Estimation of Benefits from Pedestrian and Bicycle Improvements

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Kentucky Transportation Center
College of Engineering, University of Kentucky, Lexington, Kentucky

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Commonwealth of Kentucky

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Research Report
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Estimation of Benefits from Pedestrian and Bicycle Improvements

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16. Abstract

Delivering safe mobility for all users of the transportation system is a key priority of the Kentucky Transportation Cabinet (KYTC). Because many system users rely on pedestrian and bicycle facilities, it is critical for KYTC to balance pedestrian and bicycle facility accommodations with those for motorized users. Currently, the Strategic Highway Investment Formula for Tomorrow (SHIFT) — the Cabinet's systematic approach to scoring and prioritizing proposed roadway projects — awards up to five points (out of a possible total of 100) for pedestrian and bicycle projects. But the agency lacks a robust method for estimating the benefits of pedestrian and bicycle infrastructure. Based on a benefit-cost tool initially published in NCHRP Report 552, this report describes the development of a spreadsheet tool that can be used to estimate the benefits of pedestrian and bicycle facilities. The principal benefit of the proposed method is that it leverages accessible datasets to estimate the benefits of pedestrian and bicycle facilities given a specified level of demand. Practitioners can employ the spreadsheet tool with ease. Researchers used the spreadsheet tool to model the benefits generated by SHIFT 2024 projects. Future work on the tool should focus on validating its outputs — to confirm estimated benefits are realistic for different project contexts — and improving large-scale efforts to gather data on pedestrian and bicycle volumes.

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Chapter 1 Introduction

The 2009 National Household Travel Survey (NHTS) estimated that walking and biking trips accounted for 12.9% all trips, higher than the 9.6% estimated in 2001 (The League of American Bicyclists, n.d.). However, the 2022 NHTS found a decrease in walking trips. In 2022, 6.8% of all trips were walking compared to 11.9% in 2017 (NHTS, n.d.). Methodological changes in how the NHTS collected the data may have contributed to the decline recorded in 2022. Bicycle use remained steady over the same period with bicycle trips accounting for 1.0% of all trips.

Given the number of people who rely on non-motorized modes of transport, the Kentucky Transportation Cabinet (KYTC) wants to balance pedestrian and bicycle facility accommodations with those for motorized users. Establishing a process to evaluate pedestrian and bicyclist needs and identifying projects that could address those needs is critical for achieving this objective. Objective estimation methods could help KYTC and other agencies demonstrate project benefits and establish the relative importance of each project within the roadway network.

KYTC has developed the Strategic Highway Investment Formula for Tomorrow (SHIFT) to systematically evaluate potential projects and identify those which have the greatest potential to improve the state roadway network. Under SHIFT, each project can score up to 100 points. Eighty (80) points are awarded based on a project's contribution to safety, asset management, economic growth, congestion and reliability, and resilience as well as benefit-cost analysis. The current iteration of SHIFT awards up to 2.5 points for pedestrian and 2.5 points for bicyclist projects. The final 20 points come from district and local boosts that KYTC, Area Development Districts (ADDs), and Metropolitan Planning Organizations (MPOs) can use to promote high-priority projects.

KYTC has replaced its *Pedestrian and Bicycle Travel Policy* (2002) with the *Complete Streets, Roads, and Highways Manual* (2022a) and *Complete Streets, Roads, and Highways Policy* (2022b). The new focus on Complete Streets represents a shifts from a vehicle-centric approach to one more committed to addressing multimodal transportation needs. The manual offers design guidance on solutions that support motorists, bicyclists, pedestrians, transit users, and freight carriers. An accompanying *Statewide Bicycle and Pedestrian Master Plan* (2022c) provides a framework for advancing pedestrian and bicycle projects within different Kentucky agencies. It also contains guidance for assessing existing pedestrian bicycle facilities to determine which are in need of improvement.

KYTC commissioned this report to help it and other agencies define and estimate the benefits of pedestrian and bicycle project implementation. This report draws on insights from prior efforts and evaluates current literature to understand how other agencies have addressed this issue. The research team studied efforts undertaken by multiple agencies and evaluated their approaches and databases used. Based on this review, the report advances a method KYTC can adopt to estimate the benefits of pedestrian and bicycle infrastructure.

Chapter 2 Literature Review

This chapter reviews methods for estimating pedestrian and bicyclist demand as well as the benefits conferred by pedestrian and bicycle facilities. After discussing efforts at state departments of transportation (DOTs), other work that has attempted to forecast bicycle facility travel demand is presented. The goal of this review was to identify methods that could be appropriate for use in Kentucky.

2.1 Bicycle Demand Estimation

State Efforts

Minnesota DOT

Qian (2016) sought to quantify the economic impact and assess the health effects of bicycling in Minnesota. They argued that understanding the level of bicycling in the state, including the number of people who bicycle and how far they travel, is essential for establishing policies, planning efficiently, and investing effectively in bicycling infrastructure and programs.

The report estimates bicycle trips, provides an overview of data types used to understand the demand for bicycling, including survey data and counts of bicyclists on transportation facilities. Methods used to estimate bicycle demand in Minnesota involved reviewing multiple sources of information, including Minnesota DOT (MnDOT) pilot field counts of bicycles, bicycle counts taken by local jurisdictions, trail user counts taken by the Metropolitan Council, estimates of rates of bicycle commuting in the U.S. Census Bureau's American Community Survey, estimates of bicycling frequency from the Metropolitan Council's Travel Behavior Inventory, and estimates of bicycling frequency from the MnDOT Omnibus Survey. Two methods were used to estimate the number of bicycle trips and bicycle miles traveled annually.

Method 1 uses data from the American Community Survey (ACS) and Travel Behavior Inventory (TBI), which are complementary surveys that provide different types of information about bicycling behavior. A series of steps are followed where the ACS data is first used to extract the number of workers and bicycle commuters for each county. The bicycle mode share is estimated for different regions of the state, and the TBI adjusts these rates. Various adjustments are then undertaken to account for data variability (e.g., bicycle commuters noted in ACS may not commute daily by bicycle, and estimation of the non-commuter bicyclists). These figures are aggregated at the county level to produce bicycle demand estimates.

Method 2 relies on data from the MnDOT Omnibus survey, which asked participants about their bicycling frequency. MnDOT conducts ride counts during the cycling season (April – October) and the number of bicycling trips is estimated by multiplying individuals in each response category of the Omnibus survey by the counts for the category. The sum is then calculated across all response categories. This approach does not include trips during late fall, winter, and early spring (five months). To estimate trips in these months, ratios of the TBI mode share for the seven-month (April – October) and five-month (November – March) seasons are used.

Method 1 estimated 68.4 million bicycle trips in Minnesota in 2014, while Method 2 estimated 28.4 million bicycle trips for the same year. The report states that the two methods are not directly comparable due to differences in the survey questions and methods.

The differences in results were attributed to several factors. First, the ACS and TBI surveys are designed to measure commuting or weekday trips, which undercounts bicycle trips made for purposes of recreation and fitness that disproportionately occur on weekends. Estimates based on the ACS and TBI data are therefore conservative. The use of the Omnibus survey, on the other hand, is more likely to include recreational trips, but potentially has other limitations, including sampling bias.

Vermont Agency of Transportation

Kaplan et al. (2021) described a multiphase project to develop a comprehensive improvement plan that identifies opportunities to enhance bicycle conditions on state roads designated high-use priority bicycle corridors. The report describes efforts of the first phase that focus on the categorization of state roads into high-, moderate-, and low-use corridors based on current and potential bicycle use.

The report addresses critical aspect of demand estimation for bicycle use, encompassing both transportation and recreational trips. Estimation of transportation trip demand considers land use information and the influence of each point on roadway segments to determine access for multiple destination types. This estimation process involves factors such as trip distance thresholds, destination access, trip frequency, access scores, and transportation use scores, which are calculated based on input from a crowdsourced interactive mapping tool. This tool — WikiMap — was used to gather input from the public on current and potential bicycle use, allowing users to identify common bicycling destinations and state roads they prefer to ride on and those they try to avoid. Users could also provide input by drawing new points and lines on the map, leaving comments on existing points or lines, and indicating support or disagreement with existing input through voting buttons. This tool was valuable for identifying active interest in bicycling riding and potential demand for improvement in bicycle infrastructure.

The estimation process uses Enhanced-911 (E-911) data to identify land use information and associated destination types. The area of influence for each land use was determined based on a typical riding distance for associated destination types, and the trip frequency of each destination was calculated to determine how much access each segment of roadway to different destination types.

NHTS data are compared to Vermont subset for bicycle trips and Strava data. Strava data were used to estimate recreation trips as it provides information about where people are currently riding or where they would like to ride if the roads were more accommodating. Strava data are used to estimate recreational trips as the number of riders on a road is often proportional to the number of rides captured by the Strava app. This information provides insight into current and potential recreational bicycle use, which informs the demand estimation process. Overall, the E-911, Strava and NHTS data are valuable for demand estimation and transportation trip demand, while the WikiMap dataset contributed to the calculation of a bicycle use score.

Texas DOT

Turner et al. (2019) focused on enhancing the collection, analysis, and availability of pedestrian and bicyclist count data in Texas. They reviewed approaches related to the use of crowdsourced data sources, from platforms like Ride Report and Strava Metro, to supplement traditional pedestrian and bicyclist count data. They also addressed the limitations and potential biases of crowdsourced data, offering guidance on scaling and integrating these data with traditional sources, such as the ACS and the Texas DOT Roadway Inventory.

The report describes methods for calculating pedestrian and bicycle demand. It explores the use of statistical analysis methods, such as linear regression, to analyze crowdsourced data. The authors also considered the relationship between facility type, trip purpose, and the use of crowdsourcing apps, highlighting the need for specific studies (i.e., intercept studies) to understand this relationship. Methods used to estimate pedestrian and bicycle demand include:

- Technical Count Data: A method based on the use of permanent counters, such as passive infrared sensors, inductance loops, or piezoelectric strips, to collect pedestrian and bicyclist count data. Such counters provide detailed information on the number of trips, mode, and direction of travel, which can be used to estimate demand.
- Crowdsourced data: Data from platforms like Strava Metro or Ride Report provide valuable insights into the spatial and temporal patterns of pedestrian and bicyclist traffic, particularly for recreational trips. The report highlights that these types of data may not be representative of all trip purposes or facility types and should be used with traditional count data.
- Statistical Analysis Techniques: Techniques like linear regression and the identification of key variables (e.g., functional classification, facility type) that influence the use of crowdsourcing apps were used to develop models to estimate demand.
- Comparison Analysis: A method that compares crowdsourced data to complete counts, focusing on key comparison statistics such as average percent deviation, absolute percent difference, and Pearson's correlation coefficient.

The report includes a case study that estimates total bicycle traffic on the Walnut Creek Trail North of Jain Lane in Austin, Texas. The case study utilizes crowdsourced data and statistical analysis techniques. The total bicycle traffic is estimated by combining crowdsourced counts from the Strava Metro platform with factors such as functional classification and nearby household income. Annual number of bicyclist activities logged via Strava in both directions, along with the density of households with a certain income level and functional classification of the trail, are used to estimate the total bicycle volume for this location. To calculate bicycle traffic volume for a given location, an appropriate regression equation is selected based on the functional classification and the density of households with high annual income in the area (above $200,000). That is because the study suggests that household income, while contributing to the proportion of bicyclists logging trips on Strava, is less important in models than Strava activity or functional classification, and a positive association with the number of bicycle trips recorded on Strava is observed only when there are households with income over $200,000 per year. In total, seven regression equations are presented. In the example provided, the equation for the functional classification of "Cycleway" (CLAZZ 81) is used:

$$\mathrm{AADB}_{\mathrm{WalnutCreek}} = 62 \times \mathrm{e}^{\mathrm{AADB\ Strava}_{\mathrm{WalnutCreek}}{}^{0.038}} \times \mathrm{e}^{\mathrm{Household{>}200K}_{\mathrm{WalnutCreek}}{}^{0.002}} \quad (1)$$

The values are then entered into an Excel spreadsheet to calculate the Average Annual Daily Bicyclist (AADB) traffic. For instance, with 45 Strava Metro trips and 0 high-income households in the example, the AADB at Walnut Creek is estimated at 343.

Other Reports

NCHRP Report 552

Krizec et al. (2006) provided a forecasting model for estimating bicyclists and pedestrian demand. Benefits were identified that can be used to establish a benefit/cost ratio. The report discusses strategies for estimating demand for several types of cycling facilities, which aim to assess user travel time, cost savings, reduction of traffic congestion, energy consumption, and air pollution. Also, it presents the challenges associated with predicting bicycling demand, illustrating the limitations of traditional demand modeling approaches.

The report's objectives include prediction of total bicycling in an area or on a facility, prediction of the marginal change in total demand resulting from changes in facilities or policies, and identification of areas where insufficient facilities limit bicycling potential, known as the *Latent Demand* approach. Their efforts utilize two approaches — one based on relationships between demand and underlying factors and can be transferable, another uses known demand data for an area but does not relate it to changes in the environment.

Some demand prediction models also use census commute-to-work shares, combined with other data, as a baseline for bicycle usage. Such models may compensate for unmeasured factors affecting demand. The analysis of adults and children in the report is separated, because of its focus which relies on the riding frequency as the measure of bicycling demand. The report notes that adults are less likely to ride than children, regardless of the time frame considered. The probability of people cycling is based on proximity to a bicycle facility and the assumptions made regarding the demand estimation:

i. Existing commuter cyclists near the new bicycling facility will shift from some other facility to the new one.
ii. The new facility will bring a certain number of new cyclists based on the current number of cyclists.

A three-step process was used to estimate the demand. First, the number of existing bicycle commuters is estimated based on ACS data. Then, the total number of adult cyclists is calculated based on the attraction area of the facility type, and finally new commuters and cyclists are calculated based on facility type.

NCHRP Report 552 developed a simple, straightforward method to estimate bicyclist demand. It utilizes a combination of survey data, demand modeling, and simple modeling techniques to develop estimates of total bicycling levels in specific areas and predict changes in bicycling levels under different conditions. The emphasis on simplicity, clarity, and known ranges of accuracy suggests the method is designed to be accessible and practical.

Direct-Demand Model: A Bicycle Suitability Model

Fagrant and Kockelman (2016) developed a direct-demand model for estimating peak-period cyclist counts based on trip generation and attraction factors. It is a suitability model that identifies locations where the presence of cyclists is likely to be the greatest and/or locations with potential for cycling enhancement, based on roadway conditions and several other factors. A Negative Binomial (NB) model was used to estimate the dependent peak-hour bicyclists counts at urban intersections, based on the following factors:

- Presence of separated bike paths (highest impact)
- Employment/destinations (for trip attraction)
- Population (for trip generation)
- Motorized vehicle speeds and counts
- Residential/commercial areas
- Morning/afternoon riding
- Speed limit on the road
- Road shoulder width

The authors collected bicyclist count data at 251 intersections in the Seattle metropolitan area. Intersections included those in commercial areas, as well as those on bridges near bike trails and recreational areas like parks or arenas, and in residential areas. The method involves implementing a statistical model that utilizes Poisson regression count models and a NB model to estimate cyclist counts.

The model identifies several variables that significantly influence cyclist counts at urban intersections, including:

- Population and Employment Densities: Areas with higher population and employment densities tend to have higher bicyclist counts.
- Roadway Conditions: Locations with bridges, access to bicycle trails, and wider curb lane widths have higher bicyclist counts.
- Roadway Speed: Expected counts are highest around a certain speed and decrease as speed becomes moves away from that speed.
- Separated Paths: Across all models formulated, the presence of separated paths is associated with significantly higher cyclist counts, indicating that the availability of dedicated cycling infrastructure influences bicyclist behavior and counts.

However, the model has limitations:

- Lack of heavy vehicle percentages and pavement condition data
- Time lag between Google Earth images and manual cycling counts
- Missing traffic volume data
- Influence of specific locations used in the analysis, which may not be representative of all intersections
- Need for additional variables (e.g., weather conditions).

Spatial Varying Coefficients Regression Model

Wang et al.'s (2021) study on modeling bike-sharing demand used a regression model with spatially varying coefficients to account for spatial heterogeneity in the relationships between independent variables and bike-sharing demand. They use data from the BIXI bike-sharing system in Montreal, Canada, and trip records for May – October of 2019. Trip records included six attributes for each trip: origin and destination, departure and arrival time, trip duration, and membership information. The model's captures the varying effects of factors on bike-sharing demand across different catchment areas. The model incorporates the following variables:

- Dependent Variable: Bike-sharing demand at each station
- Independent Variables: Population, commercial establishments, services, government facilities, parks, universities, public transportation infrastructure, walkability, road length, cycle paths and station capacity.

Coefficients for all stations are estimated by minimizing the sum of squared errors. Coefficients for each station vary, and the graph regularization approach ensures nearby stations have similar coefficients. The equation used for the final estimation is:

$$y = x^{T} \times \beta \qquad (2)$$

where:

- y = predicted bike-sharing demand for station i
- x^{T} = vector of independent variables for station i,
- β = vector of coefficients for station i.

A hyper-parameter tuning is performed to optimize the performance of the regression model with graph regularization. During the hyper-parameter tuning process, the Root Mean Square Error (RMSE) is used as a measure of the model's predictive performance. The RMSE is calculated for the demand prediction on the validation set, and enables comparisons of different combinations of hyper-parameter values and identification of optimal settings that result in the most accurate predictions of bike-sharing demand.

The graph regularization model had the lowest RMSE and the highest R-squared values for predicting bike-sharing demand during the afternoon peak hours, compared to other machine learning models, such as graph regularization with linear regression, random forest, and support vector machine regression models. However, there are some limitations:

- Limited set of factors that may affect the bike-sharing demand. Additional factors could be considered (e.g., events and holidays).
- The study only focuses on the BIXI bike-sharing system in Montreal, Canada, and the results may not be generalizable to bike-sharing systems in different cities.

<u>The Bikeability Index</u>

Munira and Zhang (2021) developed a direct-demand model for bicycle traffic in Austin, Texas. Data supporting the model were gathered from the following sources:

- City of Austin data portal
- 2017 American Community Survey
- City of Austin Planning and Development Review Department
- Texas Education Agency
- Austin Transportation Department Arterial Management Division
- Capital Metro
- "Bicycle" data portal
- City of Austin Transportation Department's Data and Technology Services
- Short-count (24-hour) bicycle data from the City of Austin Transportation Department
- Continuous Data from Eco-Counter

The authors used a NB model to estimate bicycle demand. They developed a comprehensive set of explanatory variables, including built environment features, demographic variables, and land use characteristics to estimate bicycle demand at the intersection level. Some of the independent variables relate to bicycle route length, comfort, connectivity, destination density, transit coverage, bike signals, and bike-accessible bridges. These variables capture and explain spatial variation of nonmotorized activity around each intersection — using different buffer widths — and to provide unique insights into the bicyclist travel behavior. A bikeability index was developed that measures the influence of explanatory variables on the environment's suitability for bicycling. This index captures the overall bike-friendliness of the network and serves as an excellent basic variable to be included in direct-demand models, in combination with additional variables, regardless of the area being investigated.

The study's results demonstrate the practical value of using the bikeability index to improve the performance of direct-demand models. The index in the model was a significant variable, indicating that it influences bicycle demand at the intersection level. However, there are some limitations:

- The study used parcel-level land use data to quantify the destination density of the bikeability index for the study area, which may not capture the attractiveness of destinations for bicyclists.
- Data collection covered only a limited number of locations, which may not be fully representative of the whole region.

Bicycle and Pedestrian Sketch Method

Griffin (2009) contrasted the simplicity and accessibility of the Bicycle and Pedestrian Sketch method with the potential complexities, data requirements, calibration challenges, and extensive data processing of other forecasting techniques. The proposed method is a simplified approach to forecasting bicyclist and pedestrian demand that leverages existing data sources and basic components of corridor-level estimation techniques. It is described as a post-model approach because it uses outputs from a travel demand model or recent traffic counts to estimate future demand. The method starts by assembling data sources such as the ACS for transportation modes and regional traffic assignments for base and forecast years. These data sources contribute to improved understanding of the current travel patterns and future traffic volumes. Forecasted automotive traffic volumes are used as a proxy for bicyclist and pedestrian trip demand in the absence of direct data on bicyclist and pedestrian traffic. Understanding the distribution and intensity of land uses helps with estimating the potential demand for active transportation modes considering factors like proximity to facilities, residential areas, and commercial spaces. Therefore, this method offers a practical and accessible way to estimate demand, especially in situations where detailed bicycle and pedestrian data may be limited. However, a travel demand model is needed as a starting point for this approach.

Bicycle and Pedestrian Forecasting Tools: State of the Practice

Aoun et al. (2015) gave an in-depth analysis of the current state of forecasting methods in pedestrian and bicycling planning. They emphasized the significance of considering the scale of influence and infrastructure, problem definition, and available data when choosing a forecasting tool, rather than assuming a one-size-fits-all approach for modeling pedestrian and bicyclist activity.

They provided an overview of simple methods used in forecasting pedestrian and bicyclist activity. These techniques include using activity levels at existing facilities to predict demand at new facilities, utilizing census data or surveys to model relationships between activity levels and contextual factors, and employing rules of thumb to estimate demand. Three levels of analysis are used that refer to the context of forecasting the pedestrian and bicycle facility. The first is the local level, where analysis is on a specific project or facility. The second is the corridor and sub-area level, where analysis covers a larger geographic area (e.g., corridor or sub-area in a city or a region). The third is the regional level, where the focus is on a larger geographic area, such as a metropolitan region or a state. These levels of analysis are important in determining the appropriate forecasting model as well as the level of detail required in data collection and analysis.

At the local level, Factors and Sketch Planning Tools offer the advantage of using existing or easily collectible data, enabling quick use for day-to-day needs such as grant applicants. However, these techniques may lack robust means of validating forecasts and exhibit limited accuracy because they do not to account for the location — or design — of specific attributes. Another drawback is that limited resources are allocated to their development.

In contrast, the corridor and sub-area level techniques, including network simulation and geospatial tools, generate more sophisticated models using attributes like land use and population densities. However, these methods may involve more intensive data collection efforts, be time- and resource-intensive to build, and require knowledge of and access to specialized software (e.g., ArcGIS).

At the regional level, regional travel demand forecasting models are used to forecast pedestrian and bicyclist activity levels along corridors. These models typically employ the traditional four-step process used for vehicle traffic and transit analysis: trip generation, trip distribution, mode choice, and traffic assignment. These models are typically used to plan and forecast roadway and transit networks, and they can be modified to incorporate bicycle and pedestrian models. However, they have significant drawbacks for planning pedestrian and bicycle facilities, such as relatively large traffic analysis zones that may not capture internal bicyclist/ pedestrian trips and a lack of the quality of the pedestrian and bicycle networks across a region. Figure 2.1 and Figure 2.2 summarize the forecasting model tools.

Table 3. Summary of Forecasting Model Tools

Method	Description	Advantages	Disadvantages
Local Level			
Factor Methods and Sketch Planning Tools *(see Table 4 for more information on these methods)*	Methods use existing bicycle and pedestrian count data, elasticities (or rules of thumb) to determine projections for new facilities	• Generally rely on data that already exist or can be collected with relative ease • Can be produced with limited software, relying mainly on spreadsheets • Suitable for practical day-to-day needs such as grant applications	• Can be difficult to validate forecasts because these tools are generally based on broad data sets or may not account for enough contextual factors
Aggregate Demand Models	Typically regression models that create an equation based on an existing data set, which would include bicycle/pedestrian data and influencing attributes such as population density, land uses, etc.	• Software requirements are usually limited to spreadsheets or standard statistical software packages • Can be created largely using existing data	• They do not take into account individual trip choices and factors • They may inaccurately correlate activity levels with adjacent land use • They are not always validated against count data not included in the model development
Bike Share Forecasting	Combine elements of Aggregate Demand Models, GIS and other spatial tools. The models apply GIS and other spatial tools to the areas surrounding existing bike share stations to compile demographic data and spatial relationships between bike share stations. These factors are then analyzed to develop a regression equation that describes observed ridership levels of existing bike share stations as indicated by station-level activity data collected by the system software.	• Existing ridership data is readily available • Demographic data is publicly accessible	• Demographic data may not reflect characteristics of "tourist" users, who frequently use bike share systems • Demographics of bike share users may not reflect broader community • Validity across data sets may not be adequate

Figure 2.1 Summary of Forecasting Model Tools — Local Level
Source: Aoun et al. (2015)

Method	Description	Advantages	Disadvantages
Corridor and Sub-area Level			
Network Simulation Tools	Uses a constructed network of links and nodes layered with other data to determine bicycle and pedestrian demand	• Adds greater sophistication to modeling efforts	• Data collection efforts can be arduous • May be time and resource-intensive to build model
GIS and Spatial Tools	Spatial modeling of built environments and proximities to determine activity levels	• Easy to update once the structure is built • Can be created using attributes like land use and population densities instead of existing count data	• Require specialized software and analysis knowledge such as ArcGIS, special extensions within ArcGIS like network or spatial analyst, and a working knowledge of tools within ArcGIS
Regional Level			
Regional Travel Demand Forecasting Models	Detailed, sophisticated models that typically employ the traditional four step process (trip generation, trip distribution, mode choice, trip assignment) to determine pedestrian and bicycle activity levels along corridors	• Regional models have been developed for all major urban areas (and thus existing travel survey data, population and employment estimates, and land uses have already been collected and analyzed) and can be modified. • Data/output from these models can be used as inputs for other models and can reduce the amount of new data and analysis that needs to be collected/ conducted.	• Conversion of existing vehicular-focused models to a pedestrian/ bicycle-scale may require significant effort. • Most regional models do not consider a "recreation" trip purpose, which comprises a significant number of pedestrian and bicycle trips. • These models require specialized software packages and expertise.
Activity and Tour-Based Models	Travel demand forecasting models that determine travel choice based on an individual's daily activity pattern in the form of trip "tours"	• Can account for effects of the built environment and travel behavior. • Output from these models can be used as inputs for others and can reduce the amount of new data or analysis that needs to be collected or conducted.	• Creation of these models is resource-intensive. • These models require specialized software packages and expertise.

Figure 2.2 Summary of Forecasting Model Tools — Corridor, Sub-Area, and Regional Levels
Source: Aoun et al. (2015)

Sobreira at al. (2023) assessed existing direct demand models and evaluates their spatial transferability for estimating annual average daily pedestrian traffic (AADPT) at signalized intersections in different jurisdictions. They applied six direct demand models to three locations (Milton, Canada; Pima County, Arizona; and Toronto, Canada) and conclude that the performance and transferability of five is effective for two reasons. The first is the similarity in pedestrian activity levels between Milton and the calibration jurisdictions where the direct demand models were originally developed. Two of the locations had low (Pima County) or very high (Toronto) pedestrian activity and thus the models did not fitting well. The second is the consistent site characteristics. Both the central tendencies and distribution of values of the explanatory variables for the sites in Milton are consistent with the range of values used to calibrate the models. They concluded that if pedestrian activity in the area being modeled is similar to the context in which the models were original developed, a model could perform better and be transferrable.

2.2 Benefit Estimation

Several researchers have estimated the impacts of bicycling and walking at the national and state levels. This section looks at studies that estimate the benefits of bikeshare systems and active transportation policies in urban environments and which account for variables such as traffic congestion, public health, and economies.

Möller et al. (2020) reviewed international literature on active transport and the cost and health benefits to understand which variables are the best predictors of the benefits of active transportation for projects in New South Wales, Australia. Key variables they identified include physical activity, air pollution and road transport injuries, all of which can be used to predict health outcomes of active transportation. However, evaluations of health measures require an in-depth review of epidemiological evidence and determination of specific health benefits. The level of effort required to accomplish this makes it a difficult approach for estimating health benefits. Hamilton and Wichman (2018) focused on how bikeshare systems influence traffic congestion by examining the effects of Capital Bikeshare in Washington D.C. The study used finely disaggregated traffic data from INRIX, focusing on city streets and arterial roads in Washington, D.C. Their methodology includes fixed effects models and other statistical techniques to establish a causal link between bikeshare availability and traffic congestion. They estimate a 4% reduction in congestion, which confers significant private and public benefits, namely environmental benefits associated with reduced congestion (e.g., lower emissions, improved air quality). In terms of safety Agarwal (2021) found that the introduction of a bicycle superhighway in Patna, India, led to a substantial increase in longer bicycle trips, resulting in the prevention of over 750 deaths annually, highlighting the potential health benefits as well as the potential to save billions in healthcare costs.

Abundant evidence demonstrates the health and economic benefits of walking and cycling. Thus, investing in infrastructure and policies which facilitate these behaviors can play a critical role in preventing deaths and generating positive health outcomes (Baker, Pillinger, Kelly, & Whyte, 2021). Gravett and Mundaca (2021) quantified the economic benefits of active transport policy pathways at the local level, using the city of Oxford, England, as a case study. They focus on benefits related to increased physical activity, which is considered an economic benefit due to its positive impact on public health, leading to reduced healthcare costs and fewer CO_2 emissions. An origin-destination matrix within an Aimsun Next model of Oxford representing traffic flows is utilized, with the result being a gross benefit that ranges from 3.45 to 11.28 billion euros over a 20-year period from 2030 to 2050 This includes economic benefits derived from the prevented premature deaths and avoided CO_2 emissions. Similarly, Rabl and De Nazelle (2012) analyzed the health benefits of physical activity, reduced air pollution for the general population, changes in air pollution exposure for individuals switching transport modes, and the impact of accidents. Using World Health Organization (WHO) data and employing a monetary valuation method of assigning monetary values to environmental benefits and health outcomes, their results indicate that the most significant benefit of this shift is the health improvement from physical activity, which outweighs the benefits of reduced air pollution for the general population. Gharibzadeh et al. (2024) reach the same conclusions examining active travel modes in Tehran, Iran. Their results emphasize the importance of promoting active transportation to improve health and achieve positive outcomes, particularly through increased physical activity.

Krizec (2007) conducted a meta-analysis of 25 previous studies to identify the economic benefits of bicycle facilities. The study documents direct benefits (mobility, health, and safety) and indirect benefits (decreased externalities, livability, fiscal) and concludes that the main benefits from investments in bicycle infrastructure facilities are higher property values, tourism revenue, job creation, health improvement and air pollution reduction. Li et al. (2014) performed a comprehensive cost-benefit analysis of added cycling facilities. The most notable and important benefits include health and economic benefits, reduced congestion, environmental sustainability, and safety improvements. The study also provides a structured method for evaluating the economic impacts of added facilities, which includes identifying associated benefit components; estimating capital, construction, maintenance, and operating costs; quantifying benefits; and conducting a cost-benefit analysis and sensitivity analysis to evaluate how changes in key variables affect outcomes. They applied this method to a case study to demonstrate the cost-benefit analysis framework.

FHWA and State DOT Efforts

<u>Federal Highway Administration</u>

In 2016, the FHWA published a guidebook for developing bicycle and pedestrian performance measures (Connor et al., 2016). The guidebook outlines several ways that the impacts of walking and bicycling can be measured while highlighting data requirements and metrics for each respective measure. Each of the 30 performance measures are tied to one or more community goals, which are divided into seven categories: connectivity, economic, environment, equity, health, livability, and safety. A breakdown of the performance measures and community goals they contribute to are shown in Figure 2.3 and Figure 2.4.

PERFORMANCE MEASURES	GOALS						
	CONNECTIVITY	ECONOMIC	ENVIRONMENT	EQUITY	HEALTH	LIVABILITY	SAFETY
Access to Community Destinations	X	X	X	X	X	X	X
Access to Jobs	X	X		X			
Adherence to Accessibility Laws	X	X		X	X	X	X
Adherence to Traffic Laws					X		X
Average Travel Time	X	X		X		X	X
Average Trip Length	X	X		X		X	X
Connectivity Index	X	X		X		X	X
Crashes				X	X	X	X
Crossing Opportunities	X			X	X	X	X
Delay				X		X	X
Density of Destinations	X	X		X	X	X	X
Facility Maintenance	X			X		X	X
Job Creation		X					
Land Consumption		X	X			X	
Land Value		X					

Figure 2.3 FHWA Performance Measures Part A

PERFORMANCE MEASURES	GOALS: CONNECTIVITY	ECONOMIC	ENVIRONMENT	EQUITY	HEALTH	LIVABILITY	SAFETY
Level of Service				X		X	X
Miles of Pedestrian/Bicycle Facilities	X			X	X	X	X
Mode Split			X	X	X	X	
Network Completeness	X	X	X	X	X	X	X
Pedestrian Space		X		X		X	X
Person Throughput		X		X			
Physical Activity and Health				X	X	X	
Population Served by Walk/Bike/Transit	X			X	X	X	X
Retail Impacts		X					
Route Directness	X	X	X	X		X	X
Street Trees			X		X	X	X
Transportation-Disadvantaged Population Served	X			X			
User Perceptions					X	X	X
Vehicle Miles Traveled (VMT) Impacts			X		X	X	X
Volume			X		X		X

Figure 2.4 FHWA Performance Measures Part B

Many of the metrics suggested for these performance measures require site-specific counts or surveys, travel demand models, databases that are updated on an annual basis (e.g., American Community Survey, property value databases), or data from user tracking apps. The lack of readily available data limits the number of performance measures that can be applied to conduct a statewide screening of bicycle and pedestrian improvements, especially at the planning stage of a project. However, several performance measures can be evaluated with metrics that can be obtained either from KYTC, other readily available data, or collected from other sources at the project level. Performance measures and their associated metrics are summarized below.

- Access to Destinations
    a. Proportion of residences within a ½-mile walking distance or 2-mile biking distance to specific key destinations, including commercial, educational, administrative, and recreational locations.
    b. Proportion of residences within ½-mile walking distance or 2-mile biking distance to specific key destinations along a completed pedestrian or bicycle facility.
- Access to Jobs
    a. Total number of jobs that may be accessed in less than 30 or 45 minutes using walking, bicycling, or transit.
- Crashes
    a. Number of bicycle-involved and/or pedestrian-involved crashes over 5 years.
    b. Number of fatal or serious injuries of bicyclists and/or pedestrians over 5 years.
- Crossing Opportunities
    a. Linear distance along a corridor between legal crossing opportunities.
    b. Linear distance along a corridor between marked crosswalks.
    c. Linear distance along a corridor between signalized crossings (or roundabouts).
- Miles of Pedestrian/Bicycle Facilities
    a. Total miles of bicycle facilities.
    b. Miles of bicycle facilities added.
    c. Total miles of sidewalks.
    d. Miles of sidewalks added.
    e. Total miles of multiuse paths.
    f. Miles of multiuse paths added.
- Pedestrian Space
    a. Width of sidewalks in a corridor or given area.
    b. Effective sidewalk width (or clear width) — measures the amount of space available for walking after accounting for street furniture and other obstacles, adjacent curbs, or adjacent buildings. Calculation is in the *Highway Capacity Manual*.
- Population Served by Walk/Bike/Transit
    a. Percent of population within a ½-mile walking distance or 2-mile biking distance to a transit stop.
    b. Percent of population within a ¼-mile network distance to sidewalk, trail, or bike facility.
    c. Percent of transit stops that are accessible to persons with disabilities.
- Street Trees
    a. Tree canopy coverage for the jurisdiction or a given area calculated using aerial imagery or Lidar data.
    b. Total number of street trees in a site plan, small area, or jurisdiction.
    c. Spacing of street trees (can be applied as a standard).
    d. Number of street trees per roadway mile.
- Transportation — Disadvantaged Population Served
    a. Percentage of transportation-disadvantaged population within a ½-mile walking distance or 2-mile biking distance to a transit stop.

b. Percentage of transportation-disadvantaged population within a ¼-mile walking distance to sidewalk, trail, or shared use path.
c. Percentage of transportation-disadvantaged population within 1/2-mile bicycling distance to on-street bicycle facility.
d. Percentage of transit stops that are accessible (boarding/alighting connected to sidewalk).
e. Percentage of transportation-disadvantaged population within a 2-mile biking distance to an off-street bicycle facility.

Agencies may track changes over specified timeframes (e.g., annually or every two years) to pedestrian and bicycle facilities, such as portion of space dedicated to pedestrians through the addition of sidewalk, roadway widening, expansion of parks and/or pedestrian plazas, addition of bicycle lanes, conversion to cycle tracks, addition of bicycle signals, and so forth.

U.S. Department of Housing and Urban Development

Levitt (2016) provided guidance and resources for creating integrated and sustainable communities that prioritize walking and cycling as viable transportation options. Key benefits of these transportation modes for individuals, communities, and society are highlighted as they underscore the importance of creating walkable and bikeable communities to improve the well-being of residents. These include health, safety, environmental, economic benefits, and quality of life benefits. Also, the report discusses metrics used to measure walkability and bikeability in communities. Nine core metrics are provided for that purpose:

1. Diversity of Land Uses within a 5-minute Walk (0.25 mile): Measures the variety of destinations within a short walking distance to promote mixed land uses and reduce the need for car trips.
2. Number of Jobs within 15 minutes (Walk/Bike): Evaluates accessibility of job opportunities within a 15-minute walking or biking radius to support active transportation and reduce commute times.
3. Percentage of Arterial and Commercial Collector Roadways with a Low Level of Traffic Stress: Focuses on the proportion of major roadways with low traffic stress levels to create safer, more comfortable walking and biking environments.
4. Percentage of Residents and Workers within a 0.25 mile of High-Quality Bike Facility: Assesses the proximity of residents and workers to high-quality bike facilities to encourage cycling as a mode of transportation.
5. Street Network: Evaluates the connectivity and layout of the street network to ensure easy access for pedestrians and cyclists to multiple destinations.
6. Site Access and Parking Topology: Examines the design and accessibility of site access points and parking facilities in commercial areas to promote walking and biking as viable transportation options.
7. Percentage of Corners with Curb Ramps: Measures the percentage of streets equipped with sidewalks to enhance pedestrian safety and comfort.
8. Distance of Corners with Curb Ramps: Assesses the presence of curb ramps at street corners to improve accessibility for individuals with mobility challenges (e.g., wheelchair users).
9. Distance Between Marked Crossings: Measures the spacing between marked crosswalks to ensure pedestrian safety and convenience in crossing streets.

The report outlines supplementary metrics that complement the core metrics. These metrics provide insights on the pedestrian environment and are classified in two categories:

1. Outcome metrics: Quantitative metrics that can be tracked over time and assess progress in improving walkability and bikeability (i.e., bicycle and pedestrian counts, crash data analysis, mode share data, economic impact assessment).
2. Actions and Initiatives: Qualitative metrics that focus on specific actions or initiatives undertaken to enhance walkability and bikeability (i.e., implementation of Complete Streets policies, installation of bike lanes and pedestrian infrastructure, community engagement events and programs, educational campaigns on pedestrian safety).

Victoria Transport Policy Institute

Litman (2024) evaluated the impacts of policies and projects that promote active transportation modes, which are commonly referred to as non-motorized transit. The report discusses methods to estimate the demand for active transportation facilities, including updating travel demand models to include active transportation users and leveraging national and local travel surveys to gauge public perception and practices relating to non-motorized transit. Additionally, the author lists strategies to increase walking and cycling activity through public policies and programs. Detailed values for identified benefits are presented in Appendix B.

Most applicable to Kentucky's needs, the study outlines costs and benefits associated with active transportation modes. Impacts include direct benefits to users and benefits that accrue to society from increased walking and cycling activity, reduced motor vehicle travel, and more compact and multimodal community development. The benefits — synthesized from previous studies in the U.S. and Canada — span seven major categories: safety, mobility, health, economy, environment, social, and user satisfaction. Each benefit is quantified using a separate data source or data collection procedure. A portion of the identified benefits are quantifiable in terms of dollars, such as reduced travel time, vehicle cost savings, and pollution reduction, among others. However, many of these financial benefits are based on studies dating back to as early as 1995 and may require methodological revision before they are applied to Kentucky's bicycle and pedestrian facilities.

USDOT

The USDOT is updating its *Benefit-Cost Analysis Guidance for Discretionary Grant Programs* (2023), which provides detailed instructions and methods for conducting benefit-cost analyses of transportation projects to ensure consistency and accuracy in evaluating the economic impacts of proposed investments. It emphasizes the importance of monetizing benefits and costs, a process that involves assigning a monetary values to projected project outcomes, allowing for a direct comparison of benefits and costs. The guidance recommends using real dollars, adjusted for inflation, to reflect the purchasing power of a specific base year (e.g., 2022 dollars for application submitted in the Fiscal Year 2024). Standardized values for different benefits and costs and using Gross Domestic Product (GDP) to convert nominal dollars into real dollars is recommended for robust benefit-cost analysis. The categories of benefits associated with transportation projects include:

1. Safety Benefits
2. Travel Time Benefits
3. Operating Cost Benefits
4. Emissions Reduction Benefits
5. Health Benefits
6. Environmental Benefits
7. Social Benefits
8. Economic Development Benefits

Recognizing the significance of monetization and quantification when assessing benefits, the report outlines methods for evaluating these categories of benefits, wherever possible. Specifically:

1. Safety benefits are assessed based on reduction in crash risk, injuries, and property damage.
2. Travel time savings are quantified by estimating the impact on user travel times.
3. Operating cost savings are determined by reductions in fuel consumption and maintenance expenses.
4. Emissions reduction benefits are valued for their environmental and health improvements.
5. Health benefits can be quantified by estimating reductions in air pollution–related illnesses, calculating changes in physical activity levels due to improved infrastructure, evaluating noise reduction effects, and estimating reductions in traffic-related injuries and fatalities.
6. Environmental benefits can be quantified by estimating emissions reductions and by calculating the value of improved air quality in terms of health benefits.
7. Social benefits quantification methods may include measuring improvements in access to transportation services for underserved populations, assessing changes in travel time and reliability for different demographic groups, and estimating the overall enhancement of quality of life for communities affected by the transportation project.
8. Economic development benefits can be quantified by estimating the direct and indirect economic impacts of the project on employment, assessing changes in property values near transportation infrastructure, evaluating the potential for increased business activity and investment, and estimating the overall economic growth and development.

Several metrics require data collection before and after project completion or modelling possible solutions. As such, they may not be applicable at the planning level.

<u>Florida DOT</u>

Eluru et al. (2018) conducted a cost-benefit analysis for SunRail system to assess its economic impact, societal benefits, and overall effectiveness in the region's meeting transportation needs. System benefits encompass a range of valuable outcomes that contribute to economic savings, environmental sustainability, and enhanced quality of life for residents:

1. Personal Automobile Cost Savings
2. Crash Cost Savings
3. Emissions Cost Savings
4. Parking Cost Savings
5. Assessed Property Value Increase

The approach followed for monetizing these benefits follows:

1. Personal Automobile Cost Savings can be monetized by:
    a. Calculating the average cost of owning and operating a vehicle, including expenses like fuel, maintenance, insurance, depreciation, and parking fees.
    b. Estimating the reduction in vehicle usage due to the availability of the SunRail System using a set rate for savings per vehicle.
2. Crash Cost Savings can be monetized by:
    a. Assessing the economic impacts of traffic accidents, including medical expenses, property damage, emergency response costs, and lost productivity.

    b. Using methods to estimate reduction in crash frequency and severity associated with increased public transit usage.
3. Emission Cost Savings can be monetized by:
    a. Evaluating the societal cost of greenhouse gas emissions and air pollution, considering factors such as health impacts.
    b. Quantifying the reduction in emissions resulting from modal shifts to the SunRail system.
4. Parking Cost Savings can be monetized by:
    a. Analyzing the average cost of parking in the areas served by the SunRail system, considering both on-street and off-street parking rates.
    b. Estimating reductions in parking demand due to increased public transit ridership.
5. Assessed Property Value Increase can be monetized by:
    a. Examining the real estate market data to determine premiums associated with properties located near transit stations or along transit corridors.

Texas DOT

The Texas A&M Transportation Institute analyzed the economic impacts of bicycling in Texas (2018) by using industry reports, economic data, health studies, transportation analyses, and specialized tools, such as the Health Economic Assessment Tool (HEAT), to quantify the economic impact of bicycling activities in five key areas:

1. Tourism and Recreation: Analyze visitor spending patterns and estimating the direct, indirect, and induced economic effects of visitor expenditures.
2. Manufacturing, Wholesale/Distribution and Retail: Assess increased demand for bicycles, accessories, and related products due to higher bicycling activity.
3. Capital Construction Spending: Evaluate job creation, local spending, and overall economic stimulus generated by investments in bikeways, bike lanes, and related infrastructure.
4. Health Benefits: Use HEAT, which calculates the monetary value of health benefits by analyzing factors like duration, distance, and trip inputs to estimate the annual benefits from reduced health risks through bicycling activities.
5. Mobility: Assess factors like reduced travel costs, improved accessibility, and efficiency gains in the transportation system.

Most of these metrics require data collection before and after a project and may not be applicable at the planning level.

Colorado DOT

The Colorado DOT evaluated the economic and health benefits of bicycling and walking in the state (BBC Research & Consulting, 2016). Economic benefits, along with the data for quantifying them, include the following categories:

1. Household Spending: Data on consumer expenditures for bicycles, accessories, maintenance, and related services are used to quantify the economic impact of bicycling.
2. Bicycling retail and manufacturing: Revenue data from local businesses involved in bicycle retail and manufacturing help assess the economic value generated by these sectors.
3. Tourism: Information on tourism revenue from biking events, tours, and related activities, as well as data on visitor spending on biking-related tourism activities, can be leveraged to monetize the tourism impact of biking.

The health benefits of bicycling, along with their monetization process, include the following categories:

1. Healthcare Savings: Data resulting from improved health outcomes.
2. Productivity Enhancement: Data on productivity gains among individuals due to improved physical and mental well-being.
3. Mortality Rate Reduction: Estimated value of a statistical life saved through reduced mortality rates.

Most of these metrics require data collection before and after a project and may not be applicable at the planning level.

New York City (NYC) DOT

The NYC DOT (2012) established metrics to assess street projects and evaluate them to demonstrate how measuring outcomes can demonstrate advancements toward creating safe, livable, and economically vibrant streets. They identified three goals and associated performance indicators to evaluate project success. These goals encompass designing for the safety and inclusivity for all street users and creating great public spaces while maintaining the flow of traffic. Each goal can be evaluated through targeted strategies:

1. Design for Safety through:
    - Designing safer streets to provide safe and attractive options for all street users.
    - Reducing delay and speeding to support faster, safer travel.
2. Design for all users of the street through:
    - Designing safer streets to provide safe and attractive options for all street users.
    - Improving bus services.
    - Reducing delay and speeding to allow for faster, safer travel.
    - Optimizing parking and loading processes for efficiency.
3. Design great public spaces through:
    - Designing safer streets to provide safe and attractive options for all street users.
    - Building great public spaces to create economic value and neighborhood vitality.

Proposed metrics include crashes and injuries to motorists and other vehicle occupants; pedestrians, cyclists, and motorcyclists vehicle volumes; bus passengers, bicycle riders, and users of public space; traffic speeds, with the aim of regulating traffic to ensure it moves efficiently without being excessively slow or fast; and economic vitality, including growth in retail activity, user satisfaction, and environmental and public health benefits.

Kansas DOT

The Kansas DOT (WSP, 2022) documented and quantified the economic benefits of active transportation investments in the state. Analysis aimed to provide a comprehensive understanding of the impact active transportation projects have on economic growth, public health, tourism, and environmental sustainability. These benefits are assessed based on four primary benefit classes:

- Tourism/Events: Derived from spending associated with tourism in areas where active transportation events attract visitors, including both Kansas residents and out-of-state visitors. Considers direct expenditures on lodging, food, equipment rentals, transportation to sites, and potential indirect benefits from these expenditures. Events encompass organized bike rides or races, trail rides, foot races, and other activities focused on active transportation.

- Retail: Focused on direct sales of equipment related to active transportation, such as from bike shops, outdoor recreation stores, and running stores. These benefits are calculated based on the estimated usage and purchasing habits of typical active transportation consumers.
- Transportation: Derived from the benefits of utilizing active transportation instead of driving a car. These include the following categories:
    - Safety: Benefits related to active transportation facilities are quantified through a systematic crash analysis methodology using Crash Modification Factors (CMFs).
    - Health: Estimated based on factors such as increased physical activity from active transportation trips, reduced healthcare expenditures due to a more active lifestyle and improved overall well-being. Analysis may consider several factors, such as:
        i. Average Active Transportation Trip Lengths: To estimate the amount of physical activity individuals engage in during these trips.
        ii. Induced Active Transportation Trips resulting from Investments: Additional trips that may be generated due to the presence of new facilities or enhancements.
        iii. Proximity of Facilities to Residential, Commercial, and Retail Areas: Analyzing the spatial distribution of facilities and their proximity to key destinations can inform estimates of potential health impacts associated with improved access to active transportation options.
    - Environment: Assessed by analyzing the reduction in vehicle miles traveled (VMT), which reduces emissions and noise pollution.
    - Economy: Reduced operating and maintenance costs are calculated by considering the reduced wear and tear on vehicles and roadways due to less vehicle usage.
    - Mobility: Travel time improvements quantified by assessing the impact of active transportation facilities on reducing congestion, enhancing connectivity, and providing efficient travel options.
- Facility Access: Benefits based on a proposed facility's integration with existing active transportation infrastructure, impact on property values, population levels, and land use patterns within certain proximity of the facility.

Safety benefits were estimated using statewide crash data to calculate average crash rates for different types of facilities in rural areas, small- to medium-sized towns, and large urban areas. Crash rates were used to predict the safety benefits of installing different types of active transportation facilities, considering reductions in bicycle and pedestrian crashes as well as single-vehicle and vehicle-vehicle crashes. They used CMFs tailored to the facility added, such as bicycle infrastructure, multiuse trails, on-street bicycle and pedestrian facilities, and road infrastructure with pedestrian facilities. This allowed for incorporating crash reduction potential into the analysis, simplifying the process of estimating safety benefits. Table 2.1 presents the CMFs for all crashes and for bike and pedestrian crashes for each active transportation project type.

Table 2.1 CMFs for Crash Type and Project Type

Active Transportation Project Type	CMF — All Crashes	Bike/Ped Crash CMF
Bicycle infrastructure only	0.72	0.55
Off-Street Multi-Use Trails	1.00	0.45
On-Street Bicycle and Pedestrian Facilities (Without Road Construction)	0.78	0.50
Pedestrian Infrastructure Only	0.79	0.45

Active Transportation Project Type	CMF — All Crashes	Bike/Ped Crash CMF
Road Infrastructure with Bicycle and Pedestrian Facilities	0.70	0.41
Road Infrastructure with Pedestrian Facilities	0.72	0.43

Kansas DOT also developed an accompanying tool that can develop a benefit-cost ratio for a project. Use of the tool could be beneficial, but it relies heavily on Kansas-specific data and requires data collection on different economic activities if it were to be calibrated for use in Kentucky.

<u>NCHRP Report 552</u>

Krizec et al. (2006) developed a method to measure and forecast recreational and commuter cyclists with the introduction of a new bicycle facility and a method to quantify the societal benefits of a new bicycle facility. The overall bicycle facility benefit, presented in terms of dollars, consists of four benefit categories: mobility, health, recreation, and reduced automobile use. A breakdown of the benefit calculations for benefit categories is presented below.

$$\text{Annual Mobility Benefit}(\$) = \text{M} * \frac{\text{V}}{60} * (\text{Existing Cyclist Commuters} + \text{New Cyclist Commuters}) * 50 * 5 * 2 \quad (3)$$

- M = Time in minutes (commuters willing to spend 20.38 min on off-street bike trail, 18.03 min using on-street bike lane with no parking, 15.83 min using on-street bike lane with parking)
- V = Hourly value of time (assumed at $12 in the report)
- 50*5*2 is the number of annual commute trips (50 weeks, 5 days/week, 2 commutes/day)

$$\text{Annual Health Benefit}(\$) = \text{Total New Cyclists} * \text{B} \quad (4)$$

- B = Annual benefit of physical activity, reported at $128 based on the median of 10 studies in the NCHRP Report 552

$$\text{Annual recreation benefit}(\$) = \text{D} * 365 * (\text{New Recreational Cyclists} - \text{New Cyclist Commuters}) \quad (5)$$

- D = Value of benefit recreational cycling provides, which is $10 according to the NCHRP Report 552

$$\text{Reduced Auto Use Benefit } (\$) = \text{New Cyclist Commuters} * \text{L} * \text{S} * 50 * 5 \quad (6)$$

- L = Average round-trip length of commute (miles)
- S = Congestion and pollution savings/mile ($0.13 for urban, $0.08 for suburban, and $0.01 for rural, as reported in NCHRP Report 552)

Krizec et al. (2006) also developed a tool to automate the calculation of all relative bicycle demand, costs, and benefits highlighted in the research, however, that tool has since been taken offline.

2.3 Summary

Researchers identified multiple bicycle demand forecasting techniques that have different levels of complexity. Most state-level efforts have used local data to develop demand prediction models, (e.g., Minnesota, Vermont, Texas).

Other efforts have relied on bike share data to generate demand models or developed a bikeability index to understand demand. All these efforts demonstrate that local data are needed to develop models to accurately capture the local demand. Of the efforts reviewed, the Krizec et al. (2006) approach could be most easily adapted for Kentucky since it is based on population estimates within a range of the facility and the percentage mode share of current commuter bicyclists to derive anticipated demand.

Few models have been developed for pedestrian demand. Aoun et al. (2015) summarized previous efforts, which assessed activity levels at existing facilities to predict demand at new facilities, used census data or surveys to model relationships between activity levels and contextual factors, and employed rules of thumb to estimate demand. Most of these approaches require specific knowledge of project designs and thus may not be easily applicable during a project's early stages.

Previous studies highlighted the positive impact of bicycle and pedestrian facilities on public health, with increased physical activity and reduced healthcare costs being significant outcomes. Additionally, economic benefits such as enhanced property values, tourism revenue, and job creation are evident, while environmental benefits are consequential as well.

Chapter 3 Recommended Approach

3.1 Bicycle and Pedestrian Demand and Benefit Tool

Krizec et al.'s (2006) model for predicting bicycle demand is relatively straightforward and feasible to implement because it does not require extensive data collection — only data on the number of people within specified distances of a proposed facility and existing bicycle commuter mode share for a locality. Krizec et al. (2006) also outlined a process for estimating benefits associated with bicycle facilities. Even though their bicycle facility benefit-cost tool is no longer available, NCHRP Report 552 thoroughly describes the calculations. Using this information, the research team recreated the tool with updated values to reflect 2024 conditions.

Researchers developed a method for estimating the number of people within, 0.25, 0.50, 0.75, and 1.00 miles of bicycle and pedestrian facilities and applied it to SHIFT 2024 projects with a pedestrian and/or bicycle component. The tool was applied to bicycle-only projects to estimate demand for proposed facilities and their associated benefits.

Population Estimating Process

The research team devised a GIS-based process to estimate the number of people living within 0.25, 0.50, 0.75, and 1.00 miles of bicycle facilities. This information can then be used to model bicycle demand.

All 2024 SHIFT projects with a pedestrian and/or bicycle component were plotted using the route identification (RSE_ID) and the beginning (BMP) and ending (EMP) mile points. Buffers were delineated for 0.25, 0.50, 0.75 and 1.00 miles from the centerline of each project (

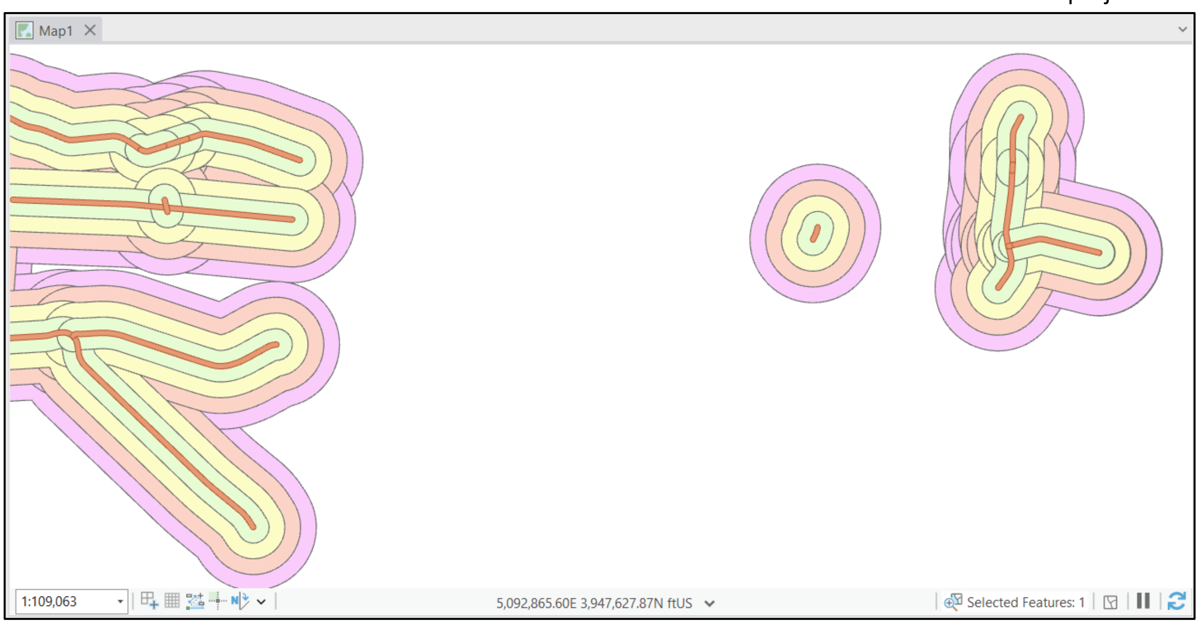

Figure **3.1**).

Block-level population data from the 2020 U.S. Census were used to estimate populations within each buffer. Using the TIGER2020 geodatabase, population and roadway information were joined using the GEOID field. The area of each census block was calculated and a ratio of buffered area to block used to calculate population within the buffers. All four overlaid layers were exported into an CVS file that was converted into an Excel file. This provides the foundation for calculating the covered population in each Census block, however, the method assumes populations are distributed homogeneously within census blocks. A step-by-step process is presented in Appendix C.

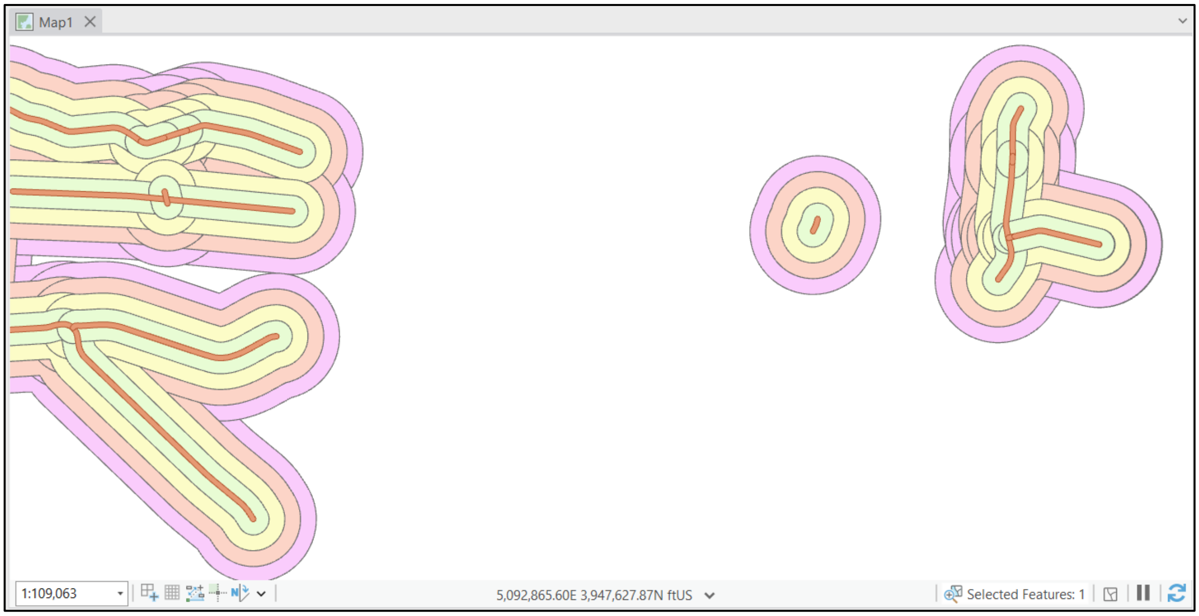

Figure 3.1 Example of Buffers Surrounding a 2024 SHIFT Project

Bicycle Demand and Benefit Estimation

Th KTC Bicycle and Pedestrian Demand and Benefit spreadsheet tool estimates bicycle demand and benefits and looks at population estimates around each project at 0.25-, 0.50-, 0.75- and 1.00-mile buffers. Krizec et al. (2006) estimated bicycle demand based on the population surrounding each bicycle facility within 400 m, 800 m and 1600 m buffers. They also considered three facility types: off-street bicycle trail, on-street bike lane with parking, and on-street bike lane without parking. To reflect current bicycle facility typology, off-street bicycle trail was assumed to be a cycle track or separated bicycle lane, and the on-street bike lane with parking was converted to use of sharrows.

Researchers determined that a separated bicycle lane will attract users from up to 1.00 mile away, so the 1.00-mile buffer population is used in the spreadsheet to estimate demand and benefits for a proposed cycle track or separated bicycle facility. Researchers assumed that on-street bicycle facilities will attract users within 0.50 miles of the facility, and sharrows will attract users within 0.25 miles of the facility. The tool can be modified to change population buffers applied if assumptions change.

The spreadsheet uses Equations 7 through 12. The KTC Bicycle and Pedestrian Demand and Benefit spreadsheet tool uses, when available, commuter shares for the project area. If these are not available, the Kentucky bicycle commute rate (0.5%) is used to estimate total adult cyclists. Once demand is estimated, the benefits of a proposed bicycle facility are calculated using Equations 3 – 6. The tool uses the same benefit calculations suggested by Krizec et al. (2006), but the dollar amounts are adjusted to 2024 dollars to reflect changes in the consumer price index since 2006.

Pedestrian Demand and Benefit Estimation

The spreadsheet uses a modified version Krizec et al.'s (2006) Equation 7 to estimate pedestrian commuters. Instead of using the bicycle commuter share percentage to estimate daily existing bicycle commuters, the pedestrian commuter share is substituted to estimate daily existing pedestrian commuters. The statewide pedestrian commuter rate is 2% according to the American Community Survey. Since pedestrian trips are typically shorter than bicycle trips, the spreadsheet uses a 0.25-mile population buffer for all pedestrian facility demand estimations. Users of the spreadsheet can also use the longer distances (i.e., 0.50-, 0.75-, and 1.0-mile buffers) for estimating the pedestrian demand based on their local conditions and knowledge of the project context. Equations 8 – 10 in Krizec et al. (2006) estimate total existing daily cyclists and are calibrated based cyclist data, meaning they cannot be modified to estimate total daily pedestrian activity. As such, the research team used the average walking trip share in Kentucky from the American Community Survey (6.8% in 2022) to estimate overall pedestrian demand. The spreadsheet multiplies the walking trip share by the 0.25-mile (or user-selected distance) population buffer to estimate total daily pedestrians. Equations 11 and 12 from Krizec et al. (2006) are used to forecast new cyclist commuters and total cyclists using estimated commuter and total bicycle demand. These equations are not cyclist-specific and can be applied to the pedestrian commuter and overall pedestrian demand estimates to forecast the number of future pedestrian users for a given facility.

Litman (2024) provides estimates for monetary benefits of active transportation, with benefits grouped into four categories: Improved Active Transport Conditions, Increased Physical Activity, Reduced Auto Use, and Community Impact. Each category has a dollar amount per person-mile benefit that differs for urban and rural locations. These benefits are reported in Appendix B. The spreadsheet applies benefit estimates to pedestrian trips estimated using the modified Krizec et al. (2006) method to quantify monetary benefits for proposed pedestrian facilities, assuming an average trip length of 1.0 miles.

Example Application

The following example demonstrates the spreadsheet and provides the foundation for identifying potential areas of future research. The project selected is along US 127 and involves adding a bicycle lane on the shoulder of roadway. The project extends from Liberty to the Lincoln County line and encompasses sections with mile points 0.000-10.686 and 15.500-23.715 (Figure 3.2).

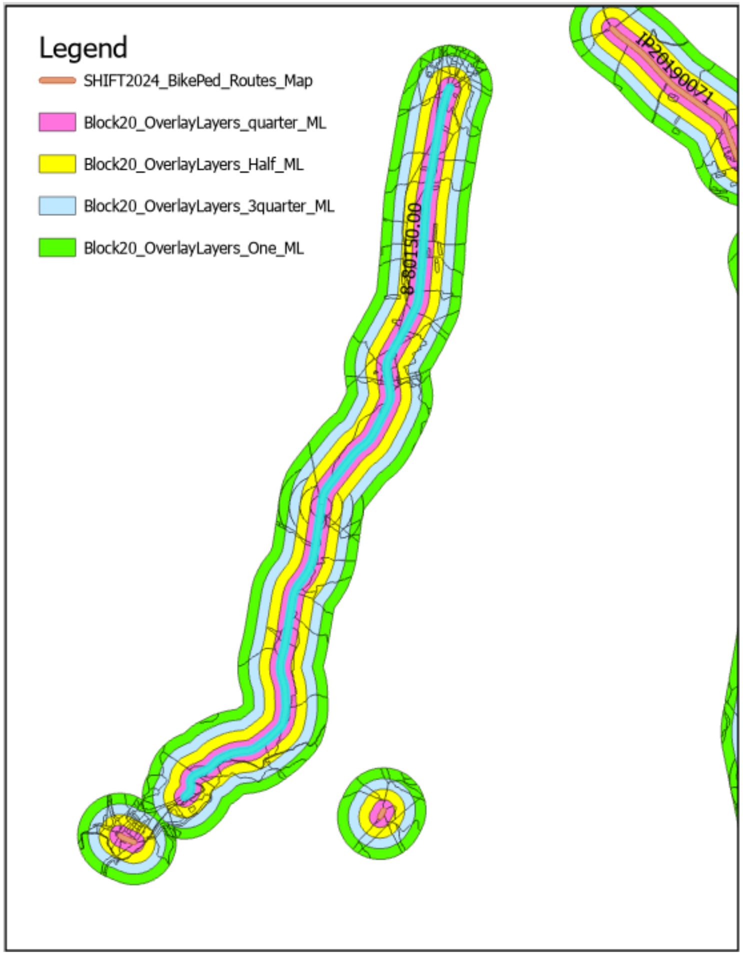

Figure 3.2 SHIFT 2024 Project 8.080150.00

The bicycle lane on the shoulder is treated a bicycle lane in the model. This example uses a 0.50-mile population catchment area, which results in a population of 2,838. No detailed information on the percentage of commuter cyclists for this area is available and thus the default 0.5% for the state is used. The resulting anticipated daily number of cyclists is 116 and the associated annual benefits are estimated at $682,825.

The tool can also be used to determine the benefits if other options are considered. In this case, the use of sharrows will reduce the number of anticipated bicyclists to 22 since it will have a smaller catchment area, (0.25 miles), which lowers the benefits to $127,710. Similarly, installing a buffered lane (or a separate off-road path) would increase the potential number of cyclists to 391, drawing from a 1.00-mile catchment area, and the benefits could be as much as $2,294,900. These projections require further evaluation, since such high bicycle demand may not be appropriate for the area. A discussion of the possible limitations and issues pertaining to this approach is discussed in the next chapter.

3.2 Other Benefit Estimation

Benefits identified by the USDOT (2023) are more applicable either at the design stages of a project, when more specific plans and data may be available, or after the project's completion, when performance can be evaluated. Safety benefits can be estimated at the planning stage using available CMFs. A Florida DOT study (2018) looked at benefits along the same lines of those identified by other studies, but they are more specific to the impacts of transit systems. They could be useful for examining alternative options at the design stage rather than developing benefit estimates at the planning stage. The Texas DOT (2018) estimated the overall benefits of bicycling for the state while the Colorado DOT (2016) identified benefits for bicycling and walking at the state level. Both studies identified key benefits that other agencies have considered, and both confirm that bicycling and walking confer health, economic, and mobility benefits.

Benefits and metrics identified in the FHWA Guidebook (2016) are most appropriate for this study due to their variety and ability to be implemented using readily available data or data that can be obtained with minimal effort. The performance measures — access to destinations, access to jobs, population served by walk/bike/ transit, and transportation-disadvantaged population served — are similar to demand measures the research team used to estimate bicyclist and pedestrian demand. The GIS method used to estimate bicyclist and pedestrian demand can be modified to estimate the number of destinations, jobs, percentage of population, and percentage of transportation-disadvantaged population within a defined distance of a bicycle or pedestrian facility data from the U.S. Census, American Community Survey, and USDOT Justice40 initiative.

The research team has access to Kentucky's crash data and can monitor bicycle and pedestrian crashes before and after the installation or improvement of a bicycle or pedestrian facility. Additionally, CMFs are useful tools for estimating crash reductions expected from a proposed facility improvement and are readily available on the CMF Clearinghouse.

Pedestrian space and street tree coverage are both performance measures the research team may be able to evaluate using statewide aerial Lidar data or aerial imagery. The percentage of a corridor's cross-sectional area dedicated to bicycle and pedestrian facilities can be measured from aerial photography. Additionally, manual counts of the number of trees per corridor can be conducted virtually or in-person. These metrics would require manual efforts at the project level to gather the necessary data.

Crossing opportunities, network completeness, and miles of bicycle and pedestrian facilities are performance measures that can be assessed by using existing GIS databases, examining design plans for a project, or through site visits (in-person or virtual).

Based on this review, researchers focused on identifying benefits that could be estimated using data available during a project's planning stages. This resulted in selecting the benefits and associated metrics presented in Table 3.1.

Table 3.1 Metrics for Pedestrian and Bicycle Facility Benefits

Category	Benefit	Metrics
Mobility	Network improvements	• Sidewalks added (mi) • Bicycle facilities added (mi by type)
	Anticipated change in LOS	• Pedestrian LOS • Bicycle LOS
Accessibility	Access to destinations	• Accessible destinations for pedestrians — within 0.5 mi of project (number) • Accessible destinations for bicycles — within 2.0 mi of project (number)
	Access to project	• Homes within 0.5 mi of project (percentage) for pedestrians

		• Homes within 2.0 mi of project (percentage) for bicyclists
	Access of disadvantaged population	• Transportation-disadvantaged population within 0.5 mi of project (percentage) for pedestrians • Transportation-disadvantaged population within 2.0 mi of project (percentage) for bicyclists
	Facility improvement	• Improvements for pedestrians (e.g., crosswalks added (number), pedestrian signals added (number), pedestrian signal improvements (type), crossing improvements (type)) • Improvements for bicyclists (e.g., sharrow conversion to bike lane (mi), bike lane conversion to cycle track (mi), bike boxes added (number), painted intersections for bicycles (number), bike signals added (number))
Safety	Crash effect	• Reduction of pedestrian crashes (number per year per mile) • Reduction of bicyclist crashes (number per year per mile)

To estimate pedestrian and bicycle crash reduction, researchers completed a systematic search of CMFs for pedestrian and bicycle facilities. The CMF Clearinghouse returns 286 CMFs when the keyword *bicycle* is used (FHWA, n.d.). These CMFs cover a wide range of countermeasures, from installing bicycle tracks to converting an intersection into single-lane roundabout. CMF values range from 0.00 to 8.76. Using the filter of Star Quality Rating of 3 and above, the most relevant CMFs to projects with a bicycle lane component are CMFs where the countermeasure is *install bicycle lanes*, resulting in values ranging from 0.435 to 1.307 for all crash types and severities.

A search using the keyword *pedestrian* returned 159 CMFs. These CMFs cover a range of countermeasures from installing raised pedestrian crosswalks to installing a pedestrian hybrid beacon, with CMF values ranging from 0.14 to 1.77. Using the filter of Star Quality Rating of 3 and above, the first relevant CMF for projects with pedestrian facilities is *install pedestrian signals*, where the CMF is calculated using Equation 7 for all crash types and severities.

$$\mathrm{CMF_{tot}} = 0.723 \times (\mathrm{V}^*_{\mathrm{M},1} \times \mathrm{V}^*_{\mathrm{m},1})^{0.057} \times \mathrm{e}^{(0.050\times\mathrm{Area}+0.121\times[1-\frac{(0.825)^{\mathrm{S}}]}{\mathrm{s}})} \quad (7)$$

where:

- $\mathrm{V_M}$ = Major Road AADT (in thousands of vehicles)
- $\mathrm{V_m}$ = Minor Road AADT (in thousands of vehicles)
- Area = Area Type Indicator (Residential = 0, Commercial = 1)
- S = Number of years since treatment installation

Another relevant CMF is *presence of a pedestrian crosswalk at midblock locations*, which has a CMF = 0.82 for vehicle/pedestrian crash type and all severities.

To explore CMFs related to sidewalk presence and/or width, researchers searched the CMF Clearinghouse using the keyword *sidewalk*, which returned 26 CMFs. These CMFs cover a wide range of countermeasures, from widening sidewalks at intersections to installing sidewalks, with CMF values ranging from 0.00 to 4.20. The CMF most relevant to projects with pedestrian facilities is *install sidewalk*, resulting in a CMF value of 0.598 for vehicle/pedestrian crash type and all severities.

Researchers created Excel files for both bicycle- and pedestrian-related CMFs. They can be accessed at the links below and used to determine appropriate CMF for the treatment under consideration.

- Excel File: CMFs for Bicycle Facilities
- Excel File: CMFs for Sidewalks
- Excel File: CMFs for Pedestrian Facilities

As Chapter 2 notes, the Kansas DOT developed a generalized CMF for pedestrian and bicycle facilities (see Table 2.1), which could be used here as well.

Chapter 4 Conclusions

KYTC has responded to recent increases in pedestrian and bicycle demand and activity levels by modifying its policies and directing more attention to accommodating non-motorized road users. To help KYTC understand the potential ramifications of installing pedestrians and bicycle facilities, researchers developed the KTC Bicycle and Pedestrian Demand and Benefit spreadsheet tool, which practitioners can use to estimate the benefits of pedestrian and bicycle facilities given a specified level of demand.

Leveraging a method proposed by Krizec et al. (2006), the spreadsheet relies on estimates of bicycle commuters for a project area and the population that may be attracted to new facilities. Benefits are estimated based on mobility gains, anticipated health benefits, potential reductions in vehicle use, and recreational benefits.

Since researchers did not identify generic demand models for estimating pedestrian demand and benefits, they used a modified version of the Krizec et al. bicycle model. Demand is estimated based on the population within 0.25 miles of a project that may be attracted to new pedestrian facilities. Benefits are estimated following Litman's (2024) approach, which involves looking at how more Active Transportation options, reduced auto use, and other positive impacts affect a community.

Table 3.1 lists other benefits of pedestrian and bicycle improvements. Among those included, safety improvements can be estimated with CMFs. Other benefits in Table 3.1 are quantifiable and could provide additional information to decision makers when evaluating possible improvement options.

4.1 Approach Validation and Limitations

Researchers used the KTC Bicycle and Pedestrian Demand and Benefit spreadsheet tool to analyze SHIFT 2024 projects that include bicycle and pedestrian facilities. This analysis uncovered limitations and ways to improve the tool.

The case study presented in Chapter 3 found that demand and benefit estimates may not be representative of actual project contexts. That case study focused on a rural area connecting Liberty to Junction City, which is located just past the Lincoln County border, where the project ends. Because the bicycle demand model uses population surrounding the project and commuter share as inputs, both can significantly affect predictions. The model uses the statewide average for bicycle commuter share, which may not apply to these areas. Moreover, demand estimates could be skewed because the towns at the project's boundaries could account for most of the population in the 0.50-mile buffer. It is important to closely examine basic model inputs and adjust them to reflect actual project contexts. This may require using different commuter shares or require a modified process for estimating the population attracted to a facility.

How accurately the model quantifies benefits is another potential limitation. The case study found benefit levels that seemed unreasonably high — $2.3 million. Roughly 92% of which was attributed to recreational benefits. This was the case for all projects examined — recreational benefits accounted for about 91% of the total benefits. As such, the contributions of each benefit category should be reviewed to determine if the overall estimate of benefits is realistic.

As numerous studies demonstrated, local data are needed to generate accurate and reasonable estimates of demand and benefits. The state-level efforts researchers reviewed were developed using local data that were modified to address state needs. KYTC needs to consider how to proceed with data collection for bicyclist and pedestrian volumes so that the proposed tools can be refined to ensure they estimate demand and benefits as accurately as possible.

The model could also be improved by looking at facility types considered, and the assumptions made to allow for their development. The model considers three facility types: sharrows, bicycle lanes, and buffered bicycle lanes. The case study in Chapter 3 included a proposed bicycle lane on the shoulder, which was assumed to be the same type of facility as a bicycle lane and is more typical of an urban setting. It is possible that using a shoulder as a bicycle lane is appropriate for advancing pedestrian and bicycle mobility in a manner consistent with *Statewide Bicycle and Pedestrian Master Plan* (2022b). However, in its current form the model cannot differentiate between bicycle lanes in urban settings and rural settings (on the shoulder). This issue needs to be examined and model adjusted accordingly.

Because the number of commuting cyclists and populations in the vicinity of a project significantly influence model predictions, it would be valuable to undertake a sensitivity analysis to clarify the relationships between model inputs and outputs. Developing a set of case studies could achieve this objective and provide valuable knowledge that can be used to refine the model and develop more accurate predictions.

4.2 Future Research

Model limitations described in the previous section can be addressed through additional research. Researchers propose the following activities:

- *Data collection of bicycle and pedestrian volumes*. The data limitations mentioned above illustrate that a process needs to be developed which KYTC can use to collect pedestrian and bicycle facility data on a large scale. This will support refinement of the spreadsheet tool and provide a foundation for more robust estimates of demand and benefits.
- *Tool validation*. The spreadsheet tool was pilot tested on 2024 SHIFT projects. Further investigations looking at the sensitivity of inputs and outputs are needed to identify applications the model can be used for as well as to refine its assumptions. This will improve the accuracy of benefit estimates.
- *Case study development*. A series of case studies for projects both completed or under development could provide the foundation for validating estimates generated by the tool. Establishing a library of cases studies will be valuable for cataloguing lessons learned and helping practitioners determine how the models can be adjusted to account for project context.
- *Benefit normalization*. Benefits are partially normalized based on anticipated demand. However, this omits project location and context, its length, affected population, and other variables. Normalization indicators could be evaluated to provide a more uniform accounting of project benefits.

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Appendix A Summary of Approaches to Forecasting Bicyclist Demand

Table A1 Summary of Forecasting Approaches for Bicycling Demand

Source	Modeling Approach – Data Needs	Characteristics	Result
STATE EFFORTS			
Minnesota DOT	Method 1: Utilizing data from US Census Bureau ACS (5-year estimates) and Metropolitan Council's Travel Behavior Inventory (TBI)	◆ Relatively complex as it relies on multiple data sources. ◆ Geographic Segmentation (cities, suburban counties, and the exurban and rural "ring" counties) ◆ Adjustments for part-time bicycle commuting and non-commuting trips. ◆ Extrapolation of results to Greater Minnesota. ◆ Manipulation of data from ACS and TBI to estimate the total number of bicycle trips in Minnesota. ◆ Provide a comprehensive understanding of bicycle traffic across the state.	Estimation of the total number of bicycle trips in Minnesota by producing two estimates: ◆ Number of Bicycle Trips (NBT) ◆ Bicycle Miles Traveled (BMT)
	Method 2: Utilizing data from US Census Bureau ACS (5-year estimates), Metropolitan Council's Travel Behavior Inventory (TBI), and Omnibus Survey.	◆ Comprehensive and technically complex due to its integration of multiple data sources. ◆ Incorporates data from the Omnibus Survey to provide a more complete estimation of bicycling behavior compared to Method 1, as it includes the seasonal variations (April – October) and trip purposes in bicycling activity. ◆ Geographic analysis like Method 1. ◆ Extrapolation of results for exurban and ring counties to Greater Minnesota. That allows for the estimation of bicycling activity beyond the specific geographic areas covered by the ACS and TBI.	Estimation of the total number of bicycle trips in Minnesota, which are lower than the estimates of the Method 1.
Vermont DOT	A data-driven and multi-factor analysis, where datasets like E-911, NHTSM, Strava and Wikimap data are incorporated.	◆ Not a simple method, but adaptable. ◆ Crowdsourced input from Wikimap. ◆ Land use analysis, trip patterns, trip distance thresholds, trip frequency, access scores and recreational cycling trends.	Estimation of transportation and recreational-based bicycle trips per year in Vermont and identification of corridors with the highest bicycle use to prioritize them for future improvements.

Source	Modeling Approach – Data Needs	Characteristics	Result
		◆ Weighting of the above factors to account for both transportation and recreational use.	
Texas DOT	Regression Models, utilizing data from Strava Metro, ACS, and TxDOT's Roadway Inventory	◆ Simple method – use of regression equations based on a few factors. ◆ Cost-effective and efficient way to collect data from Strava Metro. ◆ Use of Functional Classification in estimating bicycle volumes. ◆ Linear regression model based on factors such as household income and functional classification.	Estimation of bicycle traffic volumes for different functional classifications/type of roadway or trail segment and household income in the Waller Creek Shared-Use Path, which is a multi-use trail that runs through the central district of Austin.
U.S. DOT | NCHRP 552	Three-step demand forecasting method, using NHTS data and U.S. census commute share data	◆ Simple method and straightforward method. ◆ Population estimation within 400m, 800m and 1600m of a bicycling facility. ◆ Three steps: 1. Calculation of existing bicycle commuters (percentage of commuters from ACS). 2. Calculation of the total number of new adult cyclists. 3. Estimation of new bicyclists and commuters (function of facility)>	Estimation of the bicycling demand.
LITERATURE FINDINGS			
Fagnant (2016)	Direct-Demand – suitability – model based on cycling count data in the Seattle, Washington region, and geo-spatial data.	◆ Moderately complex method. ◆ Consideration of multiple factors and variables. ◆ Geo-spatial data gathered such as bicycle count data from 251 locations in Seattle, Population density data, employment data, physical features like curb width, roadway condition variables like bridge presence and access to bicycle trails.	Estimation of the peak-hour cyclist counts at urban intersections.
Wang et al. (2021)	Regression model with graph regularization (GR), utilizing	◆ Relatively simple to implement using machine learning libraries in Python.	Prediction of bike-sharing demand at station level.

Source	Modeling Approach – Data Needs	Characteristics	Result
	data from the BIXI bike-sharing system in Montreal, Canada.	◆ Focus on understanding how different factors (land use, social-demographic) affect bike-sharing demand at each station. ◆ Consideration of the spatial heterogeneity of stations where users of BIXI can rent and return bicycles. ◆ Estimation of spatially varying coefficients for each station. ◆ Encouragement of nearby stations to have similar coefficients because of the GR addition to the model. ◆ Hyper-parameter tuning to optimize the model's performance.	
Munira & Zhang (2021)	Negative binomial direct-demand model and Bikeability Index, utilizing short-count (24-hour) bicycle data, continuous-count data, bike-sharing data, transit data, parcel-level land use data, bicycle infrastructure data and demographic data.	◆ Not a simple method ◆ Predicts bicycle traffic at an intersection level. ◆ Involves the development of the Bikeability Index to quantify the bike-friendliness of the network and the improve the performance of the model. ◆ Collection and analysis of various types of data. ◆ Customized to account for the local characteristics of the study area.	Estimation and prediction of bicycle traffic at the intersection level in the city of Austin, Texas and development of the Bikeability index.

Appendix B VTI Method for Evaluating Active Transport Benefits and Costs

The benefits per person-mile of the four monetarily quantifiable metrics outlined in the Victoria Transport Policy Institute report titled: "Evaluating Active Transport Benefits and Costs" are presented in the following tables.

Table B1 Improving Walking and Cycling Conditions (Per Person-Mile)

Impact Category	Urban Peak	Urban Off-Peak	Rural	Overall Average	Comments
User Benefits	$0.250	$0.250	$0.250	$0.250	The greater the improvement, the greater this value.
Option Value	$.035	$.035	$.035	$.035	Half of *diversity value*.
Equity Objectives	$.035	$.035	$.035	$.035	Half of *diversity value*. Higher if a project significantly benefits disadvantaged people.

Table B2 Increased Walking and Cycling Activity (Per Person-Mile)

Impact Category	Urban Peak	Urban Off-Peak	Rural	Overall Average	Comments
Fitness and health – **Walking**	$0.500	$0.500	$0.500	$0.500	Benefits are larger if pedestrian facilities attract at-risk users.
Fitness and health – **Cycling**	$0.200	$0.200	$0.200	$0.200	Benefits are larger if cycling facilities attract at-risk users.

Table B3 Typical Values — Reduced Motor Vehicle Travel

Impact Category	Urban Peak	Urban Off-Peak	Rural	Overall Average	Comments
Vehicle Cost Savings	$0.250	$0.225	$0.20	$0.225	This reflects vehicle operating cost savings. Larger savings result if some households can reduce vehicle ownership costs.
Avoided Chauffeuring Driver's Time	$0.700	$0.600	$0.500	$0.580	Based on $9.00 per hour driver's time value.
Congestion Reduction	$0.200	$0.050	$0.010	$0.060	
Reduced Barrier Effect	$0.010	$0.010	$0.010	$0.010	
Roadway Cost Savings	$0.050	$0.050	$0.030	$0.042	
Parking Cost Savings	$0.600	$0.400	$0.200	$0.360	Parking costs are particularly high for commuting and lower for errands which require less parking per trip.
Energy Conservation	$0.030	$0.030	$0.030	$0.030	
Pollution Reductions	$0.100	$0.050	$0.010	$0.044	

Table B4 More Walkable and Bikeable Community

Impact Category	Urban Peak	Urban Off-Peak	Rural	Total	Comments
Reduced Pavement	$0.010	$0.005	$0.001	$0.002	Specific studies should be used when possible.
Increased Accessibility	$0.080	$0.060	$0.030	$0.051	Specific studies should be used when possible.

Appendix C Method for Establishing Project-Level Buffers

The detailed process for establishing project-level buffers is presented here. The process utilizes population data from the 2020 U.S. Census. Other population data (e.g., disadvantaged population, employment) or destination estimates can be obtained in a similar manner.

1. In ArcGIS Pro, plot SHIFT2024 Bike/Ped projects routes based on the route ID (RSE_ID) and the beginning (BMP) and ending (EMP) mile points. Use the KYTC HIS Allrds_M shapefile for the inputs route features. In the ArcGIS Pro *Make Route Event Layer* tool, populate fields as shown in Figure C1.

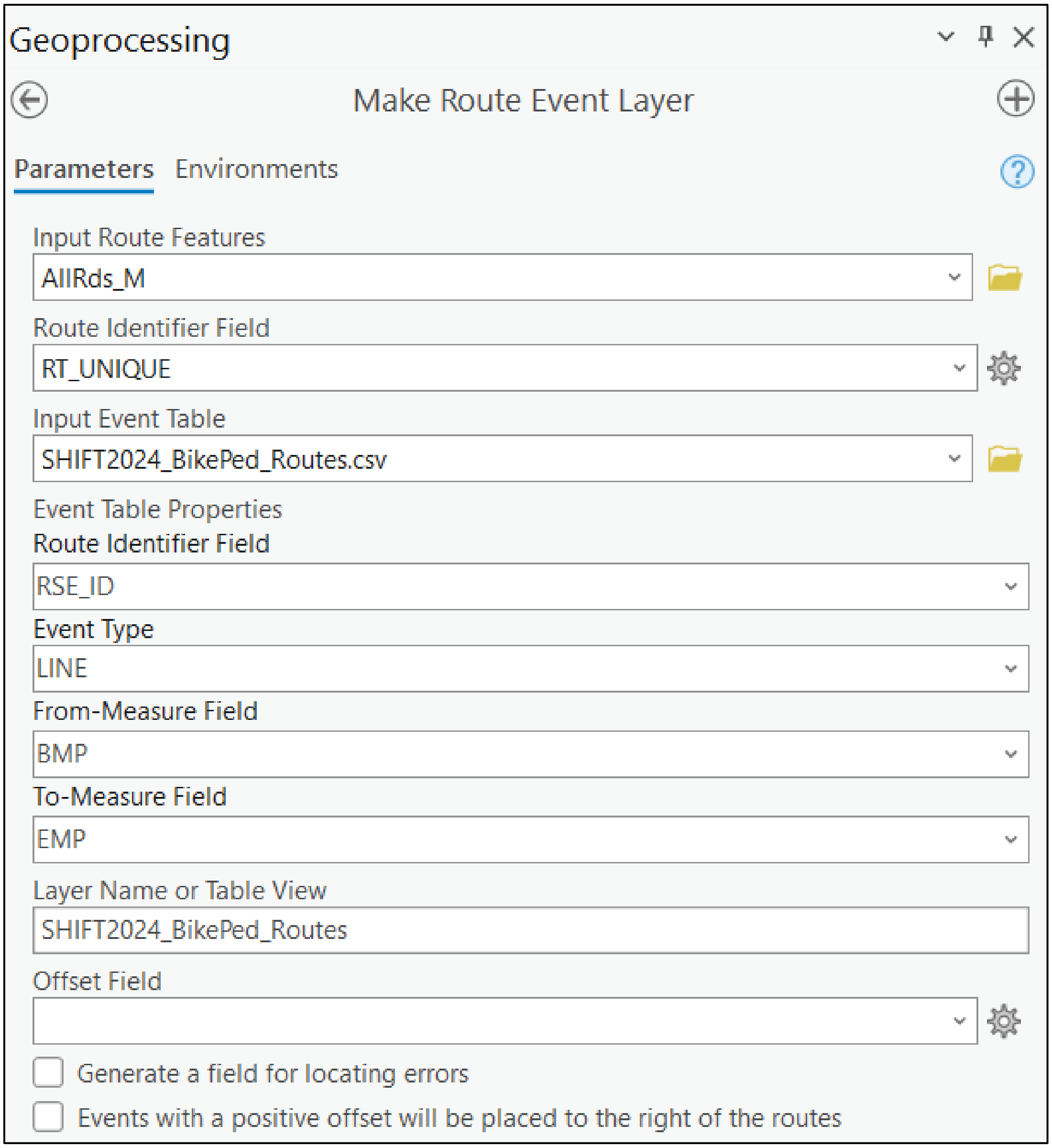


Figure C1 Make Route Event Layer Tool

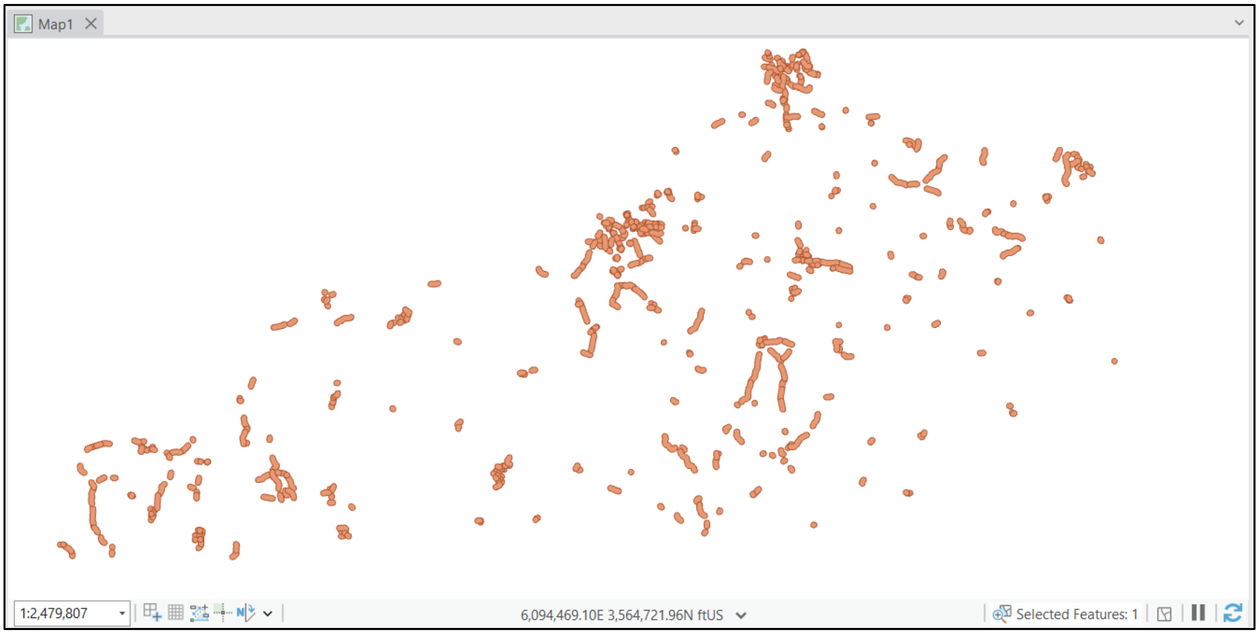


Figure C2 SHIFT 2024 Bike/Ped Routes Map

2. Use the Buffer tool to establish buffers at 0.25-, 0.5-, 0.75-, and 1.00-mile ranges from the project routes.

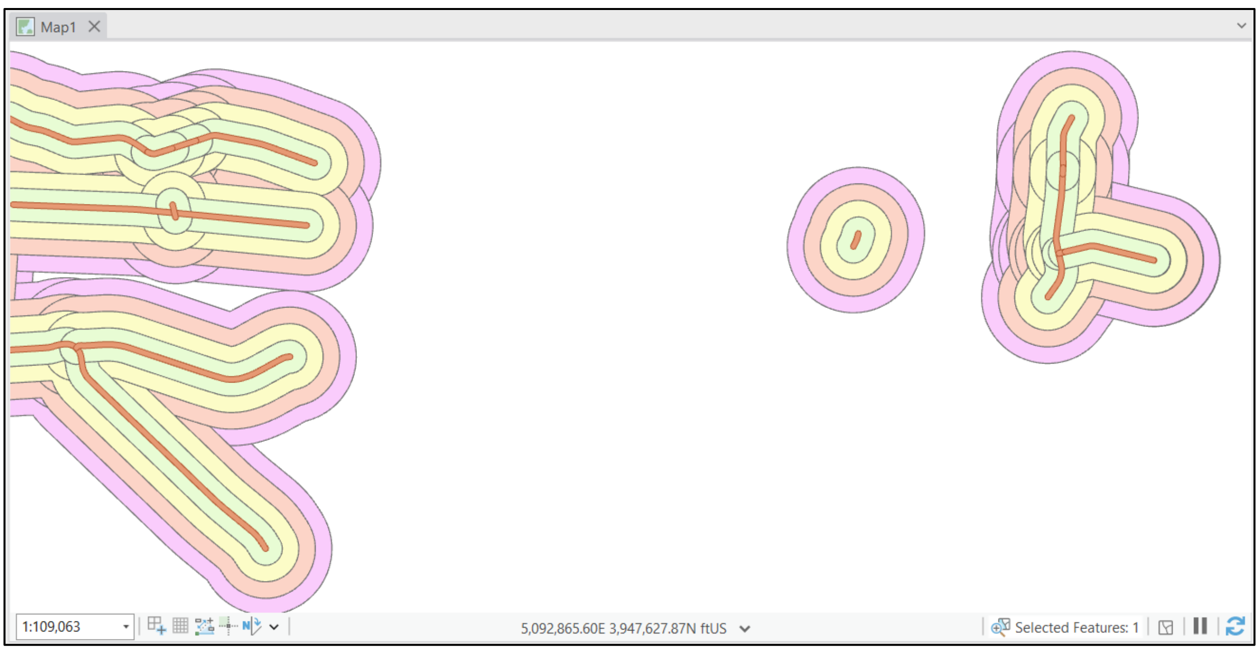
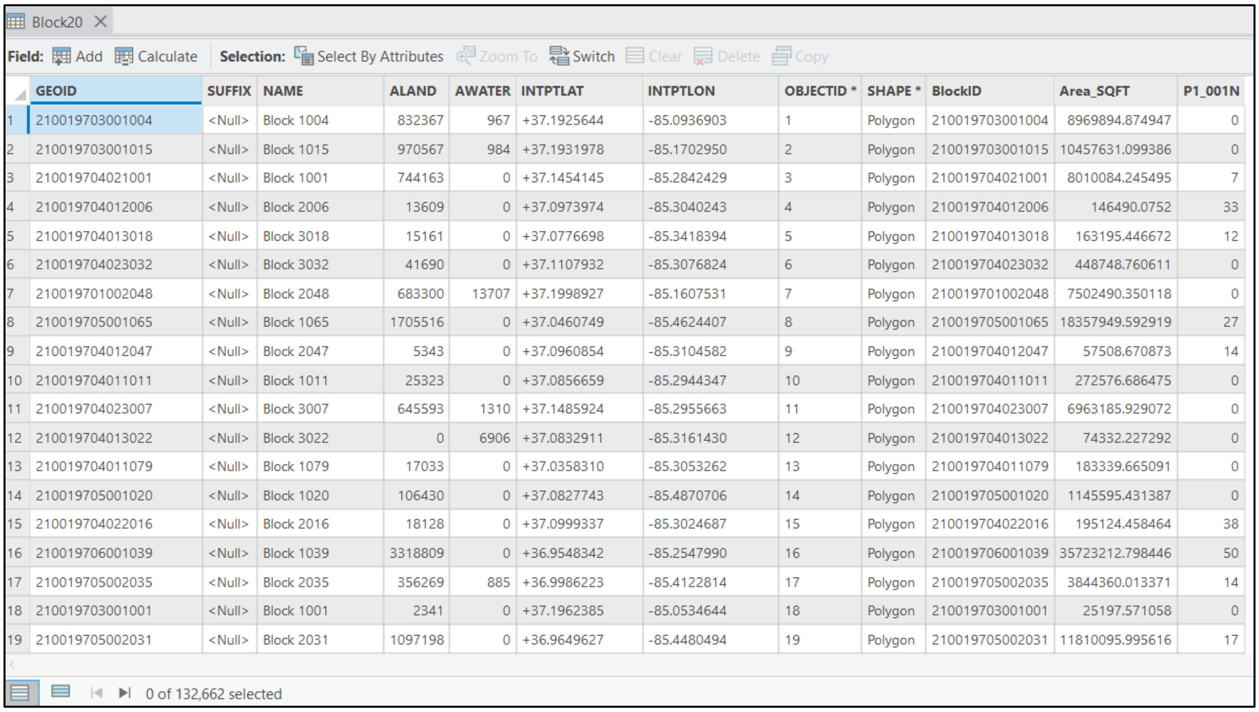


Figure C4 Buffers at 0.25-, 0.5-, 0.75-, and 1-mile ranges from the project routes

3. Download Census 2020 total population at block level — Table DECENNIALDHC2020.P1 from the Census Bureau. https://data.census.gov/table?q=DECENNIALDHC2020.P1&g=010XX00US.

4. Download the TIGER2020 geodatabase tlgdb_2020_a_21_ky.gdb for Kentucky from the Census Bureau. https://www2.census.gov/geo/tiger/TGRGDB20/.

5. Join the population “P1_001N” from DECENNIALDHC2020.P1 table to the Block20 layer from tlgdb_2020_a_21_ky.gdb using “GEOID” field.


Block20

Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy

	GEOID	SUFFIX	NAME	ALAND	AWATER	INTPTLAT	INTPTLON	OBJECTID *	SHAPE *	BlockID	Area_SQFT	P1_001N
1	210019703001004	<Null>	Block 1004	832367	967	+37.1925644	-85.0936903	1	Polygon	210019703001004	8969894.874947	0
2	210019703001015	<Null>	Block 1015	970567	984	+37.1931978	-85.1702950	2	Polygon	210019703001015	10457631.099386	0
3	210019704021001	<Null>	Block 1001	744163	0	+37.1454145	-85.2842429	3	Polygon	210019704021001	8010084.245495	7
4	210019704012006	<Null>	Block 2006	13609	0	+37.0973974	-85.3040243	4	Polygon	210019704012006	146490.0752	33
5	210019704013018	<Null>	Block 3018	15161	0	+37.0776698	-85.3418394	5	Polygon	210019704013018	163195.446672	12
6	210019704023032	<Null>	Block 3032	41690	0	+37.1107932	-85.3076824	6	Polygon	210019704023032	448748.760611	0
7	210019701002048	<Null>	Block 2048	683300	13707	+37.1998927	-85.1607531	7	Polygon	210019701002048	7502490.350118	0
8	210019705001065	<Null>	Block 1065	1705516	0	+37.0460749	-85.4624407	8	Polygon	210019705001065	18357949.592919	27
9	210019704012047	<Null>	Block 2047	5343	0	+37.0960854	-85.3104582	9	Polygon	210019704012047	57508.670873	14
10	210019704011011	<Null>	Block 1011	25323	0	+37.0856659	-85.2944347	10	Polygon	210019704011011	272576.686475	0
11	210019704023007	<Null>	Block 3007	645593	1310	+37.1485924	-85.2955663	11	Polygon	210019704023007	6963185.929072	0
12	210019704013022	<Null>	Block 3022	0	6906	+37.0832911	-85.3161430	12	Polygon	210019704013022	74332.227292	0
13	210019704011079	<Null>	Block 1079	17033	0	+37.0358310	-85.3053262	13	Polygon	210019704011079	183339.665091	0
14	210019705001020	<Null>	Block 1020	106430	0	+37.0827743	-85.4870706	14	Polygon	210019705001020	1145595.431387	0
15	210019704022016	<Null>	Block 2016	18128	0	+37.0999337	-85.3024687	15	Polygon	210019704022016	195124.458464	38
16	210019706001039	<Null>	Block 1039	3318809	0	+36.9548342	-85.2547990	16	Polygon	210019706001039	35723212.798446	50
17	210019705002035	<Null>	Block 2035	356269	885	+36.9986223	-85.4122814	17	Polygon	210019705002035	3844360.013371	14
18	210019703001001	<Null>	Block 1001	2341	0	+37.1962385	-85.0534644	18	Polygon	210019703001001	25197.571058	0
19	210019705002031	<Null>	Block 2031	1097198	0	+36.9649627	-85.4480494	19	Polygon	210019705002031	11810095.995616	17

0 of 132,662 selected

Figure C5 Join population to Census Block level.

6. Create a new field in the Block20 layer and calculate the area of each block in the Block20 layer by using *Calculate Geometry* tool. Set the coordinate system as “NAD_1983_2011_StatePlane_Kentucky_FIPS_1600_Ft_US.”

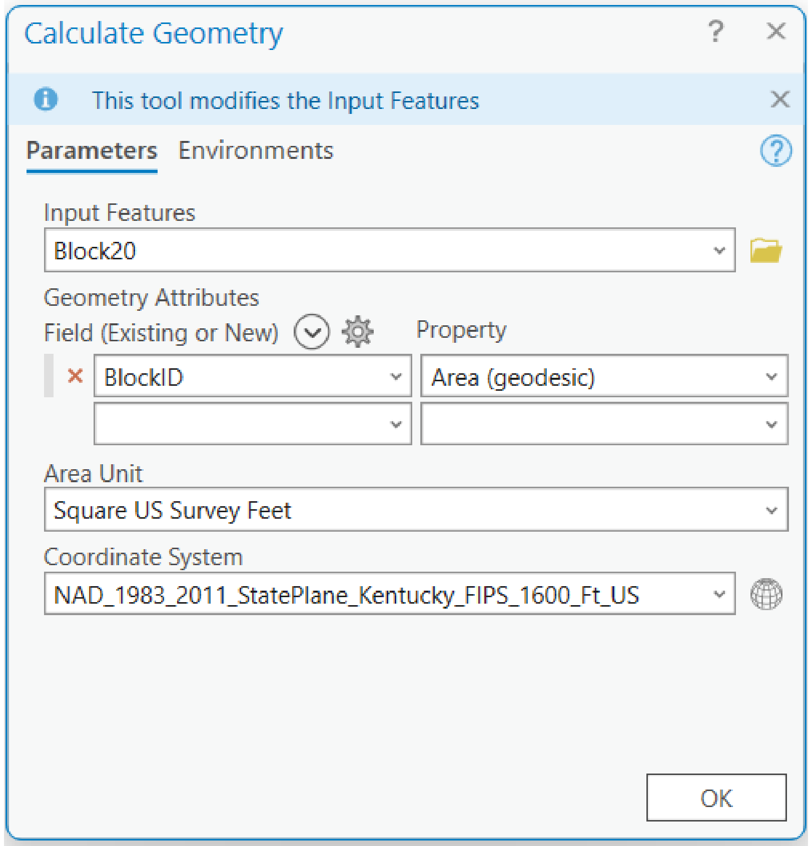


Figure C6 Calculate Areas for Census Blocks

7. Overlay the area of Census 2020 blocks in the four buffer areas using Overlay Layers tool (Figure C8) and calculate the overlay area for each block polygon in units of SQFT.

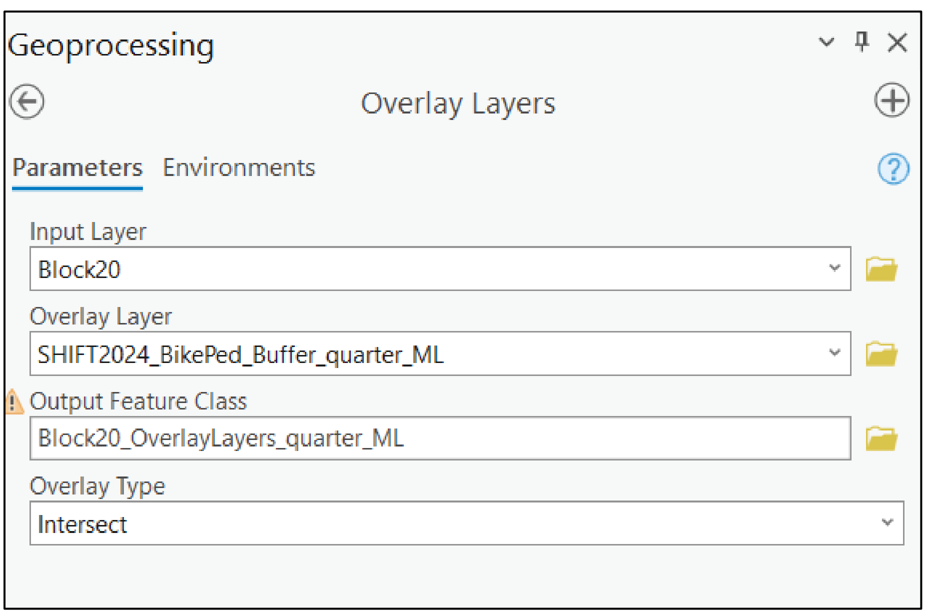


Figure C8 Overlay Census 2000 Blocks with Buffers

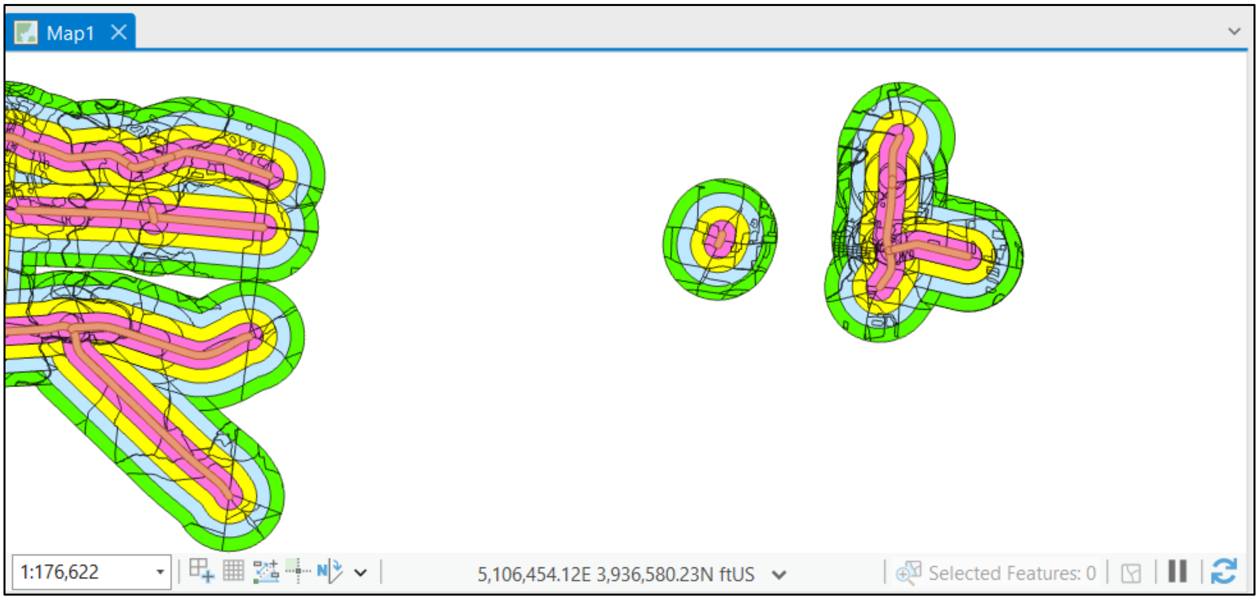


Figure C9 Results of Overlay Census Blocks with Buffers

8. Create a new field, *Overlay Area*, in each overlay layer and calculate the area of each overlay block polygon with the *Calculate Geometry* tool.

Block20_OverlayLayers_quarter_ML

Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy

	OBJECTID2 *	GEOID	BlockID	Area_SQFT	Overlay_Area	P1_001N	SUFFIX	NAME	ALAND	AWATER	INTPTLA
1	1	210290211031024	210290211031024	4910691.896105	5036.429928	0	<Null>	Block 1024	456220	0	+37.9823
2	2	210370521002009	210370521002009	118610.289933	22730.486201	53	<Null>	Block 2009	11019	0	+39.1007
3	3	212139702001030	212139702001030	464901.481238	243458.377988	39	<Null>	Block 1030	43191	0	+36.7270
4	4	212270113001013	212270113001013	2270563.419022	315496.299137	0	<Null>	Block 1013	63746	147196	+37.0288
5	5	211110100073002	211110100073002	406821.928226	3.64897	15	<Null>	Block 3002	37795	0	+38.2810
6	6	210670038031030	210670038031030	1461933.918027	292921.026738	0	<Null>	Block 1030	135819	0	+38.0771
7	7	210190306001003	210190306001003	314529.475622	17017.135658	50	<Null>	Block 1003	29221	0	+38.4624
8	8	210290211031026	210290211031026	1419142.662469	294.096438	0	<Null>	Block 1026	131844	0	+37.9587
9	9	211450315012138	211450315012138	2559082.542062	2049130.473398	30	<Null>	Block 2138	235663	2085	+37.1008
10	10	211110117071000	211110117071000	7573169.22463	8230.925988	741	<Null>	Block 1000	703130	442	+38.1105
11	11	211450314023033	211450314023033	2506144.130437	11155.930941	102	<Null>	Block 3033	232829	0	+37.0606
12	12	210150703111056	210150703111056	40986.185204	40986.288894	0	<Null>	Block 1056	3808	0	+39.0061
13	13	211170645002004	211170645002004	256340.492598	256340.27756	45	<Null>	Block 2004	23815	0	+39.0109
14	14	210150706062020	210150706062020	100898.746918	100898.765569	3	<Null>	Block 2020	9374	0	+38.8704
15	15	212270108051001	212270108051001	359789.576559	177998.393398	62	<Null>	Block 1001	33426	0	+36.9514

Figure C10 Results of Overlay Area

9. Export all four overlayed layers to CSV files and save the data to Excel files. Calculate the percentage of overlay polygon area as the total area of the original block. Next, calculate the new covered population of each Census block. Assume homogenous population distributions in each census block.

10. Build a pivot table to summarize each project's total impact/covered population.