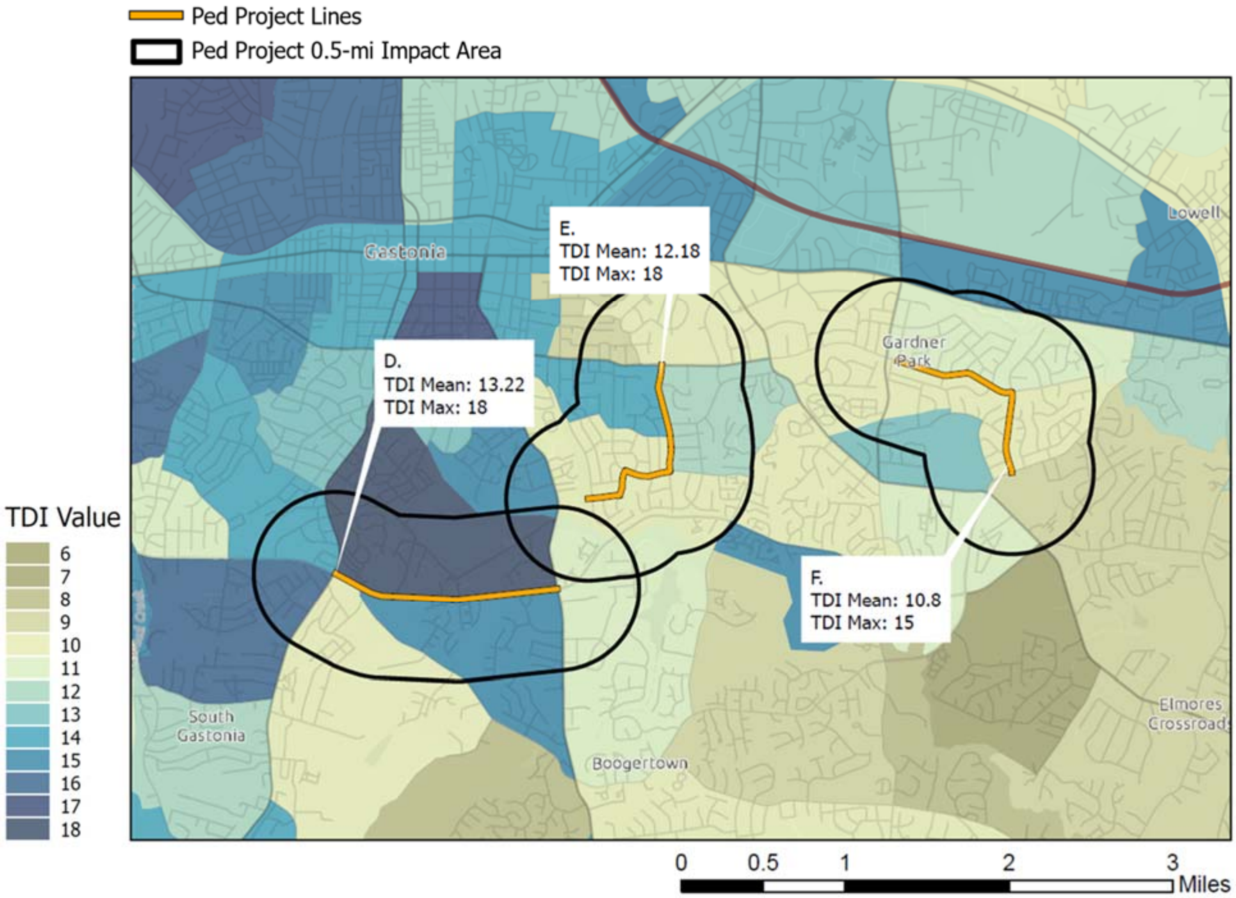


Exhibit 13. TDI Mean and Max for Smaller City Pedestrian Project Examples

Map Label	SPOT ID	Description	TDI Mean	TDI Max
D	B171729	*Sidewalk and intersection improvements along East Hudson Blvd.*	13.22	18
E	B171799	*Construction of sidewalk links along Churchill Dr.*	12.18	18
F	B171899	*Construction of sidewalk links along Gardner Park Dr. and Pamela St.*	10.8	15

The .5-mile pedestrian-project buffer for each of the projects is shown with black circles. These three projects have considerable variations in their TDI Means, as the TDIs increase going westward. Projects E & F have a similar housing density and look generally similar if driving through, but the blocks around Project E tend to include more seniors and higher rates of disability, which shows up in its higher TDI Mean. Both Projects D & E have a TDI Max of 18. For Project D, the 18 block runs along the north side of its entire length, constituting roughly one-third of the buffer area. For Project E, only a small portion of its buffer extends into this block, none of which abuts the project itself. Likewise, the majority of Project F's buffer zone is comprised of blocks that have TDIs from 8 to 11, but it does extend slightly into a 15 TDI block in the north.

Transit Case Studies

The proximity analysis methodology demonstrated in the bicycle and pedestrian case studies can be extended to the transit mode, provided that spatial data is available for analysis and subject to special consideration of each specific improvement type. The research team recommends adaptation of the methodology developed here for transit projects in the mobility category only, as these projects already have spatial analysis components readily available in P6.0. These projects are route-specific and have a geographic focus that is readily analyzed spatially.

The research team recommends the assessment of demand response and facilities projects separately. Demand response projects represent a special case for the assessment of equity and transportation disadvantage, as these projects are specifically designed to reach the most transportation-disadvantaged groups. Therefore, the research team recommends the use of the maximum possible value for the chosen scoring metric for demand response projects. Facilities projects often provide system-level benefits and may warrant alternative techniques for impact measurement. It is possible that these system-wide impact projects could be analyzed spatially using a variation of the method presented here. Parameters for this analysis should be investigated in future efforts and are not included in the scope of this report.

The transit case studies chosen for inclusion are based on route-specific mobility projects submitted in the P5.0 prioritization cycle. Unlike bicycle and pedestrian projects, spatial data for past transit project submissions was not available from the cataloged prioritization process resources. To demonstrate the use of the proximity analysis method for projects within the transit mode, the research team developed case studies for example transit projects using project descriptions in the P5.0 submissions. Project mode and location information was used to create spatial features corresponding to possible project stop locations; while these features may not precisely reflect intended project alignments and stops, they nevertheless demonstrate method application and reveal considerations for implementation within the transit context.

Impact areas for transit projects were calculated using the parameters described in Exhibit 9. Recommended Parameters for Proximity Analysis. It is important to note that transit stop features, rather than route features, are used for this analysis, as these are the only places at which the network can be accessed and used.

Urban (Raleigh-Durham) Transit Projects

Transit case studies presented here cover a variety of project types and geographic contexts. Exhibit 14 presents two transit projects in the Raleigh-Durham area. These projects demonstrate implementation considerations for transit projects in a metropolitan core setting. Exhibit 15 shows the TDI Mean and Max for each of those projects in tabular form. The two projects are:

Project I (SPOT ID T171911) is a project to construct a commuter rail service from Raleigh to Durham, including the acquisition of 4 locomotives and 8 coaches. In the absence of full project details, the research team envisioned this project extending to Garner and Duke University and including several stops between Raleigh, North Carolina State University, Cary, Morrisville, Research Triangle Park, and downtown Durham. The impact areas for this project include a diverse set of communities. Areas of greatest disadvantage are found proximate to the downtown stop locations. This project results in a TDI Mean of 9.93 and a TDI Max of 17. The TDI Max captures the high level of disadvantage found in communities proximate to the downtown Durham stop location.

Project J (SPOT ID T171927) is a project to construct bus rapid transit (BRT) service from WakeMed in east Raleigh to Triangle Town Center; the project includes 15 vehicles. In the absence of full-project details, the research team envisioned this project first linking WakeMed and Triangle Town Center via the downtown Raleigh transit center with the primary east-west alignment on New Bern Avenue and the primary north-south alignment on Capital Boulevard. The impact area for this project captures much more of the general area along the alignment as compared to Project I due to the greater frequency of stops. Communities proximate to stops in east and northeast Raleigh exhibit greater transportation disadvantage, on average, than areas to the west and northwest and from more suburban locations in the region. The TDI Mean for this project, 10.97, is significantly higher than the TDI Mean for Project I as a result. However, the TDI Max of 16 is marginally lower. In the case of Project J, the TDI max occurs in communities southeast of downtown Raleigh; TDI values in this region are slightly lower than the maximum TDI value for the communities impacted by Project I in downtown Durham.

Exhibit 14. Examples of Urban Transit Projects: Raleigh-Durham

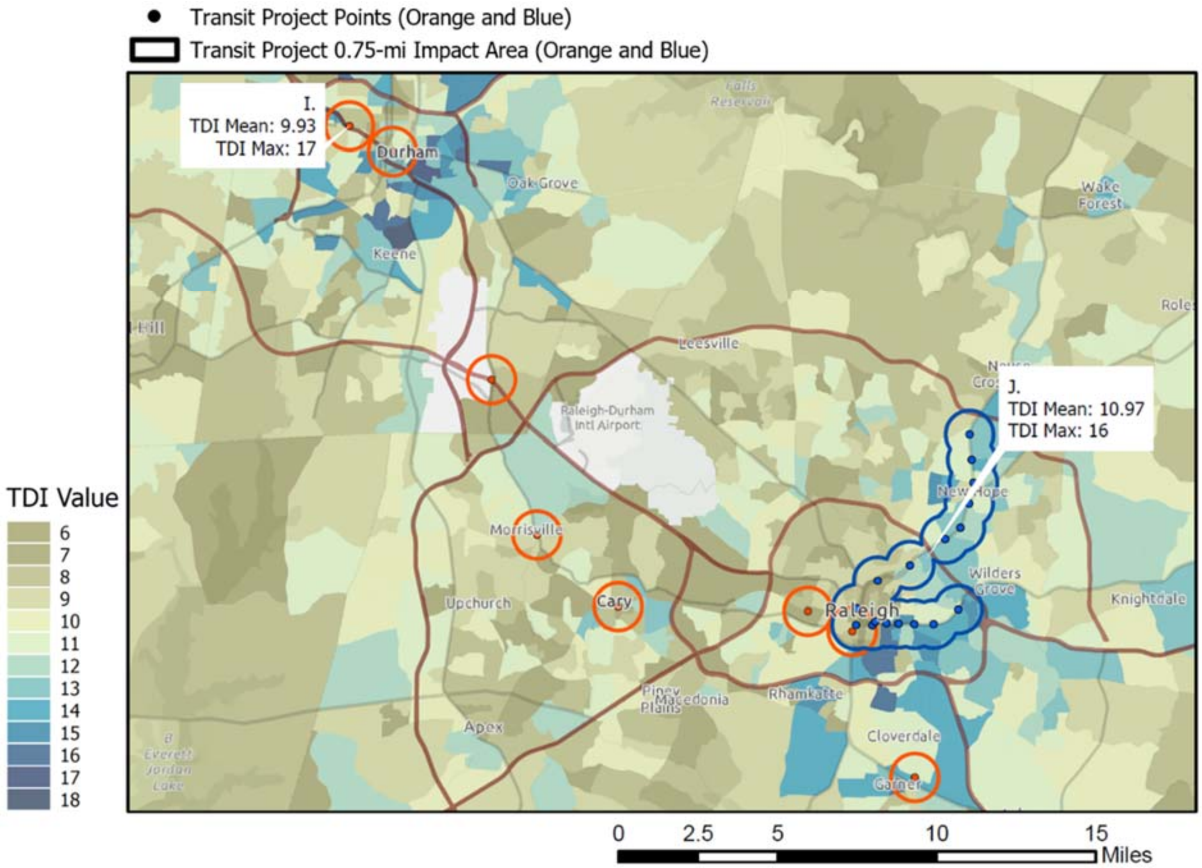


Exhibit 15. TDI Mean and Max for Urban Transit Project Examples

Map Label	SPOT ID	*Description*	TDI Mean	TDI Max
I	**T171911**	*Construction of commuter rail service from Raleigh to Durham*	9.93	17
J	**T171927**	*Purchase of bus rapid transit vehicles from WakeMed to Triangle Town Center*	12.18	18

Smaller City (Gastonia) Transit Projects

A third project, shown in Exhibit 16, demonstrates implementation for a project submitted within the mobility category that affects more than one route. Exhibit 17 shows the TDI Mean and Max for each of those projects in tabular form.

Project K (SPOT ID T171171) is a project described as adding an additional expansion bus to the Gastonia transit fleet to facilitate connections between low-income neighborhoods, workforce development sites, social services, and employment. Because the project affects the system generally, all system stops were used to calculate the project impact area. The resulting measures include a TDI Mean of 12.5 and a TDI Max of 18, reflecting the relatively high level of disadvantage observed in communities with access to the system.

Exhibit 16. Example of Smaller City Transit Projects: Gastonia

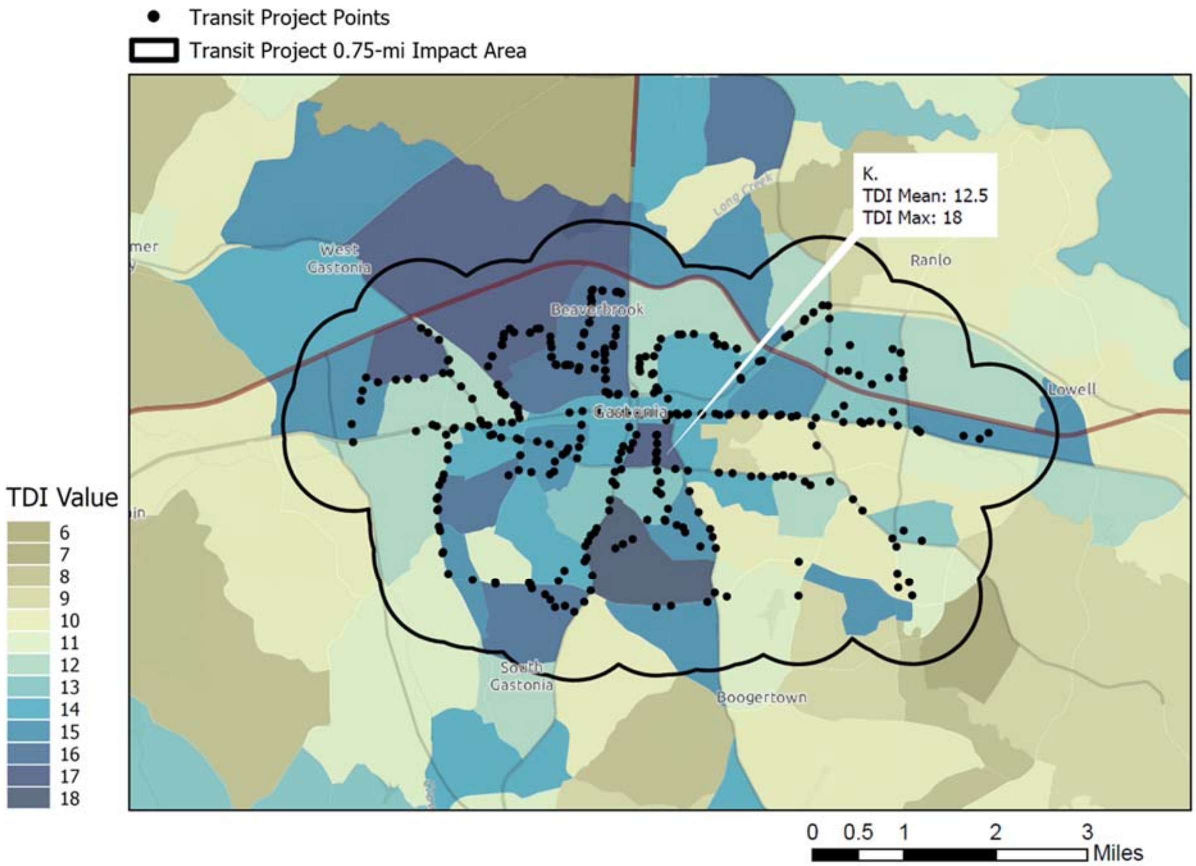


Exhibit 17. TDI Mean and Max for Smaller City Transit Project Examples

Map Label	SPOT ID	*Description*	TDI Mean	TDI Max
K	T171171	*Expansion of Gastonia transit fleet*	12.5	18

Additional transit case studies are provided in Appendix III.

Benefits Compared to RSA

The proximity analysis approach developed and demonstrated by the research team improves upon many of the limitations of the RSA approach. By using socioeconomic data without rasterization, the approach includes less pre-processing and manipulation compared to RSA. As a result, the necessary steps are more readily implemented, are more transparent, and are easier to communicate to project applicants and other stakeholders.

Another limitation of RSA is the potential for obscuring multiple variables within a single suitability score as a limitation of RSA. With the proximity analysis approach, this limitation is balanced by using the IMD TDI, which is an existing and supported index featuring a high degree of alignment with common national analysis practices. Additionally, data included in the TDI shares a common format, source, and geography. It may therefore be easier to communicate the value of summary statistics generated from the index than suitability measures developed through an RSA approach.

Supplemental Methods: Workplace Characteristics and Context-Sensitive POI Analysis

The division-based TDI analysis methodology presented in this report is used to quantify and compare the residential characteristics of communities that are likely to be impacted by projects. These residential communities describe people where they live, rather than where they work or make trips. To better capture non-residential characteristics that are important from a transportation planning perspective, the research team explored analyses to measure how transportation projects may impact access to workplaces and new approaches to measuring project efficiency in providing access to points of interest.

Workplace Characteristics Analysis

The IMD TDI analysis method is foundational for understanding the characteristics of communities that are likely to be impacted by transportation projects. These characteristics describe the area population based on places of residence. A more complete picture of impact can be obtained by augmenting the residential characteristics of the TDI analysis with the characteristics of workers whose place of work is in proximity to projects. These workers, whether residing inside or outside of the project area, may have their journey to work impacted by the project. In this section, the research team presents a method for analyzing workplace characteristics with an equity focus by summarizing the quantity and density of low-to-middle-income jobs within a specified proximity of projects.

Data Applied

Geolocated workplace area characteristics data are available in the Longitudinal Employer-Household Dynamics (LEHD) program of the Center for Economic Studies at the U.S. Census Bureau. Data in the LEHD program are sourced, in part, from the Quarterly Census of Employment and Wages (QCEW), a report produced by the Bureau of Labor Statistics and sourced primarily from state unemployment insurance programs. These programs use employer reports form employers covered by the state unemployment insurance program that includes employment, payroll, and physical workplace location information. Reports are filed at the establishment level, which represents a single physical location of work for employees. A single employer may have one or many establishments (Abowd et al., 2005).

The Workplace Area Characteristics (WAC) produced as part of the LEHD Origin-Destination Employment Statistics (LODES) contain workplace data enumerated at the census block level, a geography one level smaller than the block group. The LODES WAC data is updated annually for the year two years previous (U.S. Census Bureau, 2022b). Consequently, the analysis presented here is conducted with data produced in 2021 that describes the workplace characteristics of 2019.

In addition to other workplace characteristics, including industry sector and worker race, ethnicity, age, and sex, the WAC data provides the number of jobs per block group at three income level thresholds. The analysis in this study focuses on the locations of low-to-middle-income jobs, defined as jobs at or below the LODES WAC wage threshold of $3,333 per month. This threshold is approximately equivalent to 150% of the federal poverty level (considered “low-income”) for a four-person household with one earner (USDHHS, 2022). Because many households have fewer members or more earners, using this threshold also includes many jobs for individuals and households not considered low-income. However, the threshold still falls below the North Carolina median household income of $56,642 for 2020 (U.S. Census Bureau, 2022c).

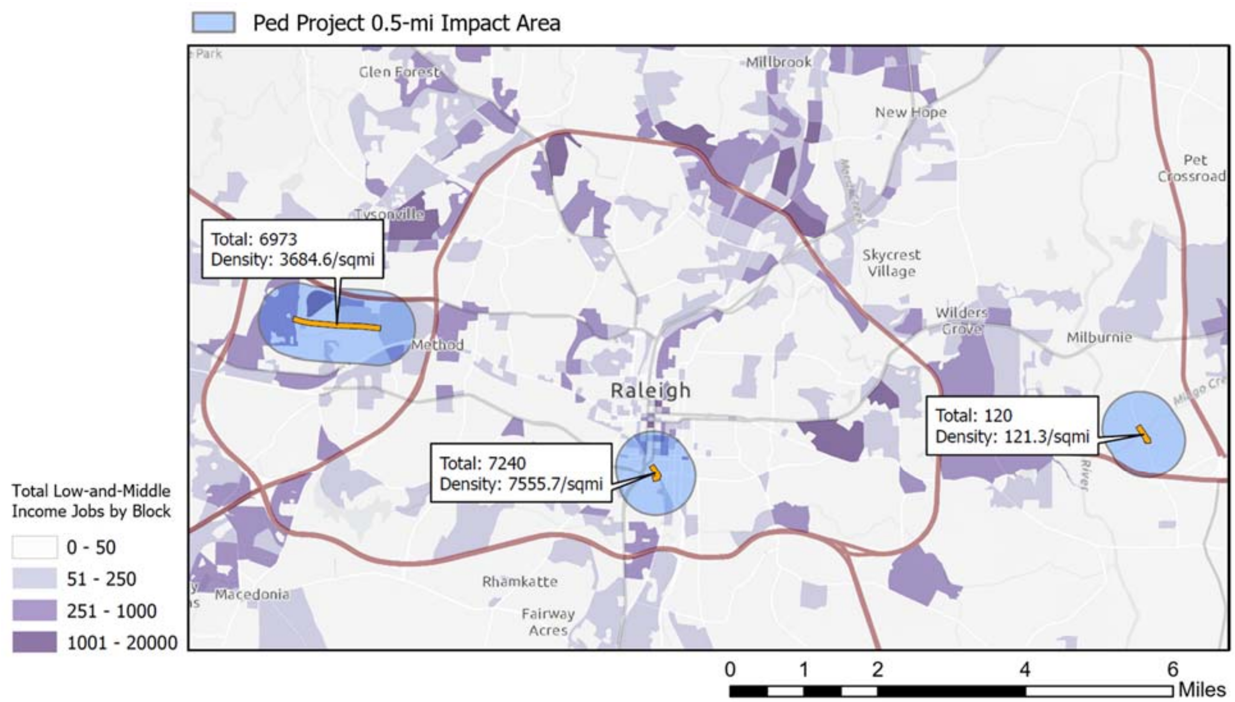
It should be noted that while LEHD data does account for the physical location of work performed, there are cases in which the establishment may not be a fully-representative workplace location for certain employee groups. These groups include, among others, employees working from home, employees engaged in regular/daily travel for work, and employees that “float” between establishments.

Potential Applications in Prioritization

The methodological parameters for analyzing workplace characteristics in relation to project location mirror those for the TDI-based method; summary statistics for each project are generated using the proximity analysis techniques detailed in Exhibit 9. Recommended Parameters for Proximity Analysis**.** Proximity analysis with workplace characteristics employs the block, rather than the block group, as the geographic level of analysis for generating summary statistics.

Two summary statistics for low-and-middle-income job analysis are recommended for consideration and inclusion in the STI process: project area sum and project area density of low-to-middle-income jobs. The project area sum provides the total number of low-and-middle-income jobs in locations intersected by the project impact area. This metric is useful as a description of the absolute impact, but advantages longer projects, as larger impact areas will likely capture a greater number of workplaces. Project area density can be considered as a balancing metric or could be used as an alternative. Project area density, calculated by dividing the total sum of low-and-middle-income jobs within the project impact area by the area of the project impact itself, reduces project-length bias and can therefore be understood as a metric of efficiency rather than total magnitude. Project area total and project area density summary statistics are shown for three example pedestrian projects in Exhibit 18.

Exhibit 18. Options for Obtaining Summary Statistics from Workplace Characteristics Analysis



Context-Sensitive Points of Interest Analysis (POIs)

Points of Interest (POI) analysis currently is used for the Prioritization 6.0 process to measure connectivity and accessibility criteria of bicycle and pedestrian projects by providing the total number of points within a distance of a project. The current approach utilizes Project ATLAS data, applicant input, and other data layers for point data and applies a proximity parameter of 1.5 miles for bicycle projects and 0.5 miles for pedestrian projects. Some POI categories are automatically measured within SPOT On!ine, such as Government buildings, Fire/EMS, Transit routes, Schools (K-12, public/private), universities, colleges, Parks (national, state, local), Tourist destinations (historic districts, major sports), Medical (hospitals and public/private clinics), Places of worship, and Adult education centers. Other POIs are manually added by project submitters: Employment centers, Tourist destinations (museums, theaters, auditoriums, historic landmarks), and Shelters.

The current approach involves summing the total points of interest within a distance of projects, which can embed bias for projects that are in densely populated areas with many POIs in the vicinity. Additionally, the process can also bias longer projects, which can cover more geographic area, and therefore POIs. Such bias can skew the results of accessibility and connectivity measures and can mask the value of more rural and/or smaller projects that could provide equity-related benefits. Analysis that considers project size and context can help remove this bias and help identify projects that are the most relatively effective in providing access to POIs.

Alternative Approach

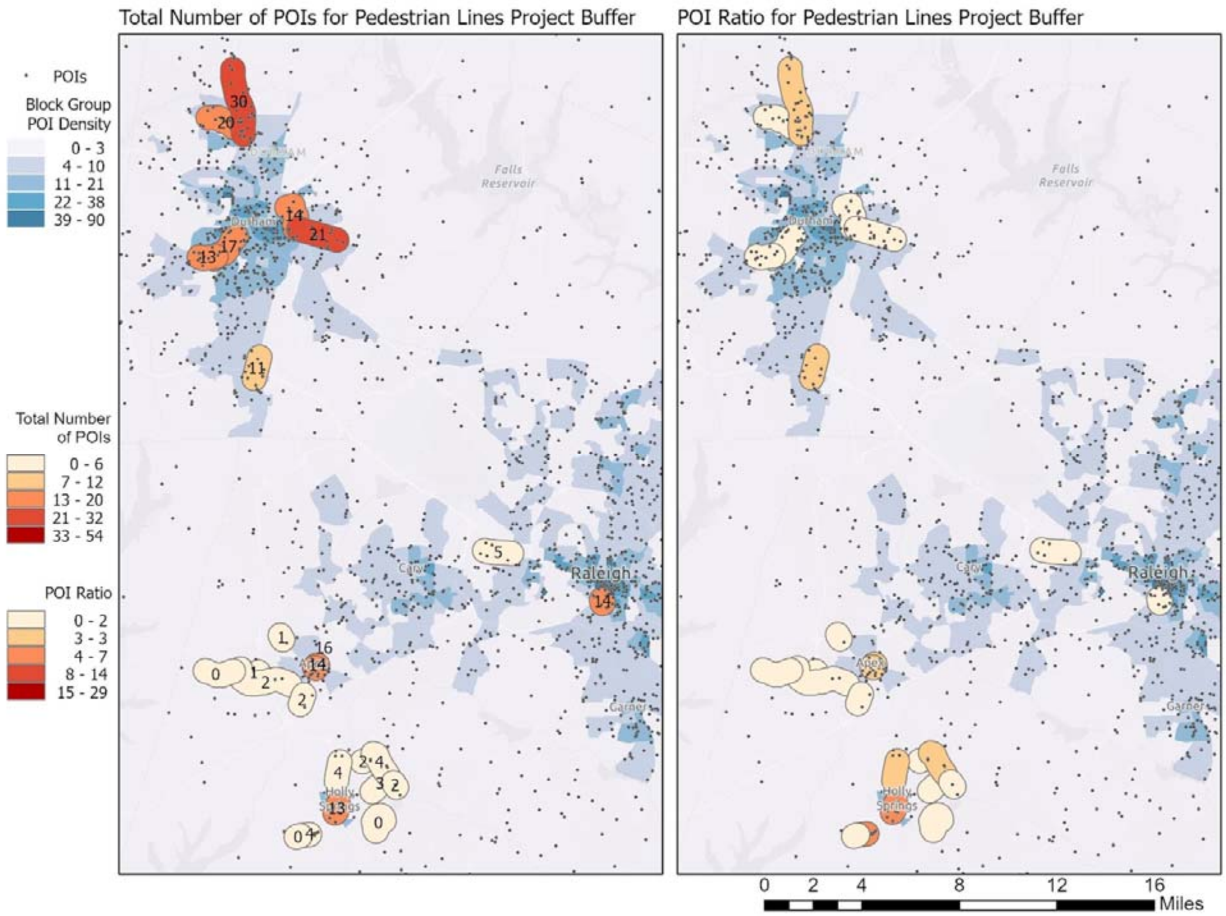
This research provides an alternative process for measuring project effectiveness in providing access and connectivity to points of interest (POI). This alternative process can be applied to any set of POIs by using existing proximity analysis parameters for POI scoring components. The context-sensitive POI analysis approach accounts for the project setting by focusing on POI density near and within the project. The recommended context-sensitive POI measure is a ratio of densities calculated using the following formula:

$$POI\ Ratio = \frac{Density\ of\ Points\ in\ Project\ Impact\ Area}{Average\ Density\ of\ Points\ of\ Intersecting\ Block\ Groups}$$

In the exploration and testing of this new approach, the research team used the existing Bike/Ped P6.0 POI dataset. The first step was to calculate the block group level POI density statewide dataset based on point data. Further calculation included Density of Points in Project Impact Area and Average Density of Points of Intersecting Block Groups, which was conducted for bicycle, pedestrian, and transit project buffers. The results of method testing show that this approach does not disadvantage projects in lower-density areas with fewer available POIs.

The context-sensitive POI ratio measure can be understood as a measurement of project performance in relation to its context: Projects with a POI ratio of less than one reach fewer points than are available on average in their proximity. Projects with a POI ratio above one reach more points than are available on average in their proximity, indicating effectiveness in providing connectivity and access. Exhibit 19 compares the current POI analysis approach used in the prioritization process to the recommended ratio-based approach.

Exhibit 19. Total Number of POIs and POI Ratio for Pedestrian Project Buffer (0.5 miles)



Transit Projects and Additional POI Options

Currently, POIs are not examined for transit projects in the STI process. However, the research team recommends that the same POIs and approaches recommended through this study be applied to transit projects. The national literature reviewed reinforced the value of analyzing POIs as part of project prioritization and exhibited that the same POIs analyzed for pedestrian and bicycle projects are also relevant for transit projects.

While the research team recommends that the POIs currently in the prioritization process should be maintained for pedestrian, bicycle, and transit projects, there are additional POI datasets that could be incorporated to provide a more equity-based analysis. One key example is data that provides POIs that provide information about access to grocery stores. The national literature review revealed that measuring how a transportation project provides access to grocery stores can serve as an indicator of a project's potential benefits to disadvantaged communities.

As such, the research team investigated and tested multiple data sources that allowed for the identification of grocery store POIs. The most promising of these was a dataset from the United States Department of Agriculture (USDA) that includes geolocated SNAP Retailer Locations. An example of this data exploration is presented in Appendix IV.

Although the USDA SNAP dataset is regularly updated, readily available, and robust, the nature of the data included makes it difficult to isolate grocery store locations from other SNAP retailers. For example, many gas stations and pharmacies that sell food are included in the dataset. It is feasible to extract local and chain grocery stores from the data, but doing so would initially require substantial pre-processing. Other dataset alternatives are either proprietary, like ArcGIS Business Analyst, or incomplete and not reliable, like OpenStreetMap Business Listings.

In spite of some of the challenges, it may be valuable for NCDOT to explore options for developing an efficient process for extracting grocery store POIs from the USDA SNAP data to include in the prioritization process given the importance of accessing fresh food.

Summary of Recommendations

Three key methods were developed through this study to support equity-related considerations as part of the NCDOT project prioritization process, including the following:

1. Transportation Disadvantaged Community Proximity
2. Workplace Characteristics Analysis
3. Context-Sensitive Points of Interest Analysis (POIs)

Each of these recommended methods can be implemented into the STI process individually or in conjunction with one another. Overall, these approaches incorporate data currently collected through the STI process as well as data from reputable sources that are frequently updated and readily available to NCDOT. While the research team developed these methods for bicycle, pedestrian, and transit SITs, they can be adapted for other modes in the future.

Transportation Disadvantaged Community Proximity

This is the core method developed through this study, which involves conducting a proximity analysis to identify the level of community need near a project. This approach incorporates the NCDOT Integrated Mobility Division's Transportation Disadvantage Index (TDI) to quantify the level of high-need communities, such as those identified as having more individuals who are low-income or carless, in the area surrounding a proposed project. Differences in communities across the state are considered through the addition of a regional-based classification of community need at the NCDOT division level in a way that supports comparison of projects across the state.

The recommended proximity analysis method can be thought of as a first step towards incorporating equity analysis into prioritization scoring. It is a high-level quantitative measure of the scale of disadvantage with regard to the transportation needs of communities in the vicinity of projects. Because it is based on an index, it is suitable for comparative purposes. Both project area mean and project area maximum may be useful summary statistics when considering the implementation of the proximity analysis methodology. While project area mean provides a blended picture of the project area, project area maximum prevents wash-out of highly disadvantaged areas.

This method does not provide a quantification of project benefits or burdens to these communities. However, it can assist in the scoring process as a screening tool and indicator for situations in which additional information about impacts on communities with transportation disadvantages should be considered. For certain modes and certain specific improvement types, the measures produced by this method may more align with a level of benefit or burden attributable to the project. However, each project and each community is unique. It is therefore a recommended practice to supplement quantitative measurement with qualitative assessments of impact and robust community engagement to comprehensively account for impacts.

Workplace Characteristics Analysis

In addition to analyzing the TDI-based characteristics of the residential areas that are near a proposed project, the research team recommends examining the characteristics of proximate workplaces. This proximity analysis can augment the Transportation Disadvantaged Community Proximity method by identifying job opportunities that people may be able to access more easily if a project is placed in the area, which the literature suggests should be considered when analyzing equity measures.

As detailed in the report, several options are available for implementing a workplace area characteristics analysis. These options are predicated on the proximity analysis parameters developed for measuring transportation disadvantage. Options for measures include the use of summary statistics like project area sum and project area density. Attention should be paid to the project context bias that could be introduced or reinforced through these measures. Fewer proximate workplaces are adjacent to projects in rural settings. However, these projects may be effective in linking employees to job centers.

Context-Sensitive Points of Interest Analysis (POIs)

Considering that community needs and access to opportunities can differ from area to area, the research team also recommends that the current POI method in the STI process be adjusted to better account for the context of the area surrounding a proposed project. Specifically, this approach can reduce bias towards projects in denser areas or with longer impact areas. While the research team recommends the approach developed through this study due to the simplicity of the analysis paired with the consideration for variance in geographic units of analysis, there are other techniques that could be applied to address the question of whether projects are effective at providing connectivity to points of interest given their context. One example is hotspot analysis, which NCDOT or future research may opt to explore.

Future Research and Considerations

Implementation

As literature was gathered and methods were developed through this study, the research team focused on approaches that could be feasibly implemented into the prioritization process. This included recommendations that incorporated data that is readily available to NCDOT and is regularly updated by reputable sources. The three method recommendations outlined in this study may be integrated into the prioritization process in several ways, together or separately. While the research team had provided NCDOT with options for implementation as part of the P7.0 Workgroup discussions, the Workgroup and NCDOT will ultimately decide how the project results are integrated into the STI process.

Regardless of how NCDOT and the P7.0 Workgroup opt to integrate these methods, the User Guide in Appendix I can serve as a user-friendly tool to support implementation.

Potential Limitations and Future Research

As with any research project, there are potential limitations to the methods developed through this study and opportunities for future research that should be considered.

Proximity Analysis

The definition of project impact areas necessarily delineates surrounding communities into one of two categories: impacted and non-impacted. In reality, local travel behavior is more complex than what can be captured through a proximity-based analysis. Therefore, the results of the methodology are most suitable for providing high-level metrics that can be used for general comparison purposes.

Also, the proximity analysis perspective is effective for identifying the likelihood of impact on transportation-disadvantaged communities and the scale of transportation disadvantage in those communities. As such, the results can be a suitable component of analysis for use in scoring metrics if the specific impact effects are known. Stated differently, the benefit or burden presented by the project to the community should be considered and paired with quantitative community measures. In analyses of community impact, it is also recommended as a best practice to pair quantitative analysis with community outreach and engagement to better understand project impacts from the community perspective (Ezike et al., 2020).

TDI Application

The IMD TDI is recommended because of a high degree of alignment with national practices and because it has institutional buy-in. However, indices such as TDI are not free of subjectivity. In the future, it may be prudent for NCDOT to continue to adjust the index to ensure alignment with evolving practices in measuring disadvantage.

Network Effects

Due to the complexity of the analysis and the project's focus on developing approaches that can be readily implemented into the STI process, the proximity analysis method recommended by the research team does not include secondary network effects that may accumulate from investments. For example, a sidewalk that is within proximity of disadvantaged communities but that is separated by a barrier, such as an interstate, will not necessarily provide an impact. Proximity analysis alone does not capture these complicated effects but it does indicate a probable impact. The results of this study can support future research investigating the larger network effects of potential projects, particularly those with a larger geographic footprint.

Community Change Over Time

Communities are in constant flux and infrastructure projects take many years to fund and construct. A particular concern when applying an equity lens is how neighborhood composition can change over time due to issues like gentrification and the suburbanization of poverty. Additionally, transportation projects themselves may play a role as forces of neighborhood change by, for example, bringing up property values and taxes in the project area. Additional investigation is needed to account for these trends across NCDOT planning processes. Within the domain of socioeconomic analysis, incorporating future projections can help prevent socioeconomic assessments from missing trends like gentrification. However, these considerations should not limit the application of study results, as all aspects of the STI process are limited to examining data from a snapshot in time due to the quantitative focus of the system.

Differences Between Project Types

Implementation of equity-based considerations within the STI scoring process is a challenging task. Equity-based considerations can vary by mode. Implementation should be sensitive to project mode and specific improvement type (SIT). Case studies were developed through this study to show a range of implementation scenarios. However, additional investigation of best practices for scoring different types of SITs, in particular for transit projects that intersect with different modes, may further support effective implementation.

Measuring Actual Outcomes

This study introduced approaches for measuring equity-adjacent measures including residential, workplace, and point of interest proximity to transportation projects and means for connecting these to transportation-disadvantaged communities. While these methods provide the first steps towards measuring the potential community impacts of projects, they are not designed to measure the actual outcomes of projects. This limitation should not limit the application of study recommendations. Rather, they can serve as the foundation for future research that seeks to improve how projects impact communities in terms of benefits and burdens, with a specific focus on those who are most transportation disadvantaged.

Balancing Measures

While the methods developed and recommended through this study can help further NCDOT's efforts to achieve more equitable project outcomes, they may be limited by other approaches embedded in the STI process. For example, Cost To NCDOT is a metric considered in the process that can potentially lead to inequitable transportation investments. This is because developing a project that passes through, but does not necessarily benefit, a transportation-disadvantaged community may be cheaper due to the cost of land compared to a more advantaged area. This is particularly true for larger investment types like highway infrastructure projects, which can require the acquisition of significant right of way (ROW). As such, NCDOT may benefit from evaluating points in the prioritization process that can introduce inequity, whether through an internal review or future research, to help ensure that the process is as equitable as possible.

Future Applications

Understanding the types of transportation needs around a proposed transportation project and the opportunities for access that such a project may provide is essential for understanding the potential equity-related implications of a given investment. As such, the methods developed and recommended through this project can serve as a foundation for other equity-related measures developed for future NCDOT prioritization cycles. For example, the Transportation Disadvantaged Community Proximity method is being considered for integration into existing research projects such as NCDOT RP 2022-069: Including Equity in Benefit-Cost Analysis, which aims to provide health and emissions prioritization measures with an equity lens.

Additionally, while the project outlined in this report specifically focused on pedestrian, bicycle, and transit projects, the recommended methods can be feasibly extended to other modes and SITs with future research. They may also be applied to consider the potential impacts of multimodal projects, examining how cross-modal investments can provide further benefits for transportation-disadvantaged communities. The results of this project could also be adapted to go beyond looking at which communities may benefit from a project to examining the burdens a potential project may place on communities.

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Appendices

APPENDIX I:
GIS & Data User Guide

RP 2021-17 Geodatabase Contents

Project Item	Item Name	Item Type	Description
Division-Based TDI Layer for 2020	TDI_20	Feature Class	Block group features for North Carolina with 2020 TDI data
Low-and-Middle Income Jobs Layer for 2019	LowMidJobs	Feature Class	Block features for North Carolina with 2019 low-and-middle-income job counts
TDI Data Download Tool	pullCensusTDI	ArcGIS Script Tool	Script tool for downloading required data for TDI and joining data layers to block groups; requires U.S. Census API key and pandas module
Project Case Studies			

I. Transportation Disadvantage Index

The Transportation Disadvantage Index (TDI) developed by NCDOT is an index constructed from six variables available in the U.S. Census American Community Survey (ACS). Factor analysis is used to develop weights for the variables included in the index. The research team recommends the use of the TDI formulated at the division level to support equity measures in the STI process. Additional documentation for the TDI, including methodology notes and updates, is available via the NCDOT Integrated Mobility Division (IMD). A full description of the steps taken to formulate the TDI for 2020 in the layer used by the research team is also provided below in the event it needs to be constructed from scratch.

Data Acquisition

The data required to create the division-based TDI includes both tabular data from the U.S. Census ACS and spatial block group data from the U.S. Census TIGER/Line Shapefiles repository. Links to download locations for both resources are provided below.

U.S. Census American Community Survey Data: https://data.census.gov/cedsci/

U.S. Census TIGER/Line Shapefiles: https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html

1. **U.S. CENSUS AMERICAN COMMUNITY SURVEY TABULAR DATA**
   The data required to construct the TDI is available from the U.S. Census ACS. Data for the index is sourced from ACS 5-year estimates, which provides data for geographies of all sizes. The use of 5-year estimates ensures data will be available for the small block group geography required for the TDI. The individual ACS variables used to produce the variables included in the TDI are provided in Table 1. Note that the data provided by these variables are, in some cases, available from other variables included in the ACS. The variables presented here are recommended for ensuring alignment with the existing IMD methodology and also to reduce the total number of variables required to obtain the necessary data.

Table 1. TDI Variables and Census Table Sources

Variable	Description	ACS Variables* (Total Count)	ACS Variable (Total for Rate)
BIPOC (Black, Indigenous, and people of color)	Percentage of population identifying as racial and/or ethnic minorities, defined as the total population identifying as non-white plus the population identifying as white and Hispanic or Latino.	B01001_001E - B03002_003E	B01001_001E
Poverty	Percentage of population reporting Household Income level below 1.5 times the Federal Poverty level. Poverty thresholds take household size and characteristics into account. For more info, see: https://www.census.gov/topics/income-poverty/poverty.html	C17002_002E + C17002_003E + C17002_004E + C17002_005E	B01001_001E
Disability	Percentage of population reporting one or more disabilities, as defined by the U.S. Census Bureau. For additional information about the definition of disability employed by the ACS, see: https://www.census.gov/topics/health/disability/guidance/data-collection-acs.html	C21007_005E + C21007_008E + C21007_012E + C21007_015E + C21007_020E + C21007_023E + C21007_027E + C21007_030E	B01001_001E
Zero Vehicle Households	Percentage of households reporting access to zero vehicles	B25044_003E + B25044_010E	B25044_001E
Seniors	Percentage of population 65 years and over	B09020_001E	B01001_001E
Youth	Percentage of population under 16	B01001_001E – B23025_001E	B01001_001E

2. **SPATIAL DATA FOR BLOCK GROUP FEATURES**

This research sources U.S. Census block group geographies from the U.S. Census TIGER/Line shapefiles available at the link below. Geographic entity codes (GEOIDs) should be preserved throughout the TDI development process so that the final TDI data can be joined to spatial block group features for use in the proximity analysis.

Classification of Variables

To construct the TDI, individual variables are classified into three classes using the natural breaks algorithm. The natural breaks algorithm is used to create classes based on variations in the data; classes are constructed by maximizing value differences between classes and minimizing value differences within classes. For the division-based TDI, this classification is conducted within each division, such that block groups are only classified against other block groups in the division in which they are located. The classification of variables must therefore be completed for each variable for each division. The highest value for each variable is assigned a value of 3, the middle class is assigned a value of 2, and the lowest class is assigned a value of 1. The use of the natural breaks algorithm results in classification breakpoints that are unique to each division. Additionally, each class is represented for each variable in each division.

Variable Weighting

Before summing variables to construct the final TDI, each variable is weighted based on a factor analysis that accounts for common variance in the variables. Variables weights calculated by VHB are provided in Table 2.

Table 2. Variable Weighting from Factor Analysis

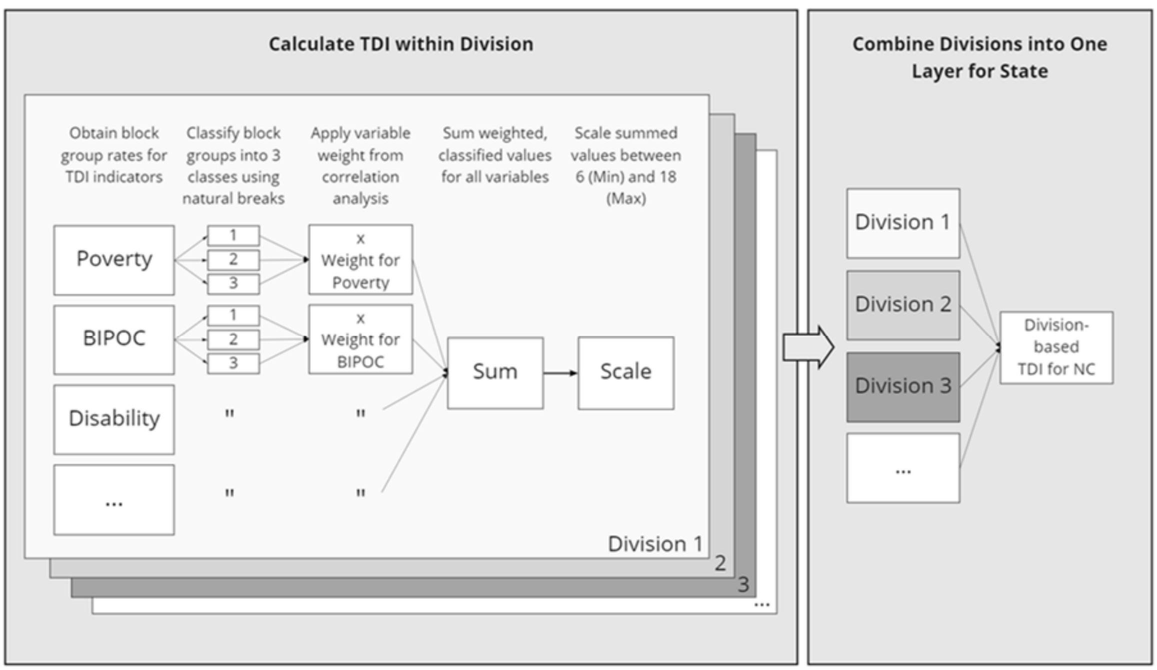
TDI Variable	Factor Group	Weight
BIPOC	1	0.56
Poverty	1	0.7
Zero Vehicle Households	1	0.57
Disability	2	0.55
Seniors	2	0.59
Youth	3	0.86

Summation and Normalization

Following weighting, the weighted variables are summed to produce an index. With the variable weighting applied, the summed value will fall between 3.83 (indicating a classification of 1 for all variables in the index) and 11.49 (indicating a classification of 3 for all variables in the index). To bring the index back to an intuitive scale reflecting three classes of six variables, the summed index value is scaled with min-max scaling so that the lowest value in the final output index is 6 and the highest value in the final output index is 18.

Merging Division Data into Final TDI Layer

Once the TDI is constructed for each NCDOT division, the resulting layers can be merged into a single statewide dataset. The final dataset contains division-based TDI values; each division contains the full range of possible TDI values, from 6 to 18.



II. Proximity Analysis & Project Impact Area Summary Statistics

The research project recommends the development of summary statistics for bicycle, pedestrian, and transit projects via geoprocessing procedures and parameters aligned with existing prioritization practices. The principal geoprocessing steps are (i) establishment of a project impact area within the specified proximity of project features based on a set Euclidean distance parameter, and (ii) calculation of summary statistics describing the set of block groups intersecting the project impact area. Geoprocessing steps can be accomplished with Buffer and Spatial Join geoprocessing tools, following the tool parameters defined below.

Project Buffering

Proximity Analysis parameters for generating project impact areas are provided in Table 3 below.

Table 3. Parameters for Project Proximity Analysis

Mode	Input Project Feature Type	Buffer Distance	Context
Pedestrian	Point or Line	0.5 Miles	Used for POI analysis for Ped projects in P6.0
Bicycle	Point or Line	1.5 Miles	Used for POI analysis for Transit projects in P6.0
Transit	Point or Multipoint	0.75 Miles	Used for Service Population analysis for Local And Express Routes in P6.0*

Joining Summary Statistics

In this research project, summary statistics are generated by spatially-joining summary attributes from features in the statewide division-based TDI layer to project impact area features. Spatial joins are conducted using intersecting features without areal weighting, such that attributes from all features in the TDI layer intersecting the project impact area are included in the summary statistics and equally weighted regardless of the proportion of the feature area that falls within the project impact area. The Spatial Join geoprocessing tool in the ArcGIS suite of products provides for the specification of merge rules for intersected features. To create the summary statistics detailed in this report, the merge rules Mean and Maximum should be used in conjunction with the field storing the final weighted and summed TDI index value for each variable. Once summary statistics are produced for each input impact area feature, these values can be joined to original project features or exported to a table format for joining to other project data using the project SPOT ID as a key.

III. Workplace Characteristics Data

Data Acquisition

The tabular data required to complete the Workplace Characteristics Analysis detailed in the research report is available from the U.S. Census Longitudinal Employer Household Dynamics (LEHD) data repository. Workplace area characteristics are available as part of the LEHD Origin-Destination Employment Statistics (LEHD) package. Workplace characteristics data (WAC) are enumerated at the U.S. Census block geography in the LEHD package. The analysis presented in the research project uses LODES7 data for North Carolina. Workplace Area Characteristics (WAC) are available for a variety of workforce segments and job types. Data for the analysis presented here and in the research report includes all workforce segments and all job types. The file naming convention for this specific dataset is *nc_wac_S000_JT00_[YEAR].csv.gz*. This data is made available annually for the year two years previous.

Data and additional documentation of LEHD and LODES products can be found using the following links. Spatial data for Census block features can be found at the TIGER/Line Shapefile Repository linked in Section I.

LEHD Data: https://lehd.ces.census.gov/data/

LODES Tech Doc: https://lehd.ces.census.gov/data/lodes/LODES7/LODESTechDoc7.5.pdf

Analysis

The workplace characteristics analysis included in the report includes only low- and middle-income jobs, defined as those jobs with less than or equal to $3,333 per month are included in the low-to-middle income job analysis. The LODES tech doc linked above contains a data catalog for WAC datasets that provides variable names for those variables required to prepare the data. For 2019, the calculation necessary to yield total low-and-middle income jobs is defined as follows:

$$CE01 + CE02$$

To be used in spatial analysis, the tabular data generated from LODES must be joined to U.S. Census block geographies, available as TIGER/Line shapefiles. GEOIDs used to join tabular and spatial data are available in both datasets. Tabular data should always be joined using the corresponding year's Census block geography.

Spatial analysis with block-level workplace characteristics is conducted in the research report using the same project parameters as described for the TDI analysis, as detailed in Table 3. However, the research report recommends multiple possible techniques for summarizing the workplace data within the impact area:

- Total count;
- Total Density;
- Conversion to points of interest (POI) and inclusion in POI analysis

Both total count and total density can be measured geospatially through the use of a spatial join of block features that intersect project impact area features and using a sum merge rule on the field containing job counts; in the case of Total Density, the resulting summed job count should be divided into the area of the project impact area.

In the case of conversion to a POI, block group centroids within a Feature to Point geoprocessing tool to convert the subset of points with a low-and-middle-income job count above a defined threshold into points. These points can then be employed within the chosen POI analysis method.

IV. Context-Sensitive POI Measurement

This research provides an alternative process for measuring project effectiveness in providing access and connectivity to points of interest (POI). This alternative process can be applied to any set of POIs by using existing proximity analysis parameters for POI scoring components.

The context-sensitive POI analysis approach accounts for the project setting by focusing on POI density near and within the project. The context-sensitive POI measure is a ratio of densities calculated using the following formula

$$POI\ Ratio = \frac{Density\ of\ Points\ in\ Project\ Impact\ Area}{Average\ Density\ of\ Points\ of\ Intersecting\ Block\ Groups}$$

Geoprocessing steps for calculating the POI Ratio measure begin with the calculation of POI densities for all block groups. Density of Points in Project Impact Area should be calculating the total count of points within the distance parameter of the project (using the existing method) and dividing the count by the total area of the project impact area. Points density of block groups should be calculated in the same manner, using a spatial join to obtain the total count of points and dividing the point county by the block group area. Average Density of Points of Intersecting Block Groups can be calculated using the method that employs a Spatial Join and summary statistic merge rules outlined in Section I. The merge rule should be set to mean using the field storing block group density information. Once the project and project context densities are available in the project features, field calculations can be used to obtain the final value for POI Ratio, following the formula provided here.

APPENDIX II: Additional Bicycle and Pedestrian Case Study Examples

Additional details on how the TDI measures are calculated for projects are presented in the following section, in addition to additional pedestrian case studies.

Case Study A Details

Project A (SPOT ID 171885), discussed in the full report and shown in Exhibit 10, is presented in detail here to more clearly show the process by which TDI Max and TDI Mean are determined and then is compared to the other projects below. Several different block groups are contained partially or wholly within the buffer zone. These 33 block groups are listed in Exhibit 20, sorted from lowest TDI to highest.

Each block group's TDI reflects the transportation need within the block group based on the six TDI measures of the TDI. If a block group scores 1 on a measure, it is roughly in the bottom third of block groups in the division for that measure (natural breaks are used rather than exact thirds). A 2 means it is in the middle third for that division and a 3 means it is in the highest third.

The individual metrics are then weighted to reach the TDI for that block group. Due to this embedded weighting factor, the TDI is not always the apparent sum of the individual measure scores. The TDI for an individual block group can thus range from 6 (a 1 for every measure) to 18 (a 3 for every measure). The TDI Mean for the project is the average of all the block group TDIs, while the TDI Max is the maximum TDI of any block group within the impact zone.

Exhibit 20. Detailed TDI Value Breakdown for Bicycle Case Study A

Map Label	SPOT ID *Description*	TDI Mean	TDI Max	Block Groups in the Buffer Zone						
				TDI	Under 16	Over 65	Disabled	Poverty	Carless Households	BIPOC
A	B171885 *Expand Atlantic Ave. bridge for bike lanes and sidewalks*	9.85	16	6	1	1	1	1	1	1
				6	1	1	1	1	1	1
				7	1	1	1	1	2	1
				7	1	1	1	1	2	1
				7	1	2	1	1	1	1
				7	2	1	1	1	1	1
				7	2	1	1	1	1	1
				8	1	1	1	1	2	2
				8	1	1	1	2	2	1
				8	1	2	1	2	1	1
				8	2	2	1	1	1	1
				9	1	2	1	2	1	2
				9	2	1	1	1	1	3
				9	2	3	1	1	1	1
				9	2	3	1	1	1	1
				9	3	1	1	1	1	1
				9	3	1	1	1	1	1
				9	3	1	1	1	1	1
				10	1	1	1	1	3	3
				10	2	1	1	2	1	2
				10	2	1	2	2	1	1
				11	2	1	2	2	1	1
				11	2	1	2	2	1	2
				12	1	2	2	2	2	3
				12	1	2	2	2	2	3
				12	1	2	3	2	3	1
				12	2	1	2	3	1	2
				12	2	2	1	3	1	2
				13	2	2	1	2	2	3
				13	3	1	1	2	2	3
				14	3	1	1	3	2	3
				15	2	1	3	3	2	3
				16	2	2	2	3	3	3

Outer Banks Pedestrian Projects

In Exhibit 21 two Outer Banks pedestrian projects are shown. With six of the lowest TDI values possible, these projects exhibit some of the lowest TDI Means in the state database. Exhibit 22 shows the TDI Mean and Max for each of those projects in tabular form.

The two projects are:

Project G (SPOT ID B141365) is a project to construct approximately 4 miles of sidewalks along US 158 through a low-density vacation area, connecting to a commercial area in Kitty Hawk. The TDI Mean for the project is 8.17 and TDI Max is 10. The block that comprises the majority of the impact area has a TDI of 10, which is around average for youth, seniors, and no-vehicle household groups. However, there are some block groups included with lower TDI values, which leads to a lower mean.

Project H (SPOT ID 150671) is a project to construct a sidewalk through a low-density vacation neighborhood with some commercial areas. The TDI Mean for the project is 7.67 and the TDI Max is 9. The majority of the impact area has TDIs of 6 (low on all characteristics). In contrast to Project G, the further away block groups have higher TDIs, raising the TDI Mean and the TDI Max.

Exhibit 21. Outer Bank Pedestrian Projects

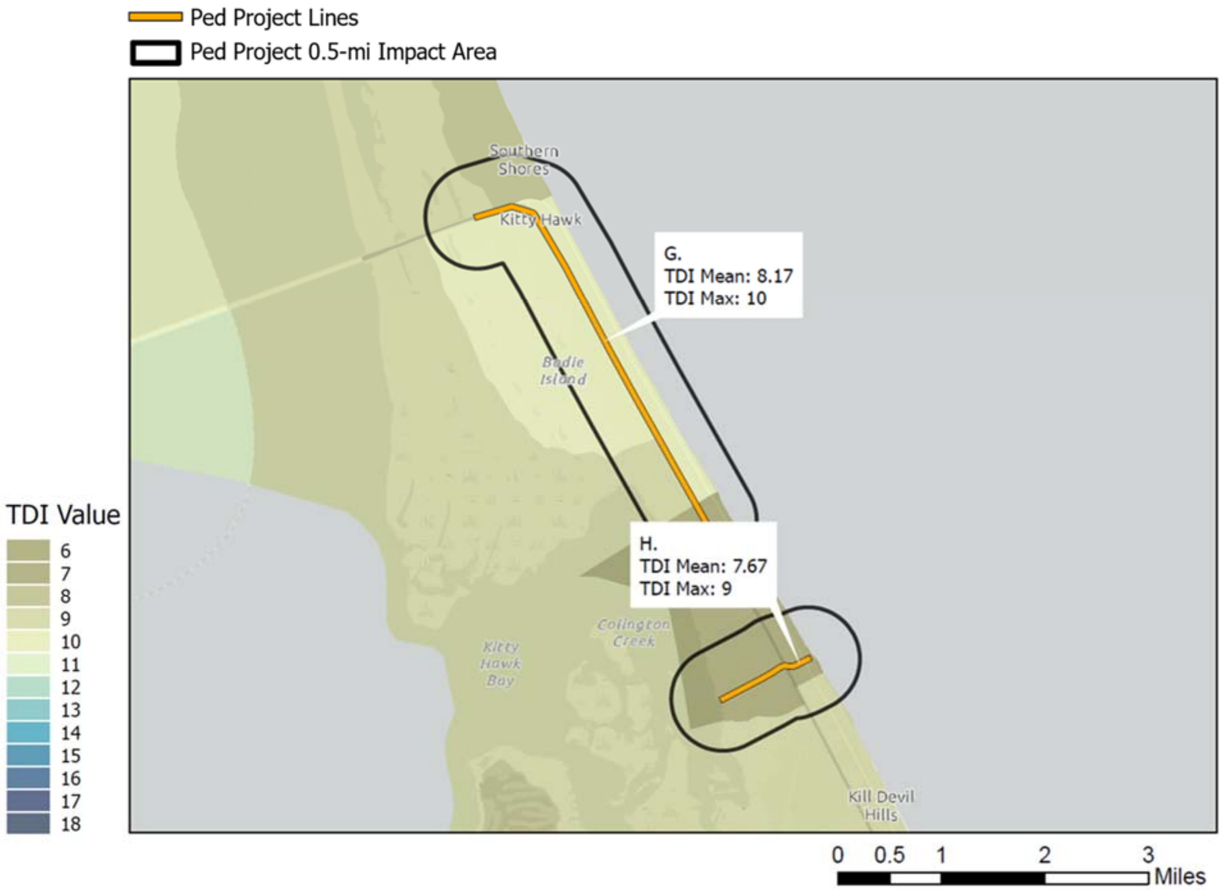


Exhibit 22. TDI Mean and Max for Outer Banks Transit Project Examples

Map Label	SPOT ID	*Description*	TDI Mean	TDI Max
G	B141365	*Construction of ~4 miles of sidewalks along US 158*	11.52	17
H	B150671	*Construction of a sidewalk in Kill Devil Hills*	10.39	17

APPENDIX III: Additional Transit Case Study Examples

Five additional transit case studies are provided below. Each case study project was submitted in P5.0 as either a Mobility (route-specific) New Service specific improvement type or a Mobility (route-specific) - Headway Reduction specific improvement type. The research team created hypothetical point data for routes using project descriptions.

These projects are shown in Exhibit 23, Exhibit 25, Exhibit 27, and Exhibit 29. The TDI Mean and Max for each of those projects are shown in tabular form in Exhibit 24, Exhibit 26, Exhibit 28, and Exhibit 30.

Urban (GoTriangle) Transit Projects

Project L (SPOT T171696) is a new service project described as the development of GoTriangle Rougemont Park & Ride and service. The project includes the construction of a park-and-ride facility and the procurement of an additional vehicle to provide new service between Rougemont (northern terminus) and downtown Durham. The research team envisioned two additional stops. Note that the recommended impact distance parameter remains 0.75 miles for park-and-ride locations.

Project M (SPOT ID T171722) is a headway reduction project to support the GoTriangle ODX Route with bus service expansion. The project includes the procurement of an additional vehicle to support headway reduction on an existing route. Project features were developed from existing route stops.

Exhibit 23. Examples of Urban Area Transit Projects: GoTriangle

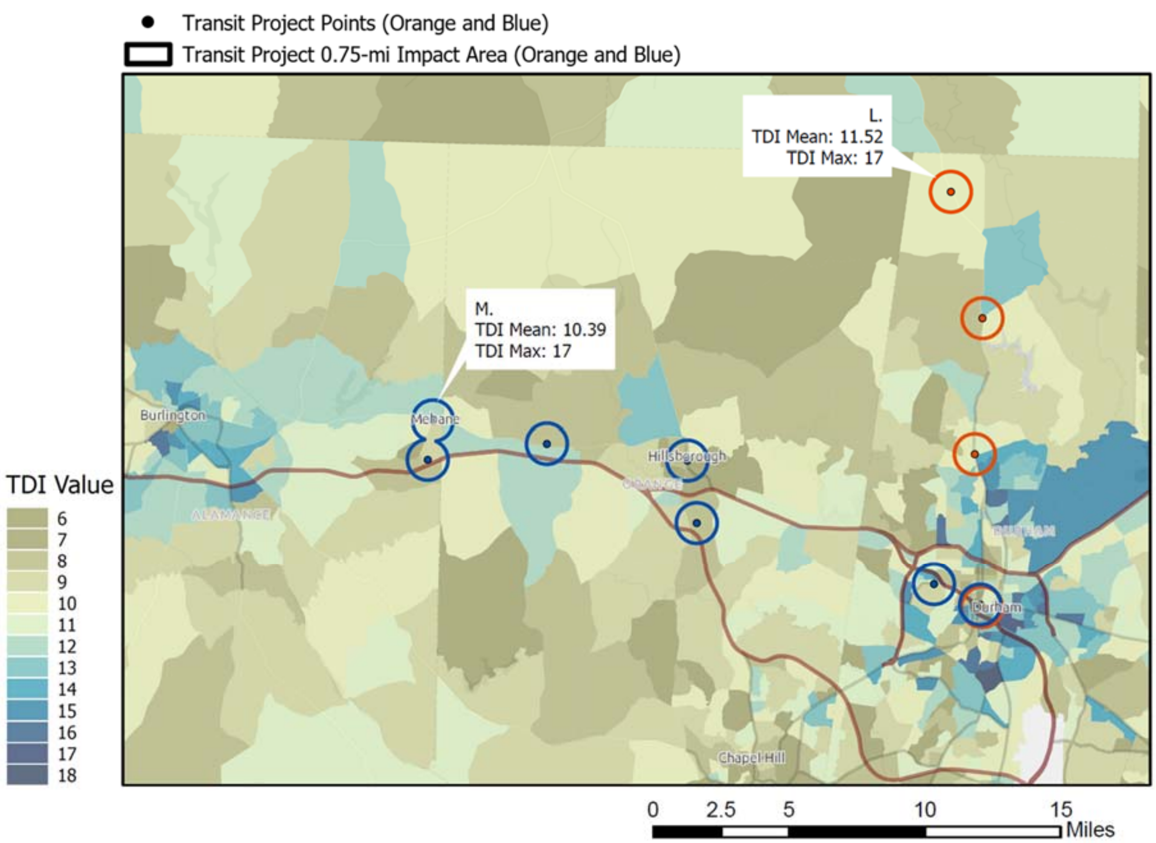


Exhibit 24. TDI Mean and Max for Urban Area Transit Project Examples

Map Label	SPOT ID	*Description*	TDI Mean	TDI Max

L	T171696	*Construction of GoTriangle Rougemont Park & Ride service facilities*	11.52	17
M	T171722	*Headway reduction project for GoTriangle ODX Route*	10.39	17

Smaller Area (Iredell County) Transit Projects

Project N (SPOT ID T171769) is a headway reduction project with the objective of procuring new buses and equipment to support all Iredell County Area Transportation System (ICATS) fixed routes. Features for this project created by the research team include all fixed ICATS routes, including the Intercounty Express Bus Connector service.

Exhibit 25. Example One of Smaller Area Transit Project: Iredell County

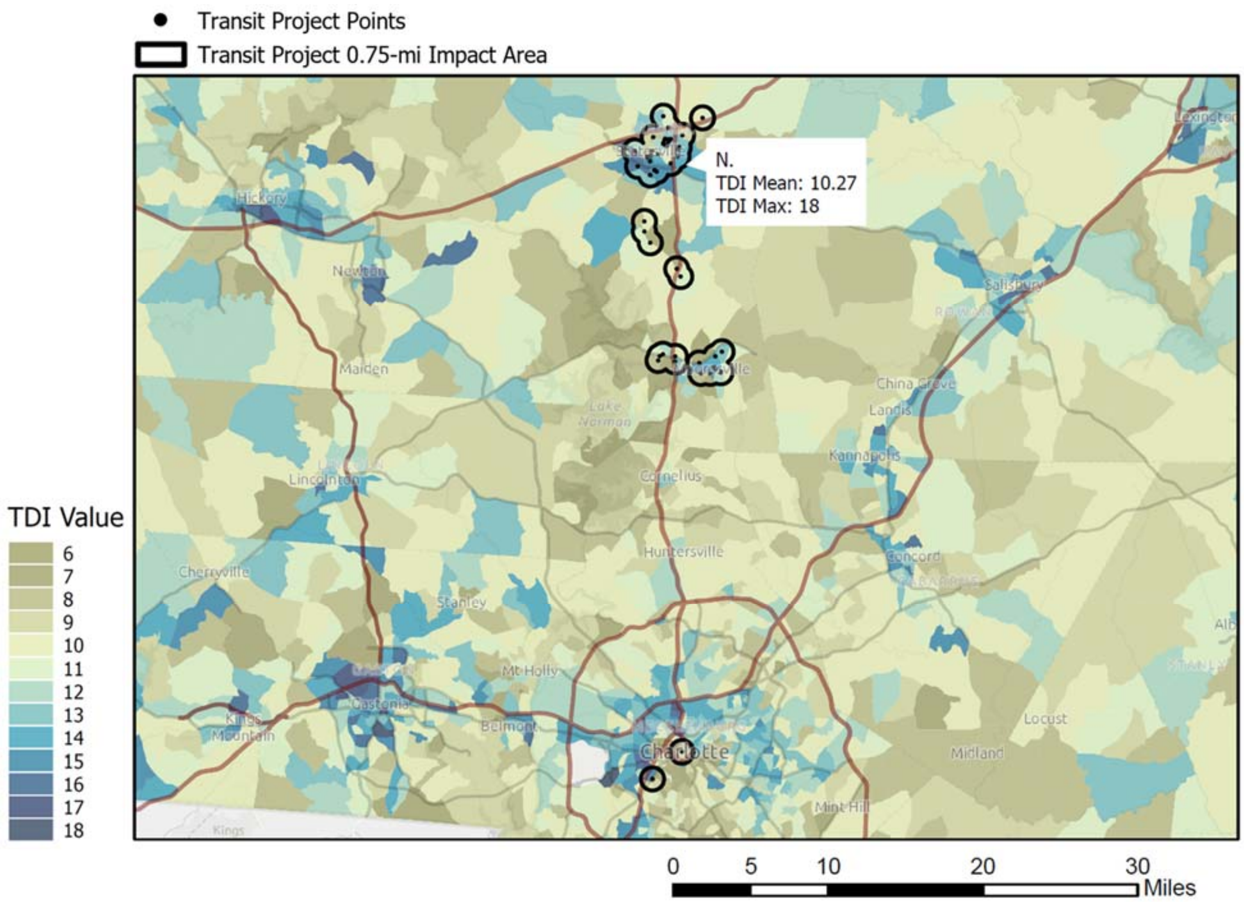


Exhibit 26. TDI Mean and Max for Smaller Area Transit Project Example One

Map Label	SPOT ID	*Description*	TDI Mean	TDI Max
N	**T171769**	*Headway reduction project for Iredell County Area Transportation System*	10.27	18

Project O (SPOT ID T171722) is a new service project with the objective of expanding the ICATS Intercounty Express Bus Connector Service. The project would include the procurement of new vehicles, bus stop shelters, and related equipment.

Exhibit 27. Example Two of Smaller Area Transit Project: Iredell County

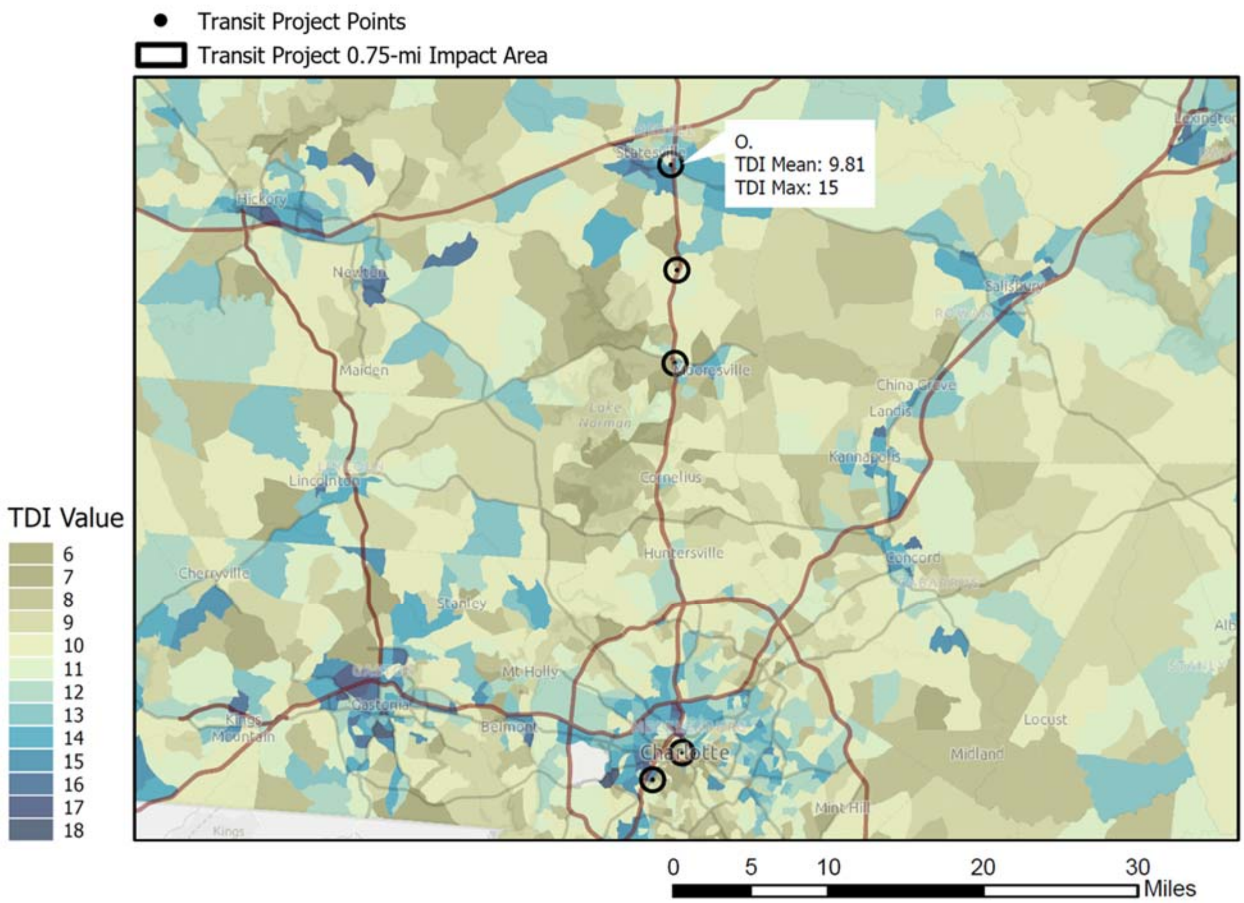


Exhibit 28. TDI Mean and Max for Smaller Area Transit Project Example Two

Map Label	SPOT ID	*Description*	TDI Mean	TDI Max
O	T171722	*Expansion of Iredell County Area Transportation System Intercounty Express Bus Connector Service*	9.81	15

Semi-Urban City (Fayetteville) Transit Project

Project P (SPOT ID T151050) is a headway reduction project aimed at improving service on the Fayetteville Area System of Transit (FAST) route 6. Project features used in the analysis reflect existing Route 6 stop locations.

Exhibit 29. Example Two of Semi-Urban City Transit Project: Fayetteville

Exhibit 30. TDI Mean and Max for Semi-Uban City Transit Project Example

Map Label	SPOT ID	*Description*	TDI Mean	TDI Max
P	T151050	*Headway reduction project on Fayetteville Area System of Transit Route 6*	11.77	17

APPENDIX IV: Geolocating Grocery Store POIs Using USDA Data

The USDA SNAP Retailer Locations (Supplemental Nutrition Assistance Program) dataset is openly available in CSV format that can be downloaded from the usda.gov website and mapped in GIS. Includes street address, city, state, zip code, and latitude and longitude coordinates. About 248,000 retailers participate in SNAP nationwide. Data includes many businesses from big-box superstores and supermarkets to specialty stores, farmers' markets, and convenience stores.

While the majority of stores fall into the convenience and grocery store categories, some as gas stations do not primarily function as grocery retailers. The dataset can be text filtered for major chain retailers, but not for all. For more information, visit https://www.fns.usda.gov/snap/retailer-locator. Exhibit 31 shows what this data looks like across the state of North Carolina.

Exhibit 31. USDA SNAP Store Locations Across North Carolina