



Influences on Mode Shift Associated With Various Classes of Bikeways

Requested by
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January 16, 2019

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Executive Summary

Background

Caltrans is seeking information that can be used to revise the current methodology that estimates the cost-effectiveness of bicycle facilities. Current practices are guided by a May 2005 California Air Resources Board (ARB) publication, *Methods to Find the Cost-Effectiveness of Funding Air Quality Projects: For Evaluating Motor Vehicle Registration Fee Projects and Congestion Mitigation and Air Quality Improvement (CMAQ) Projects*. Two inputs, or variables, included in the ARB guidance are of particular interest to Caltrans:

- *Variable A*. An adjustment on average daily traffic (ADT) for auto trips replaced by bike trips from the bike facility.
- *Variable C*. Credit for activity centers near the project.

Caltrans is also interested in the influence of network connectivity on mode choice and bicycle ridership, and other parameters that may influence adjustment to ADT.

To gather information for this Preliminary Investigation, CTC & Associates reviewed domestic research, with a focus on academic research and activities undertaken by national transportation organizations, in the following topic areas:

- Trip generation and other models or methods that are used to predict bicycle demand.
- Before-and-after studies that examine the characteristics and impacts of new bicycle facilities.
- Changes in travel behavior induced by new or upgraded bikeways.
- Factors such as facility type, proximity to the bikeway, intersection treatment, length of the bikeway, length of the connected bicycle network, commuting duration, and presence of activity centers and other amenities that influence increases in bicycle mode share and facility choice.

Summary of Findings

This report provides a sampling of recent domestic research and related publications that addresses the topic areas identified above. The tables below summarize the key publications and research in progress highlighted in this Preliminary Investigation in these topic areas:

- Tools and models.
- Bicycle networks.
- Facility and route preferences.
- Mode shift and mode share.

The tables are presented in the order of the topic areas listed above. Each table provides the publication or project title, the year of publication (research in progress is noted without a year) and a brief description of the project findings. More information about each publication, including a link to the full text or citation, can be found in the **Detailed Findings** section of this report, which mirrors the order in which the publications appear in the summary tables.

Tools and Models (See Page 9)	
Publication or Project (Year)	Description
California-Related Modeling Practices	
Methods to Find the Cost-Effectiveness of Funding Air Quality Projects: For Evaluating Motor Vehicle Registration Fee Projects and Congestion Mitigation and Air Quality Improvement (CMAQ) Projects (2005)	Presents the methods and factors used in conjunction with ARB's latest emission factors to derive estimates that are used by project planners and sponsors to compare and select proposed projects. Contains the model and variables of particular interest to Caltrans in this project.
Methodology for Assessing the Benefits of Active Transportation Projects (2015)	Uses the 2005 ARB model and expands its focus; describes other users and uses of the ARB model. Factors used are quite similar to those described in the 2005 ARB guidance. Provides details that may inform possible modifications to the ARB variables through a summary of variables and references to source material.
Toward Accurate and Valid Estimates of Greenhouse Gas Reductions From Bikeway Projects (2016)	(Project sponsored by Caltrans.) Develops and validates a new model that incorporates demographic data and changes in travel behavior when estimating greenhouse gas (GHG) reductions. Includes data that relates to ridership, bicycle volumes and facility characteristics that could inform modifications to the ARB guidance.
National Guidance	
Guidebook for Developing Pedestrian and Bicycle Performance Measures (2016)	Provides metrics that are used to assess access to community destinations and proximity of bicycle infrastructure to origins and destinations; also provides examples of how metrics are used.
NCHRP Report 803: Pedestrian and Bicycle Transportation Along Existing Roads—ActiveTrans Priority Tool Guidebook (2015)	Provides a programmed spreadsheet and step-by-step methodology for prioritizing improvements to bicycle facilities.
NCHRP Report 770: Estimating Bicycling and Walking for Planning and Project Development: A Guidebook (2014)	Offers a collection of tools to address questions related to bicycle travel behavior and demand. Includes factors relating to bicycle facilities, attitudes and perceptions, facility use estimation, and gaps in methods for estimating bicycle demand.
NCHRP Report 552: Guidelines for Analysis of Investments in Bicycle Facilities (2006)	Includes a benefit-cost analysis tool, literature review and draft sketch planning method developed for measuring and predicting bicycling demand.
State Modeling Practices	
Tools for Estimating VMT Reductions From Built Environment Changes (2013)	Discusses a range of tools used to estimate the impact of various land use and transportation inputs, including a Florida Department of Transportation (DOT) tool (see the citation below). Addresses factors associated with travel behavior and mode choice identified in other research.
Conserve by Bicycle Study (multiple years)	Describes models developed by Florida DOT that quantify the benefits of bicycling and bicycling encouragement and predict corridor-level bicycling use. Identifies factors found to influence shifts from motoring to cycling and predicts frequency of recreational cycling trips.
Estimating Land Use Effects on Bicycle Ridership (2015)	Presents models designed to explore land use, built environment, demographic, socioeconomic and travel behavior connections to bicycle ridership, and applies them to the state of Maryland.

Tools and Models (See Page 9)	
Publication or Project (Year)	Description
Other Modeling-Related Research	
A Sinusoidal Model for Seasonal Bicycle Demand Estimation (2017)	Describes an estimation method using a sinusoidal model that requires a single calibration factor to adjust for scale of seasonal demand change. Presents a model capable of estimating monthly average daily bicycle counts and average annual daily bicycle (AADB) counts.
Methods for Improving and Automating the Estimation of Average Annual Daily Bicyclists (2016)	Proposes a novel methodology that can reduce estimation error and facilitate automation of the AADB estimation process. The proposed methodology performs AADB estimation in a three-step process.
Forecasting Pedestrian and Bicycle Demands Using Regional Travel Demand Models and Local Mode Share/Trip Distance Data (2010)	Proposes a methodology to forecast bicycle travel demand that considers three primary factors related to pedestrian and bicycle demand: existing and future land uses, percentage of trips by mode, and walking and bicycling trip lengths.

Bicycle Networks (See Page 21)	
Publication or Project (Year)	Description
Guidebook for Measuring Multimodal Network Connectivity (2018)	Includes fact sheets on connectivity analysis methods and measures that include network completeness; network density; route directness; access to destinations; network quality; bicycle level of service; bicycle level of traffic stress; bicycle low stress connectivity; and bicycle route quality index.
Bikeway Networks: A Review of Effects on Cycling (2015)	Indicates that most studies suggest a positive relationship between bikeway networks and cycling levels, but notes that additional research is needed to: <ul style="list-style-type: none"> Analyze the role of specific types or features of bikeway facilities or intersection treatments. Consider the link between ridership and newer (innovative) types of infrastructure, particularly intersection treatments. Measure bikeway networks. Identify better and more systematic data collection on bikeway supply and cycling demand.
The Missing Link: Bicycle Infrastructure Networks and Ridership in 74 US Cities (2014)	Presents a standard methodology for measuring bicycle facility network quality at the macroscopic level and tests its association with bicycle commuting. Identifies need for standardized data collection and management practices for bicycle infrastructure networks and nonmotorized travel behavior.
Effect of Street Network Design on Walking and Biking (2010)	Identifies that street connectivity, street network density and street patterns are statistically significant in affecting the choice to drive, walk, bike or take transit. Increased intersection density and additional street connectivity are generally associated with more walking, biking and transit use.

Facility and Route Preferences (See Page 24)

Publication or Project (Year)	Description
<p>NCHRP 08-102: Bicyclist Facility Preferences and Effects on Increasing Bicycle Trips (Research in Progress)</p>	<p>Expected to provide guidance for predicting:</p> <ul style="list-style-type: none"> • Relative preference of current and potential bicycle users—by demographic groups including cyclist experience level—for various kinds of bicycle facilities. • Relative effectiveness of various kinds of bicycle facilities for attracting new bicycle users and increasing bicycle travel by existing bicycle users. <p>Expected completion date: August 2019.</p>
<p>Biking Practices and Preferences in a Lower Income, Primarily Minority Neighborhood: Learning What Residents Want (2017)</p>	<p>Concludes that cycle tracks in lower-income neighborhoods should be built wide enough for side-by-side riding because blacks and Hispanics want to ride with family and friends.</p>
<p>Tracking Bicyclists' Route Choices, Case Study: The Ohio State University (2017)</p>	<p>Explores the factors associated with individuals' bicycling choices. Findings suggest that riders preferred different segments as compared to those predicted by the shortest path algorithm.</p>
<p>Lessons From the Green Lanes: Evaluating Protected Bike Lanes in the U.S. (2014)</p>	<p>Evaluates protected bicycle lanes (cycle tracks) in five cities in terms of use, perception, benefits and impacts. Conclusions address bicyclists' perceptions of design-related issues such as buffer designs, intersection treatments, and support for the protected lane concept and its potential to attract new riders.</p>
<p>Roadway Design Preferences Among Drivers and Bicyclists in the Bay Area (2014)</p>	<p>Presents results from an internet survey. Findings indicate that roadway designs with barrier-separated bicycle lanes were the most popular among all groups, regardless of bicycling frequency; striped bicycle lanes received mixed reviews.</p>
<p>Bicycle Route Choice Model Developed Using Revealed Preference GPS Data (2011)</p>	<p>Uses GPS units to better understand preferences for facility types of cyclists in Portland, Oregon, coding trips to 15 unusually large and dense travel networks. Distance, turn frequency, slope, intersections, facility types and traffic volumes all contribute significantly to a route's attractiveness to bicyclists.</p>
<p>The Effects of On-Street Parking on Cyclist Route Choice and the Operational Behavior of Cyclists and Motorists (2009)</p>	<p>Evaluates the operational impacts of bicycling adjacent to on-street parking and the importance of attributes influencing bicyclists' route choice preferences. Results highlight preference for continuous bicycle facilities, lower traffic volume and lower roadway speeds, as well as fewer stop signs, red lights and cross streets.</p>
<p>Trails, Lanes or Traffic: Valuing Bicycle Facilities With an Adaptive Stated Preference Survey (2007)</p>	<p>Finds that respondents are willing to travel up to 20 minutes more to switch from an unmarked on-road facility with side parking to an off-road bicycle trail, with smaller changes associated with less dramatic improvements.</p>

Mode Shift and Mode Share (See Page 29)	
Publication or Project (Year)	Description
Effect of Bicycle Facilities on Travel Mode Choice Decisions (2016)	Uses a stated-preference survey to conclude that more than two-thirds of current bicycle facility users in Albuquerque, New Mexico, would continue to bicycle, and nearly one-third would discontinue bicycling if the bicycle facilities they regularly use did not exist.
Accounting for the Short Term Substitution Effects of Walking and Cycling in Sustainable Transportation (2015)	Develops a method to estimate the substitution effect using an intercept survey that applies the direct questioning approach. Results were expected to lead to better estimates of the environmental impacts of bicycling and walking.
Policy Brief: Impacts of Bicycling Strategies on Passenger Vehicle Use and Greenhouse Gas Emissions (2014)	Summarizes studies that examine the impact of infrastructure projects. Each study considers a specific infrastructure variable (bike lanes, bicycle parking) and a mode variable (percent commuting by bicycle, probability of bicycling) to estimate the change in mode variable for a 1 percent increase in the infrastructure variable.
Models for Anticipating Non-Motorized Travel Choices, and the Role of the Built Environment (2013)	Uses detailed travel data from the Seattle metropolitan area to evaluate the effects of built-environment variables on the use of nonmotorized travel modes.
Mode Shift: Philadelphia's Two-Wheeled Revolution in Progress (2011)	Uses bicycle counts gathered in 2009 and 2010 to conclude that better cyclist behavior goes hand in hand with better bicycling facilities. Facilities like buffered bike lanes make bicyclists feel safer.
Analyzing the Effect of Bicycle Facilities on Commute Mode Share Over Time (2009)	Applies census data to analyze changes in bicycle commuting between 1990 and 2000 in Minneapolis-St. Paul. Areas near new bicycle facilities showed a considerably greater increase in bicycle mode share than areas farther away.
The Impact of Bicycling Facilities on Commute Mode Share (2008)	Examines “possible contextual factors influencing facilities’ impact on bicycle commuting rates” in six cities. Key themes in cities that experienced bicycling commute mode share increases in connection with new bicycling facilities: <ul style="list-style-type: none"> • Location of facilities along usable commuting routes. • Overall network connectivity. • Amount of publicity and promotion dedicated to new bicycling facilities.

Gaps in Findings

The literature search did not uncover obvious replacements or significant modifications for the two model variables of interest to Caltrans (adjustment to ADT and credit for activity centers near a project). However, we did identify other users and uses of the ARB model that could provide Caltrans with opportunities for consultation to gather additional information. Several publications highlighted areas where additional research is needed, including better data collection methods and standardization in measurement.

An NCHRP project in progress—NCHRP Project 08-102, Bicyclist Facility Preferences and Effects on Increasing Bicycle Trips—is expected to conclude in August 2019. Findings from this project may prove helpful to Caltrans’ evaluation of bicycling mode shift.

Next Steps

Moving forward, Caltrans could consider:

- Consulting with users of the ARB model to identify opportunities for further modification.
- Reviewing in detail the 2016 Caltrans report that describes a modeling effort that applies demographic data and changes in travel behavior to estimate GHG reductions. Consider consulting with the principal investigator to determine if findings from the 2016 project can inform modifications to variables used in the ARB model.
- Tracking the NCHRP research in progress expected to conclude in early 2019.
- Examining the publications offering specific projections, estimates or measurements to compare and contrast researchers' findings.
- Reviewing in detail the publications that recommend areas for future research to determine how they relate to Caltrans' current inquiry.

Detailed Findings

Background

Caltrans is seeking reliable and robust methods to identify rates of and influences on mode shift from autos to various classes of bikeways. This information can be used to revise specific variables in the methodology to estimate the cost-effectiveness of bicycle facilities described in the May 2005 California Air Resources Board (ARB) publication *Methods to Find the Cost-Effectiveness of Funding Air Quality Projects: For Evaluating Motor Vehicle Registration Fee Projects and Congestion Mitigation and Air Quality Improvement (CMAQ) Projects*. (See page 9 for more information about this publication.)

Two inputs, or variables, are of particular interest to Caltrans. Below is a brief description of these variables taken from the 2005 ARB guidance:

- **Variable 'A'** (default = .0020). Adjustment on ADT [average daily traffic] for auto trips replaced by bike trips from the bike facility. Determining parameters = ADT, Project Length, City Population, University Town or Not.
- **Variable 'C'** (default = .0005). Credit for Activity Centers near the project. Determining parameters = quantity, within ½ mile, within ¼ mile.

ARB's guidance provides additional context with regard to the 'C' variable:

When evaluating the impact of a new bike project, it is important to consider the location of the bike facility. What types of destinations are accessible from the project? How many of these activity centers are within one-half mile of the facility? How many are within a quarter of a mile? Examine the activity centers in the vicinity of the project and compare them to the list below. Select the credit factor that corresponds to the number of activity centers in the surrounding area.

ACTIVITY CENTERS CREDITS		
<i>Types of Activity Centers: Bank, church, hospital or HMO, light rail station (park & ride), office park, post office, public library, shopping area or grocery store, university or junior college.</i>		
Count your activity centers.	Credit (C)	Credit (C)
If there are...	Within 1/2 mile	Within 1/4 mile
Three (3)	.0005	.001
More than 3 but less than 7	.001	.002
7 or more	.0015	.003

Below is a formula from the 2005 ARB guidance that uses these variables:

$$\text{Annual Auto Trip Reduced} = (\text{D, or Days}) * (\text{ADT}) * (\text{A} + \text{C})$$

The result of the calculation above is used to determine the reduction in vehicle miles traveled and corresponding annual emission reductions in three pollutants. A capital recovery factor is calculated to be used in the final calculation of the cost-effectiveness of funding dollars, which is reported out for CMAQ projects as emission reductions of kilograms per day.

Findings from the literature search conducted for this Preliminary Investigation are presented in four topic areas:

- Tools and models.
- Bicycle networks.
- Facility and route preferences.
- Mode shift and mode share.

While some publications cited below address more than one topic area, each publication is presented only once in this report.

Tools and Models

The publications below are organized into four categories:

- California-related modeling practices.
- National guidance.
- State modeling practices.
- Other modeling-related research.

California-Related Modeling Practices

We begin below with the publication at the heart of this investigation—the 2005 ARB guidance that presents the model Caltrans seeks to revise. A December 2015 publication demonstrates how the ARB model, with minor modifications, can be used when allocating CMAQ funding. Also highlighted below is a 2016 Caltrans study that gathers data and conducts analysis to develop and validate models that estimate a bikeway project’s greenhouse gas (GHG) reductions. While this study does not specifically address modifications to the ARB model, its findings might inform an evaluation of ARB model factors.

Methods to Find the Cost-Effectiveness of Funding Air Quality Projects: For Evaluating Motor Vehicle Registration Fee Projects and Congestion Mitigation and Air Quality Improvement (CMAQ) Projects, Air Resources Board, California Environmental Protection Agency, May 2005.

https://www.arb.ca.gov/planning/tsaq/eval/mv_fees_cost-effectiveness_methods_may05.doc

This guidance, prepared in collaboration with Caltrans, provides step-by-step instructions for using CMAQ project parameters as inputs into formulas that produce cost-effectiveness measures in the form of dollars per pound reduced of three pollutants: reactive organic gases, nitrogen oxides and coarse particulate matter. The methods and factors described in this publication are used in conjunction with ARB’s latest emission factors to derive these estimates, which are used by project planners and sponsors to compare and select proposed projects.

The 2005 ARB guidance identified the following inputs needed to calculate the cost-effectiveness of bicycle facilities (see page 29 of the ARB guide):

- Funding dollars.

- Number of operating days per year.
- Average length of bicycle trips.
- Average daily traffic volume on roadway parallel to bicycle project (current maximum is 30,000).
- City population (current threshold set at 250,000).
- Project class (Class I and Class II only).
- Types of activity centers in the vicinity of the bicycle project (adjustment factors based on quantity and vicinity of ½ and ¼ mile).
- Length of bicycle path or lane.

Note: The ARB guidance addresses only Class I and Class II bikeways. There are four classes of bikeways in California:

- *Class I.* Bike paths or shared-use paths with exclusive right of way for bicyclists and pedestrians, away from the roadway and with cross flows by motor traffic minimized.
- *Class II.* Bike lanes established along streets and defined by pavement striping and signage to delineate a portion of a roadway for bicycle travel. Buffered bike lanes provide greater separation from an adjacent traffic lane and/or between the bike lane and on-street parking.
- *Class III.* Bike routes that designate a preferred route for bicyclists on streets shared with motor traffic not served by a dedicated bikeway; provides continuity to the bikeway network.
- *Class IV.* Separated bikeway, referred to as a cycle track or protected bike lane, for the exclusive use of bicycles. Physically separated from motor traffic with a vertical feature such as grade separation, flexible posts, inflexible posts or on-street parking.

The 2005 ARB guidance also provides the following descriptions of the references and methods used to derive the adjustment factors:

Documentation: Adjustment factors were derived from a limited set of bicycle commute mode split data for cities and university towns in the southern and western United States (Source: FHWA National Bicycling And Walking Study, 1992). This data was then averaged and multiplied by 0.7 to estimate potential auto travel diverted to bikes. On average, about 70% of all person trips are taken by auto driving (Source: 2000-01 Statewide Travel Survey), and it is these trips that can be considered as possible auto trips reduced. Finally, this number was multiplied by 0.65 to estimate the growth in bicycle trips from construction of the bike facility. Sixty-five percent represents the average growth in bike trips from a new bike facility as observed in before and after data for bike projects in U.S. DOT's "A Compendium of Available Bicycle and Pedestrian Trip Generation Data in the United States." Benefits are scaled to reflect differences in project structure, length, traffic intensity, community size, and proximity of activity centers. The scale has been adapted from a method developed by Dave Burch of the Bay Area Air Quality Management District (BAAQMD).

Note 1: Because ADT represents vehicles passing a single point, it may neglect vehicles that travel only a short distance on the corridor and, as a result, underestimate total vehicle trips. Therefore, the number of vehicles diverted to bicycles may be underestimated in this method. If actual vehicle trips in the corridor are known, this number should be used in place of ADT.

Note 2: Bicycle usage data is limited. From the data currently available, a positive correlation has been observed between the percentage of an area's arterials that have full width bike lanes, and the percentage of commuters who bike to work. Simply put, more bike lanes are associated with more bike commuting. More specifically, for an area with a given ratio of bike lanes to arterials, we observe that roughly one-fourth of that ratio is equal to the percentage of commuters that bike to work. More research and data are needed to confirm this relationship and to clarify the causes of this positive correlation.

Note: The publication below uses the 2005 ARB model with minor modifications. The adjustment for ADT and treatment of activity centers employed in the 2015 model are quite similar to the factors used in the original ARB model.

The authors note that the ARB model is widely used, simple and widely applicable. The authors consider the Benefit-Cost Analysis of Bicycle Facilities model, described in the 2006 publication NCHRP Report 552, to be the "next simplest nationally applicable methodology," but that model "requires GIS analysis to identify the number of residents living near a planned facility." (See page 16 of this Preliminary Investigation for information about NCHRP Report 552: Guidelines for Analysis of Investments in Bicycle Facilities.)

Methodology for Assessing the Benefits of Active Transportation Projects, Eliot Rose and James Choe, The Trust for Public Land's Climate-Smart Cities, December 2015.

<https://www.tpl.org/sites/default/files/Climate-Smart%20Cities%20Methodology%20Active%20Transport%20report.pdf>

The authors of this report use the ARB methodology for estimating reductions in vehicle trips and vehicle miles traveled due to bicycle facilities but expand its focus. The revised methodology "converts reduced vehicle trips and vehicle miles traveled due to bicycle and pedestrian trails not only to reductions in GHG emissions and air pollutants, but also to household transportation cost savings. The methodology avoided deaths using factors drawn from best practices and peer-reviewed research. Wherever possible, we use factors that are recommended by federal agencies, including the Environmental Protection Agency and the Internal Revenue Service."

The authors note that "[s]everal metropolitan planning organizations (MPOs) have applied the ARB methodology when allocating CMAQ funding, and a few have added updates that we incorporate into our methodology. Whereas the ARB methodology focused exclusively on bicycling, the Maricopa Association of Governments (MAG) assumes that trails also induce a shift from driving to walking and uses the same calculations to quantify reduced vehicle trips due to walking as for bicycling. The Atlanta Regional Commission (ARC) incorporates this assumption and also captures mode shift to transit for trails that connect to stations."

Tables 1 and 2, appearing on page 13 of the report (page 15 of the PDF), summarize the adjustment factors and activity center credits used in the methodology. These factors are quite

similar to those used in the original ARB methodology, but there are subtle differences (for example, ADT categories apply only university or nonuniversity distinction and not general population). A summary of all variables used in the methodology begins on page 15 of the report (page 17 of the PDF). Detailed references that describe the publications used by the authors as source material and provide perspective on some of the authors' metrics begin on page 42 of the report (page 44 of the PDF).

Note: The 2016 Caltrans research report cited below examines data and modeling that could be helpful to an in-depth examination of the ARB model.

Toward Accurate and Valid Estimates of Greenhouse Gas Reductions From Bikeway Projects, Juan Matute, Herbie Huff, Jamie Lederman, Diego de la Peza and Kevin Johnson, California Department of Transportation, July 2016.

http://www.dot.ca.gov/research/researchreports/reports/2016/CA17-2919_FinalReport.pdf

In the report's introduction, researchers noted that this project was designed to produce "data and analysis to support the development and validation of models that incorporate demographic data and changes in travel behavior when estimating GHG reductions. These models can form the basis [for] decision-support tools for state agencies allocating bikeway funds, for state decision-makers programming cap and trade funds, and for local agencies who may be implementing climate action plans or simply prioritizing local transportation projects."

Though researchers note that a larger data set is needed for development of a more robust model, the work in this project identified key parameters that drive GHG emissions reductions and developed a useful model that can be improved with additional data. Below are excerpts from the report that relate to inputs currently used in the 2005 ARB model:

Ridership

- Some cities and researchers have conducted ridership studies that analyze count data from before and after bikeway changes. Ridership change findings from these reports were collected and incorporated into the authors' dataset. The authors highlighted Portland State University's *Lessons From the Green Lanes* study as being a significant source of data (see page 25 of this report for a citation for this study).
- Because ridership increase is roughly proportional to volumes before facility installation, sites where people are already bicycling are likely to have greater ridership increases. Bicycle counts at candidate bikeway sites would allow agencies to discern this.
- Recreational trips tend to draw a greater proportion of trips from cars than utilitarian trips (18 percent vs. 10 percent). This finding is notable because bikeway infrastructure funding programs have often focused on utilitarian trips, or even specifically commute trips.
- There is little research on how demographics that correlated with levels of cycling at the city, region or state level impact changes in ridership at the facility level.

Bicycle Volumes

- Volume before facility installation, along with the age of the bikeway, are the parameters most closely related to the current bicycle volume. The authors did not find a clear relationship between facility type (cycle track vs. bicycle lane with striping only) and bicycle volumes.
- The authors found no relationship between volumes before facility installation and the percent change in ridership. This is notable because it implies that ridership change can be predicted reasonably reliably by volumes observed before facility installation.

Facility Characteristics

- Physically separated bikeways draw a greater proportion of trips from cars relative to striped bicycle lanes (14 percent vs. 7 percent).
- Facility installation year is correlated with ridership change, with older facilities having larger ridership changes. This is consistent with the hypothesis that bikeways have long-term effects on behavior that are difficult to observe in intercept surveys.

Related Resource:

“Estimating Greenhouse Gas Reductions From Prospective Bikeway Projects,” Juan Matute, Jaimee Lederman and Herbie Huff, *Transportation Research Board 97th Annual Meeting*, Paper #18-01242, January 2018.

Citation at <https://trid.trb.org/view/1494800>

From the abstract: An approach was sought to accurately and validly model emissions-generating and activities, including changes in traveler behavior and thus GHG emissions in the wake of bikeway projects. The study created a consequential life-cycle assessment model for GHG emissions resulting from bikeway construction and use by those who formerly used cars, used transit, cycled on other routes, walked, or did not make trips. Intercept surveys were conducted at 20 new bikeway facilities across Los Angeles County to understand the changes in travel induced by the bikeway. Though far less GHG emissions are attributable to cycling than driving, not all prospective bikeways reduce life-cycle GHG emissions, but many do. This paper specifies the conditions under which a bikeway is more likely to reduce GHG emissions. This paper also makes recommendations to adjust an existing method used to estimate reductions in GHG emissions from bikeway projects. This research can play a key role to support future decisions to use revenues tied to GHG reductions for expenditures on bicycling infrastructure and programs.

National Guidance

Guidebooks from Federal Highway Administration provide information about the development of performance measures, metrics and models that could inform the factors Caltrans uses in modeling the impacts of bicycle-related projects.

Guidebook for Developing Pedestrian and Bicycle Performance Measures, Conor Semler, Adam Vest, Karla Kingsley, Susan Mah, Wayne Kittelson, Carl Sundstrom and Kristen Brookshire, Federal Highway Administration, March 2016.

http://www.myphip.org/content/sites/bassett/Mark_Fenton/Guidebook_for_Developing_Pedestrian_Bicycle_Performance_Measures.pdf

This report provides detailed information about a wide range of performance measures that can be used to assess bicycling and pedestrian performance.

Below is an example of how the report presents information about access to community destinations, the proximity of pedestrian, bicycle and transit infrastructure and services to origins and destinations (e.g., shopping, recreation, entertainment, etc.):

There are a variety of methods for evaluating the transportation network's effectiveness in providing access to community destinations. Each of the following measures can substitute travel time (e.g., 20 minutes) for distance (e.g., ½ mile) or vice versa:

- Proportion of residences within a ½-mile walking distance or 2-mile biking distance to specific key destinations, such as parks or elementary schools.
- Proportion of residences within ½-mile walking distance or 2-mile biking distance to specific key destinations along a completed pedestrian or bicycle facility.
- Proportion of residences with access to a predefined set of “community destinations” within a 20-minute walk or 20-minute bike ride.
- Percent of the network complete for pedestrians and bicyclists within ½ mile and 2 miles respectively of each designated destination.
- Number of destinations that can be accessed within a ½ mile along a walking network from a given point on the network.
- Number of destinations within 3 miles along a bicycling network from a given point on the network.

The report provides examples of how this metric is used:

- Oregon DOT Region 1 used “access to destinations” in the Active Transportation Needs Inventory project to help inform the evaluation and prioritization of bicycle and pedestrian investments.
- Portland, Oregon, set a 90 percent target of households within 20 minutes walking or bicycling to daily needs.
- The Atlanta Regional Commission (ARC) tracks proximity to key regional destinations—including transit, home/work, and regional trails—to assess the regional distribution of walking and bicycling potential, opportunity, and equity. ARC uses active transportation travelsheds (1 to 3 miles) and 20-minute neighborhoods as regional planning frameworks.

- The Indianapolis MPO's Central Indiana Regional Bikeways Plan tracks educational institutions, parks, recreation and fitness locations, and other destinations. Proximity and access to these destinations can make up to 23 percent of a project's score for determining priorities.

Additional metrics that may be of interest to Caltrans:

- Connectivity indices, which represent a number of specific measures used to assess walking and biking connectivity in a specific area (see page 50).
- Density of destinations, the number of desirable destinations (e.g., jobs, homes, recreation, shopping, etc.) within a specific area (see page 58).
- Level of service, described as "a quality of service measurement that reflects how users may perceive a service condition (e.g., delay, travel time, speed, comfort). Pedestrian and bicycle level of service can be assessed through various methodologies depending on context and desired outcomes, but generally focus on assessing comfort levels under specific situations. Examples of tools used by transportation agencies to track level of service are provided (see page 69).
- Network completeness, the portion of the transportation network that is usable for people walking or bicycling, and represents the minimum accommodations needed for a facility to be considered part of the walking or bicycling network (see page 74).

NCHRP Report 803: Pedestrian and Bicycle Transportation Along Existing Roads—ActiveTrans Priority Tool Guidebook, 2015.

Report available at <https://www.nap.edu/catalog/22163/pedestrian-and-bicycle-transportation-along-existing-roads-activetrans-priority-tool-guidebook>

From the foreword: This guidebook presents the "ActiveTrans Priority Tool (APT)," a step-by-step methodology for prioritizing improvements to pedestrian and bicycle facilities, either separately or together as part of a "complete streets" evaluation approach. The methodology is flexible, allowing the user to assign goals and values that reflect those of the agency and the community. It is also transparent, breaking down the process into a series of discrete steps that can be easily documented and communicated to the public. The guidebook is supplemented by a CD that contains a programmed spreadsheet to facilitate implementation of the ActiveTrans methodology, as well as a final report that documents the research approach, findings and conclusions. The guidebook will be very useful to planners and other staff responsible for the most effective allocation of scarce resources to where they will provide the most benefit.

NCHRP Report 770: Estimating Bicycling and Walking for Planning and Project Development: A Guidebook, J. Richard Kuzmyak, Jerry Walters, Mark Bradley and Kara M. Kockelman, 2014.

Report available at <https://www.nap.edu/catalog/22330/estimating-bicycling-and-walking-for-planning-and-project-development-a-guidebook>

Chapter 5, Application of Methods, which begins on page 59 of the report (page 67 of the PDF), is considered the core of the guidebook. The authors note that "[u]ntil universal tools become available, the collection of tools in this guidebook offer a credible means to address a wide range of planning questions related to bicycle and pedestrian travel behavior and demand."

Other topic areas of interest:

- Factors affecting bicycling and walking (facilities) (see page 25 of the report, page 33 of the PDF).

- Factors affecting bicycling and walking (attitudes and perceptions) (see page 28 of the report, page 36 of the PDF).
- Addressing the gaps in methods for estimating bicycle demand (see page 33 of the report, page 41 of the PDF).
- Facility-use estimation models (see page 53 of the report, page 61 of the PDF).

NCHRP Report 552: Guidelines for Analysis of Investments in Bicycle Facilities, 2006.
https://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_552.pdf

From the report description:

TRB's National Cooperative Highway Research Program (NCHRP) Report 552: Guidelines for Analysis of Investments in Bicycle Facilities includes methodologies and tools to estimate the cost of various bicycle facilities and for evaluating their potential value and benefits. The report is designed to help transportation planners integrate bicycle facilities into their overall transportation plans and on a project-by-project basis. The research described in the report has been used to develop a set of web-based guidelines, available on the Internet at <http://www.bicyclinginfo.org/bikecost/> [this link is now <http://www.pedbikeinfo.org/bikecost/>] that provide a step-by-step worksheet for estimating costs, demands and benefits associated with specific facilities under consideration.

Chapter 2, Measuring and Forecasting the Demand for Bicycling, which begins on page 21 of the report (page 29 of the PDF), includes a discussion of a literature review and the draft sketch planning method the authors developed for measuring and predicting bicycling demand. As the authors note, “[t]he method develops ranges of estimates from limited and easily available datasets.” A description of the benefit-cost analysis tool developed in this project, including the general inputs, begins on page 40 of the report (page 48 of the PDF).

Related Resource:

“Analysing the Benefits and Costs of Bicycle Facilities via Online Guidelines,” Kevin J. Krizek, Gavin Poindexter, Gary Barnes and Paul Mogush, *Planning, Practice and Research*, Vol. 22, No. 2, pages 197-213, May 2007.

<http://kevinjkrizek.org/wp-content/uploads/2012/04/Benefits-costs-via-guidelines.pdf>

From the introduction:

This research introduces a web-based tool, Guidelines for Analysis of Investments in Bicycle Facilities (‘the guidelines’), which provides planners, policy officials and decision-makers with a consistent framework to guide decisions about cycling facilities. This article serves to sketch the overall analysis strategies used to uncover reliable estimates of their costs and benefits. Our purpose herein is to provide an overview piece--applicable to practising planners and of interest to the general research community--as other publications individually describe many of the detailed analyses underlying many of the specific findings described herein. The reader is encouraged to consult several other publications that provide much of underlying primary research on which the guidelines are based (referenced in later sections, where appropriate).

The authors note that they “continue to conduct primary and secondary research to best account for:

- The number of new users induced by constructing a new bicycle facility. What research can be relied on to demonstrate the phenomenon, ‘if you build it, they will come.’
- The drawing power of different bicycle facilities for cycling for recreation versus cycling for commuting.
- The differing impact of bicycle facilities by population segments. A new off-road facility may have a larger impact for families with children versus more skilled cyclists with fewer constraints related to their cycling environment.
- The differences in cyclists’ value of time. Individuals may value time differently by geography (urban versus rural areas), temporally (morning versus evening), purpose (commuting versus recreational travel) etc.
- The differences in having a tool available for general purposes that enable comparisons across a variety of settings versus tailoring it for relatively specific applications.”

State Modeling Practices

Tools for Estimating VMT Reductions From Built Environment Changes, Anne Vernez Moudon and Orion Stewart, Washington State Department of Transportation, June 2013.
<http://depts.washington.edu/trac/bulkdisk/pdf/806.3.pdf>

Page 14 of the report (page 22 of the PDF) provides Table 2: Professional Tools for Estimating Travel and GHG Based on Land Use and Transportation Inputs, which offers an extensive list of professionally oriented tools that can assist planners in estimating the impact of various land use and development scenarios on travel. Among the tools cited here is Conserve by Bicycling and Walking, a tool developed by Florida Department of Transportation (DOT) designed to estimate corridor-level walking and bicycle use, as well as fuel and CO₂ generation savings and health benefits. (See below for more information about the Florida DOT tool.)

The authors also examined literature that addresses the factors associated with travel behavior and mode choice, noting this with regard to bicycle preferences:

- A study of cycling in Portland, Oregon, suggests that streets with bicycle infrastructure and low traffic volumes are preferred by cyclists, who also attempt to minimize waits at traffic signals and signs (or perhaps try to avoid pedaling more to regain momentum after a stop) (Dill and Gliebe 2008).
- A King County (Washington) study found that proximity to a trail was one of the only objectively measured neighborhood built environment correlates of cycling, similarly suggesting that cyclists prefer cycle infrastructure and attempt to avoid traffic (Moudon, Lee et al. 2005).

Conserve by Bicycle Study, Bicycle and Pedestrian Reports, State Safety Office, Florida Department of Transportation, 2018.

<http://www.fdot.gov/safety/4-Reports/Bike-Ped-Reports.shtm> (scroll down to “Conserve by Bicycle Phase 1 Study” and “Conserve by Bicycle Phase 2 Study”)

This web page provides links to various elements of a multiphase research study aimed at “quantifying the benefits of bicycling and bicycling encouragement.” Models developed for this study are used to predict corridor-level bicycling and walking use.

The second phase of this two-phase project involved enhancing a worksheet-based tool to calculate energy savings and health benefits associated with the predicted number of recreational and utilitarian bicycle and pedestrian trips for a roadway corridor.

Four factors were found to influence shifts from motoring to cycling on corridors of main roads:

- Higher "bicycle level of service" (perceived safety and comfort for cyclists) of the main road, or of a parallel shared-use path where available.
- Greater "bicycle network friendliness," i.e., greater extent and perceived quality (bicycle level of service) of cycling accommodation in the street network in the area surrounding the roadway.
- Shorter average trip length of travelers using the roadway.
- Greater density of the (arithmetic) product of population and employment in the area surrounding the roadway.

With data for the same 17 corridors and 25 others, another model was developed to predict frequency of recreational (i.e., all nonutilitarian) cycling trips. Five factors corresponded to increased recreational cycling in a corridor:

- Greater length of bicycle facility.
- Presence of a shared-use path, or roadway conditions with higher (perceived) quality of accommodation for cycling.
- Better aesthetic quality (including landscape interest) of a route.
- More points of interest (including amenities) along a route.
- Greater distance-weighted density of population near the facility.

Related Resources:

Phase I Report: Conserve by Bicycle Program Study, Florida Department of Transportation, June 2007.

https://nacto.org/docs/usdg/conserve_by_bicycle_fl_dot.pdf

Researchers developed the Phase I mode shift model to predict the number of existing motorized trips that will be shifted to nonmotorized modes due to the enhancement, construction or provision of bicycle and pedestrian facilities along a corridor.

Phase I Report: Appendices A through P, Conserve by Bicycle Program Study, Florida Department of Transportation, June 2007.

<http://www.fdot.gov/safety/4-Reports/Bike-Ped/CBBphase1%20Apps%20A-P.pdf>

This collection of appendices includes:

- Appendix H: Sensitivity Analysis, Mode Shift Model, by Facility Type.
- Appendix I: Sensitivity Analysis, Mode Shift Model, by Trip Length.
- Appendix J: Sensitivity Analysis, Induced Recreational Model: Varying Aesthetics, Points of Interest and Facility Type.
- Appendix K: Sensitivity Analysis, Induced Recreational Model: Varying Facility Length and Facility Type.

- Appendix L: Sensitivity Analysis, Induced Recreational Model: Varying Aesthetics, Points of Interest, Facility Length and Facility Type.

Phase II Report: Appendices, Conserve by Bicycling and Walking, Florida Department of Transportation, October 2009.

https://www.fdot.gov/docs/default-source/content-docs/safety/4-reports/bike-ped/CBBPhase-2-final-report_appendices.pdf

The Bicycle and Pedestrian Facility Benefits Calculator: User Guide begins on page 7 of the document.

“Estimating Land Use Effects on Bicycle Ridership,” Yuchen Cui, Sabyasachee Mishra and Timothy F. Welch, *TRB 94th Annual Meeting Compendium of Papers*, Paper #15-5542, 2015.
http://www.ce.memphis.edu/Proceedings/2015_TRB_LU_15_5542.pdf

The authors of this conference paper propose a series of spatial lag empirical models and apply them to the state of Maryland. The models are designed to explore land use, built environment, demographic, socioeconomic and travel behavior connections to bicycle ridership. Findings include:

- Urban, suburban and rural models show that land use patterns, socioeconomic, demographic, network and travel characteristics are positively correlated with bicycle ridership.
- Urban and suburban areas are sensitive to a change in population and school enrollment but not to changes in household density, which is a significant predictor of bicycle ridership in rural areas.
- The impacts of employment on bicycle ridership also vary by spatial topology and by employment type. This result suggests that bicycling is more attractive in densely populated neighborhoods, where limited parking space and stringent speed limits may discourage vehicle trips.
- The density of higher income (over \$60,000 annually) households and greater levels of vehicle ownership are consistent with decreased bicycle mode shares.
- A number of land-use variables such as the number of retail locations and the number of recreational locations had a positive influence on bicycle ridership in the urban and suburban models, which is consistent with findings of other studies that indicate if urban development provides opportunities for discretionary activities by locating retail stores and recreational centers in residential neighborhoods, it is likely to promote bicycling and improve general public health in these areas.
- Transit accessibility has the potential to increase bicycle trip frequency in suburban and rural areas.

Other Modeling-Related Research

“A Sinusoidal Model for Seasonal Bicycle Demand Estimation,” Nicholas Fournier, Eleni Christofa and Michael A. Knodler Jr., *Transportation Research Part D: Transport and Environment*, Vol. 50, pages 154-169, January 2017.

Citation at <https://www.sciencedirect.com/science/article/pii/S1361920916301729?via%3Dihub>
From the abstract: Estimating bicycle demand is difficult not only due to limited count data, but to the fact that bicyclists are highly responsive to a multitude of factors, particularly seasonal weather. Current estimation methods capable of accurately adjusting for seasonal demand change often require substantial data for ongoing calibration. This makes it difficult or

impossible to utilize those methods in locations with minimal continuous count data. This research aims to help mitigate this challenge by developing an estimation method using sinusoidal model to fit the typical pattern of seasonal bicycle demand. This sinusoidal model requires only a single calibration factor to adjust for scale of seasonal demand change and is capable of estimating monthly average daily bicycle counts (MADB) and average annual daily bicycle counts (AADB). This calibration factor can be established using a minimum of two short-term counts to represent the maximum and minimum monthly MADB in summer and winter. To develop the model, this research use data from bike-share systems in four cities and 47 permanent bicycle counters in six cities. Although this model is not suitable for locations with mild or atypical seasons, it successfully models MADB and serves as a useful alternative or supportive estimation method in locations where minimal demand data exist.

Note: While this literature search focuses on domestic resources, the conference paper below, authored by researchers from McGill University in Montreal, Quebec, Canada, is included given its likely relevance to bicycle-related modeling conducted in the United States.

“Methods for Improving and Automating the Estimation of Average Annual Daily Bicyclists,” David Beitel and Luis F. Miranda-Moreno, *TRB 95th Annual Meeting Compendium of Papers*, Paper #16-2842, 2016.

<http://docs.trb.org/prp/16-2842.pdf>

From the abstract: Average Annual Daily Bicyclists (AADB) is commonly used by researchers and practitioners as a metric for cycling studies (demand analysis, infrastructure planning, injury risk, etc.). It is estimated in one of two ways: by averaging the daily cyclist totals measured throughout the year using a long-term automatic bicycle counter, or by using a long-term bicycle counter to extrapolate data from a short-duration counting site. AADB extrapolation is a process that can face two issues: it can produce considerable errors when using traditional factoring methods, and it is laborious as many steps in the process require manual validation. To help lessen these two problems, this study proposes a novel methodology that can reduce estimation error and facilitate automation of the AADB estimation process. The proposed methodology performs AADB estimation in a three-step process: data validation, matching and extrapolating. The data validation process can be the most laborious process, requiring a human to sift through large datasets in search for missing and erroneous values. A method is proposed for validating long-term bicycle demand data by using other available long-term bicycle demand data. Secondly, a matching process is proposed using k-means clustering and three indexes. Lastly, for the AADB extrapolation process, two novel disaggregated factor methods (DFM)s are proposed. The results are compared to the results obtained from a previously reported method, standard DFM. The first method, the DFM with filtering, improved the AADB estimation accuracy: average absolute error was 5.6% compared to 4.2%. The second method, the DFM with separate treatment of weekdays and weekends reduced AADB estimate error from 6.0% to 4.9%.

“Forecasting Pedestrian and Bicycle Demands Using Regional Travel Demand Models and Local Mode Share/Trip Distance Data,” Zachary Horowitz, David Parisi and John Replinger, *TRB 89th Annual Meeting Compendium of Papers DVD*, Paper #10-2482, 2010.

Citation at <https://trid.trb.org/view/910544>

From the abstract: Columbia River Crossing (CRC) staff, with input from the CRC’s Pedestrian and Bicycle Advisory Committee (PBAC), developed a methodology for forecasting year 2030 pedestrian and bicycle travel demands for an improved nonmotorized facility proposed for the

replacement Interstate 5 (I-5) Bridge across the Columbia River. Forecasts took into account three primary factors related to pedestrian and bicycle demand: existing and future land uses, percentage of trips by mode, and walking and bicycling trip lengths. During peak summer conditions in 2007, about 80 pedestrians and 370 bicyclists crossed the I-5 Bridge daily. Many other pedestrians and bicyclists are discouraged from doing so because of the existing non-standard facilities on the bridge and connecting multi-modal infrastructure. Future pedestrian and bicycle trips over the I-5 Bridge were forecast using a variety of data, including mode share data from the US Census, information from local travel surveys, results from a bicycle trip study conducted by Portland State University, and travel characteristics associated with the Hawthorne Bridge, the heaviest traveled bridge by pedestrians and bicyclists in the region. Average travel times by mode were converted into trip distances by mode, creating a matrix of pedestrian and bicycle mode shares by trip length. Future scenarios, developed for sensitivity testing, considered the forecasted number of trips from the regional travel demand model and factored them by the respective pedestrian and bicycle mode share percentages. The results were a range of daily pedestrian and bicycle forecasts, all of which showed a substantial increase in travel demand.

Bicycle Networks

The publications below examine how bikeway networks impact cycling levels and identify ways to measure bicycle networks. Several of these publications also highlight the need for better data collection methods and standardization in measurement that will allow for comparisons across time and place.

Guidebook for Measuring Multimodal Network Connectivity, Hannah Twaddell, Eliot Rose, Joseph Broach, Jennifer Dill, Kelly Clifton, Claire Lust, Kimberly Voros, Hugh Louch and Erin David, Office of Planning, Environment and Realty, Federal Highway Administration, February 2018.

https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/multimodal_connectivity/fhwahep18032.pdf

From the abstract:

The Guidebook for Measuring Multimodal Network Connectivity is a guide for transportation planners and analysts on the application of analysis methods and measures to support transportation planning and programming decisions. It describes a five-step analysis process and numerous methods and measures to support a variety of planning decisions. It includes references and illustrations of current practices, including materials from five case studies conducted as part of the research process.

The publication includes fact sheets on connectivity analysis methods and measures for the following:

- Network completeness.
- Network density.
- Route directness.
- Access to destinations.
- Network quality.
- Bicycle level of service.
- Bicycle level of traffic stress.
- Bicycle low stress connectivity.
- Bicycle route quality index.

“Bikeway Networks: A Review of Effects on Cycling,” Ralph Buehler and Jennifer Dill, *Transport Reviews*, 2015.

https://pdfs.semanticscholar.org/7624/f1829ef5b4babfe5e98a98cf914f98cc8619.pdf?_ga=2.111505549.80931889.1538062778-1719725947.1538062778

While most studies suggest a positive relationship between bikeway networks or aspects of the network and cycling levels, researchers noted that an examination of the connection between bikeway infrastructure and cycling levels requires additional research, including:

- *Analyzing the role of specific types or features of bikeway facilities or intersection treatments.* There is a lack of studies identifying the role of the quality of the facility, exact design or specific location. New research could also explore the use of bollards vs. curbs for cycle tracks, one-way vs. two-way cycle tracks, contraflow bike lanes in one-way streets for cars, shared bus and bicycle lanes, or sharrows.
- *Considering the link between ridership with newer (innovative) types of infrastructure, particularly intersection treatments.* More research is needed on the effect of bicycle-specific treatments, including bike boxes, traffic signals and two-stage queue boxes, and treatments where cycle tracks reach intersections (including the newly emerging concept of protected intersections), on perceptions and cycling levels. However, effects of these treatments on ridership likely need to be assessed in the context of the larger network. More studies are also needed on the effects of bicycle boulevards and other traffic-calming infrastructure.
- *Measuring bikeway networks.* Using network measures can reveal whether the effect of the network is greater than the sum of its parts. Network measures need to incorporate features of both links and nodes. Research has revealed that one single measure might not capture all of a network’s dimensions. Empirical research linking different measures of the network to cycling rates at the individual level are needed. Longitudinal studies and research on networks that explore how the built environment moderates the effect of the bikeway network are needed. This would include both the larger scale (e.g., land-use mix and access to destinations) and microscale (e.g., building scale and tree canopy).
- *Better and more systematic data collection on bikeway supply and cycling demand.* Standardization in the measurement and regular reporting of count and bikeway data (including standardized definitions of facilities) would help researchers track changes over time and compare across cities.

“The Missing Link: Bicycle Infrastructure Networks and Ridership in 74 US Cities,”

Jessica E. Schoner and David M. Levinson, *Transportation*, Vol. 41, No. 6, pages 1187-1204, November 2014.

<https://conservancy.umn.edu/bitstream/handle/11299/180047/MissingLink.pdf?sequence=1&isAllowed=y>

Researchers developed a standard methodology for measuring bicycle facility network quality at the macroscopic level and testing its association with bicycle commuting, systematically analyzing bicycle infrastructure maps for 74 U.S. cities to evaluate their network structure. Linear regression models revealed that connectivity and directness are important factors in predicting bicycle commuting after controlling for demographic variables and the size of the city.

This study treated on-street and off-street dedicated infrastructure (bike lanes and paved trails) interchangeably for purposes of measuring network structure because they both provide a designated space for bikes, versus newer or experimental treatments like shared lane markings or bike boulevards. Mixed traffic facilities such as shared lane markings, signed bike routes and bike boulevards were completely excluded because they vary so widely in quality and definition.

Researchers also highlighted findings from other related studies:

- Cyclists value the presence of a bike as equivalent to saving about 16 minutes of travel time, while off-road improvements add less value than a quiet street without on-street parking (5 and 9 minutes, respectively).
- Bicyclist comfort level in a bike lane varies based [on] buffers, barriers and on-street parking.
- The use of [the] Bicycle Compatibility Index to model the effects of building new dedicated bike infrastructure on compatible and incompatible streets points to the information missed by not evaluating the streets on which the bike lanes are built.

Researchers note that this study “sheds light on the desperate need for standardized data collection and management practices for bicycle infrastructure networks and nonmotorized travel behavior. Given more standardized data, future study should consider hierarchies of infrastructure types within bicycle networks and complementary street networks and what effects these have on bicycling.”

“Effect of Street Network Design on Walking and Biking,” Wesley Marshall and Norman Garrick, *Transportation Research Record 2198*, pages 103-115, 2010.

Citation at <https://trrjournalonline.trb.org/doi/10.3141/2198-12>

From the abstract: The objective of this research was to investigate whether a relationship existed between street network characteristics and the transportation modes selected in a neighborhood. Factors such as street characteristics, vehicle volumes, activity levels, income levels, and proximity to limited-access highways and the downtown area were controlled for. The results suggested that all three of the fundamental characteristics of a street network—street connectivity, street network density and street patterns—were statistically significant in affecting the choice to drive, walk, bike or take transit. Both increased intersection density and additional street connectivity were generally associated with more walking, biking and transit use. Street patterns with gridded street networks, which tended to have a higher-than-average street connectivity and a much higher street network density, were associated with much more walking and biking. These results suggested that street network patterns were extremely important for encouraging nonautomobile modes of travel. As the United States begins to focus on reducing vehicle miles traveled as a strategy to combat carbon production and cut energy use, it is increasingly imperative that this relationship between the built environment and mode choice be accounted for in the planning and design of the transportation system.

Facility and Route Preferences

Bicyclists' preferences are examined in the publications and other resources cited below, beginning with an NCHRP project in progress that is expected to conclude in early 2019. Other publications describe bicyclists' practices, perceptions and choices when presented with new bicycling facilities.

Project in Progress: NCHRP Project 08-102: Bicyclist Facility Preferences and Effects on Increasing Bicycle Trips, start date: June 2015; expected completion date: August 2019.

Project description at <http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3861>

From the project objectives: The objectives of this research are to provide guidance for predicting (1) the relative preference of current and potential bicycle users—by demographic groups including cyclist experience level—for various kinds of bicycle facilities in a variety of community environments; and (2) the relative effectiveness of various kinds of bicycle facilities for attracting new bicycle users and increasing bicycle travel by existing bicycle users.

Community environment should include factors that significantly influence bicycling levels, e.g., the extent of the bicycle network, community support, population and geography. Bicycle facilities should at least include on-road and off-road facilities, intersection traffic controls, and widely used as well as less common and newer types of facilities. Other factors to be considered in the research design may include the bicycle network operating conditions and level of service; climate and weather; and maintenance practices. The research approach should leverage both innovative and commonly used survey research and data collection techniques. The guidance should assist bicycle facility planners and designers in evaluating bicycle facility design alternatives and bicycle network development strategies, and travel demand forecasters in improving the performance of travel demand models.

“Biking Practices and Preferences in a Lower Income, Primarily Minority Neighborhood: Learning What Residents Want,” Anne C. Lusk, Albert Anastasio, Nicholas Shaffer, Juan Wu and Yanping Li, *Preventative Medicine Reports*, pages 232-238, September 2017.

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5575429/>

Researchers mailed surveys to 1,537 households near a proposed cycle track in Roxbury, Massachusetts, and to cyclists in the area to examine if, in a lower-income minority neighborhood, bicycling practices and preferences of blacks and Hispanics were different from whites. Results from these surveys were supplemented by observations noted about passing cyclists' characteristics. Among the researchers' conclusions:

- Minority populations are biking and have even adopted their own bike appearance.
- Cycle tracks in lower-income neighborhoods should be built wide enough for side-by-side riding because blacks and Hispanics want to ride with family and friends.

Tracking Bicyclists' Route Choices, Case Study: The Ohio State University, Gulsah Akar and Yujin Park, NEXTRANS Center (University Transportation Centers Program), August 2017. https://www.purdue.edu/discoverypark/nextrans/assets/pdfs/171OSUY2.2_Summary%20and%20Final%20Technical%20Report.pdf

From the concluding remarks on page 51 of the report (page 60 of the PDF):

The first part of this study uses data from the 2015 Campus Travel Pattern Survey. We explored the factors associated with individuals' bicycling choices and analyzed the shortest paths that these individuals would potentially take if they were to ride bicycles to campus. We found that potential bicyclists would encounter roads with multiple BLOSs [bicycle levels of service]. For instance, individuals may ride on road segments with 'moderate' or

'residential' BLOS near their neighborhoods and close to campus, but likely face 'poor' or 'moderate' road segments in between.

The second part of the study uses smartphone GPS data to analyze bicycle route preferences and their associations with facility types. The data were collect[ed] using a smartphone app *CycleTracks*. The results show that the most frequently used street segments among the chosen routes and the shortest routes are different in terms of their locations and characteristics. These suggest that riders preferred different segments as compared to those predicted by the shortest path algorithm. Following these results, we will conduct further analysis on the determinants of route choices, particularly focusing on the factors that are closely associated with the decision to detour and the degree of diversion.

Lessons From the Green Lanes: Evaluating Protected Bike Lanes in the U.S., Chris Monsere, Jennifer Dill, Nathan McNeil, Kelly Clifton, Nick Foster, Tara Goddard, Matt Berkow, Joe Gilpin, Kim Voros, Drusilla van Hengel and Jamie Parks, National Institute for Transportation and Communities, June 2014.

https://bikeportland.org/wp-content/uploads/2014/06/NITC-RR-583_ProtectedLanes_FinalReportb.pdf

Using video, surveys and count data, researchers evaluated protected bicycle lanes (cycle tracks) in five cities—Austin, Texas; Chicago, Illinois; Portland, Oregon; San Francisco, California; and Washington, D.C.—in terms of their use, perception, benefits and impacts. From the project's findings:

- A measured increase was observed in ridership on all facilities after the installation of the protected cycling facilities, ranging from +21 percent to +171 percent.
- Established routes that are key connections saw lower growth than new connections.
- Survey data indicates that 10 percent of current riders switched from other modes, and 24 percent shifted from other bicycle routes.
- Over a quarter of riders indicated they are riding more in general because of the protected bike lanes.
- Just over 49 percent of bicyclists indicated that they were traveling on the respective routes more frequently than they were prior to protected lanes.
- Nearly 89 percent of intercepted bicyclists agreed that the protected facilities were "safer" than other facilities in their city.
- Designs with more physical separation had the highest scores. Any type of buffer shows considerable increase in self-reported comfort levels over a striped bike lane.

See page 137 of the report (page 169 of the PDF) for the study's detailed conclusions. Among the topics addressed in detail are bicyclists' perceptions of design-related issues such as buffer designs, intersection treatments and support for the protected lane concept and its potential to attract new riders.

"Roadway Design Preferences Among Drivers and Bicyclists in the Bay Area," Rebecca L. Sanders, *TRB 93rd Annual Meeting Compendium of Papers*, Paper #14-5454, 2014.

<http://docs.trb.org/prp/14-5454.pdf>

Researchers present results from an internet survey examining perceived comfort while driving and bicycling on various roadways among 263 nonbicycling drivers, bicycling drivers and nondriving bicyclists in the Bay Area. Among the study's findings:

- Roadway designs with barrier-separated bicycle lanes were the most popular among all groups, regardless of bicycling frequency. Researchers noted that “[t]hese findings corroborate past research on bicyclists’ preferences. This evidence urges the reconsideration of design standards for multilane roadways—particularly for jurisdictions seeking to attract new cyclists.”
- Striped bicycle lanes received mixed reviews: a majority of the sample believed that they benefit cyclists and drivers through predictability and legitimacy on the roadway, but the lanes were rated significantly less comfortable than barrier-separated treatments—particularly among potential bicyclists.
- Researchers noted that “the single bicycle facility that several studies (this one included) have documented as overwhelmingly popular among potential and current cyclists, irrespective of gender, age and cycling frequencies—are still not in the official AASHTO Bikeway Design Guide. Arguably, this could and should be remedied through a special edition of the AASHTO guidelines, or perhaps AASHTO’s recognition of the guidance provided through the NACTO [National Association of City Transportation Officials] design guidance.”
- Researchers recommended future research that examines the risk of injury from collisions or near misses sustained while bicycling in the bicycle lanes painted in the “door zone” of the roadway. Survey data indicates that weekly and daily cyclists worry about the risk of being hit by a car door, and many have been hit or almost hit.

“Bicycle Route Choice Model Developed Using Revealed Preference GPS Data,” Joseph Broach, John Gliebe and Jennifer Dill, *TRB 90th Annual Meeting Compendium of Papers DVD*, 2011.

https://ppms.trec.pdx.edu/media/project_files/TRB2011_Bicycle%20route%20choice%20model%20developed%20using%20revealed%20preference%20GPS%20data.pdf

Researchers used GPS units to better understand the preferences for facility types of 164 cyclists in Portland, Oregon. Cyclists recorded trip purpose and several other trip-level variables, and the resulting trips were coded to 15 unusually large and dense travel networks. Among the study’s conclusions, which begin on page 12 of the conference paper (page 14 of the PDF):

- A new choice set generation algorithm, dubbed the Calibrated Labeling Method, was developed to generate reasonable sets of alternatives after existing methods proved unsatisfactory.
- Distance, turn frequency, slope, intersections, facility types and traffic volumes all contribute significantly to a route’s attractiveness to bicyclists.
- Results highlight the importance for policymakers and planners of not only building bike facilities, but building them well.
- Details like busy street crossing treatments, route “jogs” necessitating extra turns, and siting to avoid slopes greater than 2 percent may prove as or more important than the facility itself.
- Bike boulevards and off-street bike paths appear to have inherent value to cyclists beyond the detailed facility variables we were able to measure. In other words, there is something more to a bike boulevard than low traffic volumes, improved street crossings, and “flipped” stop signs. The something more may be explained by attributes we were unable to measure, such as parking and traffic speeds, or perhaps something more subtle like perceived safety in numbers or simplified navigation.

- For now, the question of how the Portland-based data will generalize to other places remains an open one. The model presented here is currently being implemented as a component of the regional travel demand forecasting model for the Portland region.

Related Resources:

Understanding and Measuring Bicycling Behavior: A Focus on Travel Time and Route Choice, Jennifer Dill and John Gliebe, Oregon Transportation Research and Education Consortium, December 2008.

<https://nacto.org/wp-content/uploads/2012/02/Dill-and-Gliebe-2008.pdf>

This is the research report summarized in the conference paper cited above. *From the abstract:*

The project used global positioning system (GPS) technology to record where a sample of 164 adults in the Portland, OR, region rode their bicycles. Data was collected from March through November 2007. The participants in this study were primarily regular bicyclists who usually rode more than one day per week, year-round. This report uses that data to address the four primary sets of research questions: (1) How often, why, when and where do cyclists ride? How does this vary based upon rider characteristics? (2) How do cyclists' routes differ from the shortest network distance? (3) What factors influence cyclists' route choice decisions? How do personal attributes influence these decisions? (4) What is the difference in travel time between bicycling and driving?

Clearing a Path for Bicycling Investments, Project Brief, Oregon Transportation Research and Education Consortium, undated.

https://ppms.trec.pdx.edu/media/project_files/Bike%20model%20brief.pdf

This two-page project brief provides more details of project findings:

- Cyclists are willing to detour from the shortest route for a variety of bicycle facilities, intersection characteristics and other factors.
- Separated bike paths are most attractive, followed by bike boulevards, the low-traffic neighborhood streets tailored for cycling.
- Cyclists will go 26 percent out of their way to use a separated path and 18 percent to use a bike boulevard.
- Cyclists will avoid turning left at a busy intersection without a traffic light, voluntarily detouring 16 percent of their trip distance. Routes with many jogs or turns are less attractive, with each additional turn equal to adding 7 percent of the trip distance.

The Effects of On-Street Parking on Cyclist Route Choice and the Operational Behavior of Cyclists and Motorists, Kristen Torrance, Ipek Sener, Randy Machemehl, Chandra Bhat, Ian Hallett, Naveen Eluru, Ian Hlavacek and Andrew Karl, Texas Department of Transportation, April 2009.

http://ctr.utexas.edu/wp-content/uploads/pubs/0_5755_1.pdf

This study evaluated the operational impacts of bicycling adjacent to on-street parking and the importance of attributes influencing bicyclists' route choice preferences. Researchers examined field data collected in Austin, Houston and San Antonio, Texas, using multivariate regression models that were developed to predict the motorist's and cyclist's position on the roadway and the probability of motor vehicle encroachment.

Researchers examined a specific set of attributes to evaluate their influence on route choice:

- Bicyclists' characteristics.
- On-street parking.
- Bicycle facility type and amenities.
- Roadway physical characteristics.
- Roadway functional characteristics.
- Roadway operational characteristics.

Study conclusions are presented on page 101 of the report (page 113 of the PDF):

- Evaluating the influence of numerous attributes through revealed preference data alone did not provide sufficient results. A stated preference methodology was undertaken to develop a web-based survey to gather additional data from bicyclists in Texas.
- Researchers used a panel mixed multinomial logit formulation to evaluate the trade-offs of the attributes.
- Results indicate that bicyclists prefer routes without on-street parking. Among the routes with parking, bicyclists prefer routes with angle parking.
- The study also highlights the preference for continuous bicycle facilities, lower traffic volume and lower roadway speeds as well as fewer stop signs, red lights, and cross streets.
- Bicyclists generally prefer moderate hills over flat terrain.
- The analysis clearly emphasizes the sensitivity of bicyclists to travel time, and the need to consider both route-related attributes and bicyclists' demographics when selecting and designing bikeways.

Related Resource:

“An Analysis of Bicycle Route Choice Preferences in Texas, US,” Ipek N. Sener, Naveen Eluru and Chandra R. Bhat, *Transportation*, Vol. 36, No. 5, pages 511-539, September 2009.

Citation at <https://trid.trb.org/view/903060>

From the abstract: Specifically, the paper examines a comprehensive set of attributes that influence bicycle route choice, including: (1) bicyclists' characteristics, (2) on-street parking, (3) bicycle facility type and amenities, (4) roadway physical characteristics, (5) roadway functional characteristics, and (6) roadway operational characteristics. The data used in the analysis is drawn from a web-based stated preference survey of Texas bicyclists. The results of the study emphasize the importance of a comprehensive evaluation of both route-related attributes and bicyclists' demographics in bicycle route choice decisions. The empirical results indicate that travel time (for commuters) and motorized traffic volume are the most important attributes in bicycle route choice. Other route attributes with a high impact include number of stop signs, red light, and cross streets, speed limits, on-street parking characteristics, and whether there exists a continuous bicycle facility on the route.

“Trails, Lanes or Traffic: Valuing Bicycle Facilities With an Adaptive Stated Preference Survey,” Nebiyu Y. Tilahun, David M. Levinson and Kevin J. Krizek, *Transportation Research Part A: Policy and Practice*, Volume 41, No. 4, pages 287-301, May 2007.

Citation at <https://www.sciencedirect.com/science/article/pii/S096585640600108X>

From the abstract: This study evaluates individual preferences for five different cycling environments by trading off a better facility with a higher travel time against a less attractive facility at a lower travel time. The tradeoff of travel time to amenities of a particular facility informs our understanding of the value attached to different attributes such as bike lanes, off-road trails or side-street parking. The facilities considered here are off-road facilities, in-traffic facilities with [a] bike lane and no on-street parking, in-traffic facilities with a bike lane and on-street parking, in-traffic facilities with no bike lane and no on-street parking and in-traffic facilities with no bike lane but with parking on the side. We find that respondents are willing to travel up to twenty minutes more to switch from an unmarked on-road facility with side parking to an off-road bicycle trail, with smaller changes associated with less dramatic improvements.

Mode Shift and Mode Share

The publications cited below consider bicycle mode shift and mode share in connection with a range of issues, including demographic characteristics, the built environment, facility type and bicyclist behavior.

“Effect of Bicycle Facilities on Travel Mode Choice Decisions,” Gregory M. Rowangould, and Mohammad Tayarani, *Journal of Urban Planning and Development*, Vol. 142, No. 4, December 2016.

Citation at <https://ascelibrary.org/doi/10.1061/%28ASCE%29UP.1943-5444.0000341>

From the abstract: Although there has been a large amount of behavioral and observational research on bicyclists' route and facility preferences and the traveling public's mode choice decisions, there is surprisingly little evidence on the effectiveness of bicycle facilities in increasing the share of bicycling relative to vehicle use. Using a stated-preference survey, this study finds that more than two-thirds of current bicycle facility users in Albuquerque, New Mexico, would continue to bicycle, and nearly one-third would discontinue bicycling, if the bicycle facilities they regularly use did not exist. The most common alternative would be driving a car. The findings suggest that bicycle facilities can increase bicycle mode share and reduce driving by influencing the mode choice decisions of certain individuals—namely, those with the least bicycling experience. Bicycle facilities may therefore play an important role in building new bicyclist confidence.

“Accounting for the Short Term Substitution Effects of Walking and Cycling in Sustainable Transportation,” Daniel P. Piatkowski, Kevin J. Krizek and Susan L. Handy, *Travel Behaviour and Society*, Vol. 2, No. 1, pages 32-41, January 2015.

Citation at <http://dx.doi.org/10.1016/j.tbs.2014.07.004>

From the abstract: The environmental benefits of bicycling and walking depend on the degree to which their use substitutes for car driving. Assuming that every walking and bicycling trip replaces a driving trip is likely to produce overestimates of the potential for such modes to reduce vehicle travel and city-scale greenhouse gas emissions. Measuring this “substitution effect” is not straightforward. There are many dimensions of the substitution effect, including trip type, substituting mode, extent, time horizon and activity patterns. Previously used approaches to measure substitution include indirect inference and direct questioning. This study piloted an intercept survey using the direct questioning approach at five locations in two metropolitan

areas. The rate at which utilitarian walking or cycling trips substituted for auto trips ranged between 25% and 86%. Logistic regression models demonstrate that disparate factors explain walking substitution and bicycling substitution behavior; age is significantly correlated with substitutive walking behavior while number of car trips per week and helmet use are each significant predictors of bicycle substitution. This research represents a valuable first step toward developing a method to estimate the substitution effect that is useful for practitioners. Better estimates of the substitution effect will in turn lead to better estimates of the environmental impacts of bicycling and walking.

Policy Brief: Impacts of Bicycling Strategies on Passenger Vehicle Use and Greenhouse Gas Emissions, Susan Handy, Gil Tal and Marlon G. Boarnet, Air Resources Board, California Environmental Protection Agency, September 2014.

https://www.arb.ca.gov/cc/sb375/policies/bicycling/bicycling_brief.pdf

See page 4 of this report for Table 2, Infrastructure Impact on Bicycle Use, which summarizes three studies that examine the impact of infrastructure projects. Each study considers a specific infrastructure variable (bike lanes, bicycle parking) and a mode variable (percent commuting by bicycle, probability of bicycling), and estimates the change in mode variable for a 1 percent increase in the infrastructure variable.

“Models for Anticipating Non-Motorized Travel Choices, and Role of the Built Environment,” Mobashwir Khan, Kara M. Kockelman and Xiaoxia Xiong, *TRB 92nd Annual Meeting Compendium of Papers*, Paper #13-1240, 2013.

Citation at <http://trid.trb.org/view.aspx?id=1240890>

From the abstract: This paper uses detailed travel data from the Seattle metropolitan area to evaluate the effects of built-environment variables on the use of non-motorized (bike + walk) travel modes. Several model specifications are used to understand and explain non-motorized travel behavior in terms of household, person and built-environment (BE) variables. Marginal effects of covariate effects for models of vehicle ownership levels, intrazonal trip-making, destination and mode choices, non-motorized trip counts per household, and miles traveled (both motorized and non-motorized) are presented. ... The results underscore the importance of street connectivity (quantified as the number of 3-way and 4-way intersections in a half-mile radius), higher bus stop density, and greater nonmotorized access in promoting lower vehicle ownership levels (after controlling for household size, income, neighborhood density and so forth), higher rates of non-motorized trip generation (per day), and higher likelihoods of non-motorized mode choices. Intrazonal trip likelihoods rose with street connectivity, transit availability, and land use mixing. Across all BE variables tested, street structure offered the greatest predictive benefits, alongside accessibility indices (for both motorized and non-motorized access). For example, non-motorized trip counts are estimated to rise 7% following a 1% increase in this variable, and walk probabilities by 27% following a one standard deviation increase in this index at the destination zone. Regional and local accessibility and density (of population plus jobs) variables were also important, depending on response being modeled. Simulated model applications illuminate when and to what extent significant travel behavior changes may be witnessed, as land use settings and other variables are changed.

Mode Shift: Philadelphia’s Two-Wheeled Revolution in Progress, Bicycle Coalition of Greater Philadelphia, May 2011.

<https://bicyclecoalition.org/wp-content/uploads/2014/01/MODE-SHIFT-REPORT1.pdf>

The Bicycle Coalition of Greater Philadelphia conducted fall counts in 2009 and 2010 at designated intersections and Schuylkill River bridges to document the number of bicyclists who pass by a particular point, cyclists' gender, helmet usage and behavior such as riding the wrong

way or riding on the sidewalk. The summary of findings that begins on page 1 of the report (page 5 of the PDF) includes the following conclusions:

- Bike lanes, and more bicyclists, lead to better behavior. Sidewalk riding drops from 19.8 percent on streets with no bike lane to 8.6 percent on streets with a bike lane to 2.4 percent on streets with a buffered bike lane. The Bicycle Coalition's counts document that, between 2006 and 2010, while helmet use has risen, sidewalk riding and riding the wrong way have fallen at all counted locations.
- Bicyclists like bike lanes, and they like buffered bike lanes even better. The Bicycle Coalition's counts found streets with bike lanes had more cyclists than streets without them, and had more growth in bicyclists than streets without bike lanes.
- They also have more female bicyclists, less sidewalk riding, less wrong way riding, and more cyclists wearing helmets than streets without bike lanes. The buffered bike lanes had the same result, but even more amplified. These results confirm that better behavior goes hand in hand with better bicycling facilities. Facilities like buffered bike lanes make bicyclists feel safer.

“Analyzing the Effect of Bicycle Facilities on Commute Mode Share Over Time,” Kevin J. Krizek, Gary Barnes and Kristin Thompson, *Journal of Urban Planning and Development*, Vol. 135, No. 2, pages 66-73, June 2009.

Citation at <https://trid.trb.org/view/890969>

From the abstract: This study employs United States census data to analyze changes in bicycle commuting between 1990 and 2000 in the Minneapolis-St. Paul, Minnesota area. A variety of perspectives are used to understand the impact of newly created facilities. The evidence suggests that bicycle facilities significantly impact levels of bicycle commuting, although the results are not totally free of uncertainty. For example, areas near new bicycle facilities showed considerably more of an increase in bicycle mode share than areas farther away. Observing increased cycling due to these physical interventions provides a starting point to which future research could add detail that would be needed to guide infrastructure investment.

The Impact of Bicycling Facilities on Commute Mode Share, Frank Douma and Fay Cleaveland, Minnesota Department of Transportation, August 2008.

<https://www.lrrb.org/pdf/200833.pdf>

Researchers sought to build on findings from a 2005 study that examined how the addition of bicycling facilities during the 1990s influenced commuting rates in the Twin Cities. By applying the same methodology to six cities (Austin, Texas; Chicago, Illinois; Colorado Springs, Colorado; Salt Lake City, Utah; Madison, Wisconsin; and Orlando, Florida), researchers were interested in identifying “possible contextual factors influencing facilities’ impact on bicycle commuting rates in a given city.”

Page 16 of the report (page 24 of the PDF) presents the study's findings and identifies three key themes in the cities that experienced bicycling commute mode share increases in connection with new bicycling facilities:

- *Location of facilities along usable commuting routes.* Bicycling facilities lead from distant parts of the city and converge in the downtown employment hub. Bicycling facilities are most effective in highly accessible urban areas where a large number of commute trips can take place across short distances. In locations where bicycling facilities could provide viable commuting routes between residential and employment concentrations, increases in bicycle commuting rates were likely to occur.

- *Overall network connectivity.* Numerous intersections among trails allow a bicyclist to easily navigate from one section of the city to another. The addition of bicycling facilities relocated existing commuters but did not bring new block groups, and therefore commuters, into the network.

Network connectivity is one reason why the off-street facilities used in this study may not have shown the same increases in localized commuting rates as on-street trails. Construction of off-street facilities often depends on the availability of right of way, frequently found along creek beds and former rail lines. Because the primary determinant of off-street facility location may not be its relationship to other destinations, these facilities are not always situated to significantly enhance bicycle commute mode share. A separate effort focused on evaluating the uses of off-street facilities would be highly valuable in discerning their effectiveness at promoting non-motorized travel.

- *Amount of publicity and promotion dedicated to new bicycling facilities.* A bicycling facility can only be adopted by commuters if they are aware of its existence and excited to adopt bicycles as their commute mode. Promotion by city leaders is a critical component to a bicycle facility's effectiveness.

Researchers noted that while this study identifies several qualitative factors that contribute to the success of city bicycle facilities, a "methodology that quantitatively identifies and measures qualitative indicators could provide useful insight and guidance as to how city policy-makers could best address bicycle commuting in their city."