Including Equity in Benefit Cost Analysis

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16. Abstract

Transportation planning and funding decisions often have significant equity impacts; however, few transportation agencies today integrate equity considerations into their transportation prioritization processes. Most practitioners and decision-makers sincerely want to achieve equity objectives, but transportation equity can be difficult to evaluate because there are various factors such as demographics, income, ability, geographic location, and travel considerations.

The purpose of this research is to establish user-friendly approaches to integrate equity into NCDOT's BCA processes. This has involved deepening two cross-modal measures: air quality and physical health, which can be included into NCDOT's strategic planning and prioritization processes. As a key component of this study effort, the research team conducted three case studies, including a bike/ped project (Lions Park to Crabtree Creek Greenway; B172013), a bus project (CATS Intercounty Express Bus Connector Expansion; T171770), and a highways project (Bypass of Ahoskie, H090055).

In conjunction with this report, the research team has produced a GIS Web Tool and a Workbook Tool that work in tandem to account for physical health, air quality, and equity benefits or costs associated with prospective transportation projects in North Carolina.

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Table of Contents

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Executive Summary

Transportation planning and funding decisions can have significant equity impacts. However, few transportation agencies today integrate equity considerations into their transportation prioritization process. While many practitioners and decision-makers may want to support more equitable outcomes, actually evaluating outcomes associated with transportation equity can be difficult because of the various factors that need to be considered, such as demographics, income, ability, geographic location, and travel behavior.

The purpose of this research is to establish user-friendly approaches to integrate equity into NCDOT's Benefit-Cost Analysis (BCA) processes. This has involved deepening two cross-modal measures: air quality and physical health, which can be incorporated into NCDOT's strategic planning and prioritization processes. In addition to developing BCA approaches for measures associated with equity, the research team helped NCDOT develop a definition for "equity" in terms of long-range planning and the prioritization of transportation investments in North Carolina.

As a key component of this effort, the research team conducted three case studies, including a bike/ped project (Lions Park to Crabtree Creek Greenway; B172013), a bus project (CATS Intercounty Express Bus Connector Expansion; T171770), and a highways project (Bypass of Ahoskie, H090055). These projects are estimated to generate the following physical health, air quality, and equity impacts.

Lions Park to Crabtree Creek Greenway (B172013)

- ***Physical Health Benefits***: An additional 33,851 walk trips and the 16,925 cycle trips are projected to result from the completion of the Lions Creek to Crabtree Creek greenway alignment. This equates to an annual physical health benefit of $346,463.
- ***Air Quality Benefits***: In addition to physical health benefits, air quality benefits are estimated to total $14,408 annually. These benefits are associated with reductions in carbon emissions as people shift from driving to active transportation via walk or bicycle travel.
- ***Equity Impacts:*** An estimated $247,197 (68.5 percent) of the $360,872 in estimated physical health and air quality benefits would accrue within communities with moderate to high levels of transportation disadvantage (TDI score ≥ 12) and 31.5 percent of the benefits would accrue within communities with moderate to low levels of transportation disadvantage (TDI score < 12).[1]

CATS Intercounty Express Bus Connector Expansion (T171770)

- ***Physical Health Benefits:*** These benefits stem from the 104,548 bus trips that would have a walk component or the 1,208 bus trips that would have a cycling component as people get to and from a bus stop (estimated physical health benefit of $747,825 annually). It is important to note, there are also an estimated 8,500 transit trips that would have a drive component involved, which are assumed to facilitate no physical health benefits.
- ***Air Quality Benefits:*** In addition to physical health benefits, air quality benefits are estimated to total $21,817. These benefits are associated with reductions in carbon emissions as people shift from driving to bus travel.
- ***Equity Impacts:*** Analysis findings demonstrate that $210,448 (27.3 percent) of the $769,641 in estimated physical health and air quality benefits would accrue within communities with

[1] A minimum TDI score of 6 and a maximum TDI score of 18 is possible for North Carolina communities, see page 27 for more information.

moderate to high levels of transportation disadvantage (TDI score ≥ 12) and 72.7 percent of the benefits would accrue within communities with moderate to low levels of transportation disadvantage. (TDI score < 12).[2]

Bypass of Ahoskie (H090055)

- ***Physical Health Benefits:*** A relatively small physical health cost is anticipated to result from the project from an estimated 108 annual walking trips are projected to shift to driving trips within the project area.
- ***Air Quality Benefits:*** On an annual basis, the Ahoskie Bypass is projected to generate 1,521,300 induced vehicular trips. These trips would create an estimated annual emissions cost of $86,460.
- ***Equity Impacts:*** Equity Considerations: All of the $87,231 in estimated physical health and air quality cost burden would accrue within communities with moderate to high levels of transportation disadvantage (TDI score ≥ 12) and none of the costs would accrue within communities with moderate to low levels of transportation disadvantage (TDI score < 12)[3]

[2] Ibid.

[3] A minimum TDI score of 6 and a maximum TDI score of 18 is possible for North Carolina communities, see page 27 for more information.

Literature Review

Before proposing benefit-cost analysis approaches for prioritizing transportation projects, the research team reviewed dozens of existing and emerging literature sources related to the topic as part of a comprehensive literature review. This review focused on identifying best practices as well as data and methodologies required to include air quality and physical health in a benefit-cost analysis framework within NCDOT's strategic prioritization process. The literature review included a scan of peer-reviewed academic publications, industry papers, materials produced by transportation planning organizations, and information from other reputable sources.

The research team thoroughly reviewed and summarized literature focused on applications for incorporating equity measures, such as physical health and air quality, into project prioritization. The details of North Carolina's prioritization process and the state of practice for incorporating equity into long-range transportation planning in the state were also reviewed to help ensure that project approaches and recommendations could be more seamlessly implemented as NCDOT prefers. The results of this literature review were summarized in the interim deliverable "Summary of the Literature and Data Review", as presented in Appendix A. This deliverable also incorporated a review of data and analysis tools relevant to this project, which is discussed further in the "Data Review" section of this report.

The following content presents a brief description of the resources that the research team reviewed, with full descriptions of each resource presented in Appendix A.

- **The Livability Index 2018: Transforming Communities for All Ages.** The index is a research report on the AARP Livability Index tool that was first launched in 2015. The tool uses 60 indicators and 30 million data points and provides insights into how well communities support residents of all ages. The tool provides a score for every U.S. neighborhood based on the available services and amenities. The index is intended for use by data analysts and community residents looking to understand a location of interest.
- **DelDOT Project Prioritization Criteria Summary.** The Delaware Department of Transportation (DelDOT) developed its Project Prioritization Criteria to provide an updated transparent guide for the public to assess accountability as it relates to the 6-year Capital Transportation Program (CTP). The Project Prioritization criteria is also to ensure proper alignment with the mission, vision, and goals of DelDOT and accounts for physical health outcomes from transportation projects.
- **The Health Transportation Shortage Index: The Development and Validation of a New Tool to Identify Underserved Communities.** The purpose of this report is to outline the new health planning tool, The Health Transportation Shortage Index (HTSI), developed by the Children's Health Fund. The report describes why the tool was developed, the data used, and the impact on supporting communities that need greater transportation resources for child healthcare access.
- **Nashville Area MPO 2035 Regional Transportation Plan.** This Long-Range Transportation Plan (LRTP) outlines the current context, vision, strategies, and equity considerations for the Nashville Area region until 2035. The three components of the plan include expanding mass transit options, improving and expanding on active transportation

choices and walkable communities, and preserving and enhancing the strategic roadway corridors through a "fix-it-first" methodology.

- **New Zealand's Economic Evaluation Manual.** This economic evaluation manual discusses the difference between non-monetized benefit measures and monetized benefits as well as the difference between qualitative and qualitative measures. The manual is a procedural guide for transportation agencies and organizations in standardizing and monetizing social costs and benefits for investment proposals. It includes a breakdown of the basic concepts of economic evaluation procedures, simplified and full economic evaluation of procedures and activities, guidance on input values, and sample evaluation worksheets. The manual reviews the topics of healthy and safe people, resilience and security, economic prosperity, and environmental sustainability.
- **Non-Monetised Benefits Manual Qualitative and Quantitative Measures.** This resource outlines the benefits management approach and benefits framework. It discusses the difference between non-monetized benefit measures and monetized benefits as well as the difference between qualitative and qualitative measures. The manual reviews the topics of healthy and safe people, resilience and security, economic prosperity, and environmental sustainability.
- **PBIC Health and Transportation Webinar Series: Planning and Prioritizing Projects for Health.** The webinar series was informed by the NCHRP Research Report 932: A Research Roadmap for Transportation and Public Health. This webinar shares the 2020 update of Virginia's Pedestrian Safety Action Plan as a key example for illustrating a pedestrian safety analysis for prioritization efforts. This webinar reviews opportunities for using prioritization health criteria in addition to the needed collaboration between health and transportation agencies.
- **Health and Transportation Partnerships: Integrating Health Data into Transportation Planning.** This resource is from the Pedestrian and Bicycle Information Center (PBIC) Health and Transportation Webinar Series, Part 3. It focuses on the intersection between transportation and health, being inspired by the NCHRP Research Report 932: A Research Roadmap for Transportation and Public Health. The webinar discussed the pathways to health with emphasis on improving access to opportunities and services – including physical activity, mitigating human exposure to environmental hazards, preventing injuries and improving safety, supporting resiliency to extreme events, and promoting community cohesion.
- **Social-Transportation Analytic Toolbox (STAT) for Transit Networks Final Report NITC-RR-1080.** This report provides guidance on the open-source, socio-transportation analytic toolbox (STAT) intended for public transit planning. The tool's purpose is to provide a method for integrating social media and general transit feed specification (GTFS) data to improve the decision-making process for transit agencies in improving the performance of public transit systems. The tool can also aid in evaluating service networks to improve equitable access to transit systems by detecting the connectivity gaps to public transit systems for underserved populations in reaching essential services.
- **Transportation Outlook 2040.** This adopted document is the Greater Kansas City's long-range transportation plan for guiding the $33.1 billion in multimodal improvements over the next two decades. The plan was adopted on June 23, 2015, by the Mid-America Regional Council (MARC) Board of Directors. The plan provides guidance on policy, performance

measures, standard transportation matters, and matters of particular interest to this literature review, and considers environmental integration, air quality, safety, equity, and facets of public health.

- **Benefit-Cost Analysis Guidance for Discretionary Grant Programs.** This is a recent (February 2021) benefit-cost analysis guide that specifically provides a monetized breakdown of social and human health benefits and costs related to the transportation sector. The resource is a BCA guidance benchmark tool for candidates applying with USDOT's discretionary grant programs.
- **Vehicle Emissions Prediction Model: VEPM 6.2 update technical report.** This resource is to aid the understanding and assessment of the VEPM for the purpose of predicting emissions from New Zealand fleet vehicles under standard operations. The model is an emission-analysis tool that provides estimates on "air quality assessments and regional emissions inventories" for future years 2001 – 2050. The VEPM model and technical report are updated regularly to adjust for new technologies and shifts in real-world conditions.
- **United Kingdom's Guidance on Appraisal and Evaluation (Green Book).** The Green Book is produced by the United Kingdom's HM Treasury. This resource is to be used for all expenditures of public funds in the United Kingdom. The Green Book provides models and guidelines for objective appraisals of public programs and projects and their costs, benefits, and tradeoffs. The Green Book is designed to be a versatile decision-making tool, both in terms of the projects it can be applied to, and the audiences that may use it. It is not intended to be completely prescriptive, nor to be used as the sole resource.
- **Comprehensive Review of State DOT Long Range Transportation Plans (LRTPs).** LRTPs are relevant to defining equity and communities of concern as well as reviewing how various other states include (or do not include) these topics in setting the agenda for the future of transportation. For this study, 48 LRTPs were reviewed.
- **Reviewed Action Plans and Guides That Include Definitions of Equity.** Action Plans and Guides relevant to identifying the state of practice related to defining equity and communities. For this study, 23 action plans were reviewed.
- **Transportation Equity Toolkit: Transportation Equity Needs Assessment and Project Prioritization.** This toolkit is designed to serve as a resource for MPOs, transportation agencies, and communities as they work to advance equity in traditionally underserved communities. It provides a framework for a transportation equity needs assessment and an equity-based project identification and prioritization process. A variety of tools and methods are provided for these frameworks, including 1) Transportation Equity Audit Tool: a survey-based tool designed for use by agency staff, community organizers, and community members in identifying community transportation needs from an equity perspective; and 2) Transportation Equity Scorecard Tool: a spreadsheet tool to assist the staff of MPOs and other transportation planning agencies in prioritizing projects that advance equity.
- **TCRP Equity Analysis in Regional Transportation Planning Processes, Volume 1: Guide.** Volume 1 documents a five-step equity analysis framework for regional transportation plans and programs that provides a high-level overview of relevant requirements and the analysis framework. Also included are quick-reference charts of activities, resources, and guidebook sections that apply particularly to planners,

policymakers, analysts, and modelers. Foundational approaches to public and stakeholder engagement throughout the entire analysis process are outlined.

- **TCRP Equity Analysis in Regional Transportation Planning Processes, Volume 2: Research Overview.** Volume 2 describes the results of a research effort conducted to identify ways in which equity in public transportation can be analyzed through an integrated participatory and quantitative approach that is adaptable to plans and programs developed by MPOs in partnership with transit agencies and that relates to environmental justice analysis and Title VI procedures, implementation, and reporting compliance. The products of this research are designed to help transportation professionals engaged in the process of planning and programming federal transportation funds at MPOs and transit agencies.
- **The Transportation Planning Process Briefing Book: Key Issues for Transportation Decisionmakers, Officials, and Staff by the USDOT Transportation Planning Capacity Building Program.** This document provides an overview of transportation planning for government officials, transportation decision-makers, planning board members, transportation service providers, interested stakeholders, and the public. It covers the basics and key concepts of metropolitan and statewide transportation planning, along with references for additional information.
- **APA Planning for Equity Policy Guide.** This policy guide examines equity through the lens of land use and transportation planning. The target audience is the planning community, with an emphasis on explaining how equity factors into the field and how related policies can more effectively address equity issues.

Data Review

Transportation networks affect public health in several ways. Motor vehicle crashes can lead to serious injury or loss of life, tailpipe emissions can contribute to cancer and congenital anomalies, and motor-vehicle dominant travel can produce sedentary lifestyles which can lead to obesity, pulmonary conditions, and increase some forms of cancer (Litman, 2020). Meanwhile, traffic congestion or exposure to stressful travel environments can lead to anxiety and depression (Ganesh, 2019), which can diminish the quality of life and can decrease life expectancy. Furthermore, transportation networks play a critical role in connecting people to medical and healthcare destinations. Though transportation investment directly impacts public health in many ways, available data, modeling platforms, and quantification methods are still largely evolving. As such, only a limited set of public health outcomes resulting from transportation investments can be readily quantified and integrated into a benefit-cost analysis framework.

As an interim deliverable, the project team conducted a comprehensive data review, which served two primary functions. First, the data review was conducted to locate publicly available data sources that could be used to model the effect of a transportation investment on the air quality and physical health of populations impacted by a prospective transportation investment. Second, the data review was undertaken to evaluate data sources that could be used to quantify the equity impacts stemming from a proposed transportation investment.

The results of the data review were summarized in the interim deliverable "Summary of the Literature and Data Review." A brief description of the data resources that the research team reviewed is presented below, with the full descriptions available in Appendix A.

- **United Health Foundation: America's Health Rankings (AHR).** America's Health Rankings (AHR) is a web-based tool that provides data and reports on a number of measures across the United States. Data are publicly available and can be downloaded as a .csv file and is available for each state and the United States overall. Users can select a state from the thematic map, which simultaneously acts as a choropleth map ranking each state by the selected measure. Users can also navigate with a dropdown menu to choose their measure, state, and year.
- **Built Environment and Public Health Clearinghouse.** The Built Environment and Public Health Clearinghouse (BEPHC) is a publicly available resource that provides links to other resources according to six categories: data and assessment, funding opportunities, professional training, webinars, academic training, and schools.
- **Environmental Protection Agency (EPA) Smart Location Database.** The EPA Smart Location Database is a nationwide dataset including over 90 variables at the block group level. While most variables are available for all block groups in the United States, some data is limited to metropolitan regions with available transit agencies that have GTFS data. The Smart Location Database is available as a table download, GIS shapefiles, and interactive web services. Variables include transit accessibility, land use diversity, density, employment, and demographics.

- **EPA MOtor Vehicle Emission Simulator (MOVES).** EPA's MOtor Vehicle Emission Simulator (MOVES) is an emissions modeling system that estimates emissions for mobile sources for criteria air pollutants, greenhouse gases, and air toxins. Mobile sources covered by MOVES include on-road vehicles such as cars, trucks, and buses, and nonroad equipment such as bulldozers and lawnmowers. Aircraft, trains, and marine vessels are not covered.
- **Global Annual PM2.5 Grids from MODIS, MISR and SeaWiFS Aerosol Optical Depth (AOD) with GWR, v1 (1998–2016).** This geospatial data set is used to measure the global surface concentrations of mineral dust and sea-salt-filtered fine particulate matter of 2.5 micrometers or smaller (PM2.5) for worldwide health and environmental research. Because this is a global data set, each file has floating point values for PM2.5 concentration approximations. Raster grids' cell resolution is 0.01 degrees and covers the land surface from 70 degrees north to 55 degrees south. The data is in GeoTIFF (.tif) and can be downloaded as zip files from any year between 1998 – 2016.
- **Healthy Community Design Checklist Toolkit (CDC).** The Healthy Community Design Checklist Toolkit is a publicly available resource for community planning. It is comprised of four elements: (1) a healthy community design checklist, (2) a healthy community design Powerpoint presentation, (3) guidance to create a health profile of your neighborhood, and (4) a planning for health resources guide. These four resources are intended to be used together and supplement each other and are available as downloadable files.
- **Integrated Transport and Health Impact Model.** The ITHIM is a publicly available tool that compares different travel modes and planning scenarios by looking at the expected outcomes over variables such as air quality, greenhouse gas emissions, reduction in chronic disease from active transportation, reduction in fatalities from fewer automobile trips, and monetary health benefits. A number of scenarios, including state transit plans and US Surgeon General Recommendations, are included; users may also upload their own scenarios.
- **Longitudinal Employer-Household Dynamics (LEHD) Job-to-Job Flows (J2J) Data.** Job-to-Job Flows (J2J) data provides statistics on job mobility in the United States, showing job flows across different geographies, worker characteristics, and firm characteristics, reporting how workers flow through different employers. This data is available at the national, state, and metropolitan area levels. Information is organized and available for a variety of sectors based on NAICS categorization.
- **Longitudinal Employer-Household Dynamics (LEHD) Data Post-Secondary Employment Outcomes (PSEO) Data.** PSEO data is created from collaboration between colleges/universities and state agencies, considered an "experimental" data product. This data tracks the employment and earnings of college graduates by education level (Bachelors, MastersBMr, etc.). Partner systems are tracked by state; data is only available for participating states and institutions, although future releases will include more institutions. Information is reported by each participating college or university.
- **Longitudinal Employer-Household Dynamics (LEHD) Data Quarterly Workforce Indicators (QWI) Data.** QWI data provides information on firm characteristics (such as size, age, and location) linked to worker demographics (such as age, education, race/ethnicity, and sex). QWI data pulls from a variety of sources, including Unemployment Insurance Earnings Data, Quarterly Census of Employment and Wages, and Business Dynamics Statistics.

- **Longitudinal Employer-Household Dynamics (LEHD) Data Veteran Employment Outcomes (VEO) Data.** Veteran Employment Outcomes (VEO) Data is a new statistical dataset considered "experimental", examining veterans from the US Army. In the future, this data might be available for other branches of the military. Labor statistics are gathered for veterans one, five, and ten years after being discharged. Data are collected by demographics, employer industry, and military characteristics.
- **Regional Travel Demand Model Development Guidelines.** NCDOT is moving towards the development of regional travel demand models. When complete the entire state will be covered by TDMs. The specification reviewed includes a non-motorized component that may be informative towards physical health.
- **TransCAD Model (NCSTM).** The North Carolina Statewide Travel Model is a travel demand model built on the TransCAD platform and predicts future travel demand at a statewide level. It is primarily used to estimate future travel demand and travel time given certain land use and/or infrastructure scenarios. This TransCAD model is built at a higher level of TAZ (traffic analysis zone) aggregation than that found in most urban travel demand models.
- **TransModeler Model (CTM).** TransModeler is a microsimulation modeling platform that provides detailed disaggregate performance measures such as travel time, delay, queuing, and intersection level of service. TransModeler is multimodal and can be used to simulate auto, transit, and non-motorized travel. Currently, the NCDOT prioritization process requires travel time savings calculations from TransModeler for interchange, intersection, and superstreet projects. The TransModeler models used to support this analysis are built for individual intersections, interchanges, or corridors. Unlike aggregate travel demand models that estimate demand between traffic analysis zones, TransModeler simulates traffic flow for individual autos, transit vehicles or pedestrians.
- **Triangle Regional Model.** The Triangle Regional Model is a travel demand model built on the TransCAD platform to predict future travel demand for the Triangle region. It is primarily used to estimate future travel demand and various transportation system performance measures given a certain land use and/or infrastructure scenario. The TRM provides an aggregate level of analysis at the TAZ (traffic analysis zone) level. TAZs are aggregations of census blocks, and cover a smaller geography for urban regions of the model, increasing in size for rural regions of the model.
- **US Department of Transportation (USDOT) Transportation and Health Tool (THT).** The THT was developed by a collaboration between USDOT, the Centers for Disease Control (CDC), and the American Public Health Association (APHA). The tool provides data on a variety of transportation and public health indicators throughout the United States.
- **Walk Score (Redfin).** Walk Score is a privately-owned, publicly available product that provides walkability, bike-ability, and transit-friendly scores to neighborhoods. It is available for any address in the United States and Canada and reports scores for some areas in Australia.
- **World Health Organization (WHO) Health Economic Assessment Tool (HEAT).** HEAT examines walking and cycling infrastructure and provides an estimated value for the reduced mortality from this infrastructure to inform economic analysis. The tool can be used at the national, city, or sub-city level. Impacts are calculated over a number of years

selected by the user. Physical activity, air pollution, and carbon emission impacts can be selected for analysis.

- **Various Local and State Multimodal Data Sources.** North Carolina-specific data sources were given primacy for this research effort and assessed during the data review. The research team reviewed CATS ridership, GoRaleigh ridership, NCDOT Amtrak ridership, and NCDOT ferry ridership data and determined to use these datasets as key inputs for the study's benefit-cost analysis methodology.

Gap Analysis

As part of the literature and data review, the research team conducted a gap analysis, which was undertaken to improve the consideration of equity in the transportation planning process for North Carolina. The gap analysis could also be used to guide further research. A summary of the gap analysis findings from the literature and data review is included below. The full literature and data review is included in Appendix A.

Gap Analysis Approach

Sixteen planning organizations (POs) from across the country were identified, and their long-range transportation plans (LRTPs) were reviewed and rated across several common components found in LRTPs, including Vision, Stakeholder and Public Engagement, Evaluation Tools, Methods, and Data for Needs Assessment, Project Specific Considerations, Purpose and Need Statements, and Process Documentation and Implementation Plan. The LRTP documents were then evaluated across metrics critical to this research, including the definition of equity, the definition of communities of concern (CoC), and the explicit mention of data or metrics related to health and air quality. If the reviewed plan included the consideration of equity in any of the plan components or addressed any of the critical research metrics, then that element was flagged in the appropriate table.

A rating of 1 was given if the plan element included the mention of equity, a rating of 2 was given if the plan element included a discussion or presentation of data specific to equity, and a rating of 3 was given if the plan element included analytical methods tied to measuring or assessing equity related outcomes. As shown in Table 1 and Table 2, each cell has been color-coded to allow for simple identification of each tier. The POs included in this review were selected to be representative of areas of various geographic and population size, updated recently (where possible), and accessible online. While many MPOs make their LRTPs available online, the pool is considerably more limited for LRTPs from RPOs.

Summary of Findings

The results of the scan, presented in Table 1 and Table 2 show that the majority of the MPOs include equity in their planning elements from a contextual standpoint, and with the inclusion of data. What appears more challenging is the use of analytical methods tied to measuring or assessing equity-related outcomes. This is particularly concerning for the plan elements related to evaluation tools and methods, and project considerations are these two components of the planning process are most analytically driven. There is some encouragement with respect to using analytical methods for defining equity and communities of concern (CoCs), but less so with a specific focus on physical health and air quality. The analysis of RPOs tells a different story, with most only mentioning equity in their report, many also using data specific to equity, but very few using analytical methods. These results likely point to a need for establishing best practices for including equity, not just at all steps of the planning process, but related to how to move from concept to analytical methods that lead to intended outcomes.

Table 1: **Matrix displaying inclusion of equity-based best practices in MPO transportation planning documents**

Metropolitan Planning Organization	Planning Elements						Research Elements		
	Development of Community visions	Stakeholder and Public Engagement	Evaluation Tools, Methods, and Data for Needs Assessment	Project-Specific Considerations within LRTP	Development of Purpose and Needs Statements	Process Documentation and Implementation Plan	Definitions of Equity	Definitions for Communities of Concern	Physical Health & Air Quality Data
Atlanta, GA	2	2		2	2	2	3	2	2
Boston, MA	3	3	3	2	3	2	3	3	2
Broward County, FL	2	1	1	1	2	1			
Hillsborough County, FL	2	3	2	3	3	2		2	2
Indianapolis, IN	2	2	2	2	3	1		1	1
Johnson County, IA	2	1	2	2	2	2	3	2	2
Lincoln, NE	2	3	3	2	2	2	3	3	3

Source: ITRE, 2023.

Table 2: Matrix displaying inclusion of equity-based best practices in RPO transportation planning documents

Rural Planning Organization	Planning Elements						Research Elements		
	Development of Community visions	Stakeholder and Public Engagement	Evaluation Tools, Methods, and Data for Needs Assessment	Project-Specific Considerations within LRTP	Development of Purpose and Needs Statements	Process Documentation and Implementation Plan	Definitions of Equity	Definitions for Communities of Concern	Physical Health & Air Quality Data
Northern Tier, PA	2	1	1	2	2	1		1	2
Northwest Pennsylvania, PA	1	2	2	3	1				2
Southern Allegheníes, PA	2	2	1	2	2				1
Huntsville, AL	2	2	2	3	2				2
Upper Savannah, SC	2	1	1	2	1	1			1
Washington County, OK	2	2	1	3	2	2			1
Hampton Roads, VA	1	1	1	2	2				
Western Tennessee, TN	1	2	1	2	1	2			

Source: ITRE, 2023.

Definition of Equity

Developing measures for considering equity in project prioritization can be of limited value without a definition for "equity." Consequently, the research team worked with key NCDOT stakeholders to develop a definition of equity in terms of long-range planning and the prioritization of transportation investments in North Carolina. To support the development of a definition, the research team conducted a nationwide review of equity definitions in the context of planning and prioritization. These definitions were then analyzed to identify additional emerging themes and common terms that NCDOT considered when developing their own definition through several facilitated discussions.

The result of this research and extensive conversations between the NCDOT Transportation Planning Division (TPD) and Strategic Prioritization Office (SPOT) is the following definition, which is designed to provide a vision that can guide decisions related to data, measures, and actions.

> *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.*

A detailed synopsis of the definition development process and results are provided in the interim deliverable "Summary of the Equity Definition Development", as presented in Appendix E.

Data Analysis & Methodology

The primary purpose of Research Project 2022-17: Including Equity in Benefit-Cost Analysis, is to quantify how prospective transportation projects impact physical health and air quality and to assess how those impacts are distributed among individuals living within a project area. This effort required finding publicly available datasets that are routinely updated, so that physical health, air quality, and equity evaluations could be integrated into North Carolina's Strategic Transportation Investments (STI) prioritization process and remain current.

The "Literature and Data Review" efforts in this project involved selecting data sources while the "Data Analysis & Methodology Development" efforts involved determining the methodologies that would be used to evaluate the effects of prospective transportation investments on physical health, air quality, and equity. To align with many of the existing STI processes as well as standard practices used for economic evaluation, the research team implemented a benefit-cost analysis framework. This framework can serve as the guiding approach for quantifying the impact a prospective transportation project may have on society.

Benefit-Cost Analysis Framework

Benefit-Cost Analysis (BCA), also referred to as Cost-Benefit Analysis (CBA), is a systematic process for calculating and comparing the benefits and costs of a project for two purposes, (1) to determine if the project is a sound investment (justification/feasibility) and (2) to examine how the proposed project compares with alternate projects (ranking/priority assignment). Benefit-Cost Analysis works by defining the project and any alternatives, and then identifying, measuring, and valuing the benefits and costs of each (Economics and Finance Committee, 2023).

For this research effort, the physical health and air quality benefits that accrue within the project area before and after a prospective project are compared. This is considered by comparing the base case scenario to the build scenario. The data sources and methodologies discussed in this report were developed by the research team to compare those scenarios and estimate the net change in benefits or costs that accrue due to the implementation of a prospective project.

As part of the BCA framework, the research team developed approaches for analyzing the physical health, air quality, and equity impacts associated with prospective investments within highway, bicycle and pedestrian, bus, bus rapid transit, light rail, commuter rail, vehicle ferry, and pedestrian ferry modes of transportation. The methodology can be implemented using two tools developed through this study: a Workbook Tool (described on page 19) and a GIS Web Tool (described on page 23). These two tools can be used in tandem to tabulate changes in physical health, air quality, and equity benefits within a BCA framework in geographically-specific environments. Project characteristics and proximate demographic and socioeconomic information is extracted from spatial data layers using the GIS Web Tool, and impacts are quantified and described by inputting this data and other project information in the Workbook Tool. A full description of the methodology, including an explanation of the data, equations, and the BCA framework used to evaluate impacts is in the "RP: 2022-17 Task 3: Interim Deliverable" in Appendix B.

Workbook Tool

As a primary companion to this research, a Microsoft Excel-based Workbook Tool was developed. The Workbook Tool contains the research methodology for estimating physical health, air quality, and equity impacts. It is designed to be a "plug-and-play" resource that readily integrates into the NCDOT Strategic Prioritization Office's transportation prioritization workflows. This tool incorporates the quantitative inputs, equations, and an automated interface to estimate the physical health, air quality, and equity effects of highway, bus, bus-rapid transit, light rail, commuter rail, car ferry, and passenger ferry transportation projects.

The Workbook Tool was developed to be supported by the GIS Web Tool (detailed in the "GIS Web Tool" section on page 23), which enables the extraction of spatial data, including demographic and socioeconomic information, for project areas. Outputs of the GIS Web Tool are used as inputs for the Workbook Tool in conjunction with other inputs to estimate the benefits or costs stemming from prospective transportation investments. Summaries of the inputs and outputs for the Workbook Tool are presented in Table 3 and Table 4, while an image depicting the module for the highways mode with the Workbook Tool logic is shown in Figure 1.

Table 3: Workbook Tool Input Variables

Input	Description	Data Source(s)
Project Area Population	Total Population within Buffer Area	GIS Web Tool
Urban Proportion	Percentage of Project Impact Area that is in an Urban area	GIS Web Tool
Walk Proportion	Percentage of Population in Project Impact Area that Walks to work	GIS Web Tool
Bike Proportion	Percentage of Population in Project Impact Area that bikes to work	GIS Web Tool
Transit Proportion	Percentage of Population in Project Impact Area that takes transit to work	GIS Web Tool
Transportation Disadvantaged Index (TDI) Max Value	Max value of Transportation Disadvantage Index observed in project impact area	GIS Web Tool
TDI Mean Value	Max value of Transportation Disadvantage Index observed in project impact area	GIS Web Tool
Population Proportion by TDI	Percentage of Impact Area Population located within TDI categories ranging from 6-18.	GIS Web Tool
Average Posted Speed Limit	User selects whether speed limit is 0-20mph, 20-30mph, 30-40mph, or 40+ mph (used for highway projects)	User input
Sidewalks adjacent to Highway Facility	User selects whether there are 1, 2, or no sidewalks adjacent to the highway facility (used for highway projects)	User input
Sidewalk Width	User selects whether the sidewalk meets NACTO residential standards, downtown or commercial standards, or does not meet NACTO standards (used for highway projects)	User input
Proposed Facility Length	User selects 0-0.5 miles, 0.5-2.0 miles, or 2.0+ miles (used for bike/ped projects)	Calculated by the GIS Web Tool (or user input)
Number of New Stops, Stations, or Terminals in Project	User enters the number of new bus, bus rapid transit, light rail, commuter rail, or ferry stops/stations/terminals proposed in the project (used for public transportation, rail, and ferry projects)	User input
New Frequencies per Stop, Station, Terminal	User enters the number of new bus, bus rapid transit, light rail, commuter rail, or ferry frequencies are proposed in the project (used for public transportation, rail, and ferry projects)	User input

Source: ITRE, 2023

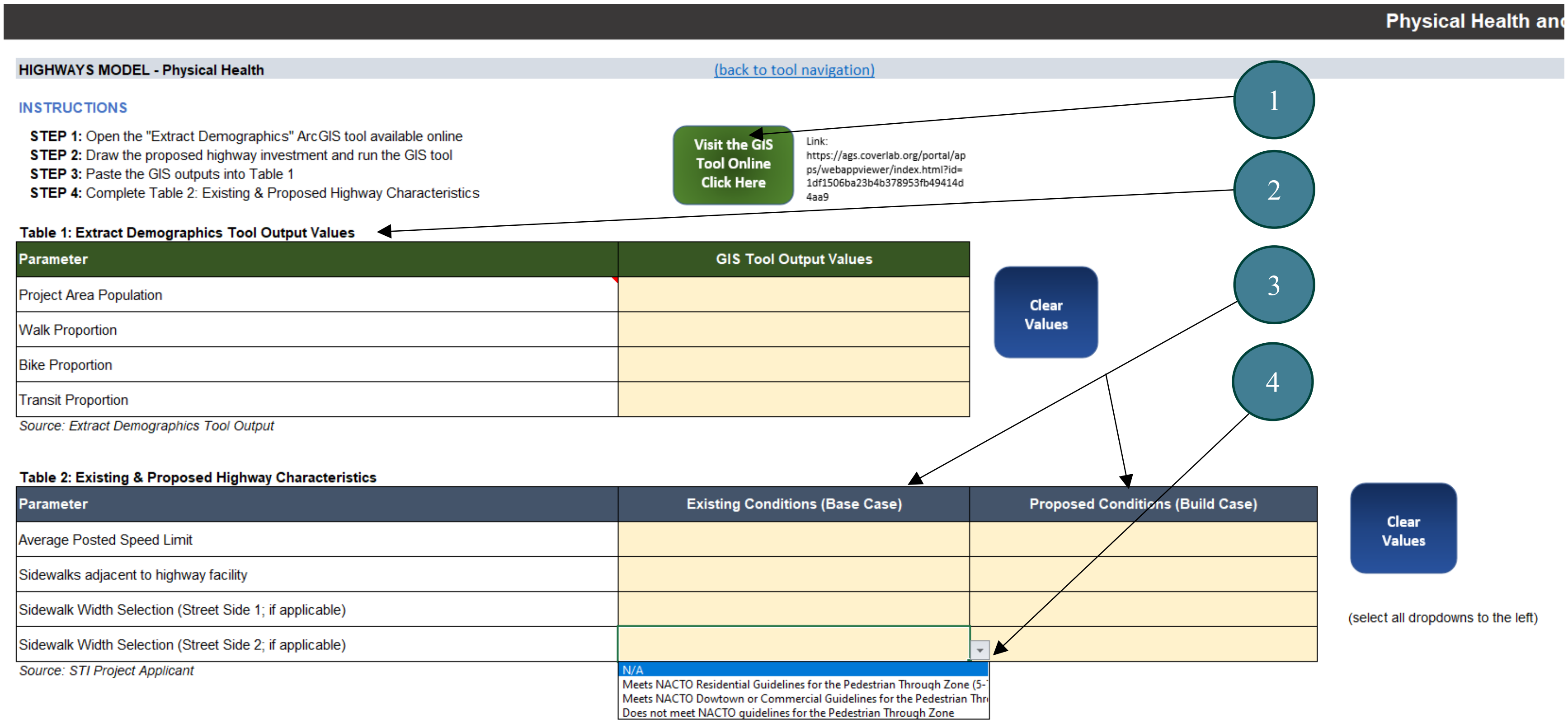
Table 4: Workbook Tool Output Values

Output	Description
Project Area Population	Both an input and output of the tool, project area population is used to derive the number of pedestrians and cyclists affected in the project area.
Physically Active Pedestrians	*Physically Active Pedestrians* is a derived measure of the number of pedestrians impacted by a proposed project. This number is estimated by multiplying the walk proportion (sourced from the GIS Web Tool) by the project area population (sourced from the GIS Web Tool). The research team recommends using a buffer of 0.5 miles to estimate the effects of a prospective transportation project on pedestrians who commute to work.
Physically Active Cyclists	*Physically Active Cyclists* is a derived measure of the number of pedestrians impacted by a proposed project. This number is estimated by multiplying the *Bike Proportion* (sourced from the GIS Web Tool) by the *Project Area Population* (sourced from the GIS Web Tool). The research team recommends using a buffer of 0.5 miles to estimate the effects of a prospective transportation project on cyclists who commute to work.
Daily Transit Users	*Daily Transit Users* is an estimate of the number of people who made a transit trip within the project area. This number is derived by multiplying the *Transit Proportion* (sourced from the GIS Web Tool) and *Project Area Population* (sourced from the GIS Web Tool). The research team recommends using a buffer of 0.5 miles to estimate the effects of a prospective transportation project on people who commute by transit for work. Transit includes bus, bus rapid transit, light rail, commuter rail, passenger ferry, and vehicle ferry modes.
Daily Walk Trips	*Daily Walk Trips* is an estimate of the number of trips made by pedestrians within the project area. This number is derived by multiplying *Physically Active Pedestrians* by estimated daily person trips (sourced from AAA, 2021). The research team recommends using 2.6 daily walk trips. *Daily Walk Trips* is an input that is used to compare benefits in the base case and build case scenarios for bike/ped and transit modes. Benefits stemming from walk commutes and the active share of transit commutes (bus, bus rapid transit, light rail, commuter rail, ferry) are evaluated.
Daily Cycle Trips	*Daily Cycle Trips* is an estimate of the number of trips made by pedestrians within the project area. This number is derived by multiplying *Physically Active Pedestrians* by estimated daily person trips (sourced from AAA, 2021). The research team recommends using 2.6 daily walk trips. *Daily Cycle Trips* is an input that is used to compare benefits in the base case and build case scenarios for bike/ped and transit modes. Benefits stemming from cycle commutes and the active share of transit commutes (bus, bus rapid transit, light rail, commuter rail, ferry) are evaluated.
Annual Walk Trips	*Annual Walk Trips* is an estimate of the number of annual walk trips made by Pedestrians within the project area. It is derived by multiplying *Physically Active Pedestrians* times *Daily Walk Trips* times 365 days.
Annual Cycle Trips	*Annual Cycle Trips* is an estimate of the number of annual cycle trips made by cyclists within the project area. It is derived by multiplying *Physically Active Cyclists* times *Daily Cycle Trips* times 365 days.
Drive to Transit Trips (Daily & Annual Trips)	*Drive to Transit Trips* is an estimate of the number of transit trips (tabulated daily and annually) made by people within the project area who drive to the transit service. These trips are estimated using Wake County Transit survey data and NCDOT Ferry data. *Drive to Transit Trips* are derived by multiplying *Daily Transit Users* times drive share. To annualize, these trips are multiplied times 365 days. Transit modes include bus, bus rapid transit, light rail, commuter rail, and ferry.
Walk to Transit Trips (Daily & Annual)	*Walk to Transit Trips* is an estimate of the number of transit trips (tabulated daily and annually) made by people within the project area who walk to the transit service.

Output	Description
	These trips are estimated using Wake County Transit survey data and NCDOT Ferry data. *Walk to Transit Trips* are derived by multiplying *Daily Transit Users times* walk share. To annualize, these trips are multiplied times 365 days. Transit modes include bus, bus rapid transit, light rail, commuter rail, and ferry.
Bike to Transit Trips (Daily & Annual)	*Bike to Transit Trips* is an estimate of the number of transit trips (tabulated daily and annually) made by people within the project area who bike to the transit service. These trips are estimated using Wake County Transit survey data and NCDOT Ferry data. *Bike to Transit Trips* are derived by multiplying *Daily Transit Users times* bike share. To annualize, these trips are multiplied times 365 days. Transit modes include bus, bus rapid transit, light rail, commuter rail, and ferry.
Annual Transit Trips Resulting from Project	*Annual Transit Trips Resulting from the Project* is an estimate of the number of annual transit trips that occur in the based case and build case scenarios. The methodology used to estimate changes in annual transit trips is in the "RP: 2022-17 Task 3: Interim Deliverable" in Appendix B.
Kg Carbon Equivalent (CO2e)	*Kg Carbon Equivalent (CO2e)* is an output that estimates the total amount of carbon emitted from existing conditions (base case scenario) and the estimated quantity of carbon emitted in proposed conditions (build case scenario; after a proposed transportation project is installed). The methodology used to estimate carbon emissions is in the "RP: 2022-17 Task 3: Interim Deliverable" in Appendix B.
Annual Appraised Physical Health Benefit	*Annual Appraised Physical Health Benefit* is an output that estimates the total benefit or cost that accrues when comparing existing conditions (base case scenario) to proposed conditions (build case scenario; after a proposed transportation project is installed). The methodology used to estimate physical health benefits or costs can be in the "RP: 2022-17 Task 3: Interim Deliverable" in Appendix B.
Annual Appraised Air Quality Benefit	*Annual Appraised Air Quality Benefit* is an output that estimates the total benefit or cost that accrues when comparing existing conditions (base case scenario) to proposed conditions (build case scenario; after a proposed transportation project is installed). The methodology used to estimate air quality benefits or costs can be in the "RP: 2022-17 Task 3: Interim Deliverable" in Appendix B.

Source: ITRE, 2023

Figure 1: The Highways Physical Health Module - An Example of the Workbook Tool's Logic



Workbook Tool Logic

(1) Users can navigate directly to the GIS Web Tool from within the Workbook Tool.
(2) The GIS Web Tool's output values that will be used within the highway's module are shown in the green table. GIS Web Tool output values are used as workbook tool inputs. Enter these values in the yellow cells within the green table (Table 1).
(3) The Workbook Tool evaluates the base case conditions and compares them to build case conditions (the conditions that are modeled to occur if a proposed transportation project is built).
(4) Users can select values from the dropdown menus for the existing conditions (base case) and proposed conditions (build case).

GIS Web Tool

The research methodology established for estimating project physical health and air quality impacts is supported by a Web Tool that uses a geographic information system (GIS) to extract geospatial data for project areas. This tool is designed with functionality that could be implemented within SPOT Onl!ne for efficient integration with existing geoprocessing workflows. In its current format, the GIS Web Tool is hosted as an ArcGIS Web App with custom geoprocessing applications supported by Python programming language scripting.

Project impact area data can be extracted by specifying two parameters for the GIS Web Tool: (1) project location and (2) buffer distance. The tool allows users to either draw features on the map or upload existing project features for geoprocessing. Buffer parameters are specified by the project and further detailed in the project documentation. Running the tool produces summary statistics for the resulting project buffer (referred to as the "impact area") as described in Table 5.

Table 5: Summary of GIS Web Tool Outputs

Output	Description	Data Source(s)
Project Length	Length of Project in Miles (not calculated for point projects)	User Input
Buffer Size	Buffer Size in Miles chosen by user	User Input
Impact Area Size	Area in Square Miles of Buffered Project in Square Miles	Tool Calculation
Total Population	Total Population within Buffer Area	U.S. Census ACS 5-Year Estimates
Urban Proportion	Percentage of Project Impact Area that is in an Urban area	U.S. Census Urban Areas, 2010
Walk Proportion	Percentage of Population in Project Impact Area that Walks to work	U.S. Census ACS 5-Year Estimates
Bike Proportion	Percentage of Population in Project Impact Area that bikes to work	U.S. Census ACS 5-Year Estimates
Transit Proportion	Percentage of Population in Project Impact Area that takes transit to work	U.S. Census ACS 5-Year Estimates
TDI Max Value	Max value of Transportation Disadvantage Index observed in project impact area	NCDOT
TDI Mean Value	Max value of Transportation Disadvantage Index observed in project impact area	NCDOT
Population Proportion by TDI	Percentage of Impact Area Population located within TDI categories ranging from 6-18.	NCDOT/U.S. Census ACS 5-Year Estimates

Source: ITRE, 2023.

Calculation of Summary Statistics

The land use and demographic characteristics extracted by the GIS Web Tool represent project area estimates derived from the intersection of buffered project features, urban area features, and U.S. Census block group features. Where buffered project features only partially intersect urban area and block group features, data estimates from intersected features are weighted based on the proportion of intersected land area, i.e., "areal weighting". Total Population, Urban Proportion, and Transportation Disadvantaged Index (TDI) Mean Value are directly calculated by areal weighting of partial features. The remaining summary outputs (Walk, Bike, and Transit Proportion and Population Proportion by TDI) apply areal weighting to population counts (rather than percentages) prior to calculating impact area summary statistics. This procedure ensures that these outputs account for varying population densities across the project impact area. The TDI

Max Value includes no areal weighting and reports the highest observed TDI value in any block group intersecting the project buffer.

Description of Data Sources
Data used in the GIS Web Tool are sourced from publicly-available sources that ensure statewide coverage and regular update frequency. The sources are as follows:

U.S. Census American Community Survey 5-Year Estimates. Population and means of transportation work data are sourced from the U.S. ACS 5-Year estimates at the block group level. The ACS 5-year estimates reflect a running average of sample data collected in a 5-year period. This data is released annually for the 5-year period ending one year prior. In addition to the basic demographic information captured in the Decennial Census, the ACS provides numerous tables related to a variety of social, economic, transportation, and housing characteristics. The GIS Web Tool uses ACS 5-Year estimates for the period of 2016-2020 for the variables presented in Table 6.

Table 6: Summary of ACS Variables Used within the GIS Web Tool

Output	ACS Table	ACS Variable
Total Population	B01003: Total Population	B01003001
Walk Proportion	B08301: Means of Transportation to Work (Workers 16 years and over)	B08301019
Bike Proportion		B08301018
Transit Proportion		B08301010

U.S. Census Urban Areas. Concurrently with the Decennial Census, the U.S. Census Bureau defines urban areas. Areas outside of urban areas are considered rural areas. This research employs the 2010 Urban Areas classification to designate urban and rural areas for the purposes of project impact area summary statistics. Areas classified by the U.S. Census as either Urbanized Areas or Urban Clusters are considered "urban" while all other areas are considered "rural". In the 2010 definition, the Census Bureau employed population density thresholds and regional economic linkages to define these urban areas.

Transportation Disadvantage Index. The Transportation Disadvantage Index (TDI) developed by NCDOT's Integrated Mobility Division is an index constructed from six variables available in the U.S. Census American Community Survey (ACS). Each variable represents a unique category for analyzing issues of transportation equity, mobility, and accessibility. The TDI is constructed at the block group level. The values for individual block groups can be formulated relative to a variety of geographies, including the county, division, or state level. This research project includes TDI values formulated relative to the division, such that each division contains areas of highest (18) and lowest (6) disadvantage.

Figure 2: Illustrative Image of the GIS Web Tool

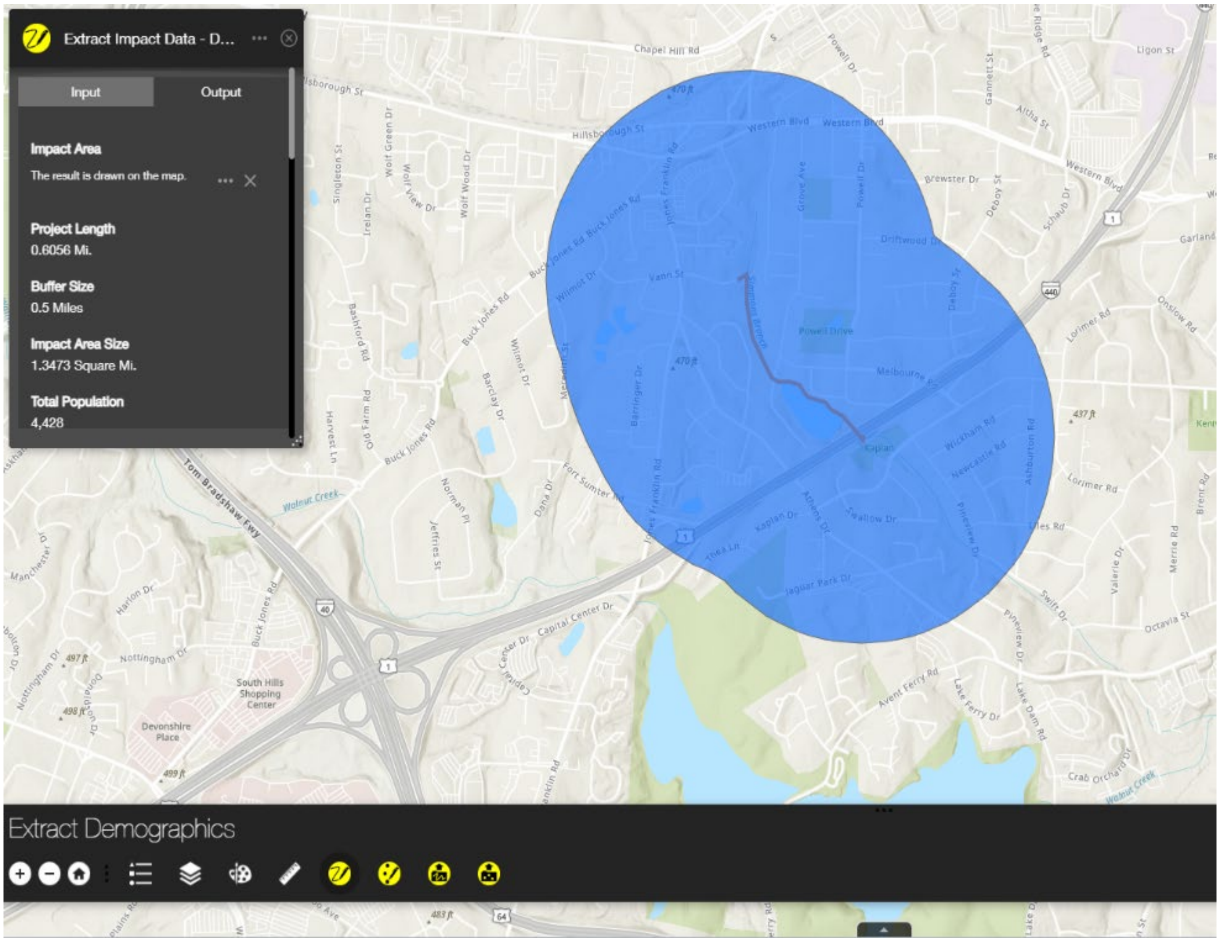


Figure 2 shows a snapshot of the GIS Web Tool, while a detailed guide on how to use the tool is in Appendix C. A full description of the methodology, including an explanation of the data, equations, and the BCA framework used to evaluate physical health, air quality, and equity is available in the “RP: 2022-17 Task 3: Interim Deliverable” in Appendix B.

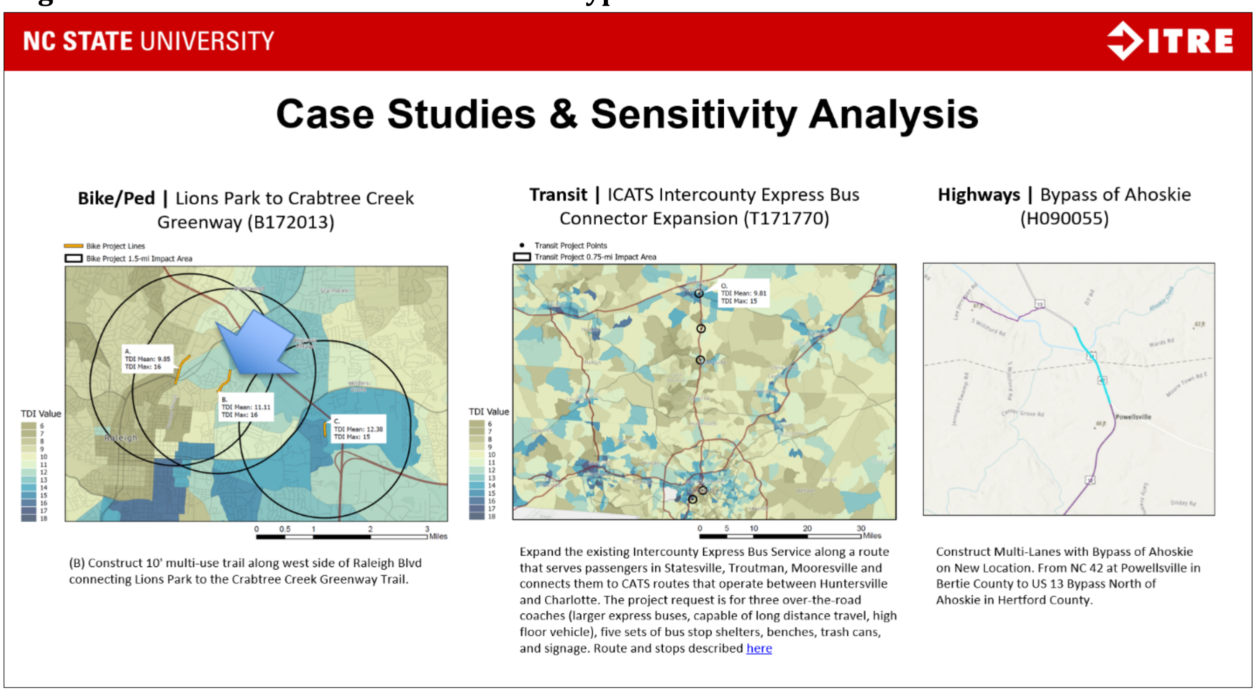
Hypothetical Prioritization Scenarios and Sensitivity Testing

Using the data acquired and the methodologies developed throughout the research, three hypothetical scenarios were tested to quantify the physical health, air quality, and equity impacts resulting from projects within the North Carolina project prioritization process.

Case Studies (Prioritization Scenarios)

The research team selected three projects from the NCDOT Prioritization 5.0 cycle with the objective of testing three projects involving different transportation modes in both urban and non-urban geographies. These case studies included a bike/ped project (Lions Park to Crabtree Creek Greenway; B172013), a bus project (CATS Intercounty Express Bus Connector Expansion; T171770), and a highways project (Bypass of Ahoskie, H090055). These projects, as shown in Figure 3, were discussed with NCDOT project leadership and then evaluated to test the physical health, air quality, and equity benefits and costs calculated using the methodology developed through this research. The three case study analyses and their results is in the "Results" section on page 30.

Figure 3: Three Case Studies Selected for Hypothetical Prioritization Scenarios



Source: ITRE, 2023.

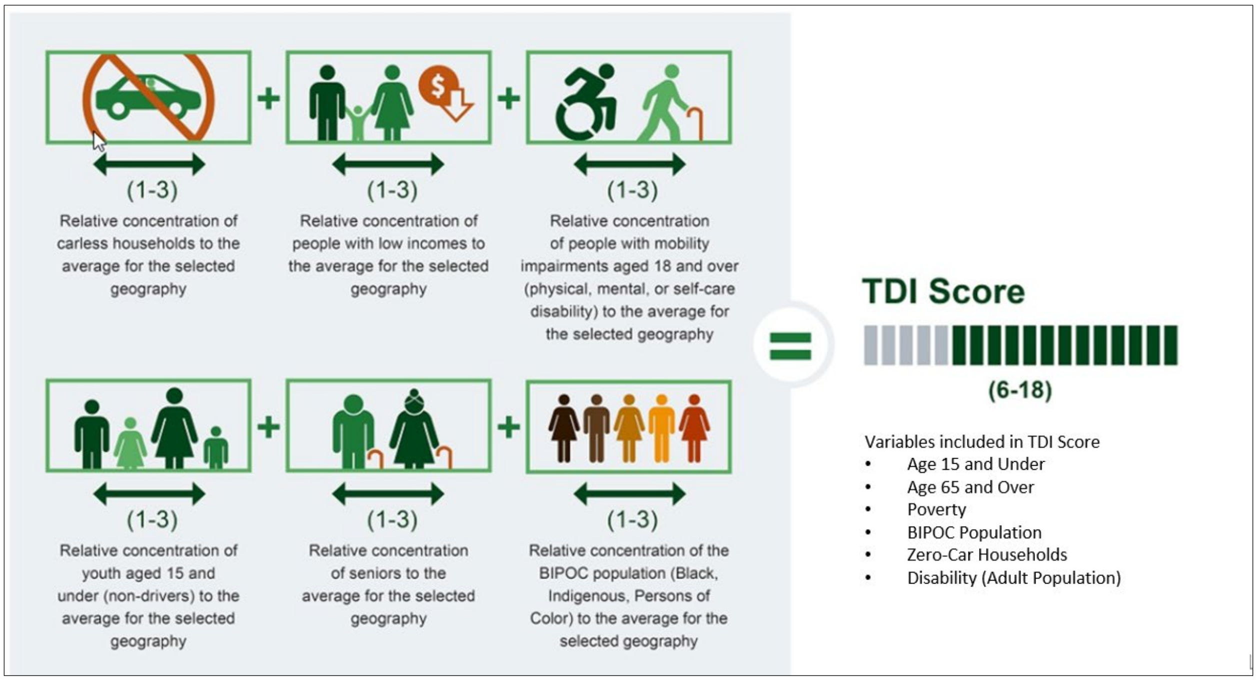
When considering the equity implications of prospective transportation projects, it is important to quantify how the benefits or costs of the project are distributed. In other words to address "*Who experiences the benefits or burdens resulting from a transportation project?*" For this research effort, the distributional impacts of physical health and air quality benefits or costs are evaluated. Though outside the scope of this research, several other benefits and costs associated with transportation projects could also be evaluated for impact on communities.

Distributional Impacts on Communities

NCDOT developed a Transportation Disadvantage IndexT DI (TDI) score that can be applied using census data (see Figure 4). There are six variables incorporated into the index including:

- Age 15 and Under
- Age 65 and Over
- Poverty
- BIPOC (Black, Indigenous, People of Color) Population
- Zero-Car Households
- Disability (Adult Population)

Figure 4: Using a Transportation Disadvantaged Index to Evaluate Equity



Source: NCDOT, 2021.

Each variable can receive a score of 1 to 3, depending on its relative concentration in a selected geography. A score of one indicates a low concentration and a score of three indicates a high concentration. Thus, when a certain geographic area is scored, it can receive a minimum score of six (denoting the lowest concentrations of all six TDI population variables within that area) and a maximum score of 18 (denoting the highest concentrations of TDI population variables within that area).

NCDOT's TDI variables and scoring were integrated into this research and used to assess how prospective transportation projects would impact equity. For example, if a project were implemented in an area that had a mean TDI score of 18, physical health and air quality benefits or costs would be distributed to populations exhibiting the highest concentration of transportation disadvantaged. Meanwhile, if a project were implemented in an area that had a TDI score of 6, its benefits and costs would be distributed to a population with the lowest concentration of transportation disadvantage.

In addition to the overall TDI score for the transportation project area, the relative concentrations of TDI populations are enumerated by each grouping. TDI scores are reported within the GIS Web Tool and used for evaluating the extent to which physical health and air quality benefits are distributed to TDI populations within a prospective transportation project area. As shown by a hypothetical project example in Table 7, the max TDI score in the project area is 17, the mean score is approximately 14.5, and the distribution of project benefits or costs would be distributed to TDI population groupings 6 - 18 with the following allocations: TDI group 10 - 0.8 percent, TDI grouping 12 - 3 percent, TDI grouping 14 - 18 percent, TDI grouping 15 - 68.3 percent, and TDI grouping 17 - 9.9 percent. If benefits were to accrue from this hypothetical project, it would likely be viewed as meeting equity objectives, because 99.2 percent of the benefits would be distributed to TDI populations with moderate (TDI ≥ 12) or high levels of transportation disadvantage.

Table 7: TDI Output Values

Output	Value
TDI Max Value	17
TDI Mean Value	14.5008
Population Proportion by TDI: 6	0
Population Proportion by TDI: 7	0
Population Proportion by TDI: 8	0
Population Proportion by TDI: 9	0
Population Proportion by TDI: 10	0.008
Population Proportion by TDI: 11	0
Population Proportion by TDI: 12	0.03
Population Proportion by TDI: 13	0
Population Proportion by TDI: 14	0.18
Population Proportion by TDI: 15	0.683
Population Proportion by TDI: 16	0
Population Proportion by TDI: 17	0.099
Population Proportion by TDI: 18	0

Source: ITRE, 2023.

When considering equity implications, it is important to know which communities are living within the project area. To be in alignment with the federal Justice40 Initiative[4], at least 40 percent of the benefits that result from a transportation project should accrue within communities that have been historically disadvantaged (TDI ≥ 12). Conversely, if a project were to result in societal costs, it is important to mitigate any disparate impacts or disproportionate burdens to those communities. To be in alignment with the Justice40 Initiative, no more than 40 percent of the burdens that result from a transportation project should accrue within communities that have been historically disadvantaged (TDI ≥ 12).

Sensitivity Testing

Sensitivity testing, also known as sensitivity analysis, is a technique used to evaluate the impact of changes in input variables on the output or outcome of a model, simulation, or system. It helps in understanding how sensitive the output is to variations or uncertainties in the input parameters. Sensitivity analysis is a valuable tool for decision-making and risk management, allowing stakeholders to assess the robustness and reliability of models and predictions. It provides

[4] USDOT. 2023. "Justice40 Initiative." Online: https://www.transportation.gov/sites/dot.gov/files/2023-05/Justice40%20Fact%20Sheetupdated.pdf

insights into the relationships between input variables and the resulting output, helping decision-makers understand the potential risks and uncertainties associated with their decisions.

For this research effort, a sensitivity analysis was conducted using the OVAT method (one-variable-at-a-time). Following this analysis method, the research team systematically varied the input variables and observed the corresponding changes in output. The purpose was to understand how any changes in the asserted values extracted from the literature affected physical health or air quality outcomes. The full sensitivity analysis is available in Appendix D.

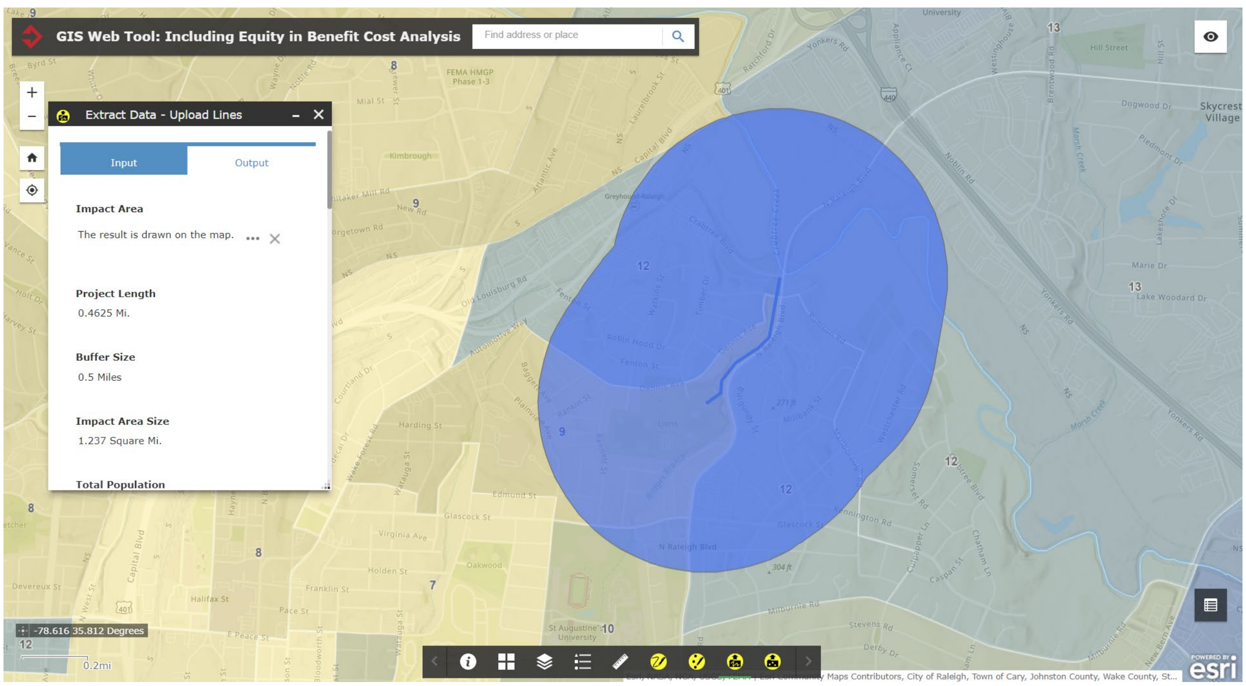
Results

As a primary component of this research, three case studies were conducted to evaluate the physical health, air quality, and equity impacts associated with a prospective transportation project. The research team selected three projects from the NCDOT Prioritization 5.0 cycle with the objective to test three different transportation modes of both urban and non-urban geographies. These case studiesies included a bike/ped project (Lions Park to Crabtree Creek Greenway; B172013), a bus project (CATS Intercounty Express Bus Connector Expansion; T171770), and a highways project (Bypass of Ahoskie, H090055).

Case Study: Bike//Ped | Lions Creek to Crabtree Creek Greenway (B172013)

This case study, shown in Figure 5, evaluates the physical health, air quality, and equity effects stemming from the construction of a 10' multi-use trail along the west side of Raleigh Blvd connecting Lions Park to the Crabtree Creek Greenway Trail. This project was included within the cohort of projects within the NCDOT Prioritization 5.0 cycle project selections. The primary purpose of this project is to improve the safety and connectivity of the bike/ped network.

Figure 5: Bicycle and Pedestrian Case Study Demonstration



Source: ITRE, 2023.

GIS Web Tool Project Rendering Method: For this analysis, a shapefile of Project B172013 – Lions Park to Crabtree Creek Greenway was uploaded directly into the GIS Web Tool. If preferred, the trail alignment could have been drawn directly in the tool.

GIS Web Tool Analysis: Physical health, air quality, and equity impacts assessed within the 0.5-mile project areas of the Lions Creek to Crabtree Creek Greenway alignment. As shown in Table 8, the GIS Web Tool produces a number of key outputs that are used to derive the benefits or costs associated with this project.

Workbook Tool Analysis: Outputs from the GIS Web Tool are used as key inputs into the Workbook Tool. As demonstrated in Figure 6, the Web Tool outputs are used as inputs for the green tables within the Workbook Tool, and these cells are then used to estimate the physical health, air quality, and equity impacts stemming from the project. Based on the information provided for this prospective project, it was assumed it will connect into a trail system spanning more than two miles and would directly impact people living within 0.5 miles of the trail (trail project area).

Table 8: Bike/Ped Case Study GIS Web Tool Outputs

Output	Value
Project Length	0.4625 Mi.
Buffer Size	0.5 Miles
Impact Area Size	1.237 Square Mi.
Total Population	3,567
Urban Proportion	1.0
Walk Proportion	0.0223
Bike Proportion	0.0001
Transit Proportion	0.0541
TDI Max Value	13
TDI Mean Value	11.5217
Population Proportion by TDI: 6	0
Population Proportion by TDI: 7	0
Population Proportion by TDI: 8	0
Population Proportion by TDI: 9	0.278
Population Proportion by TDI: 10	0.037
Population Proportion by TDI: 11	0
Population Proportion by TDI: 12	0.588
Population Proportion by TDI: 13	0.097
Population Proportion by TDI: 14	0
Population Proportion by TDI: 15	0
Population Proportion by TDI: 16	0
Population Proportion by TDI: 17	0
Population Proportion by TDI: 18	0

Source: ITRE, 2023.

Analysis Results: If it were constructed, the Lions Creek to Crabtree Creek Greenway (B172013) is estimated to generate ***a total annual benefit of $360,872*** in physical health and air quality improvements to the project area (see Table 9). Most of this benefit is projected to stem from the additional 33,851 walk trips and 16,925 cycle trips equating to an annual estimated physical health benefit of $346,463). In addition to physical health benefits, air quality benefits are estimated to total $14,408. These benefits are associated with reductions in carbon emissions as people shift from driving to active transportation via walk or bicycle travel.

Equity Considerations: When considering the equity implications of Lions Creek to Crabtree CrGreenwaynway, it is important to quantify how the benefits or costs of the project are distributed. For example, those living within proximity to the greenway are projected to experience the vast majority of the physical health benefits, while those living outside of the project area are anticipated to receive no benefits or minimal benefits. Due to the diffusive nature of vehicular emissions and their associated air quality impacts, it is more challenging to pinpoint precisely where benefits will accrue from mode shift. However, this analysis provides a starting place to anticipate where the greatest share of emissions benefits and costs are likely.

Summary: Analysis findings demonstrate that $247,197 (68.5 percent) of the $360,872 in estimated physical health and air quality benefits would accrue within communities with moderate to high levels of transportation disadvantage (TDI score ≥ 12) and 31.5 percent of the benefits would accrue within communities with moderate to low levels of transportation disadvantage (TDI score < 12, see Table 10).

Figure 6: Workbook Tool Inputs & Outputs for Tabulating the Prospective Greenway's Impacts

Bike/Ped Model - Physical Health and Air Quality (back to tool navigation)

INSTRUCTIONS

STEP 1: Open the "Extract Demographics" ArcGIS tool available online
STEP 2: Draw the proposed bike/ped investment and run the GIS tool
STEP 3: Paste the GIS outputs into Table 1
STEP 4: Complete Table 2: Proposed Facility Characteristics

Visit the GIS Tool Online Click Here

Link: https://ags.coverlab.org/portal/apps/webappviewer/index.html?id=1df1506ba23b4b378953fb49414d4aa9

Table 1: Extract Demographics Tool Output Values

Parameter	GIS Tool Output Values
Impact Area Size (Square Miles)	1.237
Project Area Population	3,567
Walk Proportion	0.0223
Bike Proportion	0.0001
Transit Proportion	0.0541

Clear Values

Table 2: Proposed Facility Characteristics

Parameter	Value
Proposed Facility Length*	(C) Greater than 2.0 miles

Clear Values

*Applies to standalone facilty length + length of connected facilities that meet NACTO residential or city width sidewalk standards

Table 3: Physical Health Output

Summary Statistic	Summary Values
Project Area Population	3,567
Pedestrians Effected	80
Cyclists Effected	0

Summary Statistic	Existing Conditions (Base Case)	Proposed Conditions (Build Case)	Net Difference
Physically Active Pedestrians	80	115	36
Physically Active Cyclists	0	18	18
Daily Walk Trips	207	300	93
Daily Cycle Trips	1	47	46
Annual Walk Trips	75,487	109,338	33,851
Annual Cycle Trips	339	17,264	16,925
Annual Appraised Physical Health Benefit	**$536,586**	**$883,050**	**$346,463**

Table 4: Air Quality Output

Summary Statistic	Existing Conditions (Base Case)	Proposed Conditions (Build Case)	Net Difference
Annual Vehicle Trips	3,126,124	3,075,348	-50,776
Annual Transit Trips	183,133	183,133	0
Annual Walk or Bike Trips	75,826	126,602	50,776
Kg Carbon Equivalent (CO2e)	17,386,152	17,109,066	-277,086
Annual Appraised Emissions Cost	**$904,080**	**$889,671**	**($14,408)**

Net AQ Benefit
$14,408

Source: ITRE, 2023.

Table 9: Net Difference in Physical Health and Air Quality Metrics from Base to Build Case Scenarios

Category	Value
Project Area Population	3,567
Walk Proportion	0.0223
Bike Proportion	0.0001
Transit Proportion	0.0541
Urban Proportion	1.0000
Proposed Facility Length*	(C) Greater than 2.0 miles
Physical Health Analysis	
Physically Active Pedestrians	36
Physically Active Cyclists	18
Daily Walk Trips	93
Daily Cycle Trips	46
Annual Walk Trips	33,851
Annual Cycle Trips	16,925
Physical Health Benefit	**$346,463**
Air Quality Analysis	
Annual Vehicle Trips	-50,776
Annual Transit Trips	0
Annual Walk or Bike Trips	50,776
Kg Carbon Equivalent (CO2e)	-277,086
Air Quality Benefit	**$14,408**
Total Benefits	**$360,872**

Source: ITRE, 2023.

Table 10: Distribution of Physical Health and Air Quality Benefits Among TDI Populations

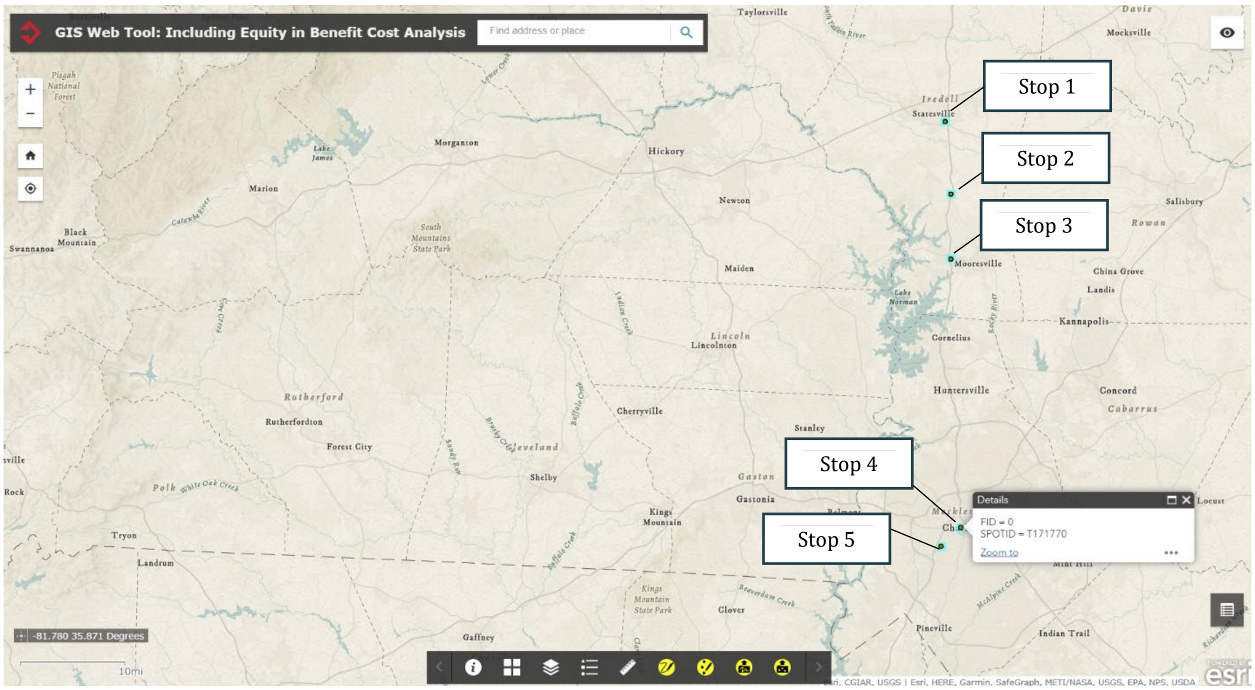
TDI Level	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
Net Physical Health Benefit	$0	$0	$0	$96,317	$12,819	$0	$203,720	$33,607	$0	$0	$0	$0	$0	$346,463
Net Air Quality Benefit	$0	$0	$0	$4,006	$533	$0	$8,472	$1,398	$0	$0	$0	$0	$0	$14,408
Total Benefit	$0	$0	$0	$100,322	$13,352	$0	$212,193	$35,005	$0	$0	$0	$0	$0	$360,872

Source: ITRE, 2023.

Case Study: CATS Intercounty Express Bus Connector Expansion (T171770)

This project, shown in Figure 7, involves the expansion of the existing Intercounty Express Bus Service along a route that serves passengers in Statesville, Troutman, Mooresville and connects them to CATS routes that operate between Huntersville and Charlotte. The project request involves five sets of bus stop shelters.

Figure 7: Public Transportation Case Study Demonstration



Source: ITRE, 2023.

GIS Web Tool Project Rendering Method: Each bus stop that was part of the proposed project was uploaded as an individual point layer shapefile and evaluated with the GIS Web ToolWT. A total of five shapefiles were uploaded and evaluated.

GIS Web Tool Analysis: Physical health, air quality, and equity impacts assessed within the 0.5-mile project areas for each of the five bus stops. As shown in Table 11, the GIS Web Tool produces a number of key outputs that are used to derive the benefits or costs associated with a prospective project.

Workbook Tool Analysis: Outputs from the GIS Web Tool are used as key inputs for the Workbook Tool. As demonstrated in Figure 8, the Web Tool outputs are used as inputs into the green tables, and these cells are then used to estimate the physical health, air quality, and equity impacts stemming from the project. For this analysis, it was assumed that each new bus stop would serve 20 frequencies per day. In actuality, the project applicant would provide the number of bus stops and bus frequencies associated with the proposed project, while all other inputs would come from the GIS Web Tool.

Table 11: Public Transportation Case Study GIS Web Tool Outputs

Output	Stop 1	Stop 2	Stop 3	Stop 4	Stop 5
Buffer Size	0.5 Miles	0.5 Miles	0.5 Miles	0.5 Miles	0.5 Miles
Impact Area Size (Square Mi.)	0.7854	0.7854	0.7854	0.7854	0.7854
Total Population	1,007	364	894	4,317	2,958
Urban Proportion	1.0	0.0069	1.0	1.0	1.0
Walk Proportion	0.0087	0.1444	0.0001	0.3065	0.0149
Bike Proportion	0.0001	0.0001	0.0001	0.0019	0.0031
Transit Proportion	0.0001	0.0001	0.0135	0.0323	0.133
TDI Max Value	15	11	13	13	15
TDI Mean Value	13.16	9.4982	10.2904	8.6451	10.8902
Population Proportion by TDI: 6	0	0	0	0.093	0
Population Proportion by TDI: 7	0	0.151	0.306	0.174	0.538
Population Proportion by TDI: 8	0	0	0	0.418	0
Population Proportion by TDI: 9	0	0	0	0.163	0.245
Population Proportion by TDI: 10	0	0.519	0.13	0.013	0.002
Population Proportion by TDI: 11	0.557	0.33	0	0	0
Population Proportion by TDI: 12	0.005	0	0.036	0.016	0
Population Proportion by TDI: 13	0	0	0.528	0.123	0
Population Proportion by TDI: 14	0.285	0	0	0	0
Population Proportion by TDI: 15	0.153	0	0	0	0.215
Population Proportion by TDI: 16	0	0	0	0	0
Population Proportion by TDI: 17	0	0	0	0	0
Population Proportion by TDI: 18	0	0	0	0	0

Source: ITRE, 2023.

Analysis Results: If constructed, the CATS Intercounty Express Bus Connector Expansion (T171770) is estimated to generate ***a total annual benefit of $769,641*** in physical health and air quality improvements to the project area (see Table 12). Most of this benefit is projected to stem from the 104,548 bus trips that would have a walk component or the 1,208 bus trips that would have a cycling component as people travel to and from the bus stop (estimated physical health benefit of $747,825 annually). It is important to note that an estimated 8,500 transit trips would have a drive component involved, which are assumed to facilitate no physical health benefits. In addition to physical health benefits, air quality benefits are estimated to be $21,817. These benefits are associated with reductions in carbon emissions as people shift from driving to bus travel. Of the 114,257 new transit trips estimated to be made with the project, 105,756 are projected to come from people who either walk or bike to a bus stop, while 8,500 trips are anticipated to stem from people driving to or from a bus stop (see Table 12).

Equity Considerations: When considering equity implications of the expansion (T171770), it is important to be able to quantify how the benefits or costs of the project are distributed. For example, those living within proximity to the project's five bus stops are projected to experience the vast majority of the physical health benefits, while those living outside of the project area are anticipated to receive no benefits or minimal benefits. Due to the diffusive nature of vehicular emissions and their associated air quality impacts, it is more challenging to pinpoint precisely where emissions costs or benefits will accrue. However, this analysis provides a starting place to anticipate where the greatest share of emissions benefits and costs are likely to accrue.

Summary: Analysis findings demonstrate that $325,238 (42.3 percent) of the $769,641 in estimated physical health and air quality benefits would accrue within communities with moderate to high levels of transportation disadvantage (TDI grouping 11-15) and 57.7 percent of the benefits ($444,402) would accrue within communities with moderate to low levels of transportation disadvantage (TDI groupings 6-10; see Table 13).

Figure 8: Workbook Tool Inputs & Outputs for Tabulating the Effects of a Proposed Bus Stop

Bus Model - ***New Bus Stop*** - **Physical Health and Air Quality** (back to tool navigation)

INSTRUCTIONS

STEP 1: Open the "Extract Demographics" ArcGIS tool available online
STEP 2: Draw the proposed stop and run the GIS tool
STEP 3: Enter the GIS outputs into Table 1

Visit the GIS Tool Online Click Here

Link: https://ags.coverlab.org/portal/apps/webappviewer/index.html?id=1df1506ba23b4b378953fb49414d

Table 1: Extract Demographics Tool Output Values

Parameter	GIS Tool Output Values
Impact Area Size (Square Miles)	0.7854
Project Area Population	2,958
Walk Proportion	0.0149
Bike Proportion	0.0031
Transit Proportion	0.1330
Urban Proportion	1.0000

Clear Values

Table 2: Bus Frequency Parameter

Parameter	Summary Values
Number of New Bus Stops in Project	1
New Frequencies per Stop (Number of Daily Boardings)	20

Clear Value

Table 3: Physical Health Output

Summary Statistic	Summary Values
Project Area Population	2,958
Transit Users	393
Drive to Transit	29
Walk to Transit	360
Cycle to Transit	4
Urban Percentage	100%

Summary Statistic	Existing Conditions (Base Case)	Proposed Conditions (Build Case)	Net Difference
Daily Transit Trips	1,023	1,097	74
Daily Transit Trips	**1,023**	**1,097**	**74**
Daily Drive to Transit Trips	76	82	6
Daily Walk to Transit Trips	936	1,004	68
Daily Bike to Transit Trips	11	12	1
Annual Transit Trips	**373,350**	**400,420**	**27,070**
Annual Drive to Transit Trips	27,776	29,790	2,014
Annual Walk to Transit Trips	341,626	366,395	24,770
Annual Bike to Transit Trips	3,948	4,234	286
Annual Appraised Physical Health Benefit (walking/biking to and from transit)	**$2,443,622**	**$2,620,798**	**$177,176**

Table 4: Air Quality Output

Summary Statistic	Existing Conditions (Base Case)	Proposed Conditions (Build Case)	Net Difference
Annual Vehicle Trips	2,383,264	2,356,194	-27,070
Annual Transit Trips	373,350	400,420	27,070
Annual Bus Trips (Resulting from Project)		27,070	27,070
Kg Carbon Equivalent (CO2e)	13,671,899	13,619,871	-52,028
Annual Appraised Emissions Cost	**$710,939**	**$708,233**	**($2,705)**

Net AQ Benefit
$2,705

Source: ITRE, 2023.

Table 12: Net Difference in Physical Health and Air Quality Metrics from Base to Build Case Scenarios

Category	Stop 1	Stop 2	Stop 3	Stop 4	Stop 5	Total
Project Area Population	1,007	364	894	4,317	2,958	9,540
Walk Proportion	0.870%	14.440%	0.010%	30.65%	1.49%	
Bike Proportion	0.010%	0.010%	0.010%	0.19%	0.31%	
Transit Proportion	0.010%	0.010%	1.350%	3.23%	13.30%	
Urban Proportion	100%	0.690%	100.000%	100%	100%	
Physical Health Analysis						
Daily Transit Trips	59	42	58	80	74	313
Daily Drive to Transit Trips	4	3	4	6	6	23
Daily Walk to Transit Trips	54	39	53	73	68	286
Daily Bike to Transit Trips	1	0	1	1	1	3
Annual Transit Trips	21,436	15,458	21,024	29,268	27,070	114,256
Annual Drive to Transit Trips	1,595	1,150	1,564	2,177	2,014	8,500
Annual Walk to Transit Trips	19,615	14,145	19,237	26,781	24,770	104,548
Annual Bike to Transit Trips	227	163	222	310	286	1,208
Physical Health Benefit	**$140,301**	**$101,179**	**$137,603**	**$191,565**	**$177,176**	**$747,825**
Air Quality Analysis						
Annual Vehicle Trips	-21,436	-15,459	-21,024	-29,268	-27,070	-114,257
Annual Transit Trips	21,436	15,459	21,024	29,268	27,070	114,257
Annual Bus Trips (Resulting from Project)	21,436	15,459	21,024	29,268	27,070	114,257
Kg Carbon Equivalent (CO2e)	-78,713	-56,764	-77,199	-107,474	-99,400	-419,551
Air Quality Benefit	**$4,093**	**$2,952**	**$4,014**	**$5,589**	**$5,169**	**$21,817**
Total Benefits	**$144,395**	**$104,131**	**$141,618**	**$197,154**	**$182,344**	**$769,641**

Source: ITRE, 2023.

Table 13: Distribution of Physical Health and Air Quality Benefits Among TDI Populations at Each of the Five Proposed Bus Stops

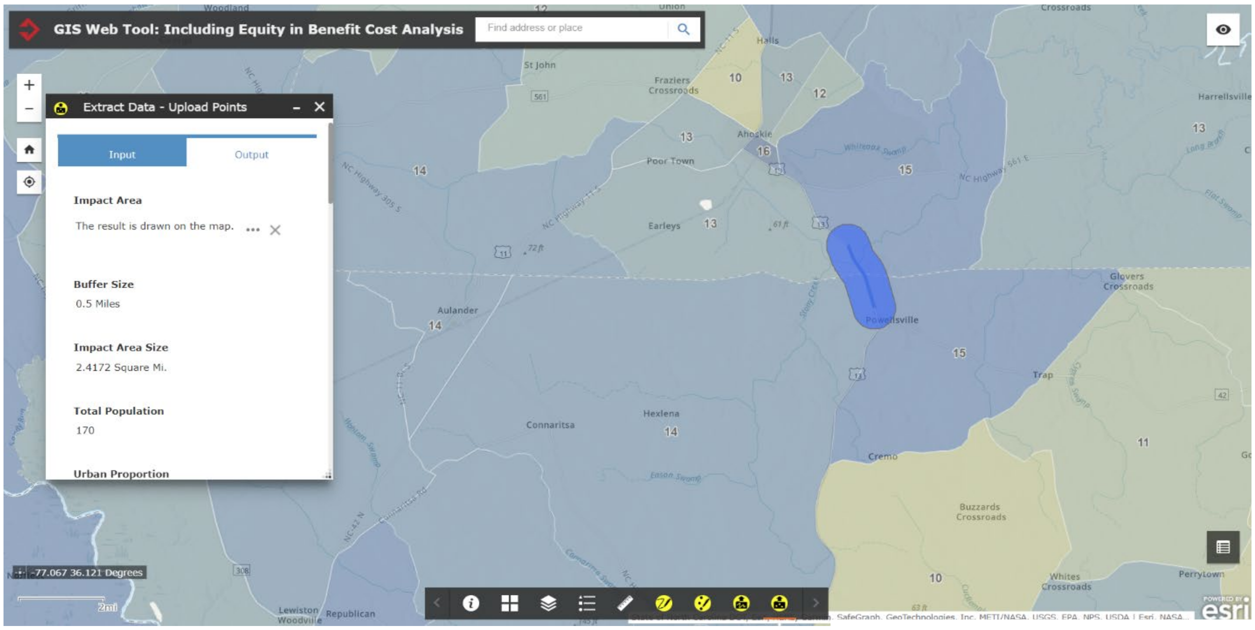
TDI Level	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
S1_PH	$0	$0	$0	$0	$0	$78,148	$702	$0	$39,986	$21,466	$0	$0	$0	$140,301
S1_AQ	$0	$0	$0	$0	$0	$2,280	$20	$0	$1,167	$626	$0	$0	$0	$4,093
S1_Total	$0	$0	$0	$0	$0	$80,428	$722	$0	$41,152	$22,092	$0	$0	$0	$144,395
S2_PH	$0	$15,278	$0	$0	$52,512	$33,389	$0	$0	$0	$0	$0	$0	$0	$101,179
S2_AQ	$0	$446	$0	$0	$1,532	$974	$0	$0	$0	$0	$0	$0	$0	$2,952
S2_Total	$0	$15,724	$0	$0	$54,044	$34,363	$0	$0	$0	$0	$0	$0	$0	$104,131
S3_PH	$0	$42,107	$0	$0	$17,888	$0	$4,954	$72,655	$0	$0	$0	$0	$0	$137,603
S3_AQ	$0	$1,228	$0	$0	$522	$0	$145	$2,120	$0	$0	$0	$0	$0	$4,014
S3_Total	$0	$43,335	$0	$0	$18,410	$0	$5,098	$74,774	$0	$0	$0	$0	$0	$141,618
S4_PH	$17,816	$33,332	$80,074	$31,225	$2,490	$0	$3,065	$23,563	$0	$0	$0	$0	$0	$191,565
S4_AQ	$520	$972	$2,336	$911	$73	$0	$89	$687	$0	$0	$0	$0	$0	$5,589
S4_Total	$18,335	$34,305	$82,410	$32,136	$2,563	$0	$3,154	$24,250	$0	$0	$0	$0	$0	$197,154
S5_PH	$0	$95,320	$0	$43,408	$354	$0	$0	$0	$0	$38,093	$0	$0	$0	$177,176
S5_AQ	$0	$2,781	$0	$1,266	$10	$0	$0	$0	$0	$1,111	$0	$0	$0	$5,169
S5_Total	$0	$98,101	$0	$44,674	$365	$0	$0	$0	$0	$39,204	$0	$0	$0	$182,344
Totals	**$18,335**	**$191,465**	**$82,410**	**$76,810**	**$75,382**	**$114,791**	**$8,975**	**$99,024**	**$41,152**	**$61,296**	**$0**	**$0**	**$0**	**$769,641**

Source: ITRE, 2023.

Case Study: Bypass of Ahoskie (H090055)

This case study, shown in Figure 9, evaluates the physical health, air quality, and equity effects stemming from the construction of a multi-lane bypass of Ahoskie in a new location. The bypass would be located from NC 42 at Powellsville in Bertie County to US 13 Bypass North of Ahoskie in Hertford County.

Figure 9: Highway Case Study Demonstration



Source: ITRE, 2023.

GIS Web Tool Project Rendering Method: For this analysis, a shapefile of Project H090055 was uploaded directly into the GIS Web Tool. If preferred, the trail alignment could have been drawn directly in the tool.

GIS Web Tool Analysis: Physical health, air quality, and equity impacts were assessed within the 0.5-mile project areas of the Ahoskie bypass alignment. As shown in Table 14, the GIS Web Tool produces a number of key outputs that are used to derive the benefits or costs associated with this project.

Workbook Tool Analysis: Outputs from the GIS Web Tool are used as key inputs into the Workbook Tool. As demonstrated in Table 14, the Web Tool outputs are used as inputs for the green tables within the Workbook Tool, and these cells are then used to estimate the physical health impacts stemming from the project. To estimate changes in air quality, the research team adapted the California Induced Travel Calculator's methodology to North Carolina's

Table 14: Highway Case Study GIS Web Tool Outputs

Output	Value
Project Length (Miles)	1.6326
Buffer Size (Square Miles)	0.5
Impact Area Size (Miles)	2.4172
Total Population	170
Urban Proportion	0
Walk Proportion	0.0269
Bike Proportion	0.0001
Transit Proportion	0.0044
TDI Max	15
TDI Median	14.3289
TDI 6	0
TDI 7	0
TDI 8	0
TDI 9	0
TDI 10	0
TDI 11	0
TDI 12	0
TDI 13	0.3
TDI 14	0.082
TDI 15	0.618
TDI 16	0
TDI 17	0
TDI 18	0

Source: ITRE, 2023.

roadway network (see Appendix B for a full description of this method). A self-contained highway air quality module is available within the Workbook Tool and is shown in Figure 11. Taken altogether, the physical health and air quality impacts are then distributed among TDI populations within the project area to derive equity impacts stemming from the project (see Table 15).

Figure 10: Workbook Tool Inputs & Outputs for Tabulating the Effects of a Proposed Highway

HIGHWAYS MODEL - Physical Health (back to tool navigation)

INSTRUCTIONS

STEP 1: Open the "Extract Demographics" ArcGIS tool available online
STEP 2: Draw the proposed highway investment and run the GIS tool
STEP 3: Paste the GIS outputs into Table 1
STEP 4: Complete Table 2: Existing & Proposed Highway Characteristics

Visit the GIS Tool Online Click Here

Link: https://ags.coverlab.org/portal/apps/webappviewer/index.html?id=1df1506ba23b4b378953fb49414d4aa9

Table 1: Extract Demographics Tool Output Values

Parameter	GIS Tool Output Values
Project Area Population	170
Walk Proportion	0.027
Bike Proportion	0.0001
Transit Proportion	0.004

Source: Extract Demographics Tool Output

Clear Values

Table 2: Existing & Proposed Highway Characteristics

Parameter	Existing Conditions (Base Case)	Proposed Conditions (Build Case)
Average Posted Speed Limit	N/A	40+ mph
Sidewalks adjacent to highway facility	No sidewalk	No sidewalk
Sidewalk Width Selection (Street Side 1; if applicable)	N/A	N/A
Sidewalk Width Selection (Street Side 2; if applicable)	N/A	N/A

Source: STI Project Applicant

Clear Values

Table 3: Physical Health Output

Summary Statistic	Summary Values
Project Area Population	170
Pedestrians Effected	5
Cyclists Effected	0

Summary Statistic	Existing Conditions (Base Case)	Proposed Conditions (Build Case)	Net Difference
Physically Active Pedestrians	5	4	0
Physically Active Cyclists	0	0	0
Daily Walk Trips	12	12	0
Daily Cycle Trips	0	0	0
Annual Walk Trips	4,340	4,231	-108
Annual Cycle Trips	16	16	0
Annual Appraised Physical Health Benefit	**$30,827**	**$30,057**	**-$771**

Source: ITRE, 2023.

When conducting the air quality analysis for highways, the amount of highway lane miles per county must be evaluated individually. The Ahoskie Bypass alignment spans two counties with 0.8463 lane miles in Bertie County and 0.7863 lane miles in Hertford County (lane mile values can be determined using the draw lines geoprocessing tool within the GIS Web Tool). Thus, two analyses using the air quality module are conducted and the total emissions impacts are summed to estimate the total air quality effects of the Ahoskie Bypass. Figure 11 and Figure 12 show the Bertie County analysis, while Figure 13 and Figure 14 show the Hertford County analysis within the highway air quality module in the Workbook Tool.

Figure 11: Ahoskie Bypass - Bertie County Air Quality Analysis within Highway's Module

(back to tool navigation)

Input Values

Select Facility Type	US or NC Routes (US) or (NC)
Select County	Bertie
Input total lane miles added	0.8463

Clear Values

Key Parameters

Highway Classification	Lane Miles
Interstate Lane Miles Used by Commute Cluster Into Bertie County	1.2
US or NC Route Lane Miles in Bertie County	187.9
Secondary Route Lane Miles in Bertie County	484.9
All Other Lane Miles in Bertie County	147.0

Skip to Results

Highway Classification for the Change in Lane Miles	Induced Demand Elasticity
US or NC Routes (US) or (NC)	0.75

Emissions Parameter	Value
Grams of Carbon Dioxide (CO_2) Released per Vehicle Mile[1,2]	404
Grams of Nitrous Oxide (NOx) Released per Vehicle Mile[1,2]	0.687
Grams of Particulate Matter ($PM_{2.5}$) Released per Vehicle Mile[1,2]	0.033
CO_2 Cost per metric ton (2022 USD)	$53
NOx Cost per metric ton (2022 USD)	$15,600
$PM_{2.5}$ Cost per metric ton (2022 USD)	$748,600
CO_2 Cost per gram (2022 USD)[3]	$0.000053
NOx Cost per gram (2022 USD)[3]	$0.0156
$PM_{2.5}$ Cost per gram (2022 USD)[3]	$0.7486
CO_2 Cost per Vehicle Mile (2022 USD)	$0.021
NOx Cost per Vehicle Mile (2022 USD)	$0.011
$PM_{2.5}$ Cost per Vehicle Mile (2022 USD)	$0.025
Total Emissions Cost per Vehicle Mile (2022 USD)	$0.057

Source: ITRE, 2023.

Figure 12: Ahoskie Bypass - Bertie County Air Quality Analysis (continued)

Model Output (Extended List)

Model Output	Value
New Lane Miles Added	0.8463
Percentage Change Lane Miles	0.4%
Induced Vehicle Miles Traveled	749,300
Induced Carbon Dioxide (CO_2) Emissions (grams)	302,717,200
Induced Nitrous Oxide (NOx) Emissions (grams)	514,769
Induced Particulate Matter ($PM_{2.5}$) Emissions (grams)	24,727
Induced Carbon Dioxide (CO_2) Emissions (metric tons)	302.7
Induced Nitrous Oxide (Nox) Emissions (metric tons)	0.5
Induced Particulate Matter ($PM_{2.5}$) Emissions (metric tons)	0.0
Total Emissions Cost ($2022)	$42,585

[1]Environmental Protection Agency. 2018. Greenhouse Gas Emissions from a Typical Passenger Vehicle.

[2]Bureau of Transportation Statistics. 2021. Estimated U.S. Average Vehicle Emissions Rates per Vehicle by Vehicle Type Using Gasoline and Diesel.

[3] USDOT BCA Guidance. 2022.

Model Output (Simplified)

Model Output	Value
New Lane Miles Added	0.8463
Induced Vehicle Miles Traveled	750,000
Total Emissions Cost ($2022)	$43,000

Results Summary

A project adding 0.8463 lane miles in Bertie County would induce an additional 750,000 vehicle miles travelled per year. This would generate an estimated annual emissions cost of $43,000 dollars.

This calculation is using an elasticity of 0.75.

Return to Start

Source: ITRE, 2023.

Figure 13: Ahoskie Bypass - Hertford County Air Quality Analysis within Highway's Module

(back to tool navigation)

Input Values

Select Facility Type	US or NC Routes (US) or (NC)
Select County	Hertford
Input total lane miles added	0.7863

Clear Values

Key Parameters

Highway Classification	Lane Miles
Interstate Lane Miles Used by Commute Cluster Into Hertford County	**3.2**
US or NC Route Lane Miles in Hertford County	**133.6**
Secondary Route Lane Miles in Hertford County	**327.1**
All Other Lane Miles in Hertford County	**142.4**

Skip to Results

Highway Classification for the Change in Lane Miles	Induced Demand Elasticity
US or NC Routes (US) or (NC)	**0.75**

Emissions Parameter	Value
Grams of Carbon Dioxide (CO_2) Released per Vehicle Mile[1,2]	404
Grams of Nitrous Oxide (NOx) Released per Vehicle Mile[1,2]	0.687
Grams of Particulate Matter ($PM_{2.5}$) Released per Vehicle Mile[1,2]	0.033
CO_2 Cost per metric ton (2022 USD)	$53
NOx Cost per metric ton (2022 USD)	$15,600
$PM_{2.5}$ Cost per metric ton (2022 USD)	$748,600
CO_2 Cost per gram (2022 USD)[3]	$0.000053
NOx Cost per gram (2022 USD)[3]	$0.0156
$PM_{2.5}$ Cost per gram (2022 USD)[3]	$0.7486
CO_2 Cost per Vehicle Mile (2022 USD)	$0.021
NOx Cost per Vehicle Mile (2022 USD)	$0.011
$PM_{2.5}$ Cost per Vehicle Mile (2022 USD)	$0.025
Total Emissions Cost per Vehicle Mile (2022 USD)	$0.057

Source: ITRE, 2023.

Figure 14: Ahoskie Bypass - Hertford County Air Quality Analysis (continued)

Model Output (Extended List)

Model Output	Value
New Lane Miles Added	0.7863
Percentage Change Lane Miles	0.6%
Induced Vehicle Miles Traveled	772,000
Induced Carbon Dioxide (CO_2) Emissions (grams)	311,888,000
Induced Nitrous Oxide (NOx) Emissions (grams)	530,364
Induced Particulate Matter ($PM_{2.5}$) Emissions (grams)	25,476
Induced Carbon Dioxide (CO_2) Emissions (metric tons)	311.9
Induced Nitrous Oxide (Nox) Emissions (metric tons)	0.5
Induced Particulate Matter ($PM_{2.5}$) Emissions (metric tons)	0.0
Total Emissions Cost ($2022)	$43,875

[1]Environmental Protection Agency. 2018. Greenhouse Gas Emissions from a Typical Passenger Vehicle.

[2]Bureau of Transportation Statistics. 2021. Estimated U.S. Average Vehicle Emissions Rates per Vehicle by Vehicle Type Using Gasoline and Diesel.

[3] USDOT BCA Guidance. 2022.

Model Output (Simplified)

Model Output	Value
New Lane Miles Added	0.7863
Induced Vehicle Miles Traveled	770,000
Total Emissions Cost ($2022)	$44,000

Results Summary

A project adding 0.7863 lane miles in Hertford County would induce an additional 770,000 vehicle miles travelled per year. This would generate an estimated annual emissions cost of $44,000 dollars.

This calculation is using an elasticity of 0.75.

Return to Start

Source: ITRE, 2023.

Table 15: Distribution of Physical Health and Air Quality Benefits Among TDI Populations

TDI Level	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
Net Physical Health Benefit	$0	$0	$0	$0	$0	$0	$0	-$231	-$63	-$476	$0	$0	$0	($771)
Net Air Quality Benefit	$0	$0	$0	$0	$0	$0	$0	-$25,938	-$7,090	-$53,432	$0	$0	$0	($86,460)
Total Benefit	$0	$0	$0	$0	$0	$0	$0	($26,169)	($7,153)	($53,909)	$0	$0	$0	($87,231)

Source: ITRE, 2023.

Analysis Results: If constructed, the Ahoskie Bypass (H090055) is estimated to generate a total annual social cost of $87,460 stemming from a degradation in physical health and air quality in the project area (see Table 15). The social cost is projected to stem from the 1,521,300 induced vehicular trips that the bypass is projected to create. These trips would create an estimated annual emissions cost of $86,460. In addition to air quality costs, a relatively small physical health cost would result from the project as 108 annual walking trips are anticipated to shift to driving trips within the project area.

Equity Considerations: When considering the equity implications of the Ahoskie Bypass, it is important to quantify how the benefits or costs of the project are distributed. Due to the diffusive nature of vehicular emissions and their associated air quality impacts, it is challenging to pinpoint precisely where costs will accrue from induced vehicular traffic. However, this analysis provides a starting place to anticipate where the greatest share of emissions benefits and costs are likely to accrue.

Summary: Analysis findings demonstrate that all of the $87,231 in estimated physical health and air quality costs would accrue within communities with moderate to high levels of transportation disadvantage (TDI score ≥ 12) and none of the costs would accrue within communities with moderate to low levels of transportation disadvantage (TDI score < 12, see Table 15).

Conclusions

Transportation planning and funding decisions can have significant equity impacts. However, few transportation agencies today integrate equity considerations into their transportation prioritization processes. While many practitioners and decision-makers may want to support more equitable outcomes, actually evaluating outcomes associated with transportation equity can be difficult. This research offers a quantitative approach to account for the equity implications of a transportation project through the evaluation of benefits and costs associated with physical health, air quality, and other factors.

The primary objective of this research was to develop a methodology and user-friendly tools that would enable physical health, air quality, and equity considerations to be included in North Carolina's prioritization process. To achieve this objective, the research team used a benefit-cost analysis framework in accordance with USDOT Benefit-Cost Analysis (BCA) practices to develop appraisal methodologies and user-friendly tools to model changes in physical health, air quality, and equity impacts within a prospective investment's project area. The methodology created through this study can be implemented using a Workbook Tool and a GIS Web Tool in tandem to assess the potential impacts of proposed transportation projects.

Sensitivity Analysis Results

Using the OVAT method (one-variable-at-a-time), the research team conducted a sensitivity analysis by systematically varying input variables while observing corresponding changes in physical health and air quality benefit/cost output. Findings demonstrated that the research team's asserted variables, as derived from the literature or available data sources, typically had a linear relationship with physical health and air quality benefits or costs. Additionally, the research team conducted three case studies: a bike/ped project (Lions Park to Crabtree Creek Greenway; B172013), a bus project (CATS Intercounty Express Bus Connector Expansion; T171770), and a highways project (Bypass of Ahoskie, H090055). These three projects had mixed equity implications. BasedBased on the analysis, the distribution of physical health and air quality benefits for the bicycle and pedestrian project would favor moderate to highly concentrated TDI populations (TDI score ≥ 12), benefits for the bus project would favor populations with moderate to low transportation disadvantage (TDI score ≤ 12), and the costs resulting from the highways project would be experienced solely by populations with moderate to high transportation disadvantage.

Additional Contributions

As an important dimension of this effort, the research team also conducted a literature review to assess how equity is currently being used in transportation planning. This study created the groundwork for a number of opportunities for including equity planning. In addition to providing a framework for quantifying how transportation benefits or costs are distributed among transportation disadvantaged populations, the research team led an interactive series of workshops to build a working definition of equity. The target audience of the workshops was key personnel from for the Transportation Planning Division and the Strategic Prioritization Office.

Future Research and Implementation Opportunities

This research focused on the equity impacts resulting from changes in physical health or air quality. Future research could evaluate the equity impacts stemming from other impacts such as safety, travel time savings, noise pollution, or other measures typically included in a BCA framework. Additionally, this research focused primarily on highway, bus, bus rapid transit, light rail, commuter rail, vehicle ferry, and passenger ferry modes of transportation. Changes in air quality and physical health resulting from aviation projects were not evaluated as part of this study due to the complexities of assessing impacts related to this mode. Research could be conducted in the future to assess impacts for aviation.

Ultimately, this research provided NCDOT with additional resources that could be used to assess benefits and costs related to equity as well as a robust literature review that can be referenced into the future. NCDOT could also leverage the equity definition development process and/or the equity definition to lay the groundwork for the development of an organization-wide definition.

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Appendices

Appendix A: Literature and Data Review

Appendix B: Data and Methodology Supplement

Appendix C: GIS Web Tool Users Guide

Appendix D: Sensitivity Analysis Supplement

Appendix E: Summary of the Equity Definition Development

February
2022

Including Equity in Benefit-Cost Analysis

Summary of the Literature and Data Review

ITRE

Planning Communities

STATE OF NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

Executive Summary

Transportation planning and funding decisions often have significant equity impacts; however, few transportation agencies today integrate equity considerations into their transportation prioritization processes. Most practitioners and decision-makers sincerely want to achieve equity objectives, but transportation equity can be difficult to evaluate because there are various factors such as demographics, income, ability, geographic location, and travel considerations. The purpose of this research is to develop the methodology, data sources, and implementation techniques that can be used to include select equity considerations in the benefit-cost analyses conducted within the North Carolina Department of Transportation (NCDOT) strategic prioritization processes. In addition, this research seeks to deliver a working definition of equity in transportation, which may include elements related to institutional practices, policies, investment, or decision making, and will focus on identifying the underserved communities, or communities of concern (CoC), that this research is intended to address.

To build a strong foundation of data sources and methodological techniques that could be used to integrate equity considerations into project prioritization, long-range transportation planning, and develop a definition of transportation equity, a comprehensive literature and data review has been conducted. Geospatial data and tools, benefit-cost analysis manuals and prioritization documentation, long-range transportation plans, transportation planning guidance documents, and other resources were reviewed. This document serves as a summary of findings, discussing valuable data, methods, and themes by subject area and sharing a review of each resource in the appendix. Key elements of the literature and data review summary include:

- A catalogue of best-practices and tools that can be used to integrate equity into transportation planning and project prioritization.
- A working definition of Equity for Transportation Planning.
- Data techniques for identifying Communities of Concern (CoC).
- A table of data sources used to measure and quantify air quality and physical health
- Documentation of Problem Identification and Gap Analysis from the literature review

Table of Contents

Importance of Equity in Transportation Decision-making

Transportation planning addresses current and future transportation, land use, economic development, public safety, health, and social needs (15 CFR § 170.5) and often has significant societal impacts. As transportation decisions fundamentally shape the way people interact with their environment and are able access places that support economic, social, and physical wellbeing, it is important to evaluate how transportation investment decisions impact both the intended users as well as all other individuals affected by the investment.

Currently, few transportation agencies integrate equity considerations into their transportation prioritization processes. Practitioners and decision-makers may want to achieve equity objectives, but transportation equity can be difficult to evaluate because there are various factors such as demographics, income, ability, geographic location, and travel priorities. Considering equity, or the fairness of how transportation project benefits and costs are distributed throughout society, requires an understanding of how projects affect service quality and access to places of interest (such as education, employment, healthcare, public facilities and services, etc.). It also requires evaluating how economic impacts, user benefits and costs, and externalities (such as impacts on business activity, property values, and economic development in an area; vehicle ownership and operation costs, tolls, fees, and public transportation fares; and air, noise, water pollution, congestion, and other impacts on community livability) are allocated to all members of society (Litman, 2021).

Transportation Emissions Impacts on Social Welfare

Transportation infrastructure projects can improve or deteriorate social welfare through a reduction or influx of air pollution, often stemming from the production and combustion of transportation fuels. The economic damages caused by exposure to air pollution represent externalities because their impacts are borne by society as a whole, rather than by the travelers and operators whose activities generate those emissions (USDOT, 2021). Transportation projects that reduce overall fuel consumption, either due to improved fuel economy or reduction in vehicle miles traveled, will typically also lower emissions, and may thus produce climate and other environmental benefits (Ibid.).

Transportation-generated emissions also have health impacts and equity implications. According to a scan of international transportation equity research, air quality and social equity are highly related. Air quality is ranked six of twelve on a list of indicators that should be used when evaluating transportation equity (Creger, Espino, and Sanchez, 2018) and is in the top fifteen in another similar list of equity indicators (Yigitcanlar et al., 2018). As NCDOT continues to enhance its prioritization process, integrating approaches to quantify air quality impacts stemming from prospective transportation projects can help improve equity outcomes related to health, well-being, and environment.

Including Equity in Benefit-Cost Analysis

Benefit-cost analysis (BCA) seeks to answer when a governmental action will make society better off with a policy or project than without (Farrow, 2009). The Army Corps of Engineers was the first agency in the United States to use BCA for evaluating infrastructure projects in the 1930s (Regulation Committee of the Administrative Conference of the United States, 2013). Since that time, executive orders issued by Presidents Ronald Reagan (EO 12291) and Bill Clinton (EO 12866) have required U.S Cabinet departments and other executive agencies (e.g., the Environmental Protection Agency, the United States Department of Transportation, etc.) to assess the costs and benefits of economically significant policy changes (Ibid.). The USDOT requires grant applicants to provide a BCA to ensure that the available funding under the program is devoted to projects that provide significant economic benefits to users and the nation, relative to the resources required to implement those projects.

In 2021, President Biden issued a memorandum instructing the Director of the Office of Management and Budget to propose recommendations for improving and modernizing regulatory review (Adler, 2021). The memorandum calls for proposals for "procedures that take into account the distributional consequences of regulations," which could initiate an important shift toward equity in benefit-cost analysis (Ibid.).

How equity is defined and measured can significantly affect benefit-cost analysis cost-benefit analysis results (Adli and Donovan, 2018). It is important that public officials, transportation professionals, and other key stakeholders understand these issues and account for them in their BCA processes. Currently, NCDOT does not have a way to quantify nor account for the externalities that are generated from transportation project investments, such as localized project impacts on air quality, water quality, noise and vibration, physical health, overshadowing and visual impacts, or community severance (discomfort or lack of access that vehicular traffic imposes on nonmotorized travel modes). Although many of these externalities are unaccounted for due to limitations with data, appraisal methodologies, or public enforcement, an increasing focus on social and environmental justice has made addressing these issues essential for local, state, and federal governments.

The purpose of this research is to assist NCDOT with the ability to include both air quality and physical health within the benefit-cost analyses conducted as part of the transportation prioritization process. Air quality and physical health outcomes stemming from transportation investment are highly correlated with quality of life outcomes and often disproportionately impact low-income or minority communities. In this way, the research aims to take a first step at equipping NCDOT with addressing equity in transportation prioritization by accounting for the air quality and physical health externalities generated from transportation investments.

Using a Data-Driven Approach to Evaluate Air Quality and Physical Health

Air quality and physical health evaluation are the key pillars of *RP 2022-17: Including Equity in Benefit-Cost Analysis*. The research team's primary objective is to assist NCDOT in accounting for air quality and physical health impacts within its strategic prioritization process. This will be done by using widely accepted BCA appraisal techniques and available data sources to both quantify impacts and integrate them into benefit-cost analyses conducted within the NCDOT prioritization process.

Literature and Data Review Goals and Objectives. The research team conducted a comprehensive literature and data review to obtain best practices as well as data and methodologies required to include air quality and physical health in NCDOT's strategic prioritization process. The primary objectives of the literature and data review are as follows:

- Review benefit-cost analysis guidance and appraisal methodologies for quantifying and monetizing benefits or costs stemming from transportation investments
- Identify datasets, models, and tools that could be used to quantify the emission of air pollutants and the prospective change in physical activity generated from transportation investments
- Leverage findings from the literature and data review to inform *Task 3: Data Analysis and Methodological Development* and *Task 4: Case Study and Sensitivity Testing* of the project

Benefit-Cost Analysis Appraisal Methodologies. NCDOT's SPOT Office is exploring ways to integrate equity into the benefit-cost analyses that are used as an integral part of its strategic prioritization process – how projects get selected and funded. State transportation agencies like the Delaware Department of Transportation may be able to offer insight, as air quality is included within the seven criteria DelDOT uses for its statewide prioritization process. Air quality is included within the broader category of *Environmental Impact / Stewardship*, which assesses "the extent to which the project mitigates the threat or damage to the environment (DelDOT, 2020)." This category accounts for 6.6 percent of a prospective project's prioritization score. If a project has a positive impact, it receives a one (1); if it has no impact, it receives a value of half-a-point (0.5); if it has a minor negative environmental impact, it receives a score of 0.2; and if a project has a major environmental impact, it receives a score of zero (0) (DelDOT, 2020). More information about DelDOT's prioritization process can be found in *Appendix A: DelDOT Project Prioritization Criteria Summary* (page 32).

In addition to insights from prioritization processes, benefit-cost analysis guidance documentation provides potential frameworks, methodologies, or suggested data sources that can be used for quantifying and monetizing the air quality benefits or costs associated with transportation investments. USDOT contains actuarial values that can be used to monetize sulfur dioxide (SO_2), nitrogen oxides (NO_X), fine particulate matter ($PM_{2.5}$), and carbon dioxide (CO_2) emissions, so that costs and benefits can be tabulated within a BCA framework. The USDOT BCA Guidance Manual also contains some contextual examples of how to calculate the emissions associated with certain types of transportation investments. More information about USDOT's BCA guidance can be found in *Appendix A: Benefit-Cost Analysis Guidance for Discretionary Grant Programs* (page 54).

International BCA guidance offers even more context that can be applied for including air quality within a benefit-cost analysis framework. The United Kingdom's Greenbook includes BCA appraisal methodologies that specifically tie into environmental valuation and provides air quality guidelines for a variety of modal contexts. New Zealand's BCA guidance manual offers additional context and directly ties into the Vehicle Emissions Prediction Model (VEPM) which predicts emissions released by mode type. More information about the Greenbook and New Zealand's BCA guidance manual can be found in *Appendix A: New Zealand's Economic Evaluation Manual* (page 38) and *United Kingdom's Guidance on Appraisal and Evaluation (Green Book)* (page 57).

Datasets, Models, and Tools Used to Quantify Air Emissions. As BCA guidance methodologies provide the approach or instructions for monetizing the air emissions benefits or costs associated with a transportation investment, the proper data, models, or tools enable air emissions to be quantified and thus the BCA approaches to be executed.

The United States' Environmental Protection Agency funds a Motor Vehicle Emission Simulator (MOVES), which is currently in its 10^{th} iteration. MOVES is an emissions modeling system that estimates emissions for mobile sources for criteria air pollutants, greenhouse gases and air toxins. Mobile sources from on-road vehicles such as cars, trucks and buses, and nonroad equipment such as bulldozers and lawnmowers are included within MOVES modeling framework. Aircraft, trains, and marine vessels are not covered. MOVES can be used to measure and quantify vehicular emissions, helping to evaluate the impact on air quality for a variety of transportation investments or policy decisions. Metropolitan Planning Organizations (MPOs) in North Carolina are required by FHWA to make conformity determinations on Metropolitan Transportation Plans (MTPs). More information about EPA MOVES can be found in *Appendix B: EPA Motor Vehicle Emission Simulator (MOVES)* (page 73). In addition to the EPA MOVES model, New Zealand's Vehicle Emissions Prediction Model (VEPN) can be used to validate and supplement mobile source emissions modeling. More information about VEPN can be found in *Appendix A: Vehicle Emissions Prediction Model: VEPM 6.2 update technical report* (page 56).

Emissions modeling systems provide the manner in which emissions by transport vehicle can be modeled. These systems, such as EPA MOVES or VEPM, provide one critical piece of the puzzle. Network travel demand, or how many transport vehicles are moving and when they are moving, is another critical piece of information needed. Transportation demand models can be used to understand travel behavior and the associated temporal travel demand. The research team is evaluating the Triangle Regional Model (TRM), the North Carolina Statewide Travel Demand Model (NCSTM), and the TransModeler platform as part of Task 3: Data Analysis & Methodology Development.

NCSTM is a travel demand model built on the TransCAD platform to predict future travel behavior and associated travel demand for the entire state of North Carolina. The traffic analysis zones (TAZs), or spatial distribution of the model, covers a national geography, with smaller TAZs in the MPO regions, and larger TAZs in the non-MPO regions. The TAZs outside of North Carolina may be the size of Census block groups, tracks, entire states, or aggregations of states depending on the distance away from the NC boarder. The modeled transportation system reflects the level of granularity captured by the TAZs and includes all major roadway facilities across the state. NCSTM is primarily used to estimate future transportation performance measures, including travel demand and travel time given certain land use and/or infrastructure scenarios. The Triangle Regional Model (TRM) predicts travel behavior and associated travel demand for a more detailed TAZ geography and transportation network. As such, the TRM is more valuable for evaluating regional or MPO level changes in air quality. A future aggregate modeling platform that should be considered are Regional Travel Demand Models (RTDM). RTDMs are cover a larger geographic region that current MPO models, and include all of the detail available in the existing MPO model. When fully implemented, RTDMs will provide detailed modeling analysis capabilities for the entire state. Meanwhile, NCDOT currently uses TransModeler, a microsimulation model, to calculate project specific travel time savings that better reflect operational conditions such as the effects of queuing and intersection delay. These operational level details could make TransModeler a strong candidate for assessing localized changes in air quality. In addition to highway performance measures, NCSTM, TRM and future RTDMs provide data either directly, or indirectly, that can be used to support multimodal analysis. More information about these modeling platforms is available in *Appendix B.*

Emissions modeling systems, transportation demand models, and microsimulation models can be used in tandem to quantify the level of network emissions resulting from one mode of travel. The research team will be developing and implementing the approaches and techniques for quantifying emissions using these modeling systems in Task 3. A snapshot of the data sources anticipated for Task 3 are found in Table 1 and an overview of the methodology that will be used to integrate air quality into NCDOT's prioritization process is shown in Figure 1.

Table 1: Data Sources and Techniques Used to Integrate Air Quality into NCDOT's Prioritization Process

Purpose	Sources
Quantify the change in network level of air emissions that would result	• EPA MOVES • Vehicle Emissions Prediction Model • Triangle Regional Model (TRM) • North Carolina Statewide Travel Demand Model (NCSTM) • TransModeler • Global Annual PM2.5 Grids
Monetize the change in social costs resulting from the change in network level air emissions	• USDOT's BCA Guidance • The United Kingdom's Greenbook • New Zealand's Monetised Benefits and Costs Manual

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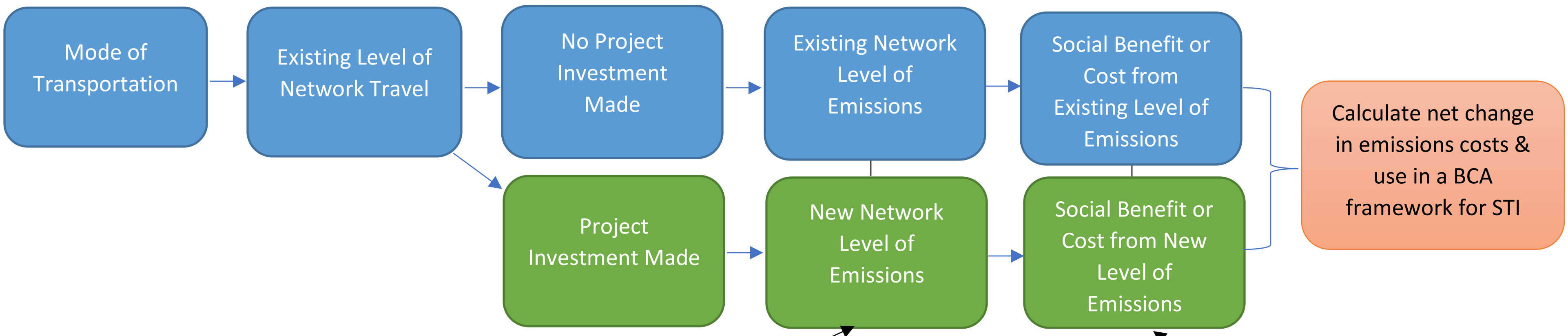


Sources identified in the literature and data review can be used to model the air emissions that are currently discharged by mode. These sources can also be used to model the changes in air emissions that would result from a transportation investment. Sources for modeling include:

- EPA MOVES
- Vehicle Emissions Prediction Model
- TransCAD (such as the TRM)
- TransModeler
- Global Annual PM2.5 Grids

The modal modeling approaches and methodologies that will be recommended for inclusion into prioritization are under development as part of Task 3: Data Analysis & Methodology Development.

Benefit-cost analysis guidance provides the standard appraisal techniques that economists use to quantify the social costs of air emissions. The literature and data review enabled the research team to review a number of BCA guidance documents, of which three nations had particularly useful and well-documented methodologies. This BCA guidance included:

- USDOT’s BCA Guidance
- The United Kingdom’s Greenbook
- New Zealand’s Monetised Benefits and Costs Manual

The BCA appraisal methodologies that will be recommended for inclusion into prioritization will be finalized as part of Task 3: Data Analysis & Methodology Development.

Figure 1: Framework for Including Air Quality in NCDOT's Prioritization Process

Datasets, Models, and Tools Used to Quantify Physical Health Outcomes. Transportation networks affect public health in several ways. Motor vehicle crashes can lead to serious injury or loss of life, tailpipe emissions can contribute to cancer and congenital anomalies, and motor-vehicle dominant travel can produce sedentary lifestyles which can lead to obesity, pulmonary conditions, and increase some forms of cancer (Litman, 2020). Meanwhile traffic congestion or exposure to stressful travel environments can lead to anxiety and depression (Ganesh, 2019), which diminish quality of life and can decrease life expectancy. Furthermore, transportation networks play a critical role in connecting people to medical and health care destinations.

Though transportation investment directly impacts public health in many ways, available data, modeling platforms, and quantification methods are still largely evolving. As such, only a limited set of public health outcomes resulting from transportation investments can be readily quantified and integrated into a BCA framework. This research focuses on modeling the prospective changes in physical activity and quantifying the associated benefits or costs stemming from various transportation investments.

Future research may consider evaluating the following external impacts resulting from transportation networks and investments:

- Stress reduction or relief
- Neighborhood cohesion or severance (discomfort or lack of access that vehicular traffic imposes on nonmotorized travel modes)
- Access to health care and health supportive resources

There are a number of disparate transportation and public health resources that provide techniques, data, or models, and when these sources are properly collated, they can be used to quantify the health impacts of transportation investments. The data sources that will be used most prominently in physical health quantification are shown in Table 2.

Table 2: Data Sources and Techniques Used to Integrate Physical Health into NCDOT's Prioritization Process

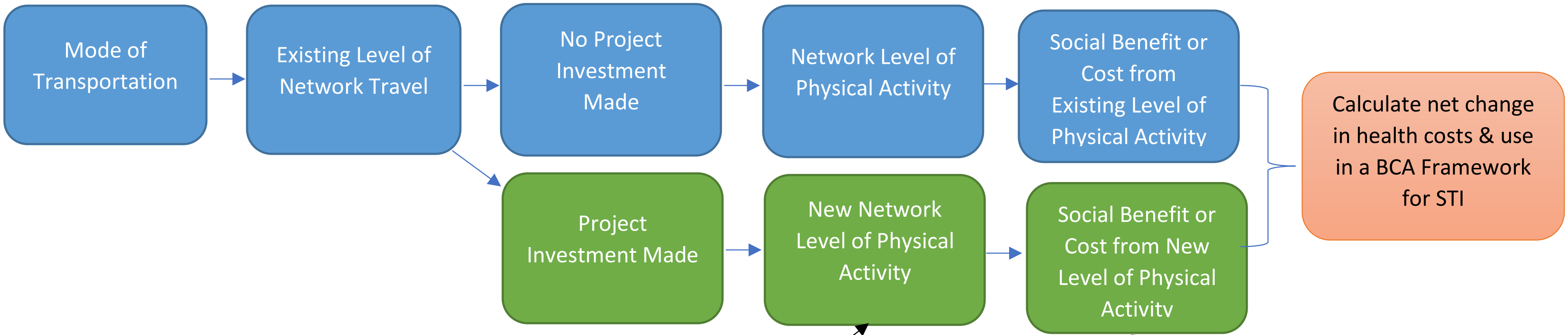
Purpose	Sources
Quantify the prospective change in network level physical activity that would result	• World Health Organization’s Health Economic Assessment Tool (HEAT) • Integrated Transport and Health Impact Modelling Tool (ITHIM) • Victoria Transportation Policy Institute’s *Evaluating Public Transportation Health Benefits*, *If Health Matters, Integrating Public Health Objectives in Transportation Planning*
Monetize the change in social costs resulting from the change in network level physical activity	• The United Kingdom’s Greenbook • New Zealand’s Monetised Benefits and Costs Manual • Victoria Transportation Policy Institute’s *Transportation Cost and Benefit Analysis*

The World Health Organization’s Health Economic Assessment Tool (HEAT) models the change in mortality (lifespan) that results from a sustained physical health intervention, such a modification in walking, cycling or running habits. The change is then appraised within the tool to derive the monetized benefit or cost of the physical health intervention. More information about HEAT can be found in *Appendix B: World Health Organization (WHO) Health Economic Assessment Tool (HEAT)* (page 95).

HEAT can be validated with other research and implemented alongside geospatial analyses to identify individuals within a transportation project’s influence area who would be subject to a physical health modification stemming from the investment. For example, the Victoria Transportation Policy Institute (VTPI) provides extensive research on the types of physical activity changes that can occur due to active transportation access. VTPI, among other researchers and institutions, can provide parameters for quantification such as:

- Typical walking or biking thresholds (walk-sheds/bike-sheds) to access active transportation nodes such as bus, bus rapid transit, rail, and light rail stops
- Mode-shift behaviors (percentage of people that change travel modes) as the result of a transportation investment
- Propensities for physical activity with respect to urban, exurban, and rural contexts

In addition to the HEAT model and VTPI research, the Integrated Transport and Health Impact Modelling (ITHIM) tool is being evaluated as part of this research. ITHIM is a publicly available tool that calculates the change in deaths, years of life shortening and disability, and costs due to these changes in air pollution, physical activity, and traffic injuries. More information about ITHIM can be found in *Appendix B: Integrated Transport and Health Impact Model* (page 78). ITHIM's modeling parameters will be compared to those of the HEAT model in Task 3. During Task 3, the research team will be developing and implementing the approaches and techniques for quantifying physical health and using these within a benefit-cost analysis framework. A summary of the data sources anticipated for Task 3 are also found in Table 2 and an overview of the methodology that will be used to integrate air quality into NCDOT's prioritization process is shown in Figure 2.



Sources identified in the literature and data review can be used to model prospective physical activity modifications that are facilitated by modal transportation investments. Sources for modeling include:

- World Health Organization's HEAT Model
- The ITHIM tool
- Victoria Transportation Policy Institute's *Evaluating Public Transportation Health Benefits*, and *If Health Matters, Integrating Public Health Objectives in Transportation Planning*

The modal modeling approaches and methodologies that will be recommended for inclusion into prioritization are under development as part of Task 3: Data Analysis & Methodology Development.

Benefit-cost analysis guidance provides the standard appraisal techniques that economists use to quantify the social costs of physical health modifications. The literature and data review enabled the research team to review a number of BCA guidance documents, of which three resources had particularly useful and well-documented methodologies. These included:

- The United Kingdom's Greenbook
- New Zealand's Monetised Benefits and Costs Manual
- Victoria Transportation Policy Institute's *Transportation Cost and Benefit Analysis*

The BCA appraisal methodologies that will be recommended for inclusion into prioritization will be finalized as part of Task 3: Data Analysis & Methodology Development.

Figure 2: Framework for Including Physical Health in NCDOT's Prioritization Process

Including Equity in Project Prioritization

In 2013, the Strategic Transportation Investments (STI) legislation was signed into North Carolina law. Its purpose was to establish a more transparent, systematic, and data-driven process, called strategic prioritization, for ranking major transportation projects across all modes including roadway, public transportation, bicycle, pedestrian, rail, and aviation. The strategic prioritization process enables NCDOT to select projects that support a region's goals and objectives, prioritized with appropriate perspective (mode and scale), and also have flexibility to take local input into consideration. Additionally, STI assists NCDOT in distributing its 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 2023-2032 is called Prioritization 6.0 (P6.0).

Benefit cost analysis is an important component of NCDOT project prioritization. Upon review of the different transportation modes, and the prospective types of projects scored within each mode, it was found that benefit-cost ratios constitute at least 5% and as much as 35% of a project's total score (see Table 3). Benefit cost analyses used for scoring projects within STI are primarily focused on quantifying a project's benefits in relation to the project's costs. The benefits defined in P6.0 methodology are primarily focused on monetized travel time savings, safety benefits, economic contribution, and additional transit trips generated. As summarized in the table below, currently no cross-modal factors evaluating equity are taken into account.

As a central tenet of this research project (RP 2022-17 Including Equity in Benefit-Cost Analysis), two cross-modal measures that are intrinsically connected with equity (air quality and physical health) are being evaluated for potential inclusion into the prioritization process.

Table 3: Benefit-Cost Analysis Elements Used in Project Prioritization

Project Type		Benefit-Cost Component in Prioritization		
		BCA-Criteria	Measure(s)	Scoring Weight
Highway	Highway Modernization	N/A	N/A	N/A
Highway	Highway Mobility	Benefit-Cost	(Travel Time Savings $ + Safety Benefits $) / Cost to NCDOT + Funding Leverage	15% - 25%
Non-Highway	Aviation	Benefit-Cost	(Total Economic Contribution / Cost to NCDOT) + Funding Leverage	10% - 20%
Non-Highway	Bike & Pedestrian	Cost Effectiveness	(Safety + Accessibility/Connectivity + Demand/Density) / Cost to NCDOT	5%
Non-Highway	Ferry	Benefits	Travel Time Savings $	10%
Non-Highway	Rail	Benefit-Cost	(Benefits / Cost to NCDOT) + Funding Leverage	10% - 35%
Non-Highway	Public Transportation	Cost Effectiveness	Additional trips / (Cost to NCDOT / Lifespan of project)	15% - 25%

Within prioritization for highways, a benefit-cost analysis applies to mobility projects which adds capacity to the roadway and contributes to 15%-25% of the scoring weight depending on funding category. Currently, benefits only include travel time saving (TTS), which is taken from the NCSTM, and safety benefit factor which is from a set of pre-defined factors depending on project type. However, along with savings in travel time, increased capacity also leads to higher traffic volumes and often degraded air quality, which is often an equity concern for disadvantaged communities.

Additionally, transportation facility cost is an important factor in this formula. For example, tolling projects could minimize its costs borne by NCDOT, and thus rank higher among competing projects. However, requiring payment for roadway access also creates burdens on low-income households.

Aviation projects are projects that increase the capacity of the airport and/or modernize the airport. The scoring formula focuses on total economic contribution as a ratio of benefit versus cost. Similar to highway projects, airport improvements also lead to more air traffic, which creates air and noise pollution.

Instead of a typical benefit-cost analysis, bicycle and pedestrian project scoring is based on cost effectiveness. The scoring formula identifies projects that can create a safer transportation environment for all users, improve accessibility and connectivity between nearby points of interest and existing bike/pedestrian networks, and are located in areas with higher concentrations of population and employment. Using a framework like this might put resources into place that are already well-served.

Similar to highway scoring, ferry scoring evaluates monetized travel time savings taken from National Mapping Software. However, ferry projects could reduce VMT by providing direct connection across water bodies, thus improving air quality.

Rail scoring is based on monetized benefits related to vehicle operating and maintenance costs, travel time savings, value of time related to cargo, environmental impacts, and safety impacts. However, rail projects can also largely reduce truck travel on the roadway, thus lead to less emission and better air quality. Such benefit is not counted in the formula.

Public transportation scoring relies on additional trips generated by the project to determine cost effectiveness. These additional trips are often calculated with the regions travel demand model where demographic data and service information is taken into consideration. If it exists, a STOPS model could also be used for this purpose. Similar to rail project scoring, this framework ignores the air quality benefits a public transportation project would gain by reducing auto travel.

Overall, the current BCA in the NCDOT prioritization scoring system consists of data-driven formulas which help promote standardized and transparent decision-making. The BCA component in the prioritization process allows projects across modes to compete for funding. However, equity considerations are not accounted for in any of the existing formulas.

Including Equity in Long-Range Transportation Planning

Tangential to the consideration of equity in the project prioritization process, NCDOT also wants to improve the consideration of equity in the long-range transportation planning process. While NCDOT is hoping to fund research specific to this topic, RP 2022-17 Including Equity in Benefit-Cost Analysis was leveraged as an opportunity to delve into the existing literature and best practices for including equity in long-range transportation planning in an effort to inform existing work flow, and future research into improved practices.

Metropolitan and Rural Planning Organizations

Federal Guidance

Federal guidance from the United States Department of Transportation (USDOT) provides an overview of transportation planning. A 2019 USDOT Transportation Planning Capacity Building Program (TPCB) briefing book notes that transportation planning typically follows a uniform process. This process involves:

- Public and stakeholder engagement,
- Monitoring of existing conditions,
- Forecasting future population and employment growth,
- Identifying current and projected transportation needs through developing performance measures,
- Analyzing transportation improvement strategies,
- Developing long and short-range programs for alternative capital improvement and management,

- Estimating how recommended improvements will impact achievement of goals and the economy and environmental quality,
- And developing a financial plan to ensure there is sufficient revenue to fund the implementation of strategies (Transportation Planning Capacity Building Program, 2019).

Other federal guidelines provide guidance for the content of transportation planning for equity via environmental justice, which ensures that all persons are treated fairly and meaningfully involved in the implementation of environmental laws and regulations (Exec. Order 12898, 1994). Legal protection from discrimination based on a variety of attributes is provided through Title VI of the Civil Rights Act of 1964, Section 162 (a) of the Federal-Aid Highway Act of 1973, Section 504 of the Rehabilitation Act of 1973, the Age Discrimination Act of 1975, the Civil Rights Restoration Act of 1987, and the Americans with Disabilities Act of 1990. Additionally, 1994 Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations,* directs Federal agencies to identify and address disproportionately high and adverse human health or environmental effects, including social and economic effects, on low-income or minority populations because of programs, policies, and activities. 2000 Executive Order 13166, *Improving Access to Services for Persons with Limited English Proficiency*, outlines guidelines for Federal agencies to provide access to benefits, services, information, and other aspects of programs for individuals with limited English proficiency. Provisions outlined in these documents are typically reflected in the transportation planning framework such as Long Range Transportation Plans.

Planning Organizations and Long Range Transportation Plans

The development of Long Range Transportation Plans (LRTPs), also referred to as Metropolitan Transportation Plans, are essential to transportation planning at the national, regional, and local level (Transportation Planning Capacity Building Program, 2019). Traditional LRTPs serve as a planning vision for the next 20 years and guide Transportation Improvement Programs (TIPs). These long range plans typically include clearly defined transportation goals and project prioritization, as well as a financial aspect that shows how these transportation goals can be enacted. More recently, many LRTPs also address equity as an important facet of transportation planning.

MPOs and RPOs, referred to as Planning Organizations (POs) are umbrella organizations responsible for long range transportation planning in the designated PO region. The POs include both professional staff, and policy boards usually comprised of local elected officials. POs typically do not own or operate the transportation systems they serve (Federal Highway Administration, 2014). Instead, they serve as overall coordinators and consensus builders in the planning process. POs perform six core functions:

- Establish a setting for effective decision-making,
- Identify and evaluate transportation improvement plans,
- Prepare and maintain a Metropolitan Transportation Plan,
- Develop a Transportation Improvement Program,
- Identify performance measure targets and monitor whether implemented projects are achieving targets, and
- Involve the public.

Problem Identification and Gap Analysis

To improve the consideration of equity in the transportation planning process for North Carolina, it is beneficial to first conduct a scan of LRTPs for POs across the country in order to identify gaps, or capitalize on best practice procedures that may already exist. To accomplish this analysis, 16 POs from across the country were identified, and their LRTPs were reviewed and rated across several common components found in LRTPs, including: Vision, Stakeholder and Public Engagement, Evaluation Tools, Methods, and Data for Needs Assessment, Project Specific Considerations, Purpose and Need Statements, and Process Documentation and Implementation Plan. The LRTP documents were then evaluated across metrics critical to this research, including: definition of equity, definition of communities of concern (CoC), and the explicit mention of data or metrics related to health and air quality. If the reviewed plan included the consideration of equity in any of the plan components, or addressed any of the critical research metrics, then that element was flagged in the appropriate table. A rating of 1 was given if the plan element included the mention of equity, a rating of 2 was given if the plan element included a discussion or presentation of data specific to equity, and a rating of 3 was given if the plan element included analytical methods tied to measuring or assessing equity related outcomes. Additionally, each cell has been color coded to allow for simple identification of each tier. The final evaluation is summarized in Tables 4 and 5.

The POs included in this review were selected to be representative of areas of various geographic and population size, updated recently (where possible), and accessible online. While many MPOs make their LRTPs available online, the pool is considerably more limited for LRTPs from RPOs.

The results of the scan show that the majority of the MPOs include equity in their planning elements from a contextual standpoint, and with the inclusion of data. What appears more challenging is the use of analytical methods tied to measuring or assessing equity related outcomes. This is particularly concerning for the plan elements related evaluation tools and methods, and project considerations are these two components of the planning process are most analytically driven. There is some encouragement with respect to using analytical methods for defining equity and communities of concern (CoCs), but less so with a specific focus on physical health and air quality. The analysis of RPOs tells a different story, with most only mentioning equity in their report, many also using data specific to equity, but very few using analytical methods. These results likely point to a need for establishing best practices for including equity, not just at all steps of the planning process, but related to how to move from concept to analytical methods that lead to intended outcomes.

State Departments of Transportation

A discussion of long range planning requirements for state Departments of Transportation (DOTs), and the consideration of equity in those plans provides important background and context for this effort.

State DOTs are tasked with preparing and maintaining Long-Range State Transportation Plans (LRSTPs), developing Statewide Transportation Improvement Programs (STIPs), identifying performance measure targets and monitoring target achievement, and involving the public in the creation and execution of all the aforementioned items (Federal Highway Administration, 2014). These documents guide policy and should ensure equity and environmental justice are included in transportation planning. Much of their content regarding equity is dictated by aforementioned federal guidelines. State-level long range transportation planning typically sets a broad goal and vision for the direction of transportation in the state, whereas plans developed by MPOs and RPOs focus on specific projects and planning to achieve these goals and visions. Defining and discussing equity in planning documents at the state level allows for the project agenda for the next 15-20 years to reflect the importance of equity.

A review of state DOT long range transportation plans suggests that state plans vary from being policy-based, vision-based, performance-based, needs-based, project-based, financially-realistic, and corridor-based, though many states address more than one of these aspects in their plans (Federal Highway Administration, 2017). For example, while Colorado's LRTP is solely corridor-focused, Nevada's LRTP is both performance-based and policy-based. Many of these plans provide a broad overview for guidance of goals, vision, policies, and projects. Specific planning criteria are not explored at the same level of depth as that found in long range transportation plans for POs.

A review of state-level LRTPs provided much more focused and involved discussion of equity. Nearly every state-level LRTP discussed either equity or communities of concern, while many discussed both, see Figure 3. This finding is perhaps not unexpected as state's generally take the lead in setting policy and direction when it comes to transportation planning initiatives. It is also true that with less rigorous technical analysis, given the policy nature of many state-level LRTPs, the discussion of equity is easier at a policy level, than is the actual implementation of analytical methods tied to measuring or assessing equity related outcomes needed for plans developed by POs.

Table 4: Matrix displaying inclusion of equity-based best practices in MPO transportation planning documents

Metropolitan Planning Organization	Planning Elements						Research Elements		
	Development of Community visions	Stakeholder and Public Engagement	Evaluation Tools, Methods, and Data for Needs Assessment	Project-Specific Considerations within LRTP	Development of Purpose and Needs Statements	Process Documentation and Implementation Plan	Definitions of Equity	Definitions for Communities of Concern	Physical Health & Air Quality Data
Atlanta, GA	2	2		2	2	2	3	2	2
Boston, MA	3	3	3	2	3	2	3	3	2
Broward County, FL	2	1	1	1	2	1			
Hillsborough County, FL	2	3	2	3	3	2		2	2
Indianapolis, IN	2	2	2	2	3	1		1	1
Johnson County, IA	2	1	2	2	2	2	3	2	2
Lincoln, NE	2	3	3	2	2	2	3	3	3

Table 5: Matrix displaying inclusion of equity-based best practices in RPO transportation planning documents

Rural Planning Organization	Planning Elements						Research Elements		
	Development of Community visions	Stakeholder and Public Engagement	Evaluation Tools, Methods, and Data for Needs Assessment	Project-Specific Considerations within LRTP	Development of Purpose and Needs Statements	Process Documentation and Implementation Plan	Definitions of Equity	Definitions for Communities of Concern	Physical Health & Air Quality Data
Northern Tier, PA	2	1	1	2	2	1		1	2
Northwest Pennsylvania, PA	1	2	2	3	1				2
Southern Alleghenies, PA	2	2	1	2	2				1
Huntsville, AL	2	2	2	3	2				2
Upper Savannah, SC	2	1	1	2	1	1			1
Washington County, OK	2	2	1	3	2	2			1
Hampton Roads, VA	1	1	1	2	2				
Western Tennessee, TN	1	2	1	2	1	2			

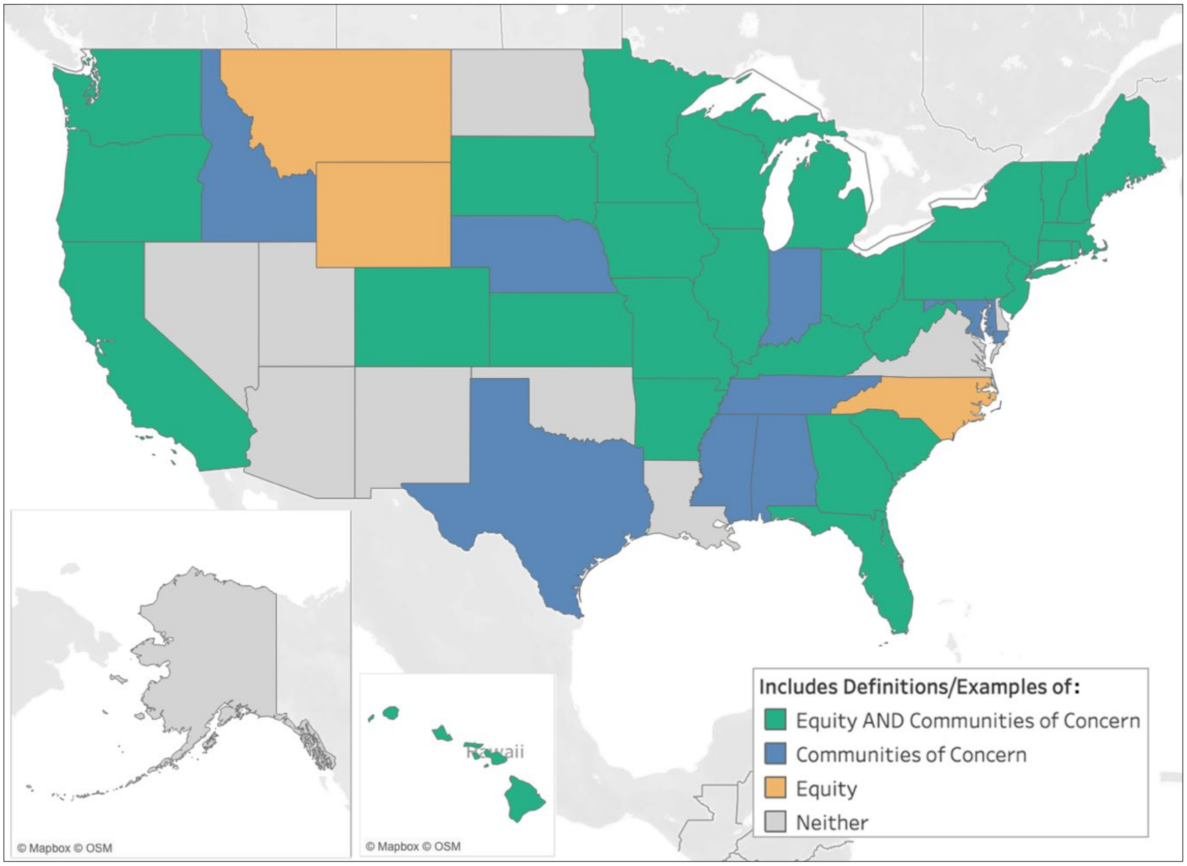


Figure 3: Map displaying inclusion of definitions of equity and Communities of Concern in state-level Long Range Transportation Plans.

Defining Transportation Equity

While LTRPs and other transportation planning documents may include references to equity, defining the term and developing a framework for improving it can be challenging. Yet, establishing a definition for "equity" is essential for effectively measuring how transportation projects and plans impact equity in communities.

Equity is influenced by the numerous systems on which human society depends – including transportation systems. Lewis, et al. (2021) notes that equity is inherently concerned with justice, and at a societal level it is related to the just distribution of resources in communities. Consequently, every aspect of transportation planning – from design and public engagement to implementation and measuring who is impacted by project outcomes long-term – is related to equity (Transit Cooperative Research Program, 2020). The American Planning Association (2019) reinforces this idea, noting that "Planning for equity means applying an equity lens — for just and fair inclusion into a society in which all can participate, prosper, and reach their full potential — to everything planners do. From the way planners work with community members creating a shared vision for their neighborhoods to advocating for policies that connect people to opportunities at the local, state, and federal levels, planning for equity is planning for all."

Analysis of Definitions

To assess the current state of the practice related to defining equity in the context of planning, the research team analyzed 22 sources that explored definitions of equity. This review included action plans and guides from 10 counties and municipal regions outside of North Carolina and 12 national agencies and organizations. The full list of these sources, all of which were published in the last 10 years, is presented in *Appendix A: Reviewed Action Plans and Guides That Include Definitions of Equity* (page 60).

Overall, the specific scope and terms used in these definitions varied. Some definitions employed by planning and transportation agencies discuss equity in general terms, as a concept that can be applied to a variety of public policies and services, such as the following example from "The Portland Plan" from City of Portland, Oregon (2012):

> *Equity is when all individuals have access to the opportunities necessary to satisfy their essential needs, advance their well-being and achieve their full potential. We have a shared fate as individuals within a community and communities within society. All communities need the ability to shape their own present and future. Equity is both the means to healthy communities and an end that benefits us all.*

Others define equity as it relates specifically to planning for transportation, land use, or both, as exemplified by this example from the USDOT Transportation Planning Capacity Building Program's "The Transportation Planning Process Briefing Book" (2019):

> *Transportation equity refers to the way in which the needs of all transportation system users are reflected in the transportation planning and decision-making process. In particular, transportation equity focuses on the needs of those traditionally underserved by existing transportation systems, such as low-income and minority households, older adults, and individuals with disabilities. Transportation equity means that transportation decisions deliver equitable benefits to a variety of users and that any associated burdens are avoided, minimized, or mitigated so as not to disproportionately impact disadvantaged populations.*

In spite of the different approaches taken to defining equity, key themes emerged. For example, several of the definitions in the sample included discussion about the need to account for past injustices when planning, acknowledging that many communities of color are transportation disadvantaged today due to policies of the past. More than 30% of the definitions included specific references to race, racism, and/or people of color. An additional 30% highlighted "social equity," which Litman (2021) says refers to equity as regarding not just the distribution of benefits and costs, but also whether that distribution is considered fair and appropriate. The Austin, Texas Strategic Mobility Plan (2019) explains that social equity is about "not only treating all people fairly, but also recognizing, acknowledging, and purposefully acting to right historical wrongs and inequities caused by transportation-related decisions."

To identify additional emerging themes in the definitions examined, the research team employed a framework proposed by The Urban Sustainability Directors Network (2014) that outlines four components of equity, described as follows:

- ***Distributional Equity***, or when programs and policies result in fair distribution of benefits and burdens across all segments of a community, prioritizing those with highest need.

- ***Transgenerational Equity***, or when decisions consider generational impacts and don't result in unfair burdens on future generations. This is also known as *Restorative Equity*.
- ***Procedural Equity***, defined as inclusive, accessible, authentic engagement and representation in processes to develop or implement programs or policies.
- ***Structural Equity**,* or when decision-makers institutionalize accountability; decisions are made with a recognition of the historical, cultural, and institutional dynamics and structures that have routinely advantaged privileged groups in society and resulted in chronic, cumulative disadvantage for subordinated groups.

Common terminology in the equity definition sample was identified and grouped into these thematic areas, as shown in Table 6.

Table 6: Thematic Categorization of Terms Commonly Utilized in Definitions of Equity

Equity Theme	*Distributional Equity*	*Transgenerational Equity*	*Procedural Equity*	*Structural Equity*
Common Terms in Definitions	options	burden	representation	historic/historically
	opportunity	disparities	engagement	sustainable
	benefit	barriers	collaboration	health/healthy
	choice	resources	accessibility (in reference to communication)	access (in reference to the ability to utilize)
	distribution / distributed		inclusive/ inclusion	
	shared (in reference to costs/benefits)		shared (in reference to decision-making)	
	just / fair			
	needs met			

Importantly, the terms identified can be tied back to the transportation planning process and related performance measures. For example, defining equity in terms of how transportation *benefits* are *distributed* may lend itself to geospatially measuring the presence of quality transportation facilities in different types of communities, and public *engagement* that involves *shared* decision-making may be measured in terms of how many public ideas were integrated into a project. This is important because the language an agency uses to define equity can influence how equity outcomes are analyzed and determined (Litman, 2021).

In addition to incorporating terms that aligned with the aforementioned themes, equity definitions that focused on transportation planning often include language more specific to transportation outcomes. These terms include:

- Efficient
- Reliable
- Safe
- Affordable
- Accessible (in reference to mobility)

Given the relationship between how equity is defined and how it is measured, it is unsurprising that the majority of the definitions analyzed go beyond briefly defining the term "equity" to incorporate aspirational language. These definitions offer a vision for what equitable actions and outcomes look like, which can help inform the development of goals, data analysis, and other tools to measure equality. The District Department of Transportation (Washington, D.C.) Equity Statement (2021) is an example:

> *Transportation Equity is the shared and just distribution of benefits and burdens when planning for and investing in transportation infrastructure and services. Transportation decisions are made in collaboration and in participation with the community DDOT serves, to establish a system that is safe, accessible, affordable, reliable and sustainable. Focused attention is given to historically under-resourced communities in order to overcome existing disparities and achieve transportation equity that include, but are not limited to:*
>
> - *People of color*
> - *People with low-income*
> - *People living with disabilities*
> - *LGBTQ+ people*
> - *Individuals who identify as female*
> - *Youth; Older adults*
> - *Residents at risk of displacement*
> - *People experiencing homelessness or housing insecurity*
> - *Immigrant and refugee communities*
> - *People with limited English proficiency and literacy*

Understanding How Communities of Concern Relate to Equity

In order to understand the extent to which transportation planning impacts are equitably distributed, planning agencies must first identify where sensitive and historically underrepresented groups are concentrated within their jurisdictions. Planning agencies have commonly defined these areas as "Communities of Concern" (CoCs), though many agencies use alternative terms (e.g., "Environmental Justice Populations", "Priority Areas", "Target Populations", "Underserved Communities").

Key Terminologies and Data Techniques for Identifying Communities of Concern

Some equity definitions also include details about specific CoCs. According to the Urban Institute (2020), CoCs are geographic areas of analysis that planning organizations construct to identify communities that are more likely to experience negative consequences due to infrastructure development and/or are less likely to have equitable access to transportation services. Williams et al. (2021) notes that identifying these communities and measuring the impact that planning decisions have on them is important because their needs have often gone unmet in the past, which can lead to inherent inequities in the transportation system and disproportionate adverse impacts on these communities.

The research team analyzed CoC terminology used in the equity definitions as well as supplemental CoC guidance that accompanied these definitions. In some cases, CoCs were described using alternative terms such as "traditionally underserved" and "socially disadvantaged," as outlined in Table 7. Common phrases and terms used to describe who is included in CoC groups is shown in Table 8.

Table 7: Terminology Commonly Used as Alternatives to "Communities of Concern"

Common CoC Alternatives
"traditionally underserved"
"historically underrepresented"
"socially disadvantaged"
"vulnerable"
"at-risk"
"in-need"
"marginalized groups"

Table 8: Terminology Commonly Used to Describe Groups Included in Communities of Concern

Attributes of Individuals Commonly Included in CoCs
Immigrant and refugee communities
Individuals who identify as female
LGBTQ+ people
Minority populations including Hispanics/Latinos, African Americans/Blacks, Asian Americans, Native American/Alaskan Natives and Native Hawaiians, and Pacific Islanders
Non-driving individuals
Older adults/elderly persons
People experiencing homelessness or housing insecurity
People living with disabilities
People of color
People with limited English proficiency and/or literacy
People with low-income
Persons otherwise adversely affected by persistent poverty or inequality
Persons who live in rural areas
Residents at risk of displacement
Transit-dependent individuals
Youth/children
Zero vehicle households

Many transportation agencies included more than half these groups in their list of CoCs, while others focused specifically on one to three of these groups in their definition. It should be noted that USDOT is working to better define CoCs as part of the Justice40 Initiative and can provide some initial guidance to transportation agencies (USDOT, 2021). Similar to the importance of the language used to define the overall meaning of equity, the terms used to describe who is included in CoCs will influence how equity is measured (Urban Institute, 2020).

While there is no standard definition or technique for CoCs and their equivalents, our review of the approaches taken by MPOs in the one hundred most populous metropolitan areas around the country reveals some notable trends (see Figure 4).

Nearly half of all definitions incorporate just two demographic factors in their definition, the most common of which are concentrations of individuals or households with low-income and/or in poverty and concentrations of racial and ethnic minorities (see Figure 4 and Figure 5). The frequency with which these factors appear is likely due to their explicit enumeration in Executive Order 12898 - Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations (Caltrans DRISI, 2021). Though many MPO's use other factors in their definitions, more than two-thirds of the reviewed definitions incorporate five or fewer factors. Additional common factors include concentrations of limited English language proficiency populations, senior/elderly populations, people with disabilities, and households without access to a vehicle (Ezike et al., 2020).

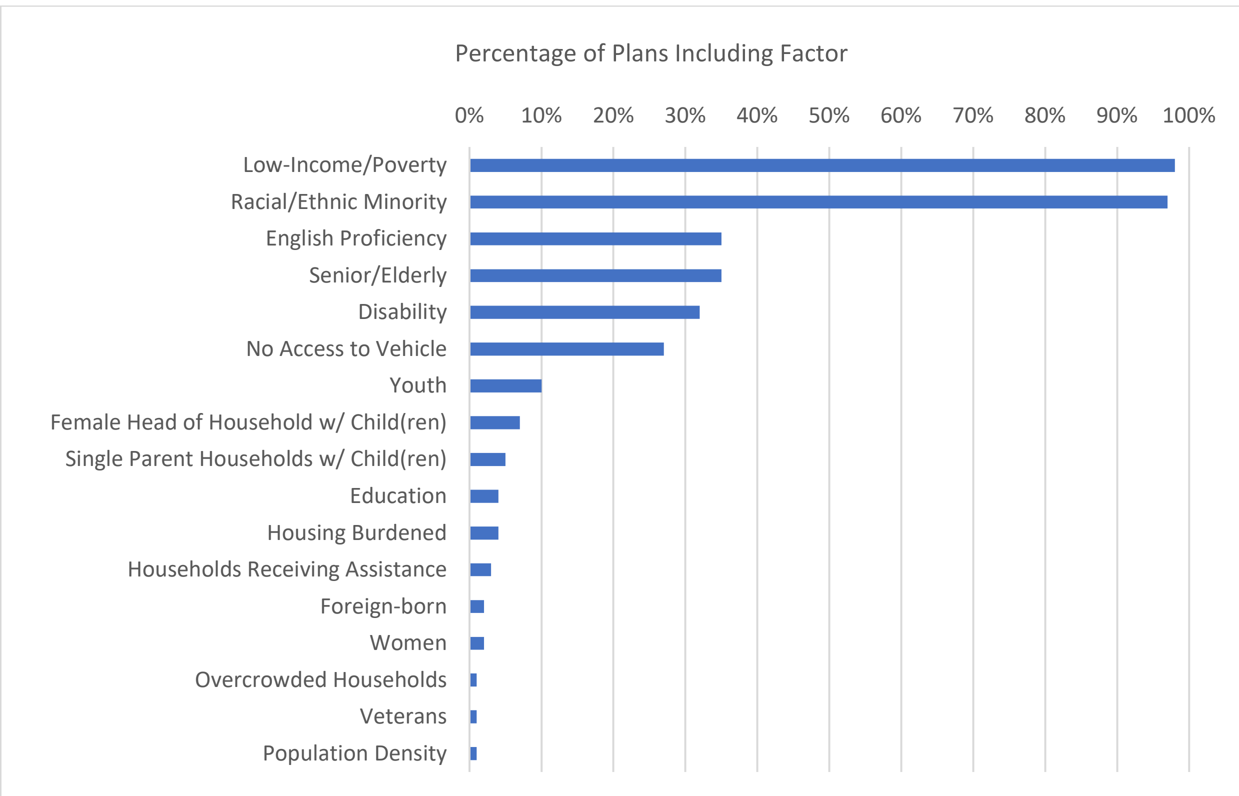


Figure 4: Demographic Factors in CoC Definitions by MPOs in 100 Most Populous U.S. Metros

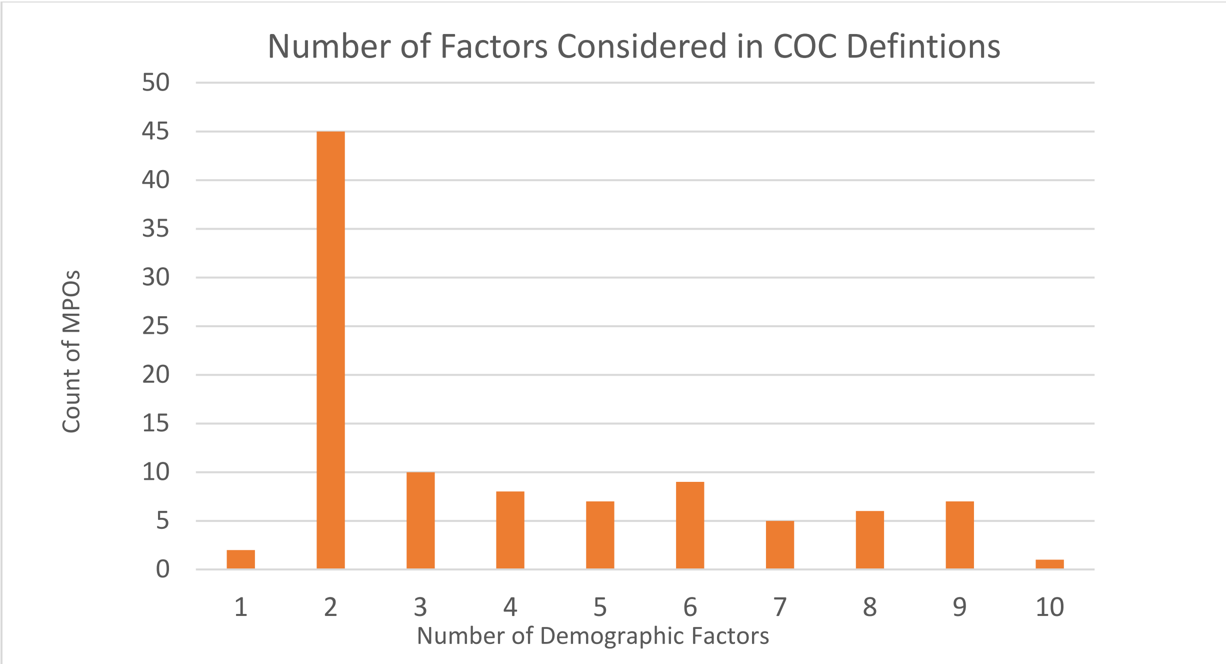


Figure 5: Count of Demographic Factors in CoC Definitions by MPOs in 100 Most Populous U.S. Metros

Second, these definitions employ a variety of thresholds for the factors used in defining CoCs. A common approach is to define a CoC as a small-scale census geography wherein the concentration of any single factor analyzed exceeds the regional mean or median. Similar approaches set concentration thresholds at a multiple of the regional mean, a number of standard deviations from the regional mean, or at explicitly defined concentrations (e.g., above 25%). Likewise, some definitions include frameworks that require the presence of a combination of factors above threshold concentrations. For example, the Metropolitan Transportation Commission of the San Francisco Bay Area defines CoCs as tracts that meet concentration thresholds for both people of color and low-income households, or that meet concentration thresholds for at least three of the remaining six factors analyzed (MTC, n.d.). The MTC and several other MPOs also uses tiered thresholds for each factor to develop multiple Communities of Concern priority levels.

Finally, while all definitions rely heavily on public demographic data provided in the U.S. American Community Survey (ACS), MPO definitions vary in the geography at which they analyze this data and define Communities of Concern. A 2020 review compiled by the Urban Institute found that 42 MPOs used census tracts, 36 used census block groups, 24 used traffic analysis zones (TAZs), and 12 used census blocks (Ezike et al., 2020). In addition to the ACS, some MPOs use other public data sources, including state and local data available for their jurisdictions.

It is important to note that many MPOs conduct equity-focused analyses with community mapping components that extend beyond Communities of Concern. Some California MPOs, for example, separately define Environmental Justice Areas (a tract-level designation) from Communities of Concern (a Census Designated Place definition) and additionally identify California Senate Bill 535 Disadvantaged Communities designated by CalEPA on the basis of disproportionate vulnerability to multiple sources of pollution (Caltrans DRISI, 2021). The Knoxville Regional Transportation Planning Organization separately analyzes three theme-based priority areas (opportunity, accessibility, and vulnerability) using 22 factors (Ezike et al., 2020).

Conclusions

As an interim deliverable for *Research Project 2022-17 Including Equity in Benefit-Cost Analysis*, the project team has summarized findings from a comprehensive literature and data review. The purpose of the review was to locate essential resources that could be used to develop two cross-modal measures (air quality and physical health), which are intrinsically linked with equity, and integrate these measures into NCDOT's prioritization process. Among approximately 40 literature and data sources that were reviewed, foundational resources were identified to quantify and monetize air quality and physical health impacts precipitated by transportation investments (pages 8 and 11 demonstrate the initial framework that the research team will be using to quantify and appraise air quality and physical health impacts and this will be fully developed in *Task 3: Data Analysis and Methodological Development*).

Foundational air quality resources identified in the literature and data review include:

- *EPA MOVES Model*
- *Vehicle Emissions Prediction Model*
- *Triangle Regional Model*
- *TransModeler*
- USDOT's Benefit Cost Analysis Guidance
- United Kingdom's "Greenbook"
- New Zealand's *Monetized Benefits and Costs Manual*
- Many other ancillary works (see Appendix A and Appendix B)

The research team also located essential resources for integrating physical health into a BCA framework. Instrumental physical health resources include:

- World Health Organization's *Health and Economic Assessment Tool*
- The *Integrated Transport and Health Impact Modeling* (ITHIM) tool
- Victoria Transportation Policy Institute's *Evaluating Public Transportation Health Benefits*, *If Health Matters, Integrating Public Health Objectives in Transportation Planning*, and its *Transportation Cost and Benefit Analysis* guidance
- The United Kingdom's "Greenbook"
- New Zealand's *Monetised Benefits and Costs Manual*
- Among many other ancillary works (see Appendix A and Appendix B)

These resources form the backbone of *Task 3: Data Analysis and Methodological Development* and *Task 4: Hypothetical Prioritization Scenarios and Sensitivity Testing* of the research effort.

The interim deliverable also aims to shine a light on a number of valuable processes and considerations that can be taken to include equity in long range transportation planning. Prior to implementing a process for addressing equity, it will be important to come to a common definition of equity in transportation and an understanding of the communities that will benefit the most from this process. As part of this interim deliverable, the project team conducted an in-depth review and analysis of a geographically varied sample of MPOs and RPOs, documenting the extent to which they include equity in long-range transportation planning as well as how these agencies define equity. Table 4 and Table 5 on page 16 show a summary of MPOs and RPOs and the extent to which they include equity in their LRTPs, while Table 6 on page 19 categorizes the terms commonly utilized when defining equity.

During the research process and tying directly into a research need to address equity in planning, the project team received input from the project sponsor that it would be valuable to be able to identify, define, and locate Communities of Concern (CoCs) in North Carolina. Part of this interim deliverable was devoted to meeting that need. The research team conducted an analysis of CoC definitions for the MPOs in the 100 most populous metros (see Figure 4 on page 22) and the demographic factors considered in those definitions (see Table 7, Table 8, and Figure 5 on pages 21 and 23. The purpose of this analysis was to equip NCDOT with the characteristics needed to identify, define, and locate CoCs.

This interim deliverable was submitted as the culmination of Task 2: Literature Review, Data Review and Data Collection. Following the submittal of this interim report, the research team will be developing a working definition of equity through a consensus process with key members of the Transportation Planning Division and SPOT office. The full research project is anticipated to be completed on July 31, 2023.

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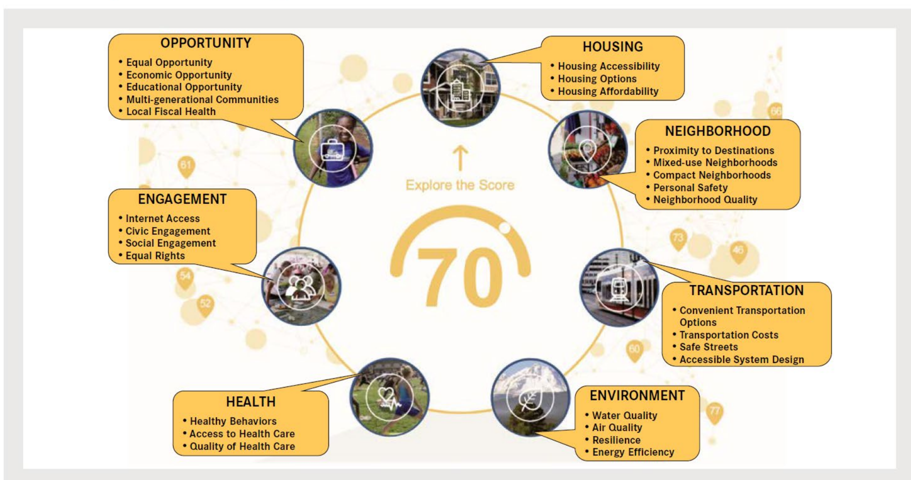
Appendix A – Literature Review Resource Summaries

LITERATURE CATEGORY	***Equity in BCA*** - ☒ Air Quality | ☒ Physical Health | ☒ Other Quality-of-Life Measure ***Equity in Planning*** - ☐ Underserved Communities | ☐ Long Range Transportation Plans | ☐ Definition of Equity | ☒ Prioritization
LITERATURE SOURCE NAME	The Livability Index 2018: Transforming Communities for All Ages
RESOURCE DESCRIPTION	The index is a research report on the AARP Livability Index tool that first launched in 2015. The tool uses 60 indicators, 30 million data points, and provides insights into how well communities support their residents for all ages. The tool provides a score for every U.S. neighborhood based on the available services and amenities. The index is intended for use by data analysts and community residents looking to understand a location of interest.
PROJECT RELEVANCE	The index is organized into seven main categories with attributes for each. Figure 1 illustrates how these categories relate and provides context for what attributes are included (see page 2).

Figure 1
Seven Categories of Livability and the Attributes Associated with Each



The report provides updates to the top-performing cities based on size and score. There are a few key themes outlined in the report. These themes are listed as follows:

1. Different Strategies Work for Different Communities
2. Communities Across the Country Are Taking Steps to Become More Livable
3. Communities Are Striving Toward Greater Population Health
4. Despite Gains in Many Areas of Livability, Us Cities Show A Disturbing Trend Toward Increasing Sprawl

There are a few references to costs in the index report. The first is indicated in the table above. Other "costs" references noted refer to the struggle with rising housing costs in the cities that rank high on the index and around recommendations for cities on how to handle the issue.

Health was mentioned throughout the report, at a high level, in combination with the other quality-of-life factors along with how key attributes impact communities collectively. Health was the focus under Theme 3: Communities Are Striving Toward Greater Population Health, and noted the positive trend for a reduction in preventable hospitalization rates among Medicare patients. The report especially emphasizes the role that policies play in increasing the score and helping communities become more livable and healthier.

The index uses a metric that could potentially be used to assess the air quality impacts of transportation investment. The index evaluates the percentage of the population living within 200 meters of a high-traffic road with more than 25,000 vehicles per day. This metric is measured at the neighborhood scale and lower values are better.

The AARP Policy Institute discusses a number of potential health issues associated high volume corridor.

> *A high-traffic road isn't just a nuisance to navigate, it can be a threat to public health, too. People who live near these roads are exposed to stressful noise pollution, not to mention exhaust and other emissions that can increase the risk of cancer and asthma. Busy roads also create barriers for pedestrians and bicyclists. The Index measures the percentage of people in a neighborhood who live close enough to high-traffic roads that they are regularly exposed to these negative impacts.*

RESEARCH OR POLICY GAPS	Air quality was noted as an attribute, but was not a focus of the report. The report overall provided ideal insights for the collective assessment of the categories, but was not comprehensive in providing cost or quantitative data for a cost-benefit analysis. Information on equity and underserved populations were also not provided.
BIBLIOGRAPHIC INFORMATION	Jana Lynott, Rodney Harrell, Shannon Guzman and Brad Gudzinas. AARP Public Policy Institute (2018, June) Research Report: The Livability Index 2018: Transforming Communities for All Ages. Retrieved October 21, 2021, from https://livabilityindex.aarp.org/.

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INCLUDING EQUITY IN BENEFIT-COST ANALYSIS | APPENDIX A

LITERATURE CATEGORY	***Equity in BCA*** - ☒ Air Quality | ☒ Physical Health | ☒ Other Quality-of-Life Measure ***Equity in Planning*** - ☒ Underserved Communities | ☒ Long Range Transportation Plans | ☐ Definition of Equity | ☒ Prioritization
LITERATURE SOURCE NAME	DelDOT Project Prioritization Criteria Summary
RESOURCE DESCRIPTION	The Delaware Department of Transportation (DelDOT) developed its Project Prioritization Criteria to provide an updated transparent guide for the public to assess accountability as it relates to the 6-year Capital Transportation Program (CTP). The Project Prioritization criteria is also to ensure proper alignment with the mission, vision, and goals of DelDOT. The department developed weighted percentages for each criterion by how each one fulfilled the mission, vision, and goals of the department. The weighted priorities were determined as follows: • Safety – 35.0% • System Operating Effectiveness – 19.1% • Multi-Modal Mobility/Flexibility/Access – 11.9% • Revenue Generation/Economic Development/Jobs & Commerce – 13.1% • Impact on the Public/Social Disruption/Economic Justice – 8.3% • Environmental Impact/Stewardship – 6.6% • State and Local Priority – 6.1%
PROJECT RELEVANCE	Some of the department's goals for which this criteria set was developed which relate to equity include providing "every traveler with access and choices" to Delaware's transportation system, "minimiz[ing] the environmental impact," and creating a place where "employees love to work." Part of serving underserved communities requires that a department operate financially sustainably and transparently, while also upholding accountability to meet the long-term needs of the communities in greatest need of alternative transportation options. The department's priority criteria was developed around goals such as these which result in an equity context being the driving influential factor - as opposed to equity being simply a *box to be checked* or a side item to include in project assessments. DelDOT describes how it will implement their Long-Range Transportation plan, *Innovation in Motion*, through operating in alignment with the plans, policies, activities, and progress being measured with the long-range goals outlined on page 4 (Summary). DelDOT uses *Environmental Impact / Stewardship* is as one its criterion for transportation project selection. The purpose of the criterion is to determine the effect of its transportation system on energy use and the natural environment. *Environmental Impact / Stewardship* accounts for 6.6 percent of a potential transportation project's prioritization score and it is used to "assess the extent to which the project mitigates the threat or damage to the environment, including Air Quality." If a project has a positive impact it receives a value of (1), if it has no impact it receives a value of (0.5), if it has a minor negative environmental impact it receives a value of (0.2), and it has a major environmental impact it receives a score of (0). *Social and Health Related Elements* is one of the criterions assessed in this document. Specifically, the summary notes that the criterion "will assess where low income and/or minority populations concentrations are located…" (page 13; Summary). The review indicates its use of data from the American Community Survey and the EPA EJScreen tool.

	For each criterion, it provides - as applicable - the percentage, the definition, its purpose, the calculation, and the rating scale.
RESEARCH OR POLICY GAPS	Aside from the "social and health related elements" criterion above, the summary does not go into detail about serving underserved communities and does not outline the definition to equity - nor does it mention it explicitly. Equity is indirectly implied in the goals and throughout the resource through incorporation of equitable principles.
BIBLIOGRAPHIC INFORMATION	Delaware Department of Transportation. (2020, February). DelDOT Project Prioritization Criteria. (Summary version). COT. Retrieved October 11, 2021, from https://deldot.gov/Publications/reports/CTP/pdfs/DelDOT_project_prioritization_criteria_summary.pdf.

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LITERATURE CATEGORY	***Equity in BCA*** - ☐ Air Quality | ☒ Physical Health | ☒ Other Quality-of-Life Measure ***Equity in Planning*** - ☒ Underserved Communities | ☐ Long Range Transportation Plans | ☐ Definition of Equity | ☒ Prioritization
LITERATURE SOURCE NAME	The Health Transportation Shortage Index: The Development and Validation of a New Tool to Identify Underserved Communities
RESOURCE DESCRIPTION	The purpose of this report is to outline the new health planning tool, The Health Transportation Shortage Index (HTSI), developed by the Children's Health Fund. The report describes why the tool was developed, the data used, and the impact for supporting communities that need greater transportation resources for child health care access.
PROJECT RELEVANCE	The HTSI tool provides users the ability to more easily assess the key factors related to transportation barriers for accessing child health care for cost efficacy. The tool assesses these factors through an objective and replicable methodology by providing a score to determine relative risk for prioritizing health care access barrier mitigation. The factors used in the tool assessment are: 1) population as a proxy for rural area and for travel distance 2) poverty as a proxy for automobile ownership 3) public transportation availability 4) health care provider workforce availability. The tool uses a point prioritization system for each factor for a total score. Higher scores signify greater risk for transportation barriers for child health care access. By identifying these sensitive areas for greatest need, transportation planners can invest resources on mitigating the transportation barrier and provide an equitable solution for underserved populations. The report recommends a set of reliable data sources for using in scoring the HTSI relating to Type of area, based on population, child poverty rate, public transportation availability, HPSA designation, and FQHC in area (for high poverty areas; with rural health clinics included). Part of the report's own literature review outlines how diabetes has a very high cost in the American health care system. According to the Centers for Disease Control and Prevention (CDC), the annual cost of medical care for diabetes was $116 billion (2007 data). Fifty percent (50%) of those costs were attributed to hospitalization and only nine percent (9%) were from ambulatory care visits. Further studies indicate that the lack of a means of transportation to health care services was a barrier to effective and proper diabetes management. Both rural and urban areas were affected by the cost and unavailability of a means of transportation (page 4). It was also noted that families in rural areas must drive 17% more miles per year than those in urban areas, resulting in gasoline and transportation costs taking up a larger percentage of their overall savings (page 6). Children's health is also of concern as it relates to hospitalization and ED visits for asthmatic conditions, resulting in one of the highest child health care costs in state Medicaid programs. The report notes that "the annual cost of pediatric asthma care exceeds $3 billion." It is further noted that such costs can be reduced through better management with primary care and would result in reduced costs for averted hospital stays and ED visits (page 5).
RESEARCH OR POLICY GAPS	This report was focused on human health with an emphasis on children. The tool was developed for identifying cost-effective prioritization needs for intervention and resource allocation among underserved populations and those in greatest need of transportation services. The topics of equity and air quality, however, were not addressed.
BIBLIOGRAPHIC INFORMATION	Grant R, Johnson D, Borders S, Gracy D, Rostholder T, Redlener I. The Health Transportation Shortage Index: The Development and Validation of a New Tool to Identify Underserved

Communities. A Monograph from Children's Health Fund. 2012. New York: Children's Health Fund. Retrieved October 20, 2021, from https://www.childrenshealthfund.org/wp-content/uploads/2020/09/the-health-transportation-shortage-index.pdf.

Litman T. Evaluating Public Transit Benefits and Costs: Best Practices Guidebook. January 2012. Victoria Transport Policy Institute. Available at: http://www.vtpi.org/tranben.pdf. Accessed January 24, 2012.

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LITERATURE CATEGORY	***Equity in BCA*** - ☒ Air Quality | ☒ Physical Health | ☒ Other Quality-of-Life Measure ***Equity in Planning*** - ☒ Underserved Communities | ☒ Long Range Transportation Plans | ☒ Definition of Equity | ☒ Prioritization
LITERATURE SOURCE NAME	Nashville Area MPO 2035 Regional Transportation Plan
RESOURCE DESCRIPTION	This Long-Range Transportation Plan (LRTP) outlines the current context, vision, strategies, and equity considerations for the Nashville Area region until 2035. The three components of the plan include expanding mass transit options, improving and expanding on active transportation choices and walkable communities, and preserving and enhancing the strategic roadway corridors through a "fix-it-first" methodology.

PROJECT RELEVANCE

The Nashville Area MPO's regional transportation plan discusses the inclusion of health within its project prioritization process. Projects are evaluated, scored and ranked by how well they serve the needs of bicyclists and pedestrians. The elements or prioritization criteria are as follows:

- LOS and Non-Motorized Potential Trips
- Connectivity
- Safety
- Congestion Mitigation
- Community Goals
- Health Impact

Prioritization evaluation methodology and process was developed based on citizen input as well as strategies identified in a bicycle and pedestrian study.

The RTP's Chapter section on *Declining Physical Activity and Personal Health* provides the current context for the region's human health concerns, notes the impact from the lack of access to healthy alternatives, and the potential impact of improving the walkability factor and how that affects human health, congestion, and air quality.

The *Transit Service Strategies and Technologies* chapter offers a variety of examples for investing in Commuter Rail, Light Rail, Bus Rapid Transit, Streetcars, and Shared-Ride/ Vanpool Service options. The table below provides an abbreviated summary and provides cost estimates that could be of value. A summary of typical costs by transit option (shown in Table 14 below) also provides costs to consider in evaluating the overall costs and benefits of public transit.

Table 14. Summary of Typical Costs by Transit Option

Transit Option	Capital Cost per Mile (millions)	Capital Cost per Vehicle (millions)	Operating Cost Per Hour (hundreds)
Commuter Rail	\$3.2 - \$5.6	\$2.7 - \$3.0	\$300 - \$400
Light Rail	\$46 - \$69	\$3.5 -\$5	\$200 - \$250
Streetcar	\$31 - \$56	\$3.5 -\$5	\$140 - \$170
Bus Rapid Transit	\$4 - 8	\$0.6 – \$1.6	\$120 - \$160
Express Bus	n/a	\$0.4 -\$0.7	\$100 - \$110
Regular Route Bus	n/a	\$0.4 -\$0.5	\$95 - 100
Door to Door/Flexibly Routed	n/a	\$0.05 - \$0.07	\$70 -\$75

Costs in 2009 Dollars. Capital costs exclude cost of Right-of-Way.

RESEARCH OR POLICY GAPS	The RTP discusses the inclusion of physical health in project prioritization, but does not provide documentation on the specific processes used for assessing health.

BIBLIOGRAPHIC INFORMATION	Nashville Area Metropolitan Planning Organization (Adopted 2010, December 15) Nashville Area MPO 2035 Regional Transportation Plan. Retrieved October 20, 2021, from http://nashvillempotest.nashville.gov/plans_programs/rtp/2035_rtp.aspx.

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LITERATURE CATEGORY	***Equity in BCA*** - ☒ Air Quality | ☒ Physical Health | ☒ Other Quality-of-Life Measure ***Equity in Planning*** - ☒ Underserved Communities | ☒ Long Range Transportation Plans | ☐ Definition of Equity | ☒ Prioritization
LITERATURE SOURCE NAME	New Zealand's Economic Evaluation Manual
RESOURCE DESCRIPTION	This economic evaluation manual discusses the difference between non-monetized benefit measures and monetized benefits as well as the difference between qualitative and qualitative measures. The manual is a procedural guide for transportation agencies and organizations in standardizing and monetizing social costs and benefits for investment proposals. It includes a breakdown of the basic concepts of economic evaluation procedures, simplified and full economic evaluation of procedures and activities, guidance on input values, and sample evaluation worksheets. The manual reviews the topics of healthy and safe people, resilience and security, economic prosperity, and environmental sustainability.

PROJECT RELEVANCE

Air Emissions

The New Zealand Transport Agency has developed procedures for calculating ambient air emission quantities. The Vehicle Emissions Prediction Model (VEPM) provides additional guidance and demonstrates how to implement these procedures.

A primary thrust of this documentation is determining methods to value the social cost or benefit of air emissions changes resulting from a potential transportation project investment. Thus, the VEPM and various elements of New Zealand's 2018 Economic Evaluation Manual can be used to inform both the potential quantity of air emissions changes associated with a specific project, as well as the social cost or benefit associated with that change.

The Vehicle emission impacts (Appendix A9) indicates a $65.58 per tonne standard value for carbon dioxide (based on June 2016 dollar values) in New Zealand. Particulate emissions were given a monetary value to be included in the BCR calculation (see table A9.1). It is further noted that "The monetary value adopted to reflect the damage costs of CO2 emissions in project evaluations has no relationship to the level of carbon tax or carbon price that the government might consider as a policy instrument to restrain CO2 emissions".

The manual breaks down the adverse health and climate change impacts from vehicle emissions by outlining the distinctions between harmful air pollutants and greenhouse gases. *Table A9.1 Damage costs for use in project evaluations $/tonne* (shown on the following page) provides values for estimating the monetary cost for New Zealand from air pollutants.

Table A9.1 Damage costs for use in project evaluations $/tonne (as at June 2016)

Pollutant	Costs in NZD/tonne	Value Base Date
PM_{10}	$460,012	2016
NO_x	$16,347	2016
CO	$4.13	2016
HC	$1,310	2016

Physical Health Impacts

The New Zealand Transport Agency has also developed procedures for calculating health benefits that accrue from active transportation. These benefits are realized by individuals who change from private vehicles to walking or cycling and experience a shift from inactive to active travel practices.

The value of walking or cycling facility user benefits (other than time saving benefits) is usually based on a willingness-to-pay value derived in a stated preference survey. Benefit values may also be derived from similar facility improvements in other areas.

The economic evaluation manual puts for two monetization tables that can be applied to:

- Composite benefits for footpaths and other pedestrian structures
- Composite benefits for cycle lanes, cycleways, or increased road shoulder widths

Table *A20.3 New pedestrian facility benefits ($/pedestrian km – 2008)* provides values for estimating the monetary benefit of footpaths and other pedestrian structures (see below). Table *A20.4 New cycle facility benefits ($/cyclist km – 2008)* provides values for estimating the monetary benefit of cycle lanes, cycleways, and increased road shoulder widths (see below)

Table A20.3 New pedestrian facility benefits ($/pedestrian km - 2008)

Benefit	Benefit per pedestrian (km)
Health	2.60
Safety	0.00
Road traffic reduction	0.10
Composite benefit	**2.70**

Table A20.4 New cycle facility benefits ($/cyclist km - 2008)

Benefit	Benefit per cyclist (km)
Health	1.30
Safety	0.05
Road traffic reduction	0.10
Composite benefit	**1.45**

Equity Impacts

Equity impacts are noted in 4.4 Evaluation of transport services, section 4.4.5 Benefits of transport services, as follows:

> "Equity impacts of transport service activities should be quantified wherever possible and reported as part of the evaluation (separately from the economic efficiency calculation). Refer to Appendix A18."

The manual mentions equity in various sections of stages of analysis (ex. 4.4.2, 4.5.2, 4.6.2,) , for which describing equity impacts refers to underserved communities similarly such as "transport disadvantaged."

In section 4.7.3 Method of evaluation, the value of travel time is an ‘equity’ approach in order to avoid preference for activities frequented by higher income populations.

Section A17 Equity impacts and external impacts describes four types of equity related to transport: egalitarianism, horizontal equity, vertical equity with respect to income, and vertical equity with regard to mobility needs and abilities.

Noise Impacts

Appendix A8 outlines one primary example of the estimated monetary value impact based on the external impact of property values in relation to road traffic noise impacts. The measurement and prediction of road traffic noise impacts include the following conversion formula to calculate Leq values from the L10 values attributed from the *UK Calculation of road traffic noise* (1988):

Leq (24 hour) = L10 (18 hour) - 3dB(A)

Leq (1 hour) = L10 (1 hour) - 3 dB(A)

The manual notes a British survey (Tinch 1995) that supports international valuations estimates that the costs of noise are roughly “0.7% of affected property values per dB. ” Similarly, a Canadian survey (Bein 1996) showed that “typical costs of 0.6% of affected property prices per dB, and the OECD recommends noise valuation based on 0.5% per dB.” For New Zealand, based on a 1.2% of value of properties affected per dB of noise increase estimate, the monetary cost impact is determined to be $350 per household or $120 per person per year (Page 5–363).

Additional Quality of Life Factors

Some measures that relate to equity and quality of life include noise and vibration, water quality, and landscape impacts, which are noted in the A8.1 summary sheet.

Worksheet A8.2 discusses adverse health impacts from long-term exposure from road traffic noise such as sleep disturbance, speech interference, psychological impacts, and other behavioral impacts that can result in physical stress and reduced wellbeing. Design guidelines for road traffic noise are also provided.

Worksheet A8.4 describes how water quality is affected, the associated impacts, mitigation efforts, measuring impacts, and the reporting of impacts on water quality. A reference to predicting impacts of water quality design manual is also noted.

Worksheet A8.5 reviews the impact considerations for special areas due to their physical or proximity to areas in terms of cultural, spiritual, archaeological, architectural, historical, or aesthetic significance.

Worksheet A8.9 outlines the personal health impacts as well as the measurement and reporting of overshadowing that are protected by law.

The manual also provides a list of benefits (page 4–78; Section 4.3.5) that can be considered as they relate to equity and transport demand management activities:

- VOC savings
- travel time cost savings
- trip reliability
- generated traffic
- spillover effects
- walking and cycling costs
- crash cost savings
- health benefits
- transport service user benefits

- parking user cost savings
- other user benefits
- carbon dioxide reduction
- other monetised and non-monetised environmental impacts
- community livability improvements
- increased consumer travel options
- adjustment for public transport fares
- disbenefits during implementation/construction
- land use benefits
- national strategic factors.

RESEARCH OR POLICY GAPS	This manual does not provide direct clarification of the definition of equity, but provides information on factors that are commonly-known for affecting and adversely impacting minority and underserved populations. Equity in this manual is embedded throughout the guide and seems to be included in the relevant areas as needed.
BIBLIOGRAPHIC INFORMATION	NZTransportAgency . (2018, July 1). Economic Evaluation Manual. (First edition, Amendment 2) Waka Kotahi NZ Transport Agency. Retrieved September 30, 2021, from https://www.nzta.govt.nz/assets/resources/economic-evaluation-manual/eem-manual.pdf.

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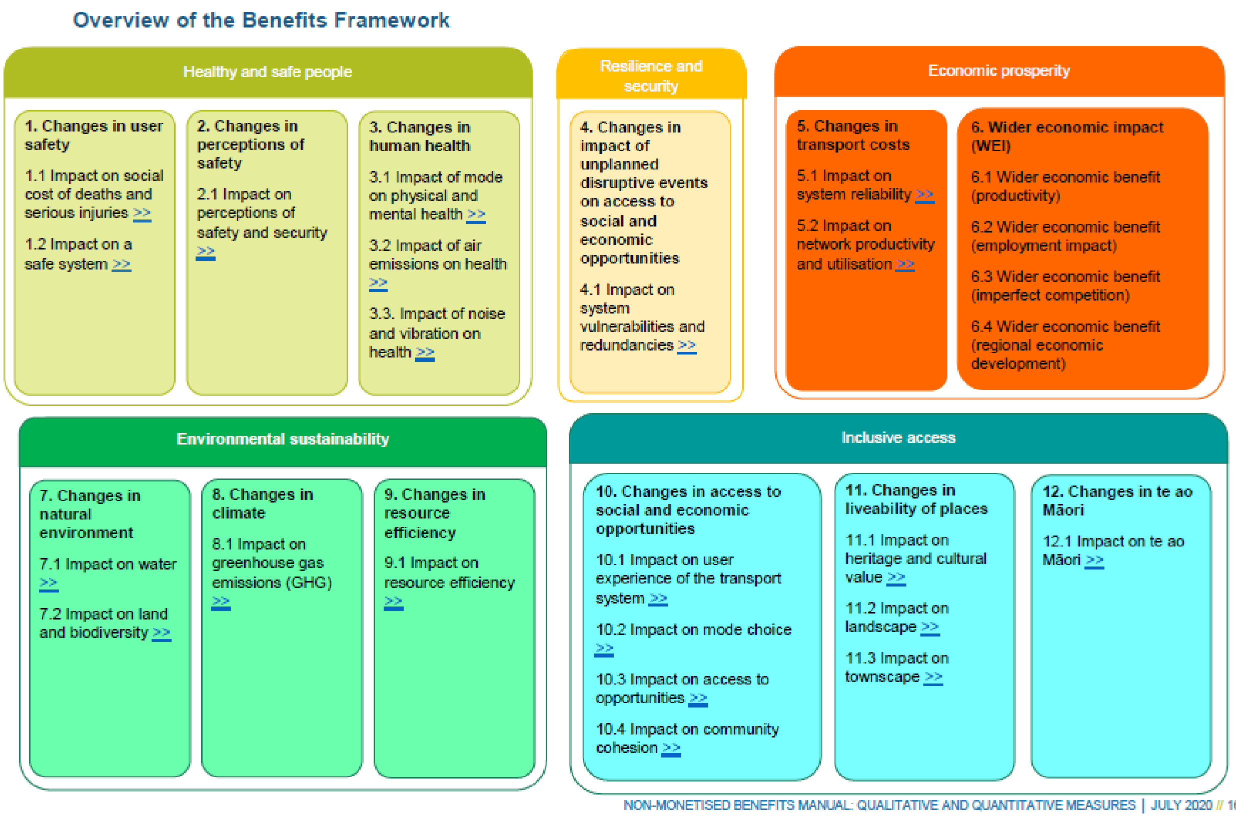
LITERATURE CATEGORY	***Equity in BCA*** - ☒ Air Quality | ☒ Physical Health | ☒ Other Quality-of-Life Measure ***Equity in Planning*** - ☐ Underserved Communities | ☐ Long Range Transportation Plans | ☐ Definition of Equity | ☐ Prioritization
LITERATURE SOURCE NAME	Non-Monetised Benefits Manual Qualitative and Quantitative Measures July 2020 | Version 1
RESOURCE DESCRIPTION	This resource outlines the benefits management approach and benefits framework. It discusses the difference between non-monetized benefit measures and monetized benefits as well as the difference between qualitative and qualitative measures. The manual reviews the topics of healthy and safe people, resilience and security, economic prosperity, and environmental sustainability.
PROJECT RELEVANCE	This guide is specifically for stakeholders such as economic evaluation analysts and transport planning practitioners in understanding non-monetized benefits measures and how to apply them. Because underserved communities are often more susceptible to the adverse effects of transportation project impacts around human health, air quality, resiliency, environmental sustainability, and economic prosperity, this resource is being reviewed to provide greater insight into equitable approaches for incorporating non-monetized benefits measures into project planning. Overall, the guide provides four qualitative benefit measures methodologies: 1. Narratives, thresholds and ranking 2. Rich narrative 3. Scoring 4. User to define It also provides Steps of scoring the methodology: 1. Scope and identify study area 2. Identify key attributes and their features 3. Set baseline of the features 4. Describe the forecast impact of investment 5. Score the forecast impact of investment

The overview of the benefits framework is as follows:



The Changes in Human Health section is used here as an example to preview what each benefits section includes. The benefits noted in the chart above are provided a similar format. Each of these benefits include a review of the intent, scope, and measure relationships such as companion and cause-effect relationships with other measures. A visual benefits relationship chart for each benefit is also included. Depending on the benefit, some are provided a method for calculating the baseline/monitoring data. If a forecasting methodology is available, it is also provided for each benefit.

RESEARCH OR POLICY GAPS	The resource document does not directly discuss how these benefits measures relate to long-range transportation or meeting the needs of underserved communities.
BIBLIOGRAPHIC INFORMATION	NZTransportAgency. (2020, July). Non-Monitised Benefits Manual: Qualitative and Quantitative Measures. (First version) Waka Kotahi NZ Transport Agency. Retrieved October 3, 2021, from https://www.nzta.govt.nz/assets/resources/non-monetised-benefits-manual/non-monetised-benefits-manual-august-2020.pdf.

LITERATURE CATEGORY

Equity in BCA - ☒ Air Quality | ☒ Physical Health | ☒ Other Quality-of-Life Measure
Equity in Planning - ☒ Underserved Communities | ☐ Long Range Transportation Plans | ☒ Definition of Equity | ☒ Prioritization

LITERATURE SOURCE NAME

PBIC Health and Transportation Webinar Series: Planning and Prioritizing Projects for Health

RESOURCE DESCRIPTION

The webinar series was informed by the NCHRP Research Report 932: A Research Roadmap for Transportation and Public Health. The questions that this research sought to answer regarding equity include:

- “How are health and equity defined within the transportation community?”
- “How can transportation practices impact health?”
- “In what ways are transportation agencies considering health in current practices?”
- “What partnerships, research, and other resources are needed to improve practice?

This section on *planning and prioritizing projects for health* is provided in the Pedestrian and Bicycle Information Center (PBIC) Health and Transportation Webinar Series, Part 4. This webinar shares the 2020 update of Virginia’s Pedestrian Safety Action Plan as a key example for illustrating a pedestrian safety analysis for prioritization efforts. This webinar reviews opportunities on using prioritization health criteria in addition to the needed collaboration between health and transportation agencies.

PROJECT RELEVANCE

The first portion of the webinar reviewed the pathways to health and APA’s Planning and Community Health (PCH) program with an introduction to the provided tools, educational materials, past projects, and support available (i.e. Plan4Health) for members in providing equity guidance in health planning. The webinar provided an overview of the research roadmap.

The Virginia Pedestrian Safety Action Plan (PSAP) review discussed the analysis of pedestrian crashes which was updated in 2020. The data analysis sought to understand related crash factors and identify crash patterns over time like where and when pedestrian deaths are happening. The PSAP 2018 safety analysis looked at crash clusters and priority clusters in the data. This method used a scoring factor of 181 priority corridors and distinguished between high, medium, and low factors (slide 29):

Using a spatial Bayesian analysis, the study found with the Health Opportunity Index that HOI and zero vehicle households were the strongest indicators of pedestrian crashes. Employment was a medium-level indicator. Population density and poverty density were low performing indicators (slide 30).

2018 PSAP Corridor Scoring Factors: 181 Priority Corridors

High	Medium	Low
• Annual average daily traffic (AADT) • Posted speed limit • Zero-vehicle households • Population density	• Roadway geometry • Urban/rural context • Employment density • Proximity to a school	• Population living below the poverty line • Pedestrian crash history • Proportion of alcohol related crashes (by district) • Proximity to a park

The 2019 PSAP Corridor Scoring Factors changed to the following factors:

The PSAP and PSAP Online Mapping Tool were such useful tools that it led to $8 million in pedestrian improvement funding approvals in 2018 and an additional $25 million in 2019.

2019 PSAP Corridor Scoring Factors

High	Medium	Low
• Annual average daily traffic (AADT) • Zero-vehicle households • Transit access • Health Opportunity Index (HOI)	• Roadway geometry • Employment density • Proximity to a school • Posted speed limit	• Pedestrian crash history • Proximity to a park • Population density • Urban/rural context • ~~Proportion of alcohol related crashes (by district)~~ • ~~Population living below the poverty line~~

The tool was branded as SMART SCALE to prioritize the “Funding the right transportation projects in Virginia” (the catchphrase). Project types included: Highway, Transit & Rail, Bicyclist and Pedestrian, and Transportation Demand Management. The assessment provided a [smart scale score card]() for project comparison and prioritization.

SMART SCALE | Funding the Right Transportation Projects in Virginia

Lee Highway Phase 3A

Widen Lee Highway to four lanes with a grass median and a 10' shared use path from 300' west of Old Airport Rd to 380' west of the Walmart entrance.

Submitting Entity:	Bristol City
Preliminary Engineering:	Underway
Right of Way:	Not Started
Construction:	Not Started
Eligible Fund Program:	Both
VTRANS Need:	CoSS (click here for details)

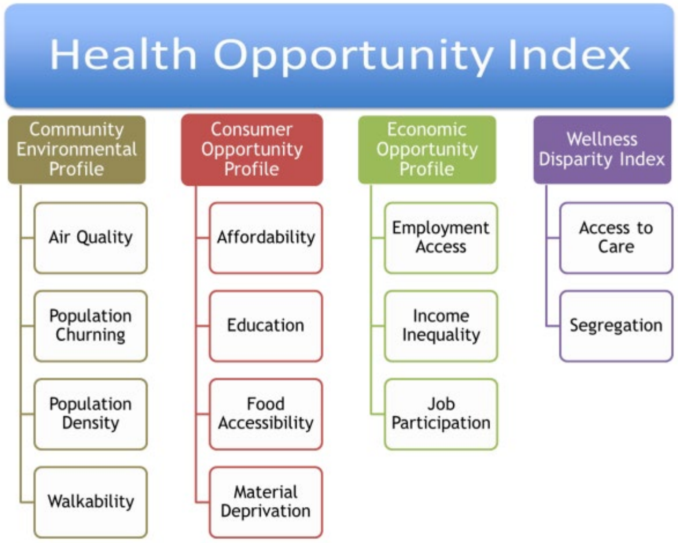
2.2 SMART SCALE SCORE	#198 OF 433 STATEW	#18 OF 44 DISTRIC

SMART SCALE Area Type D

Factor	Congestion Mitigation		Safety		Accessibility			Economic Development			Environment		Land Use	
Measure	Increase in Peak Period Person Throughput	Reduction in Peak Period Delay	Reduction in Fatal and Injury Crashes	Reduction in Fatal and Injury Crash Rate	Increase in Access to Jobs	Increase in Access to Jobs for Disadvantaged Populations	Increase in Access to Multimodal Travel Choices	Square Feet of Commercial/Industrial Development Supported	Tons of Goods Impacted	Improvement to Travel Time Reliability	Potential to Improve Air Quality	Other Factor Values Scaled by Potential Acreage Impacted	Transportation Efficient Land Use	Increase in Transportation Efficient Land Use
Measure Value	16.7 persons	1.1 person hrs.	8.0 EPDO	475.4 EPDO / 100M VMT	5.2 jobs per resident	2.1 jobs per resident	50.0 adjusted users	510,647.4 thousand adj sq. ft.	5,195.2 thousand adj daily tons	9,697,228.2 adj. buffer time index	66.7 adjusted points	1.0 scaled points	access * pop/emp density.h	access * pop/emp density change.
Normalized Measure Value (0-100)	0.1	0.0	2.3	1.0	0.1	0.0	0.2	2.6	0.1	0.2	0.5	3.1		
Measure Weight (% of Factor)	50%	50%	50%	50%	60%	20%	20%	60%	20%	20%	50%	50%	N/A	N/A
Factor Value	0.0		1.6		0.1			1.6			1.8			
Factor Weight (% of Project Score)	10%		30%		15%			35%			10%		N/A	
Weighted Factor Value	0.0		0.5		0.0			0.6			0.2			
Project Benefit	1.3													
SMART SCALE Cost	$5,827,000													
SMART SCALE Score (Project Benefit per $10M SMART SCALE Cost)	**2.2**													

The Virginia Department of Health Office of Health Equity declared their mission for identifying health inequities and the root causes for generating equitable health solutions. They defined health equity as “when everyone has the opportunity to be as healthy as possible” (slide 52).

The Social Epidemiology Division was noted in discussing the Health Opportunity Index which “identifies areas and populations that are most vulnerable to adverse health outcomes based on the Social Determinants of Health” (slide 54). The Index was divided into four main profiles, including Community Environmental Profile, which addressed air quality and walkability, among other health factors. The Index addresses other quality of life indicators as shown here:



ref: slide 58

A further breakdown of the index indicates that the following indicators were used under Air Quality Index (EPA): neurological risk, cancer risk, respiration risk, on-road pollution, non-road, and non-point. The Walkability Index included: density, diversity (land-use), design (connectivity) and distance to transit (see these and other quality-of-life indicators referenced on slides 59-64; 67-68).

RESEARCH OR POLICY GAPS	Regarding the Health Opportunity Index, the Virginia Department of Health noted a few limitations in their data analysis: standard data limitations, ecological fallacy in that individual results varied, census tracts were not equivalent to neighborhoods, the data was based on 5-year estimates, and due to it being a statewide measure (slide 69).
BIBLIOGRAPHIC INFORMATION	Pedestrian and Bicycle Information Center (2020, October 27). Planning and prioritizing projects for health, PBIC Health + Transportation Webinar Series, Part 4. Pedbikeinfo. Retrieved October 14, 2021, from https://www.pedbikeinfo.org/webinars/webseries_healthtransp.cfm.

LITERATURE CATEGORY	***Equity in BCA*** - ☒ Air Quality | ☒ Physical Health | ☒ Other Quality-of-Life Measure ***Equity in Planning*** - ☒ Underserved Communities | ☐ Long Range Transportation Plans | ☐ Definition of Equity | ☒ Prioritization
LITERATURE SOURCE NAME	Health and Transportation Partnerships: Integrating Health Data into Transportation Planning

RESOURCE DESCRIPTION

This resource is from the Pedestrian and Bicycle Information Center (PBIC) Health and Transportation Webinar Series, Part 3. It focuses on the intersection between transportation and health, being inspired by the NCHRP Research Report 932: A Research Roadmap for Transportation and Public Health. The key equity-influenced questions that this research sought to answer include:

- "How are health and equity defined within the transportation community?"
- "How can transportation practices impact health?"
- "In what ways are transportation agencies considering health in current practices?"
- "What partnerships, research, and other resources are needed to improve practice?"

The webinar discussed the pathways to health with emphasis on improving access to opportunities and services – including physical activity, mitigating human exposure to environmental hazards, preventing injuries and improving safety, supporting resiliency to extreme events, and promoting community cohesion.

PROJECT RELEVANCE

The first half of the webinar focused on transportation resources for livable communities. It gave some data-driven and qualitative examples of why this issue is of great concern. The 2040 Roadway Projects Scoring Criteria provided a project scoring criteria out of 100 points and were given a weighted priority, as follows:

- Quality Growth and Sustainable Development – 15 points
- Multi Modal Options – 15 points
- Health & Environment – 15 points
- Safety & Security – 20 points
- Congestion Management – 15 points
- System Preservation & Enhancement – 10 points
- State & Local Support/ Investment – 5 points
- Freight & Goods Movement – 5 points

The analyzed geospatial results for the research show a strong link between the lack of physical activity and human health. The Nashville Area MPO's investment strategy for its surface transportation program (STP) is discussed. The STP investment strategy for funding included:

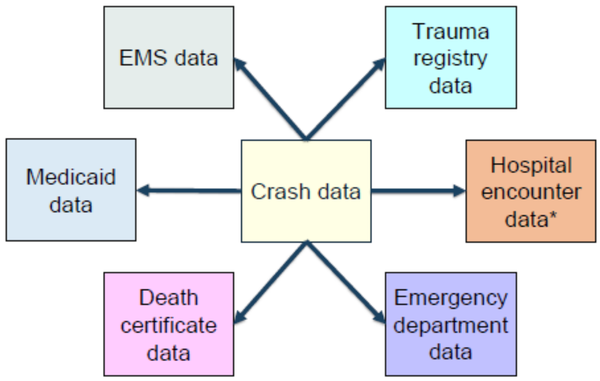
- 70% - Roadway projects that improve health
- 15% - Active Transportation Program:
  - Sidewalks, bicycle lanes, greenways, transit stops; education, enforcement and encouragement"
- 10% - Mass Transit Program
  - Combined with FTA funds to help implement regional vision for mass transit"
- 5% - Regional ITS and Systems Operations
  - Using technology to manage traffic

Nashville Area MPO discussed the implementation of active transportation projects. The MPO specifically tracked active transportation projects and their number of lane miles to assess physical health outcomes. This included assessing changes in lane miles for sidewalks, bikeways, and greenways.

The MPO also developed a transportation and health impact model, which estimated the number of active transportation miles traveled per week.

Disease and exposure related to air pollution, and collision were evaluated. The health impacts and savings were calculated by looking at the change in the disease burden and premature deaths per year which led to an estimated $116 million per year in healthcare costs savings as a potential social benefit.

The second half of the webinar discussed data linkage and it's important to consider in relation to health and transportation. The University of North Carolina's Highway Safety Research Center discussed linking public safety to transportation facilities. A project overview of North Carolina's Crash Injury Surveillance System (NC CISS) was provided. Linked data sources were discussed with the following graphic:



(refer to chart on slide 48)

The research project reviewed how it investigated four linkage methodologies and focused on deterministic linkage with consideration to strengths and the challenge of "a sufficient and representative match rate" (slide 49). Project results for pedestrian injuries and fatalities were reviewed as well to demonstrate the data-warranted complexity of the problem. The research social cost for the total combined medical and work loss costs for 5-year period was $1,524,394,000 (slide 56). This section concludes with a reference to the *North Carolina Data Integration for Motor Vehicle Crash Injury Research: The Long Road Ahead,* as a summary recommendation report.

The third section to this presentation reviews *Health and Transportation Partnerships: Integrating Health Data into Transportation Planning in San Francisco, CA.* The review contends that traffic injury in San Francisco is a major human health problem with approximately:

- 30 fatalities per year
- 500 people hospitalized with severe injuries annually in their public hospital
- $35M in medical costs per year
- City Trauma Surgeons responding to a serious traffic injury every 17 hours
- 50 percent of the patients seen in the General Trauma Center are people injured in traffic collisions

The research outlined shows how vulnerable communities and inequities are linked and can be targeted with prioritization efforts through geospatial analysis.

RESEARCH OR POLICY GAPS

Equity was not directly defined in this resource; however, it was emphasized throughout the research presented with equitable principles noted. Air pollution, quality of life measures, and underserved communities were factors briefly discussed, but not in detail.

BIBLIOGRAPHIC INFORMATION	Pedestrian and Bicycle Information Center (2020, October 22). Health and Transportation Partnerships: Integrating Health Data into Transportation Planning, PBIC Health + Transportation Webinar Series, Part 3. Pedbikeinfo. Retrieved October 11, 2021, from https://www.pedbikeinfo.org/webinars/webseries_healthtransp.cfm.

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LITERATURE CATEGORY	***Equity in BCA*** - ☒ Air Quality | ☐ Physical Health | ☒ Other Quality-of-Life Measure ***Equity in Planning*** - ☒ Underserved Communities | ☐ Long Range Transportation Plans | ☐ Definition of Equity | ☒ Prioritization
LITERATURE SOURCE NAME	Social-Transportation Analytic Toolbox (STAT) for Transit Networks Final Report NITC-RR-1080
RESOURCE DESCRIPTION	This report provides guidance on the open-source, socio-transportation analytic toolbox (STAT) intended for public transit planning. The tool's purpose is to provide a method for integrating social media and general transit feed specification (GTFS) data to improve the decision-making process for transit agencies in improving the performance of public transit systems. The tool can also aid in evaluating service networks to improve equitable access of transit systems by detecting the connectivity gaps to public transit systems for underserved populations in reaching essential services.
PROJECT RELEVANCE	The report references a few resources that emphasize the impact from public transit to quality-of-life measures: "Traffic congestion leads to travel delays, potentially resulting in significant economic losses" (Schrank et al., 2015). It notes how there was $7 billion in economic investment alongside rail lines in the Salt Lake City metro area, upon construction – and employers confirmed that the easy access to transit was a main factor in their location selection process (UDOT, 2015). Another reference indicates the qualitative value of increasing public transit which may improve air quality by reducing emissions from personal vehicles. It further notes the implications for underserved, or "less-privileged," populations who face social exclusion because of the need for public transit to reach essential services like jobs, schools, and healthcare, and grocery stores with fresh produce from limited auto ownership (SEU, 2003). The report notes how the toolbox provides transit agencies a way to assess the efficiency of a service network to improve equitable access to transit systems and determine areas for improvement in meeting transit agency objectives. The tool can be used to recommend improvements for prioritizing stations and routes, identifying the value of adding new lines within a network, etc.
RESEARCH OR POLICY GAPS	The report does not focus on physical health, other than the value added from underserved populations being able to access essential services which might include access to health-related amenities like grocery stores and healthcare. The report also does not focus on long range transportation plans, but rather more directly on public transit.
BIBLIOGRAPHIC INFORMATION	Liu, Xiaoyue Cathy, Wei, Ran, Aaron Golub and Liming Wang. Social-Transportation Analytic Toolbox (STAT) for Transit Networks. NITC-RR-1080. Portland, OR: Transportation Research and Education Center (TREC), 2019. Retrieved October 18, 2021, from https://ppms.trec.pdx.edu/media/project_files/NITC-RR-1080_Social_Transportation_Analytic_Toolbox_for_Transit_Networks_OHRKdfw.pdf Schrank D, Eisele B, Lomax T, Bak J. 2015 urban mobility scorecard. Utah Department of Transportation (UDOT) et al. Utah's unified transportation plan 2015-2040, 2015. Social Exclusion Unit. Making the connections: final report on transport and social exclusion: summary, 2003

LITERATURE CATEGORY

Equity in BCA - ☒ Air Quality | ☒ Physical Health | ☒ Other Quality-of-Life Measure

Equity in Planning - ☒ Underserved Communities | ☒ Long Range Transportation Plans | ☒ Definition of Equity | ☒ Prioritization

LITERATURE SOURCE NAME

Transportation Outlook 2040

RESOURCE DESCRIPTION

This adopted document is the Greater Kansas City's long-range transportation plan for guiding the $33.1 billion in multimodal improvements over the next two decades. The plan was adopted on June 23, 2015 by the Mid-America Regional Council (MARC) Board of Directors. The plan provides guidance on policy, performance measures, standard transportation matters, and of particular interest to this literature review, considers environmental integration, air quality, safety, equity, and facets of public health.

PROJECT RELEVANCE

The Moving Ahead for Progress in the 21st Century (MAP-21) plan outlines the requirements needed for measuring performance, which could potentially serve as prioritization criteria. The 2040 Plan uses indicators to support MARC and associated stakeholders in their evaluation review process. Performance measures are in Chapter 3 (see tables below) and Appendix F.

Some of the equity and quality of life performance factors being measured include:

	Factor	Measure	Data	Goal	Actual	Trend
Economic vitality	Freight movement	Tonnage of goods moved	2013: 239.64 million tons 2014: 264.23 million tons	↑	↑	+1.8%
	Transportation costs	Annual cost of congestion per commuter	2010: $434 2011: $584	↓	↑	+25.86%
	Activity centers	Percentage of annual Transportation Improvement Program (TIP) projects within local activity centers	2012: 65.6% 2013: 63.8%	↑	↓	-1.8%
Placemaking	Multimodal options	Percent of work trips using alternative modes (transit, bicycling, walking, etc.)	2011: 16.99% 2012: 16.56%	↑	—	Not significant
		Percentage of people driving alone to work	2011: 83.01% 2012: 83.44%	↓	—	Not significant
Equity	Environmental justice	Percent of total federal funds (Transportation Improvement Program projects) invested in environmental justice tracts	2012–2016 TIP: 49% 2014–2018 TIP: 69%	↑	↑	+20%

Some public health factors measured include:

	Factor	Measure	Data	Goal	Actual	Trend
Safety and security	Crash fatalities	Number of annual crash fatalities	2012: 198 fatalities 2013: 170 fatalities	↓	↓	-14.1%
		Number of annual crash fatalities per 100 million vehicle miles traveled	2012: 1.31 2013: 1.31	↓	—	no change
	Disabling injuries	Number of annual disabling injuries	2012: 1,337 2013: 1,269	↓	↓	-5.1%
		Number of annual disabling injuries per 100 million vehicle miles traveled	2012: 8.87 2013: 8.86	↓	↓	-0.11%

	Factor	Measure	Data	Goal	Actual	Trend
Public health	Ozone pollution	Three-year average of ground-level ozone reading (parts per billion)	2011–2013: 81 ppb 2012–2014: 76 ppb	↓	↓	-6.2%
		Number of annual ozone pollution violations	2013: 4 violations 2014: 2 violations	↓	↓	-50%
	Physical health	Percent of adults obese in Kansas City Region	2011: 30.2% 2012: 28.3%	↓	↓	-1.9%
		Percent of adults physically inactive in Kansas City Region	2011: 27.7% 2012: 20.5%	↓	↓	-7.2%

Other quality of life measures include:

System condition	Factor	Measure	Data	Goal	Actual	Trend
	Bridge conditions	Percent of structurally deficient bridges	2012: 9.14% 2013: 8.22%	↓	↓	-0.92%
		Percent of functionally obsolete bridges	2012: 17.25% 2013: 16.25%	↓	↓	-1.0%
	Pavement condition	Percent of Kansas roads in MARC region classified as "poor" condition	2013: 0.1% 2014: 0.6%	↓	↑	+0.50%
		Percent of Missouri roads in MARC region classified as "not good" condition	2012: 12.1% 2013: 12.3%	↓	↑	+0.2%

Environment	Factor	Measure	Data	Goal	Actual	Trend
	MetroGreen® network	Completed miles of the MetroGreen trails and greenways network	2011: 242 miles 2014: 324 miles	↑	↑	+33.9%

One of the key directions for the plan includes the strategy to protect and improve environmental resources. They note how they will do this by continuing to implement their metro plan for connecting trails and greenways to main corridors. The result of this will be a decrease in the use of fossil fuels and an improvement in air quality by reducing travel demand.

The environmental consideration factors Kansas City included in its environmental integration review are as follows:

- Land-use impacts.
- Farmland impacts.
- Social impacts.
- Relocation impacts.
- Economic impacts.
- Joint development.
- Considerations relating to pedestrians and bicyclists.
- Air quality impacts.
- Noise impacts.
- Water quality impacts.
- Permits.
- Wetland impacts.
- Water body modification and wildlife impacts.
- Floodplain impacts.
- Wild and scenic rivers.
- Coastal barriers (typically none in the Kansas City region).
- Coastal zone impacts (typically none in the Kansas City region).
- Threatened or endangered species.
- Historic and archeological preservation.
- Hazardous waste sites.
- Visual impacts.
- Energy.
- Construction impacts.
- Relationship of local short-term uses versus long-term productivity.
- Irreversible and irretrievable commitment of resources.

Readers may want to consider reviewing Appendix E – Financial Capacity for more detailed information on costs, financial constraints, and other related matters. One cost-benefit factor to consider that is provided is the estimated operations and maintenance (O&M) cost per mile, as outlined in this table:

Figure E.8: Federal Aid System and O&M cost per mile

O&M	KDOT	Kansas Local	MoDOT/Local
Miles	1,958	4,664	8,094
P/LM Cost	$ 2,800	$ 6,200	$ 6,800
Per Year	$ 5,482,400	$ 28,916,800	$ 55,039,200

In terms of the Transportation Costs factor, the report details how the data shows an approximate cost of $584 per commuter, when considering vehicle price, insurance, maintenance and fuel (Appendix F – Performance; F4)

	One key direction to improve quality of life is to plan for mixed uses by creating quality places to support a variety of lifestyle and transportation options from increased density with mixed-use development. The plan touches on the needs of the growing older population in addition to the increasing racially diverse communities. It notes how these residents are seeking more choices for transportation, housing, and employment. Improving access to jobs for disadvantaged populations is one of the key “opportunities to improve” performance measures for the region. One of the report’s financial conclusions after looking at financially constrained projects within environmental justice areas was that, when broken down by estimated construction costs, these areas amounted to $5,179.70 per capita for EJ areas compared to the $2,247.50 per capita for non-EJ areas. Also, “43.5 percent of roadway projects intersect or are located within EJ areas, amounting to $3,480.70 per capita compared to $2,191.4 per capita for non-EJ areas.” (Appendix J – Environmental Justice; J27).
RESEARCH OR POLICY GAPS	The chapter on air quality is thorough, but it does not include specific values that can be easily translated into costs for a benefits analysis. Chapter 14 on Equity is also a comprehensive review of the current context and strategies, but does not provide clear values which can be translated. The report primarily emphasizes underserved populations in Appendix J – Environmental Justice.
BIBLIOGRAPHIC INFORMATION	Mid-America Regional Council. (2015, June 23) Transportation Outlook 2040. Metropolitan Kansas City's Long-Range Transportation Plan. Retrieved October 19, 2021, from http://www.to2040.org/plandocs.aspx.

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LITERATURE CATEGORY	***Equity in BCA*** - ☒ Air Quality | ☒ Physical Health | ☒ Other Quality-of-Life Measure ***Equity in Planning*** - ☒ Underserved Communities | ☐ Long Range Transportation Plans | ☐ Definition of Equity | ☐ Prioritization
LITERATURE SOURCE NAME	Benefit-Cost Analysis Guidance for Discretionary Grant Programs
RESOURCE DESCRIPTION	This is a recent (February 2021) benefit-cost analysis guide that specifically provides a monetized breakdown of social and human health benefits and costs related to the transportation sector. The resource is a BCA guidance benchmark tool for candidates applying with USDOT's discretionary grant programs.

PROJECT RELEVANCE

The Benefit Cost Analysis Guidance (BCA Guidance) notes how air pollution can cause harm to people and provides appraisal methodologies and values to monetize these costs. USDOT discusses how Some transportation improvements may result in a mix of positive and negative outcomes. For example, an increase in travel speeds may be accompanied by an increase in emissions. In these cases, the negative outcomes would be characterized as "disbenefits" and subtracted from the overall total of estimated benefits.

This resource provides recommended monetized values for emission types NOX, SO2, PM2.5, and CO2 from the years 2020 – 2050 in Table A-6: Damage Costs for Emissions per metric ton (shown on the following page).

In terms of underserved communities, the BCA Guidance notes that transportation project benefits that can improve the quality of life for local or regional residents and visitors may include "improved pedestrian connectivity, increased accessibility for underserved communities, reductions in storm-water runoff, or other localized amenities". It is encouraged that applicants attempt to monetize and/or provide quantifiable data on the benefits to the best of their ability.

Directing efforts to meet the needs of underserved or disadvantaged groups was discussed in the 7.3. Distributional Effects section. It was noted that understanding the overall benefits-to-cost ratio is important for a general public overview, but that policy makers are more often concerned with how the benefits are dispersed among specific socio-economic groups in order to tailor the public investment support needed. Emphasis was placed on the importance of providing the demographics of the anticipated users and "distinguishing between public and private benefits".

This resource references the analysis guidance provided in *Guidance on Treatment of the Economic Value of a Statistical Life in U.S. Department of Transportation Analyses (2016)* to provide insight on monetizing the value of human health from the vehicle-accident fatalities perspective. *Table A-1: Value of Reduced Fatalities and Injuries* outlines the unit values from 2019 data (shown on the following page.

Appendix B contains sample calculations with examples and discussion on the following:

- Inflation Adjustment Calculation
- Discounting Calculation
- Calculation of Benefits to Existing and Additional Users
- Value of Time Savings Calculation
- Crash Modification Factor Calculation
- Safety Benefits Calculation
- Emissions Benefits Calculation
- Residual Value Calculation

Table A-1: Value of Reduced Fatalities and Injuries

Recommended Monetized Value(s)

MAIS Level	Severity	Fraction of VSL	Unit value ($2019)
MAIS 1	Minor	0.003	$32,700
MAIS 2	Moderate	0.047	$512,300
MAIS 3	Serious	0.105	$1,144,500
MAIS 4	Severe	0.266	$2,899,400
MAIS 5	Critical	0.593	$6,463,700
Fatal	Not Survivable	1.000	$10,900,000

KABCO Level	Monetized Value ($2019)
O – No Injury	$3,700
C – Possible Injury	$72,500
B – Non-incapacitating	$142,000
A – Incapacitating	$521,300
K – Killed	$10,900,000
U – Injured (Severity Unknown)	$197,600
# Accidents Reported (Unknown if Injured)	$150,200

Crash Type	Monetized Value ($2019)
Injury Crash	$284,100
Fatal Crash	$12,071,000

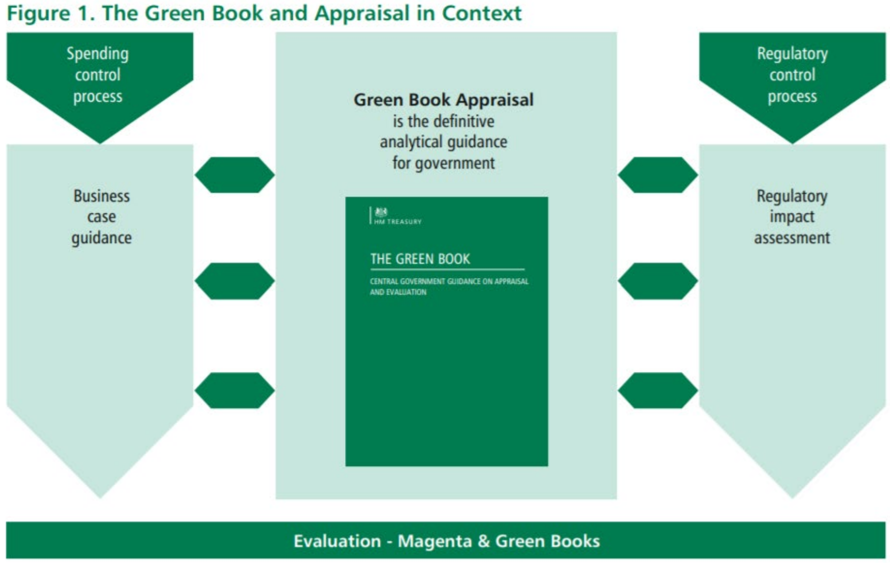
*Table A-6: Damage Costs for Emissions per metric ton**

Recommended Monetized Value(s)

Emission Type	NO_x	SO_2	$PM_{2.5}$**	CO_2
2020	$15,700	$40,400	$729,300	$50
2021	$15,900	$41,300	$742,300	$52
2022	$16,100	$42,100	$755,500	$53
2023	$16,400	$43,000	$769,000	$54
2024	$16,600	$43,900	$782,700	$55
2025	$16,800	$44,900	$796,600	$56
2026	$17,000	$45,500	$807,500	$57
2027	$17,300	$46,200	$818,600	$58
2028	$17,500	$46,900	$829,800	$59
2029	$17,700	$47,600	$841,200	$60
2030	$18,000	$48,200	$852,700	$61
2031	$18,000	$48,200	$852,700	$62
2032	$18,000	$48,200	$852,700	$63
2033	$18,000	$48,200	$852,700	$64
2034	$18,000	$48,200	$852,700	$66
2035	$18,000	$48,200	$852,700	$67
2036	$18,000	$48,200	$852,700	$68
2037	$18,000	$48,200	$852,700	$69
2038	$18,000	$48,200	$852,700	$70
2039	$18,000	$48,200	$852,700	$71
2040	$18,000	$48,200	$852,700	$72
2041	$18,000	$48,200	$852,700	$73
2042	$18,000	$48,200	$852,700	$75
2043	$18,000	$48,200	$852,700	$76
2044	$18,000	$48,200	$852,700	$77
2045	$18,000	$48,200	$852,700	$78
2046	$18,000	$48,200	$852,700	$79
2047	$18,000	$48,200	$852,700	$80
2048	$18,000	$48,200	$852,700	$81
2049	$18,000	$48,200	$852,700	$83
2050	$18,000	$48,200	$852,700	$84

Research or Policy Gaps	Identify any gaps the resource documents related to implementing equity within benefit-cost analysis, long-range transportation, or meeting the needs of underserved communities.
Bibliographic Information	Benefit-Cost Analysis Guidance for Discretionary Grant Programs. *USDOT.* 2021.Online: https://www.transportation.gov/sites/dot.gov/files/2021-02/Benefit%20Cost%20Analysis%20Guidance%202021.pdf

LITERATURE CATEGORY	***Equity in BCA*** - ☒ Air Quality | ☐ Physical Health | ☐ Other Quality-of-Life Measure ***Equity in Planning*** - ☐ Underserved Communities | ☐ Long Range Transportation Plans | ☐ Definition of Equity | ☐ Prioritization
LITERATURE SOURCE NAME	Vehicle Emissions Prediction Model: VEPM 6.2 update technical report
RESOURCE DESCRIPTION	This resource is to aid the understanding and assessment of the VEPM for the purpose of predicting emissions from New Zealand fleet vehicles under standard operations. The model is an emission-analysis tool that provides estimates on "air quality assessments and regional emissions inventories" for future years 2001 – 2050. The VEPM model and technical report are updated regularly to adjust for new technologies and shifts in real-world conditions.
PROJECT RELEVANCE	The VEPM model uses average speeds to predict emissions factors for fleets with consideration to different vehicle types and technologies, and comparative distances traveled for each vehicle class. Calculations for estimating emissions by fleets are discussed in detail. The updated data used in the model are classified into four categories: vehicle type, fuel type, engine capacity (light duty vehicles) or vehicle mass (heavy duty vehicles), and year of manufacture. A few costs to society are mentioned in the key findings from the 2016 fleet data. As the report notes: If tampering was occurring in 100% of the "vulnerable vehicles in the fleet," then the monetary impact to society could be $737 million per year resulting from increased health effects from added emissions. Such occurrence of tampering with vulnerable vehicles, however is more likely closer to 15-30% given international averages, which would be approximately $111 - $222 million per annum in health costs due to excess emissions.
RESEARCH OR POLICY GAPS	Health effects are briefly mentioned, but are not a primary focus of the report (summarized above). The report is technical regarding an in-depth discussion around the fuel and fleet context as it relates to the VEPM. Human and social elements in terms of quality-of-life measures, equity, and underserved communities are not mentioned in this report. Prioritization and long-range transportation plans are also not mentioned here.
BIBLIOGRAPHIC INFORMATION	Metcalfe J, Kuschel G & Peeters S (2021). Vehicle Emissions Prediction Model: VEPM 6.2 technical update report. Report prepared for Waka Kotahi NZ Transport Agency by Emission Impossible Ltd, July 2021. Retrieved October 12, 2021, from https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/air-quality-climate/planning-and-assessment/vehicle-emissions-prediction-model/.

LITERATURE CATEGORY	***Equity in BCA*** - ☒ Air Quality | ☐ Physical Health | ☒ Other Quality-of-Life Measure ***Equity in Planning*** - ☐ Underserved Communities | ☐ Long Range Transportation Plans | ☐ Definition of Equity | ☐ Prioritization
LITERATURE SOURCE NAME	United Kingdom's Guidance on Appraisal and Evaluation (Green Book)
RESOURCE DESCRIPTION	The Green Book is produced by the United Kingdom's HM Treasury. This resource is to be used for all expenditures of public funds in the United Kingdom. The Green Book provides models and guidelines for objective appraisals of public programs and projects and their costs, benefits, and tradeoffs. Figure 1 below shows the framework and context for the Green Book. **Figure 1. The Green Book and Appraisal in Context**  The Green Book is designed to be a versatile decision-making tool, both in terms of the projects it can be applied to, and the audiences that may use it. It is not intended to be completely prescriptive, nor to be used as the sole resource.
PROJECT RELEVANCE	The Green Book includes information on "environmental valuation." Air quality guidelines list three valuation methods based on the cost of the project and legal compliance.
RESEARCH OR POLICY GAPS	The Green Book is produced by the United Kingdom and intended for a UK audience: monetary figures are in British pounds and many measurements use the metric system. Adapting it for a United States context will require careful conversion of these figures. It is also intended as broadly applicable high level guidance for UK decision-making, and thus lacks any specific focus on transportation or equity.
BIBLIOGRAPHIC INFORMATION	H. M. Treasury, London, UK. (2020). The Green Book: Central Government Guidance on Appraisal and Evaluation. Retrieved October, 12, 2021 from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/938046/The_Green_Book_2020.pdf

LITERATURE CATEGORY	***Equity in BCA*** - ☐ Air Quality | ☐ Physical Health | ☐ Other Quality-of-Life Measure ***Equity in Planning*** - ☒ Underserved Communities | ☒ Long Range Transportation Plans | ☒ Definition of Equity | ☐ Prioritization
LITERATURE SOURCE NAME	Comprehensive Review of State DOT Long Range Transportation Plans (LRTPs)
RESOURCE DESCRIPTION	

State	Link to Plan
Alabama	https://www.dot.state.al.us/programs/pdf/SWTP/SWTP.pdf
Alaska	https://dot.alaska.gov/stwdplng/areaplans/lrtpp2016/docs/LRTPpolicyplan_finalsigned_12-16.pdf
Arizona	https://azdot.gov/sites/default/files/2019/08/adot-lrtp-final.pdf
Arkansas	https://www.ardot.gov/wp-content/uploads/2020/10/ARDOT_LRITP_ExecSummary_Final.pdf
California	https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/ctp-2050-v3-a11y.pdf
Colorado	https://www.codot.gov/programs/planning/transportation-plans-and-studies/2040-statewide-transportation-plan
Connecticut	https://portal.ct.gov/-/media/DOT/documents/dpolicy/lrp/2018lrp/FINALConnecticutSLRTP20180313pdf.pdf
Delaware	https://deldot.gov/Publications/reports/plan/pdfs/DelDOT-Long-Range-Transportation-Plan-2019-Innovation-in-Motion.pdf?cache=1642779699986
District of Columbia	https://movedc-dcgis.hub.arcgis.com/
Florida	http://floridatransportationplan.com/
Georgia	http://www.dot.ga.gov/InvestSmart/SSTP/GDOT_FINAL_2021SSTP-2050SWTP.pdf
Hawaii	https://hidot.hawaii.gov/highways/files/2014/09/Statewide-Federal-Aid-Highways-2035-Transportation-Plan_Yong.pdf
Idaho	https://apps.itd.idaho.gov/apps/plan/DRAFT_Long-Range-Plan.pdf
Illinois	https://idot.illinois.gov/transportation-system/transportation-management/planning/lrtp/index
Indiana	https://www.in.gov/indot/files/INDOT_LRTP_FINAL_FullDocWebPost.pdf
Iowa	https://iowadot.gov/systems_planning/pr_guide/Long%20Range%20Transportation%20Plan/LRTP-Guidelines-Sept-2017.pdf
Kansas	https://www.ksdot.org/Assets/wwwksdotorg/bureaus/burTransPlan/Documents/KDOT_LRTP.pdf
Kentucky	https://transportation.ky.gov/Planning/Documents/Statewide%20Plan.pdf
Louisiana	http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Multimodal/Transportation_Plan/Pages/default.aspx
Maine	https://www1.maine.gov/mdot/publications/docs/plansreports/connectingmainefulldocument.pdf
Maryland	https://www.mdot.maryland.gov/tso/pages/Index.aspx?PageId=22
Michigan	https://www.michigan.gov/mdot/0,4616,7-151-9621_14807_14809---,00.html

RESOURCE DESCRIPTION CONTINUED

State	Link to Plan
Minnesota	http://minnesotago.org/learn-about-plans/statewide-multimodal-transportation-plan
Mississippi	https://mdot.ms.gov/documents/Planning/Plan/2045%20MULTIPLAN/2045%20MULTIPLAN.pdf
Missouri	https://www.modot.org/long-range-transportation-plan
Montana	https://www.mdt.mt.gov/tranplan/
Nebraska	https://dot.nebraska.gov/media/115755/ndot-lrtp-final-document.pdf
Nevada	https://www.dot.nv.gov/doing-business/public-involvement-information/transportation-planning/connecting-nevada
New Hampshire	https://www.nh.gov/dot/org/projectdevelopment/planning/documents/CompleteLRTP083110.pdf
New Jersey	https://www.state.nj.us/transportation/works/njchoices/documents.shtm
New Mexico	https://www.tpm-portal.com/document/newmexico-lrtp/
New York	https://www.dot.ny.gov/main/transportation-plan/transportation-plan
North Carolina	https://www.ncdot.gov/initiatives-policies/Transportation/nc-2050-plan/Documents/nc-moves-final-plan.pdf
North Dakota	https://www.dot.nd.gov/projects/lrtp/ExecutiveSummary_July2021.pdf
Ohio	https://www.transportation.ohio.gov/wps/portal/gov/odot/programs/access-ohio-2045/resources/ao45-plan
Oklahoma	https://www.oklongrangeplan.org/
Oregon	https://www.oregon.gov/odot/planning/pages/plans.aspx
Pennsylvania	https://www.penndot.gov/ProjectAndPrograms/Planning/Documents/LRTP/LRTP-Nov2021-DIGITAL.v8.pdf
Rhode Island	http://www.planning.ri.gov/planning-areas/transportation/transportation-2037.php
South Carolina	https://www.scdot.org/multimodal/
South Dakota	https://dot.sd.gov/media/documents/FinalSDLRTP.pdf
Tennessee	https://www.tn.gov/tdot/long-range-planning-home/25-year-transportation-policy-plan.html
Texas	https://ftp.txdot.gov/pub/txdot/tpp/2050/ttp-2050.pdf
Utah	https://unifiedplan.org/wp-content/uploads/2020/09/UnifiedPlan_org.pdf
Vermont	https://vtrans.vermont.gov/sites/aot/files/planning/documents/planning/2040_LRTP_%20Final.pdf
Washington	https://washtransplan.com/wp-content/uploads/2017/05/wtp2035_final_21-jan-2015.pdf
West Virginia	https://transportation.wv.gov/highways/programplanning/LRTP/Documents/Final-Plan-Signed.pdf
Wisconsin	https://wisconsindot.gov/Pages/projects/multimodal/conn2030.aspx
Wyoming	http://www.dot.state.wy.us/home/planning_projects/long-range-plan.html

PROJECT RELEVANCE

LRTPs are relevant to defining equity and communities of concern as well as reviewing how various other states include (or do not include) these topics in setting the agenda for the future of transportation.

RESEARCH OR POLICY GAPS

Some state plans do not mention equity or communities of concern.

BIBLIOGRAPHIC INFORMATION

See References section and links in table.

LITERATURE CATEGORY

Equity in BCA - ☐ Air Quality | ☐ Physical Health | ☒ Other Quality-of-Life Measure
Equity in Planning - ☒ Underserved Communities | ☐ Long Range Transportation Plans | ☒ Definition of Equity | ☐ Prioritization

LITERATURE SOURCE NAME

Reviewed Action Plans and Guides That Include Definitions of Equity

RESOURCE DESCRIPTION

Community/Entity	Plan or Guide Effort	Year	Web Address
American Planning Association	Planning for Equity Policy Guide	2019	https://planning-org-uploaded-media.s3.amazonaws.com/publication/download_pdf/Planning-for-Equity-Policy-Guide-rev.pdf
Austin, TX	Austin Strategic Mobility Plan	2019	https://app.box.com/s/7aiksxmwwgymalsty0lm21wingk0slug
City of San Diego	Climate Action Plan	2016	https://www.sandiego.gov/sites/default/files/final_july_2016_cap.pdf
Cleveland	Integrating Equity in Climate Action Plan	2018	https://www.sustainablecleveland.org/climate_action
FHWA	TCRP Equity Analysis in Regional Transportation Planning Processes	2020	https://www.trb.org/Main/Blurbs/180936.aspx
Highway Safety Research Center Pedestrian and Bicycle Information Center (prepared for USDOT)	Pursuing Equity in Pedestrian and Bicycle Planning	2016	https://www.pedbikeinfo.org/cms/downloads/PBIC_WhitePaper_Equity.pdf
King County (Seattle), WA	King County Equity and Social Justice Strategic Plan	2016	https://aqua.kingcounty.gov/dnrp/library/dnrp-directors-office/equity-social-justice/201609-ESJ-SP-FULL.pdf
Minneapolis, MN	Minneapolis 2040	2019	https://minneapolis2040.com/policies/transportation-and-equity/
Multnomah County	Equity and Empowerment Lens	2014	https://multco.us/diversity-equity/equity-and-empowerment-lens
National League of Cities	Advancing Racial Equity in Your City	2017	https://www.nlc.org/resource/advancing-racial-equity-in-your-city
Portland	Portland Plan	2012	http://www.portlandonline.com/portlandplan/
Project Human City	What is Social Equity?	2017	https://projecthumancity.com/2017/02/02/what-is-social-equity/

RESOURCE DESCRIPTION CONTINUED

Community/Entity	Plan or Guide Effort	Year	Web Address
Project Human City	What is Social Equity?	2017	https://projecthumancity.com/2017/02/02/what-is-social-equity/
Puget Sound Regional Council	Vision 2050: Equity Briefing Paper	2019	https://www.psrc.org/sites/default/files/vision2050equitypaper.pdf
Safe System Consortium	Recommendations of the Safe System Consortium	2021	https://www.jhsph.edu/research/centers-and-institutes/johns-hopkins-center-for-injury-research-and-policy/our-impact/documents/recommendations-of-the-safe-system-consortium.pdf
San Francisco Bay Area	Addressing Social Vulnerability and Equity In Climate Change Adaption Planning	2012	http://www.adaptingtorisingtides.org/wp-content/uploads/2015/04/ART_Equity_WhitePaper.pdf
Smart Growth America	Smart Growth and Equity	2021	https://smartgrowthamerica.org/wp-content/uploads/2021/05/Equity-Summit-Discussion-Full-Set.pdf
The Greenlining Institute	Mobility Equity Framework: How To Make Transportation Work for People	2018	https://greenlining.org/publications/2018/mobility-equity-framework/
The Urban Institute	Access to Opportunity through Equitable Transportation Lessons from Four Metropolitan Regions	2020	https://www.urban.org/sites/default/files/publication/102992/access-to-opportunity-through-equitable-transportation_0.pdf
TransitCenter Transportation Equity Network	Equity in Practice: A Guidebook for Transit Agencies	2021	https://www.cnt.org/sites/default/files/publications/Equity-in-Practice.pdf
Urban Sustainability Directors Network (USDN)	Equity in Sustainability: An Equity Scan of Local Government	2014	https://www.usdn.org/uploads/cms/documents/usdn_equity_scan_sept_2014_final.pdf?source=http%3a%2f%2fusdn.org%2fuploads%2fcms%2fdocuments%2fusdn_equity_scan_sept_2014_final.pdf
USDOT Transportation Planning Capacity Building Program	The Transportation Planning Process Briefing Book	2019	https://www.fhwa.dot.gov/planning/publications/briefing_book/fhwahep18015.pdf
Washington, D.C.	Equity Statement	2021	https://ddot.dc.gov/page/equity-statement

PROJECT RELEVANCE

Action Plans and Guides relevant to identifying the state of practice related to defining equity and communities.

RESEARCH OR POLICY GAPS

The definitions outlined in these sources vary in nature and scope, as discussed in this report.

BIBLIOGRAPHIC INFORMATION

See sources in table.

LITERATURE CATEGORY	***Equity in BCA*** - ☐ Air Quality | ☐ Physical Health | ☐ Other Quality-of-Life Measure ***Equity in Planning*** - ☒ Underserved Communities | ☐ Long Range Transportation Plans | ☒ Definition of Equity | ☒ Prioritization
LITERATURE SOURCE NAME	Transportation Equity Toolkit: Transportation Equity Needs Assessment and Project Prioritization
RESOURCE DESCRIPTION	This toolkit is designed to serve as a resource for MPOs, transportation agencies, and communities as they work to advance equity in traditionally underserved communities. It provides a framework for a transportation equity needs assessment and an equity-based project identification and prioritization process. A variety of tools and methods are provided for these frameworks, including 1) Transportation Equity Audit Tool: a survey-based tool designed for use by agency staff, community organizers and community members in identifying community transportation needs from an equity perspective; and 2) Transportation Equity Scorecard Tool: a spreadsheet tool to assist the staff of MPOs and other transportation planning agencies in prioritizing projects that advance equity.

PROJECT RELEVANCE	This resource provides practical tools for assessing and measuring equity. The toolkit is divided into two parts:
	
	Part I - Identifying Community Needs describes the needs assessment process, includes:
	• What a needs assessment is;
	• The motivation for an equity-based needs assessment;
	• The groups that may be involved in the assessment, how they can apply it, and the benefits to them;
	• The geographic areas that may be assessed using the process and tools;
	• How to conduct a needs assessment and how the community can meaningfully participate;
	• Different approaches for evaluating the results.
	
	Part II - Screening and Prioritizing Projects, includes:
	• An explanation of the need for an equity-based screening and prioritization process;
	• The role of agency staff and community in screening and prioritization;
	• Describes the application of tools like the Transportation Equity Audit Tool and the Transportation Equity Scorecard Tool and presented through this toolbox;
	• The scorecard includes the following components:
	  ○ Access to Opportunity
	  ○ Health and Environment
	  ○ Safety and Emergency Evacuation
	  ○ Affordability
	  ○ Mobility
	  ○ Burdens

PROJECT RELEVANCE CONTINUED	This resource also includes the following definitions of interest: • Transportation Equity: a representation of fairness in the distribution of benefits and burdens • Communities of Concern (COCs): a planning term that encompasses demographic characteristics of populations that are historically disadvantaged in relation to transportation, including but not limited to low income, minority, Limited English Populations, persons with disabilities, zero-vehicle households, seniors, at-risk youth, rent burdened households, and other similar characteristics • Community services: public locations, such as community centers, parks and recreational areas, and recreation centers, that provide space for meetings, activities, events, public services, and other uses by community members. • Essential destinations: areas that people are likely to travel to in order to fulfill their daily needs or desires and include essential services and destinations, such as employment, shopping, entertainment, recreation, health care, education and other services. Food desert: an area that has limited access to affordable and nutritious food, particularly fresh produce and other unprocessed foods.
RESEARCH OR POLICY GAPS	Many facets of equity in transportation are covered, however, this source does not offer guidance for developing equity definitions.
BIBLIOGRAPHIC INFORMATION	Williams, K.M., Boyd, T., Keita, Y., and Kramer, J. (2021). Transportation Equity Toolkit: Transportation Equity Needs Assessment and Project Prioritization. Prepared for the Center for Transportation, Equity, Decisions, and Dollars (CTEDD). Retrieved on September 29, 2021 from https://www.cutr.usf.edu/wp-content/uploads/2021/09/CTEDD-Transportation-Equity-Toolkit-04212021.pdf

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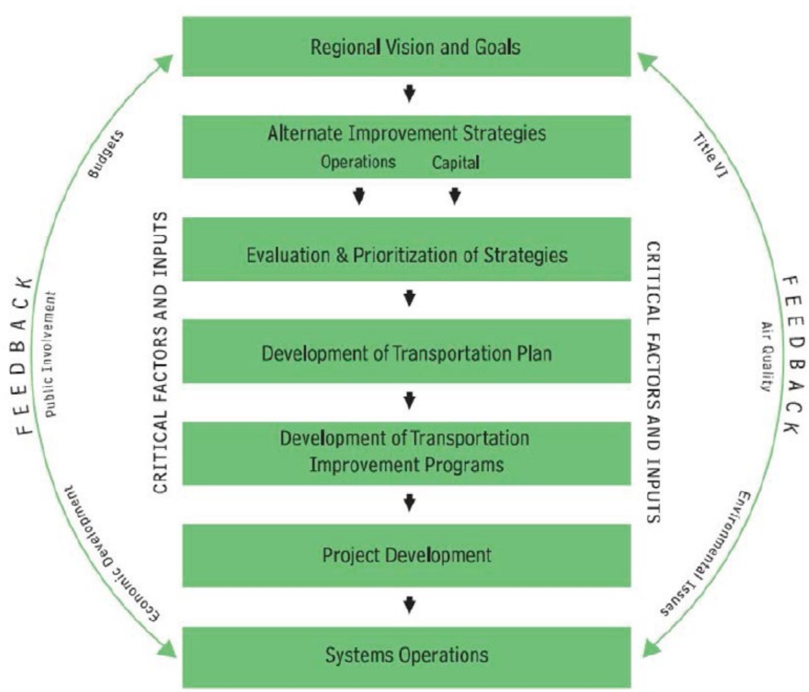
LITERATURE CATEGORY	***Equity in BCA*** - ☐ Air Quality | ☐ Physical Health | ☐ Other Quality-of-Life Measure ***Equity in Planning*** - ☒ Underserved Communities | ☒ Long Range Transportation Plans | ☐ Definition of Equity | ☐ Prioritization
LITERATURE SOURCE NAME	TCRP Equity Analysis in Regional Transportation Planning Processes, Volume 1: Guide TCRP Equity Analysis in Regional Transportation Planning Processes, Volume 2: Research Overview
RESOURCE DESCRIPTION	Volume 1 documents a five-step equity analysis framework for regional transportation plans and programs that provides a high-level overview of relevant requirements and the analysis framework. Also included are quick-reference charts of activities, resources, and guidebook sections that apply particularly to planners, policy makers, analysts, and modelers. Foundational approaches to public and stakeholder engagement throughout the entire analysis process are outlined. Volume 2 describes the results of a research effort conducted to identify ways in which equity in public transportation can be analyzed through an integrated participatory and quantitative approach that is adaptable to plans and programs developed by MPOs in partnership with transit agencies and that relates to environmental justice analysis and Title VI procedures, implementation, and reporting compliance. The products of this research are designed to help transportation professionals engaged in the process of planning and programming federal transportation funds at MPOs and transit agencies..
PROJECT RELEVANCE	Volume 1 provides step-by-step descriptions of methods, examples, and resources to help agencies develop and implement equity analyses that reflect varying regional contexts and agency capabilities are provided. Descriptions of brief pilot projects conducted with four metropolitan planning organizations (MPOs) to test different aspects of the equity analysis framework are outlined. A separate Research Overview, published as TCRP Research Report 214, Volume 2, describes the results of the research effort conducted to identify ways in which equity in public transportation can be analyzed through an integrated participatory and quantitative approach that is designed to be adaptable for MPOs in partnership with transit agencies and that relates to environmental justice analysis and Title VI procedures, implementation, and reporting compliance. Volume 2 provides information about methods, tools, and resources that agencies can use to support plans and programs that are compliant with equity-related federal requirements. The guidance and information provided in the reports do not constitute any standard, specification, or regulation.
RESEARCH OR POLICY GAPS	These guides are comprehensive in nature. The primary limitation is that this source does not address the nuances of transportation agencies. Therefore, agencies will need to apply this guidance in a manner that aligns with their resources and goals.
BIBLIOGRAPHIC INFORMATION	Twaddel, H. and Zgoda, B. (2020). Equity Analysis in Regional Transportation Planning Processes, Volume 1: Guide. Transit Cooperative Research Program Report 214. National Academies of Sciences, Engineering, and Medicine. Washington, DC: The National Academies Press. https://doi.org/10.17226/25860. Twaddel, H. and Zgoda, B. (2020).Equity Analysis in Regional Transportation Planning Processes, Volume 2: Research Overview. Washington, DC: The National Academies Press. https://doi.org/10.17226/25886.

LITERATURE CATEGORY	***Equity in BCA*** - ☐ Air Quality | ☐ Physical Health | ☐ Other Quality-of-Life Measure ***Equity in Planning*** - ☒ Underserved Communities | ☒ Long Range Transportation Plans | ☒ Definition of Equity | ☒ Prioritization
LITERATURE SOURCE NAME	The Transportation Planning Process Briefing Book: Key Issues for Transportation Decisionmakers, Officials, and Staff by the USDOT Transportation Planning Capacity Building Program
RESOURCE DESCRIPTION	This 2019 document provides an overview of transportation planning for government officials, transportation decisionmakers, planning board members, transportation service providers, interested stakeholders, and the public. It covers the basics and key concepts of metropolitan and statewide transportation planning, along with references for additional information. This resource is broken into two parts. Part I discusses transportation planning and its relationship to decisionmaking. This section is general and provides a broad introduction to the planning process, while Part II presents short descriptions of the key products that are prepared as part of the transportation planning process. The Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) regularly update this informational publication. This version replaces its predecessor of the same title last published in 2017.
PROJECT RELEVANCE	Provides a background on the importance of transportation planning and relevant federal policies. Includes comprehensive guidance for every aspect of transportation planning, including equity considerations, through the lens of the federal government. Prioritization and performance measures are also addressed. The writing style user-friendly and practical guidance for agencies is provided. The transportation planning process is described as follows: Figure 1. *The Transportation Planning Process* 

RESEARCH OR POLICY GAPS	This source only briefly addresses equity specifically, as the focus is on the larger transportation planning process. Equity is addressed using alternative terms when engagement, performace measures, prioritization, and other related steps in the process are discussed.
BIBLIOGRAPHIC INFORMATION	Transportation Planning Capacity Building Program, The Transportation Planning Process Briefing Book: Key Issues for Transportation Decisionmakers, Officials, and Staff: A publication of the Transportation Planning Capacity Building Program, USDOT Federal Highway Administration, Federal Transit Administration (2019). Retrieved on September 21, 2021 from https://www.fhwa.dot.gov/planning/publications/briefing_book/fhwahep18015.pdf.

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LITERATURE CATEGORY	***Equity in BCA*** - ☐ Air Quality | ☐ Physical Health | ☐ Other Quality-of-Life Measure ***Equity in Planning*** - ☒ Underserved Communities | ☒ Long Range Transportation Plans | ☒ Definition of Equity | ☐ Prioritization
LITERATURE SOURCE NAME	APA Planning for Equity Policy Guide
RESOURCE DESCRIPTION	Examines equity through the lens of land use and transportation planning. The target audience is the planning community, with an emphasis on explaining how equity is factors into the field and how related policies can more effectively address equity issues.
PROJECT RELEVANCE	This guide can serve as a helpful resource for breaking down the value and application of equity for planning professions using language they can understand. While the focus in on strengthening policies, the document is relevant to both policymakers as well as community planners. The intersection of equity and other areas adjacent to the planning field such as climate change and education are discussed and policy tips are provided. In addition to the text descriptions, this guide also provides succinct resources including a timeline of equity in planning and data on the demographic composition of professionals working in the planning field.
RESEARCH OR POLICY GAPS	Prioritization is not addressed in this source. Because the focus of this source is on education the planning community about equity in the field, the information presented is at the policy-making level. Therefore, limited guidance about specific data analysis and measurement approaches is provided.
BIBLIOGRAPHIC INFORMATION	The American Planning Association (2019). Planning for Equity Policy Guide. Retrieved on October 25, 2021 from https://planning-org-uploaded-media.s3.amazonaws.com/publication/download_pdf/Planning-for-Equity-Policy-Guide-rev.pdf

Appendix B – Data Review Resource Summaries

INCLUDING EQUITY IN BENEFIT COST ANALYSIS | APPENDIX B

DATA CATEGORY	Equity in BCA - ☒ Air Quality | ☒ Physical Health | ☒ Other Quality-of-Life Measure Equity in Planning - ☒ Underserved Communities | ☐ Long Range Transportation Plans | ☐ Prioritization
DATA SOURCE NAME	United Health Foundation: America's Health Rankings (AHR)
DATA DESCRIPTION	America's Health Rankings (AHR) is a web-based tool that provides data and reports on a number of measures across the United States. Data are publicly available and can be downloaded as a .csv file and is available for each state and the United States overall. User's can select a state from the thematic map, which simultaneously acts as a choropleth map ranking each state by the selected measure. Users can also navigate with a dropdown menu to choose their measure, state, and year. The author's note that AHR is based on the World Health Organization's definition of health: "Health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity." A large number of measures are available within five parent categories: health outcomes, social & economic factors, physical environment, clinical care and behaviors. These categories were created as part of a transition to a new model beginning in 2020 that "reflects a growing understanding of the impact social determinants have on health and the need for collaboration and action by stakeholders across sectors to reduce inequities and improve health outcomes." AHR also releases three reports: the Annual Report, which assesses health on a state by state basis; the Senior Report, which compares the health of older adults; and The Health of Women and Children Report, which focuses on women of reproductive age, infants and children. Rankings are based on the following data sources: • American Community Survey (ACS) • Behavioral Risk Factor Surveillance System Data (BRFSS) • National Immunization Survey • National Survey of Children's Health (NSCH) • National Survey on Drug Use and Health (NSDUH) • CDC Wonder Online Database • Pregnancy Risk Assessment Monitoring System (PRAMS)
PAST USES	AHR has been used by state agencies to inform policies and healthcare systems. Specific uses by states include efforts to reduce obesity, infant mortality, and tobacco use.
PROJECT RELEVANCE	AHR rankings intentionally include social determinants of health, and seek to identify and help rectify inequities. Downloadable datasets include measures on women and children, poverty, unemployment, homelessness, and racial disparity. While most measures are more directly related to health and sociodemographics, the "Physical Environment" category includes datasets on climate change policies and transportation. Authors note that the three reports "allow users to look at disparities in health by race/ethnicity, gender, age, education and income for a number of measures."

SIMILAR DATASETS	ASTHO's Evidence Based Public Health; The Community Guide (https://www.thecommunityguide.org/)
UPDATE FREQUENCY	AHR is updated at least annually. Datasets are available for 2016, 2018, 2019, 2020, and 2021. AHR began in 1990.
DATA CONNECTION TO EQUITY	AHR includes a focus on social determinants of health, and many measures focus specifically on women and seniors.
DATA GAPS OR LIMITATIONS	AHR is true to its name and focuses primarily on ranking states across different measures. Values for specific measures are explained, and in many cases can be understood on their own (for example, percentages of women in poverty) but at a summary level, ranks and comparisons across states are what is most evident.
BIBLIOGRAPHIC INFORMATION	United Health Foundation. (n.d.). America's Health Rankings. Retrieved October 27, 2021, from https://www.americashealthrankings.org

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DATA CATEGORY	Equity in BCA - ☒ Air Quality | ☒ Physical Health | ☒ Other Quality-of-Life Measure Equity in Planning - ☒ Underserved Communities | ☒ Long Range Transportation Plans | ☐ Prioritization
DATA SOURCE NAME	Built Environment and Public Health Clearinghouse
DATA DESCRIPTION	The Built Environment and Public Health Clearinghouse (BEPHC) is a publicly available resource that provides links to other resources according to six categories: Data and Assessment; Funding Opportunities; Professional Training; Webinars; Academic Training;, and Schools. Data and Assessment is organized under five categories: Communities, Health, Housing, Policy, and Transportation. It includes sources include the CDC, USDOT, Urban Land Institute, and more. Professional Training , Academic Training, and Schools are organized under four categories: Planning, Architecture, Transportation Engineering, and Health Impact Assessment. Professional Training resources include conferences, webinars, organizations, and more. Academic Training Resources syllabi, course curricula, and associated resources. Schools provides a list of colleges and universities by category, noting what department the associated program is under and whether it overlaps with other disciplines. The Webinars link provides webinars organized under 15 categories related to planning, transportation, public health, and safety. Most webinar links include a brief description.
PAST USES	N/A
PROJECT RELEVANCE	The BEPHC is not a dataset itself, but linked resources cover virtually every topic in planning, transportation, and health. Like other clearinghouse resources, the utility of the BEPHC is based on the resources it provides.
SIMILAR DATASETS	N/A
UPDATE FREQUENCY	The BEPHC is regularly maintained by the Georgia Institute of Technology.
DATA CONNECTION TO EQUITY	Webinar categories include specific equity topics, such as Accessibility, Aging Population, and Health Equity.
DATA GAPS OR LIMITATIONS	Since the BEPHC is a clearinghouse, it is most useful as a tool for finding other relevant resources.
BIBLIOGRAPHIC INFORMATION	Georgia Institute of Technology. (2021.). Built Environment and Public Health Clearinghouse. Retrieved October 28, 2021, from http://www.bephc.gatech.edu/.

DATA CATEGORY	Equity in BCA - ☒ Air Quality | ☐ Physical Health | ☐ Other Quality-of-Life Measure Equity in Planning - ☒ Underserved Communities | ☐ Long Range Transportation Plans
DATA SOURCE NAME	Environmental Protection Agency (EPA) Smart Location Database
DATA DESCRIPTION	The EPA Smart Location Database is a nationwide dataset including over 90 variables at the block group level. While most variables are available for all block groups in the United States, some data is limited to metropolitan regions with available transit agencies that have GTFS data. The Smart Location Database is available as a table download, GIS shapefiles, and interactive web services. Variables include transit accessibility, land use diversity, density, employment, and demographics. The Smart Location Database measures location and transportation efficiency and accessibility, especially for transit and automobile travel. Urban design variables describe street intersection and high-speed road density. Employment and housing variables are included and are evaluated with transportation network information to measure accessibility variables, displaying the workers and jobs that are accessible within a 45-minute trip according to transit and automobile modes.
PAST USES	The Smart Location Database is part one of the EPA's Smart Location Mapping resources. These resources have been used for evaluating neighborhood conditions, travel demand modeling, nationwide research, scenario planning, and more.
PROJECT RELEVANCE	The Smart Location Database includes a wealth of information on transit access, including areas where the population has access to transit services, and measures of jobs that are available within a 45-minute walk and transit trip. Higher transit accessibility allows for more emission free transportation and thus can inform air quality research. Transit access and jobs access is also measured by low and medium wage workers, which is useful for identifying underserved communities that have high or low job access.
SIMILAR DATASETS	EPA's Access to Jobs and Workers Via Transit Tool, EPA's National Walkability Index
UPDATE FREQUENCY	The database is updated intermittently with new data releases in 2011, 2013, and 2021.
DATA CONNECTION TO EQUITY	The EPA SLD helps identifying the connection between where people live, where jobs are, and the means of transportation between housing and jobs. By linking this to demographic information, one can zero in on communities of concern and the resources and challenges they face.
GAPS OR LIMITATIONS	While most attributes are available throughout the US, there are some gaps. Areas which are not served by transit agencies that share General Transit Feed Specification (GTFS) data will not have full coverage
BIBLIOGRAPHIC INFORMATION	Environmental Protection Agency. (2021). Smart Location Database, accessed on August 19, 2021 at https://www.epa.gov/smartgrowth/smart-location-mapping#SLD

DATA CATEGORY	Equity in BCA - ☒ Air Quality | ☐ Physical Health | ☐ Other Quality-of-Life Measure Equity in Planning - ☐ Underserved Communities | ☐ Long Range Transportation Plans | ☐ Prioritization
DATA SOURCE NAME	EPA MOtor Vehicle Emission Simulator (MOVES)
DATA DESCRIPTION	EPA's MOtor Vehicle Emission Simulator (MOVES) is an emissions modeling system that estimates emissions for mobile sources for criteria air pollutants, greenhouse gases and air toxins. Mobile sources covered by MOVES include on-road vehicles such as cars, trucks and buses, and nonroad equipment such as bulldozers and lawnmowers. Aircraft, trains, and marine vessels are not covered. Modeling for both on-road and nonroad emissions sources is available at the national or county scale using either model defaults or user-supplied inputs. On-road sources can be modeled at a more detailed "project" scale depending on user provided inputs. Estimates are based on fleet average emissions and not individual vehicles. MOVES adjusts emission rates to represent real-world conditions, accounting for national emission standards, vehicle populations and activity, state and local rules, fuels, temperatures & humidity. • MOVES is publicly available and can be downloaded from the EPA's website at https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves.
PAST USES	MOVES has been used for a large number of purposes and contexts. MOVES has been used by researchers, contractors, and planners. The MOVES model has been applied to international contexts, including Beijing. Specific uses include analysis on smart traffic systems, autonomous vehicles, and intersection signalization.
PROJECT RELEVANCE	MOVES can be used to measure and quantify emissions, helping to evaluate the impact on air quality for a variety of interventions.
SIMILAR DATASETS	EPA's Biodiesel Emissions Analysis Program; EPA's Complex Model Used to Analyze RFG and Anti-dumping Emissions Performance Standards; EPAct/V2/E-89 Tier 2 Gasoline Fuel Effects Study; EPA's Heavy-Duty Diesel Fuel Analysis; EPA's Ultra-Low Sulfur Gasoline Emissions Study; EPA's Tier 3 Certification Fuel Impacts Test Program; MOVESTAR: An Open-Source Vehicle Fuel and Emission Model based on USEPA MOVES

UPDATE FREQUENCY	MOVES overview documentation lists two predecessor products and 8 different public release versions, for a total of 10 entries. The following list includes the name of the release followed by the release date: • MOBILE1- MOBILE6.2 – 1978-2004 • NONROAD – 1998 – 2010 • MOVES2010 – 2010 • MOVES2010a – 2010 • MOVES2010b – 2012 • MOVES2014 – 2014 • MOVES2014a – 2015 • MOVES2015b – 2018 • MOVES3 – 2020 • MOVES3.0.1 - 2021
DATA CONNECTION TO EQUITY	MOVES does not have a direct equity connection. However, as a modeling tool, it can be applied in a variety of planning contexts. Modeling traffic emissions can help predict the impacts of specific actions and interventions.
DATA GAPS OR LIMITATIONS	MOVES is limited to on-road emissions sources - aircraft, trains, and marine vessels are not covered. As a modeling tool, it is very powerful, but unlike datasets or shapefiles, it requires the user to download an application and is not as user friendly as other resources. While default inputs are provided, applying the MOVES model more broadly requires use provided inputs.
BIBLIOGRAPHIC INFORMATION	USEPA (2021). Overview of EPA's MOtor Vehicle Emission Simulator (MOVES3). EPA-420-R-21-004. Office of Transportation and Air Quality. US Environmental Protection Agency. Ann Arbor, MI. March 2021. Retrieved: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1011KV2.pdf

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DATA CATEGORY	Equity in BCA - ☒ Air Quality | ☒ Physical Health | ☐ Other Quality-of-Life Measure Equity in Planning - ☐ Underserved Communities | ☐ Long Range Transportation Plans | ☒ Prioritization
DATA SOURCE NAME	Global Annual PM2.5 Grids from MODIS, MISR and SeaWiFS Aerosol Optical Depth (AOD) with GWR, v1 (1998 – 2016)
DATA DESCRIPTION	This geospatial data set is used to measure the global surface concentrations of mineral dust and sea-salt filtered fine particulate matter of 2.5 micrometers or smaller (PM2.5) for worldwide health and environmental research. Because this is a global data set, each file has floating point values for PM2.5 concentration approximations. Raster grids' cell resolution is 0.01 degrees and covers the land surface from 70 degrees north to 55 degrees south. The data is in GeoTIFF (.tif) and can be downloaded as zip files from any year between 1998 – 2016. The geospatial format is in raster, map, and map service. The publisher is NASA Socioeconomic Data and Applications Center (SEDAC). There are no access constraints. Potential users "are free to use, copy, distribute, transmit, and adapt the work for commercial and non-commercial purposes, without restriction, as long as clear attribution of the source is provided" (Metadata).
PAST USES	The Citations Database (found here) is a searchable collection of all the identified publications that cite the SEDAC data.
PROJECT RELEVANCE	This data set provides a large-scale overview of file particulate matter – 2.5 micrometers or smaller (PM2.5) for comparative health and environmental research analysis. The annual range of the data set may also be useful for assessing how changes in air quality are related to changes in human health, among other quality of life data sets to be analyzed. This data set may act as a control data standard for assessing alongside other air quality data sets at the local level.
SIMILAR DATASETS	PurpleAir is a private-sector air quality sensor for purchase. The PA-II sensor measures real-time PM2.5 concentrations for residential, commercial, or industrial use. The company keeps an online mapped inventory of PM2.5 conditions at its sensors; however, the inventory is not yet very robust.
UPDATE FREQUENCY	From 1998 – 2016.
DATA CONNECTION TO EQUITY	Outliers in air quality standards is one quantitative measure that may be used for identifying areas of concern that need policy and regulatory action, especially of those standards are adversely affecting communities of concern, underserved communities, and transportation disadvantaged communities. This data set may be useful for including in equity considerations as it relates to long range transportation plans (LRTPs).
DATA GAPS OR LIMITATIONS	The data is intended for for large-scale studies. Gridded data sets are at 0.01 degrees. Data sets "do not fully resolve PM2.5 gradients at the gridded resolution due to influence by information sources at coarser resolutions" (Abstract).
BIBLIOGRAPHIC INFORMATION	van Donkelaar, A., R. V. Martin, M. Brauer, N. C. Hsu, R. A. Kahn, R. C. Levy, A. Lyapustin, A. M. Sayer, and D. M. Winker. 2018. Global Annual PM2.5 Grids from MODIS, MISR and SeaWiFS Aerosol Optical Depth (AOD) with GWR, 1998-2016. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H4ZK5DQS. Accessed DAY MONTH YEAR. ENW (EndNote & RefWorks)† RIS (Others)van Donkelaar, A., R. V. Martin, M. Brauer, N. C. Hsu, R. A. Kahn, R. C. Levy, A. Lyapustin, A. M. Sayer, and D. M. Winker. 2016. Global Estimates of Fine Particulate Matter Using a Combined Geophysical-Statistical Method with Information from Satellites. Environmental Science & Technology 50 (7): 3762-3772. https://doi.org/10.1021/acs.est.5b05833 (Citations).

DATA CATEGORY	Equity in BCA - ☒ Air Quality | ☒ Physical Health | ☒ Other Quality-of-Life Measure Equity in Planning - ☐ Underserved Communities | ☐ Long Range Transportation Plans | ☐ Prioritization
DATA SOURCE NAME	Healthy Community Design Checklist Toolkit (CDC)
DATA DESCRIPTION	The Healthy Community Design Checklist Toolkit is a publicly available resource for community planning. It is comprised of four elements: • Healthy Community Design Checklist • Healthy Community Design PowerPoint Presentation • Creating a Health Profile of Your Neighborhood • Planning for Health Resources Guide The Checklist is a handout for use at public meetings. It includes informational resources and a short survey. The Checklist covers the following topics: Active Living, Food Choices, Transportation Choices, Public Safety, Social Cohesion, Social Equity, and Environmental Health. The PowerPoint Presentation is a downloadable PowerPoint file including slides and speaker notes. The presentation is customizable and is intended for users to input information about their own community. Creating a Health Profile of Your Neighborhood is a brief guide designed to help users create a health “snapshot” of their community. It includes data sources, each with a brief overview, a description of what level data are available (e.g., state, MSA), whether data are comparable, and a step-by-step guide to using the resource. The Planning for Health Resources Guide provides resources organized by actionable topics, such as “I want to have healthier and more affordable food choices.” Resources include a very brief description followed by a link. • These four resources are intended to be used together and supplement each other. With the exception of the PowerPoint presentation, all are available as downloadable PDF files.
PAST USES	The Toolkit has been used by planners and policy makers to help facilitate public meetings and other public involvement decision-making processes.
PROJECT RELEVANCE	The Toolkit can be a resource to the public or others who wish to involve their community due to it’s intended use as a customizable, user-friendly set of tools for public involvement. Creating a Health Profile of Your Neighborhood and The Planning for Health Resources Guide can be used to review other sources organized by specific topics.

SIMILAR DATASETS	CDC/DOT Transportation and Health Tool; CDC Built Environment Assessment Tool; CDC Transportation Health Impact Assessment Toolkit; CDC Parks and Trails Health Impact Assessment Toolkit; CDC Parks, Trails, and Health Workbook; Pioneer Valley Planning Commission Healthy Community Design Toolkit—Leveraging Positive Change; Tacoma-Pierce County Healthy Community Planning Toolbox; Design for Health Impact Assessment Tools and Resources; University of Minnesota Design for Health Planning Information Sheet: Integrating Health into Comprehensive Planning; Michigan Department of Community Health Healthy Community Checklist
UPDATE FREQUENCY	The Healthy Community Design Checklist Toolkit is no longer maintained or updated and was last reviewed in 2013.
DATA CONNECTION TO EQUITY	The Toolkit includes a specific focus on the connection between transportation and public health. The Creating a Health Profile of Your Neighborhood and The Planning for Health Resources Guide note resources that can be used to identify food deserts, measure active transportation metrics, and examine demographics.
DATA GAPS OR LIMITATIONS	The Toolkit's is most limited in that it is no longer maintained, having last been updated in 2013. Also, outside of if it's intended use for facilitating public involvement, its utility is limited as a guide to other resources.
BIBLIOGRAPHIC INFORMATION	Centers for Disease Control and Prevention. (2013). Healthy Community Design Checklist Toolkit. Retrieved October 26, 2021, from https://www.cdc.gov/healthyplaces/toolkit/default.htm.

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INCLUDING EQUITY IN BENEFIT COST ANALYSIS | APPENDIX B

DATA CATEGORY	Equity in BCA - ☒ Air Quality | ☒ Physical Health | ☐ Other Quality-of-Life Measure Equity in Planning - ☒ Underserved Communities | ☒ Long Range Transportation Plans | ☐ Prioritization
DATA SOURCE NAME	Integrated Transport and Health Impact Model
DATA DESCRIPTION	The ITHIM is a publicly available tool that compares different travel modes and planning scenarios by looking at the expected outcomes over variables such as air quality, greenhouse gas emissions, reduction in chronic disease from active transportation, reduction in fatalities from fewer automobile trips, and monetary health benefits. A number of scenarios, including state transit plans and US Surgeon General Recommendations, are included; users may also upload their own scenarios. Data are presented in the web browser tool as a summary report of key metrics, a series of infographics, graphs, or .csv tables; .csv files may be downloaded. The ITHIM covers most of the state of California; users can examine metrics at the state, region, or county level. While the ITHIM is based on California, other states, regions, and countries have adapted it as a template.
PAST USES	The first version of ITHIM was implemented as a spreadsheet model in Microsoft Excel. Physical activity variation between people was modelled with simple point estimate approach. ITHIM has been used to model scenarios for the UK and the USA (Woodcock et al. 2009, Maizlish et al. 2013).
PROJECT RELEVANCE	The ITHIM provides predictions of various travel mode scenarios with quantitative measures of impacts to physical health and air quality. Baseline scenarios include a transit plan, and users can upload their own custom scenarios. This provides a great deal of temporal and geographic flexibility.
SIMILAR DATASETS	USDOT THT, WHO HEAT
UPDATE FREQUENCY	ITHIM does not appear to have a regular update schedule, but was updated at least as recently as 2019.
DATA CONNECTION TO EQUITY	Health outcomes from chronic disease and air quality issues are not felt equally across racial and ethnic groups. The ITHIM includes a “Health Outcomes” webpage that discusses chronic diseases that can be mitigated by physical activity and diseases associated with air pollution; the page also reports statistics on how these conditions more severely impact racial and ethnic minorities.
DATA GAPS OR LIMITATIONS	The ITHIM by default is usable only for California. However, others have used the model as a template, applying the methodology to other states and countries.

BIBLIOGRAPHIC INFORMATION	Maizlish N, Tomari K, Jiang C, Weiher A, Grajdura S, London JK, Rudolph L. California ITHIM, R/Shiny Version. User's Guide and Technical Manual. Davis, CA: University of California; 2019. Online: https://skylab.cdph.ca.gov/HealthyMobilityOptionTool-ITHIM/#Introduction

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DATA CATEGORY	Equity in BCA - ☐ Air Quality | ☐ Physical Health | ☐ Other Quality-of-Life Measure Equity in Planning - ☒ Underserved Communities | ☐ Long Range Transportation Plans
DATA SOURCE NAME	Longitudinal Employer-Household Dynamics (LEHD) Job-to-Job Flows (J2J) Data
DATA DESCRIPTION	Job-to-Job Flows (J2J) data provides statistics on job mobility in the United States, showing job flows across different geographies, worker characteristics, and firm characteristics, reporting how workers flow through different employers. This data is available at the national, state, and metropolitan area levels. Information is organized available for a variety of sectors based on NAICS categorization. Data is available in a tabular format as either a CSV or Excel file. Users can also use J2J Explorer to view different data visualizations, charts, and maps, although J2J Explorer may not have the most up to date data and may not have all the measures available in the tabular format.
PAST USES	J2J data offers a unique opportunity to study the workforce in the early years of a business. The role that gender, age, industry experience, and experience working at other new businesses can be examined in conjunction with the success or failure of a firm. Agarwal et al. (2013) used J2J data to in conjunction with LEHD microdata to identify firm founders (Goetz et al., 2015).
PROJECT RELEVANCE	J2J data can be used to examine labor markets at a variety of geographic scales and locations organized by sector. This can help identify geographic areas that are gaining or losing jobs, and which job markets are the most prosperous. In the context of markets or employment, this dataset can be valuable to determine how these economic metrics affect underserved communities.
SIMILAR DATASETS	Quarterly Workforce Indicators, ESRI Business Analyst, Residence Area Characteristics (RAC) and Workplace Area Characteristics (WAC) files.
UPDATE FREQUENCY	Updated quarterly from 2000 Q2 to the present
DATA CONNECTION TO EQUITY	Examining job flows by NAICS categorization provides a more nuanced look at trends in the labor market. By tying this information to demographics such as gender and age, J2J data can be used to identify unique challenges faced by different workers in different industries.
GAPS OR LIMITATIONS	While most data is available up to the latest quarter, certain geographies (for example, Alaska and Arkansas) have outdated data.

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U.S. Census Bureau. 2021. Job-to-Job Flows Data (2000-2020). Washington, DC: U.S. Census Bureau, Longitudinal-Employer Household Dynamics Program, accessed on July 16, 2021 at https://lehd.ces.census.gov/data/#j2j.

Goetz, C., Hyatt, H., McEntarfer, E., Sandusky, K. (2015). The Promise and Potential of Linked Employer-Employee Data For Entrepreneurship Research. Cambridge, MA. National Bureau of Economic Research Working Paper Series, accessed on August 31, 2021.

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DATA CATEGORY	Equity in BCA - ☐ Air Quality | ☐ Physical Health | ☐ Other Quality-of-Life Measure Equity in Planning - ☒ Underserved Communities | ☐ Long Range Transportation Plans
DATA SOURCE NAME	Longitudinal Employer-Household Dynamics (LEHD) Data Post-Secondary Employment Outcomes (PSEO) Data
DATA DESCRIPTION	PSEO data is created from collaboration between colleges/universities and state agencies, considered an "experimental" data product. This data tracks the employment and earnings of college graduates by education level (bachelors, masters, etc.). Partner systems are tracked by state; data is only available for participating states and institutions, although future releases will include more institutions. Information is reported by each participating college or university. PSEO data can be downloaded in a tabular format. User can also access data with the PSEO Explorer tool, which provides visualizations and charts such as bar charts and Sankey diagrams.
PAST USES	The Institute for Higher Education Policy has used PSEO data to discuss graduates' earning potential by Classification of Instructional Programs (CIP) code.
PROJECT RELEVANCE	PSEO data can help provide a monetary value to various levels of education, which can be used to predict life outcomes for underserved communities.
SIMILAR DATASETS	Longitudinal Employer-Household Dynamics (LEHD) Origin-Destination Employment Statistics (LODES) Data, Job-to-Job Flows (J2J), Quarterly Workforce Indicators, ESRI Business Analyst, Residence Area Characteristics (RAC) and Workplace Area Characteristics (WAC) files.
UPDATE FREQUENCY	Similar to other Census Bureau experimental statistics products, feedback on the PSEO dataset and its usefulness is solicited from stakeholders. If there appears to be sufficient user demand and available resources for continued use, the PSEO may be regularly updated.
DATA CONNECTION TO EQUITY	PSEO data can provide information on earnings based on geography, degree, and institution. This can uncover earnings potential by discipline. Demographic data is not included, limiting the utility of PSEO for equity work without cross referencing it by another resource.
GAPS OR LIMITATIONS	Data is only available for 11 states, and only for the participating colleges and Universities in those states (North Carolina is not available). Demographic data is not included, further limiting the ability to zero in on select populations.
BIBLIOGRAPHIC INFORMATION	U.S. Census Bureau. 2021. Post-Secondary Employment Outcomes Data (Experimental) (2001-2015) . Washington, DC: U.S. Census Bureau, Longitudinal-Employer Household Dynamics Program, accessed on August 18, 2021 at https://lehd.ces.census.gov/data/pseo_experimental.html.

DATA CATEGORY	Equity in BCA - ☐ Air Quality | ☐ Physical Health | ☐ Other Quality-of-Life Measure Equity in Planning - ☒ Underserved Communities | ☐ Long Range Transportation Plans
DATA SOURCE NAME	Longitudinal Employer-Household Dynamics (LEHD) Data Quarterly Workforce Indicators (QWI) Data
DATA DESCRIPTION	QWI data provides information of firm characteristics (such as size, age, and location) linked to worker demographics (such as age, education, race/ethnicity, and sex). QWI data pulls from a variety of sources, including Unemployment Insurance Earnings Data, Quarterly Census of Employment and Wages, and Business Dynamics Statistics. QWI data is available at the state, county, metropolitan, micropolitan, and workforce investment area geographies.
PAST USES	The LEHD QWI explorer has been used to explore how Phoenix's employment changed over the course of a decade (documentation).
PROJECT RELEVANCE	QWI link employers and workers, allowing for a nuanced look at job flows by demographics and industry. This can help underserved communities by providing a tool to see which industries are gaining or losing workers by detailed demographics such as age and race/ethnicity.
SIMILAR DATASETS	Longitudinal Employer-Household Dynamics (LEHD) Origin-Destination Employment Statistics (LODES) Data, Job-to-Job Flows (J2J), ESRI Business Analyst, Residence Area Characteristics (RAC) and Workplace Area Characteristics (WAC) files.
UPDATE FREQUENCY	Quarterly since 1990
DATA CONNECTION TO EQUITY	QWI can be used to evaluate employment trends broken out by worker demographics including sex, age, education, and race/ethnicity. This information can be used to examine how equitable employment characteristics are within a Census geography.
GAPS OR LIMITATIONS	QWI data is not available at the census tract or block group level.
BIBLIOGRAPHIC INFORMATION	U.S. Census Bureau. 2021. Quarterly Workforce Indicators (1990-2020). Washington, DC: U.S. Census Bureau, Longitudinal-Employer Household Dynamics Program, accessed on August 18, 2021 at https://lehd.ces.census.gov/data/#qwi.

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INCLUDING EQUITY IN BENEFIT COST ANALYSIS | APPENDIX B

DATA CATEGORY	Equity in BCA - ☐ Air Quality | ☐ Physical Health | ☐ Other Quality-of-Life Measure Equity in Planning - ☒ Underserved Communities | ☐ Long Range Transportation Plans
DATA SOURCE NAME	Longitudinal Employer-Household Dynamics (LEHD) Data Veteran Employment Outcomes (VEO) Data
DATA DESCRIPTION	Veteran Employment Outcomes (VEO) Data is a new statistical dataset considered "experimental", examining veterans from the US Army – in the future this data might be available for other branches of the military. Labor statistics are gathered for veterans one, five, and ten years after being discharged. Data are collected by demographics, employer industry, and military characteristics. Data can be downloaded in a tabular format. Users can also access the VEO Explorer tool to compare data with line and bar charts. VEO data can be downloaded at a statewide geography. Data is organized in two cohorts (2000-2007 and 2008-2015). Earnings are available at the 25th, 50th, and 75th percentiles, one, five, and ten years after separation from active-duty service, by rank, occupation, and discharge cohort.
PAST USES	The Labor Market Institute used VEO data to conduct a webinar on *Statistics of Army Veterans Transitioning into the Civilian Labor Market* (link).
PROJECT RELEVANCE	Veterans often face unique challenges, especially in underserved communities. VEO data can aid in tracking the job opportunities and earnings of veterans.
SIMILAR DATASETS	Longitudinal Employer-Household Dynamics (LEHD) Origin-Destination Employment Statistics (LODES) Data, Job-to-Job Flows (J2J), Quarterly Workforce Indicators, ESRI Business Analyst, Residence Area Characteristics (RAC) and Workplace Area Characteristics (WAC) files.
UPDATE FREQUENCY	The VEO dataset is an experimental statistics product of the U.S. Census Bureau. It may be regularly updated or expanded if there is sufficient demand and resources are available.
DATA CONNECTION TO EQUITY	Data can be parsed by enlistment education level, sex, and race/ethnicity. This information can be used to evaluate earnings and employment characteristics for veterans based on social equity factors.
GAPS OR LIMITATIONS	Data is limited to a statewide geography. Unemployment insurance data (a variable within the dataset) varies by state.

BIBLIOGRAPHIC INFORMATION	U.S. Census Bureau. (2021). Veteran Employment Outcomes Data (Experimental) (2001-2015). Washington, DC: U.S. Census Bureau, Longitudinal-Employer Household Dynamics Program, accessed on August 18, 2021 at https://lehd.ces.census.gov/data/veo_experimental.html. Hahn, J., Hyatt, H., Janicki, H., McEntarfer, E., Murray, S., and Tucker, L. Veteran Employment Outcomes. December 2020, accessed on October 12, 2021 at https://lehd.ces.census.gov/doc/VEO_Tech_Doc.pdf

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INCLUDING EQUITY IN BENEFIT COST ANALYSIS | APPENDIX B

DATA CATEGORY	Equity in BCA - ☒ Air Quality | ☒ Physical Health | ☐ Other Quality-of-Life Measure Equity in Planning - ☐ Underserved Communities | ☐ Long Range Transportation Plans | ☒ Prioritization
DATA SOURCE NAME	Regional Travel Demand Model Development Guidelines (Future source of information) NCDOT is moving towards the development of regional travel demand models. When complete the entire state will be covered by TDMs. The specification reviewed includes a non-motorized component which may be informative towards physical health.
DATA DESCRIPTION	The Regional Travel Demand Model Development Guidelines is an effort NCDOT initiated to develop standard modeling procedures for each of the transportation planning regions within the State. This guideline recommends that the TDM should have a non-motorized trips estimation component for both MPO and Non-MPO regions. It will be in the form of a post generation logit model, which estimated NM trips based on urban form, density, and network. From that design it appears that non-motorized trips will be available by traffic analysis zone, both for the base year of the model and the forecast year of the model. For non-MPOs the process of network development and skimming will also be standardized which could inform the calculation of metrics for air quality. The data can be converted to shape file format. • Geospatial data • Disaggregate at TAZ level • data not currently available, good for future use Once the TDM is done and become official, we could request it from each TDM custodian.
PAST USES	Future guideline so no use in the past.
PROJECT RELEVANCE	This dataset can be used to quantify and provide measures of non-motorized trips to evaluate air quality or physical health. It also includes considerations for equity in long range transportation plans (LRTPs)
SIMILAR DATASETS	Current models exist for MPOs and most (if not all) RPO communities, but they have varying capabilities and are standards.
UPDATE FREQUENCY	Published in Sep 2021

DATA CONNECTION TO EQUITY	If this guideline is fully implemented by each MPO and non-MPO regions, we will be able to use regional TDM to estimate non-motorized trips, which could be an indicator for physical health and air quality. The Regional Travel Demand Guidelines could also potentially be used to support project prioritization.
DATA GAPS OR LIMITATIONS	Data is not readily available.
BIBLIOGRAPHIC INFORMATION	Regional Travel Demand Model Development Guidelines (DRAFT) by NCDOT

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DATA CATEGORY	Equity in BCA - ☐ Air Quality | ☐ Physical Health | ☐ Other Quality-of-Life Measure Equity in Planning - ☐ Underserved Communities | ☐ Long Range Transportation Plans | ☒ Prioritization
DATA SOURCE NAME	North Carolina Statewide Travel Model (NCSTM)
DATA DESCRIPTION	The North Carolina Statewide Travel Model is a travel demand model built on the TransCAD platform, and predicts future travel demand at statewide level. It is primarily used to estimate future travel demand and travel time given certain land use and/or infrastructure scenarios. This TransCAD model is built at a higher level of TAZ (traffic analysis zone) aggregation than that found in most urban travel demand models. Travel demand models perform aggregate level analysis and can be used for system wide or corridor level performance measures, but cannot be used to assess operational level analysis. The NCSTM is maintained by NCDOT, which can be acquired for free.
PAST USES	NCDOT uses the NCSTM to estimate travel savings for proposed projects and award points based on travel time savings in the process of SPOT.
PROJECT RELEVANCE	NCDOT currently uses NCSTM to calculate travel time savings. The model is rich with output data, and could provide additional information related to performance measures, such as accessibility, for communities of concern.
SIMILAR DATASETS	N/A
UPDATE FREQUENCY	Model updates are per request by NCDOT, and not on a set update schedule.
DATA CONNECTION TO EQUITY	Data from the NCSTM and built in procedures in TransCAD could be useful in analyzing various impacts on communities for concern.
DATA GAPS OR LIMITATIONS	Data outputs from a statewide model are more aggregate than those from an urban model, and the model is not as sensitive to multimodal analysis.
BIBLIOGRAPHIC INFORMATION	Documentation and model available by request from the Transportation Planning Division, NCDOT.

DATA CATEGORY	Equity in BCA - ☐ Air Quality | ☐ Physical Health | ☐ Other Quality-of-Life Measure Equity in Planning - ☐ Underserved Communities | ☐ Long Range Transportation Plans | ☒ Prioritization
DATA SOURCE NAME	TransModeler Modeling Platform
DATA DESCRIPTION	TransModeler is a microsimulation modeling platform that provides detailed disaggregate performance measures such as travel time, delay, queuing and intersection level of service. TransModeler is multimodal and can be used to simulation auto, transit and non-motorized travel. Currently, the NCDOT SPOT process requires travel time savings calculations from TransModeler for interchange, intersection, and superstreet projects. The TransModeler models used to support this analysis are built for individual intersections, interchanges, or corridors. Unlike aggregate travel demand models that estimate demand between traffic analysis zones, TransModeler simulates traffic flow for individual autos, transit vehicles or pedestrians.
PAST USES	NCDOT uses TransModeler to estimate travel savings for a specific group of proposed projects and awards points based on travel time savings in the SPOT process .
PROJECT RELEVANCE	NCDOT currently uses TransModeler to calculate travel time savings, but the model is rich with output data and could provide other information such as delay, queue length and also volume to capacity measures.
SIMILAR DATASETS	Other microsimulation software packages exist, but NCDOT has selected TransModeler as their preferred microsimulation platform.
UPDATE FREQUENCY	Individual TransModeler models are developed and/or updated as need to support SPOT evaluation.
DATA CONNECTION TO EQUITY	TransModeler could be used to capture detailed level performance measures related to various impacts or benefits related to communities of concern.
DATA GAPS OR LIMITATIONS	TransModeler models are very data and time intensive. Unlike travel models that cover the entire state (NCSTM) and all MPOs, TransModeler models are project specific and may not be viable as on-going data support given their data and maintenance requirements.
BIBLIOGRAPHIC INFORMATION	Information obtained through a review of TransModeler capabilities as published by Caliper, Corp. and SPOT training materials provided by NCDOT.

DATA CATEGORY	Equity in BCA - ☐ Air Quality | ☐ Physical Health | ☐ Other Quality-of-Life Measure Equity in Planning - ☐ Underserved Communities | ☐ Long Range Transportation Plans | ☒ Prioritization
DATA SOURCE NAME	Triangle Regional Model
DATA DESCRIPTION	The Triangle Regional Model is a travel demand model built on the TransCAD platform to predict future travel demand for the Triangle region. It is primarily used to estimate future travel demand and various transportation system performance measures given a certain land use and/or infrastructure scenario. The TRM provides an aggregate level of analysis at the TAZ (traffic analysis zone) level. TAZs are aggregations of census blocks, and cover a smaller geography for urban regions of the model, increasing in size for rural regions of the model. Travel demand models perform aggregate level analysis and can be used for system wide or corridor level performance measures, but cannot be used to assess operational level analysis. The TRM is maintained by ITRE, which can be acquired for by request.
PAST USES	Triangle MPOs, NCDOT, GoTriangle and ITRE use the TRM to support transportation planning and analysis projects in the Triangle region.
PROJECT RELEVANCE	Can be used as a case study to evaluate transportation equity in Triangle region. The model could provide a variety of measures by time of day and travel model.
SIMILAR DATASETS	While individual travel demand models vary in their specification and outputs, all travel demand models provide a similar set of data outputs that can be leveraged to inform equity analysis.
UPDATE FREQUENCY	The model is updated on cycle with Metropolitan Transportation Plan updates.
DATA CONNECTION TO EQUITY	The TRM can be the tool to analyze the impact on disadvantaged community from a given project using various multimodal metrics.
DATA GAPS OR LIMITATIONS	Model outputs and performance measures are system wide and corridor level. The model is not reliable for detailed level performance measures such as intersection delay.
BIBLIOGRAPHIC INFORMATION	Institute for Transportation Research and Education. *Triangle Regional Travel Demand Model.* Online: https://itre.ncsu.edu/focus/modeling-and-computation/trm/

DATA CATEGORY	Equity in BCA - ☒ Air Quality | ☒ Physical Health | ☐ Other Quality-of-Life Measure Equity in Planning - ☒ Underserved Communities | ☐ Long Range Transportation Plans
DATA SOURCE NAME	US Department of Transportation (USDOT) Transportation and Health Tool (THT)
DATA DESCRIPTION	The THT was developed by a collaboration between USDOT, the Centers for Disease Control (CDC), and the American Public Health Association (APHA). The tool provides data on a variety of transportation and public health indicators throughout the United States. Users view data by selecting their state of interest. Indicator data include metrics such as mode share, DWI fatalities, and complete streets policies and are displayed on percentile bar charts. Indicator profiles provide a detailed exploration of each of the 14 indicators. The tool also includes strategies for transportation practitioners working with health and literature resources organized by topic.
PAST USES	The THT has been used to inform transportation decision making, for research comparing transportation and public health metrics in different regions, and for improving communication and collaboration between the transportation and public health sectors.
PROJECT RELEVANCE	THT indicators such as mode share, complete streets policies, and traffic fatalities help inform physical health and air quality. Neighborhood level data are available for many indicators, allowing examination into equity issues in transportation and health, helping to aid underserved communities.
SIMILAR DATASETS	The U.S. Census Bureau’s Commuting Characteristics Table (S0801) contains commute mode share data, which is included in the THT. Additionally, National Highway Safety Administration (NHTSA) has fatality data within its Fatality Analysis Reporting System (FARS), which was used in the THT.
UPDATE FREQUENCY	The THT released its last updated version in August 2015.
CONNECTION TO EQUITY	Negative health impacts from transportation tend to fall more heavily on minority and vulnerable groups. The THT helps examine the connection between transportation and health to explore these inequities. The THT is also useful for fostering communication between different sectors, allowing professionals with different backgrounds to more easily share information and pool resources to address inequities. Additionally, the THT has a dedicated Equity section under the “Literature and Resources” page. This page: elaborates on the connections between transportation, health, and equity; describes the most relevant THT indicators to equity; and lists relevant resources and research.
GAPS OR LIMITATIONS	The THT does not examine demographics of individuals. It is also not regularly updated.

BIBLIOGRAPHIC INFORMATION	U.S. Department of Transportation. (2021). FHWA Transportation and Health Tool, accessed on August 19, 2021 at https://www.transportation.gov/transportation-health-tool

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DATA CATEGORY	Equity in BCA - ☐ Air Quality | ☒ Physical Health | ☐ Other Quality-of-Life Measure Equity in Planning - ☒ Underserved Communities | ☐ Long Range Transportation Plans | ☐ Prioritization
DATA SOURCE NAME	Walk Score (Redfin)
DATA DESCRIPTION	Walk Score is a privately-owned, publicly available product that provides walkability, bike-ability, and transit-friendly scores to neighborhoods. It is available for any address in the United States and Canada, and reports scores for some areas in Australia. Walk Score's methodology page explains how the score for each category is determined. Each score is an index that considers multiple factors. Inputs to the Walk Score index include distance to amenities, population density, block length, and intersection density. Transit Scores determine a "usefulness" value of nearby transit routes based on the frequency, mode of route (rail, bus, etc.) and distance to stops. Bike Score inputs include bike infrastructure, hills, and the number of bike commuters. The Walk Score website includes direct integration with Google Maps, allowing users to interact with geospatial data in a familiar format. Data is available as shapefiles, spreadsheets, and via API.
PAST USES	Walk Score is primarily intended as a tool for the general public to evaluate a neighborhood's walk, bike, or transit friendliness. Many use it to evaluate a neighborhood when they are moving residences. Walk Score's has many more uses for researchers and professionals. It has been used to map food deserts, inform real estate analysis, and evaluate transit-oriented development. The Walk Score website highlights a case study where the Phoenix Planning Department in Phoenix, Arizona used Walk Score to evaluate the performance of existing light rail stations and help predict the performance of proposed stations.
PROJECT RELEVANCE	Walk Score gives quantified metrics that relate to physical health and safety. Because Walk Score is a geospatial product, users can also compare transportation friendliness by mode across all neighborhoods where scores are available. This can help users to identify communities of concern where infrastructure is lacking. By combining scores with demographic information, users can evaluate if infrastructure is advantageous, and deficiencies are distributed unequally across underserved communities.
SIMILAR DATASETS	Google Maps. Open Street Maps. US Census
UPDATE FREQUENCY	Regular data updates are provided.

DATA CONNECTION TO EQUITY	While Walk Score does not specifically incorporate equity or demographics, by performing research that includes these elements, one can identify areas where non-automobile transportation infrastructure is lacking.
DATA GAPS OR LIMITATIONS	Walk Score does not include information on demographics or equity, so in order to evaluate these factors a user will have to combine other data. A 2016 blog post on stateofplace.co (https://www.stateofplace.co/our-blog/2016/10/does-walk-score-walk-the-walk) notes that walk score fails when measuring personal safety and recreational facilities, and claims that it is inaccurate in neighborhoods with scores under 70 as well as low-income areas.
BIBLIOGRAPHIC INFORMATION	Walk Score. Accessed Oct 22, 2021 at https://www.walkscore.com/

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DATA CATEGORY	Equity in BCA - ☒ Air Quality | ☒ Physical Health | ☐ Other Quality-of-Life Measure Equity in Planning - ☐ Underserved Communities | ☐ Long Range Transportation Plans
DATA SOURCE NAME	World Health Organization (WHO) Health Economic Assessment Tool (HEAT)
DATA DESCRIPTION	HEAT examines walking and cycling infrastructure and provides an estimated value for the reduced mortality from this infrastructure to inform economic analysis. The tool can be used at the national, city, or sub-city level. Impacts are calculated over a number of years selected by the user. Physical activity, air pollution, and carbon emission impacts can be selected for analysis. HEAT walks users through a series of questions where the country, mode of transportation, reference years, and other options are selected. Results are then provided, describing metrics such as premature deaths prevented and the monetary value saved from increased active transportation based on the questions answered. Results can then be downloaded as a .csv file.
PAST USES	HEAT has been used in cost-benefit analysis for planning walking and cycling infrastructure, to determine a value from reduced mortality over a period of time resulting from walking and cycling infrastructure, and to inform economic and health impact assessments.
PROJECT RELEVANCE	HEAT translates reduced mortality from air quality, physical health improvements, and other factors resulting from walking and cycling infrastructure into a monetary value. This is an excellent tool to inform active transportation planning as it quantifies mortality and health into a dollar amount.
SIMILAR MODELS	Integrated Transport and Health Impact Modelling Tool (ITHIM)
UPDATE FREQUENCY	The first version of HEAT for cycling was presented in 2007, and officially launched in 2009 as a Microsoft Excel document. The first version of HEAT for walking was launched in 2011 as a website together with an updated version of HEAT for cycling. In 2014, updated versions of the HEAT for walking and cycling were published. The HEAT model has recently been updated in 2019.
CONNECTION TO EQUITY	HEAT can be used to assess how a transportation investment results in increased walking, running, or cycling behavior and the associated impacts on physical health. If demographic information is available for community members that would benefit from the investment (such as ACS data), an assessment that relates the effects the investment to community member health can be undertaken.
GAPS OR LIMITATIONS	The HEAT Model does not include the United States as one of its countries within the model. To estimate physical health effects resulting from transportation investments in the U.S., a proxy country will need to be selected. This proxy should contain similar health characteristics for its general population.

BIBLIOGRAPHIC INFORMATION	World Health Organization. (2021). Health Economic Assessment Tool, accessed on August 19, 2021 at https://www.heatwalkingcycling.org/tool/

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Including Equity in Benefit Cost Analysis

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RP 2022-17
Task 3: Interim Deliverable

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16. Abstract

This interim deliverable contains the implementation datasets and methodologies for two cross-modal measures (air quality and physical health) to potentially be included in the prioritization process. This document also contains the approach that can be used to incorporate equity impacts into NCDOT's prioritization process. As the culmination of Task 3 for the Research Project, *Including Equity in Benefit Cost Analysis,* the implementation methodologies and their associated datasets will be evaluated with three Case Studies in Task 4.

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Table of Contents

Research Team

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Executive Summary

Transportation planning and funding decisions often have significant equity impacts; however, few transportation agencies today integrate equity considerations into their transportation prioritization processes. Most practitioners and decision-makers sincerely want to achieve equity objectives, but transportation equity can be difficult to evaluate because there are various factors such as demographics, income, ability, geographic location, and travel considerations.

The purpose of this research is to establish user-friendly approaches to integrate equity into NCDOT's BCA processes. This has involved deepening two cross-modal measures: air quality and physical health that can be included into NCDOT's strategic planning and prioritization processes. As a key component of this research, the research team has produced this interim report to demonstrate the methodological approaches, datasets, and complimentary tools that can be used to potentially include physical health, air quality, and equity into North Carolina's transportation prioritization process.

Scope and Objective

The primary objectives of this deliverable are to 1) demonstrate the datasets and methodologies for implementing physical health and air quality into the prioritization process 2) share the approach that can be used to incorporate equity impacts into the prioritization process.

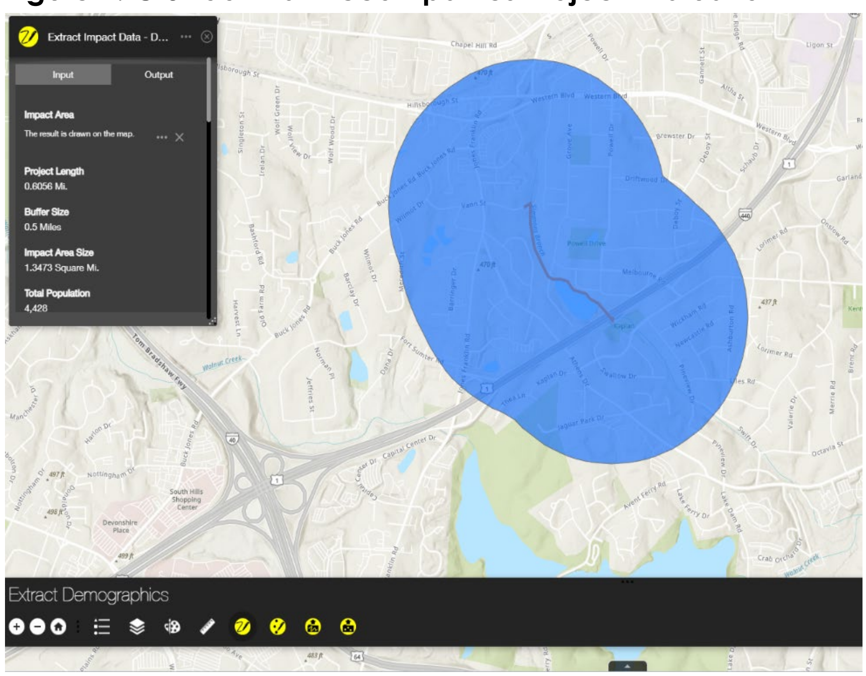
Overview of the Research Effort

After communicating with the Steering and Implementation Committee and conducting a thorough literature review,[1] the research team identified five modes of transportation for which physical health and air quality measures could be applied. These modes include bicycle and pedestrian, public transportation, passenger rail, ferry, and highway transportation. Aviation was determined to be beyond the scope of this project.

Complimentary Tools for Each Mode

As an effort to make physical health, air quality, and equity prioritization equations as implementation-ready as possible, an online GIS tool and an excel workbook were created to accompany this research. These tools are not meant to replace SPOT Onl!ne or existing prioritization spreadsheet applications, but instead provide readily understandable processes that can be used to quantify physical health, air quality and equity impacts.

Figure 1: GIS Tool that Accompanies Project Evaluation



GIS Online Tool. Many of the methodologies that were developed as part of this research rely on geospatial data as part of project evaluation criteria. For example, if a highway project were to be constructed, an evaluation of the project's monetized impacts on physical health and air quality, as well as how those impacts are distributed within the project area depend on geospatial characteristics unique to the project area. These characteristics include project area population, walk proportion, bike proportion, and transit proportion, which have been extracted from US Census data. The specific uses of the geospatial characteristics for each mode will be discussed in

[1] As part of *Research Project 2022-17: Including Equity in Benefit Cost Analysis*, a literature review entitled, "Including Equity in Benefit-Cost Analysis: Summary of the Literature and Data Review," was submitted in January 2022.

greater depth within the documentation of each modal methodology. However, it is important to note that the GIS tool was an essential enabler for quantifying physical health, air quality, and equity impacts as part of this project. It allows users to draw or upload prospective projects and extract essential quantification outputs from a prospective project area's boundary. These outputs are then used in the prioritization formulas for physical health, air quality, and equity. Figure 1 shows what the online tool looks like.

Excel Workbook Tool. The research team also developed an excel workbook tool that contains the variables and equations to evaluate the physical health and air quality impacts that a prospective project has on people living within the project area. The workbook also demonstrates how these impacts are distributed. The workbook contains physical health and air quality modules for each mode so that a project applicant could quickly input project variables into the tool and then see project impacts. Figure 2 shows what the excel workbook tool looks like.

Figure 2: Excel Workbook Tool That Accompanies Project Evaluation

HIGHWAYS MODEL - Physical Health (back to tool navigation)

INSTRUCTIONS

STEP 1: Open the "Extract Demographics" ArcGIS tool available online
STEP 2: Draw the proposed highway investment and run the GIS tool
STEP 3: Paste the GIS outputs into Table 1
STEP 4: Complete Table 2: Existing & Proposed Highway Characteristics

Visit the GIS Tool Online Click Here

Link: https://ags.coverlab.org/portal/apps/webappviewer/index.html?id=1df1506ba23b4b378953fb49414d4aa9

Table 1: Extract Demographics Tool Output Values

Parameter	GIS Tool Output Values
Project Area Population	
Walk Proportion	
Bike Proportion	
Transit Proportion	

Source: Extract Demographics Tool Output

Clear Values

Table 2: Existing & Proposed Highway Characteristics

Parameter	Existing Conditions (Base Case)	Proposed Conditions (Build Case)
Average Posted Speed Limit		
Sidewalks adjacent to highway facility		
Sidewalk Width Selection (Street Side 1; if applicable)		
Sidewalk Width Selection (Street Side 2; if applicable)		

Source: STI Project Applicant

Clear Values

Table 3: Physical Health Output

Summary Statistic	Summary Values
Project Area Population	-- Enter Value in Cell C15 --
Pedestrians Effected	-- Enter Values in Cells C15 and C16 --
Cyclists Effected	-- Enter Values in Cells C15 and C17 --

Summary Statistic	Existing Conditions (Base Case)	Proposed Conditions (Build Case)	Net Difference
Physically Active Pedestrians	--	--	--
Physically Active Cyclists	--	--	--
Daily Walk Trips	--	--	--
Daily Cycle Trips	--	--	--
Annual Walk Trips	--	--	--
Annual Cycle Trips	--	--	--
Annual Appraised Physical Health Benefit	--	--	--

Methodology and Data Sources

The primary purpose of Research Project 2022-17: Including Equity in Benefit-Cost Analysis, is to quantify how prospective transportation projects impact physical health and air quality, and to assess how those impacts are distributed among individuals living within the project area's population. This effort required finding publicly available datasets that are routinely updated, so that physical health, air quality, and equity evaluations could be integrated into North Carolina's Strategic Transportation Investments prioritization process and remain current.

Task 3 of this effort involved selecting data sources and determining the methodologies that would be required to evaluate the effects of prospective transportation investments on physical health, air quality, and equity. To align with many of the existing STI processes as well as standard practices used for economic evaluation, the research team implemented a benefit-cost analysis framework as the guiding approach to quantify prospective transportation project impacts on society.

Benefit-Cost Analysis, also referred to as Cost-Benefit Analysis, is a systematic process for calculating and comparing benefits and costs of a project for two purposes, (1) to determine if the project is a sound investment (justification / feasibility) and (2) to see how it compares with alternate projects (ranking / priority assignment). Benefit-Cost Analysis works by defining the project and any alternatives; then by identifying, measuring, and valuing the benefits and costs of each (Economics and Finance Committee, 2023). For this research effort, the physical health and air quality benefits that accrue within the project area before and after a prospective project are compared. This is considered comparing the **base case scenario** to the **build scenario**. The data sources and methodologies discussed in this document are used to compare those scenarios and estimate the net change in benefits or costs that accrue due to implementation of a prospective project.

After net benefits or costs have been estimated, an equity analysis is then conducted to estimate how benefits or costs are distributed among populations within the project area. NCDOT's composite transportation disadvantage index (TDI) scores within a census-designated block group are used to classify the populations where benefits and costs accrue. More information on equity analysis is included in the "Including Equity in the Prioritization Process" section of this document on page 38.

Physical Health Methodologies and Datasets

Transportation is a critical factor that influences people's health and the health of a community. Investments in sidewalks, bike lanes, trails, public transit, and other infrastructure that supports physical activity can result in improvements to individuals' health and decreased health care costs (Robert Wood Johnson Foundation, 2012). The purpose of including physical health into North Carolina's prioritization process is to estimate how physical activity levels change before and after the implementation of a transportation project.

Bicycle-Pedestrian

Physical Health Context. Bicycle and pedestrian infrastructure can be a key enabler for physical activity. For example, approximately $3.9 million in annual health care savings were realized by completing six trail segments within the Carolina Thread Trail network (ITRE, 2022). Cost-savings stemmed from 558,000 trail visits with an average benefit of approximately $7 per trail visit (ITRE, 2022).

Physical Health Data Sources. For this study, the research team evaluated data sources and developed a methodology to incorporate physical health as a measure within North Carolina's Prioritization Process. Nine variables from five data sources were used to estimate the changes in physical activity that would result from implementing a proposed bike/ped project. Four variables are sourced from the U.S. Census Bureau. These include project area population, walk proportion, bike proportion, and transit proportion. One variable, *Facility & Tie-in Network Length*, was developed using the same thresholds from the Locally Administered Projects Program (LAPP) of the Capital Area Metropolitan Planning Organization (CAMPO). Mean daily person trips were derived from AAA (2021) and the incremental benefits per walk trip and bike trip were sourced from USDOT BCA Guidance (2022). Variables, their data sources, and their purposes are included Table 1.

Table 1: Bike/Ped Physical Health Data Sources

Variable	Data Source	Purpose
Project Area Population	U.S. Census Bureau	Number of affected by a proposed project
Walk Proportion	U.S. Census Bureau	Percentage of people that currently walk in project area
Bike Proportion	U.S. Census Bureau	Percentage of people that currently bike in project area
Facility & Tie-in Network Length	Capital Area Metropolitan Planning Organization, Locally Administered Projects Program	Estimates level of **mode shift** associated with a proposed facility + tie-in to existing facility's total length
Mean daily person trips	AAA	Number of daily person trips made on average
Calendar days	U.S. Calendar	Annualize the benefits or costs that accrue over the course of a year
Benefit per Walk Trip	USDOT BCA Guidance	Monetized physical health benefit per walk trip

Variable	Data Source	Purpose
Benefit per Cycle Trip	USDOT BCA Guidance	Monetized physical health benefit per bike trip
Annual trips by mode	Derived from U.S. Census data (GIS tool)	Variable based on base case conditions altered by mode shift

Source: ITRE, 2023.

Physical Health Methodology. The purpose of including physical health into North Carolina's prioritization process is to estimate how physical activity levels change before and after the implementation of a transportation project. The methodology discussed in this section is specific to prospective bike/ped projects and it is derived by comparing the base case to the build case scenarios.

Base Case Scenario. First, the base case conditions of physical activity within the project area are determined. This is done by assessing the proportion of walk trips and bike trips made by people living within a half-mile of a proposed transportation project (often defined as the walk-shed or bike-shed of a transportation project).

The proportion of walk trips is multiplied by the population living within a half-mile buffer of the proposed project. This process is repeated, multiplying the proportion of bike trips times the project area population. These products provide us with the population of people within the project area who walk or cycle as means of transportation. These populations are then multiplied by daily trips (derived from AAA, 2021) and 365 days to determine the number of active walk and bike trips made each year by the project area population. Total walk trips are then multiplied by the estimated benefit per walk trip and total cycle trips are multiplied by the benefit per cycle trip to get the total monetized benefit of walking and cycling as a means of transportation for the base case scenario.

Step 1: Calculate Physical Health Benefits in Base Case Scenario

- Walk Benefit$_{BC}$ = (Project Area Population) x (Walk Proportion) x (Daily Trips) x (Annual Trips) x (Benefit per Trip)

- Cycle Benefit$_{BC}$ = Cycle Benefit = (Project Area Population) x (Bike Proportion) x (Daily Trips) x (Annual Trips) x (Benefit per Trip)

- Walk and Cycle to-and-from Transit Benefit = assume same in base case scenario and build case scenario

- Base Case Total Health Benefit = Walk Benefit$_{BC}$ + Cycle Benefit$_{BC}$

Build Case Scenario. After a proposed bike/ped project is completed, it can enable physical activity by facilitating active transportation trips. The extent to which a facility is used depends on length and connectivity. For example, does the proposed facility stand on its own, isolated from other sidewalks or paths, or does it connect to an existing bike/ped network? For this analysis, CAMPO LAPP project facility length thresholds are used to estimate mode shift (see Table 2). A facility that stands on its own or connects into a facility with a total combined length of 0-0.5 miles is anticipated to create a mode shift of 0.25 percent. Similarly, facilities with total or combined lengths of 0.5-2 miles and greater than 2 miles are anticipated to generate mode shifts of 0.5 percent and 1 percent, respectively.

Table 2: Mode Shift Assumptions that Lead to Changes in Physical Health

Proposed Facility Network Length	Mode Shift Percentage
(A) 0-0.5 miles	0.25%
(B) 0.5-2.0 miles	0.50%
(C) Greater than 2.0 miles	1.00%

To calculate physical health benefits in the build case scenario, mode shift effects are estimated. The mode shift level associated with the proposed facility (see Table 2) is added to the walk proportion in the project area. Similarly, this mode shift level is added to the bike proportion in the project area. These equations can be viewed as:

- Walk proportion + mode shift percentage
- Bike proportion + mode shift percentage

Once mode shift considerations have been accounted for, the same process that was used in the base case scenario is used in the build case scenario to tabulate physical health benefits.

Table 3: Physical Activity Benefits per Trip

Trip Type	Benefit ($2020)
Walking	$7.08
Cycling	$6.31

Source: USDOT BCA Guidance, 2022.

The proportion of (walk trips + mode shift percentage) is multiplied by the population living within a half-mile buffer of the proposed project. This process is repeated, multiplying the proportion of (bike trips + mode shift percentage) times the project area population. These products provide us with the population of people within the project area who walk, or cycle as means of transportation after the proposed facility is completed. These populations are then multiplied by daily trips (derived from AAA, 2021) and 365 days to determine the number of active walk and bike trips made each year by the project area population. Total walk trips are then multiplied by the estimated benefit per walk trip and total cycle trips are multiplied by the benefit per cycle trip to get the total monetized benefit of walking and cycling as a means of transportation for the build case scenario.

Net physical health benefits are derived by subtracting health benefits in the base case scenario from the build case scenario. The difference in monetized benefits demonstrates the net annual health benefit afforded to those living in the project area. The equations used to calculate physical health benefits are shown in **Error! Reference source not found.**.

Figure 3: Example of a Network Connection That Facilitates Physical Health Benefits

Source: ITRE, 2022.

To include equity considerations as part of this analysis, these benefits can then be distributed by transportation disadvantaged index categories within the project area. The process for including equity within the strategic prioritization process is shown on page 28.

Step 2: Calculate Physical Health Benefits in Build Scenario

- Walk Benefit' = (Project Area Population) x (Walk Proportion **+ Facility & Network Tie-in Length Category**)' x (Daily Trips) x (Annual Trips) x (Benefit per Trip)
- Cycle Benefit' = (Project Area Population) x (Bike Proportion **+ Facility & Network Tie-in Length Category**)' x (Daily Trips) x (Annual Trips) x (Benefit per Trip)
- Build Scenario Total Health Benefit = Walk Benefit' + Cycle Benefit'

Step 3: Calculate Net Change in Bike/Ped Health Benefits

Net Health Benefit = (Walk Benefit' + Cycle Benefit') - (Walk Benefit_{BC} + Cycle Benefit_{BC})

Public Transportation, Passenger Rail, and Ferry Travel

Physical Health Context. Many people struggle to find the time for physical activity, especially if they aim for one continuous 30-minute bout of exercise. Research shows, however, that activity accumulated in several bouts, a minimum of 10 minutes at a time, has similar health effects (U.S. Department of Health and Human Services, 2008). Walking or bicycling as a form of transportation or walking to public transportation stations, such as bus stops, train stations, and ferry terminals also count toward meeting the daily physical activity recommendations (Freeland et al., 2013; Besser, Dannenberg, 2005). Overall, there is a significant 12% reduction in mortality associated with active transportation (Samitz, et al., 2011), and there is an 11% reduction in risk of cardiovascular disease associated with active transportation (Hamer, et. al., 2008; Hu, et. a., 2007).

Physical Health Data Sources. A total of nineteen variables from nine data sources were used to estimate the changes in physical activity that would result from implementing bus, bus rapid transit (BRT), light rapid transit (LRT), passenger rail, passenger ferry, or vehicle ferry projects. These variables are shown in Table 4 and physical health methodologies are discussed thereafter.

Table 4: Public Transport, Passenger Rail, and Ferry Physical Health Data Sources

Variable	Data Source	Purpose
Project Area Population	U.S. Census Bureau	Number of affected by a proposed project
Walk Proportion	U.S. Census Bureau	Percentage of people that currently walk in project area
Bike Proportion	U.S. Census Bureau	Percentage of people that currently bike in project area
Transit Proportion	U.S. Census Bureau	Percentage of people that currently take transit in project area
Population Density	U.S. Census Bureau	Estimates urban population effect on mode shift. A population density scalar is multiplied times the estimated boardings per stop for bus, BRT, LRT, and commuter rail. See page 50 for more information about the scalar.
No. of Stops / Stations / Terminals Proposed	Applicant provided	Estimates number of people per stop per frequency who would board at a new station.
No. of Frequencies Proposed	Applicant provided	
Ridership per Boarding	Based on GoRaleigh, CATS, and NCDOT data	
Walk to Transit Rate	Wake County Transit Survey	Estimates how people access bus, BRT, LRT, and passenger train stations.
Bike to Transit Rate	Wake County Transit Survey	
Drive to Transit Rate	Wake County Transit Survey	
Walk to Veh. Ferry Rate	NCDOT Vehicle Ferry Data	Estimates how people access vehicle ferries
Bike to Veh. Ferry Rate	NCDOT Vehicle Ferry Data	

Variable	Data Source	Purpose
Drive to Veh. Ferry Rate	NCDOT Vehicle Ferry Data	
Walk to Pax Ferry Rate	derived from NCDOT Vehicle Ferry Data (assumed 10x walk rate of vehicle ferry)	Estimates how people access passenger ferries
Bike to Pax Ferry Rate	derived from NCDOT Vehicle Ferry Data (assumed 10x bike rate of vehicle ferry)	
Drive to Pax Ferry Rate	NCDOT Vehicle Ferry Data	
Mean daily person trips	AAA	Number of daily person trips made on average
Benefit per Walk Trip	USDOT BCA Guidance	Monetized physical health benefit per walk trip
Benefit per Cycle Trip	USDOT BCA Guidance	Monetized physical health benefit per bike trip
Annual trips by mode	Derived from U.S. Census data (GIS tool)	Variable based on base case conditions altered by mode shift

Source: ITRE, 2023.

Physical Health Methodologies. The physical methodologies for bus, BRT, LRT, passenger rail, passenger ferry, and vehicle ferry are discussed below.

Base Case Scenario. The base case conditions of physical activity within the project area are determined by analyzing the proportion of transit trips made by people living within a half-mile of a proposed transit project. It should be noted that the half-mile "transit-shed" is used by the research team, but NCDOT could adjust this project area to any buffer designation that is deemed appropriate from prioritization (i.e. ¼ mile, ¾ mile, or some other distance). The proportion of transit trips are multiplied by the population living within a half-mile buffer of the proposed project to obtain the population of people who take transit as a means of transportation. This population is then multiplied by the share of people who walk to transit or bike to transit to obtain active transportation users within the study area. Data sources shown for deriving this product is shown in Table 5.

Table 5: Data Sources for Walk and Cycle to Bus, BRT, LRT, Rail, and Ferry Transportation

Variable	Data Source(s)	Value	Purpose
Walk to Transit Rate	Wake County Transit Survey	91.50%	Estimates how people access bus, BRT, LRT, and rail
Bike to Transit Rate	Wake County Transit Survey	1.10%	
Drive to Transit Rate	Wake County Transit Survey	7.40%	
Walk to Veh. Ferry Rate	NCDOT Vehicle Ferry Data	0.28%	Estimates how people access vehicle ferries
Bike to Veh. Ferry Rate	NCDOT Vehicle Ferry Data	0.08%	
Drive to Veh. Ferry Rate	NCDOT Vehicle Ferry Data	99.60%	
Walk to Pax Ferry Rate	derived from NCDOT Vehicle Ferry Data (assumed 10x walk rate of vehicle ferry)	2.80%	Estimates how people access passenger ferries
Bike to Pax Ferry Rate	derived from NCDOT Vehicle Ferry Data (assumed 10x bike rate of vehicle ferry)	0.80%	
Drive to Pax Ferry Rate	NCDOT Vehicle Ferry Data	96.40%	

Source: ITRE, 2023.

Transit population within the study area is then multiplied by daily trips (derived from AAA, 2021) and 365 days to determine the number of active walk and bike trips made to transit each year by the project area population. Total active transportation trips are then multiplied by the estimated benefit per walk trip and total cycle trips are multiplied by the benefit per cycle trip (see Table 3) to get the total monetized benefit of walking and cycling to transit as a means of transportation for the base case scenario.

Step 1: Calculate Physical Health Benefits in Base Case Scenario

- Walk Benefit$_{BC}$ = (Project Area Population) x (Walk Proportion) x (Walk to Transit Proportion) x (Daily Trips) x (Annual Trips) x (Benefit per Trip)

- Cycle Benefit$_{BC}$ = (Project Area Population) x (Bike Proportion) x (Bike to Transit Proportion) x (Daily Trips) x (Annual Trips) x (Benefit per Trip)

- Base Case Total Health Benefit = Walk Benefit$_{BC}$ + Cycle Benefit$_{BC}$

Build Case Scenario. After a proposed bus, BRT, LRT, passenger rail, passenger ferry, or vehicle ferry stop is completed, it can enable physical activity by facilitating active transportation trips, as people walk and bike to the new stop location. To estimate the active transportation trips that a new bus, BRT, LRT, passenger rail, passenger ferry, or vehicle ferry stop would facilitate, an analysis of ridership by stop by frequency was undertaken (see "Ridership per Boarding Analysis" on page 17 for more information about this analysis.) Analysis results, as shown in Table 6, were then used to estimate the new number of individuals within the prospective project area that would take transit for each boarding (i.e. ridership per stop per frequency). Ridership by boarding estimates were then scaled by the project area's urban percentage to estimate the project area's land use characteristics as a factor on mode shift (the greater an area's urban percentage, the greater the mode shift effect). For example, if an area had a 100 percent urban population than it would generate 4.52 passengers per boarding (1.00 x 4.52 passengers per boarding), but if the project area had an urban percentage of 50 percent it would generate 2.62 passengers per boarding (0.5 x 4.52 passengers per boarding).

Table 6: Ridership per Boarding Analysis Findings

Ridership per Boarding Mode	Value	Data Source(s)
Bus	4.52 passengers per boarding	Derived from GoRaleigh Data
BRT / LRT	11.53 passengers per boarding	Derived from CATS Data
Passenger Rail	3.99 passengers per boarding	Derived from NC Amtrak Data
Vehicle Ferry	28.72 passengers per boarding	Derived from NCDOT Ferry Data
Passenger Ferry	47.09 passengers per boarding	Derived from NCDOT Ferry Data

Source: ITRE, 2023.

The scaled number of individuals by boarding were then multiplied by their walk to transit and bike to transit shares to obtain the number of new individuals who walk or cycle to transit, rail, or ferry stop. Once active transit riders were estimated for the project area in the build scenario the number of active transit riders was then multiplied by annual trips. Physical health benefits derived from annual active transit trips from the build case scenario were then estimated using the same process that was used in the base case scenario. Physical health benefits in the base case scenario were compared to those in the build case scenario.

Step 2: Calculate Physical Health Benefits in Build Scenario

- Walk Benefit' = (Project Area Population) x (Transit Proportion) x (Walk to Transit Proportion)' x (Daily Trips) x (Annual Trips) x (Benefit per Trip) + ((Stops/Stations/Terminals) x (Frequencies) x (Ridership Per Boarding) x (Urban Percentage) x (Walk to Transit Proportion) x (Trips per day) x (Days per Year))

- Cycle Benefit' = (Project Area Population) x (Transit Proportion) x (Bike to Transit Proportion) x (Daily Trips) x (Annual Trips) x (Benefit per Trip) + ((Stops/Stations/Terminals x (Frequencies) x (Ridership Per Boarding) x (Urban Percentage) x (Bike to Transit Proportion) x (Trips per day) x (Days per Year))

- Build Scenario Total Health Benefit = Walk Benefit' + Cycle Benefit'

Step 3: Calculate Net Change in Bike/Ped Health Benefits

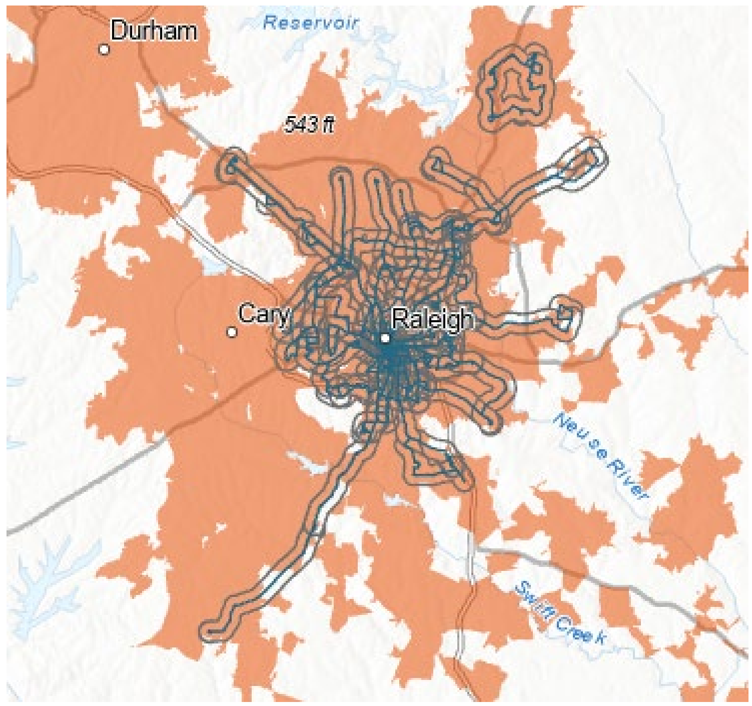
- Net Health Benefit = (Walk Benefit' + Cycle Benefit') - (Walk Benefit_{BC} + Cycle Benefit_{BC})

RIDERSHIP PER BOARDING ANALYSIS

As part of the physical health methodology for bus, BRT, LRT, passenger rail, passenger ferry, and vehicle ferry, a ridership per boarding analysis was conducted. The analysis was used to estimate the number of new individuals within a prospective project area are projected to use these modes of transportation in the event that a new stop, station, or terminal was built in their vicinity. The analysis sought to understand the number of individuals per stop, station, or terminal per frequency.

Bus Ridership per Boarding. A geospatial analysis was conducted using GoRaleigh General Transit Feed Specification (GTFS) data to assess urban and exurban routes within GoRaleigh's network. Urban boundaries are shown in Figure 4 and sourced from U.S. Census data. These classifications were used to develop ridership per boarding estimates by urban, exurban, and rural designations within North Carolina. A total of 34 bus routes were analyzed. Bus ridership, number of bus stops per route, and weekday frequencies were used to derive the average ridership per stop per weekday frequency for each route. For this analysis, GoRaleigh bus routes with more than 70 percent of their service area existing within an urban boundary were designated as *exurban* routes and routes with more than 95 percent of their service area existing within an urban boundary were designated as *urban* routes. GoRaleigh's ridership per routes ranged from 0.3-8.4 individuals per stop per frequency (see Table 7). Average values for exurban stops were 4.0 individuals and for urban stops were 4.5 individuals.

Figure 4: Urban Percentage by Route



Source: ITRE, 2023.

Bus ridership per boarding findings were integrated into the benefit-cost analysis methodology. A max value of 4.5 riders per stop per frequency was used. This value was then multiplied by the percent urban value extracted from Census Data within the GIS tool. The product of the (percent urban) x (4.5) was used to estimate riders per stop per frequency at a given bus stop location.

Table 7: Ridership per Stop

No. & Route	Ridership per Stop per Weekday Frequency	Percent Urban Route	Classification (Urban vs. Exurban)	Average
11 - AVENT FERRY	7.7	89.8%	exurban	4.0
7 - SOUTH SAUNDERS	7.7	87.9%	exurban	
7L - CAROLINA PINES	6.6	89.8%	exurban	
78X - FUQUAY VARINA EXPRESS	2.6	79.2%	exurban	
64X - ZEBULON / WENDELL EXPRESS	2.3	(not in GTFS)*	exurban	
20 - GARNER	0.4	90.9%	exurban	
33 - KNIGHTDALE	0.3	74.4%	exurban	
21 - CARALEIGH	8.4	100.0%	urban	4.5
1 - CAPITAL	8.3	100.0%	urban	
19N - MLK SUNNYBROOK	7.6	100.0%	urban	
6 - CRABTREE	7.6	100.0%	urban	
15 - WAKEMED	7.2	100.0%	urban	
5 - BILTMORE HILLS	6.7	100.0%	urban	
22 - STATE STREET	6.3	100.0%	urban	
8 - SIX FORKS	5.6	100.0%	urban	
11L - BUCK JONES	5.5	100.0%	urban	
2 - FALLS OF NEUSE	5.5	100.0%	urban	
10 - LONGVIEW	5.0	100.0%	urban	
16 - OBERLIN	4.7	100.0%	urban	
3 - GLASCOCK	4.2	100.0%	urban	
15L - TRAWICK	4.0	100.0%	urban	
70X - BRIER CREEK EXPRESS	4.0	95.2%	urban	
23L - MILLBROOK CROSSTOWN	3.9	100.0%	urban	
18 - POOLE/BARWELL	3.8	96.7%	urban	
4 - REX HOSPITAL	3.7	100.0%	urban	
24L - NORTH CROSSTOWN	3.6	100.0%	urban	
25L - TRIANGLE TOWN CENTER	3.5	100.0%	urban	
13 - CHAVIS HEIGHTS	3.3	100.0%	urban	
36 - CREEDMOOR	2.8	100.0%	urban	
27 - BLUE RIDGE	1.6	100.0%	urban	
62 - WAKE FOREST LOOP	1.4	100.0%	urban	
60X - WAKE FOREST EXPRESS	1.4	(not in GTFS)*	urban	
55X - POOLE ROAD EXPRESS	1.3	100.0%	urban	
26 - EDWARDS MILL	1.1	100.0%	urban	

Source: Derived from GoRaleigh, 2019

Light Tail Transit and Bus Rapid Transit Ridership per Boarding. Using Charlotte Area Transit System (CATS) data for the Lynx Blue Line, an analysis was undertaken to determine the number of passengers per Blue Line Station boarding. Average weekday passenger boardings in 2019 were divided by number of frequencies listed in the Lynx Blue Line timetables for 2019. Ridership for Lynx stops ranged from 1.6 to 43.4 individuals per stop per frequency. Average values for stops were 11.53 individuals (see Table 8).

For the benefit-cost analysis methodology, a max value of 11.53 riders per stop per frequency was used. This value was then multiplied by the percent urban value extracted from Census Data within the GIS tool. The product of the (percent urban) x (11.53) was used to estimate riders per stop per frequency at a given LRT or BRT station location.

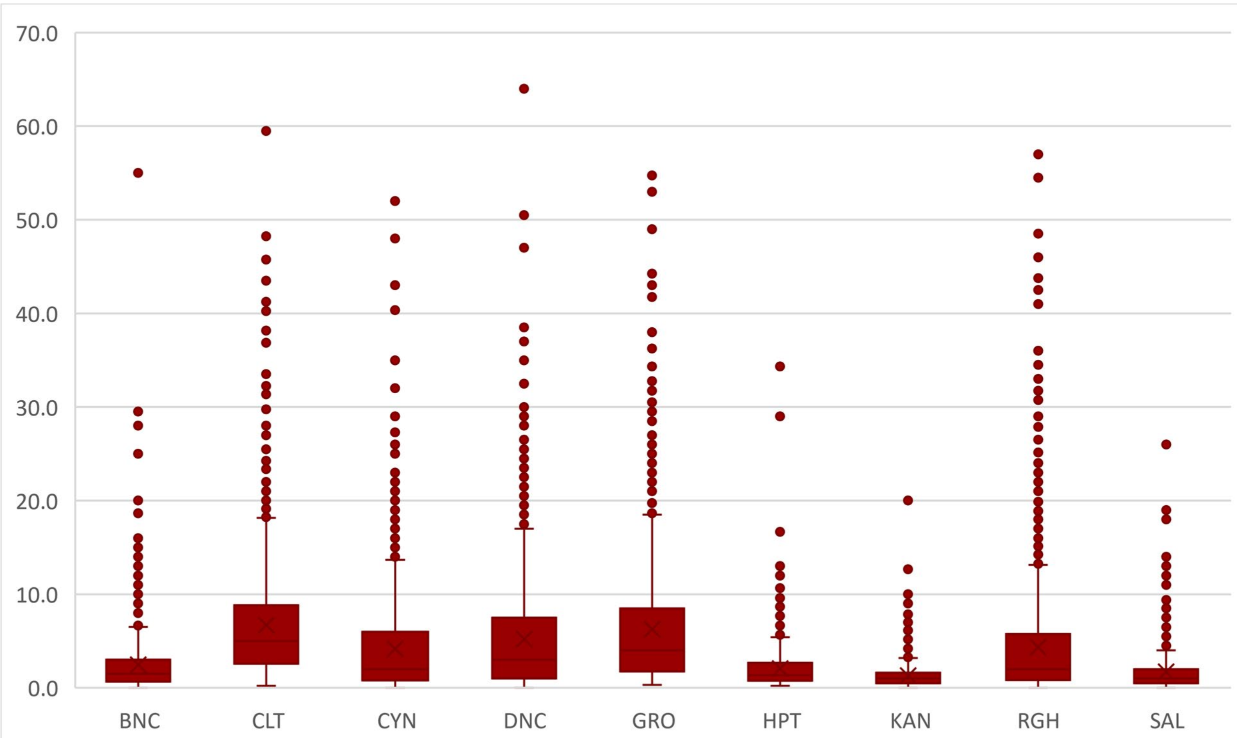
Table 8: Light Rail Passengers per Boarding

Station	Passengers per Stop per Frequency
25th St Station	1.62
McCullough Station	4.06
Carson Station	4.77
9th Street Station	5.12
Tom Hunter Station	5.65
Bland Station	6.33
Sugar Creek Station	6.45
Archdale Station	6.74
Woodlawn Station	6.84
Old Concord Road Station	7.01
University City Blvd Station	7.92
Sharon Rd West Station	8.66
Tyvola Station	8.93
New Bern Station	9.18
36th St Station	9.35
Arrowood Station	9.35
East/ West Station	10.33
Stonewall Station / Brooklyn Village	10.76
Parkwood Station	11.28
Scaleybark Station	11.38
UNC Charlotte Station	13.68
JW Clay Blvd Station	15.79
I-485 Station	22.48
7th St Station	23.90
3rd/ Convention Center Station	28.87
CTC Station	43.44
Average	**11.53**

Source: Derived from CATS 2019 data.

Passenger Rail Ridership per Boarding. Using NCDOT-provided Amtrak data, an analysis was undertaken to determine the number of passengers per train boarding. Across North Carolina's whole rail network, passengers per boarding ranged from 0 to 65 (see Figure 5). However, when assessing the average number of passengers per boarding, values ranged from 1.31 to 6.70 with an average of 3.99 passengers per boarding (see Table 9).

Figure 5: Passengers per Boarding (by Origin)



Source: Derived from NCDOT 2019 data.

Table 9: Passengers per Boarding (by Origin)

Station	Count of Boardings	Passengers per Station Boarding
CLT	1,843	6.70
GRO	1,833	6.27
DNC	1,857	5.20
RGH	1,765	4.34
CYN	1,700	4.17
BNC	1,444	2.49
HPT	1,499	2.06
SAL	1,466	1.73
KAN	1,489	1.31
Grand Total	**14,896**	**3.99**

Source: Derived from NCDOT 2019 data.

For the BCA methodology, a max value of 6.70 riders per stop per frequency was used. This value was then multiplied by the percent urban value extracted from Census Data within the GIS tool. The product of the (percent urban) x (6.70) was used to estimate riders per stop per frequency at a given train station location.

Vehicle Ferry Ridership per Boarding. Using NCDOT Ferry Division data, an analysis was undertaken to determine the number of individuals per vehicle ferry boarding. Values ranged from an average of 10.9 to 52.0 passengers per boarding, depending on the NCDOT ferry route (see Table 10). For the BCA methodology, a value of 28.7 passengers per vehicle ferry boarding was used.

Table 10: Passengers per Vehicle Ferry Boarding

Ferry Route	Count of Ferry Boardings	Passenger Sum - All Boardings	Ave Passengers per Boarding
Currituck to Knotts Island	994	10,831	10.9
Aurora to Bayview	1,335	15,438	11.6
Bayview to Aurora	1,344	17,046	12.7
Knotts Island to Currituck	971	13,744	14.2
Cherry Branch to Minnesott	5,295	89,662	16.9
Minnesott to Cherry Branch	5,278	96,614	18.3
Hatteras to South Dock	4,205	138,336	32.9
South Dock to Hatteras	4,164	138,960	33.4
Ocracoke to Swan Quarter	561	21,175	37.7
Swan Quarter to Ocracoke	564	22,610	40.1
Ocracoke to Cedar Island	544	25,315	46.5
Southport to Fort Fisher	2,862	139,262	48.7
Cedar Island to Ocracoke	560	27,987	50.0
Fort Fisher to Southport	2,859	148,721	52.0
Grand Total	**31,536**	**905,701**	**28.7**

Source: Derived from NCDOT ferry data, 1998-2017.

Passenger Ferry Ridership per Boarding. Using NCDOT Ferry Division data, an analysis was undertaken to determine the number of individuals per passenger ferry boarding. Both pedestrians and cyclists board NCDOT passenger ferries as shown in Table 11 and Table 12. Values ranged from an average of 46.63 to 47.60 passengers per boarding, depending on the NCDOT ferry route (see Table 13). For the BCA methodology, a value of 28.7 passengers per vehicle ferry boarding was used.

Table 11: Pedestrians per Passenger Ferry Boarding

Pax Ferry Service	Count of Ferry Boardings	Sum of Pedestrians	Ave Ped / Boarding
Passenger - Hatteras to Ocracoke	190	8,379	44.10
Passenger - Ocracoke to Hatteras	173	7,795	45.06
Grand Total	**363**	**16,174**	**44.56**

Source: NCDOT, 2022

Table 12: Cyclists per Passenger Ferry Boarding

Pax Ferry Service	Count of Ferry Boardings	Sum of Cyclists	Ave Cyclists / Boarding
Passenger - Hatteras to Ocracoke	190	481	2.53
Passenger - Ocracoke to Hatteras	173	440	2.54
Grand Total	**363**	**921**	**2.54**

Source: NCDOT, 2022

Table 13: Passengers per Boarding

Pax Ferry Service	Passengers per Boarding
Passenger - Hatteras to Ocracoke	46.63
Passenger - Ocracoke to Hatteras	47.60
Grand Total	**47.09**

Source: NCDOT, 2022

Highways

Physical Health Context. Low-speed streets that make it safer for people to walk and bike can both promote physical activity and reduce the climate impact of urban transport (Clark, 2015). A pilot study conducted in Edinburgh, Scotland, found multiple benefits in walking, biking, and the number of children allowed outside occurred as speed limits were reduced to 20 miles per hour. Pilot results showed that those considering cycling to be unsafe fell from 26 to 18 percent, walking trips rose 7 percent, and cycling trips rose 5 percent (Brasuell, 2014).

Physical Health Data Sources. For this study, 10 variables developed from eleven data sources were used to estimate the changes in physical activity that would result from implementing a proposed highway project (see Table 14). Three variables are sourced from the U.S. Census Bureau. Two variables are developed using a combination of six literature sources that provide posted speed limit thresholds and sidewalk characteristics that affect mode shift. One variable was developed using NACTO sidewalk width thresholds. And the other four variables are sourced from AAA, USDOT BCA Guidance, and Census Data.

Table 14: Highways Physical Health Data Sources

Variable	Data Source	Purpose
Project Area Population	U.S. Census Bureau	Number of affected by a proposed project
Walk Proportion	U.S. Census Bureau	Percentage of people that currently walk in project area
Bike Proportion	U.S. Census Bureau	Percentage of people that currently bike in project area
Posted Speed Limit	*Multiple sources	estimates posted speed limit effect on mode shift
Sidewalk existence	*Multiple sources	estimates sidewalk existence effect on mode shift
Sidewalk width	NACTO	estimates sidewalk width effect on mode shift
Mean daily person trips	AAA	Number of daily person trips made on average
Benefit per Walk Trip	USDOT BCA Guidance	Monetized physical health benefit per walk trip
Benefit per Cycle Trip	USDOT BCA Guidance	Monetized physical health benefit per bike trip
Annual trips by mode	Derived from U.S. Census data (GIS tool)	Variable based on base case conditions altered by mode shift

* The six sources used to develop the posted speed limit and sidewalk existence variables that affect mode shift include (1) Vision Zero Success Depends on Manging Speed for Safety. 2022. Online: https://visionzeronetwork.org/resources/speed-management/; (2) Caravajal, K. and Lungu, E. 2021. Building "Streets for Life" The Many Benefits of Lower Speed Limits. Online: https://blogs.worldbank.org/transport/building-streets-life-many-benefits-lower-speed-limits; (3) Clark, A. 2015. "Slower Speed Limits Give Cities a New Attitude About Biking, Walking, Breathing." Online: https://nextcity.org/urbanist-news/slow-speed-limits-cities-edinburgh-20mph; (4) Brasuell, J. 2014. Pilot 20 mph Speed Limit Shows Multiple Benefits. Online: https://www.planetizen.com/node/71374; (5) AARP. 2022. Sidewalks: A Livability Fact Sheet. Online: https://legistarweb-production.s3.amazonaws.com/uploads/attachment/pdf/334359/Attachment__3_-_Sidewalk_Factsheets.pdf; (6) Bakhit, B. and Asgary, A. 2017. Assessing the Value of Sidewalk Safety Attributes Affecting Individual's Walking Mode Choices Using a Choice Experiment Method in Amirabad Neighbourhood. Online: https://yorkspace.library.yorku.ca/xmlui/bitstream/handle/10315/34710/MESMP02759.pdf?sequence=2&isAllowed=y

Physical Health Methodology. The methodology discussed in this section is specific to prospective highway projects and it is derived by comparing the base case to the build case scenarios.

Base Case Scenario. First, the base case conditions of physical activity within the project area are determined. The same methodology used for bicycle and pedestrian projects is also used for highway projects. This is done by assessing the proportion of walk trips and bike trips made by people living within a half-mile of a proposed highway project.

The proportion of walk trips is multiplied by the population living within a half-mile buffer of the proposed project. This process is repeated, multiplying the proportion of bike trips times the project area population. These products provide us with the population of people within the project area who walk or cycle as a means of transportation given the existing highway network context.

The proportion of walk trips is multiplied by the population living within a half-mile buffer of the proposed project. This process is repeated, multiplying the proportion of bike trips times the project area population. These products provide us with the population of people within the project area who walk or cycle as a means of transportation. These populations are then multiplied by daily trips (derived from AAA, 2021) and 365 days to determine the number of active walk and bike trips made each year by the project area population. Total walk trips are then multiplied by the estimated benefit per walk trip and total cycle trips are multiplied by the benefit per cycle trip to get the total monetized benefit of walking and cycling within the existing highway context in the project area for the base case scenario.

Step 1: Calculate Physical Health Benefits in Base Case Scenario

- Walk Benefit$_{BC}$ = (Project Area Population) x (Walk Proportion) x (Trips per Day) x (Trips per Year) x (Benefit per Trip)

- Cycle Benefit$_{BC}$ = Cycle Benefit = (Project Area Population) x (Bike Proportion) x (Daily Trips) x (Annual Trips) x (Benefit per Trip)

- Base Case Total Health Benefit = Walk Benefit$_{BC}$ + Cycle Benefit$_{BC}$

Build Case Scenario. After a proposed highway project is completed, it can enable physical activity by facilitating walking or biking depending on its posted speed limit, whether it is accompanied by sidewalks, and the width of any accompanying sidewalks. Mode shift assertions relative to these variables are shown in Table 15.

Table 15: Prospective Highway Project Mode Shift Variables and Asserted Values

Variable	Base Case Scenario	Build Case Scenario	Mode shift Percentage
Speed Limit	0-20mph	0-20mph	0.00%
Speed Limit	0-20mph	20-30mph	-3.50%
Speed Limit	0-20mph	30-40mph	-7.00%
Speed Limit	0-20mph	40+ mph	-9.50%
Speed Limit	20-30mph	0-20mph	3.50%
Speed Limit	20-30mph	20-30mph	0.00%
Speed Limit	20-30mph	30-40mph	-3.50%
Speed Limit	20-30mph	40+ mph	-6.00%
Speed Limit	30-40mph	0-20mph	7.00%
Speed Limit	30-40mph	20-30mph	3.50%
Speed Limit	30-40mph	30-40mph	0.00%
Speed Limit	30-40mph	40+ mph	-2.50%
Speed Limit	40+ mph	0-20mph	9.50%
Speed Limit	40+ mph	20-30mph	6.00%
Speed Limit	40+ mph	30-40mph	2.50%
Speed Limit	40+ mph	40+ mph	0.00%
Speed Limit	n/a	0-20mph	7.00%
Speed Limit	n/a	20-30mph	3.50%
Speed Limit	n/a	30-40mph	0.00%
Speed Limit	n/a	40+ mph	-2.50%
Sidewalk Existence	No sidewalk	No Sidewalk	0.00%
Sidewalk Existence	No sidewalk	Sidewalk on one side	2.50%
Sidewalk Existence	No sidewalk	Sidewalk on both sides	5.00%
Sidewalk Existence	Sidewalk on one side	No Sidewalk	-2.50%
Sidewalk Existence	Sidewalk on one side	Sidewalk on one side	0.00%
Sidewalk Existence	Sidewalk on one side	Sidewalk on both sides	2.50%
Sidewalk Existence	Sidewalk on both sides	No Sidewalk	-5.00%
Sidewalk Existence	Sidewalk on both sides	Sidewalk on one side	-2.50%
Sidewalk Existence	Sidewalk on both sides	Sidewalk on both sides	0.00%

Variable	Base Case Scenario	Build Case Scenario	Mode shift Percentage
Sidewalk Width	Does not meet NACTO guidelines for the Pedestrian Through Zone	Does not meet NACTO guidelines for the Pedestrian Through Zone	0.00%
Sidewalk Width	Does not meet NACTO guidelines for the Pedestrian Through Zone	Meets NACTO Residential Guidelines for the Pedestrian Through Zone (5-7 feet)	1.25%
Sidewalk Width	Does not meet NACTO guidelines for the Pedestrian Through Zone	Meets NACTO Dowtown or Commercial Guidelines for the Pedestrian Through Zone (8-12 feet)	3.75%
Sidewalk Width	Meets NACTO Residential Guidelines for the Pedestrian Through Zone (5-7 feet)	Does not meet NACTO guidelines for the Pedestrian Through Zone	-1.25%
Sidewalk Width	Meets NACTO Residential Guidelines for the Pedestrian Through Zone (5-7 feet)	Meets NACTO Residential Guidelines for the Pedestrian Through Zone (5-7 feet)	0.00%
Sidewalk Width	Meets NACTO Residential Guidelines for the Pedestrian Through Zone (5-7 feet)	Meets NACTO Dowtown or Commercial Guidelines for the Pedestrian Through Zone (8-12 feet)	2.50%
Sidewalk Width	Meets NACTO Dowtown or Commercial Guidelines for the Pedestrian Through Zone (8-12 feet)	Does not meet NACTO guidelines for the Pedestrian Through Zone	-1.25%
Sidewalk Width	Meets NACTO Dowtown or Commercial Guidelines for the Pedestrian Through Zone (8-12 feet)	Meets NACTO Residential Guidelines for the Pedestrian Through Zone (5-7 feet)	-2.50%
Sidewalk Width	Meets NACTO Dowtown or Commercial Guidelines for the Pedestrian Through Zone (8-12 feet)	Meets NACTO Dowtown or Commercial Guidelines for the Pedestrian Through Zone (8-12 feet)	0.00%
Sidewalk Width	n/a	Does not meet NACTO guidelines for the Pedestrian Through Zone	0.00%
Sidewalk Width	n/a	Meets NACTO Residential Guidelines for the Pedestrian Through Zone (5-7 feet)	1.25%
Sidewalk Width	n/a	Meets NACTO Dowtown or Commercial Guidelines for the Pedestrian Through Zone (8-12 feet)	3.75%
Sidewalk Width	n/a	n/a	0.00%

The sources used to develop the posted speed limit, sidewalk existence, and sidewalk width variables that affect mode shift include (1) Vision Zero Success Depends on Manging Speed for Safety. 2022. Online: https://visionzeronetwork.org/resources/speed-management/; (2) Caravajal, K. and Lungu, E. 2021. Building "Streets for Life" The Many Benefits of Lower Speed Limits. Online: https://blogs.worldbank.org/transport/building-streets-life-many-benefits-lower-speed-limits; (3) Clark, A. 2015. "Slower Speed Limits Give Cities a New Attitude About Biking, Walking, Breathing." Online: https://nextcity.org/urbanist-news/slow-speed-limits-cities-edinburgh-20mph; (4) Brasuell, J. 2014. Pilot 20 mph Speed Limit Shows Multiple Benefits. Online: https://www.planetizen.com/node/71374; (5) AARP. 2022. Sidewalks: A Livability Fact Sheet. Online: https://legistarweb-production.s3.amazonaws.com/uploads/attachment/pdf/334359/Attachment__3_-_Sidewalk_Factsheets.pdf; (6) Bakhit, B. and Asgary, A. 2017. Assessing the Value of Sidewalk Safety Attributes Affecting Individual's Walking Mode Choices Using a Choice Experiment Method in Amirabad Neighbourhood. Online: https://yorkspace.library.yorku.ca/xmlui/bitstream/handle/10315/34710/MESMP02759.pdf?sequence=2&isAllowed=y; (7) Boston Complete Streets Guidelines. 2013. Online: https://nacto.org/wp-content/uploads/2016/04/1-6_BTD_Boston-Complete-Streets-Guidelines-2.4-6-Sidewalk-Widths_2013.pdf

The posted speed limit, sidewalk existence, and sidewalk width all have an effect on mode shift. These effects are summed together to derive the total mode shift percentage a prospective project facilitates. The mode shift percentage is then converted into a multiplier and applied to the equations below. These equations are used to quantify the physical health benefits or costs within the project area of a prospective highway project.

Step 2: Calculate Physical Health Benefits in Build Scenario

Walk Benefit' = (Project Area Population) x (Walk Proportion) x (1+ (Posted Speed Limit Mode Shift Percentage) + (Sidewalk Existence Mode Shift Percentage) + (Sidewalk Width Mode Shift Percentage)) x (Trips per Day) x (Trips per Year) x (Benefit per Trip)

Cycle Benefit' = (Project Area Population) x (Cycle Proportion) x (1+ (Posted Speed Limit Mode Shift Percentage) + (Sidewalk Existence Mode Shift Percentage) + (Sidewalk Width Mode Shift Percentage)) x (Trips per Day) x (Trips per Year) x (Benefit per Trip)

Build Scenario Total Health Benefit = Walk Benefit' + Cycle Benefit'

Net Change in Health Benefits

Net Health Benefit = (Walk Benefit' + Cycle Benefit') - (Walk BenefitBC + Cycle Benefit_{BC}

Air Quality Methodologies and Datasets

Air pollution emitted from transportation contributes to smog, and to poor air quality, which has negative impacts on the health and welfare of U.S. citizens (EPA, 2023). Pollutants that contribute to poor air quality include particulate matter (PM), nitrogen oxides (NOx), and volatile organic compounds (VOCs). The transportation sector is responsible for: Over 55% of NOx total emissions inventory in the U.S., less than 10% of VOCs emissions in the U.S., and less than 10% of PM2.5 and PM10 emissions in the U.S. (EPA, 2023).

Bicycle-Pedestrian, Public Transportation, Passenger Rail, and Ferry Travel

For this study, the research team evaluated data sources and developed a methodology to incorporate air quality as a measure within North Carolina's Prioritization Process. Integral to the analysis, the research team needed to quantify air emissions that accrue per passenger mile of travel for each mode. First trip lengths for each travel mode were evaluated. Table 16 shows the modal segments and the estimated travel distances that comprise one commute trip. For example, if an individual were to make a bus trip and decided to walk to the bus, it is estimated that an individual would walk 0.4 miles to the bus stop and then commute for five miles on the bus. This information was paired with emissions per person-mile by transportation mode (see Table 17) to estimate the carbon-dioxide-equivalent emissions released per mile of travel. This information could then be used to estimate emissions per trip.

Emissions per trip estimates were multiplied by daily and annual trips by mode to obtain annual emissions estimates by mode of travel. To estimate the change in emissions within the project area before (base case scenario) and after a project (build scenarios), an inventory of emissions within the project area needed to be derived with existing conditions. This level of emissions was then compared to projected emissions in the project area after the implementation of modal project. Base case and build case emissions methodologies are discussed below.

Base Case Scenario. An inventory of existing emissions within the project area was derived. U.S. Census data were used to obtain the share of walk, bike, transit, and drive share in the project area. These shares were multiplied by the population living within the prospective project area (within a half-mile buffer of the proposed project) to obtain the number of people within the project area who walk, cycle, take public transportation, or drive as means for commuting. These populations' daily trips (derived from AAA, 2021) are then multiplied by their walk, bike, drive, and transit segment distances (Table 16) and the emissions per-person-mile factors shown in Table 17. Daily trips are then multiplied by 365 to obtain emissions per year. Emissions costs are then monetized using USDOT's BCA guidance to obtain emissions costs by mode within the project area over the course of a year.

Table 16: Estimated Commute Lengths by Mode

Trip Type	Walk Trip Length	Bike Trip Length	Drive Trip Length	Bus Trip Length	Bus Rapid Transit Length	Light Rail Trip Length	Commuter Rail Trip Length	Ferry Trip Length	Total Trip Length
Walk Commute[1]	**1.19**	--	--	--	--	--	--	--	1.19
Bike Commute[2]	--	**3.5**	--	--	--	--	--	--	3.5
Walk + Bus[3,4]	**0.4**	--	--	**5**	--	--	--	--	5.4
Bike + Bus[3,4]	--	**0.6**	--	**5**	--	--	--	--	5.6
Drive + Bus[3,4]	--	--	**2.48**	**5**	--	--	--	--	7.48
Walk + Bus Rapid Transit[3,4]	**0.4**	--	--	--	**5.2**	--	--	--	5.6
Bike + Bus Rapid Transit[3,4]	--	**0.6**	--	--	**5.2**	--	--	--	5.8
Drive + Bus Rapid Transit[4,5]	--	--	**2.48**	--	**5.2**	--	--	--	7.68
Walk + Light Rail[3,4]	**0.4**	--	--	--	--	**5.2**	--	--	5.6
Bike + Light Rail[3,4]	--	**0.6**	--	--	--	**5.2**	--	--	5.8
Drive + Light Rail[4,5]	--	--	**2.48**	--	--	**5.2**	--	--	7.68
Walk + Commuter Rail[3,4]	**0.4**	--	--	--	--	--	**9.6**	--	10
Bike + Commuter Rail[3,4]	--	**0.6**	--	--	--	--	**9.6**	--	10.2
Drive + Commuter Rail[4,5]	--	--	**2.48**	--	--	--	**9.6**	--	12.08
Walk + Ferry[3]	**0.4**	--	--	--	--	--	--	Use Actual Dist.	0.4
Bike + Ferry[3]	--	**0.6**	--	--	--	--	--	Use Actual Dist.	0.6
Drive + Ferry[5]	--	--	**2.48**	--	--	--	--	Use Actual Dist.	2.48

[1]Walk commute from National Household Travel Survey, 2017
[2]Bike commute adapted from ACS Report: Travel Time to Work in the United States, 2019 (Census report an average bike commuting time of 21.2 minutes, which suggests around 2.8 miles (at 8 mph), or 4.2 miles at 12 mph. So, assuming most bike commuters fall in the middle of that range, then 3-4 miles is a reasonable estimate of average distance.)
[3]Walk and bike distance to public transportation from Agarwal et al., 2008
[4]Bus, light rail, commuter rail, from APTA's Transit Factbook, 2021. Bus Rapid Transit values derived from public transportation distances within the Factbook.
[5]Drive commute from National Household Travel Survey, 2017

Table 17: Emissions per Person-Mile

Mode	Operational Emissions per Person Mile (kg CO_2e)	Source
Battery Electric Bus	0.12	National Academies of Sciences, 2021.
Non-Electric Bus	0.35	National Academies of Sciences, 2021.
Heavy Rail	0.08	National Academies of Sciences, 2021.
Commuter Rail	0.16	National Academies of Sciences, 2021.
Light Rail	0.15	National Academies of Sciences, 2021.
Van	0.65	National Academies of Sciences, 2021.
Ferry (Vehicle)	0.38	Derived from FerryGoGo, 2022 & NAS, 2021.
Ferry (Passenger)	0.23	Derived from NAS, 2021 & NCDOT, 2021.
All Transit Modes	0.23	National Academies of Sciences, 2021.
Private Gasoline Vehicle	0.51	National Academies of Sciences, 2021.
Private Electric Vehicle	0.14	National Academies of Sciences, 2021.

Sources: National Academies of Sciences, 2021; FerryGoGo, 2022; NCDOT, 2021.

Table 18: Ridership per Boarding

Ridership per Boarding Mode	Value	Data Source(s)
Bus	4.52 passengers per boarding	Derived from GoRaleigh Data
BRT / LRT	11.53 passengers per boarding	Derived from CATS Data
Passenger Rail	3.99 passengers per boarding	Derived from NC Amtrak Data
Vehicle Ferry	28.72 passengers per boarding	Derived from NCDOT Ferry Data
Passenger Ferry	47.09 passengers per boarding	Derived from NCDOT Ferry Data

Calculating Air Quality Benefits in Base Case Scenario

Step 1: Calculate Annual Emissions Costs from Those Making Walk Trips in the Project Area

(A) Annual Person Trips by Walking = (Project Area Population) x (Walk Proportion) x (Daily Trips) x (Annual Trips)

(B) Annual Emissions Cost = Assume Zero Emissions

Step 2: Calculate Annual Emissions Costs from Those Making Cycling Trips in the Project Area

(A) Annual Person Trips by Cycling = (Project Area Population) x (Bike Proportion) x (Daily Trips) x (Annual Trips)

(B) Annual Emissions Cost = Assume Zero Emissions

Step 3: Calculate Annual Emissions Costs from Those Making Transit Trips in the Project Area

(A) Annual Person Trips by Transit = (Project Area Population) x Transit Proportion) x (Daily Trips) x (Annual Trips)

(B) Annual Emissions Cost = (Annual Person Trips by Transit) x (Miles per Transit Trip) x (Kg of CO_2 per Transit Passenger Mile)

Step 4: Calculate Annual Emissions Costs from Those Making Vehicle Trips in the Project Area

(A) Annual Person Trips by Vehicle = (Project Area Population) x (Drive Proportion) x (Daily Trips) x (Annual Trips)

(B) Annual Emissions Cost = (Annual Person Trips by Vehicle) x (Miles per Vehicle Trip) x (Kg of CO_2 per Vehicle Passenger Mile)

Base Case Total Emissions Costs = Vehicle Emissions Costs + Transit Emissions Costs + Walk Emissions Costs + Cycle Emissions Costs

Build Scenario. The same methodology used in the base case scenario is used in the build case scenario with two primary adjustments. First, mode shift is assessed for each travel mode. Mode shift accounts for the trips that will be diverted from vehicle travel and absorbed by the prospective transportation project mode (i.e., bike/ped, bus, BRT, LRT, passenger train, passenger ferry, and vehicle ferry). The mode shift evaluation approaches by mode are discussed below.

Bike-Ped. Mode shift for bicycle and pedestrian projects will depend on the length of the proposed bike-ped facility plus the length of the network it ties into. If the proposed project creates a total network of 0-0.5 miles it will induce mode shift of +0.25 percent, 0.5-2.0 miles will induce mode shift of +0.5 percent, and the creation of a network of greater than 2.0 miles will induce a mode shift of 1.0 percent (see Table 2). This mode shift will be directly added to the base case walk and cycle shares (see example below).

- Cycle trips in build scenario = (Project Area Population) x (Cycle Proportion **+ mode shift increment**) x (Daily Trips) x (Annual Trips)

- Walk trips in build scenario = (Project Area Population) x (Walk Proportion **+ mode shift increment**) x (Daily Trips) x (Annual Trips)

Bus, BRT, LRT, Train, Ferry. Mode shift for transit modes will depend on the projected ridership attracted to each new transit boarding in the project area. Results from the "Ridership per Boarding Analysis" discussed on page 17 show the following number of passengers per boarding attracted to each new stop, station, or terminal within the project area: bus (4.52), BRT and LRT (11.53), commuter rail (6.70) passenger ferries (47.09), and vehicle ferries (28.72). These new passengers per boarding are multiplied by the number of new frequencies to get new passenger boardings per day. These boardings can then be multiplied by 365 to get annual passenger boardings by transit mode (see example below).

- Trips shifted to transit trips in build scenario = (Project Area Population) x (Transit Proportion) x (Daily Trips) x (Annual Trips) + ((No. of new bus stops in project area) x (4.52) x (Daily Transit Frequencies) x (365)

Second, the number of trips added to the travel mode of a prospective project (i.e., bike/ped, bus, BRT, LRT, passenger train, passenger ferry, and vehicle ferry) are assumed to be diverted from auto commute trips. Thus, diverted trips will be subtracted from vehicle trips in the base case scenario. The equations used to calculate air quality benefits are shown on the following page.

Calculating Air Quality Benefits in Build Scenario

Step 1: Calculate Annual Emissions Costs from Those Making Walk Trips in the Project Area

(A) Annual Person Trips by Walking = (Project Area Population) x (Walk Proportion **+ mode shift increment**) x (Daily Trips) x (Annual Trips)

(B) Annual Emissions Cost = Assume Zero Emissions

Step 2: Calculate Annual Emissions Costs from Those Making Cycling Trips in the Project Area

(A) Annual Person Trips by Cycling = (Project Area Population) x (Bike Proportion **+ mode shift increment**) x (Daily Trips) x (Annual Trips)

(B) Annual Emissions Cost = Assume Zero Emissions

Step 3: Calculate Annual Emissions Costs from Those Making Transit Trips in the Project Area

(A) Annual Person Trips by Transit = (Project Area Population) x Transit Proportion) x (Daily Trips) x (Annual Trips) **+ ((No. of new transit stops in project area) x (Population Density Scalar[A]) x (Passengers per Boarding) x (Daily Transit Frequencies) x (365))**

(B) Annual Emissions Cost = (Annual Person Trips by Transit) x (Miles per Transit Trip) x (Kg of CO2 per Transit Passenger Mile)

Step 4: Calculate Annual Emissions Costs from Those Making Vehicle Trips in the Project Area

(A) Annual Person Trips by Vehicle = (Project Area Population) x (Drive Proportion) x (Daily Trips) x (Annual Trips) - **(Annual Trips Diverted to Other Mode)**

(B) Annual Emissions Cost = (Annual Person Trips by Vehicle) x (Miles per Vehicle Trip) x (Kg of CO2 per Vehicle Passenger Mile) x (Cost of CO2e per Kg)

Base Case Total Emissions Costs = Vehicle Emissions Costs + Transit Emissions Costs + Walk Emissions Costs + Cycle Emissions Costs

[A]The population density scalar is applied to bus, BRT, LRT, and passenger rail modes. It is not applied to vehicle or passenger ferry modes because it is assumed that a large portion of the ridership is met from areas that are not within close proximity to the ferry terminals.

Highways

Air Quality Context. In many areas, vehicle emissions have become the dominant source of air pollutants, including carbon monoxide (CO), carbon dioxide (CO2), volatile organic compounds (VOCs) or hydrocarbons (HCs), nitrogen oxides (NOx), and particulate matter (PM) (Transportation Research Board, 2002). The increasing severity and duration of traffic congestion has the potential to greatly increase pollutant emissions and to degrade air quality, particularly near large roadways. These emissions contribute to risks of morbidity and mortality for drivers, commuters and individuals living near roadways, as shown by epidemiological studies, evaluations of proposed vehicle emission standards, and environmental impact assessments for specific road projects (World Health Organization, 2005; Health Effects Institute, 2010).

Attempts to address traffic congestion commonly rely on increasing roadway capacity, e.g. by building new roadways or adding lanes to existing facilities (Handy, 2015). But studies examining that approach indicate it is only a temporary fix. They consistently show that adding roadway capacity actually increases network-wide vehicle miles traveled (VMT) by a nearly equivalent proportion within a few years, reducing or negating any initial congestion relief (Handy and Boarnet, 2014). That increase in VMT is called "induced travel."

Air Quality Methodology and Data Sources. The National Center for Sustainable Transportation developed the *California Induced Travel Calculator*, which is used by CalTrans models induced vehicle miles traveled stemming from highway investments. The calculator allows users to estimate the VMT induced annually as a result of adding general-purpose lane miles, high-occupancy vehicle (HOV) lane miles, or high-occupancy toll (HOT) lane miles to publicly owned roadways.

- Induced Travel Demand Calculator Link: https://travelcalculator.ncst.ucdavis.edu/

As part of research project 2022-17: Including Equity in Benefit Cost Analysis, the *California Induced Calculator*, has been adapted to North Carolina's context. It includes North Carolina's road network and has been expanded to include all potential highway investments, not just Class 1, 2, or 3 facilities, and incorporates U.S. Census Data.

Figure 6: Induced VMT Methodology

Data and Elticities

To estimate the induced VMT for capacity expansion projects, the Calculator solves the following equation based on the user-specified project geography and lane mile length:

%∆ Lane Miles x Existing VMT x Elasticity = Project-Induced VMT

Source: National Center for Sustainable Transportation, 2019

To estimate a prospective project's effect on air quality, several methodological steps are undertaken. First, project-induced VMT has to be derived. This is done by providing inputs for the number of existing lane miles, vehicle miles traveled, and the elasticity for a specific roadway type. For example, if two miles of interstate were going to be built in Wake County, information on the number of existing interstate miles within the Wake County commute cluster (see definition in Figure 8) would need to be recorded. Then the change in lane miles would need to be derived. The change in lane miles would then be multiplied by existing VMT and the induced VMT elasticity to get the overall magnitude of change in VMT resulting from the project, also known as project-induced VMT. The methodology and variables used to derive induced VMT and their data sources are discussed in Figure 7 and Figure 8.

Figure 7: Methodology for Estimating Induced VMT from Investment

%Δ Lane Miles x Existing VMT x Elasticity = Project-Induced VMT

Figure 8: Data Sources and Methodology for Estimating Project-Induced VMT

- **Commute Cluster**. A commute cluster is defined as the commute pattern for North Carolina residents traveling from home to work. This information was extracted from the U.S. Census Bureau's "Residence County to Workplace County Commuting Flows for the United States and Puerto Rico Sorted by Residence Geography: 5-Year ACS, 2011-2015" table. These data provided commuting patterns and was paired with NCDOT's Roadway Characteristics Shapefile to derive commuting patterns by roadway type. Altogether, these data were used to estimate the lane miles traversed by highway facility type when starting from a given county.

- **Change in Lane Miles.** Commute cluster and NCDOT Roadway Characteristics data are used to derive existing lane miles traversed. Then a project submitter provides data on the total number of lane miles that would be added to for a given facility. The change in lane miles of a given facility type are then calculated as part of the equation to estimate project-induced demand (see Figure 7).

- **Existing VMT**. Existing VMT data comes from NCDOT's Public Transportation Division. County VMT are used as the measure for existing VMT. VMT by highway facility type are distributed using a crosswalk for VMT to AADT derived from FHWA,2013. NCDOT data with AADT by facility type are used to allocate existing VMT by facility type using the AADT crosswalk.

- **Elasticity**: For this research, elasticity measures the sensitivity of which a new highway facility will induce demand. Interstate facilities generate the greatest level of induced demand followed by US or NC routes, secondary routes, and then all other routes (see Table 17).

Table 19: Induced VMT Elasticities by Road Type

List	Elasticity
Interstate (I)	1.00
US or NC Routes (US) or (NC)	0.75
Secondary Route (SR)	0.50
All Other	0.25

Source: Derived from the National Center for Sustainable Transportation, 2019.

Once Induced VMT is calculated, then emissions per VMT are estimated. Three sources are used to estimate the quantity and cost of emissions. These sources include USDOT's BCA Guidance, the Bureau of Transportation Statistics' average vehicle emissions rates, and the Environmental Protection Agency's greenhouse gas emissions from a typical vehicle. Emissions costs per vehicle mile are calculated. These incremental costs are then multiplied by induced VMT to obtain the cost of induced VMT. For this analysis, it is assumed that induced VMT values are representative of what would occur 10 years after a highway project is implemented.

Figure 9: Equity in BCA Air Quality Impacts Tool

(back to tool navigation)

Input Values

Select Facility Type	Interstate (I)
Select County	Wake
Input total lane miles added	5

Clear Values

Key Parameters

Highway Classification	Lane Miles
Interstate Lane Miles Used by Commute Cluster Into Wake County	142.4
US or NC Route Lane Miles in Wake County	443.1
Secondary Route Lane Miles in Wake County	2162.8
All Other Lane Miles in Wake County	4018.7

Skip to Results

Highway Classification for the Change in Lane Miles	Induced Demand Elasticity
Interstate (I)	1.00

Emissions Parameter	Value
Grams of Carbon Dioxide (CO_2) Released per Vehicle Mile[1,2]	404
Grams of Nitrous Oxide (NOx) Released per Vehicle Mile[1,2]	0.687
Grams of Particulate Matter ($PM_{2.5}$) Released per Vehicle Mile[1,2]	0.033
CO_2 Cost per metric ton (2022 USD)	$53
NOx Cost per metric ton (2022 USD)	$15,600
$PM_{2.5}$ Cost per metric ton (2022 USD)	$748,600
CO_2 Cost per gram (2022 USD)[3]	$0.000053
NOx Cost per gram (2022 USD)[3]	$0.0156
$PM_{2.5}$ Cost per gram (2022 USD)[3]	$0.7486
CO_2 Cost per Vehicle Mile (2022 USD)	$0.021
NOx Cost per Vehicle Mile (2022 USD)	$0.011
$PM_{2.5}$ Cost per Vehicle Mile (2022 USD)	$0.025
Total Emissions Cost per Vehicle Mile (2022 USD)	$0.057

Figure 9 and Figure 10 provide an example of an induced VMT calculation. It estimates the emissions costs associated with the projected induced VMT that would result from adding five interstate lane miles in Wake County, North Carolina. These impacts are anticipated to occur in year 10 of project operation (in other words, the tool estimates annual emissions costs approximately 10 years after the project has been built).

Figure 10: Equity in BCA Air Quality Impacts Tool (Continued)

Model Output (Extended List)

Model Output	Value
New Lane Miles Added	5
Percentage Change Lane Miles	3.4%
Induced Vehicle Miles Traveled	55,069,200
Induced Carbon Dioxide (CO_2) Emissions (grams)	22,247,956,800
Induced Nitrous Oxide (NOx) Emissions (grams)	37,832,540
Induced Particulate Matter ($PM_{2.5}$) Emissions (grams)	1,817,284
Induced Carbon Dioxide (CO_2) Emissions (metric tons)	22,248.0
Induced Nitrous Oxide (Nox) Emissions (metric tons)	37.8
Induced Particulate Matter ($PM_{2.5}$) Emissions (metric tons)	1.8
Total Emissions Cost ($2022)	$3,129,748

[1]Environmental Protection Agency. 2018. Greenhouse Gas Emissions from a Typical Passenger Vehicle.

[2]Bureau of Transportation Statistics. 2021. Estimated U.S. Average Vehicle Emissions Rates per Vehicle by Vehicle Type Using Gasoline and Diesel.

[3] USDOT BCA Guidance. 2022.

Model Output (Simplified)

Model Output	Value
New Lane Miles Added	5
Induced Vehicle Miles Traveled	55,100,000
Total Emissions Cost ($2022)	$3,100,000

Results Summary

A project adding 5 lane miles in Wake County would induce an additional 55,100,000 vehicle miles travelled per year. This would generate an estimated annual emissions cost of $3,100,000 dollars.

This calculation is using an elasticity of 1.

Return to Start

Including Equity in the Prioritization Process

Transportation equity analysis can be difficult because there are several types of equity, various ways to categorize people for equity analysis, numerous impacts to consider, and various ways of measuring these impacts (Litman, 2006). As a result, transport equity impacts tend to be evaluated inconsistently, or simply dismissed as “intangibles,” with the implication that they are unmeasurable and can be ignored. But equity analysis is often important and unavoidable (Litman, 2006). The United States is afflicted by distributional inequities along racial, gender, socioeconomic, and other dimensions (Adler, 2021). As a result, regulatory impact analysis is being reviewed to determine improved methods to account for a proposed policy or investment’s distributional impacts (Adler, 2021).

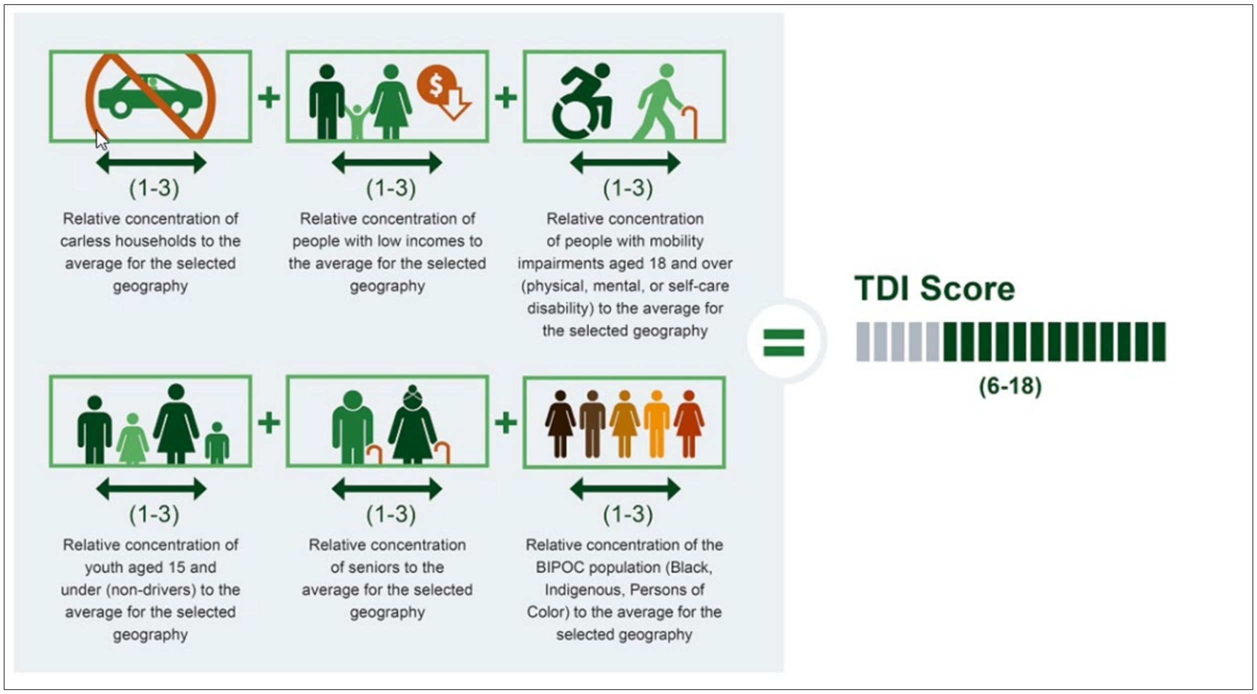
Most planning professionals sincerely want to address equity concerns and are happy to incorporate equity into their analysis, but few resources exist to provide guidance on how to do this in an objective, comprehensive and effective way. Recently, the N.C. Department of Transportation has developed web-based tools that display data to illustrate the disproportionate impact transportation outcomes may have on North Carolina’s communities. The Transportation Disadvantage Index, or TDI, tool is a customized approach to support a high-level assessment of equity impacts (NCDOT, 2023). It focuses on race (Black, Indigenous and persons of color), income, personal vehicle access, people with mobility impairments, the elderly and youth. A TDI score of six within indicates the lowest level of disadvantage while a score of 18 indicates the highest level of disadvantage (see Figure 11).

NCDOT’s transportation disadvantage index methodology was implemented for this research to quantify the varying levels of disadvantage within a prospective project’s impact area.[3] TDI was integrated within the research team’s GIS tool (see Figure 12) and workbook tool (see Figure 13). The primary purpose of including TDI was to demonstrate how project benefits or costs would be allocated to communities of varying levels of disadvantage within the project area. Net physical health benefits and costs are allocated in the project area by using the following methodology:

- The proportion of TDI populations by severity (TDI populations 6 through 18) are multiplied by the net physical health and air quality benefits or costs in the project area (see Figure 13).

[3] For this research, a project’s impact area has been defined as the population within its walkshed, which is typically assigned as a half-mile buffer around the project. It’s important to note; however, that the quantitative methods used for this research can be applied to any sized project area or buffer. The research team developed its BCA methodologies and associated GIS and workbook tools with dynamic buffering capabilities.

Figure 11: NCDOT Transportation Disadvantaged Index Scoring Methodology



Source: NCDOT, 2023.

Figure 12: GIS Tool to Accompany Physical Health and Air Quality Benefit-Cost Analyses

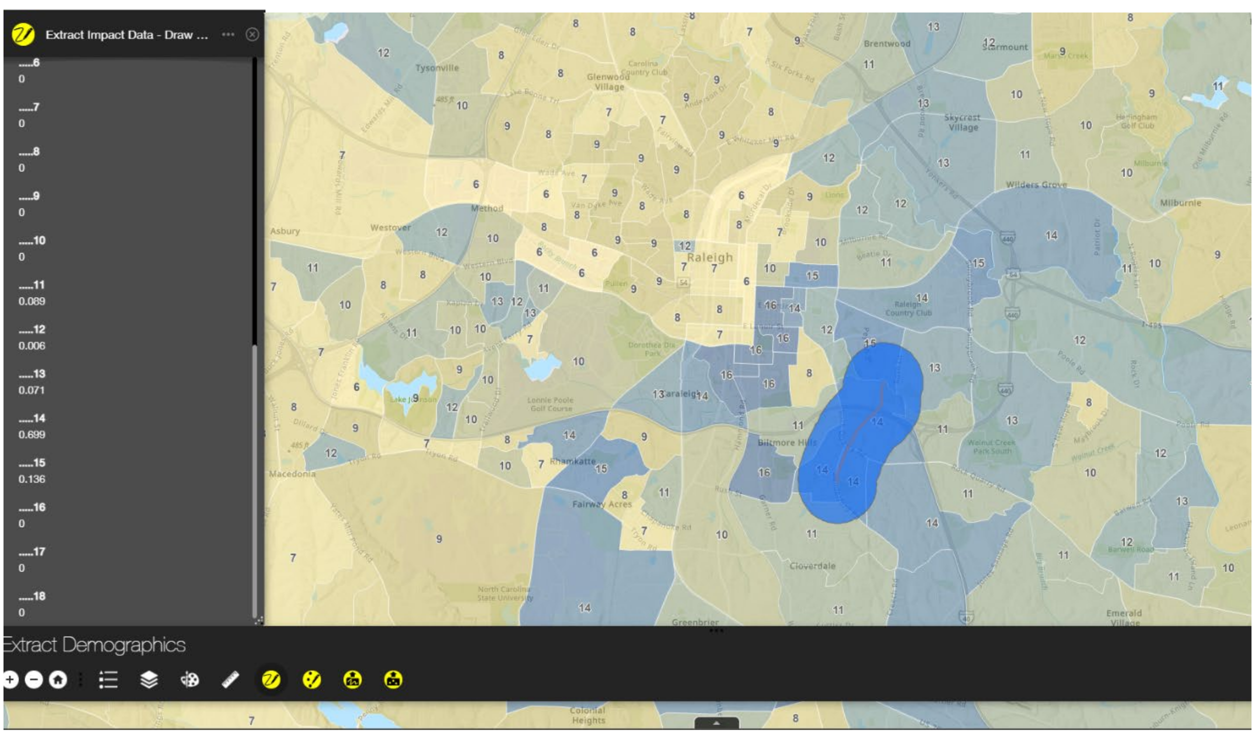


Figure 13: Excel Workbook Tool to Accompany Physical Health and Air Quality Benefit-Cost Analyses

Physical Health and Air Quality Models

Table 1: Extract Demographics Tool Output Values

Parameter	GIS Tool Output Values
Project Area Population	10,000
Walk Proportion	0.01
Bike Proportion	0.005
Transit Proportion	0.1

Clear Values

Table 2: Proposed Facility Characteristics

Parameter	Value
Proposed Facility Length*	(C) Greater than 2.0 miles

Clear Values

*Applies to standalone facilty length + length of connected facilities that meet NACTO residential or city width sidewalk standards

Table 3: Physical Health Output

Summary Statistic	Summary Values
Project Area Population	10,000
Pedestrians Effected	100
Cyclists Effected	50

Summary Statistic	Existing Conditions (Base Case)	Proposed Conditions (Build Case)	Net Difference
Physically Active Pedestrians	100	200	100
Physically Active Cyclists	50	150	100
Daily Walk Trips	260	520	260
Daily Cycle Trips	130	390	260
Annual Walk Trips	94,900	189,800	94,900
Annual Cycle Trips	47,450	142,350	94,900
Annual Appraised Physical Health Benefit	**$971,302**	**$2,242,013**	**$1,270,711**

Equity Implications: Distribution of Health Impacts

TDI Level	Population Proportion	Net Benefit
6		$0
7		$0
8		$0
9		$0
10		$0
11	0.089	$113,093
12	0.006	$7,624
13	0.071	$90,220
14	0.698	$886,956
15	0.136	$172,817
16		$0
17		$0
18		$0
Total	1.000	$1,270,711

Source: ITRE, 2023

Conclusions

Findings Relevant to NCDOT

Transportation planning addresses current and future transportation, land use, economic development, public safety, health, and social needs (15 CFR § 170.5) and often has significant societal impacts. As transportation decisions fundamentally shape the way people interact with their environment and are able access places that support economic, social, and physical wellbeing, it is important to evaluate how transportation investment decisions impact both the intended users as well as all other individuals affected by the investment.

The evaluation of a transportation project's impact on physical health, air quality, and the distribution of physical health and air quality benefits and costs within a transportation's project's impact area are the key pillars of *RP 2022-17: Including Equity in Benefit-Cost Analysis*. The research team's primary objective is to assist NCDOT in accounting for air quality and physical health impacts within its strategic prioritization process. This can be done by using widely accepted BCA appraisal techniques and available data sources to both quantify impacts and integrate them into benefit-cost analyses conducted within the NCDOT prioritization process.

This interim deliverable presents the data sources and methodologies that can be used to evaluate the effects a prospective transportation project has on physical health, air quality, and their distributive impacts within a prospective project's impact area. The next phase of the research will involve testing the methodologies documented on this deliverable on three case studies and conducting a sensitivity analysis on asserted BCA values. This process will help refine the overall BCA approach potentially used to include physical health, air quality, and equity within NCDOT's prioritization process.

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Appendices

Summary data tables used for evaluating physical health and air quality in benefit-cost analysis are shown in Table 20 and Table 21.

Table 20: Variables and Data Sources Used for Physical Health and Air Quality Measures

Variable	Data Source(s)	Dimension	Purpose	Bike / Ped		Bus		LRT / BRT		Pax Train		Veh. Ferry		Pax Ferry		High-ways*	
				P H	A Q	P H	A Q	P H	A Q	P H	A Q	P H	A Q	P H	A Q	P H	A Q
Project Area Population	U.S. Census Bureau	Variable based on aerial weighting	Number of people affected by a proposed project														
Walk Proportion	U.S. Census Bureau	Variable based on aerial weighting	Percentage of people that currently walk in project area														
Bike Proportion	U.S. Census Bureau	Variable based on aerial weighting	Percentage of people that currently bike in project area														
Transit Proportion	U.S. Census Bureau	Variable based on aerial weighting	Percentage of people that currently take transit in project area														
Population Density	U.S. Census Bureau	Variable based on aerial weighting	estimates population effect on mode shift														
PH Benefit per Walk Trip	USDOT BCA Guidance	$7.08	Monetized physical health benefit per walk trip														
PH Benefit per Cycle Trip	USDOT BCA Guidance	$6.31	Monetized physical health benefit per bike trip														
Cost of CO2 per kg	USDOT BCA Guidance	$0.052	Monetized air quality cost per kg of CO2 emissions														
Mean daily person trips	AAA	2.6	Number of daily person trips made on average														
Calendar Days	U.S. Calendar	365	Annualize benefits or costs														
Posted Speed Limit	multiple sources	(mph): 0-20, 20-30, 30-40, 40+ Mode shift rate: 1.07, 1.04, 1.00, 0.95	estimates posted speed limit effect on mode shift														
Sidewalk existence	multiple sources	Categories: both sides, one side, none Mode shift rate: 1.05, 1.25, 1.00	estimates sidewalk existence effect on mode shift														
Sidewalk width	NACTO Guidelines	Categories: meets NACTO Res., meets NACTO urban, does not comply Mode shift rate: 1.25, 1.25, 0.975	estimates sidewalk width effect on mode shift														
Facility & Tie-in Network Length	Capital Area Metropolitan Planning Organization, Locally Administered Projects Program	(miles): 0-0.5, 0.5-2.0, 2.0+ Mode shift rate: +0.25%, +0.5%, +1.0%	Estimates level of mode shift associated with a proposed facility + tie-in to existing facility's total length														

Variable	Data Source(s)	Dimension	Purpose	Bike / Ped		Bus		LRT / BRT		Pax Train		Veh. Ferry		Pax Ferry		High-ways*	
				PH	AQ	PH	AQ	PH	AQ	PH	AQ	PH	AQ	PH	AQ	PH	AQ
Stops / Stations / Terminals Added	Applicant provided	Applicant provided	Estimates number of people per stop per frequency who would board at a new station.														
No. of Frequencies	Applicant provided	Applicant provided															
Ridership per Boarding	based on GoRaleigh, CATS, and NCDOT data	Bus: 4.52; BRT / LRT: 11.53; Rail: 3.99; Veh. Ferry: 28.72; Pax Ferry: 47.09															
Walk to Transit Rate	Wake County Transit Survey	91.50%	Estimates how people access transit														
Bike to Transit Rate	Wake County Transit Survey	1.10%															
Drive to Transit Rate	Wake County Transit Survey	7.40%															
Walk to Veh. Ferry Rate	NCDOT Vehicle Ferry Data	0.28%	Estimates how people access vehicle ferries														
Bike to Veh. Ferry Rate	NCDOT Vehicle Ferry Data	0.08%															
Drive to Veh. Ferry Rate	NCDOT Vehicle Ferry Data	99.60%															
Walk to Pax Ferry Rate	derived from NCDOT Vehicle Ferry Data (assumed 10x walk rate of vehicle ferry)	2.80%	Estimates how people access passenger ferries														
Bike to Pax Ferry Rate	derived from NCDOT Vehicle Ferry Data (assumed 10x bike rate of vehicle ferry)	0.80%															
Drive to Pax Ferry Rate	NCDOT Vehicle Ferry Data	96.40%															
Transit Trip Segments - Trip Lengths	multiple sources	See Table XX	Estimates the effect of a trip segment length on carbon dioxide emissions														
Emissions per person-mile	National Academies of Sciences, 2021.	See Table YY															
Annual per trips by mode	Derived from U.S. Census data (GIS tool)	Variable based on base case conditions altered by mode shift	Used to estimate effect of prospective trips on physical health and air quality														

*To estimate a prospective project's air quality impacts the National Center for Sustainable Transportation's Induced Travel Calculator was adapted to a North Carolina context. Highways AQ data variables are shown in another table.

Figure 14: Data Sources and Methodology for Estimating Project-Induced VMT

- **Commute Cluster**. A commute cluster is defined as the commute pattern for North Carolina residents traveling from home to work. This information was extracted from the U.S. Census Bureau's "Residence County to Workplace County Commuting Flows for the United States and Puerto Rico Sorted by Residence Geography: 5-Year ACS, 2011-2015" table. These data provided commuting patterns and was paired with NCDOT's Roadway Characteristics Shapefile to derive commuting patterns by roadway type. Altogether, these data were used to estimate the lane miles traversed by highway facility type when starting from a given county.

- **Change in Lane Miles.** Commute cluster and NCDOT Roadway Characteristics data are used to derive existing lane miles traversed. Then a project submitter provides data on the total number of lane miles that would be added to for a given facility. The change in lane miles of a given facility type are then calculated as part of the equation to estimate project-induced demand (see Figure 7).

- **Existing VMT**. Existing VMT data comes from NCDOT's Public Transportation Division. County VMT are used as the measure for existing VMT. VMT by highway facility type are distributed using a crosswalk for VMT to AADT derived from FHWA,2013. NCDOT data with AADT by facility type are used to allocate existing VMT by facility type using the AADT crosswalk.

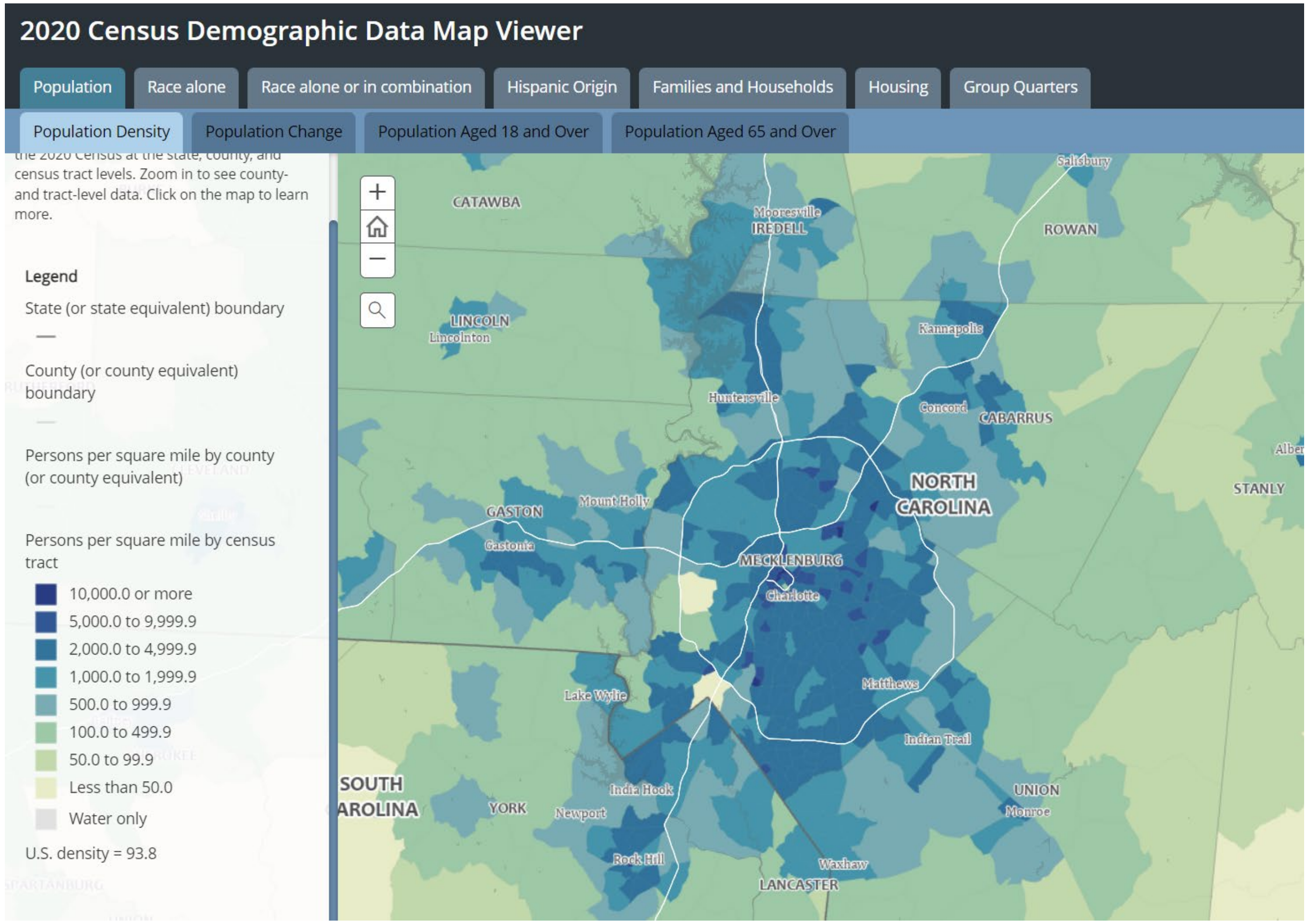
- **Elasticity**: For this research, elasticity measures the sensitivity of which a new highway facility will induce demand. Interstate facilities generate the greatest level of induced demand followed by US or NC routes, secondary routes, and then all other routes (see Table 17).

Source: ITRE, 2023

Figure 15: Integration of Population Density As a Mode-Shift Scalar – Building a Population Density Index

Persons per Square Mile	Index Score
10,000+	1.000
5,000-9,999	0.875
2,000 to 4,999.9	0.750
1,000 to 1,999.9	0.625
500 to 999.9	0.500
100 to 499.9	0.375
50 to 99.9	0.250
Less than 50	0.125

U.S. Census Data were used to develop a population density index that could be used as a scalar for mode shift. Population density is a measure of persons per square mile.



Source: ITRE, 2023.

Figure 16: Population Density Scalar Values

Persons per Square Mile	Index Score
10,000	**1.0000**
9,900	0.9975
9,800	0.9950
9,700	0.9925
9,600	0.9900
9,500	0.9875
9,400	0.9850
9,300	0.9825
9,200	0.9800
9,100	0.9775
9,000	0.9750
8,900	0.9725
8,800	0.9700
8,700	0.9675
8,600	0.9650
8,500	0.9625
8,400	0.9600
8,300	0.9575
8,200	0.9550
8,100	0.9525
8,000	0.9500
7,900	0.9475
7,800	0.9450
7,700	0.9425
7,600	0.9400
7,500	0.9375
7,400	0.9350
7,300	0.9325
7,200	0.9300
7,100	0.9275
7,000	0.9250
6,900	0.9225
6,800	0.9200
6,700	0.9175
6,600	0.9150
6,500	0.9125
6,400	0.9100
6,300	0.9075
6,200	0.9050
6,100	0.9025
6,000	0.9000
5,900	0.8975
5,800	0.8950
5,700	0.8925
5,600	0.8900
5,500	0.8875
5,400	0.8850
5,300	0.8825
5,200	0.8800
5,100	0.8775
5,000	**0.8750**
4,900	0.8708
4,800	0.8667
4,700	0.8625
4,600	0.8583
4,500	0.8542
4,400	0.8500
4,300	0.8458
4,200	0.8417
4,100	0.8375
4,000	0.8333
3,900	0.8292
3,800	0.8250
3,700	0.8208
3,600	0.8167
3,500	0.8125
3,400	0.8083
3,300	0.8042
3,200	0.8000
3,100	0.7958
3,000	0.7917
2,900	0.7875
2,800	0.7833
2,700	0.7792
2,600	0.7750
2,500	0.7708
2,400	0.7667
2,300	0.7625
2,200	0.7583
2,100	0.7542
2,000	**0.7500**
1,900	0.7375
1,800	0.7250
1,700	0.7125
1,600	0.7000
1,500	0.6875
1,400	0.6750
1,300	0.6625
1,200	0.6500
1,100	0.6375
1,000	**0.6250**
900	0.6000
800	0.5750
700	0.5500
600	0.5250
500	**0.5000**
400	0.4688
300	0.4375
200	0.4063
100	**0.3750**
50	**0.2500**
0	**0.1250**

Source: ITRE, 2023.

The population densities and scalar values are shown in Figure 16. The GIS Web Tool for this project calculates the total population and the total project area in square miles (also known as project impact area). Total population is divided by project impact area to get population density and then density is used to determine the appropriate density scalar. Density scalars are used in the derivation of physical health and air quality benefits for bus, BRT, LRT, and passenger rail modes.

GIS Web Tool User Guide

This web application allows users to extract geospatial data for user-defined or user-uploaded project features. This application was created using ArcGIS Web AppBuilder. Project locations may be either drawn by users or uploaded from existing datasets. Additionally, users may browse the underlying spatial data layers that are used within the data extraction tools. This User Guide describes this functionality in greater detail.

Contents

I. Accessing the Application

This application is publicly accessible at the link below. Anyone with the link to the web tool may access the application.

Link: GIS Web Tool: Including Equity in Benefit Cost Analysis

II. Basic Operation

When the application is first launched, users will be shown a "splash" screen that introduces the application. By selecting "OK", users can open the application and access its functions.

This application contains data layers for browsing and several tools. Users can navigate the map by clicking and dragging. Users can zoom in and out with the + and - icons in the top left corner, or by using the scroll wheel. The zoom will return to its original statewide extent by selecting the home button in the top left corner.

This application contains several tools on the bottom ribbon. Users are encouraged to explore these tools. The table below summarizes the functions of each. The "Extract Data" tools are custom tools created for this web application and are explained in detail in sections below.

Icon	Name	Function
	Information	Open an Information panel with a link a description of the tools included in the application.
	Basemap Gallery	Select a Basemap to display on the map. The Basemap is a contextual background layer.
	Layer List	Open the Layer List, which allows users to turn map layers on or off. Users can also adjust layer transparency and access layer attribute table from the sub-menu for each layer.
	Legend	Open the Legend, which displays entries for visible map layers.
	Measurement	Opens the Measurement tool, which allows users to estimate polygon areas, line distances, and coordinates using a variety of units.
	Extract Data – Draw Lines	Allows users to draw linear project features directly on the map and extract data based on project buffers.
	Extract Data – Draw Points	Allows users to draw point project features directly on the map and extract data based on project buffers.
	Extract Data – Upload Lines	Allows users to draw linear project features directly on the map and extract data based on project buffers.
	Extract Data – Upload Lines	Allows users to draw linear project features directly on the map and extract data based on project buffers.

III. Map Layers

The following layers are available for display within the Layer List tool. For additional information about each data source, see the full report.

Urban Areas

- Displays U.S. Census 2010 Urban Areas. Areas outside of urban areas are considered Rural.

Total Population

- Displays total population by block group from U.S. Census ACS 2016-2020 5-Year Estimates.

Walk Rate

- Percentage of population by block group that walks to work from U.S. Census ACS 2016-2020 5-Year Estimates.

Bike Rate

- Percentage of population by block group that walks to work from U.S. Census ACS 2016-2020 5-Year Estimates.

Transit Rate

- Percentage of population by block group that takes transit to work from U.S. Census ACS 2016-2020 5-Year Estimates.

Transportation Disadvantage Index

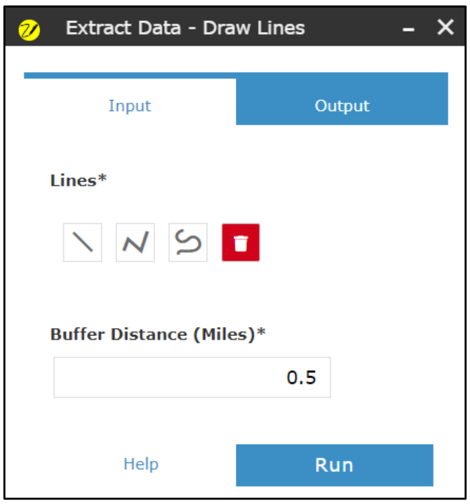
- Division-based Transportation Disadvantage Index developed by NCDOT's Integrated Mobility Division.

IV. Running Extract Data Tools for Drawn Features

Extract Data – Draw Lines

Extract Data – Draw Points

Example Input Window



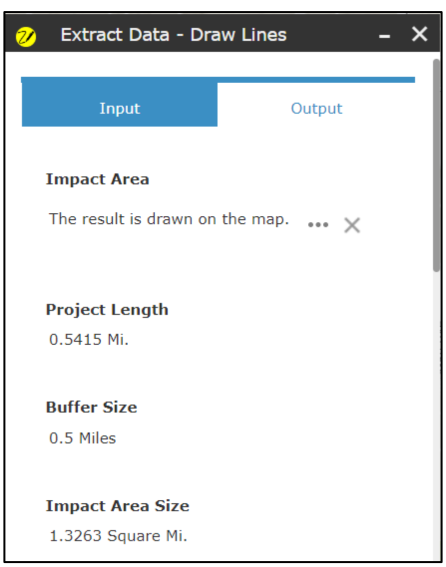
The user is prompted to draw lines or points using a drawing tool. There are three-line type tools and a single point-type tool.

- Click the drawing tool type you would like to use, then select any point on the map. Follow the prompt near your cursor to draw a line or point.
- To delete lines or points drawn on the map, click the trash can icon. This is also important when re-running the tool for a different project.
- Set the buffer distance corresponding to your project.
- If your project is composed of more than one line or point, use the steps above to draw your first line or point. Then reselect a line or point drawing tool you for your additional line(s) and draw your additional lines or points.

Select "Run" to run the tool.

NOTE: This tool will take a few seconds to complete.

Example Output Window



The buffered project impact area is added to the map.

The output tab becomes active on the tool. This tab contains extracted data for use in the Workbook Tool section of the research project. Note: Scroll down in the output tab to view all extracted data.

To clear the buffer area from the map, click the grey X next to the Impact Area section of the Output tab.

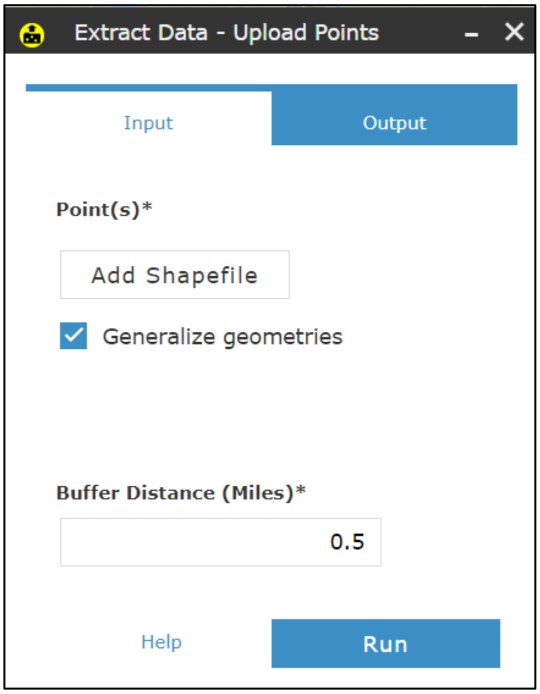
To re-run the tool from here, reselect the "Input" tab of the tool, clear existing features as desired, and restart your analysis.

V. Running Extract Data Tools for Uploaded Features

Extract Data – Upload Lines

Extract Data – Upload Points

Example Input Window



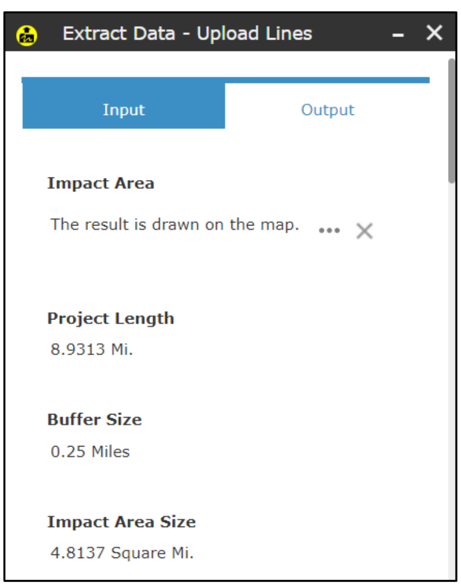
The user is prompted to upload a shapefile or for project lines or points and select a buffer distance:

- Shapefiles should be uploaded as a .zip file.
- Users may "generalize geometries" but leaving this box unchecked is recommended.
- Set the buffer distance corresponding to your project.
- Note that shapefiles may contain more than one project feature. This may be the case for projects that contain multiple segments or locations. In these cases, all of the uploaded features in the shapefile will be interpreted as a single project.
- You may delete uploaded features by selecting "Clear" on the Input tab of the tool.

Select "Run" to run the tool.

NOTE: This tool will take a few seconds to complete.

Example Output Window



The buffered project impact area is added to the map. Note that this output window contains the same contents as projects that are drawn.

The output tab becomes active on the tool. This tab contains extracted data for use in the Workbook Tool section of the research project. Note: Scroll down in the output tab to view all extracted data.

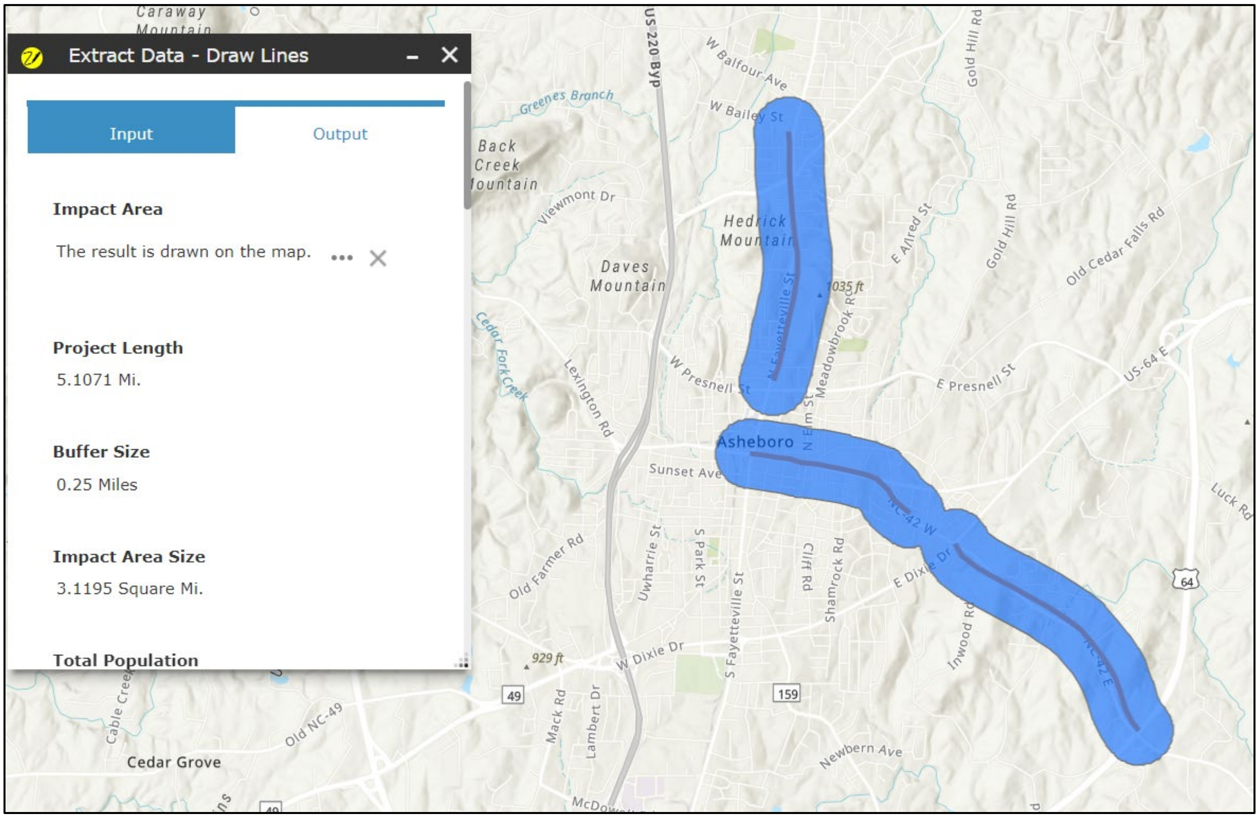
To clear the buffer area from the map, click the grey "X" next to the Impact Area section of the Output tab.

To re-run the tool from here, reselect the "Input" tab of the tool, clear existing features as desired, and restart your analysis.

VI. Buffered Outputs

The buffered project area is added to the map. Notes that when projects are composed of more than one non-contiguous feature (as drawn or uploaded by the user), the resulting impact area will be the dissolved (rather than composed of overlapping buffers).

Example buffered outputs for projects with multiple noncontiguous sections:



Sensitivity Analysis

As part of Task 4, the research team conducted a sensitivity analysis to evaluate the impact of changes in asserted input variables on output values (physical health and air quality benefits or costs). Sensitivity analyses were conducted for the three hypothetical prioritization scenarios: (1) constructing a bicycle/pedestrian facility in Wake County (the Lions Creek to Crabtree Creek Greenway), (2) implementing the ICATS Intercounty Express Bus Connector Expansion (in Iredell and Mecklenburg Counties), and (3) constructing the Bypass of Ahoskie (in Bertie and Hertford Counties).

Contents

Lions Creek to Crabtree Creek Greenway – Effect of Asserted Variables on Physical Health Output

The table below shows the anticipated physical health benefits that would occur from constructing the greenway. The rows highlighted in green show the asserted variables that are tested during the sensitivity analysis.

Table 1: Physical Health Benefits Anticipated from Constructing the Greenway (Asserted Values Highlighted in Green)

Bike-Ped: Physical Health and Air Quality Variables - Sensitivity Analysis

Scenario	Proposed Facility Length*
Build Scenario	(C) Greater than 2.0 miles

**Applies to standalone facility length + length of connected facilities that meet NACTO residential or city width sidewalk standards*

Inputs	Value	Type	Data Source
Project Buffer Area	0.500	GIS-dependent	Census / GIS Tool
Project Area Population	3,567	GIS-dependent	Census / GIS Tool
Walk Proportion	0.022	GIS-dependent	Census / GIS Tool
Bike Proportion	0.0001	GIS-dependent	Census / GIS Tool
Transit Proportion	0.054	GIS-dependent	Census / GIS Tool
Benefit per Walk Trip ($2022)	$7.08	GIS-dependent	Census / GIS Tool
Benefit per Bike Trip ($2022)	$6.31	GIS-dependent	Census / GIS Tool
Mean Person Trips per Day	2.600	Asserted	AAA, BTS
Days per Year	365	Fixed	U.S. Calendar
Proposed Facility Length - Walk Mode Shift Factor	0.010	Asserted, based on base-case & build scenarios	Multiple, Lit Review
Proposed Facility Length - Bike Mode Shift Factor	0.005	Asserted, based on base-case & build scenarios	Multiple, Lit Review

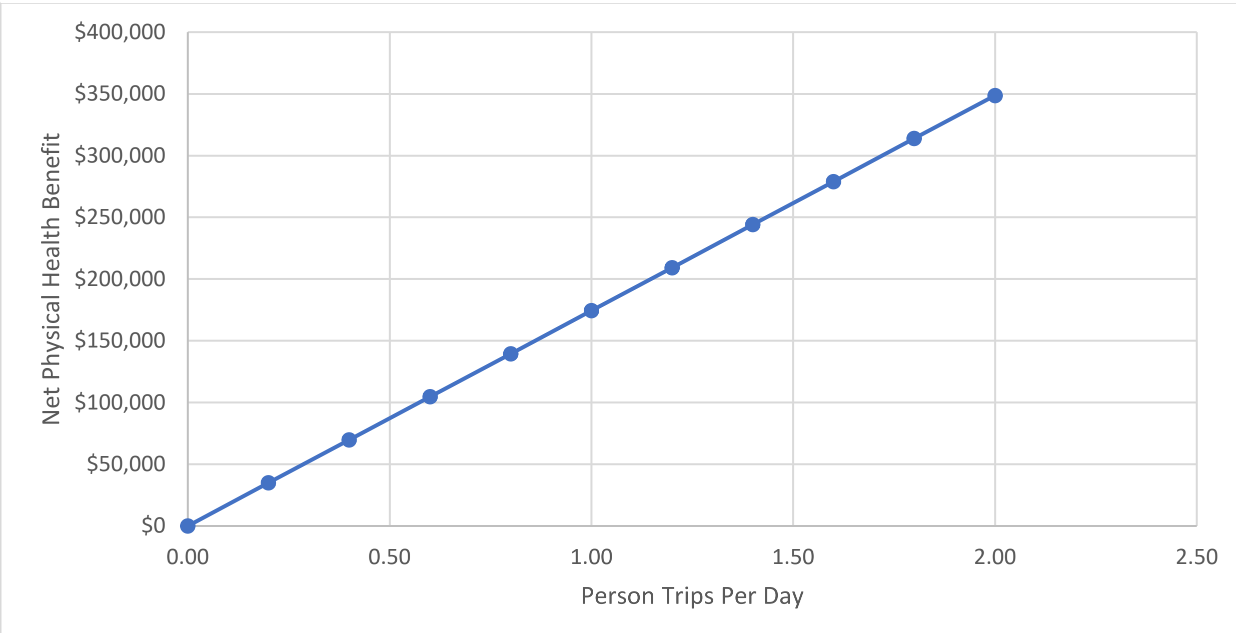
PH Item	Base-Case Outcome	Build Scenario Outcome	Net Physical Health Benefit
Physical Health Benefits	$536,586	$883,050	**$453,263**

Facility Length Scenario	Walk Mode Shift %	Bike Mode Shift %
(A) 0-0.5 miles	0.25%	0.13%
(B) 0.5-2.0 miles	0.50%	0.25%
(C) Greater than 2.0 miles	1.00%	0.50%

Change in Asserted Variables' Impact on Physical Health Outcomes

A sensitivity analysis was conducted on the *number of person trips per day* variable used in the modeling methodology. Results show that the effect from changing the variable is linear. Additionally, the change is unit elastic (elasticity = 1), meaning that for every 1 percent change in person trips, there is a one percent change in the derived net physical health benefit (see Figure 1, Table 3, and Table 4).

Figure 1: Person Trips per Day - Asserted Variable Analysis



Source: ITRE, 2023.

Table 2: Person Trips per Day – Asserted Variable Analysis

Person Trips per Day	Base Case Scenario (PH Benefit)	Build Case Scenario (PH Benefit)	Net Physical Health Benefit
0.00	$0	$0	$0
0.20	$41,276	$67,927	$34,866
0.40	$82,552	$135,854	$69,733
0.60	$123,828	$203,781	$104,599
0.80	$165,104	$271,708	$139,465
1.00	$206,379	$339,634	$174,332
1.20	$247,655	$407,561	$209,198
1.40	$288,931	$475,488	$244,064
1.60	$330,207	$543,415	$278,931
1.80	$371,483	$611,342	$313,797
2.00	$412,759	$679,269	$348,664

Source: ITRE, 2023.

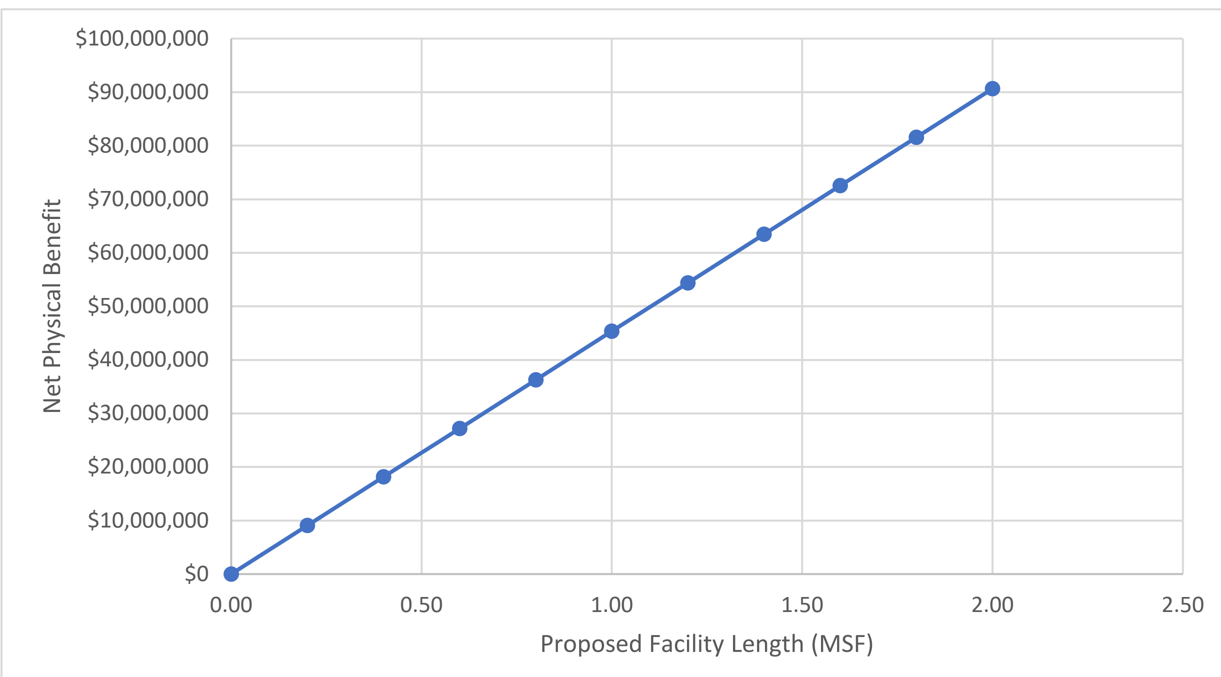
Table 3: Person Trips per Day – Asserted Variable Analysis (continued)

Person Trips per Day	Net Physical Health Benefit	% Change in Variable	% Change in Output	Elasticity
0.00	$0			
0.20	$34,866			
0.40	$69,733	100.0%	100.0%	1.0
0.60	$104,599	200.0%	200.0%	1.0
0.80	$139,465	300.0%	300.0%	1.0
1.00	$174,332	400.0%	400.0%	1.0
1.20	$209,198	500.0%	500.0%	1.0
1.40	$244,064	600.0%	600.0%	1.0
1.60	$278,931	700.0%	700.0%	1.0
1.80	$313,797	800.0%	800.0%	1.0
2.00	$348,664	900.0%	900.0%	1.0

Source: ITRE, 2023.

A sensitivity analysis was conducted on the *proposed facility length walk & bike mode shift factor* variables used in the modeling methodology. Results show that the effect from changing the mode shift variables is linear. Additionally, the change is unit elastic (elasticity = 1), meaning that for every 1 percent change in proposed facility length walk or bike mode shift factor variables, there is a one percent change in the derived net physical health benefit (see Figure 2, Table 5, and Table 6).

Figure 2: Proposed Facility Length – Walk & Bike Mode Shift Factor Variable Analysis



Source: ITRE, 2023.

Table 4: Proposed Facility Length – Walk & Bike Mode Shift Factor Variable Analysis

Proposed Facility Length (MSF)	Base Case Scenario (PH Benefit)	Build Case Scenario (PH Benefit)	Net Physical Health Benefit
0.00	$536,586	$643,386	$0
0.20	$536,586	$5,436,663	$9,065,252
0.40	$536,586	$10,229,941	$18,130,505
0.60	$536,586	$15,023,218	$27,195,757
0.80	$536,586	$19,816,496	$36,261,009
1.00	$536,586	$24,609,773	$45,326,261
1.20	$536,586	$29,403,051	$54,391,514
1.40	$536,586	$34,196,328	$63,456,766
1.60	$536,586	$38,989,606	$72,522,018
1.80	$536,586	$43,782,884	$81,587,270
2.00	$536,586	$48,576,161	$90,652,523

Table 5: Proposed Facility Length – Walk & Bike Mode Shift Factor Variable Analysis (continued)

Proposed Facility Length (MSF)	Net Physical Health Benefit	% Change in Variable	% Change in Output	Elasticity
0.00	$0			
0.20	$9,065,252			
0.40	$18,130,505	100.0%	100.0%	1.0
0.60	$27,195,757	200.0%	200.0%	1.0
0.80	$36,261,009	300.0%	300.0%	1.0
1.00	$45,326,261	400.0%	400.0%	1.0
1.20	$54,391,514	500.0%	500.0%	1.0
1.40	$63,456,766	600.0%	600.0%	1.0
1.60	$72,522,018	700.0%	700.0%	1.0
1.80	$81,587,270	800.0%	800.0%	1.0
2.00	$90,652,523	900.0%	900.0%	1.0

Source: ITRE, 2023.

Lions Creek to Crabtree Creek Greenway – Effect of Asserted Variables on Air Quality Output
In addition to analyzing how changes in asserted variables affected physical health output, an analysis was performed to analyze how asserted variables affect air quality output. The table below shows the anticipated air quality benefits that would occur from constructing the greenway. The rows highlighted in green show the asserted variables that are tested during the sensitivity analysis.

Table 6: Air Quality Benefits Anticipated from Constructing the Greenway (Asserted Values Highlighted in Green)

Air Quality Inputs	Value	Type	Data Source
Mean Person Trips per Day	2.600	Asserted	AAA, BTS
Drive Only (Trip Segment Length)	10.70	Asserted	Multiple, Lit Review
Private Gasoline Vehicle (kg CO2e per person mile)	0.51	Asserted	National Academies of Sciences, 2021.
Carbon Cost per Kg	$0.052	Fixed	USDOT BCA Guidance

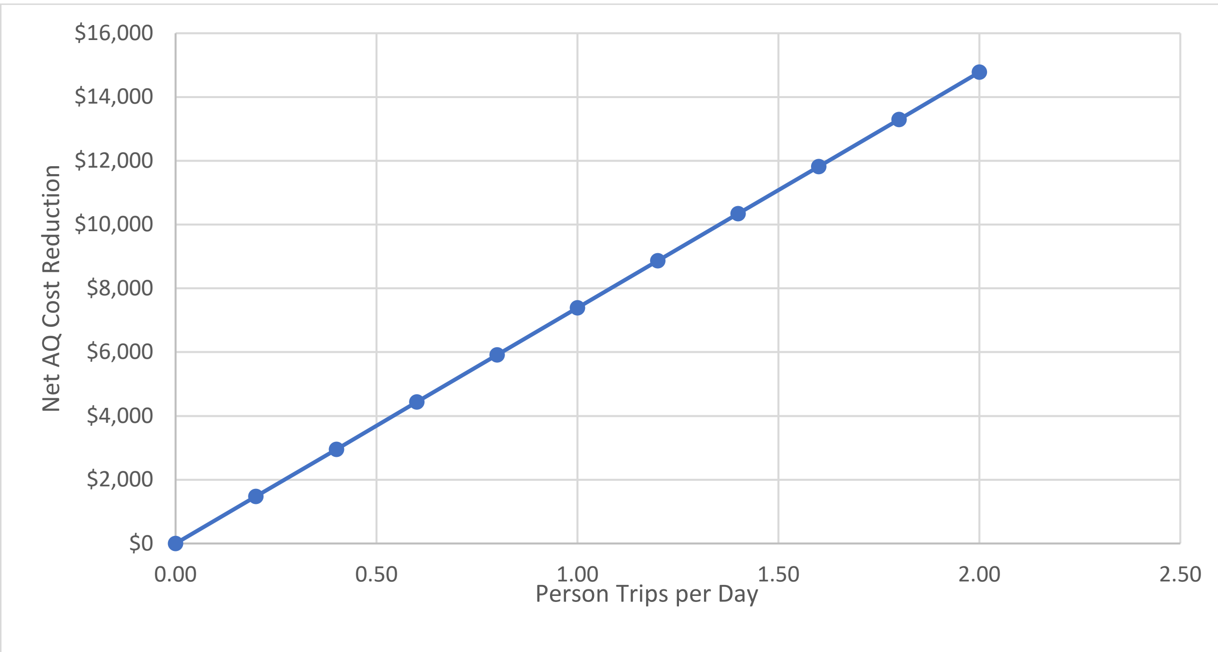
AQ Item	Base-Case Outcome	Build Scenario Outcome	Net Cost Reduction
Annual Vehicle Trips	3,126,124	3,058,422	
Annual Transit Trips	183,133	183,133	
Annual Wike or Bike Trips	75,826	143,528	
Kg Carbon Equivalent	17,386,152	17,016,704	
Air Quality Cost	$904,080	$884,869	$19,211

Source: ITRE, 2023.

Change in Asserted Variables' Impact on Air Quality Outcomes

A sensitivity analysis was conducted on the *number of person trips per day* variable used in the modeling methodology. Results show that the effect from changing the variable is linear. Additionally, the change is unit elastic (elasticity = 1), meaning that for every 1 percent change in person trips, there is a one percent change in the derived net air quality benefit (see Figure 1, Table 3, and Table 4).

Figure 3: Person Trips per Day – Asserted Variable Analysis



Source: ITRE, 2023.

Table 7: Person Trips per Day – Asserted Variable Analysis

Person Trips per Day	Base Case Scenario	Build Case Scenario	Net AQ Cost Reduction
0.00	$0	$0	$0
0.20	$69,545	$68,067	$1,478
0.40	$139,089	$136,134	$2,956
0.60	$208,634	$204,200	$4,433
0.80	$278,178	$272,267	$5,911
1.00	$347,723	$340,334	$7,389
1.20	$417,268	$408,401	$8,867
1.40	$486,812	$476,468	$10,345
1.60	$556,357	$544,535	$11,822
1.80	$625,901	$612,601	$13,300
2.00	$695,446	$680,668	$14,778

Source: ITRE, 2023.

Table 8: Person Trips per Day – Asserted Variable Analysis (continued)

Person Trips per Day	Net Air Quality Benefit	% Change in Variable	% Change in Output	Elasticity
0.00	$0			
0.20	$1,478			
0.40	$2,956	100.0%	100.0%	1.0
0.60	$4,433	200.0%	200.0%	1.0
0.80	$5,911	300.0%	300.0%	1.0
1.00	$7,389	400.0%	400.0%	1.0
1.20	$8,867	500.0%	500.0%	1.0
1.40	$10,345	600.0%	600.0%	1.0
1.60	$11,822	700.0%	700.0%	1.0
1.80	$13,300	800.0%	800.0%	1.0
2.00	$14,778	900.0%	900.0%	1.0

Source: ITRE, 2023.

A sensitivity analysis was conducted on the *proposed facility length walk & bike mode shift factor* variables used in the modeling methodology. Results show that the effect from changing the mode shift variables is linear. Additionally, the change is unit elastic (elasticity = 1), meaning that for every 1 percent change in proposed facility length walk or bike mode shift factor variables, there is a one percent change in the derived net air quality benefit (see Figure 4, Table 9, and Table 10).

Figure 4: Proposed Facility Length Mode Shift Factor – Asserted Variable Analysis

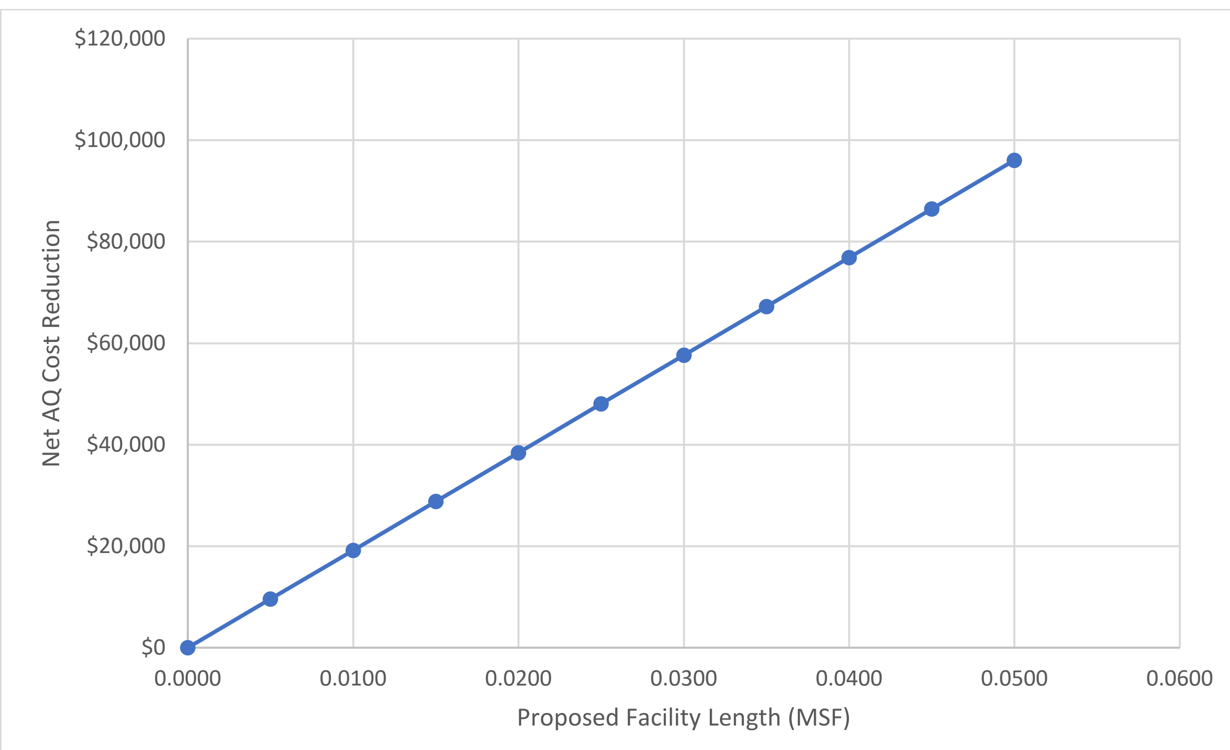


Table 9: Proposed Facility Length Mode Shift Factor – Asserted Variable Analysis

Proposed Facility Length (MSF)	Base Case Scenario	Build Case Scenario	Net AQ Cost Reduction
0.0000	$904,080	$904,080	$0
0.0050	$904,080	$894,474	$9,606
0.0100	$904,080	$884,869	$19,211
0.0150	$904,080	$875,263	$28,817
0.0200	$904,080	$865,657	$38,423
0.0250	$904,080	$856,052	$48,028
0.0300	$904,080	$846,446	$57,634
0.0350	$904,080	$836,840	$67,240
0.0400	$904,080	$827,235	$76,845
0.0450	$904,080	$817,629	$86,451
0.0500	$904,080	$808,023	$96,056

Source: ITRE, 2023.

Table 10: Proposed Facility Length Mode Shift Factor – Asserted Variable Analysis (continued)

Proposed Facility Length (MSF)	Net Air Quality Benefit	% Change in Variable	% Change in Output	Elasticity
0.000	$0			
0.005	$9,606			
0.010	$19,211	100.0%	100.0%	1.0
0.015	$28,817	200.0%	200.0%	1.0
0.020	$38,423	300.0%	300.0%	1.0
0.025	$48,028	400.0%	400.0%	1.0
0.030	$57,634	500.0%	500.0%	1.0
0.035	$67,240	600.0%	600.0%	1.0
0.040	$76,845	700.0%	700.0%	1.0
0.045	$86,451	800.0%	800.0%	1.0
0.050	$96,056	900.0%	900.0%	1.0

Source: ITRE, 2023.

A sensitivity analysis was conducted on the *drive only trip segment length* variable used in the modeling methodology. Results show that the effect from changing the mode shift variables is linear. Additionally, the change is unit elastic (elasticity = 1), meaning that for every 1 percent change in proposed facility length walk or bike mode shift factor variables, there is a one percent change in the derived net air quality benefit (see Figure 4, Table 9, and Table 10).

Figure 5: Personal Vehicle Trip Segment Length – Asserted Variable Analysis

Source: ITRE, 2023.

Table 11: Personal Vehicle Trip Segment Length – Asserted Variable Analysis

Drive Only (Trip Segment Length)	Base Case Scenario	Build Case Scenario	Net AQ Cost Reduction
1	$99,903	$98,108	$1,795
3	$265,713	$260,326	$5,386
5	$431,522	$422,545	$8,977
7	$597,332	$584,764	$12,568
9	$763,142	$746,983	$16,159
11	$928,951	$909,201	$19,750
13	$1,094,761	$1,071,420	$23,341
15	$1,260,571	$1,233,639	$26,932
17	$1,426,380	$1,395,858	$30,523
19	$1,592,190	$1,558,076	$34,114
21	$1,757,999	$1,720,295	$37,704

Source: ITRE, 2023.

Table 12: Personal Vehicle Trip Segment Length – Asserted Variable Analysis (continued)

Drive Only (Trip Segment Length)	Net Air Quality Benefit	% Change in Variable	% Change in Output	Elasticity
1.00	$1,795			
3.00	$5,386			
5.00	$8,977	400.0%	400.0%	1.0
7.00	$12,568	600.0%	600.0%	1.0
9.00	$16,159	800.0%	800.0%	1.0
11.00	$19,750	1000.0%	1000.0%	1.0
13.00	$23,341	1200.0%	1200.0%	1.0
15.00	$26,932	1400.0%	1400.0%	1.0
17.00	$30,523	1600.0%	1600.0%	1.0
19.00	$34,114	1800.0%	1800.0%	1.0
21.00	$37,704	2000.0%	2000.0%	1.0

Source: ITRE, 2023.

ICATS Intercounty Connector – Effect of Asserted Variables on Physical Health Output

The table below shows the anticipated physical health benefits that would occur from adding one of the five bus stops of the intercounty connector. The rows highlighted in green show the asserted variables that are tested during the sensitivity analysis.

Table 13: Physical Health Benefits Anticipated from Adding a Bus Stop (Asserted Values Highlighted in Green)

Inputs	Value	Type	Data Source
Project Buffer Area (miles)	0.500	GIS-dependent	Census / GIS Tool
Impact Area (square miles)	0.7854	GIS-dependent	Census / GIS Tool
Population Density	1,282	GIS-dependent	Census / GIS Tool
Population Scalar	0.6500	GIS-dependent	Census / GIS Tool
Project Area Population	1,007	GIS-dependent	Census / GIS Tool
Walk Proportion	0.009	GIS-dependent	Census / GIS Tool
Bike Proportion	0.0001	GIS-dependent	Census / GIS Tool
Transit Proportion	0.000	GIS-dependent	Census / GIS Tool
Urban Proportion	1.000	GIS-dependent	Census / GIS Tool
Benefit per Walk Trip ($2022)	$7.08	GIS-dependent	Census / GIS Tool
Benefit per Bike Trip ($2022)	$6.31	GIS-dependent	Census / GIS Tool
Mean Person Trips per Day	2.600	Asserted	AAA, BTS
Days per Year	365	Fixed	U.S. Calendar
Number of New Bus Stops in Project	1	Asserted, based on submitter input	Submitter Input
New Frequencies per Stop	20	Asserted, based on submitter input	Submitter Input
Ridership per Stop per Weekday Frequency (select mode)	4.52	Derived	GoRaleigh Data

Transit Mode (for Transit Access Percentages)	Bus, BRT, LRT, or Commuter Rail

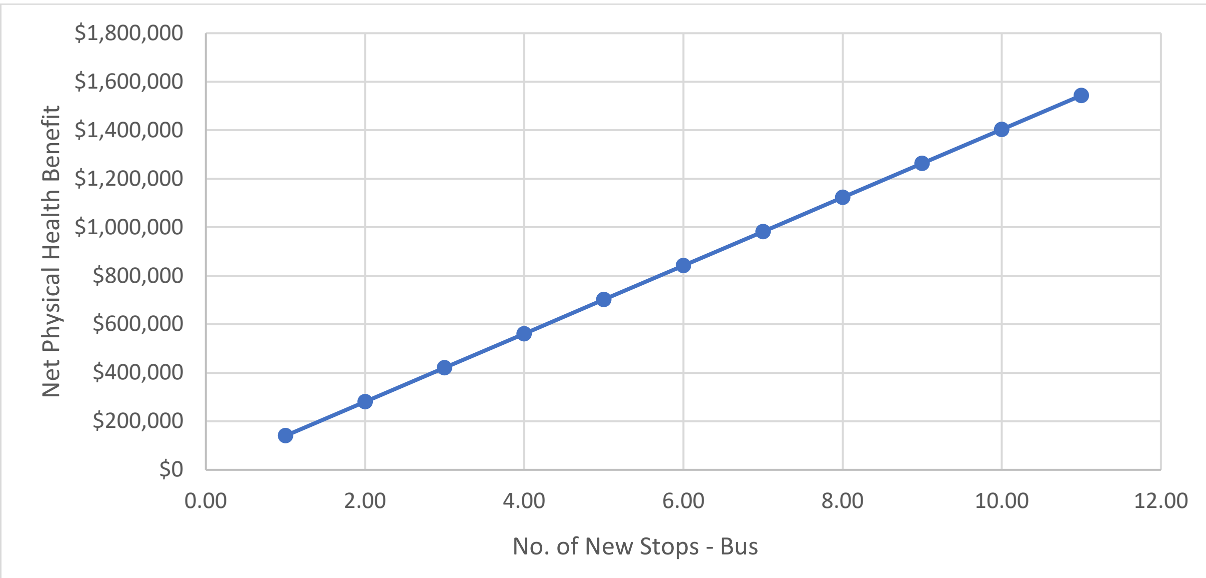
Drive to Transit Percentage	7.4%	Derived, depends on mode (see table below)	Wake Transit Survey & Ferry Data
Walk to Transit Percentage	91.5%	Derived, depends on mode (see table below)	Wake Transit Survey & Ferry Data
Bike to Transit Percentage	1.1%	Derived, depends on mode (see table below)	Wake Transit Survey & Ferry Data

PH Item	Base-Case Outcome	Build Scenario Outcome	Net Difference
Annual Drive to Transit Trips	7	6,386	$6,379
Annual Walk to Transit Trips	87	78,546	$78,458
Annual Bike to Transit Trips	1	908	$907
Physical Health Benefits	$625	$140,927	$140,301

Change in Asserted Variables' Impact on Physical Health Outcomes

A sensitivity analysis was conducted on the *number of new stops in the project* variable used in the modeling methodology. Results show that the effect from changing the variable is linear. Additionally, the change is unit elastic (elasticity = 1), meaning that for every 1 percent change in person trips, there is a one percent change in the derived net physical health benefit (see Figure 6, Table 14, and Table 15).

Figure 6: Number of New Stops – Asserted Variable Analysis



Source: ITRE, 2023.

Table 14: Number of New Stops – Asserted Variable Analysis

Number of New Bus Stops in Project	Base Case Scenario	Build Case Scenario	Net Physical Health Benefit
1.00	$625	$140,927	$140,301
2.00	$625	$281,228	$280,603
3.00	$625	$421,530	$420,904
4.00	$625	$561,831	$561,206
5.00	$625	$702,133	$701,507
6.00	$625	$842,434	$841,809
7.00	$625	$982,736	$982,110
8.00	$625	$1,123,037	$1,122,411
9.00	$625	$1,263,338	$1,262,713
10.00	$625	$1,403,640	$1,403,014
11.00	$625	$1,543,941	$1,543,316

Source: ITRE, 2023.

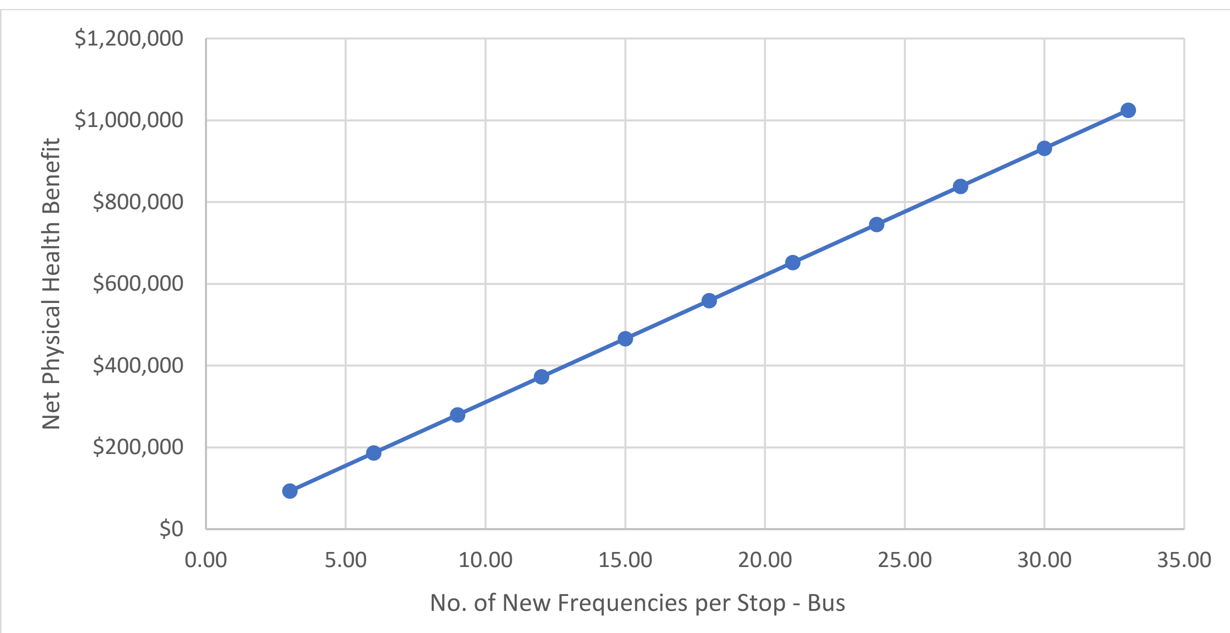
Table 15: Number of New Stops – Asserted Variable Analysis (continued)

Number of New Bus Stops in Project	Net Physical Health Benefit	% Change in Variable	% Change in Output	Elasticity
1.00	$140,301			
2.00	$280,603	100.0%	100.0%	1.0
3.00	$420,904	200.0%	200.0%	1.0
4.00	$561,206	300.0%	300.0%	1.0
5.00	$701,507	400.0%	400.0%	1.0
6.00	$841,809	500.0%	500.0%	1.0
7.00	$982,110	600.0%	600.0%	1.0
8.00	$1,122,411	700.0%	700.0%	1.0
9.00	$1,262,713	800.0%	800.0%	1.0
10.00	$1,403,014	900.0%	900.0%	1.0
11.00	$1,543,316	1000.0%	1000.0%	1.0

Source: ITRE, 2023.

A sensitivity analysis was conducted on the *number of new frequencies per stop* variable used in the modeling methodology. Results show that the effect from changing the variable is linear. Additionally, the change is unit elastic (elasticity = 1), meaning that for every 1 percent change in person trips, there is a one percent change in the derived net physical health benefit (see Figure 7, Table 16, and Table 17).

Figure 7: Number of New Frequencies per Stop – Asserted Variable Analysis



Source: ITRE, 2023.

Table 16: Number of New Frequencies per Stop – Asserted Variable Analysis

New Frequencies per Stop	Base Case Scenario	Build Case Scenario	Net Physical Health Benefit
3.00	$625	$93,795	$93,170
6.00	$625	$186,965	$186,340
9.00	$625	$280,135	$279,510
12.00	$625	$373,305	$372,679
15.00	$625	$466,475	$465,849
18.00	$625	$559,645	$559,019
21.00	$625	$652,815	$652,189
24.00	$625	$745,984	$745,359
27.00	$625	$839,154	$838,529
30.00	$625	$932,324	$931,699
33.00	$625	$1,025,494	$1,024,869

Source: ITRE, 2023.

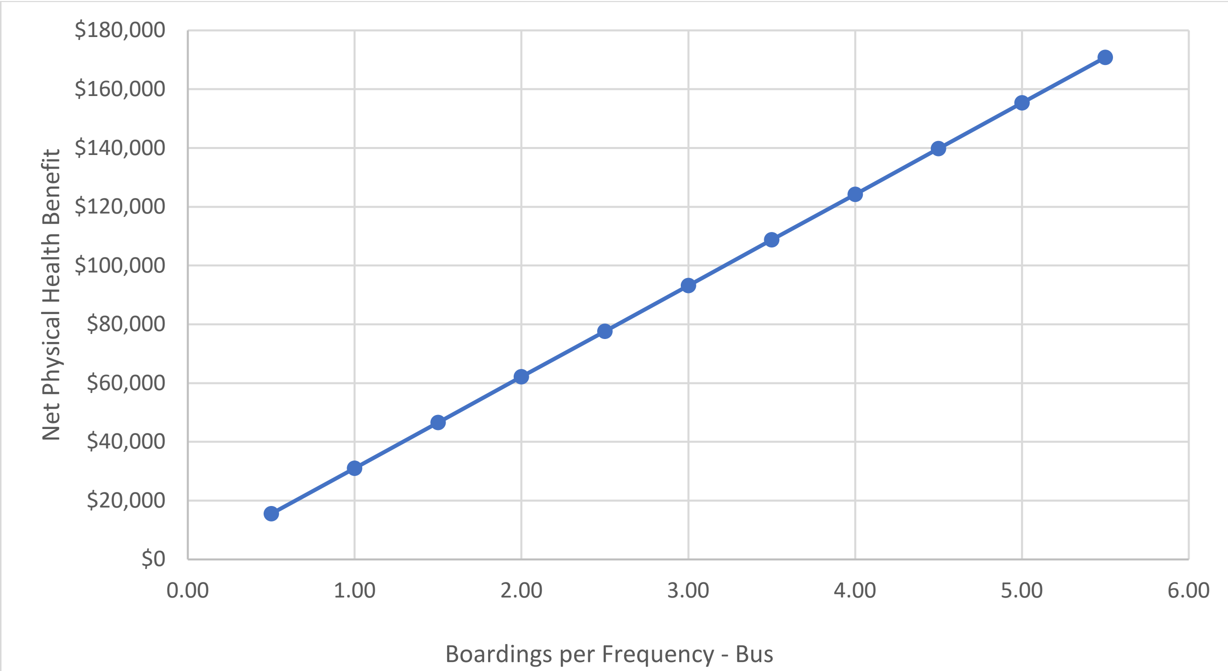
Table 17: Number of New Frequencies per Stop – Asserted Variable Analysis (continued)

New Frequencies per Stop	Net Physical Health Benefit	% Change in Variable	% Change in Output	Elasticity
3.00	$93,170			
6.00	$186,340	100.0%	100.0%	1.0
9.00	$279,510	200.0%	200.0%	1.0
12.00	$372,679	300.0%	300.0%	1.0
15.00	$465,849	400.0%	400.0%	1.0
18.00	$559,019	500.0%	500.0%	1.0
21.00	$652,189	600.0%	600.0%	1.0
24.00	$745,359	700.0%	700.0%	1.0
27.00	$838,529	800.0%	800.0%	1.0
30.00	$931,699	900.0%	900.0%	1.0
33.00	$1,024,869	1000.0%	1000.0%	1.0

Source: ITRE, 2023.

A sensitivity analysis was conducted on the *boardings per frequency* variable used in the modeling methodology. Results show that the effect from changing the variable is linear. Additionally, the change is unit elastic (elasticity = 1), meaning that for every 1 percent change in person trips, there is a one percent change in the derived net physical health benefit (see Figure 8, Table 18, Table 19).

Figure 8: Boardings per Frequency – Asserted Variable Analysis



Source: ITRE, 2023.

Table 18: Boardings per Frequency – Asserted Variable Analysis

Boardings per Frequency	Base Case Scenario	Build Case Scenario	Net Physical Health Benefit
0.50	$625	$16,154	$15,528
1.00	$625	$31,682	$31,057
1.50	$625	$47,210	$46,585
2.00	$625	$62,739	$62,113
2.50	$625	$78,267	$77,642
3.00	$625	$93,795	$93,170
3.50	$625	$109,324	$108,698
4.00	$625	$124,852	$124,226
4.50	$625	$140,380	$139,755
5.00	$625	$155,909	$155,283
5.50	$625	$171,437	$170,811

Source: ITRE, 2023.

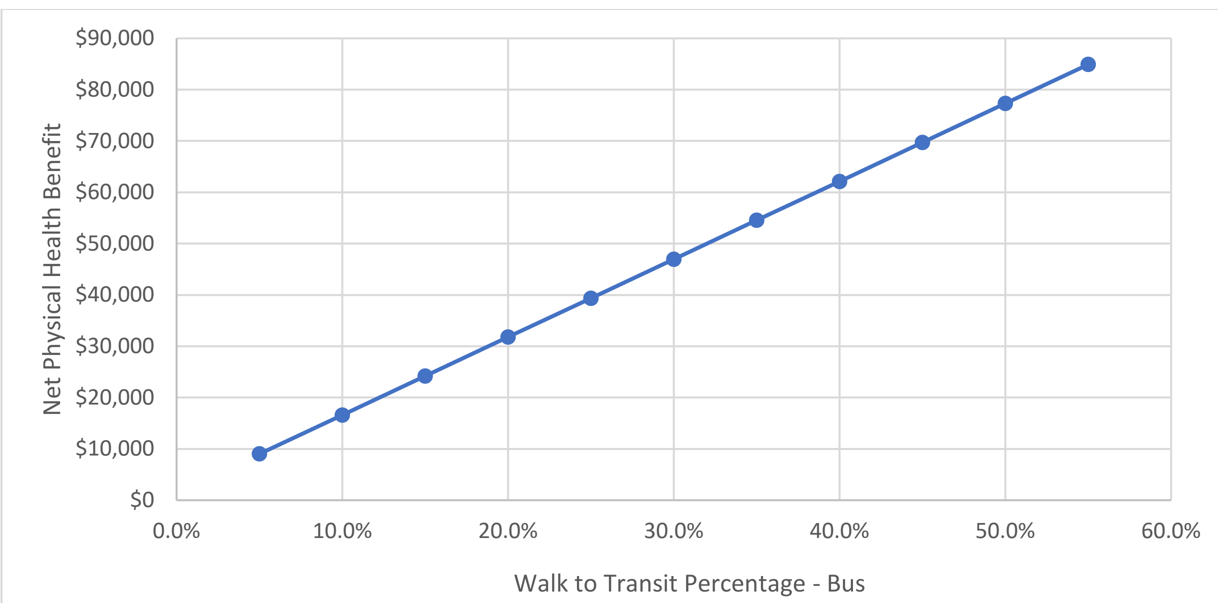
Table 19: Boardings per Frequency – Asserted Variable Analysis (continued)

Ridership per Stop per Weekday Frequency (select mode)	Net Physical Health Benefit	% Change in Variable	% Change in Output	Elasticity
0.50	$15,528			
1.00	$31,057	100.0%	100.0%	1.0
1.50	$46,585	200.0%	200.0%	1.0
2.00	$62,113	300.0%	300.0%	1.0
2.50	$77,642	400.0%	400.0%	1.0
3.00	$93,170	500.0%	500.0%	1.0
3.50	$108,698	600.0%	600.0%	1.0
4.00	$124,226	700.0%	700.0%	1.0
4.50	$139,755	800.0%	800.0%	1.0
5.00	$155,283	900.0%	900.0%	1.0
5.50	$170,811	1000.0%	1000.0%	1.0

Source: ITRE, 2023.

A sensitivity analysis was conducted on the *walk to transit percentage* variable used in the modeling methodology. Results show that the effect from changing the variable is linear. Additionally, the change is slightly elastic (elasticity = 1.2), meaning that for every 1.2 percent change in person trips, there is a one percent change in the derived net physical health benefit (see Figure 9, Table 20, and Table 21). Walk to transit trips comprise the largest access mode to transit (91.5%), followed by driving (7.4%) and biking (1.1%). This explains why the change in the walk to transit percentage has a relatively high impact on the overall physical health benefits experienced in the project area, but is not unit elastic.

Figure 9: Walk to Transit Percentage – Asserted Variable Analysis



Source: ITRE, 2023.

Table 20: Walk to Transit Percentage – Asserted Variable Analysis

Walk to Transit Percentage	Base Case Scenario	Build Case Scenario	Net Physical Health Benefit
5.0%	$40	$9,059	$9,019
10.0%	$74	$16,681	$16,607
15.0%	$108	$24,303	$24,195
20.0%	$142	$31,926	$31,784
25.0%	$176	$39,548	$39,372
30.0%	$209	$47,170	$46,961
35.0%	$243	$54,792	$54,549
40.0%	$277	$62,414	$62,137
45.0%	$311	$70,036	$69,726
50.0%	$345	$77,659	$77,314
55.0%	$379	$85,281	$84,902

Source: ITRE, 2023.

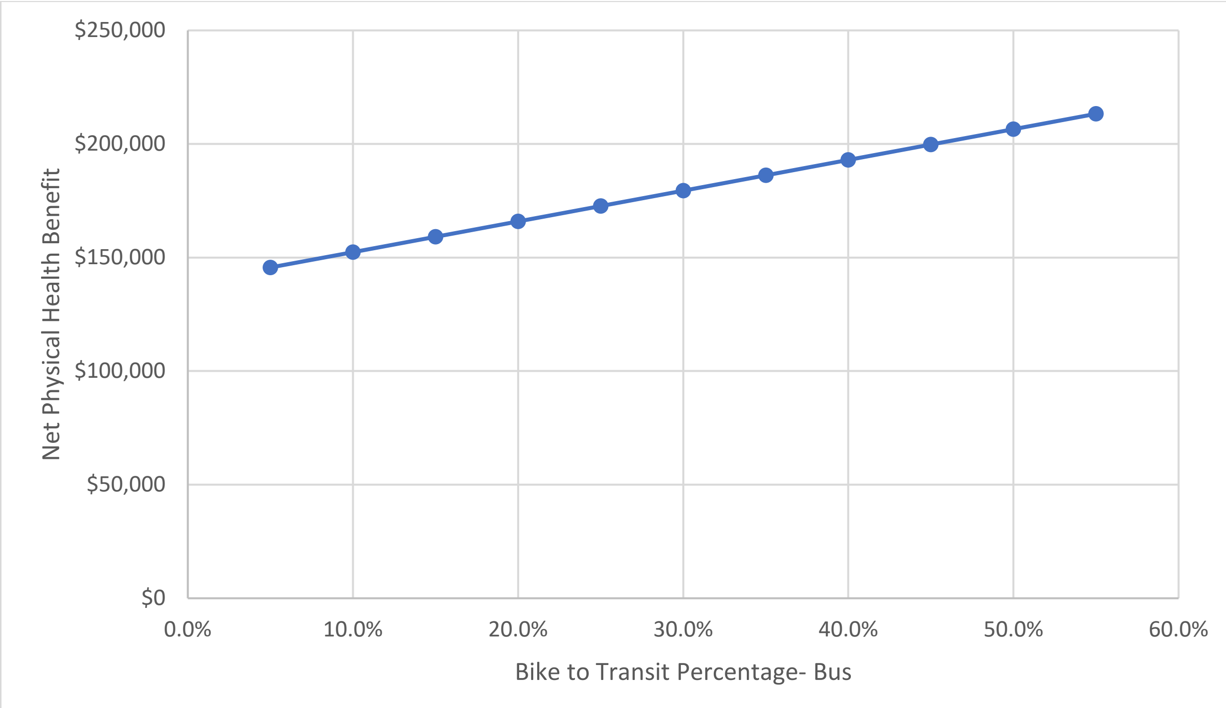
Table 21: Walk to Transit Percentage – Asserted Variable Analysis (continued)

Walk to Transit Percentage	Net Physical Health Benefit	% Change in Variable	% Change in Output	Elasticity
0.05	$9,019			
0.10	$16,607	100.0%	84.1%	1.2
0.15	$24,195	200.0%	168.3%	1.2
0.20	$31,784	300.0%	252.4%	1.2
0.25	$39,372	400.0%	336.6%	1.2
0.30	$46,961	500.0%	420.7%	1.2
0.35	$54,549	600.0%	504.8%	1.2
0.40	$62,137	700.0%	589.0%	1.2
0.45	$69,726	800.0%	673.1%	1.2
0.50	$77,314	900.0%	757.3%	1.2
0.55	$84,902	1000.0%	841.4%	1.2

Source: ITRE, 2023.

A sensitivity analysis was conducted on the *bike to transit percentage* variable used in the modeling methodology. Results show that the effect from changing the variable is linear. Additionally, the change is highly elastic (elasticity = 21.5), meaning that for every 21.5 percent change in bike to transit percentage, there is a one percent change in the derived net physical health benefit (see Figure 10, Table 22, and Table 23). Walk to transit trips comprise the largest access mode to transit (91.5%), followed by driving (7.4%) and biking (1.1%). This explains why the change in the *bicycle to transit percentage* has a relatively small impact on the overall physical health benefits experienced in the project area.

Figure 10: Bike to Transit Percentage – Asserted Variable Analysis



Source: ITRE, 2023.

Table 22: Bike to Transit Percentage – Asserted Variable Analysis

Bike to Transit Percentage	Base Case Scenario	Build Case Scenario	Net Physical Health Benefit
5.0%	$649	$146,283	$145,634
10.0%	$679	$153,077	$152,397
15.0%	$710	$159,870	$159,160
20.0%	$740	$166,663	$165,923
25.0%	$770	$173,456	$172,686
30.0%	$800	$180,249	$179,449
35.0%	$830	$187,043	$186,212
40.0%	$860	$193,836	$192,976
45.0%	$890	$200,629	$199,739
50.0%	$921	$207,422	$206,502
55.0%	$951	$214,215	$213,265

Source: ITRE, 2023.

Table 23: Bike to Transit Percentage – Asserted Variable Analysis (continued)

Bike to Transit Percentage	Net Physical Health Benefit	% Change in Variable	% Change in Output	Elasticity
1.00	$145,634			
2.00	$152,397	100.0%	4.6%	21.5
3.00	$159,160	200.0%	9.3%	21.5
4.00	$165,923	300.0%	13.9%	21.5
5.00	$172,686	400.0%	18.6%	21.5
6.00	$179,449	500.0%	23.2%	21.5
7.00	$186,212	600.0%	27.9%	21.5
8.00	$192,976	700.0%	32.5%	21.5
9.00	$199,739	800.0%	37.2%	21.5
10.00	$206,502	900.0%	41.8%	21.5
11.00	$213,265	1000.0%	46.4%	21.5

Source: ITRE, 2023.

ICATS Inter County Connector – Effect of Asserted Variables on Air Quality Output
The table below shows the anticipated air quality benefits that would occur from adding one of the five bus stops of the intercounty connector. The rows highlighted in green show the asserted variables that are tested during the sensitivity analysis.

Table 24: Air Quality Benefits Anticipated from Adding a Bus Stop (Asserted Values Highlighted in Green)

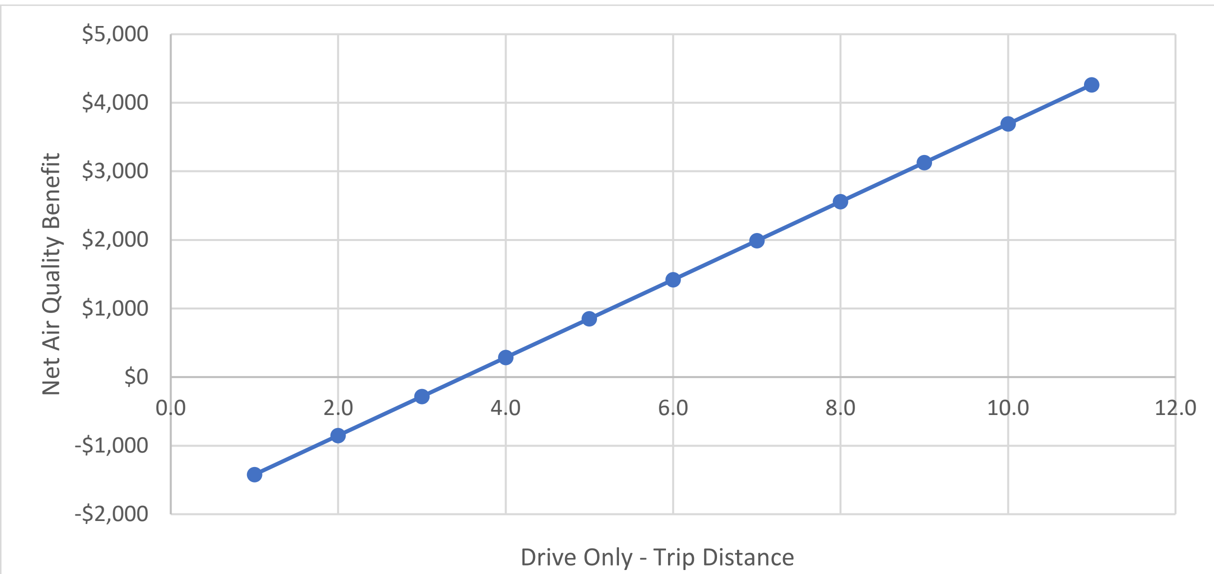
Air Quality Inputs	Value	Type	Data Source
Drive Trip (Trip Segment Length)	10.70	Asserted	Multiple, Lit Review
Transit Trip: (Trip Segment Length)	5.10	Asserted	Multiple, Lit Review
Non-Electric Bus (kg CO2e per person mile)	0.35	Asserted	National Academies of Sciences, 2021.
Private Gasoline Vehicle (kg CO2e per person mile)	0.51	Asserted	National Academies of Sciences, 2021.
Carbon Cost per Kg	$0.052	Fixed	USDOT BCA Guidance

AQ Item	Base-Case Outcome	Build Scenario Outcome	Net Cost Reduction
Annual Vehicle Trips	947,138	925,702	
Annual Transit Trips	96	21,532	
Annual Wike or Bike Trips	8,410	8,410	
Kg Carbon Equivalent	5,168,701	5,089,988	
Air Quality Cost	$268,772	$264,679	$4,093

Source: ITRE, 2023.

A sensitivity analysis was conducted on the *drive trip distance* variable used in the modeling methodology. (This variable denotes the length of trips made driving instead of taking transit or some other mode.) Results show changing the variable has a linear effect with the change in air quality benefits. Additionally, the change is slightly elastic (elasticity = 2.5), meaning that for every 2.5 percent change in driving trip length, there is a one percent change in the derived net air quality benefit (see Figure 11, Table 25, Table 26). At first it may seem counterintuitive that as the drive trip length goes up so does the air quality benefit. The way to think about these changes is that as the drive trip length goes up, so do the air quality costs on a per trip basis. Thus, in the build scenario, when a transit trip is substituted for a drive trip it offers greater emissions savings.

Figure 11: Drive Trip Distance – Asserted Variable Analysis



Source: ITRE, 2023.

Table 25: Drive Trip Distance – Asserted Variable Analysis

Drive Trip Distance	Base Case Scenario	Build Case Scenario	Net Physical Health Benefit
1.0	$25,127	$26,548	-$1,421
2.0	$50,245	$51,098	-$853
3.0	$75,363	$75,647	-$284
4.0	$100,481	$100,197	$284
5.0	$125,599	$124,747	$853
6.0	$150,717	$149,296	$1,421
7.0	$175,836	$173,846	$1,990
8.0	$200,954	$198,395	$2,558
9.0	$226,072	$222,945	$3,127
10.0	$251,190	$247,495	$3,695
11.0	$276,308	$272,044	$4,264

Source: ITRE, 2023.

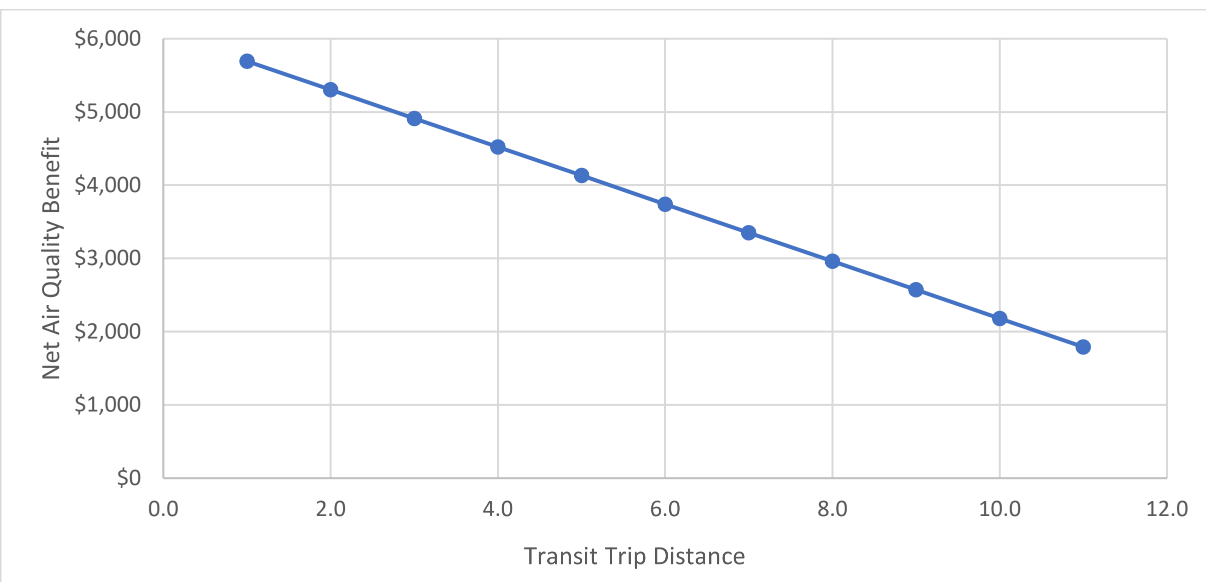
Table 26: Drive Trip Distance – Asserted Variable Analysis (continued)

Drive Trip Distance	Net Physical Health Benefit	% Change in Variable	% Change in Output	Elasticity
1.00	-$1,421			
2.00	-$853	100.0%	40.0%	2.5
3.00	-$284	200.0%	80.0%	2.5
4.00	$284	300.0%	120.0%	2.5
5.00	$853	400.0%	160.0%	2.5
6.00	$1,421	500.0%	200.0%	2.5
7.00	$1,990	600.0%	240.0%	2.5
8.00	$2,558	700.0%	280.0%	2.5
9.00	$3,127	800.0%	320.0%	2.5
10.00	$3,695	900.0%	360.0%	2.5
11.00	$4,264	1000.0%	400.0%	2.5

Source: ITRE, 2023.

A sensitivity analysis was conducted on the *transit trip distance* variable used in the modeling methodology. (This variable denotes the length of the average bus trip being made.) Results show changing the variable has a linear effect with the change in air quality benefits. Additionally, the change is elastic (elasticity = -14.6), meaning that for every 14.6 percent change in transit trip distance, the derived net air quality benefit decreases by one percent (see Figure 12, Table 27, Table 28). This intuitively aligns with what is expected – as the average length of a transit trip increases so do associated emissions, eroding net air quality benefits.

Figure 12: Transit Trip Distance – Asserted Variable Analysis



Source: ITRE, 2023.

Table 27: Transit Trip Distance – Asserted Variable Analysis

Transit Trip Length	Base Case Scenario	Build Case Scenario	Net Physical Health Benefit
1.0	$268,765	$263,073	$5,693
2.0	$268,767	$263,465	$5,302
3.0	$268,769	$263,856	$4,912
4.0	$268,771	$264,248	$4,522
5.0	$268,772	$264,640	$4,132
6.0	$268,774	$265,032	$3,742
7.0	$268,776	$265,424	$3,352
8.0	$268,778	$265,816	$2,962
9.0	$268,779	$266,208	$2,572
10.0	$268,781	$266,600	$2,181
11.0	$268,783	$266,991	$1,791

Source: ITRE, 2023.

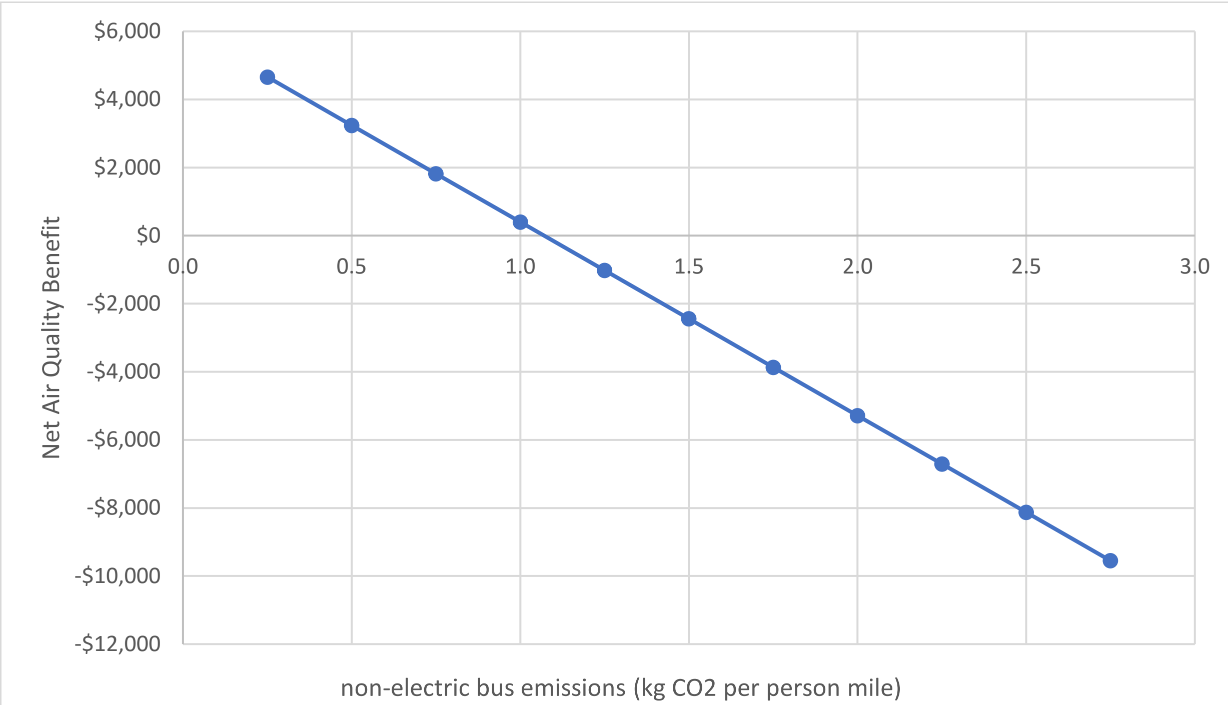
Table 28: Transit Trip Distance – Asserted Variable Analysis (continued)

Transit Only: (Trip Segment Length)	Net Physical Health Benefit	% Change in Variable	% Change in Output	Elasticity
1.00	$5,693			
2.00	$5,302	100.0%	-6.9%	-14.6
3.00	$4,912	200.0%	-13.7%	-14.6
4.00	$4,522	300.0%	-20.6%	-14.6
5.00	$4,132	400.0%	-27.4%	-14.6
6.00	$3,742	500.0%	-34.3%	-14.6
7.00	$3,352	600.0%	-41.1%	-14.6
8.00	$2,962	700.0%	-48.0%	-14.6
9.00	$2,572	800.0%	-54.8%	-14.6
10.00	$2,181	900.0%	-61.7%	-14.6
11.00	$1,791	1000.0%	-68.5%	-14.6

Source: ITRE, 2023.

A sensitivity analysis was conducted on the *non-electric bus emissions (kg CO2e per person mile)* variable used in the modeling methodology. (This variable denotes average emissions per person for each bus-mile traveled.) Results show changing the variable has a linear effect with the change in air quality benefits. Additionally, the change is elastic (elasticity = -3.3), meaning that for every 3.3 percent change kilograms of CO2e emitted per person mile, the derived net air quality benefit decreases by one percent (see Figure 13, Table 29, Table 30). This intuitively aligns with what is expected – as the average quantity of emissions per person mile increases, it erodes net air quality benefits stemming from using transit.

Figure 13: Non-Electric Bus Emissions – Asserted Variable Analysis



Source: ITRE, 2023.

Table 29: Non-Electric Bus Emissions – Asserted Variable Analysis

Non-Electric Bus (kg CO2e per person mile)	Base Case Scenario	Build Case Scenario	Net Physical Health Benefit
0.25	$268,770	$264,108	$4,662
0.50	$268,776	$265,536	$3,240
0.75	$268,783	$266,963	$1,819
1.00	$268,789	$268,391	$398
1.25	$268,795	$269,819	-$1,023
1.50	$268,802	$271,246	-$2,444
1.75	$268,808	$272,674	-$3,866
2.00	$268,814	$274,101	-$5,287
2.25	$268,821	$275,529	-$6,708
2.50	$268,827	$276,956	-$8,129
2.75	$268,833	$278,384	-$9,551

Source: ITRE, 2023.

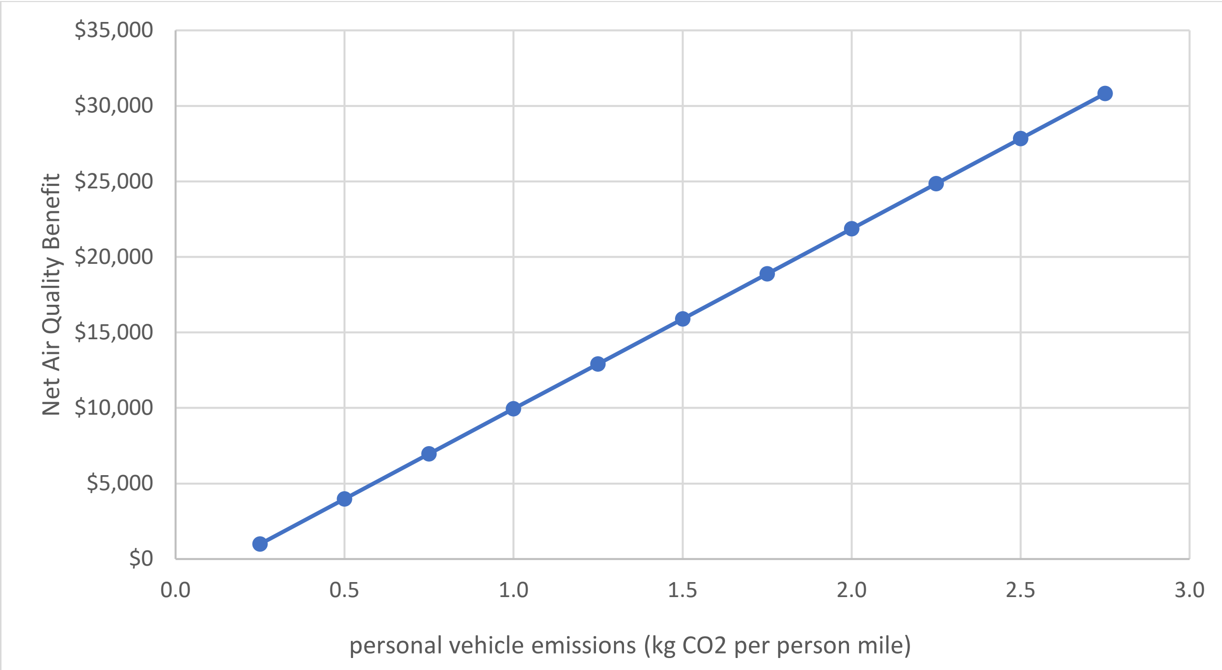
Table 30: Non-Electric Bus Emissions – Asserted Variable Analysis (continued)

Non-Electric Bus (kg CO2e per person mile)	Net Physical Health Benefit	% Change in Variable	% Change in Output	Elasticity
1.00	$4,662			
2.00	$3,240	100.0%	-30.5%	-3.3
3.00	$1,819	200.0%	-61.0%	-3.3
4.00	$398	300.0%	-91.5%	-3.3
5.00	-$1,023	400.0%	-122.0%	-3.3
6.00	-$2,444	500.0%	-152.4%	-3.3
7.00	-$3,866	600.0%	-182.9%	-3.3
8.00	-$5,287	700.0%	-213.4%	-3.3
9.00	-$6,708	800.0%	-243.9%	-3.3
10.00	-$8,129	900.0%	-274.4%	-3.3
11.00	-$9,551	1000.0%	-304.9%	-3.3

Source: ITRE, 2023.

A sensitivity analysis was conducted on the *private gasoline vehicle (kg CO2e per person mile)* variable used in the modeling methodology. (This variable denotes average emissions per person for each personal vehicle-mile traveled.) Results show changing the variable has a linear effect with the change in air quality benefits. Additionally, the change is inelastic (elasticity = 0.3), meaning that for every 0.3 percent change kilograms of CO2e emitted per person mile traveled in a passenger vehicle, the derived net air quality benefit increases by one percent (see Figure 14, Table 31, Table 32). At first it may seem counterintuitive that as vehicle emissions per person mile increase, so does the air quality benefit. The way to think about these changes is that as personal vehicle-related emissions goes up, so do the air quality costs on a per trip basis. Thus, in the build scenario, when a transit trip is substituted for a drive trip it offers greater emissions savings.

Figure 14: Personal Gasoline Vehicle – Asserted Variable Analysis



Source: ITRE, 2023.

Table 31: Personal Gasoline Vehicle – Asserted Variable Analysis

Private Gasoline Vehicle (kg CO2e per person mile)	Base Case Scenario	Build Case Scenario	Net Physical Health Benefit
0.25	$131,756	$130,764	$992
0.50	$263,503	$259,529	$3,974
0.75	$395,249	$388,294	$6,956
1.00	$526,996	$517,059	$9,937
1.25	$658,743	$645,824	$12,919
1.50	$790,490	$774,589	$15,901
1.75	$922,237	$903,354	$18,883
2.00	$1,053,984	$1,032,119	$21,864
2.25	$1,185,731	$1,160,885	$24,846
2.50	$1,317,478	$1,289,650	$27,828
2.75	$1,449,224	$1,418,415	$30,810

Source: ITRE, 2023.

Table 32: Personal Gasoline Vehicle – Asserted Variable Analysis (continued)

Private Gasoline Vehicle (kg CO2e per person mile)	Net Physical Health Benefit	% Change in Variable	% Change in Output	Elasticity
1.00	$992			
2.00	$3,974	100.0%	300.6%	0.3
3.00	$6,956	200.0%	601.1%	0.3
4.00	$9,937	300.0%	901.7%	0.3
5.00	$12,919	400.0%	1202.2%	0.3
6.00	$15,901	500.0%	1502.8%	0.3
7.00	$18,883	600.0%	1803.4%	0.3
8.00	$21,864	700.0%	2103.9%	0.3
9.00	$24,846	800.0%	2404.5%	0.3
10.00	$27,828	900.0%	2705.1%	0.3
11.00	$30,810	1000.0%	3005.6%	0.3

Source: ITRE, 2023.

Bypass of Ahoskie – Effect of Asserted Variables on Physical Health Output

The table below shows the anticipated physical health costs that would result from adding the Ahoskie Bypass, which has a speed limit of more than 40mph and no sidewalks. The rows highlighted in green show the asserted variables that are tested during the sensitivity analysis.

Table 33: Physical Health Benefits Anticipated from the Ahoskie Bypass (Asserted Values Highlighted in Green)

Highways: Physical Health Variables - Sensitivity Analysis

Scenario	Speed Limit	Sidewalk Presence	Sidewalk 1 Width	Sidewalk 2 Width
Base-Case Scenario	N/A	No Sidewalk	N/A	N/A
Build Scenario	40+ mph	No Sidewalk	N/A	N/A

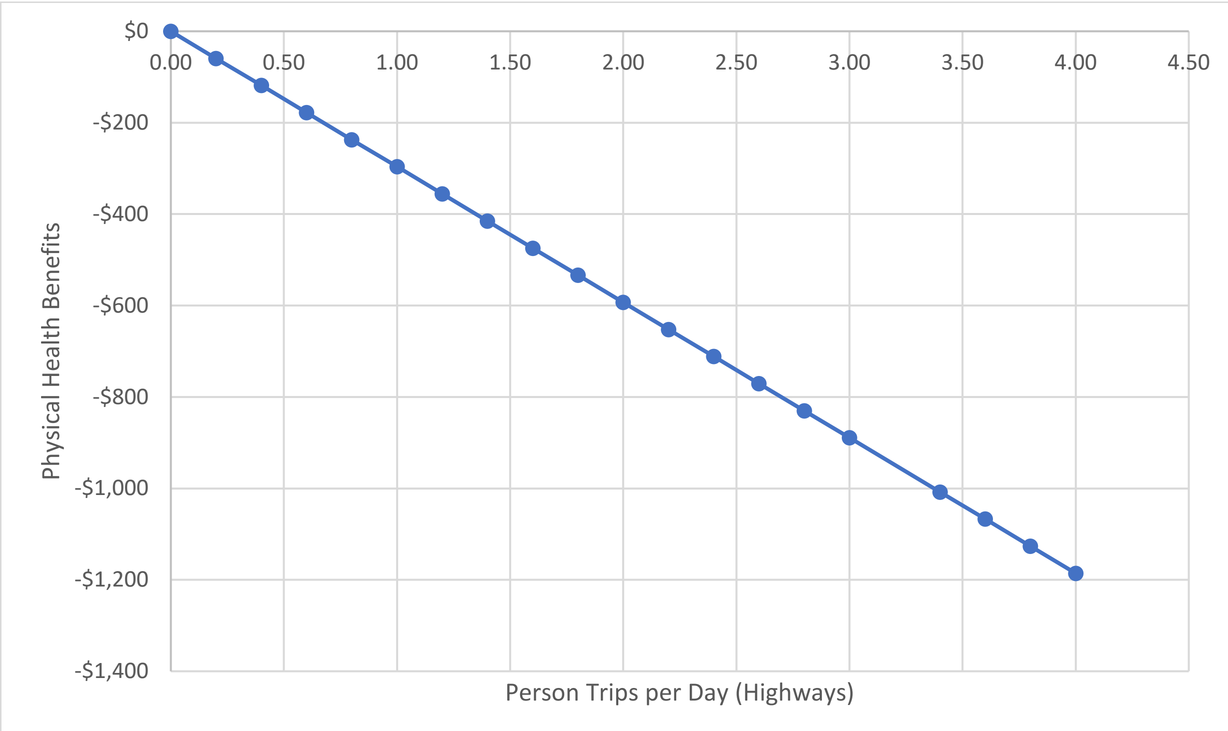
Inputs	Value	Type	Data Source
Project Buffer Area	0.500	GIS-dependent	Census / GIS Tool
Project Area Population	170	GIS-dependent	Census / GIS Tool
Walk Proportion	0.027	GIS-dependent	Census / GIS Tool
Bike Proportion	0.0001	GIS-dependent	Census / GIS Tool
Transit Proportion	0.004	GIS-dependent	Census / GIS Tool
Benefit per Walk Trip ($2022)	$7.08	GIS-dependent	Census / GIS Tool
Benefit per Bike Trip ($2022)	$6.31	GIS-dependent	Census / GIS Tool
Mean Person Trips per Day	2.600	Asserted	AAA, BTS
Days per Year	365	Fixed	U.S. Calendar
Posted Speed Limit (Mode Shift Factor)	0.975	Asserted, based on base-case & build scenarios	Multiple, Lit Review
Sidewalk Existence (Mode Shift Factor)	1.000	Asserted, based on base-case & build scenarios	Multiple, Lit Review
Sidewalk Width (Mode Shift Factor)	1.000	Asserted, based on base-case & build scenarios	Multiple, Lit Review

PH Item	Base-Case Outcome	Build Scenario Outcome	Net PH Benefit
Physical Health Benefits	$30,827	$30,057	-$771

Source: ITRE, 2023.

A sensitivity analysis was conducted on the *person trips per day* variable used in the modeling methodology. Results show that changing the variable has a linear effect with the change in physical health benefits. Additionally, the change is unit elastic (elasticity = -1.0), meaning that for every 1 percent change daily person trips in a passenger vehicle, the derived net physical health benefit decreases by one percent (see Figure 15, Table 34, Table 35).

Figure 15: Person Trips per Day – Asserted Variable Analysis



Source: ITRE, 2023.

Table 34: Person Trips per Day – Asserted Variable Analysis

Person Trips per Day	Base Case Scenario	Build Case Scenario	Net Physical Health Benefit
0.00	$0	$0	$0
0.20	$2,371	$2,312	-$59
0.40	$4,743	$4,624	-$119
0.60	$7,114	$6,936	-$178
0.80	$9,485	$9,248	-$237
1.00	$11,857	$11,560	-$296
1.20	$14,228	$13,872	-$356
1.40	$16,599	$16,184	-$415
1.60	$18,971	$18,496	-$474
1.80	$21,342	$20,809	-$534
2.00	$23,713	$23,121	-$593
2.20	$26,085	$25,433	-$652
2.40	$28,456	$27,745	-$711
2.60	$30,827	$30,057	-$771
2.80	$33,199	$32,369	-$830
3.00	$35,570	$34,681	-$889

Source: ITRE, 2023.

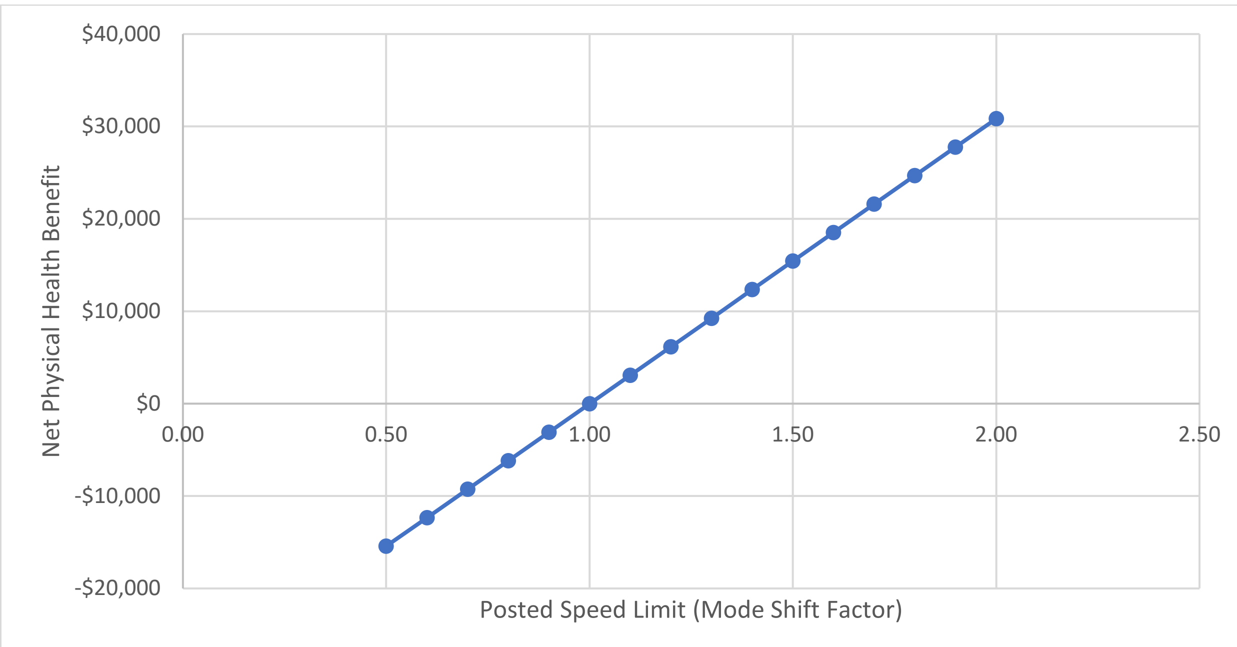
Table 35: Person Trips per Day – Asserted Variable Analysis (continued)

Person Trips per Day	Net Physical Health Benefit	% Change in Variable	% Change in Output	Elasticity
0.00	$0			
0.20	-$59			
0.40	-$119	100.0%	-100.0%	-1.0
0.60	-$178	200.0%	-200.0%	-1.0
0.80	-$237	300.0%	-300.0%	-1.0
1.00	-$296	400.0%	-400.0%	-1.0
1.20	-$356	500.0%	-500.0%	-1.0
1.40	-$415	600.0%	-600.0%	-1.0
1.60	-$474	700.0%	-700.0%	-1.0
1.80	-$534	800.0%	-800.0%	-1.0
2.00	-$593	900.0%	-900.0%	-1.0
2.20	-$652	1000.0%	-1000.0%	-1.0
2.40	-$711	1100.0%	-1100.0%	-1.0
2.60	-$771	1200.0%	-1200.0%	-1.0
2.80	-$830	1300.0%	-1300.0%	-1.0
3.00	-$889	1400.0%	-1400.0%	-1.0

Source: ITRE, 2023.

A sensitivity analysis was conducted on the *posted speed limit mode shift factor* variable used in the modeling methodology. Results show that changing the variable has a linear effect with the change in physical health benefits. Additionally, the change is unit elastic (elasticity = 1.0), meaning that for every 1 percent change in the posted speed limit's mode shift factor, the derived net physical health benefit increases by one percent (see Figure 16, Table 36, Table 37). At first this may seem counterintuitive. The way to interpret what is occurring is to understand what the mode shift factor is describing. Mode shift increases as the speed limit decreases, so when evaluating an increase in mode shift it is akin to evaluating a decrease in the posted speed limit.

Figure 16: Posted Speed Limit (Mode Shift Factor) – Asserted Variable Analysis



Source: ITRE, 2023.

Table 36: Posted Speed Limit (Mode Shift Factor) – Asserted Variable Analysis

Posted Speed Limit (MSF)	Base Case Scenario	Build Case Scenario	Net Physical Health Benefit
0.50	$30,827	$15,414	-$15,414
0.60	$30,827	$18,496	-$12,331
0.70	$30,827	$21,579	-$9,248
0.80	$30,827	$24,662	-$6,165
0.90	$30,827	$27,745	-$3,083
1.00	$30,827	$30,827	$0
1.10	$30,827	$33,910	$3,083
1.20	$30,827	$36,993	$6,165
1.30	$30,827	$40,076	$9,248
1.40	$30,827	$43,158	$12,331
1.50	$30,827	$46,241	$15,414
1.60	$30,827	$49,324	$18,496
1.70	$30,827	$52,407	$21,579
1.80	$30,827	$55,489	$24,662
1.90	$30,827	$58,572	$27,745
2.00	$30,827	$61,655	$30,827

Source: ITRE, 2023.

Table 37: Posted Speed Limit (Mode Shift Factor) – Asserted Variable Analysis (continued)

Posted Speed Limit (MSF)	Net Physical Health Benefit	% Change in Variable	% Change in Output	Elasticity
0.50	-$15,414			
0.60	-$12,331			
0.70	-$9,248	40.0%	40.0%	1.0
0.80	-$6,165	60.0%	60.0%	1.0
0.90	-$3,083	80.0%	80.0%	1.0
1.00	$0	100.0%	100.0%	1.0
1.10	$3,083	120.0%	120.0%	1.0
1.20	$6,165	140.0%	140.0%	1.0
1.30	$9,248	160.0%	160.0%	1.0
1.40	$12,331	180.0%	180.0%	1.0
1.50	$15,414	200.0%	200.0%	1.0
1.60	$18,496	220.0%	220.0%	1.0
1.70	$21,579	240.0%	240.0%	1.0
1.80	$24,662	260.0%	260.0%	1.0
1.90	$27,745	280.0%	280.0%	1.0
2.00	$30,827	300.0%	300.0%	1.0

Source: ITRE, 2023.

A sensitivity analysis was conducted on the *sidewalk existence mode shift factor* variable used in the modeling methodology. Results show that changing the variable has a linear effect with the change in physical health benefits. Additionally, the change is slightly elastic (elasticity = 1.05), meaning that for every 1.05 percent change in the sidewalk existence mode shift mode shift factor, the derived net physical health benefit increases by one percent (see Figure 17, Table 38, Table 39).

Figure 17: Sidewalk Existence (Mode Shift Factor) – Asserted Variable Analysis

Source: ITRE, 2023.

Table 38: Sidewalk Existence (Mode Shift Factor) – Asserted Variable Analysis

Sidewalk Existence (MSF)	Base Case Scenario	Build Case Scenario	Net Physical Health Benefit
0.50	$30,827	$14,643	-$16,184
0.60	$30,827	$17,726	-$13,102
0.70	$30,827	$20,809	-$10,019
0.80	$30,827	$23,891	-$6,936
0.90	$30,827	$26,974	-$3,853
1.00	$30,827	$30,057	-$771
1.10	$30,827	$33,139	$2,312
1.20	$30,827	$36,222	$5,395
1.30	$30,827	$39,305	$8,478
1.40	$30,827	$42,388	$11,560
1.50	$30,827	$45,470	$14,643
1.60	$30,827	$48,553	$17,726
1.70	$30,827	$51,636	$20,809
1.80	$30,827	$54,719	$23,891
1.90	$30,827	$57,801	$26,974
2.00	$30,827	$60,884	$30,057

Source: ITRE, 2023.

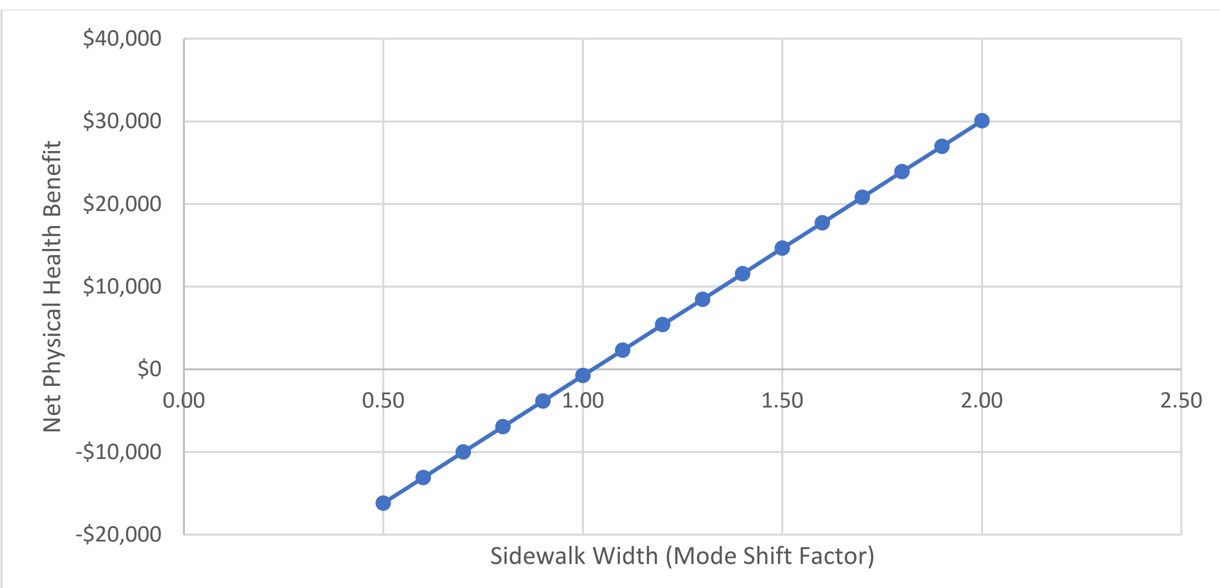
Table 39: Sidewalk Existence (Mode Shift Factor) – Asserted Variable Analysis

Sidewalk Existence (MSF)	Net Physical Health Benefit	% Change in Variable	% Change in Output	Elasticity
0.50	-$16,184			
0.60	-$13,102			
0.70	-$10,019	40.0%	38.1%	1.05
0.80	-$6,936	60.0%	57.1%	1.05
0.90	-$3,853	80.0%	76.2%	1.05
1.00	-$771	100.0%	95.2%	1.05
1.10	$2,312	120.0%	114.3%	1.05
1.20	$5,395	140.0%	133.3%	1.05
1.30	$8,478	160.0%	152.4%	1.05
1.40	$11,560	180.0%	171.4%	1.05
1.50	$14,643	200.0%	190.5%	1.05
1.60	$17,726	220.0%	209.5%	1.05
1.70	$20,809	240.0%	228.6%	1.05
1.80	$23,891	260.0%	247.6%	1.05
1.90	$26,974	280.0%	266.7%	1.05
2.00	$30,057	300.0%	285.7%	1.05

Source: ITRE, 2023.

A sensitivity analysis was conducted on the *sidewalk width mode shift factor* variable used in the modeling methodology. Results show that changing the variable has a linear effect with the change in physical health benefits. Additionally, the change is slightly elastic (elasticity = 1.05), meaning that for every 1.05 percent change in the sidewalk width mode shift mode shift factor, the derived net physical health benefit increases by one percent (see Figure 18, Table 40, and Table 41).

Figure 18: Sidewalk Width (Mode Shift Factor) – Asserted Variable Analysis



Source: ITRE, 2023.

Table 40: Sidewalk Width (Mode Shift Factor) – Asserted Variable Analysis

Sidewalk Width (MSF)	Base Case Scenario	Build Case Scenario	Net Physical Heatlh Benefits
0.50	$30,827	$14,643	-$16,184
0.60	$30,827	$17,726	-$13,102
0.70	$30,827	$20,809	-$10,019
0.80	$30,827	$23,891	-$6,936
0.90	$30,827	$26,974	-$3,853
1.00	$30,827	$30,057	-$771
1.10	$30,827	$33,139	$2,312
1.20	$30,827	$36,222	$5,395
1.30	$30,827	$39,305	$8,478
1.40	$30,827	$42,388	$11,560
1.50	$30,827	$45,470	$14,643
1.60	$30,827	$48,553	$17,726
1.70	$30,827	$51,636	$20,809
1.80	$30,827	$54,719	$23,891
1.90	$30,827	$57,801	$26,974
2.00	$30,827	$60,884	$30,057

Source: ITRE, 2023.

Table 41: Sidewalk Width (Mode Shift Factor) – Asserted Variable Analysis (continued)

Sidewalk 1 Width (MSF)	Net Physical Health Benefit	% Change in Variable	% Change in Output	Elasticity
0.50	-$16,184			
0.60	-$13,102			
0.70	-$10,019	40.0%	38.1%	1.05
0.80	-$6,936	60.0%	57.1%	1.05
0.90	-$3,853	80.0%	76.2%	1.05
1.00	-$771	100.0%	95.2%	1.05
1.10	$2,312	120.0%	114.3%	1.05
1.20	$5,395	140.0%	133.3%	1.05
1.30	$8,478	160.0%	152.4%	1.05
1.40	$11,560	180.0%	171.4%	1.05
1.50	$14,643	200.0%	190.5%	1.05
1.60	$17,726	220.0%	209.5%	1.05
1.70	$20,809	240.0%	228.6%	1.05
1.80	$23,891	260.0%	247.6%	1.05
1.90	$26,974	280.0%	266.7%	1.05
2.00	$30,057	300.0%	285.7%	1.05

Source: ITRE, 2023.

Bypass of Ahoskie – Effect of Asserted Variables on Air Quality Output

The National Center for Sustainable Transportation developed the California Induced Travel Calculator, which is used by CalTrans models induced vehicle miles traveled stemming from highway investments. The calculator allows users to estimate the VMT induced annually as a result of adding general-purpose lane miles, high-occupancy vehicle (HOV) lane miles, or high-occupancy toll (HOT) lane miles to publicly owned roadways.

As part of research project 2022-17: Including Equity in Benefit Cost Analysis, the California Induced Calculator, has been adapted to North Carolina's context. It includes North Carolina's road network and has been expanded to include all potential highway investments, not just Class 1, 2, or 3 facilities, and incorporates U.S. Census Data. To estimate a prospective project's effect on air quality, several methodological steps are undertaken, which are described in Appendix B. Due to the adherence to the California Induced Travel Calculator methodology, a sensitivity analysis was not conducted for air quality impacts stemming from the Bypass of Ahoskie.

E-1

July
2022

Including Equity in Benefit-Cost Analysis

NCDOT RP 2022-069

Summary of the Equity Definition Development

ITRE

Planning Communities

Executive Summary

Defining "equity" is essential for effectively measuring how transportation projects and plans impact equity-related outcomes in communities. Consequently, the North Carolina Department of Transportation (NCDOT) aimed to develop a definition of equity for long-range planning and the prioritization of transportation investments in North Carolina. This definition is designed to provide a vision that can guide decisions related to data, measures, and actions.

In February 2022 and June 2022, members from the Institute for Transportation Research and Education (ITRE) research project team facilitated three workshops with representatives from NCDOT's Transportation Planning Division (TPD) and Strategic Prioritization Office (SPOT) with the goal of developing a common equity definition for planning and prioritization. This group collaborated to develop the following definition of equity for long-range planning and the prioritization of transportation involving the North Carolina Department of Transportation:

> *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.*

Developing a definition is the first step in improving and assessing outcomes related to equity. To implement this definition, SPOT and TPD can identify their Communities of Concern (CoCs), or geographic areas of analysis where sensitive and historically underrepresented groups are located, and can then prioritize these communities in equity-related analyses. SPOT and TPD can employ their joint equity definition and defined CoCs to inform how equity is measured in terms of data collection and application as well as to define short-term and long-term goals tied to equity-related outcomes.

Table of Contents

Purpose of Developing a Definition for Equity

Defining "equity" is essential for effectively measuring how transportation projects and plans impact equity-related outcomes in communities. Consequently, the North Carolina Department of Transportation (NCDOT) aims to develop a definition of equity for long-range planning and the prioritization of transportation investments in North Carolina. This definition is designed to provide a vision that can guide decisions related to NCDOT data, measures, and actions.

Development Approach

In February 2022, members from the Institute for Transportation Research and Education (ITRE) research project team facilitated two workshops with representatives from NCDOT's Transportation Planning Division (TPD) and Strategic Prioritization Office (SPOT) with the goal of developing a common equity definition for planning and prioritization. The group reconvened in June 2022 to further revised their jointly-developed definition.

Model Equity Definition

During the workshops in February 2022, NCDOT representatives were asked to respond to the following equity statement from the District Department of Transportation (Washington D.C. area) as a model example:

> *"Equity in transportation is the shared and just distribution of benefits and burdens when planning for and investing in transportation infrastructure and services. Transportation decisions are made in collaboration and in participation with the community DDOT serves, to establish a system that is safe, accessible, affordable, reliable, and sustainable. Focused attention is given to historically under-resourced communities in order to overcome existing disparities and achieve transportation equity."*

Participants discussed the aspects of the definition they may want to incorporate into a definition for NCDOT planning and prioritization as well as elements they may want to address differently.

Common Themes and Terms

Following a discussion on the model definition, the research team shared the results of a scan of more than 20 equity statements and definitions. The four common equity themes identified by the Urban Sustainability Directors Network (USDN), were used as a framework for organizing the trends seen in the definition data. These themes are described by USDN (2014) as follows:

- **Distributional Equity**, or when programs and policies result in fair distribution of benefits and burdens across all segments of a community, prioritizing those with the highest need.
- **Transgenerational Equity**, or when decisions consider generational impacts and don't result in unfair burdens on future generations. This is also known as Restorative Equity.
- **Procedural Equity**, defined as inclusive, accessible, authentic engagement and representation in processes to develop or implement programs or policies.
- **Structural Equity**, or when decision-makers institutionalize accountability; decisions are made with a recognition of the historical, cultural, and institutional dynamics and structures that have

routinely advantaged privileged groups in society and resulted in chronic, cumulative disadvantage for subordinated groups.

Terms frequently included in equity definitions were organized by four common equity themes identified by USDN, as shown in Exhibit 1.

Exhibit 1. Common Equity Terms by Theme

Equity Theme	*Distributional Equity*	*Transgenerational Equity*	*Procedural Equity*	*Structural Equity*
Common Terms in Definitions	options	burden	representation	historic/historically
	opportunity	disparities	engagement	sustainable
	benefit	barriers	collaboration	health/healthy
	choice	resources	accessibility (in reference to communication)	access (in reference to the ability to utilize)
	distribution / distributed		inclusive/ inclusion	
	shared (in reference to costs/benefits)		shared (in reference to decision-making)	
	just / fair			
	needs met			

Additional common transportation-specific terms identified were also shared, as shown in Exhibit 2.

Exhibit 2. Common Transportation-Specific Equity Terms

	Transportation-Specific Language
Common Terms in Equity Definitions	efficient
	reliable
	safe
	affordable
	accessible (in reference to mobility)

Discussion of the terms and themes ensued.

Term Prioritization

Following this discussion, the NCDOT representatives were broken up into two groups: the SPOT Group and the Planning Group. Using a virtual poster board and virtual sticky notes, the groups were asked to prioritize the aforementioned terms based on their values related to equity. Each term was presented on a card that was color-coded to correspond with the most appropriate thematic group. These color codes are presented in Exhibit 3. The participants were also given the opportunity to add their own terms for consideration, which were recorded on purple cards.

Exhibit 3. Color Codes for Term Thematic Groupings

Distributional Equity Terms	Transgenerational Equity Terms	Procedural Equity Terms	Structural Equity Terms	Common Transportation Terms

The results of this exercise are as shown in Exhibit 4 and Exhibit 5. The two groups prioritized each word as either “must have,” “nice to have,” or “can live without” in terms of inclusion in their definition.

Exhibit 4. Planning Group Prioritization

Exhibit 5. SPOT Group Prioritization

Following the exercise, all participants reconvened. Both the Planning Group and SPOT Group discussed the reasoning behind their prioritization of terms.

Planning Group Discussion

The Planning Group shared that they prioritized terms with consideration for how equity can impact, and be impacted by, community engagement and data analysis. This group noted that the idea of who benefits from, and who carries the burdens of, transportation investments was key. They conveyed that burdens should not be shared equally in cases where some groups are already overburdened. “Quality of life” was a new “umbrella” term added by the Planning Group to tie together many of the other terms they prioritized. The mission and vision of NCDOT and TPD were considered, as was the importance of including terms that point to goals that can be measured early in the planning process to set the stage for long-term success. The Planning Group noted that success should be defined based on what a given community identifies as their needs and whether NCDOT meets those needs.

SPOT Group Discussion

The SPOT Group shared that the overall theme that guided their term prioritization was “moving forward,” emphasizing the importance of collaborative decision-making and considering the long-term impacts of transportation decisions. This group noted that such a forward-thinking approach to equity needs to involve prioritizing investments that are “less disruptive” to communities and learning from mistakes of the past. Honest public engagement that helps NCDOT understand the context of community needs and perspectives was identified as key to making decisions that lead to more equitable outcomes. The SPOT Group also noted that people’s ability to utilize transportation options in their daily lives should be incorporated when determining how to invest in transportation infrastructure.

Similarities and Differences Discussion

After presenting their prioritized terms and perspectives, the two groups then discussed the differences and similarities between their prioritization results. Details of this discussion are summarized in Exhibit 6 in the following section.

Analysis of Workshop Results

Following the workshop, the research team analyzed exercise and discussion results. This analysis guided the development of a proposed definition of equity for planning and prioritization. The terms identified as “must have'' by each group were documented in a table. To identify terms valued by both groups, cases in which a “must have” term for one group was earmarked as a “nice to have” term for the other group were also documented.

Trends and commonalities between group priorities were summarized as shown in Exhibit 6. Additionally, the Notes column in Exhibit 6 presents relevant context shared by participants during the workshop discussions, including their interpretations of terms and their perspectives about the relationships between different terms.

Exhibit 6. Prioritization Summary

Common Words	SPOT		Planning		Notes
	Must Have	Nice to Have	Must Have	Nice to Have	
Benefit	Y		Y		Related to identifying needs early with goal of meeting them long-term
Collaboration	Y		Y		Related to decision-making processes, being forward-thinking
Reliable	Y		Y		
Barriers	Y		Y		Related to identifying needs early with goal of meeting them long-term
Inclusive/ inclusion	Y		Y		Identified as an umbrella term related to engagement and fair share of resources
Shared (decision making)	Y			Y	Relationship to representation and inclusion
Access (the ability to utilize)	Y			Y	Need to convey this in way that this clear this is about usability – in that case, this is tied to attainable
Historic / historically	Y				Traditionally underserved is similar and resonated more with the Planning Group; SPOT Group noted we don't want to make past mistakes
Options	Y				Choice is similar and could be a suitable synonym
Sustainable	Y				SPOT Group thinks of this as sustaining a way of life, functionality, or environment; related to being less disruptive; want to sustain people's ability to utilize
Burden		Y	Y		Burdens should not be shared equality in cases where some groups are already overburdened
Choice		Y	Y		Option is similar could be a suitable synonym
Health/ healthy		Y	Y		Related to quality of life
Safe		Y	Y		
Efficient			Y		
Attainable*			Y		About realistic options for people; Planning Group considered affordability to be related; needs-based, not one-size-fits-all; may vary by community – need to ask what is attainable means for different people
Traditionally underserved*			Y		Historically provides similar context
Quality of life*			Y		Related to most other terms on list, relationship to sustainable but has more specific meaning; used to capture concept of what is success, especially long-term

* = term originated by given group during workshop — Y = identified as a "must have" term

Bold text = incorporated into proposed definition — Y = identified as a "nice to have" term

Proposed Definition

These prioritized terms, paired with context gained during the workshop discussions, were used to draft the following proposed definition of equity for NCDOT's long-range planning and prioritization efforts in February 2022:

> *Equity is improving **quality of life** by balancing transportation **benefits** and **burdens** in a **sustainable** way. Planning and investment decisions are made through **inclusive collaboration** to provide **safe, reliable, and attainable** transportation **options**. Acknowledging and mitigating **barriers** to **access** experienced by **historically underserved** communities is key to better meeting the needs of all North Carolinians.*

This definition was further revised by SPOT and TPD through a third workshop in June 2022. This revised definition reads as follows:

> *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 is designed to be concise and easy to understand while framing the terms NCDOT prioritized to convey their intended meaning. Words highlighted in bold are key terms prioritized by one or both of the breakout groups during the aforementioned workshops.

The research team made efforts to include all terms identified by NCDOT as "must have." However, some of these terms were not incorporated, primarily due to their similarity to other terms used. Altogether, 13 terms prioritized by NCDOT were included. Comments made by NCDOT during the workshop were also considered when deciding which words to incorporate into the definition. For more details, see Exhibit 6.

Implementation

Developing a definition is the first step in improving and assessing outcomes related to equity. The next step in the process to implement the definition is internally discussing and confirming Communities of Concern (CoCs), or geographic areas of analysis where sensitive and historically underrepresented groups are located. As part of this process, SPOT and TPD can identify the term they prefer to use to refer to CoCs as well as what criteria will be used to define CoCs. These criteria can be informed by the types of communities SPOT and TPD consider to be of particular concern in terms of equity. These CoCs can also accompany the definition of equity wherever it is posted, if NCDOT prefers.

Following these efforts, SPOT and TPD can employ their equity definition and defined CoCs to inform how equity is measured in terms of data collection and application as well as to define short-term and long-term goals tied to equity-related outcomes.