NCHRP

REPORT 552

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Guidelines for Analysis of Investments in Bicycle Facilities

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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SUBJECT AREAS
Planning and Administration • Highway and Facility Design

Research Sponsored by the American Association of State Highway and Transportation Officials
in Cooperation with the Federal Highway Administration

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WASHINGTON, D.C.
2006
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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NCHRP REPORT 552

Price $36.00

Project 7-14

ISSN 0077-5614

ISBN 0-309-09849-1

Library of Congress Control Number 2006922678

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Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at:
http://www.national-academies.org/trb/bookstore

Printed in the United States of America

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FOREWORD

By Christopher J. Hedges
Staff Officer
Transportation Research Board

This report presents methodologies and tools to estimate the cost of various bicycle facilities and for evaluating their potential value and benefits. The results will help transportation planners make effective decisions on integrating bicycle facilities into their overall transportation plans and on a project-by-project basis. In the past, planners and stakeholders have been faced with considerable challenges in trying to estimate the benefits of bicycle facilities. The authors have developed criteria for identifying benefits that will be useful and effective for urban transportation planning, and they have provided a systematic method to estimate both direct benefits to the users of the facilities and indirect benefits to the community. 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/ that provide a step-by-step worksheet for estimating costs, demands, and benefits associated with specific facilities under consideration.

Transportation decision makers at the federal, state, and local levels are examining the role of bicycling in response to traffic congestion, increased travel times, and environmental degradation. Through federal highway legislation, funding has been made available to develop bicycle facilities, both on and off road; however, greater public investment in bicycle facilities warrants a more comprehensive analysis of the costs and benefits. The U.S. DOT *National Bicycling and Walking Study* (1994) called for doubling the percentage of trips made by bicycling and walking to 15 percent of total trips. To make the best use of transportation funds, there is a need for better information on (a) the effects of bicycle-facility investment on bicycle use and mode share and (b) the resulting environmental, economic, public health, and social benefits. Under NCHRP Project 07-14, "Guidelines for Analysis of Investments in Bicycle Facilities," a research team led by the University of Minnesota conducted an extensive analysis of the costs and benefits associated with bicycle facilities and developed a methodology that can be applied by transportation planners to assist with decision making in their own jurisdictions. The research results were used to develop web-based, step-by-step guidelines for evaluating the cost, demand, and potential benefits for bicycle facilities in support of investment decisions. These guidelines are available on a website maintained by the Pedestrian and Bicycle Information Center (PBIC) at www.bicyclinginfo.org/bikecost/. The PBIC is a clearinghouse for information about health and safety, engineering, advocacy, education, enforcement, and access and mobility. The interactive guidelines lead the user through a series of questions, starting with the geographic location and the type of facility under consideration, and working through more specific issues to an estimate of the costs, demand, and potential benefits of the proposed facility.

PBIC is funded by the U.S. DOT and the Centers for Disease Control and Prevention. The PBIC is part of the University of North Carolina Highway Safety Research Center.

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SUMMARY

BACKGROUND

Transportation planning and policy efforts at all levels of government aim to increase levels of walking and bicycling. To make the best use of limited transportation funds there is a critical need for better information about two important considerations relating to bicycle facilities. The first of these is the cost of different bicycle investment options. The second is the value of the effects such investments have on bicycle use and mode share, including the resulting environmental, economic, public health, and social benefits. Decisions on transportation projects are typically based on the potential for the project to contribute to broad public policy goals. As such, information on the benefits and costs of bicycle facility projects will help decisionmakers develop modal options and provide travelers with more transportation choices.

ESTIMATING BICYCLE FACILITY COSTS

The purpose of the benefit-cost analysis is to provide transportation planners with information to estimate costs of different types of bicycle facilities. The facilities described are generic and independent of specific locations. The discussion therefore provides a preliminary cost estimate. As more specific information is gathered about a proposed facility, the planner, engineer, or project manager can develop more refined estimates to reflect these specifics or replace them with more detailed project-specific estimates.

Costs for infrastructure projects are commonly divided into two major categories: capital costs and operating costs. Capital costs are expenditures for constructing facilities and procuring equipment. These are viewed as one time costs that have both a physical and an economic life of multiple years. Capital facilities and equipment have a multi-year life, and therefore are assets whose value can be amortized over time and financed over time with instruments such as municipal bonds.

Operating costs generally result in no tangible asset. Such recurring expenses are commonly funded through annual budgets. Operating costs for public facilities include maintenance such as cleaning, landscaping, equipment repair, security and safety, and supplies needed to conduct these activities. Some or all of these operating costs may be

subsumed into public agency operating budgets and be difficult to identify as discrete project-specific costs.

In this report, bicycle facilities are divided into three categories: on-street, off-street, and equipment. A bicycle facility project may include elements in one or more categories. There are different facility types within each of the categories, each of which are grouped in the cost model as described below.

- On-Street Facilities: On-street bicycle facilities include bike lanes, wide curb lanes, shared streets, and signed routes.
- Off-Street Facilities: Off-street bicycle facilities are separate from the motor-vehicle oriented roadway and are often shared use paths or trails. The trails may be adjacent to the roadway, on an abandoned railroad right of way (ROW), or on another separate facility such as through public parks. The three types of path surfaces reviewed were stone dust (fine crushed stone), bituminous concrete, and portland cement concrete. Other elements that can cause costs to vary widely are bridges, drainage, and fencing.
- Equipment: Bicycle facility equipment includes signs, traffic signals, barriers, parking, and conveyance. Installation costs will vary depending on the type of equipment.

To identify and develop input data for the bicycle facility cost model, the research team reviewed a broad range of data sources. The objective was to identify unit costs for the project elements described. Data sources included transportation professionals, a literature review, and industry information drawn from completed projects, agency estimates, and bid prices.

The research team used this information to develop an interactive spreadsheet for transportation planners that estimates costs for new bicycle facilities. The tool uses a database of unit cost to allow planners to develop a preliminary cost estimate for various facilities. The cost model provides a comprehensive estimate of capital costs including construction, procurement and installation of equipment, design, and project administration costs. Costs are based on typical standard facilities constructed in the continental United States and are represented in year 2002 dollars. Indices are provided to adjust for inflation to the project build year and regional variations in construction costs. As projects advance from early planning into design, project specifications will become more precise and the design engineer's estimates will provide a more reliable estimate of construction costs. Accordingly, this application includes substantial contingencies to account for both the preliminary nature of the cost estimates and the absence of detailed project specifications.

MEASURING AND FORECASTING THE DEMAND FOR BICYCLING

Estimating the demand for different types of cycling facilities forms the basis to estimate user travel time and cost savings as well as reduced traffic congestion, energy consumption, and air pollution. Several relatively comprehensive reviews exist that estimate the demand for non-motorized travel. Rather than simply review these existing reports, the focus here is on supplementing the knowledge gained from these reports with new perspective and original research. Doing so provides two contributions: (1) a better understanding of the actual amount of cycling based on different types of settings and (2) a detailed analysis to predict the amount of cycling relative to cycling facilities for the cities of Minneapolis and St. Paul, Minnesota. The former is a basis for a simple sketch planning model for bicycle planners to estimate demand in local areas. The latter describes many of the difficulties associated with suggested practices of predicting demand. Such difficulties limit the applicability of traditional demand modeling applications.

The findings in this report are based on the research detailing the relationship between an individual's likelihood to bike and the proximity of that individual's residence to a bike facility. The report is also based on research that indicates that the majority of bicycle riding is done by a small percentage of the population. Bicycle commuters primarily make up this subset of the population. Thus, areas with large numbers of bicycle commuters usually indicate locations where more bicycling takes place.

BENEFITS ASSOCIATED WITH THE USE OF BICYCLE FACILITIES

A key aspect of promoting bicycling and walking is to ensure that adequate facilities exist to encourage use of these modes. For walking, this includes sidewalks, public spaces, and street crossings. For bicycling, this includes paved shoulders, bicycle lanes, wide curb lanes, on-street or off-street bike paths, and even parking or showers at the workplace. However, bicycle facilities cost money and their merits are often called into question. Many consider spending public monies on them a luxury. Planners and other transportation specialists often find themselves justifying these facilities, claiming that they benefit the common good and induce additional bicycle use. Especially in austere economic times, planners often seek ways to "economize" such facilities.

A review of existing literature reveals wide variation in perspectives and in the kinds of information expected by different stakeholder groups. The central challenge for urban planners, policy officials, and researchers from closely aligned fields is to focus on the benefits of bicycle facilities that pointedly satisfy certain criteria. After reviewing existing literature, canvassing available data and methods, and consulting a variety of policy officials, the team suggests that to be most useful for urban transportation planning, bicycling benefits need to be

- Measured on a municipal or regional scale,
- Central to assisting decision-makers about transportation/urban planning,
- Estimable via available existing data or other survey means,
- Converted to measures comparable to one another, and
- Described for both users and non-users (i.e., the community at large).

There are several ways to describe the different types of benefits and to whom they apply. The suggested strategy for considering benefits of different facilities is guided by previous research. The first level distinguishes between benefits realized by the user versus the community at large. These can also be thought of as direct and indirect benefits. Within each of these user groups, one can identify specific types of benefits. The team identifies, prescribes, and demonstrates strategies to measure different types of benefits within each user group.

BENEFIT-COST ANALYSIS OF BICYCLE FACILITIES

The team completed extensive research to reliably quantify the value individuals ascribe to various bicycle facilities. For example, using a combination of primary data analysis, secondary data analysis, and literature review, this research uncovered the following:

- An on-street bicycle lane is valued at 16.3 min, not having parking along a route is valued at 8.9 min, and an off-road improvement is valued at 5.2 min, assuming a typical 20-min bicycle commute;
- Three types of facilities are valued differently by urbanites and suburbanites when measuring the effect of access to cycling-related infrastructure on home values. For example, a home 400 m closer to an off-street facility in an urban area nets $510;
- Individuals who attain at least 30 min of physical activity per day receive an annual per capita cost savings of between $19 and $1,175 with a median value of $128;
- Savings per mile in terms of reducing congestion are assumed to be 13 cents in urban areas, 8 cents in suburban areas, and 1 cent in towns and rural areas.

Based on such findings and other analysis, the team crafted a set of guidelines to be used by transportation professionals and government agencies to better integrate the planning of bicycle facilities into the transportation planning process. The web-based guidelines (available at: http://www.bicyclinginfo.org/bikecost/) assist state departments of transportation and other state, regional, and local agencies in considering bicycling in all transportation projects. Additionally, the guidelines will support local agencies' review of bicycle projects as part of their transportation improvement plan.

Transportation planners will be able to use the guidelines for the following purposes:

- Estimating the cost of specific facilities on the basis of type and key characteristics,
- Estimating how a facility will impact the overall bicycling environment in an area, and implicitly how it will affect the amount of riding based on characteristics of the facility and of the surrounding area,
- If information is available for calibration, estimating the usage of a facility and the change in usage of complementary and/or competing facilities,
- Estimating the specific types of benefits and their relative sizes based on characteristics of the facility and of the surrounding area.

The guidelines consist of a "tree" of questions, starting with general information and working toward more specific details. The first step of the interactive tool is to choose the geographic location and type of facility to be considered. Questions then work from the general to the specific, refining the results (and the subsequent questions) as more information becomes available. The program only asks questions applicable to the facility type and types of analysis requested. For example, pavement type only applies to cost analysis, but the setting (urban/suburban/rural) applies to cost, demand, and benefits. In the end, users are presented with an estimate of the costs, demand, and benefits of the proposed facility.

While all the cost, demand, and benefit figures in the tool are calculated from previously available sources, the web tool is the first attempt to bring this kind of information together in an easy-to-use application. The tool can be used at many levels: a neighborhood group considering lobbying for a facility might input minimal specifications to get ballpark figures, while a professional planner could enter highly detailed information and receive substantially more accurate cost, demand, and benefit output.

INTRODUCTION

Planning and policy efforts at all levels of transportation planning aim to increase levels of walking and bicycling. Such enthusiasm is shared by travel researchers, transportation professionals, public health practitioners, and policymakers. In many cases, initiatives are motivated by a desire to reduce auto use and its attendant environmental consequences (e.g., pollution and natural resource consumption). They may also be motivated by concerns of livability, public health, or physical activity. In response, urban planners, transportation specialists, elected officials, and health advocates are all looking to non-motorized travel to address myriad concerns, whether they are environmental, congestion, health, or quality of life.

Such initiatives are not new. For example, 10 years ago *The National Bicycling and Walking Study* (*1*) put forth the goal to double the level of bicycling (and walking) in the United States. A Federal Action Plan was subsequently developed to spur this process. In the period since this landmark publication, much has been done to promote bicycling for recreation and as a mode of transportation, including increased funding for facilities. However, there remains a particularly weak foundation of knowledge to guide estimates for how facilities for bicycling and walking could be better valued.

To make the best use of limited transportation funds there is a critical need for better information about two important aspects of bicycle facilities. The first is the costs of different bicycle investment options. The second is the value and effects such investments will have on bicycle use and mode share, including the resulting environmental, economic, public health, and social benefits. Decisions on transportation projects are typically based on the potential for the project to contribute to broad public policy goals. Such information as it relates to bicycle projects assists decisionmakers in developing modal options and providing travelers with more transportation choices.

This research project developed guidelines to measure the benefits and costs in order to achieve the following principal objectives:

- Help compare investments in bicycling with other modes,
- Provide tools and knowledge for choosing bicycle facilities, and
- Integrate cycling—and its benefits and costs—into the general transportation planning process.

Some goals, such as minimizing costs, can be quantified and are relatively straightforward. Such analysis is usually addressed as an element of traditional benefit-cost analysis and this estimation is essential to capital improvement project evaluation. The degree to which such estimates have been applied to bicycle facilities is scant. Estimating the benefits is considerably more challenging due to lack of data and lack of available robust methodologies. Even procedures for estimating the demand of cycling are fraught with difficulty. Assuming the demand for cycling is known and can be quantified, its value is difficult to convert to a monetary measure. For example, levels of various types of air pollutants are continually measured, but there is a range of estimates around the monetary value that should be associated with a given level of a pollutant. Other benefits, such as the ability to contribute to strong communities or "smart growth" initiatives are particularly elusive. This report contains the results of research centered on three contributions that pertain to cycling facilities including determining costs, the demand, and monetary benefits that result.

The guidelines developed as part of this project are designed to be used by transportation planners, policy advisors, elected officials, project managers, engineers, and advocates and representatives from neighborhood organizations. This report refers to this broad group as planners or transportation planners.

The report is made up of three parts. The first part (Chapter 1) describes a method for transportation planners to estimate the costs of different types of bicycle facilities. The model responds to user inputs (based on characteristics of a proposed bicycle facility) and provides the user with baseline knowledge on estimated costs. An example of the cost model is shown in Table 1.

The second part (Chapter 2) outlines a "sketch planning" method to estimate the number of daily bicyclists in an area using readily available data. The sketch planning tool is based on extensive literature review and research that drive its application. Two aims of this application are to (1) ascertain the nature of the facility being considered (e.g., geographic scope, type of facility) and (2) determine the type of demand estimate desired (e.g., use of a particular facility and expected increase in total demand resulting from a new facility). The tool provides a range of possible demand levels for a given situation based on National Household Travel Survey (NHTS) and census commute to work data. This research provides the impetus for creating a tool in which the user is also able to choose an estimate based on a range by applying local knowledge.

The third part (Chapters 3, 4, and 5) describes the process used to develop guidelines to measure benefits associated with bicycle mobility improvement. Chapter 3 offers strategies used to estimate various types of economic benefits from bicycle facilities. Benefits to users include increased mobility, health, and safety. Benefits to the community include decreased auto use and improved livability and fiscal conditions (see Figure 1). Chapter 4 describes how the research from the previous three chapters is translated into guidelines. Chapter 5 provides ideas for applying the guidelines to the transportation planning process. Appendices A through J follow the main body of the report and provide details on the methodology for the research contained with this report.

TABLE 1 Cost worksheet example

ITEM	DESCRIPTION	Input: Units	Input: Length (Feet)	Input: Width (Feet)	Input: Depth (Inches)	English Units: BASE YR (2002)	English Units: UNIT	Itemized COSTS
	City	Boston						
	State Code	MAB						
	Build Year	2002						
1.00	**Roadway Construction**							
1.10	Earthwork							
1.11	Clearing and Grubbing					$ 1,703	acre	$ -
1.12	Excavation				6	$ 15	cu yd	$ -
1.13	Grading					$ 2,108	acre	$ -
1.14	Pavement Removal					$ 14	cu yd	$ -
1.15	Curb/Gutter Removal					$ 4	l ft	$ -
-	*Earthwork Contingency*					10%		$ -
1.20	Pavement							
1.21	Portland Cement Concrete Pavement				5	$ 142	cu yd	$ -
1.22	Bituminous Concrete Pavement				3	$ 135	cu yd	$ -
1.23	Crushed Stone Surface				3	$ 37	cu yd	$ -
1.24	Aggregate Base				4	$ 28	cu yd	$ -
1.25	Curbing					$ 22	l ft	$ -
1.26	Curb Ramps					$ 1,068	each	$ -
1.30	Drainage							
1.31	Storm Drains					$ 113	l ft	$ -
1.40	Pavement Markings							
1.41	Bicycle Arrow					$ 53	each	$ -
1.42	Bicycle Symbol					$ 71	each	$ -
1.43	Bicycle Box (colored pavement)					$ 9	sqft	$ -
1.44	Lane Striping					$ 3,266	mile	$ -
1.45	Shared Lane Marking (sharrow)					$ 71	each	$ -
1.50	Landscaping							
1.51	Landscaping - Grass					$ 1,363	acre	$ -
1.52	Landscaping - Trail					$ 27,188	mile	$ -
1.53	Root Dams					$ 11	l ft	$ -
2.00	**Structures**							
2.10	Bridge							
2.12	Bridge Deck (concrete or steel)			16		$ 91	sqft	$ -
2.13	Abutments					$ 17,273	each	$ -
-	*Bridge Contingency*					10%		$ -
2.20	Underpass							
2.21	Underpass					$ 3,840	l ft	$ -
-	Construction Estimate							$ -
-	Location Index					125%		$ -
-	*Construction Contingency*					10%		$ -
	TOTAL CONSTRUCTION COST							$ -

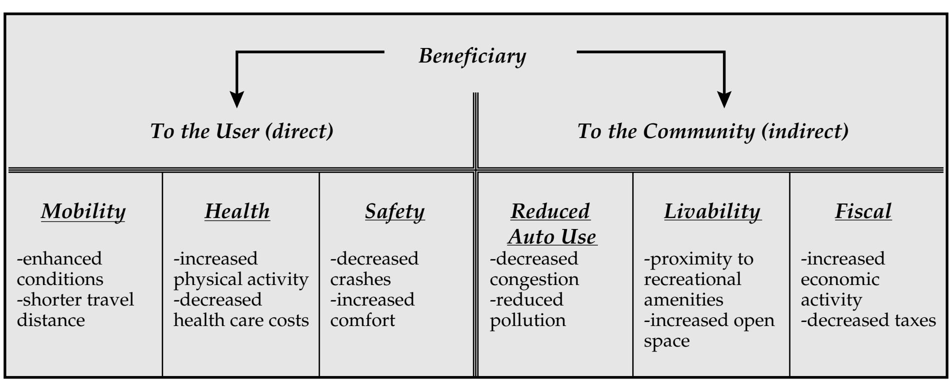

Figure 1. Schematic presentation of benefits by type.

CHAPTER 1

ESTIMATING BICYCLE FACILITY COSTS

IDENTIFYING COSTS

Purpose

The purpose of the cost analysis is to provide transportation planners with a tool to estimate costs of different types of bicycle facilities. The facilities described herein are generic and independent of specific locations. The description therefore provides preliminary cost estimates. As more specific information is gathered about a proposed facility, the planner or engineer can develop more refined estimates to reflect these specifics or replace them with more detailed project-specific estimates. The preliminary cost estimates can be used as part of initial planning efforts to identify project funding and develop project support.

Cost Elements

Costs for infrastructure projects are commonly broken into two major categories: capital costs and operating costs. Capital costs are expenditures for constructing facilities and procuring equipment. These are viewed as one-time costs that have both a physical and economic life of multiple years. Capital facilities and equipment have a multi-year life, and therefore are assets whose value can be amortized over time and financed over time with instruments such as municipal bonds.

For bicycle facilities, capital costs include all costs needed to construct a facility or install equipment. Major elements of capital costs include facility design, equipment procurement, real estate acquisition, and construction. Other elements include planning, administration, and construction inspection.

Operating costs generally result in no tangible asset. Such recurring expenses are commonly funded through annual budgets. Operating costs for public facilities include maintenance such as cleaning, landscaping, equipment repair, security and safety, and supplies needed to conduct these activities. Some or all of these operating costs may be subsumed into public agency operating budgets and be difficult to identify as discrete project-specific costs.

In this report, bicycle facilities are divided into three categories: on-street, off-street, and equipment. A bicycle facility project may include one category or more. There are different facility types within these categories. The facility types are grouped in the cost model as described in the following subsections.

On-Street Facilities

On-street bicycle facilities include bike lanes, wide shoulders, wide curb lanes, shared streets, and signed routes. For cost estimation, this application describes the following construction activities:

Full Depth Pavement. Full depth construction includes either a new road or complete reconstruction of an existing road. Full depth construction may extend the width or length of an existing road. The cost of including a bike lane or additional width for bicycles is considered as part of the larger full depth construction roadway project.

Overlay. Overlay pavement applies a new layer of bituminous concrete pavement to an existing paved surface. The overlay pavement also may add paved shoulders over an existing gravel shoulder.

Striping. Striping includes removing, changing, or adding street striping to provide a designated roadway space for bicycles. The space may be used exclusively for cyclists (e.g., a separate bicycle lane) or shared (e.g., a wide curb lane). Roadway paving is typically not required. Travel lanes may be removed, moved or narrowed to provide space for a bicycle lane or wide curb lane.

Roadway striping is usually an element of paving projects. As a freestanding project, roadway striping can be implemented in a relatively short time period and at a relatively low cost compared with roadway construction projects. Local public works or streets departments can conduct striping using agency staff or a contractor.

Signed Route. A signed route applies directional signs to an existing roadway, identifying a single or series of bicycle routes. A signed route is often located on a street with low traffic volume or a route that connects two or more desirable destinations. Route signs may be placed in intervals as needed. A signed route may be included as part of a larger full depth construction, overlay, or striping project.

Off-Street Facilities

Off-street bicycle facilities are separate from the motor-vehicle oriented roadway and often are shared use paths or trails. The trails may be adjacent to the roadway, or on an abandoned railroad ROW, or on another separate facility such as through public parks. The three types of path surfaces reviewed were stone dust (fine crushed stone), bituminous concrete, and portland cement concrete. The cost of off-street facilities varies widely based upon the pre-construction condition of the ROW and the elements that may be included in the project. Preparing an individual site can be expensive if the path is through an overgrown ROW with rocky or poor draining soil or less expensive if on ballast of an abandoned rail bed with rail and ties removed.

Other elements that can cause costs to vary widely are bridges, drainage, and fencing. For each of these elements the costs can range from zero with natural drainage and no bridges, fencing, or lighting to substantial amounts for multiple custom bridges, a piped storm drain system, and a fully fenced and fully lighted ROW. Landscaping can also vary from low-cost loam and seed to more expensive planting of shrubs, trees, benches, water features, and interpretive signs typical of an urban park.

Other elements of off-street facilities such as striping and signage are described in the On-Street Facilities subsection.

Equipment

Bicycle facilities also include several types of equipment. Installation costs will vary depending on the type of equipment.

Signs. Signs are the principal cost of bicycle routes. Sign types include regulatory signs, warning signs, and guide signs. Signs are typically placed in accordance with the *Manual of Uniform Traffic Control Devices* (*MUTCD*) (*2*).

Traffic Signals. Typical traffic signals include pedestrian walk signals. Cost estimates are provided for two- and four-leg intersections.

Barriers. Protection for bicycles and other vehicles may be provided with gates or bollards at trailheads and fencing along roads or trails as needed.

Parking. Bicycle parking equipment includes racks, lockers, and rooms. Bicycle racks vary in size and price and can be customized to a particular location. For cost estimation purposes, the "ribbon" or wave rack is used. It is important to mention, however, that in some cases this type of rack often leads to misparked bicycles which limit its capacity. The advantage is that this rack can be installed in lengths as needed. In some settings, an inverted "U" type rack is considered more of an industry standard. Bicycle lockers are typically installed in public locations such as transportation centers or city properties, and in private locations such as company parking lots. The typical design of a locker unit has capacity for two bicycles.

Conveyance. Conveyance equipment is the equipment needed to transport bicycles on public transit. Typically, this equipment is a bus rack, which holds up to two bicycles. Variations include bus racks that hold three bicycles and interior racks on rail systems.

Bicycle Facility Cost Research

To identify and develop input data for the bicycle facility cost model, the team reviewed a broad range of data sources. The objective was to identify unit costs for the project elements previously described.

Data Sources

There were three principal sources used to collect bicycle facility cost data.

Transportation Professionals. A survey of transportation professionals and suppliers was conducted to collect information on costs of bicycle facilities and equipment. The following groups or persons were contacted:

- Bicycle coordinator/planners at all state DOTs, and in federal agencies,
- Selected local and regional transportation planners, bicycle program managers, and transportation project managers,
- Advocacy organizations such as the Rails to Trails Conservancy, and
- Requests for information distributed to the following email lists:
  - Association of Pedestrian and Bicycle Professionals (APBP),
  - Institute of Transportation Engineers (ITE)—Pedestrian and Bicycle Council,
  - Bicycle Transportation Committee of the Transportation Research Board (TRB), and
  - "Centerlines"—the bi-weekly e-newsletter of the National Center for Bicycling & Walking.

Literature Review. A review of literature was conducted, with a strong focus on available cost information through an extensive Internet search.

Industry Information. Researchers reviewed construction industry data sources to identify unit prices for common construction elements such as bituminous or concrete paving.

In addition, industry data were used to identify and create indices for geographic and temporal variations in both construction and real estate costs: Engineering News Record (ENR) for construction cost information (*3*) and U.S. Department of Labor for consumer price index (*4*).

The methodologies used for developing each individual unit cost are described in the following section.

Data Types

Available information on the costs of bicycle facilities varies considerably. In most instances, data were obtained from cost estimates of individual projects and contractors' bid prices. In a few cases, data were gleaned from completed construction projects.

Completed Projects. Several cost estimates were obtained from completed projects, particularly rail trails and highway construction projects. Although this data provides the most reliable overall cost information, it generally was not available in sufficient detail to develop unit costs. For example, the Rails to Trails Conservancy provides a comprehensive database of trails built in the last 20 years throughout the United States. Available information includes trail costs, length, and year constructed. However, the database did not provide information about unique features of a given project such as number of bridges, soil conditions, and drainage.

Agency Estimates. Several state DOTs developed unit cost estimates based on data that they have collected over time. Specifically, the states of Florida, Iowa, and Vermont developed cost estimate reports that outline unit costs, as well as provide project level costs (e.g., bicycle trails per mile).

Bid Prices. Bid prices were also reviewed to identify unit costs. Unit bid prices can sometimes vary from actual cost when contractors include an allowance in the bid price for uncertainty on actual quantities needed to complete the construction.

METHODOLOGY FOR DETERMINING COSTS

This section describes an interactive online tool for transportation planners to develop preliminary cost estimates for new bicycle facilities. The tool is based on a database built of unit cost and cost indices. Users are prompted to enter several characteristics about the size and type of a proposed facility in three or four modules. The user is then provided with a preliminary cost estimate for the proposed bicycle facility.

The cost model provides a comprehensive estimate of capital costs including construction, procurement and installation of equipment, design, and project administration costs. Costs are based on standard facilities constructed in the continental United States and are represented year 2002 dollars. Indexes are provided to adjust for inflation to the project build year and regional variations in construction costs. As projects advance from early planning into design, project specifications will become more precise and design engineers' estimates will provide a more reliable estimate of construction costs. Accordingly, this application includes substantial contingencies to account for both the preliminary nature of the cost estimates and the absence of detailed project specifications.

Table 2, Table 3, and Table 4 display the cost model tables. These spreadsheets show the cost models interface with the user. The web page prompt instructs the user to designate the broad category of facility desired:

- On-Street Facility Lane with Parking
- On-Street Facility Lane without Parking
- Off-Street Facility
- Bicycle-Related Equipment (Cost estimate only)

Geography

Cost values for each element were gathered from a number of sources around the country. To normalize each cost element to a national level, a construction cost index by state or region was developed. The index is the Construction Cost Index as published in the Engineering News Record (ENR), June 30, 2003. This ENR index was chosen because it identifies regional construction costs relative to the national base of 1.00. The index identifies 36 major construction markets throughout the country. All major cities are not listed, nor are all states represented. Table 5 shows the geographic index that was used to control for regional differences in the construction costs.

For ease of use, the team developed an index for each state based on the ENR index. Additionally, in states with significant variance in construction costs for urban centers, an index for those urban areas was developed. In cities that have high labor and or material costs, specifically New York City, Boston, Philadelphia, and the Bay Area in California, separate rates were developed.

The 36 construction markets were mapped and then abutting states/regions with similar characteristics were assigned to similar values. All states and select regions were assigned a construction value. (See the chart below for the Normalized Index.)

The geographic index was applied to selected unit costs to normalize base values geographically. When the model user enters a project location (city and state) into the cost model, the model applies the geographic index to the construction cost to reflect costs for that state or urban area.

No data were available for Alaska or Hawaii. The user may use the default national values, though it is suspected that construction costs in both states may be higher than average

TABLE 2 Cost descriptions and instructions

ITEM	DESCRIPTION	INSTRUCTIONS
	City	Enter city name from list in Downtown Table if applicable
	State Code	Postal Code for state in which project is located with 4 exceptions: Boston area-MAB, Phil-PAP,NYCity-NYC;San Fran-CAS
	Build Year	Projected mid-year of construction
1.00	**Roadway Construction**	
1.10	Earthwork	
1.11	Clearing and Grubbing	Clearing and grubbing is calculated by acre. Use the total acreage of the project that will be cleared of native vegetation
1.12	Excavation	Unit cost is proviided in cubic yards. Estimate the total volume of excavation for specific project conditions.
1.13	Grading	Based on grading costs for a path with an assumed width of 10'
1.14	Pavement Removal	Unit price is based on removal of a cubic yard of either portland cement or bituminous concrete pavement.
1.15	Curb/Gutter Removal	Removal of existing curbs
-	*Earthwork Contingency*	Contingency for earthwork is variable. Use default or input best guess based on specifics of the project.
1.20	Pavement	Identify the surface treatment. For full depth construction, aggregate base is necessary. Default depth of pavement is ____. Default depth of base is ____
1.21	Portland Cement Concrete Pavement	Assumes a 5 inch pavement depth
1.22	Bituminous Concrete Pavement	Assumes a 3 inch pavement depth
1.23	Crushed Stone Surface	Assumes a 3 inch stone surface depth
1.24	Aggregate Base	Assumes a 4 inch base. Use if full depth pavement construction.
1.25	Curbing	Unit cost is median cost of cast-in-place concrete or granite curb. Concrete curbs may vary due to project size. Roadway projects will have smaller unit cost
1.26	Curb Ramps	Cost to install a single curb ramp. Includes removal of existing concrete sidewalk and replacing with a ramp.
1.30	Drainage	
1.31	Storm Drains	Drainage provided
1.40	Pavement Markings	Markings needed vary by location, geometrics, sight distance, and local requirements. Consult AASHTO and MUTCD for guidelines.
1.41	Bicycle Arrow	Directional arrow as defined by AASHTO and MUTCD. Used in tandem with bicycle symbol. Usually, 2/bike lane/intersection.
1.42	Bicycle Symbol	Bicycle Symbol as defined by AASHTO and MUTCD. Used in tandem with bicycle arrow. Usually, 2/bike lane/intersection.
1.43	Bicycle Box (colored pavement)	Colored box used as needed to increase visability. Unit cost for Thermoplastic application. Usually 2 per lane per intersection.
1.44	Lane Striping	Striping for a bike lane (one side) or trail centerline. Assumes a 4" wide solid line.
1.45	Shared Lane Marking (sharrow)	No default cost provided for a sharrow. Assuming the cost of a bicycle symbol. Enter in local cost if known.
1.50	Landscaping	Landscaping costs are variable by terrain, adjacent land use, and existing conditions.
1.51	Landscaping - Grass	Unit cost is for basic seeding and mulching. Input higher estimated cost for other landscaping such as trees, sod, or furniture.
1.52	Landscaping - Trail	Unit cost assumes a "complete" landscaping effort including grading, grass, plantings, trees, etc as required.
1.53	Root Dams	Cost of root dam to protect tree roots from buckling pavement. Assume 18" deep plastic sheeting
2.00	**Structures**	
2.10	Bridge	Bridge costs are highly variable, especially the abutments. Unit costs for pre-fab steel structures are relatively constant.
2.12	Bridge Deck (concrete or steel)	Unit cost for the bridge structure, not including abutments. Bridge structure may be concrete or steel. Trail bridges are often prefabricated.
2.13	Abutments	Highly variable. Rule of thumb provided. Best to use a project specific cost if available. Unit cost is for 2 abutments or for 1 bridge.
-	*Bridge Contingency*	
2.20	Underpass	
2.21	Underpass	Cost of constructing an underpass of a roadway to accommodate bicycles.
-	Construction Estimate	
-	Location Index	Enter the location based on the Location Chart
-	*Construction Contingency*	
	TOTAL CONSTRUCTION COST	
3.00	**Equipment**	
3.10	Signs	Sign content and frequency vary by project, by state, and region.
3.12	Sign with Post	Unit cost includes sign, post, and installation for a bike lane sign or bicycle route sign (12' x 18'). Use actual local cost if available.
3.20	Traffic Signals	
3.21	Bicycle Signal	Unit cost for a bicycle or pedestrian signal
3.22	Pedestrian Signal Activation - 4 Way	Cost for installation of a 4-way pedestrian/bicycle activated signal to an existing signalized intersection
3.23	Pedestrian Signal Activation - 2 Way	Cost for installation of a 2-way pedestrian/bicycle activated signal to an existing signalized intersection
3.24	Loop Detector	Cost of installation of a loop detector in the pavement to detect bicycles
3.30	Barriers	
3.31	Gates	Gate for a trail or other purpose. Use local cost if available
3.32	Trail Bollards	Unit cost provided for single trail bollard.
3.33	Fencing	Materials $43,000/mile. Installation assumed at $48,000. Highly variable. Use local cost if available.
3.40	Parking	
3.41	Bicycle Rack (Inverted U, 2 bicycles)	Single rack assumes the use of an inverted "U", a standard rack type. Unique designs may have a higher cost.
3.42	Bicycle Rack (Coathanger or similar, 6 bicycles)	Racks designed to hold multiple bicycles. Can be customized to the desired length/capacity. "Coathanger" style racks are a good acceptable example.
3.43	Bicycle Locker (2 bicycles)	Assumes each locker unit holds two bicycles. Other designs are commercially available.
3.44	Bike Station	No default cost provided. Enter the estimated cost if known.
3.50	Conveyance	
3.51	Bus Rack	Cost is the average cost from Sportworks, the primary supplier of bus racks in the US. High quantity
3.52	Interior Train Rack	No default cost provided. Enter the estimated cost if known.
3.60	Lighting	
3.61	Street Lights	Street Light purchase and installation
3.70	Security	
3.71	Emergency Call Boxes	Unit cost for a call box is provided. Call box is typical of what would be found on a road shoulder or sidewalk for emergency use.
3.72	Security Cameras	Unit cost for a security camera is an estimate and will vary based on location, means of data transimission, and hardware needs. Use local cost if known.
	TOTAL EQUIPMENT COST	
4.00	**Real Estate**	
4.01	Rural/Undeveloped	If the project is located in an undeveloped or rural area, enter city name from drop-down menu, if applicable
4.02	Suburban/Single Family Residential	If the project is located in a primarily single family residential area, enter the value from the Residential Chart
4.03	Urban/High Density Residential	If the project is located in a high density residential area, enter the value from the Urban Chart
4.04	Urban CBD	If the project is located in the downtown area of a city on the Downtown Chart, enter the value in the 2002 Rate column
-	*Real Estate Contingency*	
	TOTAL REAL ESTATE COST	
-	Administration (Construction)	
-	Planning (Construction)	
-	Design/Engineering	
-	Field Inspection	
	SUBTOTAL PROJECT COST	
-	*Project Contingency*	Overall project contingency.
	TOTAL BASE YEAR CAPITAL COST	Default base year is 2002. Unit prices reflect 2002 costs.
	TOTAL BUILD YEAR CAPITAL COST	The build year is the midpoint of construction period of the project.
5.00	**Operations and Maintenance**	
5.10	Maintenance	Enter in mileage of trail or road maintenance. Output will be the cost of maintenance per year
	TOTAL OPERATIONS AND MAINTENANCE	

TABLE 3 Cost worksheet, part 1

		Input				English Units		Itemized COSTS
ITEM	**DESCRIPTION**	**Units**	**Length (Feet)**	**Width (Feet)**	**Depth (Inches)**	**BASE YR (2002)**	**UNIT**	
	City	Boston						
	State Code	MAB						
	Build Year	2002						
1.00	**Roadway Construction**							
1.10	Earthwork							
1.11	Clearing and Grubbing					$ 1,703	acre	$ -
1.12	Excavation				6	$ 15	cu yd	$ -
1.13	Grading					$ 2,108	acre	$ -
1.14	Pavement Removal					$ 14	cu yd	$ -
1.15	Curb/Gutter Removal					$ 4	l ft	$ -
-	*Earthwork Contingency*					10%		$ -
1.20	Pavement							
1.21	Portland Cement Concrete Pavement				5	$ 142	cu yd	$ -
1.22	Bituminous Concrete Pavement				3	$ 135	cu yd	$ -
1.23	Crushed Stone Surface				3	$ 37	cu yd	$ -
1.24	Aggregate Base				4	$ 28	cu yd	$ -
1.25	Curbing					$ 22	l ft	$ -
1.26	Curb Ramps					$ 1,068	each	$ -
1.30	Drainage							
1.31	Storm Drains					$ 113	l ft	$ -
1.40	Pavement Markings							
1.41	Bicycle Arrow					$ 53	each	$ -
1.42	Bicycle Symbol					$ 71	each	$ -
1.43	Bicycle Box (colored pavement)					$ 9	sqft	$ -
1.44	Lane Striping					$ 3,266	mile	$ -
1.45	Shared Lane Marking (sharrow)					$ 71	each	$ -
1.50	Landscaping							
1.51	Landscaping - Grass					$ 1,363	acre	$ -
1.52	Landscaping - Trail					$ 27,188	mile	$ -
1.53	Root Dams					$ 11	l ft	$ -
2.00	**Structures**							
2.10	Bridge							
2.12	Bridge Deck (concrete or steel)			16		$ 91	sqft	$ -
2.13	Abutments					$ 17,273	each	$ -
-	*Bridge Contingency*					10%		$ -
2.20	Underpass							
2.21	Underpass					$ 3,840	l ft	$ -
-	Construction Estimate							$ -
-	Location Index					125%		$ -
-	*Construction Contingency*					10%		$ -
	TOTAL CONSTRUCTION COST							$ -

because of their remote locations. The user is encouraged to enter construction factors if known.

Inflation

The team researched cost values for each cost element. One or more cost values were obtained for each element. The team chose the cost from the source determined to be the most reliable, representative, or current.

The Producer Price Index for highway and street construction was used to adjust construction costs to the base year. The Consumer Price Index for housing was used for real estate costs. Both indexes are compiled by the U.S. Bureau of Labor Statistics. Data for the years 1987–2003 were collected for both indexes.

All construction values were normalized to a base year of 2002. Inflation factors were developed to convert unit costs from 2002 levels to the build year. Growth rates for both the construction and real estate costs were projected from the 1987–2003 data by the Microsoft® Excel growth function. The growth function predicts the exponential growth by using the existing data. The projected growth rates were then used to predict construction and real estate costs up to the year 2012 based on the midpoint of construction entered by the user.

The user is then asked to provide more specifics on *facility type* (those selecting on-street facilities will be asked to choose bicycle lanes or paved shoulders, for example, while those choosing equipment would see bus racks and bicycle lockers as options). Each of these facility types, in turn, triggers additional user prompts on site characteristics (terrain, current land ownership, etc.) and specifications (width, length, number of signs). The database has been set up to be as comprehensive as possible given available cost data, while being sufficiently simple to allow planners to generate preliminary cost estimates quickly without exhaustive research into specific project components at an early stage of planning.

The final column in the *interface* section of the spreadsheet provides preliminary estimates of capital costs for specific facility types. The resultant cost estimate along with the

TABLE 4 Cost worksheet, part 2

3.00 Equipment							
3.10 Signs							
3.12 Sign with Post					$ 200	each	$ -
3.20 Traffic Signals							
3.21 Bicycle Signal					$ 10,000	each	$ -
3.22 Pedestrian Signal Activation - 4 Way					$ 3,900	each	$ -
3.23 Pedestrian Signal Activation - 2 Way					$ 1,900	each	$ -
3.24 Loop Detector					$ 1,500	each	$ -
3.30 Barriers							
3.31 Gates					$ 1,500	each	$ -
3.32 Trail Bollards					$ 130	each	$ -
3.33 Fencing					$ 13	l ft	$ -
3.40 Parking							
3.41 Bicycle Rack (Inverted U, 2 bicycles)					$ 190	each	$ -
3.42 Bicycle Rack (Coathanger or similar, 6 bicycles)					$ 65	per bike	$ -
3.43 Bicycle Locker (2 bicycles)					$ 1,000	each	$ -
3.44 Bike Station					$ 200,000	each	$ -
3.50 Conveyance							
3.51 Bus Rack					$ 570	each	$ -
3.52 Interior Train Rack					$ -	each	$ -
3.60 Lighting							
3.61 Street Lights					$ 3,640	each	$ -
3.70 Security							
3.71 Emergency Call Boxes					$ 5,590	each	$ -
3.72 Security Cameras					$ 7,500	each	$ -
TOTAL EQUIPMENT COST							$ -
4.00 Real Estate							
4.01 Rural/Undeveloped					$ 9,234	acre	$ -
4.02 Suburban/Single Family Residential					$ 65,805	acre	$ -
4.03 Urban/High Density Residential					$ 23	sqft	$ -
4.04 Urban CBD					$ 56	sqft	$ -
- *Real Estate Contingency*					20%		$ -
TOTAL REAL ESTATE COST							$ -
- Administration (Construction)					6%		$ -
- Planning (Construction)					2%		$ -
- Design/Engineering					10%		$ -
- Field Inspection					2%		$ -
SUBTOTAL PROJECT COST							$ -
- *Project Contingency*					30%		$ -
TOTAL BASE YEAR CAPITAL COST					1.00	2002	$ -
TOTAL BUILD YEAR CAPITAL COST					100%	2002	$ -
5.00 Operations and Maintenance							
5.10 Maintenance		0			$ 6,500	mile/yr	$ -
TOTAL OPERATIONS AND MAINTENANCE							$ -

formula is presented on the final module. The formulas consist of unit cost figures (such as paving per cubic yard and land cost per acre), quantities and dimensions (length, width, number) as well as indices to adjust to regional or subregional (urban/suburban/rural) markets.

A draft catalog of these unit costs and other input is included in the box in the upper right corner of the spreadsheet. Some of these values (e.g., regional cost indices) are included in the cost database; others (e.g., project specifications and location) are input by users as they respond to prompts. In addition to the cost estimate, the final screen also allows users to access information on the source of all values (i.e., ENR regional construction cost indices). All basic inputs to the cost computation are default values that can be adjusted according to user specifications. For example, the user can provide more accurate land cost information for the facility site than the default value.

The following text, which corresponds to Tables 1–4, describes each cost component and the justification of the default value (indicated by "*" in the following subsections).

1.00 Roadway Construction

1.10 Earthwork

1.11 Clearing and Grubbing. The Iowa DOT's *Iowa Trails 2000* report was the only source that identified a specific cost for the clearing and grubbing component of trail construction. Estimated at $2,000 per acre, this figure was

TABLE 5 Normalized index by state or region

Normalized Index by State or Region		
State	Location	Index
AK	All	
AL	All	0.90
AR	All	0.90
AZ	All	1.00
CA	Except Bay Area	1.10
CAS	Bay Area	1.40
CO	All	1.00
CT	All	1.15
DC	All	1.05
DE	All	1.05
FL	All	0.90
GA	All	0.95
HI	All	
IA	All	1.15
ID	All	0.95
IL	All	1.20
IN	All	1.00
KS	All	0.90
KY	All	0.95
LA	All	0.90
MA	Western	1.10
MAB	Eastern	1.25
MD	All	1.05
ME	All	1.10
MI	All	1.15
MN	All	1.15
MO	All	1.15
MS	All	0.90
MT	All	0.95
NB	All	0.95
NC	All	0.90
ND	All	0.95
NH	All	1.10
NJ	All	1.25
NM	All	0.95
NV	All	0.95
NY	Upstate NY	1.10
NYC	New York City Metro	1.40
OH	All	1.00
OK	All	0.90
OR	All	1.10
PA	Except Philadelphia	1.05
PAP	Philadelphia Area	1.25
RI	All	1.15
SC	All	0.90
SD	All	0.95
TN	All	0.90
TX	All	0.90
USA	All	1.00
UT	All	0.95
VA	All	0.95
VT	All	1.10
WA	All	1.15
WI	All	1.10
WV	All	1.00
WY	All	0.95

adjusted to $1,703* to reflect construction costs in 2002 in Ohio, the baseline location for regional variations in construction costs (*5*).

1.12 Excavation. An Internet search was conducted to identify estimated excavation costs. The expectation was that information would not be available specifically for bike trail projects. However, general excavation costs for roadway projects were sought to approximate bike trail excavation costs, as well as a bike lane's share of roadway excavation costs. A review of several websites resulted in a range of excavation costs, typically provided in cost per cubic yard. The Contra Costa Bicycle Pedestrian plan uses a wide range of $10–$50 per cubic yard for excavation for a shared use pathway (6). Advanced Drainage Systems, the largest manufacturer of drainage equipment, identified $5 to $15* per cubic yard as the national standard range for excavation costs (7). Because this factor is based on volume rather than facility length, its use will require some understanding of excavation needs for the specific bike facility.

1.13 Grading. Trail grading estimates were also taken from the Iowa Trails 2000 report with the same adjustments made for regional differences and cost escalation to arrive at $2,555* per trail mi (5). The Iowa report estimate was based on a 10-ft wide hard surface trail.

1.14 Pavement Removal. A layer of pavement is often removed prior to an overlay. An engineering estimate from the city of Chino in southern California identifies both portland cement and bituminous concrete pavement removal at $15.60* per cubic yard (8).

1.15 Curb/Gutter Removal. Removal of curbing was given in a report from the San Francisco Department of Parking and Traffic at a cost of $5* per linear ft (9). This cost is used in the model.

1.20 Pavement

Bicycle facilities on roadways are typically paved in bituminous concrete or portland cement concrete. Brick, paving stones, or other materials are occasionally used in select situations. Trails may also be paved in a soft surface such as crushed stone, or a natural surface. The cost model provides the user with a selection of the three most common trail surfaces; portland cement concrete, bituminous concrete, and crushed stone. Depth of pavement and aggregate base will vary at the project and at the regional level.

The unit cost of an installed concrete path was derived from the survey of bikeway projects. However, the survey data were highly variable in the specificity of information provided about the facility and what elements of construction were included in the costs. In addition, unit costs were often provided using different methods such as miles or square feet. To normalize the cost data to a common measure, all costs were converted to cubic yards. In instances in which all pathway dimensions were not provided, standard dimensions were assumed for pathway width and depth. Bike paths were assumed to be 10 ft wide and bike lanes on roadways, 5 ft wide. Depth of finish pavement was assumed to be 5 in. for portland cement, 3 in. for bituminous concrete and 3 in. for stone dust surfaces. Depth of pavement will vary by location, soil conditions, climate, cost, and other factors. The aggregate base was assumed to be 4 in. deep. These assumptions are derived from the survey results. The cubic yard measures were further adjusted to a 2002 base year using the factors described at the end of this section for adjusting costs by year of construction. Factors for regional cost variance as described earlier were applied to further normalize the costs. The model user should also be aware that pavement design could affect the functional and, in turn, the economic life of the pavement. Because pavement life depends on a number of variables unique to a site, no adjustment has been made for life of pavement in the model.

The resulting unit costs still had wide variation most likely resulting from varying scope. Some costs may have been limited to the marginal cost of additional paving as part of a roadway project. Others may have included clearing and grubbing, excavation, and drainage. Median values from the sample were used to provide an estimate of paving costs.

1.21 Portland Cement Concrete Pavement. Portland cement concrete pavement is used in many regions of the country. Ten of the surveyed projects specified concrete paths and the median unit cost is employed in the model. The selected median value of $142/cubic yard* is between the low cost of $84/cubic yard for an Iowa DOT project (5) and the high of $189/cubic yard for widening a bike lane by 1 ft in Wisconsin (10).

The research on concrete pavement provided a wide range of values. Given this range and the skew, it was decided a median value would best reflect the value at the national level of concrete pavement. State or regional conversions factors would then be applied to convert to local costs.

1.22 Bituminous Concrete Pavement. Bituminous concrete pavement is the most common surface for both roadways and trails. The unit cost of $135/cubic yard* for bituminous concrete paving used in the cost model represents the median cost from a sample of 26 bikeway projects that specified the use of bituminous concrete paving. The value falls between the cost of widening a bike lane by 1 ft in Wisconsin in 2002 (10) and the 2004 estimated cost of adding 4-ft wide shoulders to a roadway in South Dakota (11).

1.23 Crushed Stone Surface. A crushed stone surface is a commonly used lower cost method of surfacing for trails with low use, in rural areas, in environmentally sensitive areas to minimize run-off, or other reasons as locally specified. Only two of the sample responses specified costs for a stone-surfaced path. A cost range of $240 to $359/cubic yard was derived from estimates provided by The Rails to Trails Conservancy (12). A cost of $37/cubic yard* was derived from a 2000 Iowa DOT report cost (5). This value is consistent with other paving values whereas the Rails to Trails numbers appear to represent full trail construction rather than just the cost of surfacing.

1.24 Aggregate Base. A value of $28/cubic yard* for a granular base was derived from the Iowa Trails 2000 (5). This was the only source in the survey that specified a cost for the granular base.

1.25 Curbing. Curbing is often required when a road is built or rebuilt. Curbing is typically cast-in-place concrete; however, in the Northeast region, granite or other stone material is often used as a curb material. The Vermont Agency of Transportation (VTrans) projects a range of costs for concrete curbing. Cast-in-place concrete curbing is $16 to $22 per linear ft as part of a larger roadway project and $26 to $37 per linear ft as part of a sidewalk project. The cost of granite curbing is estimated at $24 per linear ft* (13), which is an average of the midpoint values of concrete and granite curbing costs.

1.26 Curb Ramps. Curb ramps are located at the corners of intersections (either one or two per corner) providing accessible access between the sidewalk and street. According to the Public Works director at the City of Berkeley, the typical cost is $1,200 to install a curb ramp, including removal of existing curbs (14).

1.30 Drainage

1.31 Storm Drains. The best information found on drainage costs was in the Dutchess County, New York: 2002 Hopewell Hamlet Pedestrian Plan (15). This planning document included cost information on dozens of components of a village-wide pedestrian improvement project. Costs were identified as $113 per linear ft* for drainage pipes.

Storm drains include only the cost of the pipe by length. Drainage is site specific and varies significantly. This report included only the cost of the pipes as a representative indicator of drainage costs. Complete estimation of drainage cost would include the cost and number of drain grates and excavation and fill requirements. Those factors are difficult to estimate at the planning level; hence the cost is based solely on the length of the pipe. At one extreme, no formal drainage may be provided. This could be on flat terrain with soil and vegetation along the edges to absorb and retain the runoff. At the other extreme, storm drains could include catch basins with sumps, grates, and a network of pipes. Because of the wide variance in drainage scope and cost, as determined by site conditions and facility design, only cost of the pipes is included.

1.40 Pavement Markings

1.41 Bicycle Arrow

1.42 Bicycle Symbol. Cost information on pavement arrow markings (which include the use of a typical bicycle symbol) were collected during an interview with the Cambridge, Massachusetts, bicycle coordinator (16). The city has used both tape and thermoplastic markings. However, the more expensive tape markings ($150 each) are more durable than the less expensive thermoplastic ($60 each*) when installed properly. The city has had problems with tape installation in the past and so it has shifted to thermoplastic exclusively.

Guidelines for the number of arrows and symbols needed are as follows: bicycle arrows and symbols "shall be placed immediately after an intersection and at other locations as needed" (*2, 17*).

1.43 Blue Bike Lanes. Recently, bike lanes in high traffic or congested areas have been identified with color markings to increase lane visibility. Color markings have been used in Europe for a number of years and more recently in the United States. Portland, Oregon, and Cambridge, Massachusetts, mark the pavement in blue while Burlington, Vermont, uses a blue-green color.

In Portland, Oregon, in a study conducted by Hunter et al. (*18*), the city identified seven different materials that can be used to mark the pavement. The materials were tested for durability, visibility, and cost. Recent experience by the City of Cambridge has identified thermoplastic as the material of choice because of its combination of durability and affordability. The cost of materials and installation in Cambridge was reported to be $10/sqft*.

1.44 Lane Striping. Lane striping delineates travel lanes, shoulders, and bike lanes. The most common width for bicycle lane striping is 4 in. The Virginia Department of Transportation, as reported by the Pedestrian and Bicycle Information Center, has estimated the cost of a 4-in. bike lane stripe at $0.60 per linear ft or $3,405 per mi* (19). The Oregon Bicycle and Pedestrian Plan identifies a cost of "as little as $2,000 per mile" (20).

1.45 Shared Lane Marking. The shared lane marking is a recent evolution in bicycle facility implementation. The marking is used on roadways where significant volumes of bicycles may be present but there is no physical space for a bicycle lane. These markings are often used on roadways with two or more lanes in the direction the symbol is applied. The shared lane marking typically consists of a bicycle symbol with a directional arrow. California now uses a bicycle symbol and two chevrons. Given the similarity in size and application to the bicycle lane symbol, the cost of the bicycle lane application is used for the shared lane marking.

1.50 Landscaping

1.51 Landscaping—Grass

1.52 Landscaping—Trail. Although information specific to bicycle lanes or trails was preferred, landscaping costs associated with highway projects should provide comparable cost information. Two sources in North Carolina provided per mile landscaping costs for bicycle lane median landscaping—Cary (21) and the Asheville Greenway 2003 Master Plan (22). Both sources recorded landscaping costs to be roughly $25,000/mi*. Additional information was provided by the Iowa Department of Transportation (5). The Iowa cost was for basic seeding and mulching by acre of land and was based on highway projects. Figures from these sources are included in the cost model to provide the user with a range of choices from basic loam and seed (Landscaping—Grass) to more park-like landscape treatment (Landscaping—Trail).

1.53 Root Dams. Root dams are installed around street trees that are next to the roadway and sidewalk. The root dam directs the roots downward, therefore preventing shallow roots that heave the sidewalk, road, or trail over time. The cost of root dams ($10/linear ft) was taken from a rail trail project on Cape Cod in Massachusetts (23).

2.00 Structures

2.10 Bridge

Bridge costs are presented in two categories: bridge decks and bridge abutments. The cost of bridge decks is more predictable, and for short spans can be addressed with modular structures. If circumstances require custom design then, with the variety of bridge types and configurations, bridge costs can become quite unpredictable. Bridge abutments are necessarily site specific in design and costs are difficult to predict reliably.

2.12 Bridge Decks (concrete or steel). A number of sources for bridge costs were consulted including state DOTs in Iowa (5), Florida (24), Vermont (13), and Wisconsin (10). Ultimately, the Vermont data on bridge costs were selected because they were specific to bike and pedestrian facilities and because they included a unit cost (square feet) that could readily be applied to the model. The Vermont estimate of $100/sqft* for bridge construction also appeared to be consistent with the range of costs from the other state DOTs. It should be noted, however, that the Vermont figures were for spans of 100 ft or less.

2.13 Abutments. Bridge abutments support the bridge span at either end and link it to the trail surface. Abutment design can vary widely based on topography, geology, and environmental constraints (wetlands in particular). Therefore little information on cost of abutments is transferable from one setting to another. Users are encouraged to input their own abutment cost based on local conditions if available. The Wisconsin DOT provided a bridge abutment cost of $9,500 each* with the caveat that this cost is highly variable (10).

2.20 Underpass

2.21 Underpass. Grade separation of pedestrian and bicycle paths is desirable when traffic volumes and speeds discourage safe crossing of a highway, or railroad tracks, or when necessitated by the crossing of a limited access highway. Cost estimates for underpasses will vary considerably, depending on the geometric requirements of the specific site method of construction, potential disruption to the surface roadway or rail tracks, and the construction phasing required. A 100-ft long pedestrian underpass under Route 1 in Woolwich, Maine, was built in 1999 for a cost of $400,000 or $4,000/ft* (25).

3.00 Equipment

3.10 Signs

3.11 Sign with Post. Studies and reports where sign costs had been specifically identified were reviewed to develop estimates for the cost of providing signs along a bicycle facility. The data sources did not always identify whether or not costs included signposts or cost of installation or only the cost of the uninstalled sign.

The Asheville Greenways 2003 Master Plan (*22*) provided cost information for different sign types (informational, direction, warning, etc). The New York City Bicycle Coalition provided information from Pittsburgh's experience with sign costs including installation and posts. Although there was a range of sign costs from these sources ($55 to $1,000 per sign), most examples for installed signs were between $100 and $250, with $200* being an amount identified by three different sources (*26*).

3.20 Traffic Signals

3.21 Bicycle Signal. Bicycle signals provide an exclusive (or shared crossing with pedestrians or motorists) crossing at an intersection. The cost element is the installation of a bicycle signal. The county of San Francisco provided an estimate of $10,000* to install a bicycle signal (27).

3.22 Pedestrian Signal—4 Way

3.23 Pedestrian Signal—2 Way. Bicycles are legal vehicles on the roadway; therefore, when riding on a roadway, cyclists are required to follow the same traffic signal directions as motorists. In addition to roadway signals, there are instances where a specific bicycle signal would be useful, such as at road crossings of multipurpose trails. According to the Florida DOT (24), a two-corner walk/don't walk signal system with a signal head and activator costs $1,900.* A four-corner system (with eight of each unit) costs $3,900.* Additional costs result if a full signal system is installed.

3.24 Loop Detector. Loop detectors are typically used at intersections to detect traffic. When activated, the detector will initiate change of the signal to a programmed sequence. However, not all loop detectors detect bicycles. Loop detector designs that accommodate bicycles are available. An estimate of $1,500* developed for the County of San Francisco is used in the cost model (28).

3.30 Barriers

3.31 Trail Gates. Gates are sometimes required on bicycle trails to prevent access by private motor vehicles while providing access to public safety and security and maintenance vehicles. Cost information on security gates was not available from the survey. Gate prices are being sought from suppliers.

3.32 Trail Bollards. Typically bollards are placed at the intersection of a trail with local streets or other locations where passage of motor vehicles is prohibited and bicycles is permitted.

The City and County of Denver, Colorado, prepared a report of bid cost data of road construction projects for 1999 identifying a unit cost for bollards of $130 each* (*29*).

3.33 Fencing. Fencing is used for safety in some ROWs that are shared with other vehicles. Fencing is also used in some locations to protect private property, particularly in densely developed urban areas. The per mile cost of 6-ft black vinyl chain link fence with a top rail was developed using a suppliers online calculator (30). The estimated cost was $43,000/mi uninstalled. The developed cost of installation was estimated at $24,000/mi, for a total estimated cost of $67,000/mi.* The installation cost assumes a five-person crew for 2 weeks at $2,400/day.

3.40 Parking

Bicycle racks are the most common method of securing a bicycle. Bicycle lockers are also used, primarily at public facilities including train stations and other city property. Bicycle lockers have the advantage of weather protection and greater security for bicycles and gear.

3.41 Bicycle Rack (Inverted U, 2 bicycles). The most common bicycle rack, particularly on city streets, is the inverted U rack. In Boston, U racks were installed in 2003 for a total cost including installation of $190 each* (31).

3.42 Bicycle Rack (Ribbon or similar, 6 bicycles). High capacity bicycle racks are used at shopping malls, businesses, hospitals, and other locations with high demand for bicycle parking. Most racks may be ordered in a desired length and capacity as needed.

Virginia DOT reports a rack that holds 10 to 12 bicycles to have an installed cost range from $325 to $730 (*26*). Using the high-end number, the cost is estimated at $65 per bicycle space.* Length and quantity of racks ordered will affect the unit cost.

3.43 Bicycle Locker (2 bicycles). Bicycle locker units typically hold two bicycles each. Installed bicycle locker costs are reported by the Pedestrian and Bicycle Information center as $1,000 per locker (32).

3.44 Bicycle Station. Bicycle stations are relatively new in the United States. Bicycle stations vary in what is provided. They typically include bicycle storage facilities, showers, bicycle and bicycle repair equipment rental, and information about biking in the local area. Cost estimates to develop a bicycle station will vary widely based on location. The City of Bellevue in Washington State received a federal grant of $200,000* to fund a bike station. This number is used as a unit cost. Given the potential variability in cost, model users are encouraged to seek a local cost if available.

3.50 Conveyance

3.51 Bus Rack. Bus racks have been institutionalized throughout the country on many public transit systems. Bus racks are mounted on the front of the bus and fold up when not in use. The rack can hold two bicycles securely. The racks, in constant view of the driver, are quite secure.

The primary supplier for bus racks is Sportworks located in Woodinville, Washington. Sportworks reports the cost of a bicycle rack as "approximately $549 per unit*" (*33*).

3.52 Interior Train Rack. Bicycle racks have been installed in public transportation vehicles, particularly light rail and commuter rail cars. Installations to date have been unique from agency to agency and even from vehicle to vehicle. One transit agency reported that installation of racks added no cost to vehicle procurement. Due to the low cost and limited availability, it is recommended that the cost model user input an estimated cost based on local conditions.

3.60 Lighting

3.61 Street Lights. Street lighting will typically be a part of a larger roadway project; however, lighting may be installed as part of a trail project. A street light cost estimate for the City of Chino, California, was $3,640 per fixture* (8).

3.70 Security

3.71 Emergency Call Boxes. Emergency call boxes may be a part of a bicycle facility project, particularly off-street trails. The U.S. DOT Benefits and Costs Database provides information on a call box project in Georgia. The average cost for each call box including installation costs was about $5,590* (34).

3.72 Security Cameras. Security cameras are often used in public places and therefore may be used on public streets or trails. The U.S. DOT Benefits and Costs Database includes the cost of a roadside detection camera using a closed-circuit television (CCTV) video camera. The estimated cost of this camera is $7,500* to $17,000. The low end of this cost is used for the cost model. The cost cited includes installation of a color video camera with pan, tilt, and zoom (PTZ) (35).

4.00 Real Estate

Alternative Sources of Data on Land Values

The procedures and data provided in the model are intended as default values if other more traditional methods of obtaining land values are not used. The most direct method of obtaining an estimate of land value is to consult a local real estate broker. If the land is "on the market," a value can be immediately determined. A real estate broker can provide advice on the difference between the asking price and the projected sales price. Property is almost always listed at a price higher than the seller is willing to accept.

Another source of information on land values is the local property assessor's office. Property assessments are made for all property in a municipality and are a matter of public record. Staff is available in the office to aid in finding land value data for a specific property. It is important to apply a factor that represents the ratio of assessed value to market value. Assessed values are generally conservative and below market values. Assessors usually keep information on the ratio of assessed to market values.

A third method of estimating the value of a given property is to have a land appraiser provide an estimate of value. Land appraisals are normally done at later stages in a project and can be expensive. Often three appraisals are required to firmly establish the value of land. Appraisers often will provide a "preliminary" estimate or "windshield appraisal" of land value for a smaller fee, in anticipation of a full appraisal when one is required for a project. Actual purchase prices can be higher than the appraised value if the purchase is negotiated or if a property value is contested in court.

Real Estate Values

Real estate values vary markedly by location throughout the country and by density of development in the project area. Unit prices for land acquisition were estimated for four settings—rural, suburban, urban residential, and urban central business district (CBD).

Rural and Suburban Land Values. Estimates of per acre land costs for rural and suburban areas by state were obtained from the U.S. Census of Agriculture (rural land) and the U.S. Census of Housing (suburban land). The latest data from the Census of Agriculture (which is taken every 5 years) are for 2002. The latest data from the Census of Housing (which is taken every 10 years) are for 2000. Data were updated to 2002 using the Consumer Price Index (CPI) for housing, published by the U.S. Department of Labor's Bureau of Labor Statistics (4). An extrapolation of the data between 1987 and 2003 resulted in an annual rate of inflation of 2.5%.

Data are compiled by state in both the Census of Agriculture and Census of Housing. State-level data were thought to be most appropriate for use because they reflect regional variation in land costs and can be readily identified by the cost estimator. Rural land value is reported by acre and can be used directly (adjusted in accordance with the CPI for year). Suburban property values are reported as the estimated value for a home. To estimate the value of suburban land, the property value must be divided into land and building (improvements) components. Typically, the value of land accounts for one-third of the total property value of single-family detached housing (*36*). This factor was used to derive estimates of median land value by state from housing values reported in the Census of Housing.

Urban Land Values. Urban land prices were estimated from an extensive listing of commercial property for sale compiled by C. B. Richard Ellis Company (*37*). There were not enough listings for each state to provide a statistically defensible land value for each state. Using all the data of several hundred listings yields a statistically defensible price for land at the national level. The national price was estimated and indexed for each state using the state's median household income. The derived U.S. average of $18.91/sqft* seems reasonable absent more site-specific data.

Urban CBD Land Values. Estimates of land values for 53 downtown areas in U.S. cities were derived from rental rates from a Spaulding & Slye Colliers Survey of Class A Downtown Office Space Prices. Property value is generally between 6 and 9 times annual gross rent and CBD land values are approximately 20% of the value of commercial property (*38*). Land prices for 53 urban CBDs were estimated based on property values equal to 7.5 times annual rental rates and a value of land equal to 20% of the property value.

Applying the Real Estate Component of the Model

Analysts using the model to estimate the land cost must identify the following:

- The state in which the project is located,
- The city in which the project is located (if land is to be acquired in a major urban CBD), and
- Whether the land is in a rural (undeveloped area), a suburban (single family home area), an urban (dense residential area), or an urban CBD area.

Whether an area is defined as urbanized or is in a metropolitan area can be determined from U.S. Census information (accessible on the U.S. Census website at http://www.census.gov/). The predominant land use of an area can be determined from a land use map or an aerial photograph. A zoning map may help as well because land values are partially determined by zoning.

Other Capital Costs

In any construction, there is a need for design, construction inspection, and administrative services.

Planning

Planning activities such as identification of project needs, definition of project objectives, project evaluation, and general definition of project scope tend to cost about 2% of the project cost for major transit projects. This value is also the estimated cost of planning used by the state of Iowa as identified in the survey of bicycle facility cost data.

Design/Engineering

Design services are typically divided into basic services and special services. Basic services are the efforts required to perform basic design for a simple project. In addition to basic services, most projects require special services for such things as environmental assessment and permitting, community coordination, and custom design of features such as special landscaping or designing for unique soil conditions. From the survey of bicycle project cost data, Iowa estimated design fees as 7% of construction costs with an additional 5% for construction phase services for a total of 12%. Vermont estimated design fees at 10 to 30% of project costs (*13*). Design fees for the General Services Administration, Property Development generally range from 8% to 12% of project cost (*39*). Commonly, total design fees for public facilities average about 10%. Based on the foregoing information, for purposes of this project, a design fee of 10% of the construction cost has been used as a default value in the cost model.

Inspection

Field inspection is required to ensure that work is being performed in accordance with the construction contract requirements and to ensure that quality standards are met. Agency engineering staff would commonly perform inspection. Depending on the size of the job and availability of agency staff, an agency might hire a separate contractor to perform these services such as a "clerk of the works," who might provide both inspection and administration services. For large transit projects, field inspection costs are about 2% of construction costs.

Administration

From the survey of bicycle projects, Vermont identified administration costs as 10% of construction, real estate, and design costs and Iowa cited project administration as 5% of total costs. Project administration costs typically run at 6% of construction costs + 2 % of planning and design costs for major FTA-funded projects. Since planning and design costs are typically a small portion of overall project costs, project administration costs of 6% of construction estimates have been assumed for cost estimating purposes.

Contingencies

Contingencies are included in cost estimates to reflect uncertainty. Uncertainty in construction project costs is a function of several factors:

- Specificity of project scope,
- Time lag between estimate and actual construction, and
- Changing market conditions.

Project Scope

As projects advance from concept through design to construction, the scope of the project becomes increasingly better defined. As a result, uncertainty declines and the appropriate contingency in the cost estimate correspondingly declines. Even with this progression, certain construction elements are better specified than others (e.g., installing stock items, such as signs or fences, is clearly specified with predictable costs). Custom items (e.g., constructing bridge abutments, items involving earthwork) are less well specified. Even with soil sampling, actual soil conditions are only fully identified during excavation.

Time Lag

The greater the lag in time between preparation of the cost estimate and project construction, the greater the potential for change in costs. An example of this is the increase in cost of bituminous concrete with increasing oil prices. The base year for the cost estimates is 2002. The contingency should reflect the uncertainty of future costs.

Market Conditions

An additional element of uncertainty is market conditions at the time of cost negotiations. Construction costs vary depending on how active the construction industry is in the area at the time project bids are sought. Additionally, real estate values can be very unpredictable.

Considering the foregoing, an overall project contingency of 20% has been applied to the base year of 2002 capital cost estimate to reflect the uncertainty of future conditions. An additional contingency of 10% has been applied to the construction cost estimate to reflect the general nature of the project scope. Within construction, an additional 10% in contingency has been added for more unpredictable construction activities, specifically earthwork and the construction of bridge abutments. Finally, an additional 20% contingency has been added to the real estate cost estimate to reflect the uncertainty in predicting real estate markets.

It is recommended that the model user review the application of contingencies and adjust the contingencies in the model as indicated by the level of uncertainty associated with specific cost elements of the proposed project.

Total Build Year Capital Costs

Unit costs in the cost model are based on a base year of 2002. The year 2002 is the latest year for which a substantial amount of cost data is available for all elements. The construction, equipment, real estate, and contingency costs are summed to obtain the total project cost in 2002 dollars.

Project construction occurs several years into the future. To provide a more accurate assessment of the project cost, the "build year" or midyear of construction is identified. For example, if construction is predicted to take 4 years and will start in 3 years (from 2004), the project completion year will be 2011. The build year or midpoint of the construction will be 2009.

Researchers developed an inflation factor by extrapolating the Producer Price Index Industry Data for Highway and Street Construction from the period 1987 through 2003. When the cost model user enters the build year into the model, the index for the build year is applied to the 2002 base year costs to provide estimated build year costs.

5.00 Operations and Maintenance

Operations cost for bicycle facilities typically includes the cost of security or policing the facility. Maintenance includes pavement (sweeping, snow removal, and repair), drainage (cleaning and repair of storm drains), traffic controls (pavement marking, signs, and traffic signal maintenance), and landscape maintenance.

When bicycle facilities are elements of other, larger facilities, the maintenance costs are often subsumed into the cost of the maintenance of the larger facility. Often the marginal or incremental costs of added maintenance are so modest that they are not accounted for as discrete facility costs. For example, for a roadway-widening project, it is difficult to discretely identify the added operations and maintenance (O&M) costs associated with the widening from the overall costs of maintaining the road. Accordingly, for most facilities it is assumed that the added O&M costs are negligible.

A typical exception to this assumption is the cost of landscape maintenance for bicycle trails as discussed in section 5.10.

5.10 Maintenance

Research into trail maintenance costs identified a data source that has been widely used by trail proponents to estimate costs. Although independent sources were also identified, several trail proponents used a Rails to Trails Conservancy breakdown of maintenance costs for the year 2000. The cost items include drainage maintenance, sweeping, trash removal, weed control, mowing, minor repairs, supplies, and fuel. The total annual per mile cost is estimated at $6,500 (*40*).

CHAPTER 2

MEASURING AND FORECASTING THE DEMAND FOR BICYCLING

INTRODUCTION

This chapter describes strategies to estimate the demand for different types of cycling facilities. Such estimates form the basis for user travel time and cost savings as well as estimates of reduced traffic congestion, energy consumption, and air pollution. Several relatively comprehensive reviews exist that estimate the demand for non-motorized travel. These reports range from adapting traditional transportation modeling applications to devising specific applications and tools. Rather than simply review these existing reports, this chapter focuses on supplementing the knowledge gained from these reports with new perspective and original research.

The team presents a way to understand the actual amount of cycling based on different settings (as opposed to how it is modeled or predicted). While several surveys and datasets describe the amount of bicycling in the United States and various smaller areas within it, no single effort has previously reconciled the results of these different surveys and data sources to develop a general overview of the amount of bicycling. Supplementing its own data analysis with these previous efforts, the team reconciles several seemingly conflicting survey results and sets bounds on the amount of bicycling that occurs in various geographic areas. The team uses this as a basis for a simple sketch planning model for bicycle planners to estimate demand in local areas.

The team also presents a detailed model to predict the amount of cycling relative to cycling facilities in the cities of Minneapolis and St. Paul, Minnesota. This analysis helps advance the state of the art beyond simply describing the techniques for demand modeling to evaluating how these techniques can be reasonably applied by a planner seeking reasonable results with limited resources. A principal utility of this exercise was to present many of the difficulties associated with practices of predicting demand. Such difficulties illustrate the limitations of applying traditional demand modeling applications.

The detailed bicycling demand analysis led to conclusions regarding the most practical ways of measuring and predicting demand from the standpoint of a planner working with limited resources and data. Based on these conclusions, the team developed a draft sketch planning method for measuring and predicting bicycling demand.[i] The method develops ranges of estimates from limited and easily available datasets. A model easy to understand, use, and explain has more value even if it is necessarily limited in its detail and precision. This method has been incorporated into the guidelines.

The literature review is described as follows: first is the literature on measuring demand, including some original contributions; second is the literature on modeling demand, that is, relating demand to bicycle facilities (the team makes original contributions by developing a demand model for the Twin Cities area); and third is the demand literature discussion, which evaluates many of the problems with the traditional approach of predicting demand by relating demand to underlying explanatory factors.

LITERATURE REVIEW

Simple and reliable tools to estimate and predict the amount of bicycling in a given area, and how this amount depends on the availability of bicycle facilities and other conditions, would be useful for a variety of investment and policy decisions. However, while the desirability of such tools is generally recognized, and there have been a number of efforts to model demand either specifically or generally, no modeling technique or set of parameter values or even rules of thumb have emerged as definitive. Measuring the amount of bicycling occurring is an inexact science.

A good first step in thinking about how to model bicycling demand is to understand the types of questions that the model might be used to answer. Porter, Suhrbier, and Schwartz (*41*) list three major questions, paraphrased as follows:

- How many people will use a new facility?
- How much will total demand increase given an improved facility or network?
- How does bicycling affect public objectives such as reduced congestion and better air quality?

This question could be added: What are the total benefits that bicycling creates, including the benefits to cyclists themselves, such as improved health and recreational opportunities? The answer to this and the previous questions could be useful in justifying public spending on bicycle-related projects. The answers to the first two questions are likely to be more useful for technical analyses to prioritize projects given limited resources.

Another way of approaching the problem is to note that there are three different demand prediction objectives:

- Predicting the total amount of bicycling in an area or on a facility,
- Predicting the marginal amount that total demand will change given a change in facilities or policy, and
- Identifying areas where inadequate facilities appear to be holding the level of bicycling below its potential, as in the "Latent Demand" approach (*42*).

In principle, a model that explains the total amount of bicycling as a function of "basic" factors including demographic, policy, and facility variables would answer all of these questions at the same time. Most past work has taken this kind of approach. The FHWA (*43*) and Texas Transportation Institute (*44*) completed major surveys of non-motorized modeling techniques in the late 1990s; the majority of the efforts they describe focused on predicting either commute shares or total bicycle travel by referring to characteristics of the population and land use of the area being considered and to some measure of the bicycling environment.

A second, less common type of demand prediction method uses census commute-to-work shares, often combined with other data, to provide an area-specific baseline of bicycle usage. This can substitute for some of the unmeasured factors, attitudes toward bicycling in community and accessibility of neighborhoods to employment centers, that typically are found to have a large and often unpredictable impact on demand in the more "traditional" models.

At the extreme, these represent two completely different ways of approaching the problem. Use of the traditional approach relies on an (often unstated) assumption that relationships between demand and underlying explanatory factors will be stable over time and transferable from one place to another. The second approach relies more directly on what is already known to be true about demand in a given area. This method in principle is more limited because it does not directly relate demand to changes in the underlying environment. However, within the short to medium time frames that most bicycling forecasts are concerned with, it is more accurate to base predictions on known facts rather than on theoretical and possibly unproven relationships.

Section 2.21 describes the results of several surveys and other measurements of general bicycling demand that have been done during the last decade. The central aim is to describe the results of these many different measurements in one place to show that they are all roughly consistent when differing methodologies are considered and to place general bounds on the numbers that are likely to be observed. This information forms the basis for the demand prediction guidelines. Section 2.22 describes the existing demand prediction literature as well as efforts to develop a demand model for the Twin Cities area. The team does not describe existing literature in depth. It has already been well covered in recent reports. It does address applying these models to practical demand estimation, especially in situations where a planner is constrained by limited data, time, or technical expertise.

These issues are explored in depth in section 2.23, which develops an argument that the common demand modeling objective to develop relationships between facilities and usage by comparing different geographic areas is unlikely to provide useful results for a variety of reasons. These reasons are derived from the analysis of bicycling rates and from some findings from the team's attempt to develop a demand model for the Twin Cities area.

Measuring Bicycling Demand

This section describes the results of several surveys and other measurements of general bicycling demand that have been conducted during the last decade. The first objective here is to combine the results of many different measurements to show that they are in fact all roughly consistent and to place general bounds on the numbers that are likely to be observed. The second objective is to demonstrate that the various measures of bicycling demand can be reconciled by a conceptual framework in which there is a distribution of bicycle riding frequencies over the population (see Appendix A).

Most of the information about the amount of bicycling addresses the number of people who ride bikes, as opposed to the number of trips or miles of riding. Because of the amount of information that is available about riding frequency, the team uses this as the measure of bicycling demand. At the end of this section, the team addresses how this can be converted into trips or distance calculations.

The surveys and other sources that address the frequency of bicycling produce a wide variety of results. Each source asks about a different time frame; the number of people who ride a bike in a week will be larger than the number who ride in a day. A key distinction that has to be tracked is that adults are considerably less likely to ride a bike than are children, regardless of the time frame being considered. These two groups must be studied separately to avoid confusion or ambiguity. This is generally not an issue with most bicycling surveys, which tend to focus on adults. It is, however, a factor in deriving numbers from general travel data collection surveys. In the ensuing discussion and tables, the numbers refer to adults 18 years old and older. In each case, the survey sample was randomly selected households, regardless of their propensity or use of cycling. A summary of the findings of all these sources is shown in Table 6.

Davis (*50*) takes a different approach by actually counting the number of bikes on a fairly large sample of roads and bike facilities in the Twin Cities and calculating the total amount of biking in the region. In this approach, there is no information on who is biking or why, but only an estimate of the total

TABLE 6 Measures of adult bicycling frequency

Source and Area	Measure	Average	Range
Travel Behavior Inventory, Twin Cities MSA	%/day	1.4%	-
National Household Travel Survey, U.S. Total (*45*)		0.9%	-
NHTS, U.S. MSAs		-	0.2%-2.4%
NHTS, U.S. States		-	0.0%-2.2%
NHTS, U.S. Total	%/week	6.7%	-
NHTS, U.S. MSAs		-	4.5%-12.7%
NHTS, U.S. States		-	3.5%-12.4%
Parkwood Research Associates (*46*)	%/month	-	16.6%-21.2%
Bureau of Transportation Statistics (*45, 47*)	%/summer	27%	
Parkwood Research Associates (*46*)	%/year		37%-46%
National Sporting Goods Association (*48*)	%/6 times per year	10.7%	-
Minnesota DOT (*49*)	%/ever ride	50%	-

amount being done (and where it is being done, to some extent). Davis's approach provides a very powerful and objective alternative to the biases that are always inherent in survey-based data (for example, the number of people who say they would consider commuting by bike exceeds by a factor of 20 the number who ever actually do). It is also a method that could be exactly duplicated in other cities and towns, providing an objective baseline of how much cycling actually takes place, and how it might vary by location, facility, and even weather conditions. Finally, this method has the advantage over surveys of being a relatively inexpensive method for the amount of information that is generated.

Some users cycle almost every day; others may only ride once per year. The longer the time frame being considered, the more people will have ridden at least once. It is possible to divide the population into different frequencies of riding in a way that is consistent with these numbers derived from different time frames. Table 7 shows an example of what such a breakdown might look like, based on trial and error.

These riding probabilities and population frequencies are mathematically consistent with about 1% of adults riding in a given day, 5.3% in a week, 16% in a month, 29% in a summer, 40% in a year, and 50% "sometimes" riding, although not necessarily in a given year. Mathematically consistent here means that the fraction of each population frequency group who will ride during a given time span can be calculated using a simple probability formula, and the groups summed to arrive at a population total.

TABLE 7 Cycling frequency

Frequency of cycling	% of adults
3 of every 4 days	0.1%
1 of every 2 days	0.2%
1 of every 4 days	0.5%
1 of every 10 days	1.2%
1 of every 20 days	3%
1 of every 50 days	10%
1 of every 100 days	15%
1 of every 200 days	20%
Never	50%

Evidence from the TBI and NHTS, although not exactly consistent, can be interpreted to imply that the average person-day of cycling for an adult generates about 40 minutes and 7 to 8 mi of riding, although there is a great deal of variation around these averages.

Modeling and Predicting Bicycling Demand

The objectives in this literature review are to outline the general types of models and methodologies that have been used and to evaluate their potential usefulness to planners seeking demand estimates with practical value. The team considers three criteria that are likely to be important to planners: accuracy, data requirements, and ease of use. The focus is on the FHWA report (*51*) of 1999 because it is the most recent comprehensive survey. The earlier TTI report (*52*) provides more detail on specific models and methods but does not add to the breadth of the FHWA report.

The major FHWA report documenting non-motorized travel estimation methods identifies five major methods. The first two of these, comparison studies and aggregate behavior models, are criticized by FHWA for their low accuracy. The low accuracy is derived from the difficulty of comparing one location with another (or transferring parameter values estimated in one location to another) because of the large impact of unobservable factors such as attitudes. While these methods can be easy to use, and could require limited data, the difficulty of not knowing the area(s) from which the demand numbers were generated severely limits its applicability.

Comparison studies attempt to predict bike use in one area or facility by measuring use in a similar area. However, it is difficult to know whether the two locations are similar. Areas identical in demographics and land use can generate bicycling rates that differ by a factor of 10 or more. Similarly, for aggregate behavior models, the fact that a certain relationship exists in one area between the amount of bicycling and certain explanatory variables generally does not mean that the same relationship will exist in other similar areas. Even if relationships were not consistent across places, these types of models could still be useful if the range of likely error is known and is relatively small. But this does not appear to be the case.

The third method, sketch planning, is described as relying on data that already exist or can be collected easily, such as census data. This is the sort of model that is described later in this report. Sketch planning methods use readily available data such as commute to work shares from the census as a tool for estimating behaviors of interest, rather than estimating these behaviors directly from underlying conditions. The FHWA report rates these methods as not being very accurate, although this assessment seems to be derived from the fact that these methods are simple and rely on limited data. It is not clear that the relative accuracy of sketch planning methods compared with others has ever been formally evaluated.

This method has been criticized for being difficult to apply accurately to other geographical areas. The team is not convinced that this is the case. While the relationship between commute shares and other measures of bicycling may not be perfectly consistent from one place to another, it does seem from the analysis to fall within a fairly limited and predictable range. The team believes that such methods could be quite accurate, especially when supplemented with local knowledge and judgment. Perhaps even more important, the degree of accuracy can be known with some precision. This can make the forecasts more useful to planners hoping to do a risk analysis. And, these methods can have other advantages of being very easy to use (and explain to policymakers) and requiring limited and easily accessible data.

The last two methods described in the FHWA report, discrete choice models and regional travel models, are widely respected in the transportation profession because of their longstanding application to the forecasting of auto and transit travel. However, it is not clear that they are appropriate for understanding bicycle travel, in part because of the significant amount of data and technical expertise that is needed to execute them and in part because "unobservable" factors play a greater role in determining the amount of bicycle travel than they do in either auto or transit.[ii]

Both these types of models are based on the assumption that bicycle trips are made after considering a decision among a number of alternate modes. However, the evidence strongly suggests that a majority of bicycle trips are recreational in nature—a person going for a bike ride for fun probably did not consider whether to go for a drive or a bus ride instead. Recreational bike trips are probably made in addition to, rather than instead of, auto trips; they would not be captured by a model that starts out by assuming that a given household will make a certain number of trips (as these models do). Ignoring recreational trips could be justified if it were assumed that they had no value to society (or at least a very small value compared with a "utilitarian" trip) but the team is not willing to make this assumption, and indeed the benefits analysis indicates that it is probably not true. A good model of bicycling demand should capture all types of bike trips.

To these criticisms could be added that the accuracy of these models is unproven in the context of bicycle forecasting. FHWA rates these types of models as highly accurate, but it is not clear whether this rating is based on actual comparisons with other models or on their complexity and high data needs.

To supplement the research associated with this task, the team conducted original research based in the Twin Cities metropolitan area. This application develops a disaggregate model relating bicycle facilities to the probability of an individual riding a bicycle in a given day. The work is described in detail in Appendix B. The following text provides an overview of the methods and results of this analysis.

The primary aim of the investigation was to understand the effect of proximity to a bike facility on the odds of cycling. In other words, does living closer to a bike facility increase the likelihood of traveling by bike? The hypothesis is that subjects living in closer proximity to a bike facility will be more likely to travel by bike compared with those who live more than 1 mi from the nearest bike facility.

The outcome of interest (any bicycle use in the preceding 24 hours) was ascertained from standard travel data furnished by the Twin Cities Travel Behavior Inventory. The explanatory variable (or exposure) of interest is the proximity of bicycle facilities in the form of on- and off-road bicycle lanes and trails. Three continuous distance measures were calculated using global information system (GIS) layers furnished by the Minnesota DOT, with separate map layers for on-street and off-street trails. Using household locations (x-y coordinates) and the GIS map layers, the distance in meters was calculated to the nearest on-street bicycle lane, the nearest off-road trail, and the nearest bike facility of either type.

Distance variables were used to classify subjects into one of four categories. The four categories represent the distance from home to the nearest bike facility as less than 400 meters (one-quarter mi), 400 to 799 m, 800 to 1,599 m, and 1,600 m or greater (greater than 1 mi). Given that distance cut-points with relatively simple interpretation were used, it provides a compelling way to grasp the reported findings in terms of comparing individuals who live within 400 m of a bike trail and those who live more that 1,600 m from a bike trail. Attributes of the built environment are theorized to influence the likelihood of cycling—namely, having destinations to which individuals can bicycle matters. Three spatial attributes were measured that are indicative of one's home location—open space, regional accessibility, and neighborhood retail.

For the sample of central city residents studied, 86 subjects (4.8%) had at least one documented bike trip. This rate is higher than both the larger TBI sample and national averages, which tend to hover around 1 to 2% of the population (*53*). As expected, the proportion of bikers varied with proximity to bike facilities, with more bikers living closer to bike trails and fewer bikers living further from bike trails. Of interest, these distributions differed depending on which measure of bicycle facility proximity was used.

A priori, it was assumed that the type of bicycle facility matters, that is, the type of bike facility may have different effects on the likelihood of bicycle use. Therefore, the team used separate models to estimate the effect of proximity to off-road facilities on the odds of bike use. Examining the simple logistic regression model to the fully adjusted model for off-road bicycle facilities, the odds of bike use did not differ significantly by proximity to a trail. *No effect of proximity to off-road bike facilities on bicycle use was detected* (see Appendix B for details).

Finally, the effect of proximity to on-road bike facilities on the odds of bike use was examined. Using a series of logistic regression models, *it was found that subjects living within 400 m of an on-road bike facility had significantly increased odds of bike use compared with subjects living more than 1,600 m from an on-road bike facility.* As expected, those that lived within 400 to 799 m of an on-road bike facility also had significantly increased odds of bike use compared with subjects living more than 1,600 m from an on-road bike facility, although the odds of bike use were slightly lower than for those living closest to an on-road facility.

After adjusting for individual, household, and neighborhood characteristics, the effects were somewhat attenuated. Subjects living near an on-road facility (less than 400 m) still had statistically significantly increased odds of bike use compared with subjects living more than 1,600 m from an on-road bike facility. Subjects within 400 to 799 m still tended toward increased odds of bike use, but this failed to reach the level of statistical significance. While not the focus of this analysis, this part of the study reaffirmed that many of the socio-demographic and economic variables used in other studies are important. Bicyclists are more likely to be male, to be college educated, to come from households with children, and to have higher income.

Discussion of Prediction Methods

Traditional approaches to modeling bicycle demand derive at some level from the standard methods used for forecasting auto travel (i.e., they start from basic information about the people and the transportation environment in an area and use this in some way to predict an amount of bicycle travel, either directly, or as the solution to a mode choice problem in a larger travel model).

This section discusses some issues with using this approach to model bicycling demand. The arguments are based in part on some of the facts about bicycling discussed in the previous section, and in part on some preliminary findings from an original attempt to estimate a demand model for the Twin Cities area. While this model is not described here, in part due to the lack of useful results, it is used to illustrate some of bicycle demand modeling issues more generally.

There are several reasons why a bicycling demand model derived from basic information is not likely to be accurate or useful. These can be illustrated in part by the team's own attempt at developing a demand model, in which was found a statistically significant result that off-road paths were associated with lower rates of bicycling. This result is counterintuitive. Davis (*50*) found that off-road facilities in the Twin Cities are more intensively used than other options. The team's result was not due to an obviously underspecified model; a wide variety of demographic and land use variables were included in the regressions. There are several reasons for this outcome.

One is a possible shortcoming related to measurement; the manner in which facilities were defined did not correspond to how people perceive them. For example, many of the suburban "off-road" facilities run next to busy highways, with all the associated crossing of driveways and roads. They are off-road in the sense that there is a barrier separating them from the road, but they are not off-road in the sense of eliminating potential conflicts or of being appealing facilities on which to cycle. For example, it is conceivable that elaborate bicycle modeling efforts would incorporate traffic volumes on major streets, travel times by bicycle (given traffic signals and other sources of delays), crash locations, or number of street crossings by off-road paths. Such data are available in many metropolitan planning organizations. Other issues and factors include lane width, pavement quality, and the presence of on-street parking. These measures were not captured because they are considerably more difficult to obtain. Proximity to high traffic corridors along a route also has important implications. It would be useful to have information about impedance factors along a specific route, difficulties with the transit/cycling interface, or other issues. These factors are important and the fact that they were absent from the data might limit the broader applicability of the results. This problem is only compounded when trying to develop a model based on results in different locations because cities may have different ways of defining and measuring their own facilities.

The second issue with this sort of model is that there are very large and seemingly random differences from one place to another. In one area in Minneapolis, 16% of the adults made bike trips on the day they were surveyed, while the rate in many other areas was 0%. Even across entire metropolitan areas the differences can be large; the metropolitan areas and states with the most bicycling can have rates that are 10 times that of the places with the least. While there are some well-documented population and land use characteristics that are associated with higher levels of bicycling, the impact of these factors can account for only a small fraction of the total variations that are observed. Other, seemingly unobservable attitudinal and possibly historical factors seem to dwarf the effect of the factors that planners and policymakers can control.

The report contains findings for residents of Minneapolis and St. Paul. The team is not convinced that these findings are applicable to other locations. Twin Cities' residents may differ from those of other places with respect to lifestyles and preferences for bike use. Even within the Twin Cities area, the same regressions yielded different results depending on the geographical scope of the study area, that is, including suburbs in the analysis changed the results. The options, availability, and manner in which bicycle facilities are valued likely differ substantially between populations, especially urban versus suburban (*54*).

Because the impact of the unobservable variables are large relative to the variables of interest, it is likely that what is being observed, both in this model and in others, is the effect of attitudinal variables acting on policy variables through spurious correlations. What seems to have been observed in this model are geographic spikes in bicycling. These spikes happened to be positively correlated with some facility measures and negatively with others, but that in a causal sense had little or nothing to do with any of them. While other work of this type in the literature has typically not had to deal with quite such a wide range of bicycling levels, it seems probable that these types of correlations might be driving their results to a large extent, too, given the typically low explanatory power of these models.

A third issue is that because the level of bicycling is so low, the range of sampling error can be many times larger than the sample mean for any realistic sample size. The effect is that the regression is trying to predict (measured) variable values that could be off by a factor of five or more from their true values. A sample of 1,000 people would yield 9 cyclists on a given day at the national average level; the 95% confidence interval for this sample ranges from 3 to 15 cyclists. This is a very big difference in relative terms. Seemingly very high or low levels could easily just be sampling aberrations. Yet these inaccurate measurements could strongly influence the estimated parameter values. Obviously this will be a problem with any model of bicycling behavior, but it seems likely to be compounded by the need in traditional models to incorporate a large number of explanatory variables.

Finally, there is always the problem that even a positive correlation between riding and facilities could be causation in the other direction—that is, the large number of cyclists creates the political climate to build the facilities in the first place. Given limited funds, agencies are unlikely to spend them on striping bike lanes unless there is a problem such as crashes, or bikes and motor vehicle conflicts. Thus, retrofitted lanes are probably a response to existing cycling to a large extent, and thus will naturally be associated with high levels of cycling after they are built. *Indeed, the other main "result" of the Twin Cities model was that on-street bike lanes were very strongly and positively associated with increased riding.* By contrast, lanes in some newer cities in California do not seem to have high riding levels (*55*), possibly because they were designed into new roads, that is, built in anticipation of riding rather than in response to it.

Seemingly, the only way around these problems would be to study the same geographic area over a period of time as facilities change. The relevant comparison is not comparing people living at location A to different people living at location B, but rather comparing the people at A with themselves as the provision of facilities changes over time. This would be an expensive prospect using surveys; development of a low cost method of counting bikes over a large number of different streets and bike facilities would be of great value for this purpose.

A SKETCH PLANNING METHODOLOGY

This section outlines a simple sketch planning method to estimate the number of daily bicyclists in an area using readily available data. This method could be used for general political purposes, justifying expenditures by reference to the number of bicyclists and the benefits that they receive from cycling. It could be used to estimate demand on new facilities by assuming that it will be some fraction of the total amount of riding in the surrounding area. Finally, this method could be used indirectly to estimate changes to the amount of cycling resulting from facility improvements, assuming that changes will be some (probably small) fraction of the existing total.

Discussion

The basic assumption that motivates the model described here is the idea that a large portion of total bicycling is done by a small fraction of cyclists who ride frequently, and that many of these frequent riders are bike commuters who will be observed as such in the census commute to work data. The assumption is that the basic riding frequency table described in the previous section will hold more or less across different areas, so that an area with a lot of commuter cyclists will also have a lot of total cycling, and an area with few commuters will have little total riding. In other words, commuting by bike, while it is a small fraction of the total bicycling in a given area, can still be used as a "leading indicator" of what might be happening with other types of cycling.

The team used three different geographical divisions to study the relationship among commute shares, total daily bicycling rates, and total weekly bicycling rates. These divisions were metropolitan statistical areas, states, and zones of 10,000 to 30,000 people within the Minneapolis-St. Paul area. The results of these analyses are described in more detail in Appendix A. The primary results are summarized in the following subsections, along with some key facts from the demand measurement analysis.

On any given day, roughly 1% of the adults in the United States ride a bicycle. Over large geographic areas such as metropolitan areas or states, this number could range roughly between about 0.3% and 2.5%. Over smaller areas such as specific parts of metropolitan areas, the range could go as high as 15%. The possible range can be reduced somewhat for a given area by considering the bicycle commute to work share. The best fit for a regression relating percentage of adults who bicycle in a given day to the census bike commute to work share varies considerably across different sized geographic units.

However, based on this analysis, it appears that bounds can be placed on the range of values that are likely to be observed. The observed lower bound for the number of daily adult bicyclists is equal to the commute share (even though in this case there are more total bicyclists than commuters, since they are calculated from different denominators). A "most likely" value would be 0.4% plus 1.2 times the commute share; this was the best fit at the MSA level, and also describes the United States as a whole. An upper bound would be about 0.6% plus 3 times the commute share; this is slightly higher than the slope observed at the neighborhood level.

Two important points are worthy of note. First, the range is large in relative terms; bicycling days per adult are 8 to 10 times larger in the high-bicycling cities and states compared with the lower level places. The difference between neighborhoods within a city can be even larger. These variations seem far larger than can be reasonably explained by differences in formal policies and facilities, especially given that some low-cycling areas have similar circumstances to other high-cycling areas. It seems that local attitudes and perhaps history play a substantial role in the perception of bicycling as an appealing or normal thing for an adult to do. Thus, these guidelines leave considerable scope for the planner to apply local knowledge and judgment to modify the estimated range of demand levels estimated.

The second important point is that while the range is very large in relative terms, it is very small in absolute terms. An estimate of total usage or total benefits in a given local context is unlikely to be off by very much in absolute terms because the numbers overall are so small. Because costs tend to be relatively small as well, even somewhat inaccurately predicted demand is unlikely to lead to poor decisions on major investments. The demand model outlined should be accessible to decision-makers and provide a known range of outcomes.[iii]

Description of Process

The process for estimating the increase in demand due to a facility is based on two steps derived from the team's research described in this chapter and in the Appendix A and B. The first step uses the bicycling commute share in the area around the proposed facility to generate low, medium, and high estimates of the total number of current adult bicyclists in the area (i.e., the average number on a given day). This is a baseline level of demand. Then the findings for the higher levels of bicycling for residents in the immediate vicinity of a facility are applied to this baseline to estimate the rates that would exist after the facility is built. This process is described in more detail in Chapter 4.

It should be noted that this process is estimating the daily average number of adult bicyclists from the area around the facility, based on observed relationships from around the United States. It is not estimating the number of people who will actually use the facility itself. A given facility will likely be used by many people who do not live near it, and some local residents may ride but not on the facility. For purposes of estimating benefits, one wants to know the number of cyclists in general (on or off the facility), and how the presence of a facility might impact that number, based on empirical observation. Estimating total users, including those from outside the immediate area, would have required a level of data that is not available and details of local geography that would be hard to account for in a general way.

Once the demand estimate has been reduced to a range of possible values based on readily available data and a set of tested relationships between different measures of bicycling demand, the user can apply his or her own judgment and local knowledge to choose a most likely point within the range that has been determined. It could be that circumstances are so unusual in a given situation that the user will even want to choose a point outside the recommended range.

The kinds of factors that the user might want to consider in this step could be things like design details of the facility, special local land uses that could affect bicycling demand, how the facility might fit into a larger system, and so on. These kinds of factors would not be included in the primary demand range estimate for two reasons. First, there is no compelling evidence in terms of how these factors affect demand or that the effect is sufficiently predictable and reliable that it can be included in a model that can be applied across a variety of locations. For example, universities tend to be associated with higher levels of bicycling in general, but the size of this effect seems to be highly variable depending on the specific situation. Second, the number of possible local details would be so large as to be unmanageable, especially when there is no basis for attaching specific numbers to most of them anyway. Although examples can be listed to prompt the user to think of additional local factors, putting together a comprehensive list would be nearly impossible.

The demand estimation method, in summary, provides a range of possible demand levels for a given situation, based on a simple method derived from high quality, nationally consistent data and from well-tested relationships among various measures of bicycling demand. The user would then be able to choose a most likely estimate based on this range by applying local knowledge and judgment regarding other more qualitative factors.

CHAPTER 3

BENEFITS ASSOCIATED WITH THE USE OF BICYCLE FACILITIES

PREVIOUS APPROACHES

A key to encouraging bicycling and walking is to ensure that adequate facilities exist to use these modes. For walking, this includes sidewalks, public spaces, and street crossings. For bicycling, this includes relatively wide curb lanes, on-street bike lanes or off-street bike paths, and even parking and showers at the workplace. But bicycle facilities cost money, their merits are often called into question, and many consider spending on them a luxury. Planners and other transportation specialists often find themselves justifying that these facilities benefit the common good and that they induce increased use. Especially in austere economic times, planners are often looking for ways to economize such facilities.

Urban planners, policy officials, and decisionmakers have lacked a consistent framework from which to understand the merits of such facilities. These officials are often presented with information on how much these facilities cost. Opponents of bicycle projects consistently use such information to contend that trimming particular projects would preserve funds that could be used for other purposes. Cost data are readily obtained; it is relatively straightforward to account for the acquisition, development, maintenance, and other costs for site-specific or aggregate cases. The benefits of such facilities, however, are considerably more difficult to estimate. To respond to such policy and planning needs, the purpose of this section of the report is twofold. The first is to review and interpret existing literature evaluating the economic benefits of bicycle facilities. The second is to suggest methods and strategies to create guidelines.

The purpose of a framework for organizing and categorizing benefits is to provide a clear means of identifying the myriad benefits being discussed and who benefits from them. This is important because different types of benefits, even if they appear similar, may be of different magnitudes, or stem from different policy decisions or facility investments. The benefits of bicycling are largely a function of the amount of cycling; they will invariably depend on finer details such as the location, purpose, person cycling, and characteristics of the facility being used. Understanding the size of the benefit requires at least a reasonable estimate of how large they are in one's own local area. Information on the size of benefits will be useful in justifying expenditures on cycling in general; while understanding how they might change over time will help in evaluating and prioritizing specific investments.

OVERVIEW OF ISSUES

To estimate the economic benefits of bicycle facilities it is necessary to provide an overview of the main issues involved, the matters that confound such endeavors, and a justification for more structured research.

The overarching issue is reliably determining an economic value for a facility for which there is no market value and little data for its use. Bicycle facilities, like wilderness, a clean environment, and access to open space, represent non-market goods not bought or sold. There are no prices for their use that can be manipulated and, as a result, they represent a good for which it is extremely difficult to derive an economic value. Furthermore, given current levels of bicycling use, one person's use does not interfere significantly with another's and the costs of restricting entry to the facility outweigh any revenue that could be raised. Bicycle facilities exhibit characteristics closely resembling what economists call "public goods."

But if certain goods are thought to contribute positively to human well being, they are considered to have economic value (the reverse is also true). Under these circumstances, literature from the field of economics and transportation has devised general methods for estimating economic values attached to non-market goods and services. These include methods to measure both revealed and stated preferences for a good. Revealed preferences are used to identify ways in which non-market goods influence the actual market for some other goods and are estimated using methods such as hedonic pricing, travel cost, or unit day values. Stated preferences are used to construct markets, asking people to attach an economic value to various goods and services and are estimated using methods such as contingent valuation or conjoint analysis.

Measuring any aspect of bicycling facilities is also complicated because discussion of transportation facilities typically considers matters in terms of auto, transit, or non-motorized travel; doing so aggregates walking and cycling. For abstract or general purposes, this may suffice and is often done in transportation research. In terms of daily use and facility planning, however, bicycling and walking differ significantly.

Pedestrian travel and infrastructure have the following unique characteristics. First, all trips—whether by car, rail transit, or bus—require pedestrian travel because they start and end with a walk trip. Second, sidewalks and other pedestrian related amenities are often standard requirements in zoning codes. Third, pedestrian concerns typically relate to relatively confined travel-sheds or geographic scales (e.g., city blocks). Bicycle travel and facilities, on the other hand, tend to apply to longer corridors, fail to be used as readily and frequently as walking facilities, and are therefore considered more discretionary in nature. Most important, whereas pedestrian planning applies to a clear majority of the population (nearly everyone can walk), bicycle planning applies to a considerably smaller market of travelers—those who choose to ride a bicycle. During the summer months in most of the United States, this includes slightly more than one-quarter of the population (*47*).

Poor data are a concern for all analysis of non-motorized transportation (bicycling or walking). There exists a variety of sources from which basic bicycle behavior can be determined, for example, the census, metropolitan/nationwide travel surveys, facility specific surveys or counts, and national surveys such as that administered by the Bureau of Transportation Statistics (*47*). Specific use and facility information may be available for select areas throughout the country. The strengths and weaknesses of these data sources are adequately documented in a report issued by the U.S. Department of Transportation (*56*). A common theme is that existing behavioral bicycle data lack the breadth and quality necessary for reliable analysis. Analysis of cycling use has been especially marginalized because of the relatively low levels of bicycling (compared with other transportation modes).

Such data deficiencies are recognized by the transportation planning community, and procedures and protocol for bicycle data collection are improving. Bicycle and pedestrian travel are increasingly apparent outside the transportation community, including in matters related to livability and public health. For example, transportation and urban planning researchers are joining forces with public health researchers to better understand both derived and non-derived forms of "active" transportation (i.e., bicycling and walking). These improvements are noteworthy and will surely benefit transportation research.

There remains considerable range in how to measure benefits of bicycle facilities. Reviewing past research on the subject in a systematic manner is challenging. Geographic scale, research depth, overall quality, and focus of past study vary considerably. The research is not cumulative (i.e., studies do not build on previous efforts). It is also challenging to find such research. The research team cast a relatively wide net to identify papers on bicycle benefits. The team's definition includes any research effort describing or attributing an economic value to bicycling or bicycle facilities. These studies are described in detail in Appendix C.

A review of the studies suggests there are at least four issues that confound research on this topic: (1) what is the geographic scale or type of facility? (2) who benefits from the facility? (3) which benefits apply to the facility? (4) what units and methods are used? How does one compare the economic benefits gained from Colorado's mountain biking industry to the quality of life or neighborhood-scale benefits from building a neighborhood bike path for children? How do the air pollution benefits of increased cycling relate to quality of life benefits from the serenity of a nearby rail-trail? How reliable are the safety estimates for different types of bicycle facilities, especially given existing debate over on-road versus off-road facilities (*57, 58*)? The studies and approaches to date represent initial attempts to understand such benefits. They often do so, however, by estimating them over inconsistent geographic scales and making a variety of assumptions (some of which go unstated or are extremely case specific). Each consideration is described in the following subsections.

What is the Geographic Scale or Type of Facility?

The first consideration pertains to the geographic scale of the inquiry or facility in question. Past work has analyzed the benefits of a specific greenway or active recreation trail (*59–65*), a specific trunk roadway (*66*), a region (*67, 68*), an entire city (*69*), or an entire state (*70*). Some studies focus on a system of bicycle trails across the state. Others focus on the benefits of on-road versus off-road facilities. Different geographic scales demand different data requirements, ranging from individual counts of a facility to aggregated counts or numbers for a specific area extrapolated to an entire state.

Who Benefits from the Facility?

A second matter relates to the population for whom the benefits apply. Benefits can be determined in a number of ways depending on the audience of interest and the geographic scope. State legislators may be interested in understanding how bicycling, the bicycle industry, or bicycle-oriented tourism impacts a state's economy. Such analysis would resemble input/output models examining expenditures across an entire state. In contrast, a city council member may seek to learn how bicycle facilities enhance quality of life for a given municipality. Advocates want to document induced or latent demand for facilities and possible relationships to decreased traffic congestion. Public health professionals are concerned about the safety benefits of such facilities.

Can a single review do justice to the myriad interests and beneficiaries involved? This depends on the level of specificity and need of the study. There are competing interests and multiple perspectives to capture. While actual users are likely to be the same for any given facility (i.e., people riding bicycles), the information likely to be of benefit to the state bureau of tourism differs from a municipality looking to justify different types of bicycle investments.

One report identifies three user groups impacted by cycling facilities: road users, non-road users (e.g., occupants of adjacent properties), and planning/financing agencies (*66*). The first group of road users includes all users, cyclists, motorists, pedestrians, horse riders, and public transport. Alternatively, some studies divide the benefits of non-motorized travel into internal versus external benefits. The former include the financial savings, health benefits, increased mobility, and overall enjoyment for cyclists; the latter include the benefits to others, such as reduced (a) congestion, (b) road and parking facility expenses, (c) motor vehicle crashes, (d) air and noise pollution, and (e) natural resource consumption.

One of the most contentious issues is adequately accounting for benefits accrued by cyclists of different ages. Adults and children value different types of facilities. Children enjoy trails for recreational purposes. Programs such as "Safe Routes to Schools" are also becoming important. However, it is difficult to obtain reliable data for an adult cycling population much less for a population of children. For this reason, almost all analysis of bicycle facilities, including the research reported herein, is based on the preferences of an adult population.

Which Benefits Apply to the Facility?

The range of benefits of cycling facilities include, but are not limited to, reduced pollution, congestion, capital investments (at least compared with roads and auto use), and increased livability, health, well-being, and quality of life. But anecdotally describing such benefits has limited value. Politicians and lobbyists seek reliable and quantifiable estimates. Specific benefits range from the direct and easy-to-understand to the difficult to reliably calculate. Counting the number of cyclists using a new bicycle trail is relatively straightforward after the fact. The challenge is translating such levels of ridership into an economic value.

One study suggests seven benefits to consider when estimating the economic value of walking: livability, accessibility and transportation costs, health, external costs, efficient land use, economic development, and equity (*71*). Focusing just on greenways, Lindsey (*72*) articulates six valued benefits: recreation, health/fitness, transportation, ecological biodiversity and services, amenity visual/aesthetic, and economic development. Which benefits are most important? Is it those that are accrued, those in which the sponsoring agency is primarily interested, or those for which there is available data?

What Units and Methods are Used?

The last issue involves the units and methods used to calculate different benefits. An ideal analysis considers benefits in a framework using a common unit. But how does an increase in riders compare with a reduced need for parking spaces? How does increased livability compare with decreased health concerns? With adequate data, it would be possible to count riders on existing facilities and possibly determine induced riders on a new facility. However, this is just one benefit and it remains unclear to which categories it applies. One article focuses exclusively on methods, reviewing the Travel Cost Method (TCM) to determine economic value and suggesting better alternatives for measurement (*73*). When it comes to estimating, many studies "guesstimate" to solve the problem. Each of the methods and units are different, yielding varied output that precludes the desired aim of a common unit.

Previous work provides the most precise guidance by suggesting a unit by which each characteristic could be measured. These range from simple counts (e.g., reduction of casualties) to decibels to monetary amounts (e.g., vehicle operating costs) to descriptive measures (e.g., overall convenience). More often, general measuring techniques are offered. For example, it is suggested that hedonic pricing could be used to measure livability or amenity visual/aesthetic values; economic input/output models could describe economic development; time could be used to measure transportation savings; and surveys of different kinds (e.g., contingent valuation) could be used to capture a host of values or benefits.

PROPOSED BENEFITS AND METHODS

Past research offers varying perspectives on the bicycle facility information different audiences require. The central challenge for urban planners, policy officials, and researchers focuses on the benefits of bicycle facilities that pointedly satisfy certain criteria. After reviewing existing literature, canvassing available data and methods, and consulting a variety of policy officials, the team has determined that bicycling benefits need to satisfy five criteria: (1) be measured on a municipal or regional scale, (2) be focused on transportation and urban planning, (3) be estimable via available existing data or other survey means, (4) be converted to measures comparable with one another, and (5) be measured benefits for both users and non-users (i.e., the community at large).

It is also important to describe the range of benefits, to whom they apply, and to suggest compelling methods in which they could be measured. The list of benefits is guided by previous research and includes *direct* benefits to the user—in the form of mobility, health, and safety benefits—and *indirect* benefits to society—in the form of decreased externalities, increased livability, and fiscal savings.

Other benefits certainly exist, but the beneficiaries are not always clear. The aim is not to dismiss their significance but merely suggest that practical considerations related to data, methodologies, and measurement often preclude more detailed analysis. The benefits mentioned usually have different beneficiaries. These range from society-at-large to individual users (potential and current) to agencies; there is crossover between beneficiaries for each benefit. Consider, for example, that the most common argument in favor of cycling suggests that an increase in facilities will result in increased levels of cycling. This assumed increase in cycling will be derived from (1) existing cyclists whose current levels of riding will be heightened (because of more attractive facilities) and (2) potential cyclists whose probability for riding will be increased. Thus, there are potential benefits for two different populations (current and potential cyclists). But if any of these heightened levels of cycling result in decreased auto use, then a third beneficiary results—society-at-large—in terms of reduced congestion and resource consumption.

Descriptions follow of what each benefit refers to, the primary user group to whom it applies, and a thumbnail explanation of strategies that could be used to measure such benefit. The proposed method is not to imply there is a single strategy for estimating this benefit but merely to provide the reader and researcher with an example of how it could be measured. Figure 1 (in the Summary) shows a simplified depiction of potential beneficiaries along with an indication of the primary benefit.

Mobility

The most directly cited benefits are often from bicycle facility users. These come in the form of greater satisfaction of existing cycling (e.g., cyclists would be able to reach their destination faster, safer, via a more attractive means). However, existing information by itself (e.g., ridership counts) cannot reliably shed light on this issue. For this reason, the different transportation benefits for the user are best uncovered through stated preference surveys or experiments. Because stated preference methods provide individuals with hypothetical situations, it becomes feasible to analyze situations that are qualitatively different from the actual ones seen in practice (*74*).

Because individuals respond to several different hypothetical choice situations offered to them, the efficiency of data collection is improved; enough data is hence available to calculate functions describing their preferences or utility. The disadvantage in stated preference methods is that people may not always do what they say. Individuals' stated preferences might not be the preferences they actually show (*75*). The differences arise because of the systematic bias in survey responses or because of the difficulty in carrying out the posed task.

Two techniques used in stated preference analyses are contingent valuation and conjoint analysis. Contingent valuation is based on the premise that the best way to find out the value an individual places on something is by asking. Like other non-market goods, the concept has been applied to wilderness, open space, or even more specifically to greenways (*76*). The second stated preference technique, conjoint analysis, uses experiments to obtain the preferences of the customer. This market research technique can provide important information about new product development, forecasting market segmentation, and pricing decisions. In this case, it would help to understand the type of cycling facilities residents value. Conjoint analysis enables researchers to calculate the value that people place on the attributes or features of products and services; the aim is to assign specific values to the options that buyers look for when making a decision to use a good. It is a technique used to explore trade-offs to determine the combinations of attributes that satisfy the consumer.

In these cases, an individual is provided a choice of alternatives; for example, the various travel routes by which a particular travel destination can be reached. The choice of a particular mode is assumed to depend on the relative attractiveness of the various travel options that the individual faces. These methods use experimental procedures to obtain preferences based on the individual's evaluation of the various options given. Typically, these experiments provide hypothetical travel scenarios to obtain an individual's preferences (*77*).

Stated preference surveys need to be stratified by audience: current users versus potential users. Current cyclists could be asked to respond to questions about factors that would provide for a more attractive cycling environment through different types of environments or facilities. It is necessary to have forced trade-offs so that a better environment might be coupled with higher costs for bicycle storage or a higher travel time. This will allow one to value each component of the user's preference. These preferences can then be translated to economic benefits using consumers' surplus measures (*78*) to determine, for example, the value of an off-road bicycle facility for users of that facility.

For potential users, it is important to create scenarios based on constructed markets, asking people to attach a value to goods or services. This technique quantifies the benefits that non-bicycling residents would accrue from a more desirable bicycling infrastructure. For example, questions could be what mode they would choose for work and non-work trips based on the quality of the transportation environment, including travel by auto, walking, transit, and bicycle. It would query residents about the degree to which they perceive different bicycling services or how facilities will improve the conditions of their commute, recreational activities, and so forth. By measuring how demand might change, one can ascertain the preferences for current non-users, some of whom would become users if a certain infrastructure package were constructed.

The team's approach to determining user mobility benefits is described in detail in Appendix D. It quantitatively evaluates individual preferences for five different cycling environments. The respondent is asked to trade off a higher travel time as a cost incurred to choosing a better facility while allowing the respondent the option of selecting a less attractive facility at a lower travel time. The trade-off of travel time to amenities of a particular facility determines the value attached to different attributes such as bike lanes, off-road trails, or side street parking. The facilities considered in this application are off-road facilities, in-traffic facilities with bike lane and no side street parking, in-traffic facilities with a bike lane and side street parking, in-traffic facilities with no bike lane and no side street parking and in-traffic facilities with no bike lane but with street side parking. *The results indicate that respondents are willing to travel up to 20 min more to switch from an unmarked on-road facility with side parking to an off-road bicycle trail, with smaller changes for less dramatic improvements.*

Health

Scientific literature from researchers and practitioners from a variety of disciplines show relationships between community design, transportation facilities, and levels of physical activity (*79, 80*). "Sprawling" land use practices and resulting auto-dependent travel are themes that now have moved to the front of the American consciousness; the link to public health and obesity remains an important component of this discussion (*81–83*). One goal of this research is to learn the extent to which rates of physical inactivity can be linked to features of the built environment (see Krizek et al. [*84*]). At a regional or neighborhood level, most inquiries focus on land use patterns characterized by relatively scattered, single use and low-density development. At a street or facility level, such research focuses on access to sidewalks, trails, other non-motorized facilities, and destinations. While recent research has linked neighborhood design to travel behavior (*85, 86*), little of it has exclusively focused on relationships between specific facilities, bicycling and walking travel, and levels of physical activity.

To establish a health-care, cost-based reason for bicycle facilities, several types of specific empirical evidence must be gathered and communicated to interested parties. Using reasoning from Goetzel et al. (*87*), researchers must first demonstrate relationships between a given feature of the built environment (e.g., a bicycle facility) and levels of cycling. This activity is similar to methodologies previously described to measure the demand induced from various facilities. International research on this question is likely to have reliable results that can enhance this line of inquiry in relatively short order time (i.e., a couple of years). Second, any amount of induced cycling that could be "teased" out from a facility would then need to be translated into an average percentage of one's weekly physical activity. For example, the daily recommended level of physical activity is defined as 30 min of moderate physical activity on 5 or more days per week (*88, 89*). Cycling 5 mi in 30 min or 4 mi in 15 min would meet these current public health guidelines for physical activity (*90–92*).[iv]

Third, researchers must then demonstrate that lack of physical activity—because it is indicative of certain risk factors—imposes a financial burden to the individual or to society. A fourth step would be to show that improving certain risk factors (i.e., increasing physical activity) does result in reduced cost. The final step is for researchers to demonstrate that health habits can be changed and that the resultant lower risk can be maintained over time. As can be seen, the challenges associated with documenting a health financial payback from a bicycle facility are significant. Looking at the problem optimistically and from the perspective of needing analytical justification, such exercise is not completely out of the realm of possibility. For this reason, these later steps (three through five) constitute the focus of the following review.

The benefits of physical activity in enhancing overall health are well established. The task of attaching monetary value to levels of physical activity is a more challenging endeavor. One attempt is offered by Wang et al. (*93*) who derive cost-effectiveness measures of bicycle/pedestrian trails by dividing the costs of trail development and maintenance by selected physical activity-related outcomes of the trails (e.g., number of trail users). The average annual cost for persons becoming more physically active was found to be $98; the cost was $142 for persons who are active for general health, and the $884 for persons who are active for weight loss.

Estimating the effect of physical inactivity on direct medical costs is a strategy more often employed, though considerably less straightforward. Part of the reason for ambiguity in this research is that the amount of physical activity required to realize certain health benefits is relatively unknown (i.e., what is the elasticity?) (*88, 94, 95*). In the field of public health, this matter is often approached from the perspective of dose-response relationships. The aim is to learn what change in amount, intensity, or duration of exposure (in this case, cycling) is associated with a change in risk of a specified outcome (in this case, cost of health care).

Existing literature examining relationships between levels of physical activity and health costs varies considerably in methodology and scope. The majority of existing studies pursue a dichotomized approach, separating respondents into two classes: those that satisfy an accepted dose of 30 min per day for 5 days and those who do not. In this first group of studies, there are at least five statewide reports whose methodology and assumptions are relatively general in nature. In most cases, estimates are derived from an aggregation of medical expenditures that can in some form be traced back to physical inactivity. For example, a study commissioned by the Michigan Fitness Foundation (*96*) concentrated on the economic costs to the residents of Michigan. The authors used estimates (acknowledged to be conservative) to derive direct costs (e.g., medical care, workers' compensation, lost productivity) and indirect costs (e.g., inefficiencies associated with replacement workers). The final amount totaled $8.9 billion in 2003 ($1,175 per resident). A 2002 report from the Minnesota Department of Health (*97*) estimates that in 2000, $495 million was spent treating diseases and conditions that would be avoided if all Minnesotans were physically active. This amount converts to more than $100 per resident. Additional reports claim that too little physical inactivity was responsible for an estimated $84.5 million ($19 per capita) in hospital charges in Washington State (*98*), $104 million ($78 per capita) in South Carolina (*99*), and $477 million in hospital charges in Georgia ($79 per capita) (*100*).

These reports from various state agencies are complemented with more academically oriented research. For example, Colditz (*101*) reviewed literature on the economic costs of inactivity and concluded that the direct costs for those individuals reporting lack of physical activity was estimated to average approximately $128 per person. A separate analysis by Pratt et al. (*102*) analyzed a stratified sample of 35,000 Americans from the 1987 national Medical Expenditures Survey. Examining the direct medical costs of men and women who reported physical activity versus those who did not reveals that the mean net annual benefit of physical activity was $330 per person in 1987 dollars. An alternative method used a cost-of-illness approach to attribute a proportion of medical and pharmacy costs for specific diseases to physical inactivity in 2001 (*97*). The authors first identified medical conditions associated with physical inactivity and then collected claims data related to those conditions from approximately 1.6 million patients 16 years old and older from a large, Midwest health plan. While the resulting conditions from lack of physical inactivity include depression, colon cancer, heart disease, osteoporosis, and stroke, the results from this study conclude that the costs of claims to the health plan attributable to physical inactivity translates to $57 per member. One challenge of these analyses is the decision whether to include diseases causally related to obesity.

A different approach than the dichotomized strategy estimates the impact of different modifiable health risk behaviors and measures their impact on health care expenditures. After gathering information from more than 61,500 employees of 6 employers gathered over a 5-year study period, Goetzel et al. (*87*) focused on a cohort of slightly more than 46,000 employees. The analysis found that a "risk-free" individual incurred approximately $1,166 in average annual medical expenditures while those with poor health habits had average annual medical expenditures of more than $3,800. Thus they estimated the per-capita annual impact of poor exercise habits to be approximately $172. Pronk et al. (*89*) also identify the relationship between modifiable health risks and short-term health care charges. This research surveyed a random sample of 5,689 adults 40 years old or older enrolled in a Minnesota health plan. Multivariate analysis on the modifiable health risks (diabetes, heart disease, body mass index, physical activity, and smoking status) concluded that an additional day of physical activity (above zero) would yield a 4.7% reduction in charges (or a $27.99 reduction). The overarching result of the study is that obesity costs approximately $135 per member, per year and those with low fitness (inactivity) cost approximately $176 per member per year.

Several matters should be noted when determining values for health benefits. First, annual per capita cost savings vary between $19 and $1,175 with a median value of $128 (see Table 25 in Appendix E). Second, some studies are disaggregate in nature and estimate costs by inpatient, outpatient, and pharmacy claims; others compare average health care expenditures of physically active versus inactive individuals. Third, some use a dichotomized approach to determine who constitutes a physically active individual while others employ a modifiable health risks approach and do so in a relatively continuous scale. The studies are difficult to compare, however, because some include different conditions, outpatient and pharmacy costs, and actual paid amounts rather than charges. Nonetheless, existing literature provides adequate, though developing, methodologies for estimating the public health impact of bicycle facilities in economic terms.

These approaches have recently been made more accessible to planners, decisionmakers, and the public through the Robert Wood Johnson's Active Leadership Program. The physical inactivity calculator available on the website (*103*) provides an easy-to-use tool to estimate the financial cost of physically inactive people to a particular community, city, state, or business. It also supplies companion resources and information needed to re-allocate resources and plan for healthier workplaces and communities that are more supportive of physical activity.

Safety

Increased cyclist safety is an often assumed, poorly understood, and highly controversial benefit of bicycle facilities. The task of establishing a safety derived, cost-based justification for bicycle facilities is similar to the process described in the previous section for estimating public health benefits, albeit with different data. Researchers must first demonstrate relationships between a given cycling facility and safety outcomes. Then they need to demonstrate that the measured outcome of conditions with decreased safety imposes a financial burden to the individual or to society.

In general, the literature about the safety dimensions of bicycling manifests itself in three primary aspects: (1) helmet use, (2) safety programs, and (3) number of crashes or perceived level of safety that can be ascribed to facility design. The last category is most germane to the construction of facilities and is the center of the following discussion. One issue is how to combine data about safety (e.g., crashes or perceived comfort) with different attributes of cycling facilities. The team's aims to understand the degree to which different cycling facilities lead to an incremental safety benefit, measured in terms of decreased crashes or medical costs.

Existing literature measures safety in one of three ways: (1) number of fatalities, (2) number of crashes, and (3) perceived levels of comfort for the cyclist. Key explanatory variables behind these outcome measures are myriad and complex to identify. For example, the overwhelming majority of bicycle crashes resulting in fatalities are caused by collisions with motor vehicles (*104*). Less severe crashes tend to occur at intersections or at locations where motor vehicles and bicycles come in contact with each other (*105*); it is further suggested that crashes are caused by differing expectations between auto drivers and bicyclists (*106*). However, there is evidence to suggest that some bicycle crashes do not involve any other party (*107, 108*); this is especially true for children (*109*).

The prevailing argument is that enhanced facilities—bike lanes, bikeways, and special intersection modifications—improve cyclist safety (*83*). This claim, however, is controversial and a source of debate between Forester (*57*) and Pucher (*58*). One of the issues concerns differences between what cyclists state they prefer (i.e., their perception) and what studies with collision data actually reveal.

It is widely acknowledged that increased perception of safety is important to encourage cycling as a means of transportation and recreation (*51, 110*). Subsequently, providing separated bicycle facilities along roadways is mentioned as a key to increased perception of safety according to the literature related to bicycle-related stress factors (*111*); bicycle interaction hazard scores (*112*), relative danger index (*113*), compatibility indexes (*114*).

The goal of these works is to determine and predict conditions for safe bicycling based on different cyclists' perceptions of safety. The culmination of these works can best be described under the banner of level of service (LOS) models, originally developed in 1987 in Davis, California (*115, 116*). The participants of these studies were of diverse demographic and skill backgrounds and cycled 30 roadway segments. Including the variables of traffic volume per lane, posted speed limit weighted with the percentage of heavy vehicles, adjoining land use, width of outside through lane, and pavement conditions, the researchers were able to explain almost 75% of the variation of perceived safe conditions. The model consists of four basic factors—pavement conditions, traffic speed, lane width, and traffic volume per lane which aim to serve as a tool for predicting perceived safety and comfort along roadways between automobiles and bicycles.

The bulk of the existing literature on bicycle LOS and perceived safety focuses primarily on through travel on mid-block roadway segments. Previous research has rarely considered bicycle lanes separately from other shared use conditions (wide curb lanes or paved shoulders) and rarely considered the role of intersections. While stretches of roadways are important, often the most significant and complex design and safety challenges occur at street intersections (*117*). Two recent research papers focused on this matter (*118, 119*). Landis' recent work (*118*) derived a model to evaluate the perceived hazard of bicyclists riding through intersections. Again, with a highly varied demographic and cyclist ability sample, this study produced a model with a high degree of explanatory power ($R^2 = 0.83$) for bicycle intersection LOS. Significant variables included motor vehicle volume, width of the outside lane, and the crossing distance of the intersection. In this study, there was no control for the presence or absence of a bicycle lane, but the width of the outside lane variable did include the bicycle lane were it present. The research by Krizek and Roland (*119*) analyzed the severity of instances where existing bicycle lanes terminated and their corresponding physical characteristics. The findings suggest that bicycle lane discontinuations ending on the left side of the street, increased distance at intersection crossings, parking after a discontinuation, and width of the curb lane are statistically significant elements that contribute to higher levels of discomfort for the cyclist.

The degree to which perception of safety translates into actual increased safety, however, is still debated. It is difficult to translate perceived measures of safety into quantifiable or economic estimates.

There is evidence to support the notion that collision-type crashes are lower on off-road paths (*120*). Using before and after analysis, Garder's research (*121*) found raised bicycle crossings to be more appealing and safer for cyclists than at-grade crossings. However, there exists an equal, if not greater body of research suggesting no relationship or a relationship in the opposite direction. Research examining conflicts at approaching intersections on bike lane and wide curb lane segments determined that both facilities improve riding conditions for bicyclists, but that the two facilities themselves are not different in safety (*122*). Smith and Walsh analyzed before and after crash data for two bike lanes in Madison, Wisconsin, finding no statistically significant difference (*123*). Also, Hunter's analysis of a bike box in Eugene, Oregon, showed that the rate of conflicts between bicycles and motor vehicles changed little in the before and after periods (*124*). No conflicts took place while the box was used as intended. Hunter also evaluated colored (blue) pavement and accompanying signing used in weaving areas at or near intersections in Portland, Oregon (*125*). The colored rectangular area within the bike land came to be known as "blue bike lanes," even though only the weaving area was colored. Although conflicts were rare, the rate of conflict per 100 entering bicyclists decreased from 0.95 in the before period to 0.59 in the after period. In addition, significantly more motorists yielded to bicyclists in the after period.

There appears to be good reason for the existing debate over the safety benefits of bicycle facilities. While there is considerable literature suggesting cyclists perceive greater safety with facilities—and advocates certainly argue for such—the bottom line is that there is little conclusive evidence to suggest this. One theory suggests that if a particular setting is deemed unsafe, a cyclist will likely be vigilant and avoid an incident. As a result, the number of incidents may be no greater with an unsafe condition than a safe condition. However, such argument does not support the conclusion that both conditions are equally safe. In the less safe condition, the cyclist will either avoid it or endure a cost of stress to use it.

Yet an alternative theory, not directly applicable to specific facilities, is derived from the concept of safety in numbers where the likelihood of bicycle-automobile crashes interact in a nonlinear manner (the exponent for growth in injuries is roughly 0.4) for an entire metropolitan area. Applying this concept, one would need to calculate the total bicyclists at the metropolitan level (X). Then one could compute 1.X exp 0.4. This number provides the additional bicycle safety cost of adding bicyclists. The cost of car crashes could even be reduced by the proportional reduction in cars on the road. Then, each additional bicyclist increases the total number and thus the total cost of bicycle crashes (though not the per unit cost). In low-volume portions of the nonlinear relation, the decrease in fatality rate outpaces the increase in volume so that, even with more cyclists, the *number* (not just the rate) of fatalities decreases. Values for the benefits and costs of such crashes could be obtained from third party sources (e.g., http://www.oim.dot.state.mn.us/EASS/) which typically summarize the cost per injury of car crashes per type.

Reduced Auto Use

The most common assumption is that cycling trips substitute for auto trips, yielding transportation benefits to society-at-large such as decreased congestion, improved air quality, and decreased use of non-renewable energy sources. While the substitution element may hold true for some cyclists it is extremely difficult to reliably determine the trips that would otherwise be made by car.

The nature and magnitude of any substitution is important to determine and could be estimated via a variety of means. In some instances, a bike trip may replace a car commute; in many cases, however, bicycle trips are likely made in addition to trips that would otherwise occur (*126*) or for a different reason (e.g., recreation). Assuming a fixed demand of overall travel, a best-case scenario for bicycle substitution stems from an assumption well known in the field of travel behavior modeling referred to as Independence from Irrelevant Alternatives (IIA). That is, bicycles draw from other modes in proportion to their current mode shares. For instance, bicycles would draw 85% from current drive alone trips, 5% from auto passenger trips, 5% from transit trips, and 5% from walk trips. This of course is unlikely to be strictly true, so an important part of the benefit analysis would be to determine which of these groups are more likely to switch to bicycling and furthermore, which socio-economic characteristics could be targeted to result in higher rates of cycling.

Assuming bicycling facilities can help bicyclists travel faster, more safely, in a better environment or for shorter distances, its utility compared with other modes will increase. There may be an estimable effect in terms of substitution, and there are different approaches for measuring this phenomenon. At a crude level, one could estimate the number of bicycle miles of travel and auto miles of travel. Assuming a fixed rate of substitution (i.e., 60% of all cycling trips are utilitarian in nature and are substituting for a car trip), one could estimate an upper bound of all mileage that is substituted and the overall social costs being saved. However, this does not account for the possibility that bicycle trips may be substituting for modes other than driving. Furthermore, it says little about how many additional trips from potential cyclists could be induced. Such information would be most reliably obtained by estimating a mode-choice model for different types of cycling trips and calculating the likelihood of substitution rates in that manner. The latter strategy is subject to elaborate modeling schemes and survey data.

It is important to recognize, however, that any reduced congestion benefit to society needs to be tempered by an induced demand phenomenon which may obviate congestion or pollution reductions due to diversion (*127*). This implies that reduced traffic congestion that may result from the construction of an additional bike lane may largely (though not entirely) be consumed by other drivers making additional trips, drivers lengthening trips, and additional development. This suggests that any reduction in congestion (and subsequently pollution and energy benefits) will be small at best. Nevertheless, the additional opportunities for drivers to pursue activities that previously had been too expensive prior to the capacity expansion (of roads or bike lanes) engender some benefits for new drivers.

Livability

Another benefit refers to social attributes accrued by individuals who receive benefits of such facilities, either directly or indirectly. One of the reasons people pay a premium to live in desirable areas is that they are paying for the option to use specific facilities, whether or not they actually do. For instance people may pay a premium to live near a bike path despite not cycling themselves because they might want to in the future. In this respect, such proximity would be valued by current and potential users. These benefits are revealed through preferences that represent an elusive phenomenon to which an economic value can be attached. A compelling strategy to measure these non-market goods analyzes the choices people reveal in their purchase of home locations in efforts to understand how they implicitly or explicitly evaluate the desirability of a certain good. A revealed preference approach would measure individuals' actual behavior, and this can be done through hedonic modeling to learn if and how much residents value accessibility to bicycle facilities.

Discerning the relative value of non-market goods using hedonic modeling techniques is a method that has been employed for years since its first applications by Lancaster (*128*) and Rosen (*129*). An extensive review of this literature (*130*) contains nearly 200 applications that have examined home purchases to estimate values of several home attributes including structural features (e.g., lot size, a home's finished square feet, and number of bedrooms), internal and external features (e.g., fireplaces, air conditioning, garage spaces, and porches), the natural environment features (e.g., scenic views), attributes of the neighborhood and location (e.g., crime level, golf courses, and trees), public services (e.g., school and infrastructure quality), marketing, and financing. The application germane to this inquiry focuses on the relative impact of bicycle lanes and trails. It is important, however, to understand the relative value of different types of facilities as they may have substantially different appeal. Some trails are on existing streets (demarcated by paint striping); some are next to existing streets (separated by curbs); others are clearly separated from traffic and often contained within open spaces. The last category, being the most attractive for many bicyclists, is likely to have the largest effect. To effectively estimate the value of such facilities, it is important to be able to explain and control for the degree to which open space versus the bike trail contained within the open space contributes to a home's value. In many metropolitan areas, bike trails and open space share a spatial location and at minimum exhibit similar recreational qualities. Any research failing to account and control for such correlation would be misguided in its attempt to estimate the independent value of bicycle trails. For this reason, not only is it important to control for structural attributes of the home, characteristics of the neighborhood, and geographic location, but it is also important to consider the value of adjacent open space. The value of open space has been estimated in several applications of hedonic regression (*131–136*).

The hedonic pricing method is appealing because it is rooted firmly in market prices and provides a strategy to perform an economic valuation for non-market facilities. To the team's knowledge, the only attempt to extend such methodology to bicycle facilities was conducted by Lindsey et al. (*72*) who analyze the property value using a one-half mi buffer around a greenway. The outcome of this methodology would then be econometric models that can be used to reliably measure if residents value access to bicycle facilities and if so, to what degree. This value could then be easily converted to monetary amounts.

Fiscal

ROW preservation is the process of preserving land needed for future infrastructure, most often in the form of transportation. It is a benefit reaped exclusively by the public agencies planning such facilities. Consider the situation where there may be a plan to build a rail transit corridor in 10 years; it may be economically prudent to acquire the land sooner rather than later for several reasons (*137*). First, the price of land may rise faster than inflation. Second, acquiring the land now may ensure it is not developed, while not acquiring it now may require the destruction of recently constructed buildings. There are, of course, risks associated with ROW preservation. Land may be acquired but the resources never found to complete the project. ROW acquired prior to use for a future road or transit line may still be used for transportation. Placing a bicycle facility along the ROW is relatively inexpensive, ensures a transportation use for the corridor (ensuring it will not be viewed as park land) and provides user benefits.

The economic value of ROW preservation can be estimated by multiplying the probability of use in the future by the difference of the net present value of future cost if not preserved and the present cost. Because acquiring ROW that is already developed is more expensive, this should output a positive value. The probability of future use is an important variable that is usually case specific. For example, a plan may suggest three alternative ROWs for a route. The probability of any route would then be less than one-third. Thus, the ROW preservation benefit would depend on the difference in costs multiplied by that probability. There are similar ways of estimating this value that might produce different results.

For example, the present cost of the ROW could be estimated in the cost category, and then consider "selling" the ROW in the future to the other transportation project as part of the salvage value of the bicycle facility. This salvage value is an estimate of the market value of the land. If the net present value of the salvage value exceeds the present cost, there may also be a right of preservation benefit. In such deliberations, it would be important to account for the discount value of completing the project—the present value of using available funds to complete a project and buying land for future projects later. For example, a benefit-cost ratio of 1.1 that would imply that 1 million dollars spent on a project will generate stream of benefits worth 1.1 million in present dollars. This is the baseline to compare with early ROW purchase. That is, the baseline is that some amount of money "*x*" greater than 1 million dollars will be spent to buy ROW in the future.

To estimate the present value of using the 1 million dollars to buy ROW for future use, delaying a hypothetical project that would have been done with that money, consider how that the benefit stream would change. First, a given project may eventually generate the same stream of benefits, but delayed by *n* years, giving a lower present value. However, the money that is saved (*x* minus $1M) by not paying a higher land price later, means that an additional project can be done at that time, yielding extra benefits, again starting *n* years in the future.

CONCLUSIONS

For such information to be useful in policy circles, several actions need to be taken (in addition to improving data collection efforts). First, the majority of past work has a clear advocacy bent; it is not always known how and where much of the data are derived. It is unclear from most of the studies if the available data were analyzed in a completely objective manner. Second, it is important to focus the discussion and analysis at an appropriate scale and for a particular purpose.

Third, such analysis and frameworks need to be better incorporated into policy discussions. In its current state, this research lacks appeal because many studies are conducted at a relatively abstract scale rather than at a project scale.

For this reason, it is suggested that benefits be estimated on a municipal (or regional) scale or in even more disaggregate units. Finally, there exists considerable room for improving the manner in which these methodologies are approached. The intent is to provide the foundation for urging a consistent framework in which different benefits can be estimated and subsequently compared. If the goal is to implement plans that systematically integrate or account for such consideration, then such methods and improvements will ultimately lead to more sound policy decisions and bicycle facility investment.

CHAPTER **4**

BENEFIT-COST ANALYSIS OF BICYCLE FACILITIES

INTRODUCTION AND PURPOSE

Based on the research conducted for this project, the team crafted a set of guidelines to be used by transportation professionals and government agencies to better integrate the planning of bicycle facilities into the transportation planning process. The web-based guidelines will assist state DOTs and other state, regional, and local agencies in considering bicycling in all transportation projects. Additionally, the guidelines will support local agencies' review of bicycle projects as part of the transportation improvement plan.

Transportation planners will be able to use the guidelines for the following purposes:

- Estimating the likely cost of specific facilities based on type and on key characteristics,
- Estimating how a facility will impact the overall bicycling environment in an area, and implicitly how it will affect the amount of riding based on characteristics of the facility and of the surrounding area,
- If information is available for calibration, estimating the usage of a facility (and the change in usage of complementary and competing facilities), and
- Estimating the specific types of benefits and their relative sizes based on characteristics of the facility and of the surrounding area.

TRANSLATING DEMAND AND BENEFITS RESEARCH INTO GUIDELINES

Demand

Estimating the use of a new facility rests on two main assumptions. First, all existing commuter bicyclists near a new facility will shift from some other facility to the new one. Second, the new facility will induce new bicyclists as a function of the number of existing bicyclists. Research for this project uncovered that people are more likely to ride a bicycle if they live within 1,600 m (1 mi) of a facility than if they live outside that distance (Appendix B). The likelihood of bicycling increases even more at 800 m and 400 m. The team therefore estimates existing and induced demand using 400-, 800-, and 1600-m buffers around a facility.

Estimates of existing bicycling demand are based on U.S. census journey to work mode shares. Establish the number of residents within 400-, 800-, and 1,600-m buffers of the facility by multiplying the area of each buffer by a user-supplied population density. Multiply the number of residents in each buffer (R) by 0.4, assuming the national averages of 80% of residents are adults and 50% of adults are commuters, to calculate the number of daily commuters. Then multiply this number of commuters in each buffer by the region's bicycle commute share (C). Use the bicycle commute share for the Metropolitan Statistical Area (MSA) as the default value; the user has the option to enter a commute share for the specific area if it is known.

$$\text{Daily existing bicycle commuters} = R \cdot C \cdot 0.4$$

Adult commuters represent only a portion of adult bicyclists. The team compared U.S. census commute shares to NHTS data and found that the total adult bicycling rate ranges from the census commute rate at the low end to 0.6% plus three times the commute rate at the high end (Appendix A). This allows the use of readily available census commute shares to extrapolate total adult bicycling rates (T).

$$T_{\text{high}} = 0.6 + 3C$$

$$T_{\text{moderate}} = 0.4 + 1.2C$$

$$T_{\text{low}} = C$$

Multiply the estimated low, moderate, and high rates by the number of adults—estimated to be 80% of the population—in each buffer to arrive at the total number of daily adult cyclists.

$$\text{Total daily existing adult cyclists} = T_j \cdot R \cdot 0.8$$

Additional research (Appendix B) found that people who live near a facility are more likely to bike than those that do not; multipliers were developed to describe these probabilities. Multiplying the numbers of both commuters and total adult cyclists by the likelihood multipliers found in this research for various buffers around the proposed facility provides an estimated number of induced cyclists in each group.

$$\text{New commuters} = \sum \left(\text{Existing commuters} * \left(L_d - 1 \right) \right)$$
$$d = 400,\ 800,\ 1{,}600$$
$$\text{New adult cyclists} = \sum \left(\text{Existing adult cyclists} * \left(L_d - 1 \right) \right)$$
$$d = 400,\ 800,\ 1{,}600$$

Where

$L_{400\text{m}} = 2.93$
$L_{800\text{m}} = 2.11$
$L_{1600\text{m}} = 1.39$

Mobility Benefit

This research, based on stated preference analysis, found that bicycle commuters are willing to spend, on average 20.38 extra minutes per trip to travel on an off-street bicycle trail when the alternative is riding on a street with parked cars (*6*). Commuters are willing to spend 18.02 min (M) for an on-street bicycle lane without parking and 15.83 min for a lane with parking. Assuming an hourly value of time (V) of $12, the per-trip benefit is $4.08, $3.60, and $3.17, respectively. Multiply the per-trip benefit for the appropriate facility by the number of daily existing *and* induced commuters, then double it to include trips both to and from work. This results in a daily mobility benefit. Multiplying the daily benefit by 50 weeks per year and 5 days per week results in the following annual benefit:

$$\text{Annual mobility event} = M \cdot V/60 \cdot \left(\text{existing commuters} + \text{new commuters} \right) \cdot 50 \cdot 5 \cdot 2$$

It should be noted that this methodology assumes that no bicycle facility previously existed nearby, aside from streets with parking. In the this equation, V is divided by 60 because the M is in minutes and V is in hours; dividing V by 60 converts it to minutes so that the result can easily be multiplied by the minutes.

Health Benefit

An annual per-capita cost savings from physical activity of $128 is determined by taking the median value of 10 studies (Appendix E). Then multiply $128 by the total number of new bicyclists to arrive at an annual health benefit.

$$\text{Annual health benefit} = \text{total new cyclists} \cdot \$128$$

Recreation Benefit

The "typical" day involves about 1 hr of total bicycling activity, which is valued at $10 ($D$), based on a wide variety of studies of outdoor recreational activities (Appendix G). From both NHTS and Twin Cities TBI, the average adult cycling day includes about 40 min of cycling. This is the amount used, plus some preparation and cleanup time. Multiply this by the number of new cyclists minus the number of new commuters. (The value of the facility to new commuters is counted in the mobility benefit.)

$$\text{Annual recreation benefit} = D \cdot 365 \cdot \left(\text{new cyclists} - \text{new commuters} \right)$$

Reduced Auto Use Benefits

These benefits apply only to commuter and other utilitarian travel, because it is assumed that recreational riding does not replace auto travel. These include reduced congestion, reduced air pollution, and user cost savings. Multiply the total benefit per mile by the number of new commuters, multiplied by the average round trip length from NHTS (L).

Then consider two offsetting adjustments that ultimately leave the total number unchanged. First, there are utilitarian riders in addition to commuters and some of these trips will replace auto trips. Second, not all new bike commuters and utilitarian riders would have made the trip by car; evidence from NHTS suggests that something less than half of bike commuters use driving as their secondary commuting mode. For simplicity, assume that these two factors offset each other, and thus the total amount of new bike commuter mileage is a reasonable number to use to represent the total amount of new bike riding substituting for driving.

The benefit per mile of replacing auto travel with bicycle travel is a function of location and the time of day. There will be no congestion-reduction benefits in places or at times when there is no congestion. Pollution-reduction benefits will be higher in more densely populated areas and lower elsewhere. User cost savings will be higher during peak periods when stop-and-go traffic increases the cost of driving.

Based on reasoning documented in Appendix G, congestion savings will be 0 to 5 cents per mile and pollution savings from 1 to 5 cents per mile depending on conditions. Assume the high end of this range in central city areas, the middle range in suburban areas, and the low end in small towns and rural areas. For simplicity, assume that all commuting and utilitarian trips are during congested periods. User cost savings were determined to be 3 cents per mile during congested peak periods and 0 otherwise; thus, these are scaled by location in the same way as congestion savings.

Overall, the savings per mile (S) is 13 cents in urban areas, 8 cents in suburban areas, and 1 cent in small towns and rural areas.

$$\text{Reduced auto use benefit} = \text{new commuters} \cdot L \cdot S \cdot 50 \cdot 5$$

BENEFIT-COST ANALYSIS TOOL

The guidelines, titled Benefit-Cost Analysis of Bicycle Facilities, can be found at http://www.bicyclinginfo.org/bikecost/. These guidelines provide planners, policy officials, and decisionmakers with the ability to use a standard method to analyze the costs, benefits, and induced demand associated with a planned bike facility in their community. These guidelines allow the user the ability to tailor the information to a particular project. Figure 2 presents a brief outline of the sequence of logic and process contained within the web-based guidelines.

The guidelines include useful accompaniments such as “i” buttons and a “Bicyclopedia.” The “i” buttons help explain variables so that the user can better understand the information that is being requested (Figure 3). The Bicyclopedia comprises a glossary of terms, a guide on how to use the guidelines, and a brief description of the methodology that was used to develop the guidelines. The explanations associated with the “i” buttons and the glossary appear in separate popup windows so that data entered by the user are retained.

General Inputs

When determining the benefits and costs of a bicycle facility, the guidelines allow the user to tailor the outputs to the specific project that is being proposed. The user first selects a metropolitan area. Second, the user specifies if the proposed facility will be located in the city or suburbs (Figure 4). Such options allow the user to tailor output to local conditions. The user is asked to specify characteristics of the project that is being proposed. Options include on-street bicycle lanes with or without parking, off-street bicycle trails, and bicycle-related equipment.

During the general input portion of the tool, it prompts the user for information about the proposed facility. The information that the tool requires depends on the different characteristics of the facility that the tool is analyzing. The following is the detailed logic tree that tool goes through for the general input portion of the tool.

The user is prompted by the following general inputs:

1. Are you interested in: Costs, Demand, Benefits? Or a combination of the three?
2. In which metro area will the facility be located? Central city or Suburb?
3. Mid-year of project?
4. Type of facility?
   a. On-street with parking
      1. Restripe
      2. Overlay
      3. Full Depth
      4. Signed Route
   b. On-street without parking
      1. Restripe
      2. Overlay
      3. Full Depth
      4. Signed Route
   c. Off-street
      1. Stone trail
      2. Asphalt trail
      3. Concrete Trail
   d. Bicycle-Related Equipment

Costs

The guidelines prompt the user to select various features of a trail such as dimensions, signals, landscaping, and materials used for the trail. The guidelines provide the user the ability to enter a cost for various features or to use default settings as outlined in Chapter 1 of this report (see Figure 5). Based on such inputs, the tool calculates the cost of the facility.

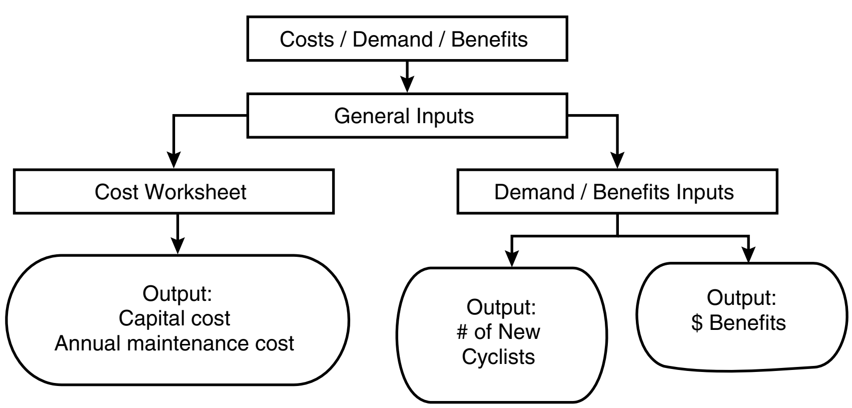

Figure 2. Flow chart showing structure of the guidelines.

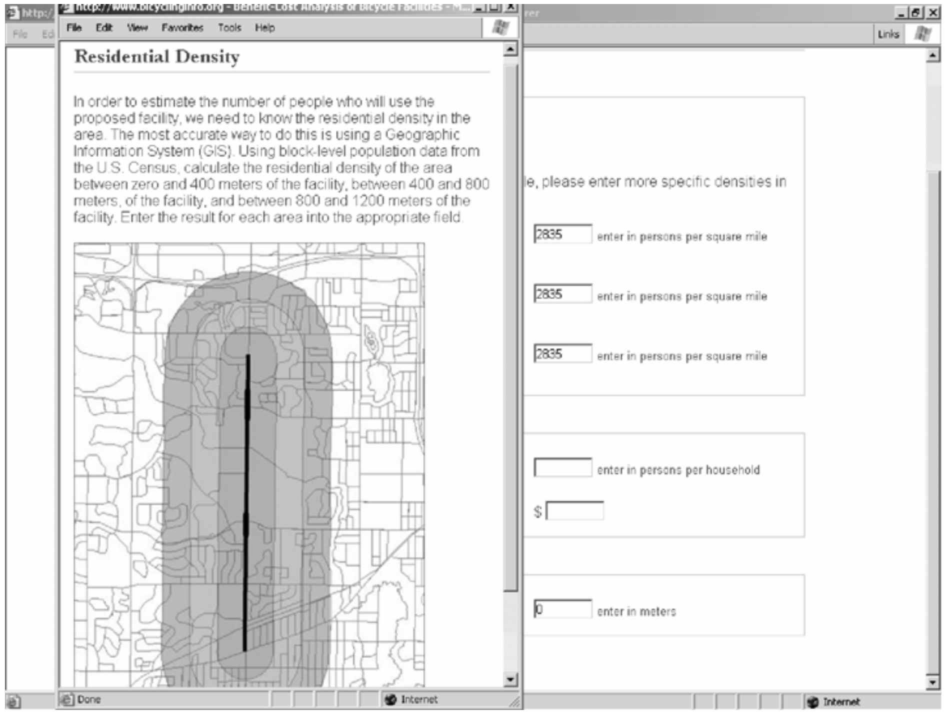

Figure 3. Information from "i" buttons explaining the input variables provided in separate popup windows.

Figure 4. General inputs.

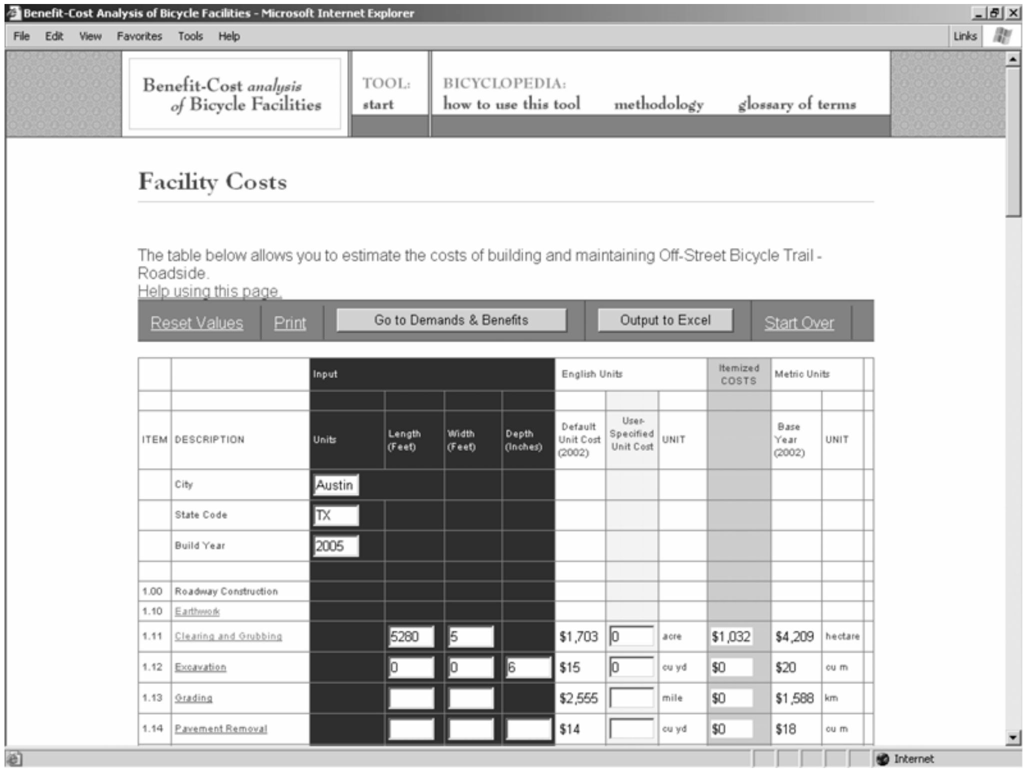

Figure 5. Facility costs spreadsheet.

Demand

The next process estimates the induced demand as a result of the facility. In doing so, the guidelines consider the existing bicycle commute share, residential density at 400, 800, and 1,600 m from the facility, household size, and length of facility. The guidelines have default settings for each metropolitan area. However, the user has the ability to change these figures if better information about the area around the facility is available (Figure 6).

Output

The guidelines present the user with easy to read tables showing the costs of a new facility and the induced demand and benefits related to mobility, recreation, health, and reduced auto use (Figure 7).

APPLICATION TO PEDESTRIAN FACILITIES

Introduction

Some of the difficulty in planning for bicycling and walking is that the bulk of the literature and subsequent planning tools typically aggregate these two modes. For abstract or general purposes this may suffice; the two modes are almost always aggregated in transportation research. In terms of daily use, facility planning, and community design, bicycling and walking differ substantially. The cost, demand, and benefit tool for this project were developed specifically with bicycle facilities in mind. Many elements of the tool, however, can be applied to pedestrian facilities. For example, cost information can readily be adapted for pedestrians to the existing cost model, given the constraints described in this section. On the other hand, demand and benefit calculations would need to be considerably modified to meet the unique characteristics of pedestrians. This section describes the manner in which the designed tool could be applied to matters of pedestrian planning and some of the issues involved.

Important Issues to Consider

It is helpful to draw attention to two points when considering specific facilities. The first is that there are facilities developed specifically for pedestrian use and most of the time *only* pedestrian use (e.g., sidewalks, stairs, and street crossing improvements). Other facilities suitable for bicycle use, however, tend to be used by pedestrians as well. The second point is that pedestrians, in a strict definition, are meant to include people walking, versus variants such as running and skating. There is an important difference in terms of speed and typical distances covered that impact how demand and benefits will be impacted by facilities.

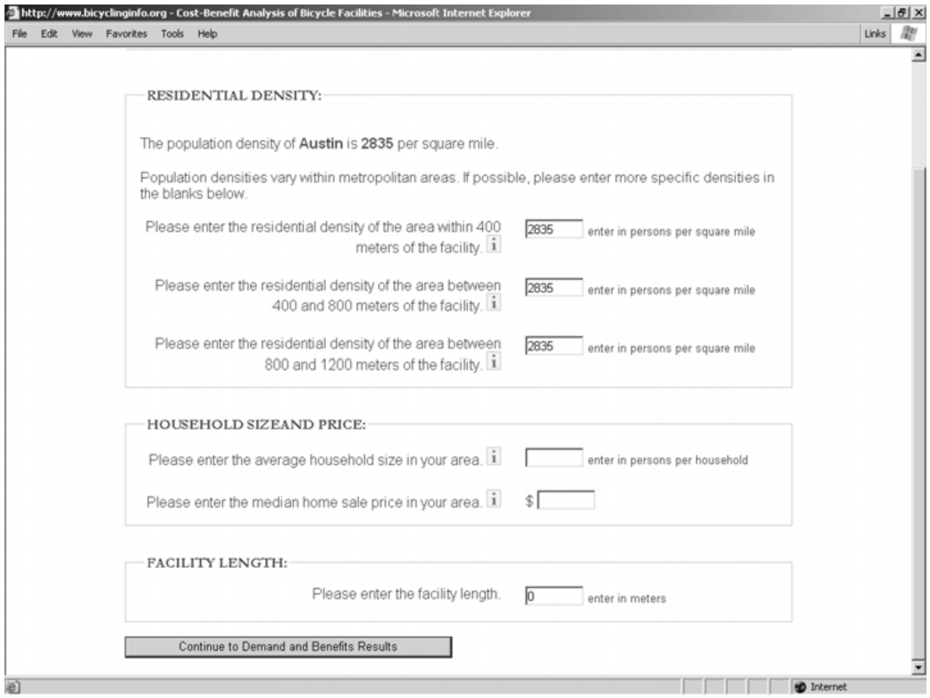

Figure 6. Demand inputs.

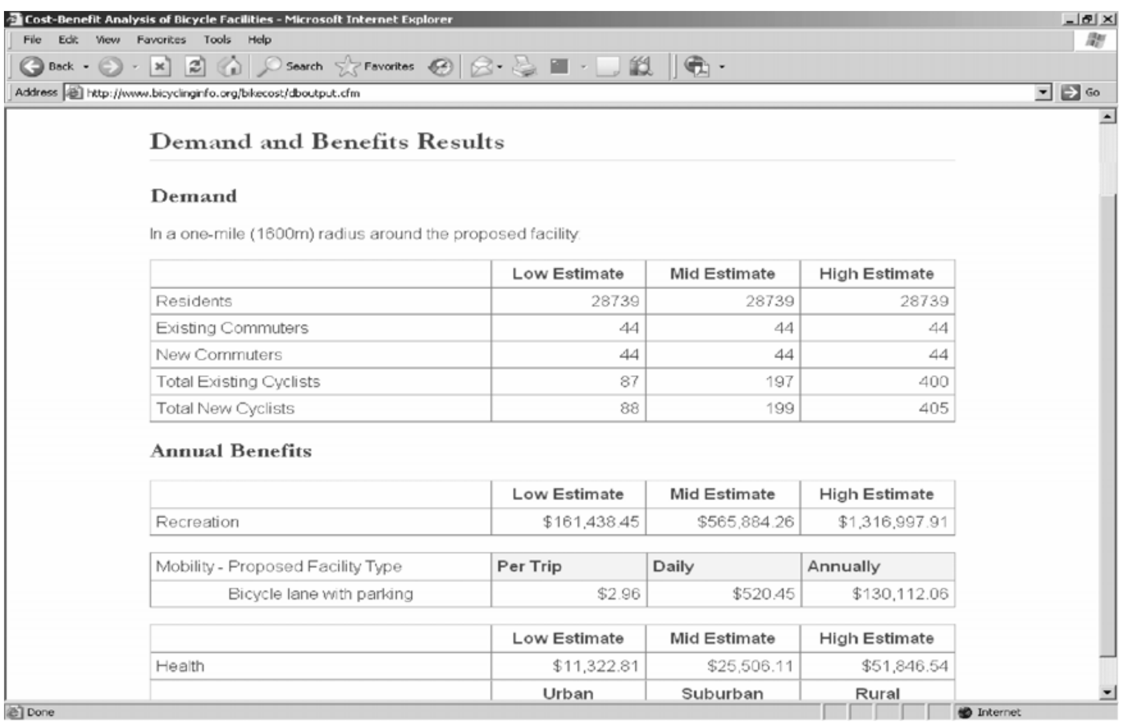

Figure 7. Output of guidelines.

The first distinction between facility types primarily affects cost estimates. Facilities that are intended for mixed use including bicycles can obviously be addressed using the cost tool in the guidelines. However, it may not be possible to estimate costs for facilities that are for pedestrian use only, unless the physical characteristics of the facility have a close parallel to the bicycle facilities included in the model.

Demand and benefit estimates tend to be more influenced by the second point. Specific facilities and environments that may be very useful to walkers may not be as suitable for higher speed alternatives like running and skating. Conversely, the value of a continuous off-road facility may be greater for higher-speed users, which in turn will influence how far they will go out of their way to use these facilities, which will impact demand.

A final matter is that walking is 10 times as common as bicycling. An estimated 70% of adults walk at least once per week (in the NHTS baseline sample) while about 7% bike. Because so many people walk already it seems unlikely that new facilities will have a significant impact on total demand, although they may influence where walking is done. The major impact on benefits will likely be the value of improved safety or general conditions for the already large number of existing pedestrians, rather than the value of additional activity by new users, as was the case with many of the bicycling benefits.

Costs

Costs and benefits obtained from a self-contained project such as a multipurpose trail, striping of an existing roadway for bicycles, or construction of a sidewalk next to an existing roadway, are relatively easy to estimate by applying the guidelines. However, bicycle facility costs as an element of much larger road construction costs are more difficult to reliably estimate.

In like manner, the guidelines can be more readily applied to self-contained pedestrian paths than sidewalks built as part of roadway projects, particularly in urban environments. Urban roadway projects will often include essential elements to create a quality pedestrian facility which include not only the sidewalk material but also street trees, landscaping, benches, trash bins, and public art—all of which are often important to creating inviting pedestrian environments.

The cost model was designed to estimate bicycle facility construction and design cost for all types of on-street and off-street facilities, equipment such as racks, and real estate costs. Bicycle facilities may exclude pedestrians or be shared with pedestrians and other non-motorized users. Table 8 identifies, based on location, shared facilities for cyclists and pedestrians as well as exclusive facilities.

Having identified the correspondence between the bicycle and pedestrian facility type, the next step is to identify the construction elements required for exclusive pedestrian facilities. Updating the cost model to include construction elements for sidewalks and trails would require minimal effort as most construction elements are already included in the cost model.

Table 9 identifies construction elements that are exclusive to bicycles and pedestrians as well as those that are shared. Note that most elements are shared and included in the existing model.

To use the tool to estimate the cost of the bicycle facility, the user inputs information (such as path width) for the applicable elements of the pedestrian facility type, thereby generating the appropriate cost estimate.

Demand

Demand in terms of new bicycle users is generated based on an extrapolation from existing mode share of bicycle commuters to find the number of new users attributed to a given facility. This is based on two different calculations: first, estimating the total number of bicyclists in an area based on the commute share and second, estimating the number of new cyclists as a function of the current number. Both of these calculations are based on the results of the research done for this project.

Development of an equivalent demand estimation methodology for pedestrians should be considered carefully. There is no reason to believe a priori that observed relationships between recreational and commuter bicycling would hold for walking or other potential facility uses. Nor is there any reason to think that there would be a similar relationship between marginal improvements to facilities and the amount of walking. Indeed, there are good reasons to believe that these relationships would not hold.

1. Adequate facilities for walking are much more widespread (e.g., sidewalks). There may not be good facilities on specific roads, but most people have some place that is reasonable for walking. In general, because of the

TABLE 8 Conveyance

Location	Bicycle	Shared	Pedestrian
Street	Bike Lane Shared Lane	Paved Shoulder -	Shared Street -
Adjacent Street	Side Path Cycle Track	- -	Sidewalk -
Off-Street		Multipurpose Path	Walking Trail Stairs

TABLE 9 Construction elements

Bicycle	Shared	Pedestrian
Pavement Markings	Earthwork	Benches
Bicycle Parking	Pavement	
Bus Racks	Drainage	
	Landscaping	
	Bridges	
	Underpasses	
	Signs	
	Traffic Signals	
	Barriers	
	Lighting	
	Security	
	Real Estate	
	Operations Costs	
	Maintenance Costs	

wealth of existing pedestrian facilities, new pedestrian facilities are less likely to create major changes to the overall opportunity set as they often do for cycling. They seem unlikely to have a major impact on the *total* amount of walking, although they may impact where it is done and the benefits that it provides (e.g., providing a sidewalk connecting two formerly auto-oriented centers).

2. In more developed areas, pedestrians are generally separated from traffic; therefore, off-road facilities do not create the same kind of unique advantages that they do for bicycles, at least in the case of walking (this would be different in rural areas). However, for runners and skaters, their higher speeds and longer distances could mean that facilities without frequent intersections could be advantageous.
3. The relevant travelshed for walking is smaller than for cycling. Most walking trips are quite short; unless a facility is extremely close to a person's home or work, they are unlikely to use it much. There could still be drive-in traffic for recreational walking, but only if the facility is special in some way (e.g., scenic).
4. Cycling also tends to be more influenced by attitudes and facilities; rates of commuting are an indicator of these attitudes and facilities that can also be used to predict recreational cycling. Commuting and recreational cycling to some extent benefit from the same kinds of conditions. Walking does not seem subject to the same cultural and facility limitations. Furthermore, commuting by walking is strongly constrained by local land use density due to the short distances involved, whereas walking for recreation is not. So there is no reason to believe that there would be a strong relationship between commuting and total walking at a neighborhood or even an urban area level, as there appears to be for cycling.

The conclusion that follows from these points is that not only is the bicycling demand model in the guidelines not applicable to pedestrians; in fact, it cannot even be adapted because of the significant differences in the underlying circumstances for the two user types.

In two respects, estimating pedestrian demand is simpler and more reliable than estimating bicycling demand. First, because walking is so much more common, there will not be such large variations across different cities or between different parts of the same city. Because it is more common, it would be much easier to complete representative counts in a given area to estimate local demand. Furthermore, local variations are smaller; it is therefore appropriate to estimate demand on a new or improved facility based on known demand on a similar facility at a different location.

The second reason estimating pedestrian demand is more straightforward stems from the fact that walking facilities are also more common. For any facility with given characteristics—a sidewalk in a suburban commercial area—it is likely that one or more very similar facilities exist in the same urban area, and if not, then almost certainly in some other similar city. Thus estimating demand by comparing existing facilities is more feasible for walking facilities than it is for bicycling facilities, and probably more accurate as well. This is likely true of mixed use as well as pedestrian-only facilities, although some basic research to confirm these hypotheses would be valuable.

Benefits

Three bicycling benefits included in the guidelines rely in part on demand estimates. The number of new bicyclists is multiplied by a per-person dollar amount to calculate health, recreation, and mobility benefits. Of these, health and recreation could directly apply to pedestrian facilities without further study, assuming an established methodology for estimating induced pedestrian demand. It could be assumed that pedestrian facilities would generate $128 per year in health benefits to new pedestrians who did not formerly engage in physical activity. The same assumption would hold true for recreation; new pedestrians would value their recreational time at the same rate as their cycling counterparts.

The mobility benefit also relies on an estimate of demand, but cannot be applied directly to pedestrian facilities. The methodology employed to assign value to bicycle facilities did not consider pedestrian facilities. To determine the mobility benefit, the research team used an adaptive stated preference survey to assign value to five types of bicycle facilities. A similar survey could be used for pedestrian facilities, but would require a new framework for considering different types of facilities.

The externalities benefit assumes that new bicycle commuters induced by a new facility will generate benefits in the form of less congestion and air pollution. The former relies on the fact that bicycle facilities typically separate cyclists from autos. Applying this logic to pedestrian facilities presents the problem that increased pedestrian traffic, even on sidewalks, can actually increase automobile traffic congestion at intersections. For this reason, the methodology employed to calculate the externalities benefit would need to be substantially modified to apply it to pedestrian facilities.

CHAPTER 5

APPLYING THE GUIDELINES

The previous chapters described several issues surrounding any analysis of investments in bicycle facilities; the web-based tool provides the user with a means to performing such analysis. This chapter describes how to apply the guidelines in the field.

Applying the described tool—Benefit-Cost Analysis of Bicycle Facilities—provides the project proponent with the basic technical information needed to advance a proposed project through the development process. The project proponent will have an initial estimate of capital costs, including cost of design, real estate acquisition and construction, and operations and maintenance costs. Additionally, the proponent will have an estimate of use and associated benefits. With this information, the project proponent can develop public support for the project (a key step to success in project implementation) and proceed into the transportation project development process.

In addition to defining the project and its benefit-cost characteristics and initiating efforts to develop public support, an important early development task is to identify potential funding sources and the path to securing project funding. Principal sources of potential project funding include federal transportation programs. Some state and private programs may also be sources of project funding.

FEDERAL FUNDING SOURCES

Federal funds represent the largest potential source of funding for bicycle facilities. The U.S. DOT's FHWA administers the largest of these funding programs. The principal federal funding sources for bicycle facilities are the Transportation Enhancements (TE) and the Congestion Mitigation and Air Quality (CMAQ) programs. Bicycle projects are also eligible for funds from FHWA-administered programs such as National Highway System (NHS), Federal Lands Highways, National Scenic Byways, and Recreational Trails.

Transportation Enhancements

The Intermodal Surface Transportation Efficiency Act (ISTEA) established the TE grant program in 1991. TE funds can be used to fund a variety of "non-traditional" projects, such as bicycle facilities. Since the creation of the program, 45% of TE funds have been spent on bicycle and pedestrian facilities. Bicycle facilities that are primarily designed for transportation rather than recreational uses are eligible for TE funds.

The Transportation Equity Act for the 21st Century, authorized in 1998, provided that 10% of Surface Transportation Program (STP) funds authorized be set aside for TE funding. This TE set aside is estimated between $500 million and $750 million per year. Each state's DOT is charged with determining project eligibility for TE funding. In some states, a sitting "enhancement committee" is given this responsibility, as well as the responsibility for establishing project priorities. Most states also require matching funds from the project sponsor of at least 20% of the project budget, with the remaining funding coming from the federal TE funds. The recently passed transportation bill, SAFETEA-LU, also provides substantial funds devoted exclusively to constructing bicycle facilities.

CMAQ

In 1991, ISTEA also created the CMAQ program. The CMAQ program, jointly administered by the FHWA and the FTA and reauthorized under TEA-21, provides more than $1.3 billion per year to state DOTs, Metropolitan Planning Organizations (MPOs), and regional transit agencies (RTAs) to invest in projects that reduce targeted air pollutants from transportation-related sources.

Because CMAQ funds are intended to improve air quality, funds must be spent on projects in air quality non-attainment or maintenance areas. A non-attainment area is an area currently designated by EPA as not meeting the national ambient air quality standards (NAAQS). A maintenance area is one that was at one time a non-attainment area but currently meets NAAQS and has been re-designated by EPA. Designated areas are described in the Code of Federal Regulations. Although all states receive CMAQ funds, those that have non-attainment areas receive proportionally more CMAQ funding than other states.

Historically, only 3% of CMAQ funds annually have been used to build bicycle and pedestrian facilities. The overwhelming majority of CMAQ funding has been used for traffic flow measures and for transit projects. Eligible bicycle projects include trails, storage facilities, and marketing programs.

Other FHWA Programs

Other federal funding programs for which bicycle facilities are eligible provide much lower funding levels than TE and CMAQ and are more restricted in their use. Although NHS funding levels are comparable with overall STP funding levels ($5.5 billion in FY 2003), use of the funds is limited to roadways that are part of the interstate or national highway systems. There is no set aside for enhancements, although up to 50% of NHS funds can be transferred to the CMAQ program.

The Federal Lands Highways Program receives approximately $700 million per year, all of which must be spent on parkways, Indian reservation roads, or public lands roads. National Scenic Byways funds can only be applied to designated All-American roads or National Scenic Byways, and funding levels are $25 million per year. The Recreational Trails program is funded at $50 million per year. States must spend at least 30% of their apportionment for this program on recreational trails for motorized vehicles such as snowmobiles.

Department of Interior—Land and Water Conservation Fund (LWCF)

The LWCF program provides matching grants to states and local governments for the acquisition and development of public outdoor recreation areas and facilities, including bicycle facilities. In FY 2004, $160 million was provided to the states through this fund. States receive individual allocations of LWCF grant funds based on a national formula (with state population being the most influential factor). Then states initiate a statewide competition for the amount available. Projects are scored and ranked according to the project selection criteria and successful applications are then forwarded to the National Park Service for formal approval and obligation of federal grant monies. The first step for potential applicants is to contact the cooperating state office to find out about local application deadlines, state priorities and selection criteria, and what kinds of documentation are required to justify a grant award.

Federal Planning Funds

In addition to the federal capital funding sources described above, bicycle projects obtain federal planning funds. FHWA planning funds (3C PL) and State Planning and Research (SPR) funds are two common sources for funding planning studies. Each state receives funding from FHWA based on an allocation formula. The states then distribute 3C PL funds to MPOs and other agencies for funding decisions. MPO recipients program these planning funds through the Unified Planning Work Program (UPWP). Decisions on SPR funds are typically made at the state level. The preliminary estimates of bicycle project costs and benefits developed through application of the guidelines can be valuable in conveying the relative merits of a project planning study for 3C PL and SPR funds.

NON-FEDERAL FUNDING SOURCES

The federal government is not the only source for bicycle funding. State and local governments all have the capacity to spend general revenue funds or dedicated revenue on transportation projects, including bicycle facilities. The processes for selecting projects can vary widely across state and local governments. Although it is not possible to cover each project selection process in detail, the nature of the estimates generated through the guidelines is such that it should be applicable to any set of criteria or evaluation methods.

In addition to government funding for bicycle facilities, some private and non-profit organizations provide grants specifically for the development of bicycle facilities. Two examples of these grants are the Bikes Belong program and the Kodak American Greenways awards.

Bikes Belong Coalition Grants

In 1999, bicycle industry leaders founded this organization in Boulder, Colorado, with the mission of "putting more people on bikes more often." Bikes Belong grants are in amounts up to $10,000, with funding goals including increased bicycle ridership, leveraging additional funding, building political support, and promoting cycling. These guidelines can assist an applicant in making the case that a project will increase ridership and promote cycling. Bike paths, trails, and lanes are among the facilities eligible for Bikes Belong grants, with non-profit organizations and public agencies (not individuals) being eligible grant recipients. The grant program has strived to fund important and influential projects that leverage TEA-21 money and build momentum for bicycling. From 1999 to 2002, Bikes Belong funded 53 projects for a total of $530,000, with $460,000 in bicycle facility grants leveraging $246 million in federal funding in 23 states.

Kodak American Greenways Awards

Since 1992, the Kodak American Greenways program has awarded nearly 500 groups across the nation with seed grants to support the development of community-based, action-oriented greenways projects. The program defines greenways as "corridors of protected, public and private land established along rivers, stream valleys, ridges, abandoned railroad corridors, utility rights-of-way, canals, scenic roads, or other linear features. They link recreational, cultural, and natural features, provide pathways for people and wildlife, protect forests, wetlands, and grasslands, and improve the quality of life for everyone." In 2004, grants were awarded to 39 projects. Although only one was specifically identified as a bicycle facility, many of the projects are multi-use trails that would accommodate bicycles, and bicycle trails are designated as an eligible grant project on the grant application. Grant applications are completed online, and provide several opportunities for applicants to describe project benefits in detail.

Securing Federal Funding Through State and MPO Processes

As a condition of eligibility for federal funding, transportation projects must be included in a federally certified transportation planning process. In urban areas, MPOs are responsible for complying with federal planning requirements. In non-urban areas state DOTs are responsible for transportation planning.

In accordance with the federal planning requirements, projects proposed for federal highway capital funds like TE and CMAQ and the others previously described must be programmed in a Transportation Improvement Program (TIP). The federal regulations require the submittal of TIPs on a biennial basis. Project planning is also eligible for federal funding. Planning efforts must be included in the federally required UPWP to be considered for funding.

Project sponsors attempting to finance a bicycle facility with CMAQ, TE, or other federal highway funds, need to first submit their project to the state DOT or committee responsible for determining funding eligibility. Once project eligibility has been confirmed, sponsors must propose their project for funding through the TIP development process. In urbanized areas UPWPs and TIPs are developed by MPOs, the body responsible for planning and programming all of the federal surface transportation funds allocated to the urban area. Participation in the broader MPO planning and programming process is helpful in advancing projects into the UPWP and TIP.

In non-urban areas of states, federal programming decisions are the responsibility of the state DOT. Although there are some states, such as Massachusetts, where regional bodies in non-urban areas are still given the authority to prioritize eligible projects for CMAQ or TE funds, in most states both eligibility and prioritization are within the purview of the state DOT.

Information resulting from the application of the guidelines provides preliminary estimates of project cost and identifies project benefits to assist state DOTs in understanding a new proposal's overall effectiveness particularly as it relates to furthering achievement of air quality improvements. In addition, it permits evaluators to better assess the proposed bicycle project relative to other candidates for funding. As some DOTs and MPOs take steps to create a more transparent planning process with clearly defined criteria, the guidelines become an important tool for planners to refer to as their proposed project undergoes MPO evaluation.

Project Development

Transportation projects typically go through several phases in planning and development. Simple projects, such as purchase and installation of bike racks, would bypass most development phases and would likely be limited to minimal design, acquisition, and installation efforts. More complex projects such as a major regional bike path may require addressing more of the phases described in the following steps to implementation although it is expected that most facilities would require minimal comprehensive planning and fewer design phases than major transportation projects.

Information from application of these guidelines for market demand and project benefits would likely remain unchanged through the development process unless the scope of the project were to change to provide a substantially different LOS to the cyclist than that of the original proposal. Regional transportation system models are generally not designed to project bicycle market information in sufficient detail to improve upon the estimates of facility use and benefits provided by application of the guidelines. As project scope becomes better defined through the development process, more reliable project specific information on construction and real estate costs should become available. This more specific information should be used to update or replace the cost information in the guidelines as needed to make decisions on funding and programming the proposed project.

- Regional Planning—the regional planning process is typically a comprehensive long-range (20-year horizon) review of the region's transportation needs and goals and identification of plans to meet those needs. The results of the process are presented in the Regional Transportation Plan (RTP). Regional bicycle program goals might be considered in such a process but specific bicycle facilities would not likely be addressed other than as elements of a broadly described program. Information resulting from application of the guidelines should be sufficient to evaluate proposed bicycle facility projects, such as paths, in the RTP.
- Alternatives Analysis/Corridor Studies—When projects are not well defined, area or corridor studies are conducted to develop, evaluate, and define specific project proposals. The product of this effort is typically identification of a preferred project with design and construction cost estimates developed to the conceptual/schematic design (5 to 10%) level. This analysis is typically reserved for major projects as a means of avoiding costly design in later development stages on projects

that may not be economically feasible. Bike facilities are typically sufficiently well defined by their setting and of modest cost relative to major roadway or transit projects to preclude the need for this step in the development process. Should analysis at this level be conducted for a proposed bicycle path, the work could be eligible for federal funding assistance through the UPWP. At this level of analysis, guideline information on construction costs would be updated based on schematic design and real estate costs would be updated based on estimates from local assessors or realtors.

- Preliminary Engineering Design/Environmental Impact Analysis—Major transportation projects and projects with potentially significant environmental impacts are usually advanced through design in two phases: Preliminary Engineering (PE) design/Environmental Impact Statement (EIS), and Final Design. At the completion of a PE, the project scope and real estate requirements should be specifically identified and National and State Environmental Analyses should be completed. Federal funding assistance for this and all subsequent project development phases would usually come from capital funding sources, requiring the project be included in the TIP. Construction costs developed from the guidelines should again be updated at completion of this development phase. If property acquisition is required detailed property plans should be completed at the end of this development stage.
- Final Design—Final Design consists of developing plans and specifications in sufficient detail to construct the project. This project phase results in final pre-construction cost estimates. If property acquisition is required, the real estate acquisition process, which can be time consuming, should be initiated early in this phase of project development with preparation of appraisals followed by acquisition. Both construction and real estate estimates can again be updated in this phase.
- Construction, Operation, and Maintenance are the final project phases.

The prescribed tool provides a reliable starting point for urban planners, policy officials, and decision-makers to understand the merits and costs of bicycle facilities. These officials are often presented with information about how much these facilities cost. Opponents of bicycle projects consistently use such information to demonstrate how trimming particular projects would preserve funds that could be used for other aims. The described tool and guidelines—and in many respects the underlying research—provide planners, decision-makers, and policy officials with a reliable, consistent method to compare bicycle facilities and measure often stated benefits. Such analysis could allow for better use of limited transportation funds. Having a constant measure of the costs and benefits of the bicycle facilities will help decision-makers to pursue broader public policy goals of increased cycling and a healthier population.

ENDNOTES

[i] In theory, this task could assume proportions considerably more complex and sophisticated not pursued in this application for several reasons. Some literature attempts to relate the amount of bicycling to facility measurement, but with very limited accuracy. Other literature discusses possible ways of describing the bicycle environment but does not relate this empirically to the amount of bicycling in an empirical measurement. The team believed that a framework that required planners to evaluate the detailed bicycling environment of their area would be exceedingly complex and labor intensive for the planners, and difficult for us to explain in an unambiguous way that would be easy to apply. Even conceptually simple measures such as miles of off-road bike paths proved hard to define in a way that would allow comparability across different locations. Local subtleties of design and location can be vitally important in issues that might arise in different places, let alone place values on them that could be used to develop an overall environment rating.

[ii] The amount of data needed for bicycle forecasting using these methods is actually much larger than for an auto forecasting model for two reasons. First, because so few people ride bikes in any short period, relative to the number that drive cars. To have a large enough sample of bicyclists to have some sense of their geographic distribution would require a very large survey; of the roughly 10,000 adults in the Twin Cities Travel Behavior Inventory, only about 200 rode a bike on their survey day, not nearly enough to estimate a regional model. Second, because the number of factors that might influence bicycling decisions is much larger than for car or transit travel, which are typically just assumed to rely on travel time and monetary cost. By contrast, highly subjective factors such as perceived safety and pleasantness of the riding environment could play major roles in bicycling decisions.

[iii] In addition, it may in fact be more useful than a more complex model that may be slightly more accurate, but that given the issues discussed may also have only the appearance of accuracy.

[iv] Based on an analysis of several sources (e.g. travel dairies such as the National Household Travel Survey, direct questionnaires administered by the Bureau of Transportation Statistics), the team project's that approximately 3% of the U.S. population cycles one day per week and an estimated one percent of the U.S. population receives their recommended weekly level of physical activity by cycling.

[v] A quick look at the data shows that 69% of our adult subjects within Minneapolis and St. Paul have a retail location within 400 meters of their home.

[vi] Households were recruited to participate in the TBI using a stratified sampling design. Telephone interviews were used to collect both household and individual socioeconomic and demographic data. Subsequent to the demographic interview, households were assigned a travel day on which 24-hour travel diaries were completed for all household members five years or older.

[vii] Home phone call interview information helped ensure the reliability of these self reported measures of walking and/or cycling.

[viii] The sample was restricted to residents of Minneapolis and St. Paul primarily because theses two cities—as opposed to the suburbs—had adequate representations of walking and cycling behavior. Of the adults who completed a bicycle trip during their diary day (a total of 138 throughout the seven county area), 86 of them (62%) were from the Minneapolis or St. Paul.

We also only included the population who reported having completed any type of travel during their assigned travel diary day, a procedure consistent with other transportation-related research (177. Zahavi, Y. and J. M. Ryan, Stability of Travel Components Over Time. In *Transportation Research Record 750,* TRB, National Research Council, Washington, D.C., 1980, p. 19–26). Of the original 1,801 individuals, 148 individuals (8.2%) took no trips on the travel diary day and were thus excluded. This left us with an effective sample size of 1,653 subjects (91.8% of our original sample). The 148 subjects that were excluded were not significantly different from subjects retained for analysis with respect to the likelihood of living in a household with kids or living in Minneapolis. However, compared with excluded subjects, included subjects were more likely to be employed (83% vs. 41%, $p < 0.001$); more likely to have a college education (64% vs. 20%, $p < 0.001$) and more likely to be male (48% vs. 35%, $p = 0.002$). Included subjects were also less likely to live in households with an annual income less than $50,000 (36% vs. 56%, $p < 0.001$) and less likely to be over 60 years of age (15% vs. 37%, $p < 0.001$).

[ix] Such data was obtained from 2001 employment records of the Minnesota Department of Employment and Economic Development.

[x] When measuring this dimension, it is important to measure the diversity of different types of retail establishments while controlling for the potential disproportionate drawing power of larger establishments (e.g., a large clothing store offers high employment but little diversity). The upper limit is set at businesses containing more than 200 employees and the number of employees for each area is tallied. The final measure is the number of employees within the "neighborhood retail" subset within 1,600 meters of each home location.

[xi] These include all businesses in the following NAICS categories:

- Food and Beverage Stores (e.g., grocery, supermarket, convenience, meat, fish, specialty, alcohol)
- Health and Personal Care (e.g., pharmacy, drug store)
- Clothing and Clothing Accessory Stores (e.g., shoe, jewelry, luggage)
- Sporting Goods, Hobby (e.g., needlepoint, musical instrument), Book, and Music Stores
- General Merchandise Stores (e.g., includes department stores)
- Miscellaneous Store Retailers (e.g., florists, novelty, used merchandise, pet, art, tobacco)
- Food Services and Drinking Places (e.g., restaurants)

[xii] The principal reason from these breakpoints was to ensure adequate distribution across each category. For example, 32 percent of the households had a retail establishment within 200 m, 37 percent within 400 m, 21 percent within 600, and 10 percent for the remaining.

[xiii] A continuous measure assumes that for each additional meter of distance closer/farther there is a consistent incremental increase/decrease in the odds of bike or walk use.

[xiv] One potential disadvantage is that by subclassifying into categories, a strong homogeneity assumption is imposed. That is, the team assumes that the effects are the same for everyone within a given category regardless of their individual proximity to a bike

trail. For example, the effect of living 400 meters from a bike trail is no different than living 799 meters from a bike trail. However, given that the increments are within roughly 400 meter, there is relatively little difference, if any.

[xv] Outside the downtown core of each city (for which there are very few respondents in the TBI), there is similar housing density spread across mostly all neighborhoods.

[xvi] These 86 cyclists completed between 1 and 10 bike trips on the assigned travel day (mean = 2.9, SD = 1.79). For 73 of these cyclists (85%) the total distance traveled by bicycle is also calculated, which ranged from 0.74 km to 36.71 km (mean = 8.64, SD = 7.10). As expected, the proportion of bikers varied across levels of bike facility proximity, with more bikers living closer to bike trails and fewer bikers living further from bike trails. Of interest, these distributions differed depending on which measure of bicycle facility proximity was used. In other words, the distribution of cyclists across categories of proximity to any bike facility was not statistically significant, nor was the distribution of bikers across categories of proximity to an off-street facility. However, the distribution of cyclists across categories of proximity to an on-street facility was statistically significantly different, with increasing proportions of cyclists in the hypothesized direction (chi-square = 13.42; p = 0.004).

[xvii] Our definition of "walkers" did not include people who only reported a walk trip from a different location (e.g., work or other). Individuals who only reported such walk trips are not included in an effort to more cleanly identify correlations between the residential environment and walking.

[xviii] This in turn can lead to an increase in the Type I error rate; that is, finding a statistically significant effect, when in fact there is none.

[xix] Some respondents may be pursuing walk trips from work or other types of locations. Only walk trips from home were considered. An additional 137 people report having a completed a walk trip, however, none of the walk trips they reported were from home.

[xx] As mentioned, this analysis only included residents from Minneapolis and St. Paul. Most other communities within the metropolitan area are more suburban in nature in terms of lower density, lower accessibility, and other related urban form features.

[xxi] To be technically correct, sampling weights should have been employed. Given the secondary nature of the analysis and the fact that a sub-sample was selected, proper survey sampling weights were not available.

[xxii] Our sample began with 42,750 records. Geocoding and removing records with missing or unreasonable data (e.g., homes with zero bathrooms, zero square feet, or built before 1800) reduced our sample to 35,002. The relatively small number of records removed still provided an even distribution of home sales across the metro area.

[xxiii] Active open spaces are primarily used for recreation, and consist of neighborhood parks and some regional parks. Passive open spaces are less accessible on foot. They include areas such as golf courses, cemeteries, and large regional parks that are accessible only through designated entrance points and often only by car.

[xxiv] Open space and bicycle variable names are prefixed by a c for city and s for suburb.

[xxv] In Minneapolis, several of the streets in the downtown core have bicycle lanes (although there are few home sales downtown). Most other on-street bicycle lanes are on busy commuting arterials or around the University of Minnesota commercial district. On-street lanes in St. Paul are a different story. They tend to be along a well maintained boulevard-type corridor (Summit Avenue) and the Mississippi River corridor. These counteracting effects between Minneapolis and St. Paul may possibly cancel out one other.

[xxvi] The median sale prices in the city and suburbs for 2001 were $148,475 and $184,500, respectively. No significant relationship was found between home prices in the city and proximity to on-street bicycle lanes, so no effect is estimated in Table 27.

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APPENDIX A

ESTIMATING BICYCLING DEMAND

INTRODUCTION

Transportation investment decisions often require estimates or predictions of the amount of bicycling in a given area, as well as how this amount depends on facilities and other conditions. Despite a variety of publications describing efforts to model bicycle demand, no modeling technique or set of parameter values or even rules of thumb has emerged as definitive.

A first step in thinking about how to model bicycling demand is to understand the types of questions that the model might be used to answer. Porter, Suhrbier, and Schwartz (*41*) list three major questions, paraphrased here:

- How many people will use a new facility?
- How much will total demand increase given an improved facility or network?
- How does bicycling affect public objectives such as congestion and air quality?

The last of these could be expanded to include the benefits to cyclists themselves, such as improved health and recreational opportunities. The answer to this question could be useful politically, in justifying public spending on bicycle-related projects. The answers to the first two questions are likely to be more useful for technical analyses, in prioritizing projects given limited resources.

Another way of approaching the problem is to note that there are three different demand prediction objectives:

- Predicting the total amount of bicycling in an area or on a facility,
- Predicting the marginal amount that total demand will change given a change in facilities or policy, and
- Identifying areas where inadequate facilities appear to be holding the level of bicycling below its potential, as in the "Latent Demand" approach (*42*).

In principle, a model that explains the total amount of bicycling as a function of "basic" factors including demographic, policy, and facility variables would answer all of these questions at the same time. Most past work has taken this kind of approach. Federal Highway Administration (*43*) and Texas Transportation Institute (*44*) completed major surveys of non-motorized modeling techniques in the late 1990s; the majority of the efforts they describe focused on predicting either commute shares or total bicycle travel by reference to these types of basic factors. More recent work such as Dill and Carr (*55*) has also used this methodology.

Results of these efforts have been mixed. While certain demographic and geographic variables routinely emerge as important, evidence linking bicycle facilities and policies to levels of cycling has proven hard to come by; Dill and Carr note that there is somewhat of a consensus that such evidence has not been established. In general it has been hard to find strong relationships because the differences in levels of bicycling across different areas can be very large in relative terms, much larger than can reasonably be explained by differences in the bicycling environments. Unmeasured factors, perhaps cultural or historical, appear to play an extremely large role in determining the level of cycling in an area.

A second, less common type of demand prediction method uses census commute-to-work shares, often combined with other data, to provide an area-specific baseline of bicycle usage; this can help to neutralize or perhaps proxy for some of the unmeasured factors that can have such a large impact on demand. Epperson (*138*) in Miami used census data combined with demographic factors for estimating bicycling demand generally. Goldsmith (*139*) in Seattle used census data combined with local information to predict likely changes in bicycle commuting due to facility improvements.

This appendix approaches the demand prediction problem more from this second philosophical perspective; that is, to use known information about commuter bicycling to develop estimates of total bicycling levels in an area. These estimates would provide an area-specific baseline that could then be supplemented with other information to predict how the number might change under various conditions. There are three major steps in developing a tool based on this approach.

The first part of the appendix describes the results of several surveys and other measurements of general bicycling demand completed over roughly the last decade. The aim is to bring together the results of these many different measurements, to show that the statistics are all roughly consistent when their differing time frames are considered, and place general bounds on the sizes of numbers that are likely to be observed.

The second part of the appendix argues that, for a variety of reasons, the common demand modeling objective to develop relationships between facilities and use by comparing different geographic areas is not likely to provide models that are consistently successful. The reasons are derived in large part from some problematic findings from our own attempt to develop a demand model for the Twin Cities area.

The third part of the appendix discusses a simple model relating current total bicycling rates to census commute to work shares. We describe estimates of this relationship across several geographic scales. This method is advantageous because it is simple to estimate, understand, and explain to policymakers, and has a known range of accuracy.

THE AMOUNT OF BICYCLING IN THE U.S.

This section describes the results of several surveys measuring general bicycling demand that have been completed over roughly the last decade. The primary objective here is to bring together the results of many different measurements, to show that they are roughly consistent when their differing time frames are considered, and to place general bounds on the sizes of numbers that are generally likely to be observed. A secondary objective is to demonstrate how a conceptual framework in which there is a distribution of bicycle riding frequencies over the population can reconcile the various measures of bicycling demand.

Measurements of Bicycling Frequency

Most of the available information about the amount of bicycling addresses the number of cyclists, as opposed to number of trips or miles of cycling. Because of the amount of information that is available about riding frequency, we use this as our measure of bicycling demand. The end of this section briefly addresses some other measures.

The surveys and other sources that address the frequency of bicycling produce a wide variety of results. Each source asks about a different time frame; the number of people who cycle in a week will be larger than the number who ride in a day. A key distinction to keep in mind is that (empirically) adults are considerably less likely to ride a bike than are children, regardless of the time frame being considered. These two groups must therefore be studied independently to avoid confusion or ambiguity. This is generally not an issue with most bicycling surveys, which tend to focus on adults, but it is a factor in deriving numbers from general travel data collection surveys. In the ensuing discussion and tables, the data refer to adults 18 years and older.

We derived measures of the number of people who ride a bicycle in a given day from two sources. The Twin Cities Travel Behavior Inventory (TBI) from 2001 (*140*) was a daily diary survey of about 5,000 households in the Minneapolis-St. Paul metropolitan statistical area (MSA). This was done primarily during the spring and summer. The National Household Travel Survey (NHTS) of 2001 (*45*) was a similar survey done over the entire United States; roughly 25,000 households were sampled in the general survey that we examined for this study. This survey was done over an entire year, which makes it possible to measure seasonal variations. Both of these surveys involved households keeping travel diaries on a randomly assigned day; these days were spread throughout the week, and throughout the year for each geographic area.

The NHTS also identifies households in about 20 Metropolitan Statistical Areas (MSAs) and 34 states, allowing us to calculate averages for these areas. It should be noted that samples for many of these were fairly small, so the number for a specific area could be well off the true value. However, this probably gives a reasonable estimate of the range of values that might be observed over areas with large populations. The NHTS also asks about whether the individual completed bicycle trips during the last week; again it is possible to calculate this at the level of specific MSAs and states.

There are several national bicycling-specific surveys addressing longer time periods than a week. Rodale (*46*) reports on U.S. surveys done in 1992 and 1995. They report the percent of adults bicycling in the last year, and it is possible to calculate the percent bicycling in the last month. The Bureau of Transportation Statistics (*47*) conducted a U.S. survey asking about riding done during the summer of 2002, defined as a three-month period. A more general Minnesota Department of Transportation (Mn/DOT) survey (*141*) from 2003 asks whether respondents bicycle for exercise, but does not ask about frequency. The 2002 National Sporting Goods Association survey (*48*), asks about participation in a variety of recreational activities; here the standard is riding a bike at least 6 times in the year.

Finally, the U.S. Census asks detailed questions, including mode choice, about the commute to work of about 10% of the residents of the U.S. These are summarized for use by transportation planners in the Census Transportation Planning Package (*142*). These data have the advantage of being by far the largest and most geographically comprehensive bicycle-related data sample available. The disadvantage is that they capture only commute to work trips, which are a small minority of all bicycling trips (*47*). Table 10 summarizes the results from the sources described here and in the preceding paragraphs.

Some people ride almost every day; others may only ride once a year. The longer the time frame being considered, the more people will have ridden at least once. It is possible to divide the population into different frequencies of riding in a manner consistent with the above numbers derived from different time frames. If each member of a group of people has a probability p of riding a bicycle in a given day, then the expected fraction n of that group that will ride at least once in a span of x days is given by the formula:

$$n = 1 - p^x \tag{1}$$

Groups with different riding probabilities, p, will generate different expected numbers of riders over a given time frame, and the

TABLE 10 Measures of adult bicycling frequencies

Source and Area	Measure	Average	Range
TBI, Twin Cities MSA	% per day	1.4%	-
NHTS, U.S. Total		0.9%	.56% winter .88% spring-fall 1.1% summer
NHTS, U.S. MSAs		-	0.2% - 2.4%
NHTS, U.S. States		-	0.0% - 2.2%
NHTS, U.S. Total	% per week	6.7%	-
NHTS, U.S. MSAs		-	4.5% - 12.7%
NHTS, U.S. States		-	3.5% - 12.4%
Rodale	% per month	-	16.6% - 21.2%
BTS	% per summer	27%	
Rodale	% per year		37% - 46%
NSGA	% 6 times per year	10.7%	-
Mn/DOT	% that ever ride	50%	-
U.S. Census	Commute to work %	0.4%	
U.S. Census, MSAs			0.1 - 1.4%
U.S. Census, states			0.1 - 1.1%

numbers from each group can then be summed to arrive at a population total. Table 11 shows an example of how the population can be allocated to groups with different probabilities of riding in a given day, in order to match known overall population bicycling rates over different time frames. These riding probabilities and population frequencies are mathematically consistent with about 1% of adults riding in a given day, 5.3% in a week, 16% in a month, 29% in a summer, and 40% in a year, and with 50% "sometimes" riding, although not necessarily in a given year.

The numbers deriving from the population frequencies do not exactly correspond to the national averages over the medium time frames. This is probably because the national averages may be slightly overestimated in these cases. Intermediate time frames such as "this week" or "the last month" contain some room for personal interpretation; a person who rode ten days ago might consider that to be close enough to count as part of the last week. Evidence that this is happening can be seen in the fact that the fraction of adults in the NHTS who report riding in the last week is more than seven times the number that rode on their survey day. Given that survey days covered all days of the week, and that every day will not be a completely new set of people, this result should be logically impossible.

If this frequency table is roughly right, there are some interesting implications. The top four lines are the people who ride at least once every ten days. They are 2% of the adult population, or 5% of the adults who cycle in a given year. But they constitute 42% of the riders on any given day. That is, the 5% most active cyclists generate about half the riding days, the other 95% generate the other half. Because so many of the trips are generated by such a small number of people, a relatively small part of the population can have a big impact on the total amount of cycling. If 4% of the public were in the "frequent" category, rather than the 2% that probably are now, that could conceivably lead to a 40% increase in the total amount of biking. Something like this may be what is happening in areas that generate very high levels of bicycling.

Evidence from the TBI and NHTS, although not exactly consistent, shows that on the average day when an adult rides a bicycle, he or she rides about 40 minutes. The NHTS also reports distances, however, these seem extremely unreliable. Considering the total daily ride durations in these data, assuming plausible average speeds, and assuming that those people who ride longer times will also go faster, gives a likely daily average distance of perhaps 7 to 10 miles. Those people riding more than 60 minutes in a day, while they are only one-quarter to one-third of all cyclists in a given day, ride about two-thirds of the total miles.

TABLE 11 Possible population distribution of bicycling frequencies

Frequency of cycling	% of adults
3 of every 4 days	0.1%
1 of every 2 days	0.2%
1 of every 4 days	0.5%
1 of every 10 days	1.2%
1 of every 20 days	3%
1 of every 50 days	10%
1 of every 100 days	15%
1 of every 200 days	20%
Never	50%

MODELING BICYCLING DEMAND

Traditional approaches to modeling bicycle demand are derived from the standard methods used for forecasting auto travel. That is, they start from basic information about the people and the transportation environment in an area and use this in some way to predict an amount of bicycle travel, either directly, or as the solution to a mode choice problem in a larger travel model.

This section discusses some problems with using this approach to model bicycling demand, some of which appear intractable. The arguments are based in part on some of the facts about bicycling discussed in the previous section, and in part on some preliminary findings from our own attempt to estimate a demand model for the Twin Cities area. While this model is not described here, in part due to the lack of useful results, it is used to illustrate some of bicycle demand modeling more generally.

There are several reasons a bicycling demand model derived from basic information about land use, demographics, and the transportation system is likely to be of limited utility. These can be illustrated in part by our own attempt at developing a demand model, in which we found a statistically significant result that off-road paths were associated with lower per person levels of bicycling for nearby residents. This result makes no sense intuitively; at worst residents should ignore the paths. Empirically, Davis (*50*) found that off-road facilities in the Twin Cities were in fact much more intensively used in all parts of the city than other options such as streets and on-street bike lanes. Our result was not due to an obviously underspecified model; a wide variety of demographic and land use variables were included in the regressions. There are several possible reasons for this problematic outcome.

One is a possible shortcoming in the analysis; the way facilities were defined did not correspond to how people perceive them. For example, many of the suburban "off-road" facilities run next to busy highways, with all the associated crossing of driveways and roads. They are off-road in the sense that there is a barrier separating them from the road, but they are not off road in the sense of eliminating potential conflicts, or of being appealing to ride on. However, the development of a more general measure of the bicycling environment, going beyond simple number of miles of facilities, is a difficult problem for many reasons.

Another reason is that a large fraction of bicycle riding is recreational. Intuitively, the sorts of land use and transportation facilities that would be ideal for utilitarian riding (dense development, a grid network, etc.) seem very different from what would be ideal for recreational riding (infrequent intersections, density of little importance). That is, the value of a facility may depend on the use to which it is being put. As a related point, the skill level of the rider likely also influences perceptions of the riding environment. These are significant conceptual difficulties, since it would seem that there is no single land use-transportation type that is ideal for all bicycling activities or people, and hence no unambiguous way of defining the "quality" of the environment.

The second problem with this sort of model is that there are large and seemingly random differences from one place to another. In one area we analyzed in Minneapolis, 16% of the adults made bike trips on the day they were surveyed, while the rate in many other areas was 0%. Even across entire metropolitan areas or states, differences of a factor of ten can be seen.

There are some well-documented population and land use characteristics that are associated with higher levels of bicycling. For example, people with college educations are more likely to bicycle, but the difference is on the order of a factor of two compared with less educated people. A similar difference exists for factors such as income, development density, and gender. None of the known factors, alone or together, can come close to explaining why people in some places are ten or more times as likely to ride bikes as people in other places. Other attitudinal and possibly historical factors seem to dwarf the effect of the factors that planners and policymakers can control.

Because the impact of the unobservable variables are so big relative to the variables of interest, it seems highly likely that what is being observed, both in our model and in others, is the effect of attitudinal variables acting on policy variables through spurious correlations. Our model seems to have been driven by geographic spikes in riding that happened to be positively correlated with some facility measures and negatively with others, but that in a causal sense had little or nothing to do with any of them. It seems possible that these types of spurious correlations might also be driving the results of other work of this type in the literature, given the typically low explanatory power of these models.

A third problem is that low levels of bicycling cause the range of sampling error to be many times larger than the sample mean for any realistic sample size. The effect is that the regression is trying to match measured variable values that could be off by a factor of five or more from their true values. A sample of 1,000 people would yield 9 cyclists on a given day at the national average level; the 95% confidence interval for this sample ranges from 3 to 15 cyclists. This is a large difference in relative terms, and observed extremes could easily just be sampling aberrations. Yet these inaccurate measurements could strongly influence the estimated parameter values.

Finally, there is always the problem, noted by Dill and Carr (*55*) and others, that even a positive correlation between riding and facilities could be causation in the other direction, that is, the large number of cyclists creating the political climate to build the facilities, rather than the facilities encouraging more riding. For example, bike lanes in some cases may be a response to existing situations such as bikes interfering with traffic. In these cases retrofitted lanes will often be associated with high levels of cycling after they are built. By contrast, lanes in some newer cities in California do not seem to have high riding levels (*55*), possibly because they were designed into new roads, that is, built in anticipation of riding rather than in response to it.

Seemingly the only way around these problems would be to study the same geographic area over a period of time as facilities change. The relevant question for policy is not comparing people living at location A with different people living at location B, but rather comparing the people at A with themselves as the provision of facilities changes over time. This would be an expensive prospect using surveys; development of a low cost method of counting bikes over a large number of different streets and bike facilities, such as is outlined in Davis (*50*), would be of great value for this purpose.

A MODEL OF TOTAL BICYCLING DEMAND

This section outlines a simple "sketch planning" method for estimating the number of daily bicyclists in an area using easily available data from the CTPP (*142*). An estimate of the current number of bicyclists in an area could be used for general political purposes, justifying expenditures by reference to the number of bicyclists and the benefits that they receive from cycling. However, the more interesting problems for planners are predicting how the number of cyclists will change as a result of a facility or other improvement, and knowing how many cyclists use or will use a specific facility.

While this model does not directly address these questions, we believe that it is still useful because the answers to these questions will in general need to be conditioned on the number of current bicyclists. This is not to say that the number of cyclists in an area cannot grow; the examples of many high-cycling cities show what is possible. However, in general any growth will probably be gradual rather than abrupt, and will likely depend on continued improvement of the cycling environment. Thus the rules of thumb developed here are not intended to represent permanent bounds on possible cycling levels, but only to provide a range of likely short-term changes.

Similarly, while use of a given facility will probably depend on a host of site-specific factors, in most cases it will also be limited in the short term by existing bicycling habits among the surrounding population. A thousand daily users may be realistic in an area where 2,000 people a day currently ride bikes; it is probably not realistic in an area where 200 do. This is not to say that facilities are only justifiable in areas that already have a lot of cyclists, or that a facility cannot increase the number of cyclists. The point, again, is only to provide an empirical basis for developing realistic expectations regarding short-term results.

The basic assumptions motivating this analysis are that a large fraction of total bicycling is done by a small fraction of cyclists who ride frequently and that many of these frequent riders are bicycle commuters observed in the census commute to work data. The hypothesis that we test in this section is that the basic riding frequency table described in the previous section will hold more or less across different areas. Thus an area with many commuter cyclists will also have more total cycling, and an area with few commuters will have little total riding. In other words commuting by bike, while it is a small fraction of the total bicycling in a given area, can still be used as a "leading indicator" of what might be happening with other types of cycling.

Three different geographical divisions are examined to study this issue. First is a set of 15 MSAs for which we could match CTPP commute to work shares with NHTS (*45*) daily bicyclist counts. Next are states; there are 34 for which both census and NHTS data were available. Last is an analysis of 66 "zones" of the Minneapolis-St. Paul MSA using data from the TBI (*140*), showing that the basic principle still works at this very different geographic scale.

The TBI and NHTS, like most travel diary data, are limited by small sample sizes for specific geographic areas. Because of this and the low level of cycling, the expected number of cyclists in the sample for a given area could vary by a factor of 10 or more from the low to high end of the range. Ordinary measures of goodness of fit have little meaning in this sort of environment; we focus instead on more heuristic measures such as the number of observations that fit within the predicted confidence interval.

Metropolitan Statistical Areas

Combining census data with our NHTS analysis produced 15 MSAs for which we had both commute to work shares by bike and total percent of adults biking on their survey day. The commute shares ranged from 0.1% (Cincinnati and Dallas) to 1.4% (Sacramento). The daily adult biking shares ranged from 0.18% (Houston—although this is probably a sampling problem as 4.2% rode during the previous week), to 2.45% (Portland, OR, with Sacramento close behind at 2.25%). We estimated parameter values as shown in equation 2; the R squared for this equation was about 0.7.

$$A = 0.3\% + 1.5 * C \tag{2}$$

where A = % of adult population who bicycle in a day

C = bicycle commute share %

This equation can be used to generate a predicted total riding share for each city. Given this predicted share and the NHTS sample size, a 95% confidence interval of expected number of adult bicyclists in the sample can be calculated assuming a binomial function. For 14 of the 15 cities, the actual number of bicyclists fell within this confidence interval. The one exception was Chicago, which generated 19 actual cyclists compared with a predicted level of 9.

The performance of this model at predicting the observed number of cyclists for the cities with the biggest samples (and presumably the most reliable numbers) is quite good, again with the exception of Chicago: New York had 20 predicted, 23 actual; Los Angeles had 23 predicted, 22 actual; San Francisco had 21 predicted, 19 actual; and Boston had 9 predicted, 7 actual. At the low and high ends of the commuter cyclist ranges, Cincinnati had 1 predicted and 1 observed, Dallas was 3 predicted, 3 observed; Portland was 6 predicted, 10 observed; and Sacramento 9 predicted, 8 observed. Portland was among the worst-predicted cities, but was still within a 95% confidence interval. Overall, as Figure 8 shows, the hypothesis that overall bicycling rates will correlate with bicycle commuting rates seems to be supported; indeed the correlation seems quite strong at this geographic level. Figure 8 shows performance of the model, the points represent actual commute rates for cities and the lines represent levels that the model predicted.

The equation is also exactly consistent with the U.S. as a whole (0.4% commute share, 0.9% total daily cyclists), and with a division into larger and smaller cities, in which the same figures are observed.

States

There were 34 states with data from both the census and the NHTS. Alabama had the lowest bicycle commute share at 0.07%, Oregon the highest at 1.07%. Arkansas has the lowest rate of total bicycling at 0% (again, a sampling problem as 3.4% rode during the preceding week), and Florida the highest at 2.21%. Equation 3 shows the estimated parameter values, which are slightly different from that observed at the MSA level. The R squared of this model was about 0.3.

$$A = 0.4\% + 1.1 * C \tag{3}$$

Using either these parameter values or those derived from the MSA level, the same predictive results emerge. Of the 34 states, 30 have actual counts within a 95% confidence interval of their predicted values; the exceptions are all underpredicted. Of the states with good sample sizes (over 1,000) about half were predicted with good accuracy (less than one standard deviation), the other half were farther off the mark, with predictions both too high and too low.

Twin Cities Zones

The final level of analysis considered variations within the Minneapolis-St. Paul MSA, using 65 "zones" that had been defined for a different project. These were largely based on political boundaries, with the two central cities divided into a number of zones based on natural and artificial divisions and neighborhood characteristics. Populations of the zones ranged from about 10,000 to 30,000. While this analysis was based on the TBI, which was a large local survey, there were still only 139 adults in the survey who made bike trips (whose home location could be mapped to a zone in this area), and one-third of these were in four zones in Minneapolis. Thus the estimated bicycling rates for most of the zones are extremely unreliable. The results of this regression are shown in Equation 4.

$$A = 0.6\% + 2.5 * C \tag{4}$$

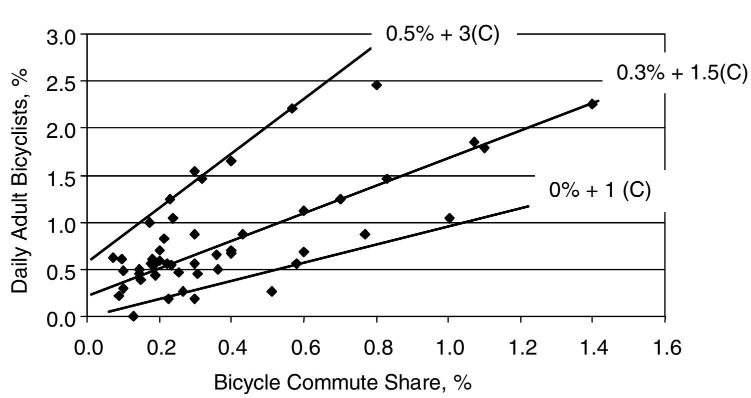


Figure 8. Daily bicyclists and commute share, combined MSAs and states.

The relatively high slope and intercepts of this equation are likely a reflection of the "outlier" nature of the Twin Cities compared with the areas on which the previous two regressions were based. That is, depending on the measurement, the Twin Cities have an overall adult bicycling rate of 1.6% to 2%, which is quite high compared with their bike commute share of 0.4%. Thus overall bicycling here is about twice as high as would be predicted by the earlier regressions; given this information, perhaps it is logical that the estimated parameter values with data drawn from this region would be about twice as high as well.

In most of the zones the sample size was too small to present an interesting prediction problem; that is, for these zones both the prediction and the actual count were either one or zero. For those 15 zones where the predicted number was two or more, 12 were predicted within a 95% confidence interval, while three had actual values in excess of the predicted range. Although the high bicycling zones were not predicted accurately in absolute terms, the general relationship between commuting and total bicycling held. The six zones where commuting by bike exceeded 2% generated six of the seven highest rates of overall daily bicycling.

CONCLUSION

On any given day, roughly 1% of the adults in the United States ride a bicycle. Over large geographic areas such as metropolitan areas or states, this number could range roughly between about 0.3% and 2.5%. Over smaller areas such as specific parts of metropolitan areas, the range could go as high as 15%. These variations are far larger than can be reasonably explained by differences in formal policies and facilities. It seems that local or even "subcultural" attitudes and perhaps history play a very substantial role in the perception of bicycling as an appealing or even "normal" thing for an adult to do, although without further study it is difficult to imagine how these factors might exert their influence.

When the actual percentage of cyclists in an area is not known, it can be estimated with reasonable accuracy by considering the bicycle commute to work share. A "most likely" value would be 0.3% plus 1.5 times the commute share; this was the best fit at the MSA level, and also describes the U.S. as a whole. Figure 8 shows lines representing rough boundaries on the observed values for daily cyclists, as they relate to bicycle commute shares at the MSA and state level. These lines appear in fact to represent three distinct relationships between these two variables that are observed in the data, but at this point this must be considered a sampling coincidence.

The model described here has important practical advantages. It is simple enough to be understandable to makers of funding decisions, and provides a known range of possible outcomes derived from a wide variety of locations and different geographic scales. However, it does fall short of the modeling ideal of directly describing a relationship between the provision of bicycling facilities and the amount of bicycling that will take place. The formulas we derive simply describe the amount of bicycling that is currently taking place; they do not relate this amount in a causal way to explanatory factors, or explain how it might change. We believe that this compromise is necessary because of the findings described in the first two sections of this appendix.

By helping the planner to estimate a range of the number of bicyclists currently riding in a given geographic area, the model establishes a baseline that can be used to develop more informed estimates about how this number might change given a change to the facilities or cycling environment. Such a baseline is necessary for any more detailed estimates or predictions because there is such a high degree of variation in bicycling demand levels in different locations. This model represents a first step in such a methodology; the question of how to get from a general estimate of current bicycling levels to predictions about general or facility-specific future levels is left to later research.

More qualitative research to better understand the "outliers" could also be useful. Some MSAs and states have very high or low levels of bicycle commute shares and/or daily adult bicyclists. Over such large populations, this seems unlikely to be due to demographic differences. More detailed case studies of places that generate these very high or low rates of bicycling could be enlightening, especially if "soft" factors such as culture and attitudes can be probed in some systematic way.

APPENDIX B

BICYCLING DEMAND AND PROXIMITY TO FACILITIES

The Effect of Bicycle Facilities and Retail on Cycling and Walking in an Urban Environment

INTRODUCTION

Urban planners and public health officials have been steadfast in encouraging active modes of transportation over the past decades. While the motives for doing so differ somewhat between professions—urban planning to mitigate congestion, public health to increase physical activity—both have ardently aimed to increase levels of walking and cycling among the U.S. population. Decisions to walk or bike tend to be the outcome of myriad factors. Conventional thinking suggests two dimensions are important: for cycling, this includes the proximity of cycling-specific infrastructure (i.e., bicycle lanes or off-street paths); for walking, this includes the proximity of neighborhood retail (i.e., places to walk to).

This study focuses on two modes of active transportation—walking and cycling—and two different elements of the physical environment that are often discussed in policy circles, respectively, neighborhood retail and bicycle facilities. Our work aims to answer the following questions: (a) does having a bicycle lane/path close to home increase the propensity to complete a cycling trip and (b) does having neighborhood retail within walking distance increase the propensity to complete a walk trip from home? The primary advantage of this work is that it carefully analyzes these relationships for an urban population employing detailed GIS/urban form data and a robust revealed preference survey. The study uses multivariate modeling techniques to estimate the effect of features of the built environment on outcomes related to bicycling and walking.

We first briefly review directly relevant literature to this pursuit and describe some issues that limit the utility of previous research. We explain the setting for this application, the travel data, and the detailed urban form data. We then report the results of our analysis in two different tracks: one to estimate the odds of cycling; another to estimate the odds of walking. The final section discusses these results and offers policy implications.

EXISTING LITERATURE AND THEORY

Attempts to document correlations between active transportation and community design have been a focus of much of the recent urban planning and public health literature. Available literature underscores the importance of this research (*143, 144*), establishes a common language for both disciplines (*79, 145*), helps refine approaches for future studies (*146*), and comprehensively reviews available work (*147*). Existing research, however, varies in geographical scope, the manner in which it captures different dimensions of active transportation, and the strategies used to measure key features of the built environment. Some of the difficulty in tackling the literature on community design and physical activity—namely walking and cycling—is that the bulk of the literature aggregates these two modes. Some known work coming from the non-motorized community on the environmental determinants of bicycling and walking dually considers both modes (*148, 149*). For abstract or general purposes this may suffice; the two modes are almost always aggregated in transportation research. In terms of daily use, facility planning, and community design, however, bicycling and walking differ substantially. The following paragraphs point the reader to some of the salient literature related to walking and cycling and assesses some of the theoretical differences between the two modes.

Pedestrian travel and infrastructure have the following distinguishing characteristics. First, all trips—whether by car, rail transit, or bus—require pedestrian travel because they start and end with a walk trip. Second, sidewalks and other pedestrian related infrastructure (e.g., crosswalks, public spaces) are now often incorporated into zoning codes. Third, pedestrian concerns typically apply to confined travel-sheds or geographic scales (e.g., city blocks). Finally—and most germane to the analysis presented herein—pedestrian travel usually tends to be influenced by a broad array factors that go beyond simply sidewalks and other infrastructure. This means that both the attractiveness of features along the route (e.g., interesting facades, a variety of architecture, the absence of long, blank walls) and destinations (e.g., close-by stores) are important.

Early research on pedestrian travel underscored the importance of neighborhood retail in creating inviting pedestrian environments (*150–152*). Several studies offer detailed strategies using these measures (*153–157*). Much of the empirical work matches measures of pedestrian behavior with assorted place-based destinations in their work (*158, 159*) or even select measures of retail (*160–166*). However, much of the available work on pedestrian behavior vis-à-vis retail tends to lack detailed spatial attributes or be specific to urban design features such as benches, sidewalk width or other streetscape improvements (*167*); few studies examine such behavior over an entire city with detailed measures of retail activity.

Bicycle travel and facilities, on the other hand, apply to longer corridors, and fail to be used as frequently as walking facilities. Such trips are usually considered more discretionary in nature. Where pedestrian planning applies to a clear majority of the population (nearly everyone can walk), bicycle planning applies to a considerably smaller market of travelers—those who choose to own and ride a bicycle. During the summer months in most of the U.S., this includes just over a quarter of the American population (*47*). Bicycle travel has a longer travel shed and most of the population has a heightened sensitivity to potentially unsafe conditions (e.g., shared facilities with autos speeding by). The quality of the facility is often paramount. Such facilities along a route include wide curb lanes, and on-street or off-street bike paths.

Similar concerns pervade available literature on cycling and the provision of cycling-specific infrastructure. There is considerable enthusiasm about the merits of bicycle trails and paths to induce use (*55, 168–170*). Little work, however, has rigorously tested such claims. Existing studies have examined the use of particular trails

(*171–173*), cycling commute rates vis-à-vis bicycle lanes (*174, 175*) or their impact on route choice decisions (*176*). Again, there exists a dearth of empirical knowledge about the merits of such cycling infrastructure using disaggregate data for individuals who may live across entire cities.

SETTING AND DATA

Our research is based on the Twin Cities of Minneapolis and St. Paul, Minnesota, which border one another and are roughly the same geographic size (approximately 57 square miles each). The separate central businesses districts for each city are less than ten miles from one another. According to the 2000 Census, Minneapolis has roughly 100,000 more residents than St. Paul (382,618 versus 287,151). The setting of these cities proves to be almost ideal for several reasons. Both Minneapolis and St. Paul are well-endowed with both on-street and off-street bicycle paths. Figure 9 shows a combined 60 miles of on-street bicycle lanes and 123 miles of off-street bicycle paths. Furthermore, the population comprise residents who appear to cherish such trails, particularly in the summer months. Minneapolis ranks among the top in the country in percentage of workers commuting by bicycle (*175*). For the walking query, each city also has a wide distribution of retail activity across the city (see the top half of Figure 10) and many homes with close proximity to neighborhood retail.[v]

Our knowledge of who walked and cycled is derived from a home interview survey known as the 2000 Twin Cities Metropolitan Area Travel Behavior Inventory (TBI). This survey captures household travel behavior and socio-demographic characteristics of individuals and households across the 7-county metropolitan area, encompassing primarily the urbanized and suburbanized parts of Twin Cities of Minneapolis and St. Paul metropolitan area. The TBI data were originally collected via travel diaries in concert with household telephone interviews.[vi] Participants were asked to record all travel behavior for a 24-hour period in which they documented each trip that was taken, including the origin and destination of the traveler, the mode of travel, the duration of the trip, and the primary activity at the destination, if one was involved.[vii] Household characteristics and household location were attributed to each individual. We additionally linked households with neighborhood spatial attributes relative to their reported home location. We selected all subjects from the TBI diary database who were residents of Minneapolis or St. Paul and 20 years of age or older (n = 1,653).[viii] A key feature of this investigation is that it applies to two entire central cities, rather than precise study areas or specific corridors of interest.

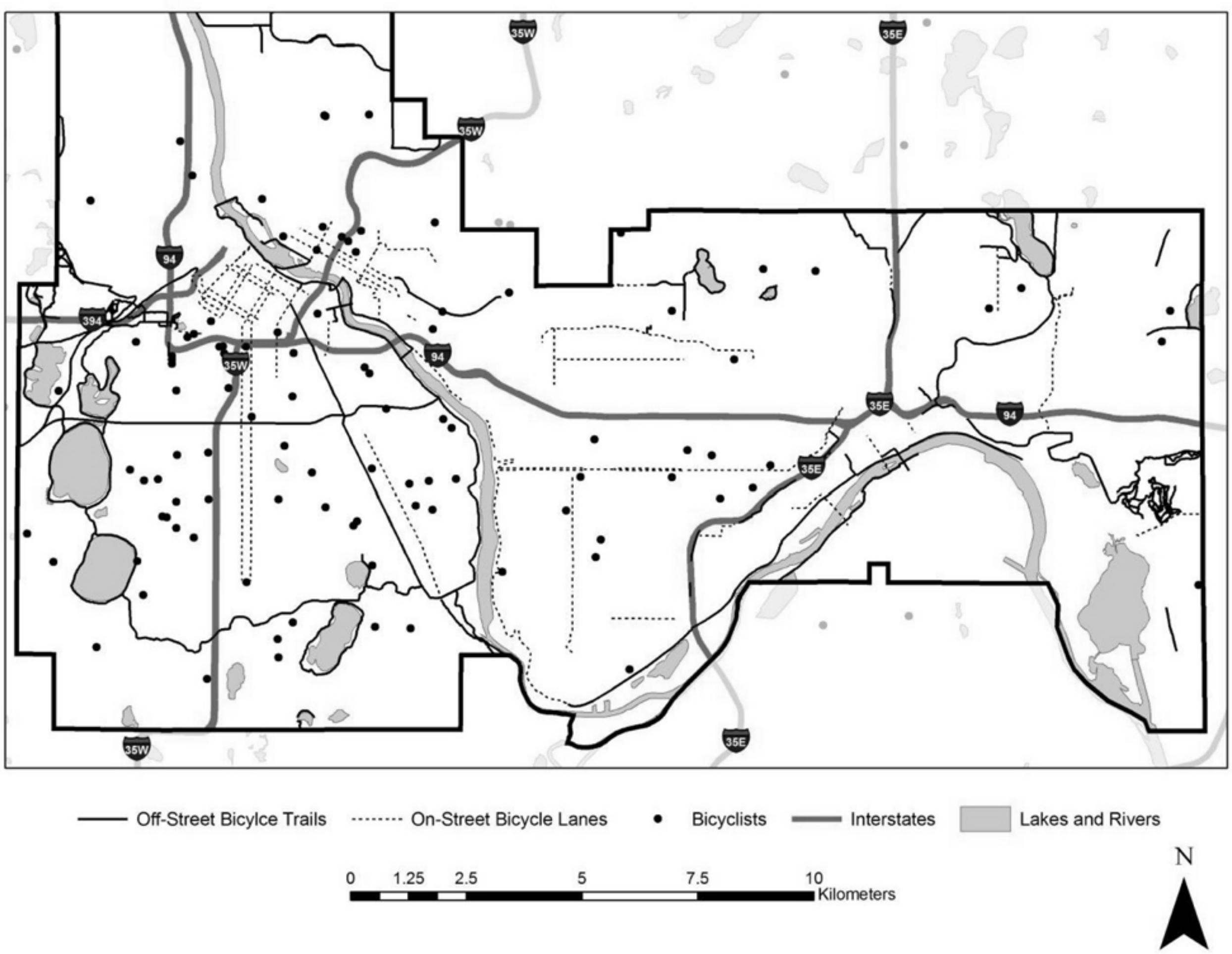


Figure 9. Map of study area showing bicycle facilities and home location of cyclists.

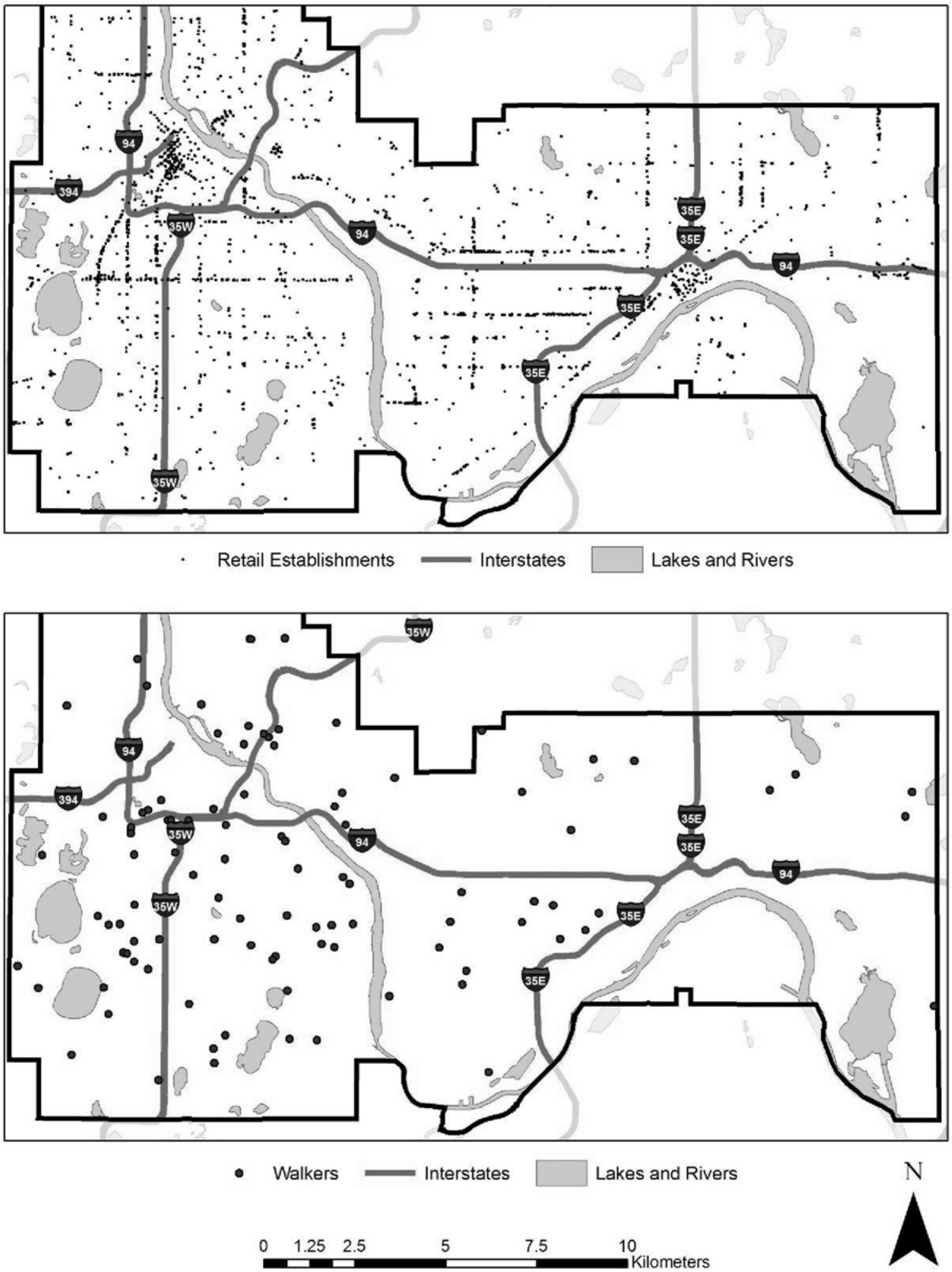


Figure 10. Maps of study area showing location of retail establishments (top) and home location of walkers (below).

POLICY VARIABLES OF INTEREST

Our policy variables of interest differ for each mode and are based on distance which is often mentioned as a suitable measure of impedance (*178*). For cycling, our analysis examines the proximity of bicycle facilities in the form of on-street bicycle lanes and off-street bicycle paths (Figure 11). Three continuous distance measures were calculated using GIS layers furnished by the Minnesota Department of Transportation, with separate map layers for on-street and off-street trails. Marrying this data with precise household locations, we calculated the straight-line distance in meters to the nearest on-street bicycle lane, the nearest off-street trail, and the nearest bike facility of either type. Four distinct categories represent the distance from one's home to the nearest bicycle trail as < 400 meters (one-quarter mile), 400–799 meters, 800–1,599 meters, and 1,600 meters or greater (greater than one mile).

For walking, we measure neighborhood retail in a detailed and rigorous manner. We first obtained precise latitude and longitude information for each business in Minneapolis and St. Paul.[ix] Relying on the North American Industrial Classification System (NAICS),[x] we included businesses such as general merchandise stores, grocery stores, food and drinking establishments, miscellaneous retail and the sort.[xi] These types of businesses were retained because they would likely attract walking trips for neighborhood shopping *and* be representative of good walking environments that would likely generate non-shopping walking trips. We again combined this information with household location data. Finally, we calculated the *network* distance between the home location and the closest retail satisfying the above criteria. For analysis, we used the distance variables to classify subjects into one of four categories. The four categories represent the distance from home to the nearest retail establishment as < 200 meters (one-eighth mile), 200–399 meters, 400–599 meters, and 600 meters or greater.[xii] To provide the reader with visual representations of the retail "catchment" areas for varying distances, we provide Figure 12 showing a home location (in the center) and retail establishments within varying walking distances from the home.

When measuring each of the policy relevant variables, a four-level ordinal variable is advantageous over the continuous distance measure in two respects. First, the categorical measure allows us to relax the strong linearity assumption that underlies continuous measures.[xiii] Second, the four-level categorical measure allows flexibility relative to ease of presentation and intuitive interpretation. Given that we used distance cut-points with relatively simple interpretation, it provides a compelling way to grasp the reported findings in terms of comparing individuals who live within 400 meters of a bike trail and those who live more that 1,600 meters from a bike trail.[xiv]

COVARIATES

We identify several covariates to represent individual, household, and other characteristics. These covariates represent factors that may differ across exposure levels and thus could potentially confound our effect estimates. To help free our estimates from confounding explanations we use these covariates to statistically equate subjects on observed characteristics across exposure groups; therefore, the only measured difference between them is the proximity to either the retail or the bicycle facilities.

For individual characteristics, we use age, gender, educational attainment (college degree or not), and employment status (employed or not). For household characteristics, we use household income (five categories), household size, and whether the household had any children younger than 18 years old. We also use two other measures: household bikes per capita and household vehicles per capita. We calculate these by dividing the total number of bicycles by household size and dividing the total number of vehicles by household size.

Spatial measures and other attributes of the built environment in this study are limited to proximity to retail or bicycle facilities. Focusing on a sample contained within the boundaries of Minneapolis and St. Paul helps to control for other variation among spatial measures by nature of the research design. For example, our sample has little variation in density,[xv] regional accessibility, and access to open space. Other than a few small bluffs—where there are few known residences—there is little variation in topography. And, almost every neighborhood street in Minneapolis and St. Paul has sidewalks on both sides, thereby controlling for an often cited important urban design feature.

RESULTS AND INTERPRETATION

Overall, our sample was nearly evenly split on gender (52% female vs. 48% male) and two-thirds (67%) were residents of Minneapolis (as opposed to St. Paul). Most subjects were employed (83%) and had at least a 4-year college degree (63%). The majority lived in households with no children (80%) and reported household incomes less than $50,000 per year (36%).

Figure 11. Representative photographs of off-street trail and on-street bicycle lane (respectively).

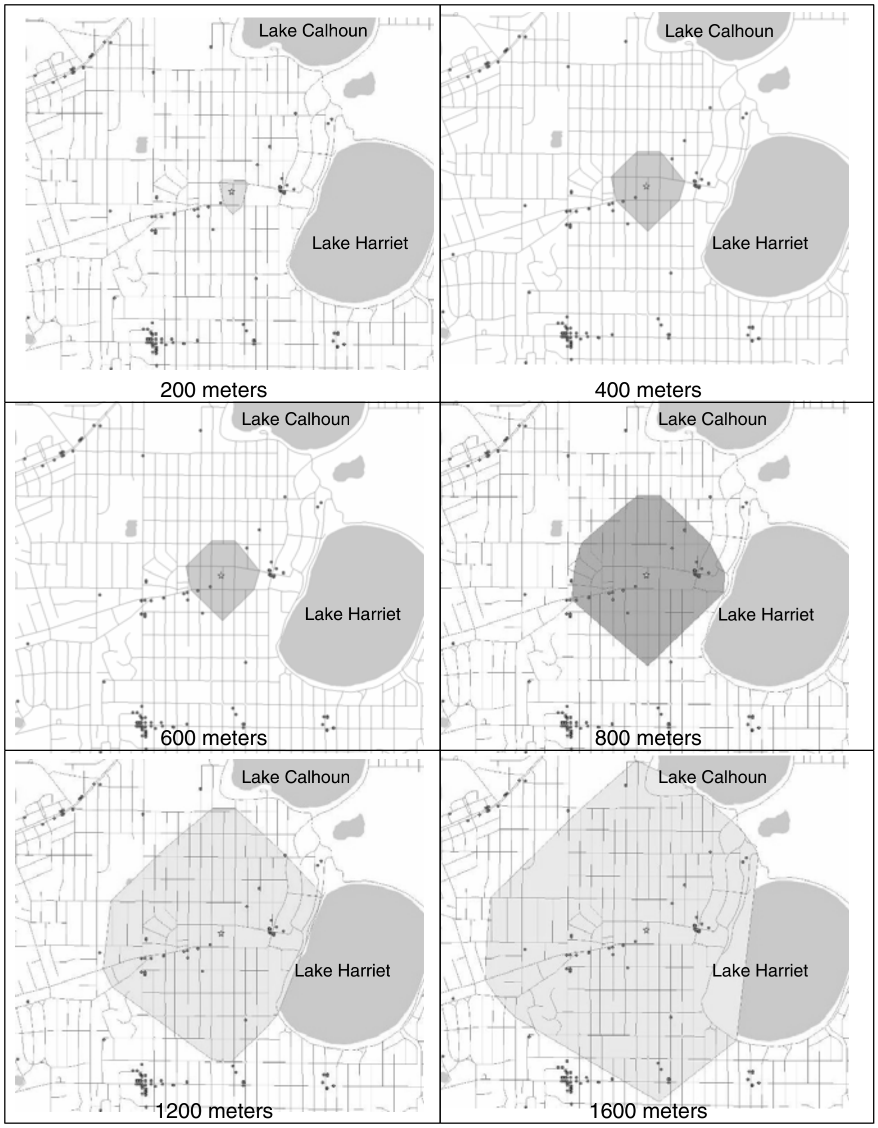


Figure 12. Retail "catchment" areas for an example home (shown in the center) and varying network walking distances. Dots represent retail locations; polygon shaded areas represent a catchment area.

We first used descriptive techniques (i.e., chi-square and t-tests) to characterize our sample by proximity to each type of facility. We explored the distributions of individual and household characteristics for subjects at each level of exposure. Subjects living within different proximity levels to bike facilities or retail differ somewhat with respect to many of the individual and household characteristics. For example, subjects living in close proximity to any bicycle facility are more likely to be 40 or older, have a college degree, and live in households with no children than subjects living farther away from a bike facility. Different covariate patterns emerge depending upon which proximity measure we examine.

The outcomes of interest in this application are twofold; both were operationalized in a dichotomous manner. The first is whether the respondent completed a bicycle trip as documented in the 24-hour travel behavior diary. A total of 86 individuals from our 1,653 individuals reported doing so (5.2 percent).[xvi] While this rate is higher than both the larger TBI sample and national average—which tend to hover around two percent of the population (*179*)—one needs to recognize this is a relatively small number. However, a close look at this population showed that they did not have exceptional or peculiar characteristics (e.g., the majority of them showing up near the university). The second outcome of interest was if the respondent completed a walking trip from home, 12.4 percent of our sample (n = 205).[xvii]

Because our outcome measures are dichotomous, we use multiple logistic regression models to examine the effect of facilities and retail on bicycling or walking. For each proximity measure (e.g., distance to any trail, distance to on-street trail, distance to off-street trail, distance to retail), we conduct a series of analyses; they build from a simple logistic regression of the exposure on the outcome to a multiple

TABLE 12 Models comparing the effect of distance to an on-street bicycle facility on odds of bike use (Models 1a-1c) and the effect of distance to neighborhood retail on odds of making a walk trip from home (Models 2a–2c)

	Bicycle Use				Walk use		
	Model 1a	Model 1b	Model1c		Model 2a	Model 2b	Model 2c
Distance to nearest on-street bicycle path				**Distance to nearest retail establishment**			
< 400 meters	2.933	3.101	2.288	< 200 meters	3.098	3.060	2.348
	(3.11)**	(3.21)**	(2.23)*		(3.41)**	(3.36)**	(2.51)*
400 – 799 m	2.108	2.012	1.511	200 – 399 m	1.653	1.616	1.316
	(2.05)*	(1.89)	(1.07)		(1.48)	(1.41)	(0.80)
800 – 1599 m	1.390	1.361	1.163	400 – 599 m	1.448	1.422	1.288
	(0.88)	(0.81)	(0.39)		(1.02)	(0.97)	(0.69)
>= 1600 m	referent	referent	referent	>= 600 m	referent	referent	referent
Individual Characteristics							
Male subject		2.015	2.160			0.760	0.787
		(2.96)**	(3.12)**			(1.80)	(1.57)
College		1.753	2.840			1.113	1.271
		(2.15)*	(3.47)**			(0.68)	(1.42)
Employed		0.783	1.187			0.771	0.901
		(0.71)	(0.43)			(1.24)	(0.49)
40-59 years		0.520	0.623			1.004	1.112
		(2.73)**	(1.83)			(0.03)	(0.64)
>=60 years		0.081	0.115			0.769	0.752
		(3.49)**	(2.98)**			(1.03)	(1.10)
Household Characteristics							
$15,000 - $49,000			0.402				0.874
			(2.30)*				(0.41)
$50,000 - $74,999			0.293				0.704
			(2.83)**				(1.00)
>= $75,000			0.206				0.880
			(3.33)**				(0.35)
Income missing			0.172				0.886
			(3.00)**				(0.32)
Household w/ kids			0.640				0.790
			(2.21)*				(2.08)*
HH bikes per capita			2.463				0.892
			(7.85)**				(0.80)
HH vehicles per capita			0.114				0.300
			(5.29)**				(4.56)**
		Wald chi-square =	137.65			Wald chi-square =	55.61
		Log pseudolikelihood =	-262.34			Log pseudolikelihood =	-583.69
		Pseudo R-square =	0.224			Pseudo R-square =	0.058

# of observations in all models = 1653
Odds ratios, robust z statistics in parentheses.
* significant at 5 %; ** significant at 1 %

logistic regression fully adjusted for all subsets of covariates (Models 1 and 2 in Table 12).

Because our data are hierarchically structured—individuals are nested within households—we use robust standard errors to account for the effects of this clustering. Subjects who reside in the same household are more alike within a household than they are with subjects residing in other households. Accordingly, less independent information is contributed by individuals from the same household, which may artificially decrease the standard error of the estimate.[xviii]

Bicycling

Our first models explore the odds of bicycle use and proximity to any type of bicycle facility. From the simple logistic regression model to the fully adjusted model, the odds of bike use did not differ significantly by proximity to *any* bike facility (this includes either on-street bicycle facility or off-street bicycle trails). Our model suggests that there is no effect of proximity to any bike facility on bike use. We therefore used a separate model to estimate the effect of proximity to off-street facilities on the odds of bike use. Examining the simple logistic regression model to the fully adjusted model for off-street bicycle facilities, the odds of bike use did not differ significantly by proximity to a trail. We detected no effect of proximity to off-street bike facilities on bicycle use.

Finally, we examined the effect of proximity to on-street bicycle facility on the odds of bike use. In the simple logistic regression model (Model 1a in Table 12), subjects living within 400 meters of an on-street bicycle facility had significantly increased odds of bike use compared with subjects living more than 1,600 meters from an on-street bike facility. As expected, those that lived within 400 to 799 meters of an on-street bike facility also had significantly increased odds of bike use compared with subjects living more than 1,600 meters from an on-street bike facility, although the odds of bike use were slightly lower than for those living closest to an on-street facility.

After adjusting for individual and household characteristics, the effects were somewhat attenuated (see Models 1b and 1c). Subjects living in close proximity to an on-street facility (< 400 meters) still had statistically significantly increased odds of bike use compared with subjects living more than 1,600 meters from an on-street bike facility. However, subjects within 400 to 799 meters still tended toward increased odds of bike use, however this failed to reach the level of statistical significance. Consistent with prevailing theories of bicycle use, our models show that cyclists tend to be male, from older populations, and from households with children.

Walking

We employed a similar approach to examine walking behavior vis-à-vis retail and discovered similar results. In the simple logistic regression model (Model 2a in Table 12), subjects living within 200 meters of a retail establishment had significantly increased odds of making a walk trip compared with subjects living more than 600 meters away from retail. Households living between 200–400 meters and 400–600 meters of retail, however, failed to reach a level of statistical significance.

Again, after adjusting for individual and household characteristics, the effects were somewhat attenuated (see Models 2b and 2c). Subjects living in close proximity to retail (< 200 meters) still had statistically significantly increased odds of walking. Interestingly enough, however, household with children was the only household characteristic variable that was significant.

In each model, the results suggest that distance to bicycle facilities and retail is statistically significant; however, the relationship is not linear. The most important point is that close proximity matters, which challenges conventional wisdom that people are willing to walk up to one-quarter mile as well as analogous cycling specific hypotheses.

CONCLUSION

This research reports the results of individual level models predicting bicycling and walking behavior and correlations with proximity to bicycle paths and neighborhood retail, respectively. We do so focusing on particular behavior—whether an individual biked or walked from home—and robustly measuring policy relevant dimensions of the built environment. The travel, bicycle facility, and the retail data we employed are the most precise among city-wide measures for a metropolitan area in the U.S. The primary merits of this exercise focus specifically on measuring the exposure measures, each of which have direct policy relevance. To our knowledge, this question has not previously been asked or answered across an entire city.

We separated facilities into two categories: off-street bicycle trails and on-street bicycle lanes. For the former group of facilities, there is no effect of proximity to off-street bike facilities on bicycle use. For on-street bicycle lanes, subjects living within 400 meters of a bike facility had significantly increased odds of bike use compared with subjects living more than 1,600 meters from an on-street bike facility. Walking use increases if retail is within 200 meters. While not the focus of this analysis, our study reaffirmed that many of the socio-demographic and economic variables used in other studies are important.

Some officials have supported the use of community design to induce or enable physical activity, but this analysis suggests that the argument is more complex. First, our results underscore the fact that we are addressing fringe modes and rare behavior (*180*). Even among the urban population, only five percent cycled and twelve percent walked. And, the criteria for satisfying this measure were generous—any cycling or walking trip from home that was reported by the individual over a 24-hour period.[xix] Second, the research supports the theory that the built environment matters; however, it suggests that one needs to live *very* close to such facilities to have an statistically significant effect (i.e., less than 400 meters to a bicycle trail for bicycling and less than 200 meters to retail for walking—approximately the length of two football fields). While the odds-ratios for longer distances failed to reach levels of statistical significance, it is important to mention that in all model estimations, they were *always* in decreasing orders of magnitude and *always* in the assumed direction. Planners need to be aware of such distance considerations when designing mixed land use ordinances (*181*).

The results, however, need to be viewed in the following light. The first consideration is that the analysis is reported for only an urban and adult population. Conventional wisdom suggests children (*84*), rural or suburban residents (*182*) may value different features of the built environment.[xx] The second is that the original TBI survey was the result of a complex sampling design which needs to be taken into account.[xxi]

Being based on cross-sectional analysis, these results cannot be used to infer causal relationships (*183*). We can conclude that respondents living very close to bicycle paths or retail bike or walk more than their counterparts further away. However, consistent with emerging theories about travel behavior, the decision to live in close proximity to such features is likely endogenous (*184*). There are likely attitudes, preferences, or other attributes motivating such bicycling or walking behavior (*185, 186*). Such attributes are not directly captured in this analysis—and, strictly using the results from this research, we would be remiss to conclude that adding retail or bicycle paths would directly induce such behavior.

This investigation makes progress by using focused research and carefully measured variables. The work raises a number of important data, measurement, and methodological issues for future researchers endeavoring to predict levels of walking or bicycle use for entire cities or metropolitan areas. We make headway in learning that distance matters—particularly close distance. Relative to the larger picture of travel behavior, however, our understanding remains unclear. The evidence suggests that features of the built environment matter, although it is hardly compelling. Statistical analysis like ours needs to be complemented with more direct sampling as well as qualitative modes of analysis to shed light on different factors and attitudes as well as sorting out the issue of residential self-selection. Further work will inevitably allow planners and modelers to better understand relationships between cycling and walking infrastructure and physical activity. Continued and thorough understanding will therefore assist policymakers to construct better informed policies about using features of the built environment to induce physical activity, namely walking and cycling.

APPENDIX C
LITERATURE RESEARCHING BICYCLE BENEFITS

Conventional evaluation techniques suggest that any bicycle facilities should be considered in the same manner as other transportation facilities (e.g., roadways, light rail, HOV lanes) or, for that matter, any major public capital investment (e.g., wastewater treatment plant, sports stadium). Doing so subjects bicycle facilities to the same methodologies or criteria used in these projects such as benefit/cost analysis, economic impact assessment (local, regional or state), cost-effectiveness evaluation, and financial or risk analysis. Of these approaches, benefit/cost analysis is the most well-known and most frequently relied on in transportation projects. It provides a means of comparing the effects of contemplated policies or projects on social welfare. It requires identifying all project impacts (positive or negative) in the present and the future and then assigning an economic value to these impacts.

A handful of research studies attempt to calculate benefit-cost ratios for bicycle-specific projects. The general approaches and data used in doing so are presented in Table 13, together with values. As can be seen, all show that benefits exceed costs. Such consensus is a reflection of a variety of factors, including the inexpensive nature of bicycle facilities (i.e., a low valued denominator) and optimistic adoption rates of such facilities.

REVIEW OF PREVIOUS RESEARCH

Reviewing past research on this subject in a systematic manner is challenging because geographic scale, research depth, overall quality, and focus of past study varies considerably, and few studies build on previous efforts. To the extent that some of the measured benefits overlap (see Table 14), we present values derived from six different studies. There remains considerable disparity between values that are imputed.

A second observation is that there is no clear strategy to delineate what constitutes such a benefit. We cast a relatively wide net in what we consider a study of bicycle benefits. Our definition includes any research effort describing or attributing an economic value to bicycling or bicycle facilities.

By our tally this includes more than 25 studies, which comes close to representing the universe of all available and published research efforts. Each of these studies are presented in alphabetical order (author's name) in Table 15 showing the date, title, and geographic level to which the study applies and an indication of whether the report appears in a peer-reviewed outlet. The research ranges from general overview pieces to those examining ridership data within a traditional benefit-cost framework. Eleven are published in peer reviewed outlets. Many of the studies have a tone of advocacy to their analysis and findings. Below we provide a brief review of each of these studies.

The first—and largest—geographic area includes a series of studies conducted for individual states to calculate the economic impact of cycling and related industries. In Colorado, more than 6,000 households and a selection of bicycle manufacturers, retail bicycle shops, and ski resort operators were surveyed to glean a better understanding of the impact bicycling has on Colorado's economy in the form of production, sales, jobs and income and tax revenue (*70*). Extrapolating data in concert with household information, this research assessed the impact of bicycling in the form of expenditures, production, employment, income and tax revenues. A study from Maine conducted for the Department of Transportation surveyed bicycle tour operators to estimate the total economic impact of bicycle tourism in the state and to develop marketing recommendations to increase bicycle tourism (*187*). From this research, they estimated the size and characteristics of the bicycle tourism market in terms of socioeconomic class, spending patterns, direct and indirect impacts. Finally, Michigan has also estimated spending by users of local rail-trails while participating in organized bike rides (*188*).

A second level of analysis focuses on regional geographic areas or entire cities. Buis (*69*) offers an international application describing the results of calculations in Amsterdam, Bogotá, Delhi, and Morogoro. Using existing data from each municipality about proposed or existing bicycle policy, such as investments in infrastructure and reported saved motorized journeys, this research attempts to capture the cost of the facilities. The benefits in the four different cities, while not calculated consistently for each setting due to the availability of data, used infrastructure, user, and safety information that were translated into U.S. dollar amounts. In each case, the calculations demonstrate that the benefits exceed the costs; the benefit-cost ratio was more pronounced in cities that have not yet invested in cycling facilities. A study prepared on behalf of the Institute of Transport Economics in Oslo is in many respects, among the most robust of available work (*189*). This research estimates the average bicycle ridership in three Norwegian cities (Hokksund, Hamar and Trondheim) and determines a project's calculated profitability, or net benefit. This research claims to have used low benefit estimates, and concludes that spending money on future infrastructure benefits society in those three cities. Saelensminde ascribes monetary values to all aspects from security and crash reduction to health benefits and parking.

Using a slightly different geographic unit, research by Fix and Loomis (*67*) use a travel cost model to estimate the economic benefits to users of mountain bike trails in Moab, Utah. They did so measuring consumer surplus and individual per-trip values. The second of these studies, also focusing on the Moab area, compared nonmarket valuation techniques by applying the TCM and the dichotomous choice contingent valuation method (CVM) (*68*). Also included in this group of studies is an exercise, now more than 25 years old, that created a computer model analyzing savings reaped from increased cycling on a college campus (*190*). The computer simulation results generate a benefit-cost ratio by multiplying the benefits per mile for each commuter type by the miles per year traveled by that commuter type and sums it over commuter types and years. Subsequent research discusses the applicability of applying management economic techniques to bicycle and pedestrian transportation systems (*191*).

Next are a handful of studies that focus on specific facilities. The Sharples work (*66*) is valuable because it lists a variety of

TABLE 13 Cost-benefit studies

Author/Date	Context	Ratio	Comments
Everett (1976)	University of So. Mississippi	1.7 : 1	Uses computer and hand-calculations to estimate benefits and costs on a university campus. Dated, difficult to replicate.
Buis (2000)	Amsterdam, Netherlands	1.5 : 1	Each case attempts to answer: "What economic benefits can be attributed to an increase in bicycle use due to local bicycle policies?" Wealthier, currently bicycle-friendly countries benefit to a lesser degree than do poorer, less well-invested countries.
	Bogotá, Colombia	7.3 : 1	
	Morogoro, Tanzania	5 : 1	
	Delhi, India	20 : 1	
Saelensminde (2002)	Hokksund, Norway	4.09 : 1	Ratio based on "best estimates" of future cycling/pedestrian traffic. Cities with the least amount of infrastructure in place see the most benefit from new infrastructure.
	Hamar, Norway	14.34 : 1	
	Trondheim, Norway	2.94 : 1	
Przybylski & Lindsey (1998)	Central Indianapolis Waterfront Greenway	1.43 : 1	Estimates benefits by Unit Day Values and costs (based on construction costs) to establish cost-benefit ratio.
	Ohio River Greenway	1.9 : 1	

considerations that are applicable and subsequently demonstrates in a specific application how to evaluate related costs and benefits (*192*). She generates specific values around such diverse costs as air pollution and crash reduction. However, her benefits rely almost exclusively on first-hand experience of one particular corridor using personally collected data. Lindsey and Knaap (*76*) use contingent valuation to understand how much residents are willing to spend for a greenway facility. A different approach applied unit day values to estimate the benefits of proposed greenway projects (*193*). Using a rating system established by the U.S. Army Corps of Engineers (USACE), scores based on the USACE project evaluation scheme are converted to dollar values, also established by the USACE. While useful for estimating value, this work is limited because it only estimates use value. The same study also estimates use and net benefits of the greenway projects and includes a regional economic impact analysis for the two trails.

TABLE 14 Benefits from six studies

	Betz	Fix & Loomis	Lindsey	Litman	Nelson	Sharples
Benefit						
Air Pollution				$0.20 - $0.40	$0.24 - $0.40	184 kg of CO2
Congestion				$0.04 - $0.40	$0.03 - $0.32	varies
Earnings			$14,434,000			
Ecological/ Environmental				$0.23	$0.23	
Economic Benefits	$18.46 - $29.23 (surplus)	$197 - $205 (surplus)	$1.43-$6.13 UDV			
Energy Costs					$0.10 - $0.12	
Jobs			982 FTE			
Noise				$0.05 - $0.10	$0.02	1.5 dB
Parking				$0.25 - $1.50	$0.23 - $2.25	varies
Road Maintenance				$0.05 - $0.10	$0.02	varies
Road Safety						£450,000
Sales (from derived demand)			$21,000,000 est.			
User Savings/ Driver Costs				$0.55 - $0.85	$0.40 - $0.60	£7,472
Total				$1.37 - $3.20	$1.27 - $3.42	

TABLE 15 Summary of literature examining economic aspects of bicycle facilities

Author (date)	Title	Geography	Summary	Peer Review
Argys, Mocan (2000)	Bicycling and Walking in Colorado	State	Provides statistical information regarding the economic impact of bicycling in Colorado, and documents bicycling behaviors and attitudes of residents of Colorado.	No
Buis (2000)	The Economic Significance of Cycling	City	The results of four cost-benefit calculations: Amsterdam, Bogotá, Delhi, Morogoro.	No
Everett (1976)	Measuring the Economic Value of Exercise in Labor-Intensive Urban Transportation Systems	University campus	Analysis of how labor-intensive transportation modes provide needed exercise. Quantifies health benefits and the economic benefit of reducing coronary heart disease.	Yes
Everett, Dorman (1976)	New Approach to Economic Evaluation of Labor-Intensive Transportation Systems	University campus	Applies managerial economics tools to quantify the benefits of a proposed bicycle-pedestrian transportation system.	Yes
Fix, Loomis (1997)	The Economic Benefits of Mountain Biking at One of Its Meccas	Mountain bike trails, Moab, Utah	Compares non-market valuation techniques by applying a data travel cost method and contingent valuation method to mountain biking.	Yes
Fix, Loomis (1998)	Comparing the Economic Value of Mountain Biking Estimated Using Revealed and Stated Preference	Mountain bike trails, Moab, Utah	Estimates the value of mountain biking using travel cost method.	Yes
Lindsey et. al (2002)	Use of Greenway Trails in Indiana	Greenway system	Informational report on trail use in Indiana.	No
Lindsey, Knaap (2003)	Sustainability and Urban Greenways (Indiana)	Greenway system	This case study examines whether the greenways system in Indianapolis, Indiana, is sustainable using a framework based on six principles of sustainability recently proposed in the planning literature.	Yes
Lindsey, et al (2003)	Amenity and Recreation Values of Urban Greenways (Indiana)	Greenway system	Presents a taxonomy of the values of greenways and demonstrates how different values can be measured using complementary techniques.	No
Litman (2002)	Economic Value of Walkability	General	Uses economic evaluation methods to investigate the value of walking. Analysis may be applied to other non-motorized travel modes.	No
Litman (1999)	Quantifying the Benefits of Non-Motorized Transport for Achieving TDM	General	Examines the degree to which non-motorized travel help achieve Transportation Demand	No

(continued)

TABLE 15 (Continued)

	Objectives		Management objectives, including congestion reduction, road and parking facility cost savings, consumer cost savings, etc.	
Maine DOT (2001)	Bicycle Tourism in Maine	State (three trails)	Summarizes study to estimate the total economic impact of bicycle tourism by estimating the tourism market.	No
Moore (1994)	The Economic Impact of Rail-Trails	Three trails	Examined economic impact generated by three diverse rail-trails in Iowa, Florida, and California. Impacts were broken down into users expenditures related to trail visits.	Yes
Moore, Barthlow (1998)	The Economic Impacts and Uses of Long-distance Trails	Trail	Investigates use patterns and economic impacts of long distance trails. Case study of Overmountain Victory National Historical Trail.	No
Nelson A. (1995)	Private Provision of Public Pedestrian and Bicycle Access Ways	National	Presents findings to support that implementing bicycle and pedestrian access ways will result in economic benefit.	Yes
Vogt, Nelson (2002)	A Case Study Measuring Economic and Community Benefits of Michigan's Pere Marquette Rail-Trail	Trail	Compiles executive summaries from research reports that have been completed as part of this case study. Includes economic benefit generated by trails used for organized rides, property owners' opinions.	No
PKF Consulting (1986)	Analysis of Economic Impacts of the North Central Rail Trail (Maryland)	State	Investigated seven categories including tourism, property values, local resident expenditures and public sector expenditures to determine an economic value.	No
Przybylski, Lindsey (1998)	Economic Evaluation of Major Urban Greenway Projects	State	Describes procedures used in economic evaluations of two major greenway projects in Indiana. Includes benefit-cost analyses and regional economic impact analyses.	No
Saelensminde (2002)	Walking- and cycling-track networks in Norwegian Cities	City	Cost-benefit analyses of walking- and cycling-track networks based on use of the networks.	No
Schutt (1998)	Trails for Economic Development: A Case Study	Trail	Summarizes a user and economic impact study of the Bruce Trail in Ontario.	Yes
Sharples (1995)	A framework for the evaluation of facilities for cyclists – Part 1	General	Suggests framework for how to determine who will be affected by new cycling infrastructure	Yes

(continued)

TABLE 15 (Continued)

			and how.	
Sharples (1995)	A framework for the evaluation of facilities for cyclists – Part 2	Roadway	Applies the above framework to Wilmslow Road Corridor in Manchester, England.	Yes
Siderlis, Moore (1995)	Outdoor Recreation Net Benefits of Rail-Trails	Trails in multiple states	Estimates net economic values with the individual travel cost method for three rail trails in different U.S. Regions.	Yes
Sumathi, Berard (1997)	Mountain Biking the Chequamegon Area of Northern Wisconsin	Trail system	Profiles mountain biking user characteristics from the Chequamegon Area Mountain Biking Association trail system.	No
Wittink (2001)	On the Significance of Non-Motorized Transport	City	Presents the effectiveness of non-motorized transport in relation to economic growth, poverty reduction and quality of life urban areas and on the applicability of arrangements in the Netherlands.	No

Betz et al. (*62*) combine contingent valuation and TCM methods to estimate demand for visiting a greenway in northern Georgia and measures of consumer surplus. More recently, Lindsey et al. (*72*) demonstrated how different values of a specific greenway could be estimated using complementary techniques. They measured the impacts of greenways on property values in Indianapolis using residential real estate sales data, GIS, and hedonic price modeling. Recreation values for the trail were estimated using the TCM method. A more general work absent of a geographical context (*71*) focuses on walking aspects that can also serve as useful reference for cycling research. This piece suggests that benefit-cost analysis offers the broadest brush at identifying the full range of benefits but again stops short of suggesting specific methods and strategies for doing so.

APPENDIX D

USER MOBILITY BENEFITS

Trails, Lanes, or Traffic: Valuing Bicycle Facilities with an Adaptive Stated Preference Survey

INTRODUCTION

If bicycling is to be a viable mode of transportation, it must have appropriate facilities. Evaluating what is appropriate requires an understanding of preferences for different types of cycling facilities. In this study we explore and provide a quantitative evaluation of individual preferences for different cycling facility attributes. This understanding can be incorporated into an evaluation of what facilities are warranted for given conditions.

The facilities considered here are A) Off-road facilities, B) In-traffic facilities with bike lane and no on-street parking, C) In-traffic facilities with a bike lane and on-street parking, D) In-traffic facilities with no bike lane and no on-street parking, and E) In-traffic facilities with no bike lane but with on-street parking. The aim is to understand what feature people desire by quantifying how many additional minutes of travel they would be willing to expend if these features were to be available. This added travel time is the price that individuals are willing to pay for the perceived safety and comfort the attributes provide.

A computer based adaptive stated preference survey was developed and administered to collect data for this study. To understand if the value that people attach to attributes of facilities is systematically related to different individual and social characteristics, the study has also collected demographic, socioeconomic, household, and current travel mode information from each participant. This information is then used to build an empirical model to evaluate relationships between these independent variables and the additional travel time that people are willing to expend for different attributes of cycling facilities. In addition to giving a measure of the appeal of the attributes under discussion, the model also highlights the social and individual factors that are important to consider in evaluating what facilities to provide.

Interest in studying bicyclists and cycling environments is growing. Recent papers by a number of authors have investigated preferences of cyclists and the bicycling environment as well as the relationship between the supply and use of facilities. Availability of cycling facilities and the type and quality of a cycling facility are important determinants of how well they are used. Studies by Dill et al. (*55*) and Nelson et al. (*174*) have shown that there is a positive correlation between the number of facilities that are provided and the percentage of people that use bicycling for commuting purposes. While both studies state that causality cannot be proved from the data, Nelson and Allen (*174*) state that in addition to having bicycle facilities, facilities must connect appropriate origins and destinations to encourage cycling as an alternative commuting mode.

Bovy and Bradley (*194*) used stated preference (SP) to analyze bicycle route choice in the city of Delft. Their work looked at facility type, surface quality, traffic levels and travel time in route choice. They found that travel time was the most important factor in route choice followed by surface type. Another study by Hopkinson and Wardman (*195*) investigated the demand for cycling facilities using stated preference in a route choice context. They found that individuals were willing to pay a premium to use facilities that are deemed safer. The authors argue that increasing safety is likely more important than reducing travel time to encourage bicycling.

Abraham et al. (*196*) also investigated cyclist preferences for different attributes using a SP survey again in the context of route choice. Respondents were given three alternate routes and their attributes and were then asked to rank the alternatives. The responses were analyzed using a logit choice model. Among other variables that were of interest to their study, the authors found that cyclists prefer off-street cycling facilities and low-traffic residential streets. But the authors also claim that this may be due to an incorrect perception of safety on the part of the respondents, and education about the safety of off-road facilities may change the stated choice.

Shafizadeh and Niemeier (*197*) investigate the role that proximity to an off-road bicycle trail plays in route choice decisions. Using intercept surveys along the Burke-Gilman trail in Seattle, they find that among people who reported origins near the off-road facility, travel time gradually increases as they are further from trail to a point and then decreases, leading them to speculate that there may be a 0.5 to 0.75 mile "bike shed" around an off-road bike path, within which individuals will be willing to increase their travel time to access that facility and outside of which a more direct route seems to be preferred.

Aultmann-Hall, Hall, and Beatz (*198*) use GIS to investigate bicycle commuter routes in Guelph, Canada. While comparing the shortest path to the path actually taken, they found that people diverted very little from the shortest path and that most bicycle commuters use major road routes. They found little use of off-road trails. While this may be due to the location of the trails and the O-D pair they connect, even in five corridors where comparably parallel off-road facilities do exist to in-traffic alternatives, they found that commuters used the in-traffic facilities much more often. Only the direct highest quality off-road facility (one that is "wide with a good quality surface and extends long distance with easy access points") seemed to be used relatively more.

Stinson and Bhat (*199*) using data from a web based stated preference survey estimate a logit model to understand important attributes for commuter cyclist route choice. They find that respondents preferred bicycling on residential streets to non residential streets, likely because of the low traffic volumes on residential streets. While their model showed that the most important variable in route preference was travel time, the facility was also significant. It was shown that cyclists preferred in-traffic bike lanes more than off-road facilities. Both facility types had a positive effect on utility but the former added more to utility than the latter. In addition they find that cyclists try to avoid links with on-street parking. Another study by Taylor and Mahmassani (*200*), also using a SP survey to investigate bike and ride options, finds that bike lanes provide greater incentives to inexperienced cyclists (defined as those with a "stated low to moderate comfort levels riding in light traffic") as compared with more experienced cyclists, with the latter group not showing a significant preference to bike lanes over wide curb lanes.

The results from these papers seem somewhat mixed. Though some of the research has shown a stated preference and revealed preference with some constraints for off-road facilities, others have shown that cyclists generally prefer in-traffic cycling facilities with bike lanes. Especially in revealed preference cases, the apparent preference for in-traffic routes may be due to their ability to connect to many destinations in a more direct fashion and therefore leading to a lower travel time. In addition, route choice may be restricted by facility availability, geographic features or missing information. It may also be that for people who regularly bicycle, who are most likely the subjects of the revealed preference studies, travel time and not perceived safety are likely of utmost importance, as these individuals are more likely to be conditioned to the cycling environment. The actual preference therefore may not be for the in-traffic facility; however, it may be the best alternative available to the cyclists.

Commuter choices are clearly limited by facilities that are available to them. Understanding preferences and behavior is crucial to providing choices that people desire. This can be best accomplished when the value of any given improvement in facility attribute is known. Valuation of facility attributes can be done by considering what people are willing to pay for using these facilities. In this study we try to uncover this value by measuring how much additional time individuals would be willing to spend bicycling between a given origin and destination if alternate facilities with certain attributes were available to them.

In the next section we present the methodology in detail. This is followed by a description of the survey instrument and design. The analysis methodology is presented, and then the results.

METHODOLOGY

The methodology we follow to extract this valuation of attributes uses an Adaptive Stated Preference (ASP) survey. While both revealed and stated preference data can be used to analyze preferences, there are certain advantages to using the latter method in this case. In using consumer revealed preference, often a limitation arises because only the final consumer choice is observed. This makes it difficult to ascertain how consumers came to their final decision. This complication arises because the number of choices that are available to each consumer may be very large, and information on those alternatives that went into an individual's decision may not be fully known. Even in cases where all possible alternatives are known, it is difficult to assess whether the decisionmakers considered all available alternatives. In addition, the exact tradeoff of interest may not be readily available. Even in cases where the tradeoffs seem to be available, one cannot be certain that the consumer is acting out his preference for the attributes we are observing. The lack of appropriate data can pose a major challenge in this respect.

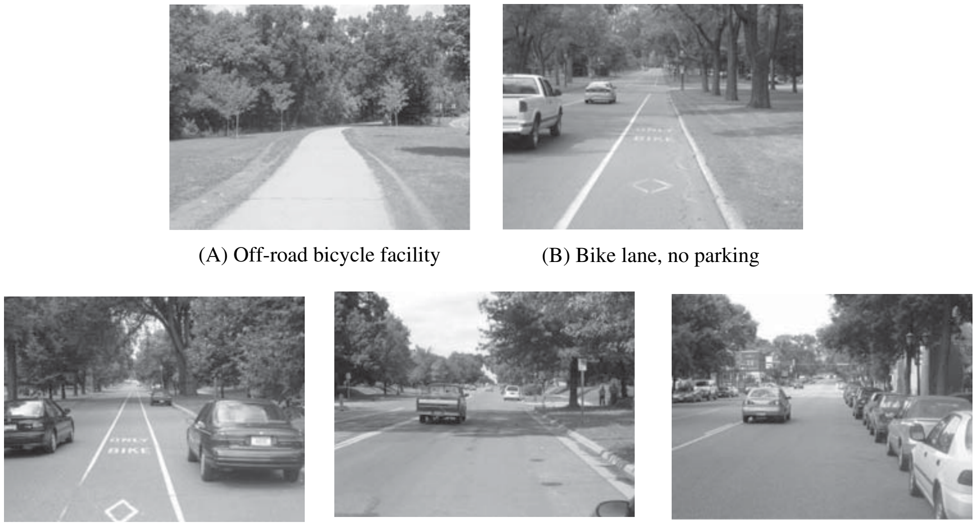
Stated preference surveys overcome these complications because the experimenter controls the choices. In SP settings, the experimenter determines the choices and the respondent considers. While this may not reflect the actual market choice that individual would make because of the constraints the survey places on the choice set, it allows us to measure attribute differences between the presented alternatives. Further, by using specialized forms of SP such as ASP, one can measure the exact value individuals attach to attributes of interest. In this type of survey each option is presented based on choices the respondent has already made. This allows for the presentation of choices that the individual can actually consider while removing alternatives that the respondent will surely not consider. This methodology has been adopted in a number of contexts, including value of time for commercial vehicle operators (*201*), in mode choice experiments (*202*), and in evaluating transit improvements (*203*).

SURVEY INSTRUMENT, DESIGN, AND ADMINISTRATION

All respondents of the ASP survey were given nine presentations that compared two facilities at a time. Each presentation asks the respondent to choose between two bicycle facilities. The respondent is told that the trip is a work commute and the respective travel time they would experience for each facility is given. Each facility is presented using a 10-second video clip taken from the bicyclists' perspective. The clips loop three times and respondents are able to replay the clip if they wish.

Each facility is compared with all other facilities that are theoretically of lesser quality. For example, an off-road facility (A) is compared with a bike lane no on-street parking facility (B), a bike lane with parking facility (C), a no bike lane and no parking facility (D), and a no bike lane with parking facility (E). Similarly, the four other facilities (B, C, D and E) are each compared with those facilities that are theoretically deemed of a lesser quality. The less attractive of the two facilities is assigned a lower travel time and the alternate (higher quality) path is assigned a higher travel time. The respondent goes through four iterations per presentation with travel time for the more attractive facility being changed according to the previous choice. The first choice set within each presentation assigns the lesser quality facility a 20-minute travel time and the alternate (higher quality) path a 40-minute travel time. Travel time for the higher quality facility increases if the respondent chose that facility, and it decreases if the less attractive facility was selected. A bisection algorithm works between 20 and 60 minutes either raising or lowering the travel time for the alternate path so that it becomes less attractive if it is chosen or more attractive if the shortest path is chosen. By the fourth iteration, the algorithm converges on the maximum time difference where the respondent will choose the better facility. This way the respondent's time value for a particular bicycling environment can be estimated by identifying the maximum time difference between the two route choices that he/she will still choose the more attractive facility. Pictures of these facilities are shown on Figure 13. Figure 14 maps the locations of the facilities where the videos were taken in St. Paul, Minnesota.

The procedure used to converge on the time trade-off for the particular facility is illustrated as follows. If the subject first chose the longer option, then the next choice set assigns a higher travel time for the higher quality path (raised from 40 minutes to 50 minutes). If the respondent still chooses the longer option, the travel time for that choice increases to 55 minutes and the choice is posed again. If on the other hand, the 50-minute option is rejected and the respondent chose the 20-minute route, the bisection algorithm will calculate a travel time that is between the now rejected option and the previously accepted option, in this case 45 minutes. By the time the respondent makes a fourth choice, the survey will have either narrowed down the respondent's preference to within 2 minutes or the respondent will



(A) Off-road bicycle facility

(B) Bike lane, no parking

(C) Bike lane, on-street parking

(D) Bike lane, no parking

(E) No bike lane, on-street parking

Figure 13. Cycling facilities used in the study.

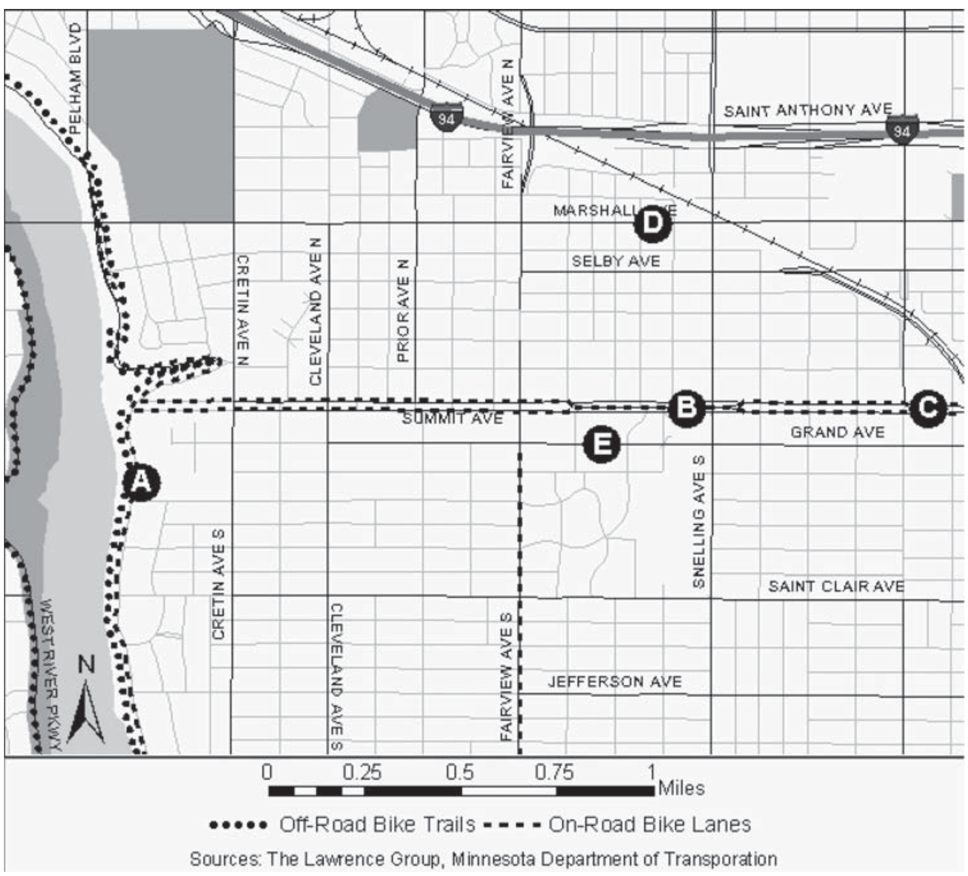


Figure 14. Location of facilities used in the Adaptive Stated Preference survey. (Note: (A) off-road facility; (B) bicycle lane, no parking facility; (C) bicycle lane, on-street parking facility; (D) no bicycle lane, no parking facility; (E) no bicycle lane, on-street parking facility.)

TABLE 16 Facility pairs compared in the ASP survey

		Base Route			
		B Bike lane, no parking	C Bike lane with on-street parking	D No bike lane, no parking	E No bike lane with on-street parking
Alternate routes	A off-road	$\mathbf{T}_1$	$\mathbf{T}_2$	$\mathbf{T}_3$	$\mathbf{T}_4$
	B Bike lane, no parking	N/A	$\mathbf{T}_5$	$\mathbf{T}_6$	$\mathbf{T}_7$
	C Bike lane with on-street parking	N/A	N/A	N/A	$\mathbf{T}_8$
	D No bike lane, no parking	N/A	N/A	N/A	$\mathbf{T}_9$

T_i represents the average additional travel time users are willing to travel.

have hit the maximum travel time that can be assigned to the longer trip, which is 58.5 minutes. Table 16 shows the pairs of comparisons that were conducted and used in the analysis. Table 17 shows a sample series of travel time presentations and Figure 15 shows sample screenshots of the survey instrument.

The survey was administered in two waves, once during winter and once during summer. The winter and summer respondents were shown video clips that reflected the season at the time of the survey taken at approximately the same location. Our sample for both waves comprised employees from the University of Minnesota, excluding students and faculty. Invitations were sent out to 2,500 employees, randomly selected from an employee database, indicating that we would like them to participate in a computer based survey about their commute to work and offering $15 for participation. Participants were asked to come to a central testing station, where the survey was being administered. A total of 90 people participated in the winter survey and another 91 people participated in the summer survey, making a total of 181 people. Among these, 13 people had to be removed due to incomplete information, leaving 168 people. Of these 168, 68 people indicated that they have bicycled to work at least once in the past year. Thirty-eight of these 68 identified themselves as regular bicycle commuters at least during the summer. Also, 127 of the 168 people said they have bicycled to somewhere, including work, in the past year. Further demographic information on the respondents is given in Table 18.

TABLE 17 Choice order for a sample presentation

Presentation	Facility Travel Time		Choice
	Route 1	**Route 2**	
choice set **1**	40 min	20 min	Route 2
choice set **2**	30 min	20 min	Route 1
choice set **3**	35 min	20 min	Route 1
choice set **4**	37 min	20 min	Route 2
$\mathbf{T_i}$	36 min		

MODEL SPECIFICATION AND RESULTS

Switching Point Analysis

The adaptive nature of the survey allows us to extract the actual additional minutes each individual is willing to travel on an alternate facility. In the context of the survey, this is the maximum travel time beyond which the respondent would switch to use the base facility. For each pair of facilities that are compared during the summer and the winter, the averages of this switching point are computed and plotted in Figure 16. On average, individuals are willing to travel more on an alternate facility when the base facility is E (undesignated with on-street parking), followed by D (no bike lane without parking) and C (bike lane with parking). For example, individuals are willing to travel further on facility B when the base facility is E, as opposed to D or C.

Figure 16 shows the hierarchy between facilities clearly—each of the lines plotted connects the average additional travel time that individuals are willing to bicycle over the 20 minutes that they would have bicycled if they had chosen the base facility. For example, looking at the winter data, the top solid line connects the average additional time individuals say they would travel on an alternate facility when the base facility is E (in-traffic with parking at 20 minutes). The alternate facilities are as shown on the horizontal axis. For example, on average respondents are willing to travel about 22 additional

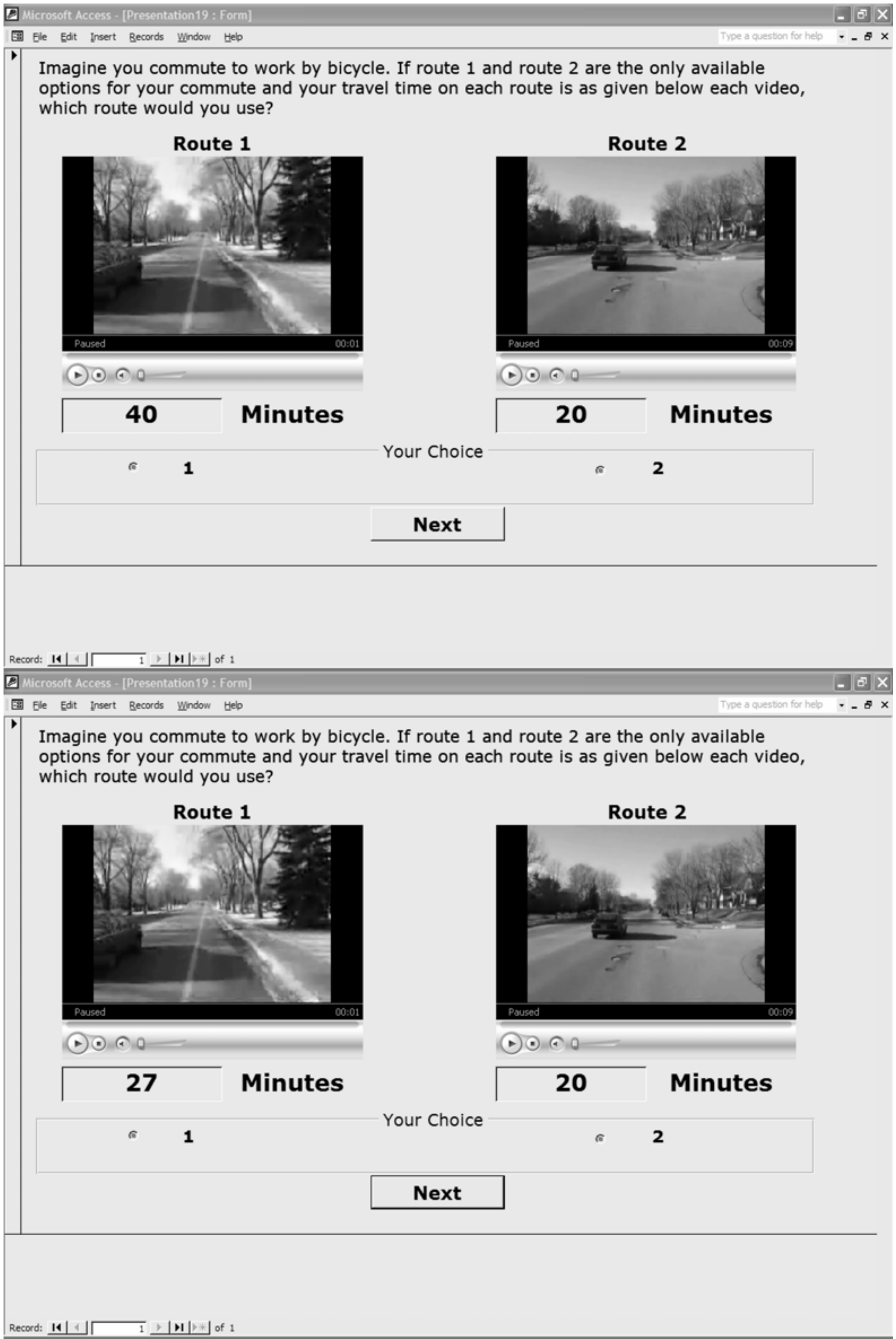


Figure 15. Top: comparing designated bicycle lanes with no parking with in-traffic bicycling with no parking. Bottom: same presentation three iterations later.

TABLE 18 Demographic distribution of respondents

Number of subjects		168
Sex		
	% Male	34.5%
	% Female	65.5%
Age	Mean (Std. deviation)	44.19 (10.99)
Usual mode (Year round)		
	%Car	69.7%
	%Bus	18.5%
	%Bike	9.2%
	%Walk	2.6%
Bike commuter		
	All season	9.2%
	Summer	22.6%
HH income		
	< $30,000	8.3%
	$30,000 - $45,000	14.3%
	$45,000 - $60,000	19.6%
	$60,000 - $75,000	15.5%
	$75,000 - $100,000	20.2%
	$100,000 - $150,000	17.9%
	> $150,000	4.2%
HH Size		
	1	25.0%
	2	32.7%
	3	16.7%
	4	20.8%
	> 4	4.8%

minutes if an off-road bike path is available if the alternative is to bike in traffic. We can further describe the data by employing techniques such as the non-parametric bootstrap. The bootstrap approximates the sampling distribution of the mean by repeatedly sampling with replacement from the original data. We employ the nonparametric bootstrap where no prior assumptions are made on the distribution of the statistic. The bootstrap approach was first developed by Efron in 1979 (*204*).

Consider the histogram shown in Figure 17, it reflects the additional travel times individuals in the sample said they would travel between facilities A (off-road) and C (in traffic with parking). It is difficult to make any distributional assumptions based on the observed sample. Employing the nonparametric bootstrap on this data with 5,000 resamples (Figure 18), we can see that the bootstrap distribution of the mean is very close to normal, and hence a normal interval can be built around it. The bootstrap distributions of all nine pairs of comparisons lead to very symmetric distributions that show no evidence of non-normality. The percentile confidence interval based on the actual 2.5% and 97.5% values of the bootstrapped mean are also computed. The bootstrap also allows us to estimate the bias of the sample mean. The sample mean, the estimate of the bias and the confidence interval (CI) using the normal distribution and the percentile of the bootstrap are reported in Table 19 for each pair of comparisons both for the combined and season specific data.

Model

We start with the economic paradigm of a utility maximizing individual, where given a bundle of goods the individual chooses that bundle which results in the highest possible utility from the choice set. In the current context then, given two alternatives, the chosen alternative is the one that the respondent derives a higher utility from. We can then break down each bundled alternative to its components to understand what amount each contributes to utility. This will enable us to extract the contribution of each feature of the facility in the choice consideration of the individual. Mathematically, we would state this as alternative A is selected if U_A is greater than U_B, where A and B are the alternatives and U is the utility function.

We hypothesize that the utility a user derives from using a bicycle facility depends on the features of the facility and the expected travel time on the facility. Choices are also affected by individual characteristics that we may not directly observe but can try to estimate using individual specific variables such as income, sex, age etc. As discussed earlier, each individual records a response over various alternatives, and therefore the data reflects the repeated choices over the same respondent. This implies that the errors are no longer independently distributed. To overcome this problem one can use a generalized linear mixed model which would estimate a random effect for the between-subject effect, thus separating the within-subject and between-subject errors. Both subject random effects are assumed to have a normal distribution with zero mean and separate variances. The error term of the utility's linear component is assumed to have a Gumbel distribution. The model's linear utility component is specified as follows:

U = f (Facility, Travel Time, Season, Individual Variables)

The utility of a particular alternative can be written as follows:

$$U_{iA} = V_{iA} + \epsilon_{iA}$$

$$V_{iA} = \beta_0 + \beta_1 W_{iA} + \beta_2 O_{iA} + \beta_3 B_{iA} + \beta_4 P_{iA} + \beta_5 T_{iA} + \beta_6 S_{iA} + \beta_7 A_{iA} + \beta_8 I_{iA} + \beta_9 H_{iA} + \beta_{10} C_{iA}$$

Where:

W = Weather (winter = 1, summer = 0)
O = dummy indicating whether the facility is off-road (1 = Yes, 0 = No)
B = dummy indicating whether the facility has a bike lane (1 = Yes, 0 = No)
P = dummy indicating whether on-street parking is absent or present (1 = absent, 0 = present)
T = Expected travel time on the facility being considered
S = Sex (Male = 1, Female = 0)
A = Age
I = Household Income (Inc/1000)
H = Household Size (>2 = 1, Otherwise = 0)
C = Cyclist at least during summer (Yes = 1, No = 0)
β = estimable coefficient
$\epsilon \sim$ Gumbel $(0, \lambda)$

To interpret the model appropriately it is important to note how the dummy variables are coded (Table 20). Variable B represents whether a facility has a designated bike lane, O represents whether

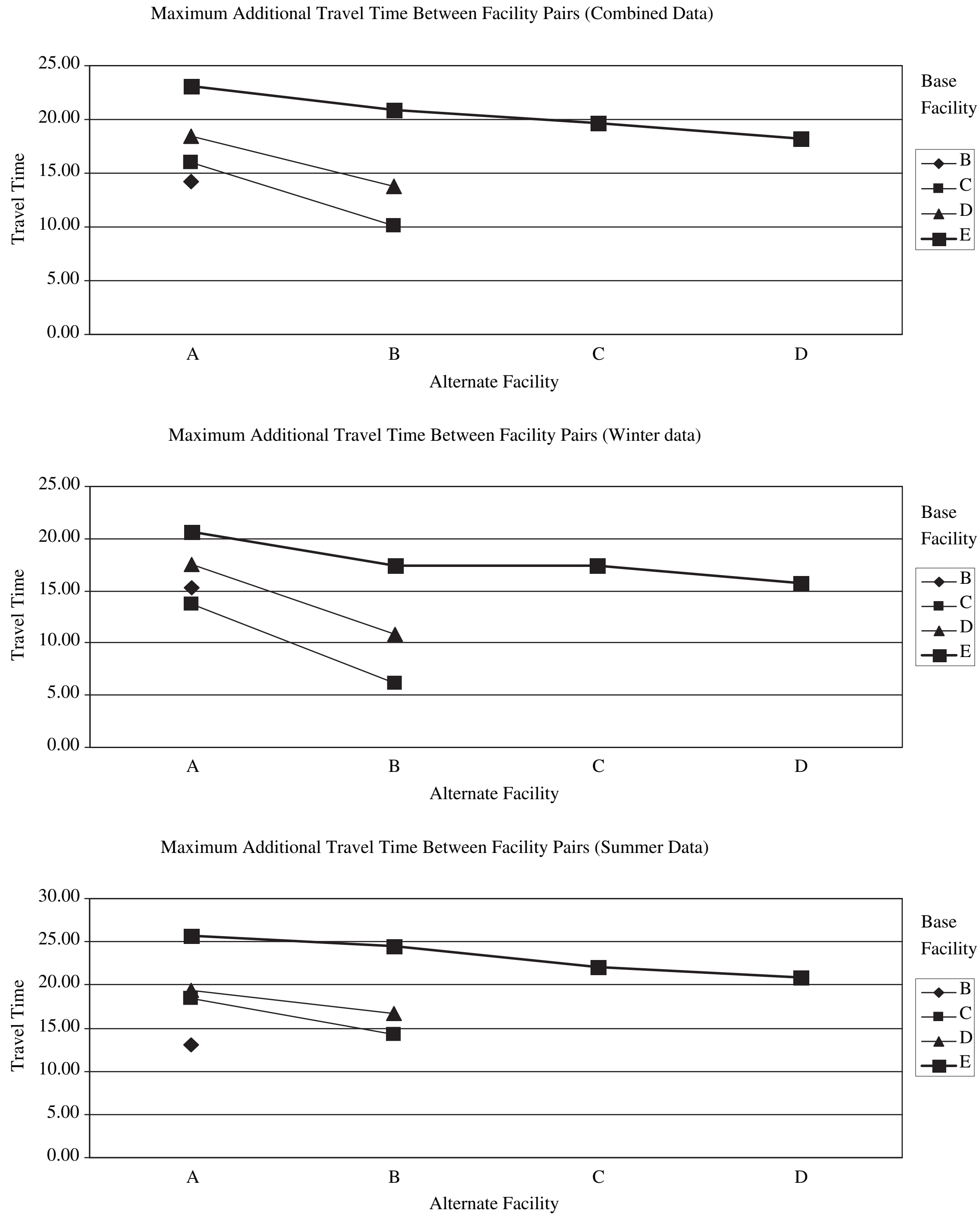


Figure 16. Hierarchy of facilities. (Note: (A) off-road facility; (B) a bike lane, no parking facility; (C) a bike lane, on-street parking facility; (D) a no bike lane, no parking facility; (E) a no bike lane, on-street parking facility.)

the facility is off-road, and P represents whether a facility has no parking adjacent to it. This would allow separately valuating bike lanes as well as being off-road. It should be observed that 'O' is not equivalent to an off-road trail. 'B' and 'O' together constitute an off-road trail.

The parameter estimates of binomial logit model are given in Table 21. The model is estimated such that the results indicate the odds of choosing the theoretically better facility. Choices depend on the attributes of the facilities, the travel time the user experiences on the facilities, and individual characteristics. The signs of the estimated parameters are as expected. The travel time is negative showing an aversion to longer trips. The improvements (off-road, bike lane and no parking) all have a positive and significant influence on choice of different magnitudes. Of these three, a bike lane improvement

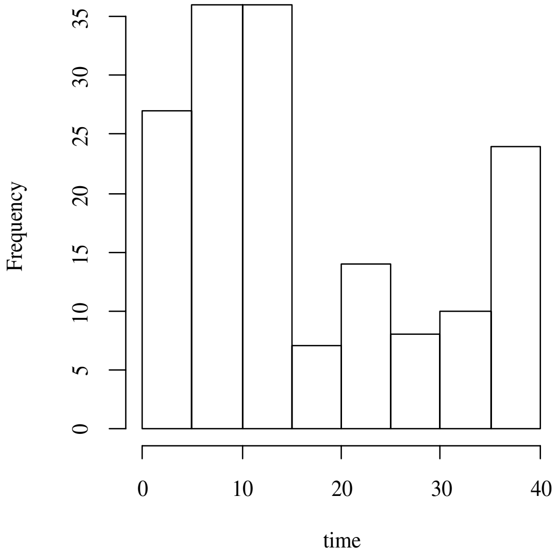


Figure 17. Distribution of additional travel time for facility C over facility A.

increases the odds much more than a parking elimination or that of an off-road improvement alone.

The season variable is negative and significant, indicating that people have lower odds of choosing the higher travel time facility during winter than during summer. Looking at the individual covariates that are used, income and sex are not significant at the 0.10 level; however the signs seem to indicate that women have a higher tendency to choose the facilities that are perceived safer (better quality) than men (p-value = 0.11); and higher incomes seem to be associated with a tendency to choose the better quality facility (p-value = 0.11). The cyclist variable, which indicates if the respondents use bicycling as their main mode at least during summer, is highly insignificant;

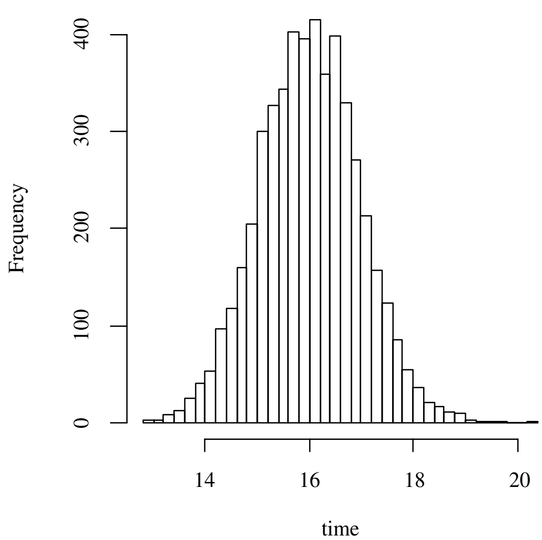


Figure 18. The bootstrapped mean for the additional travel time between facilities A and C (based on 5,000 resamples).

indicating that preferences are not dictated by experience at least in this SP context. The model also tells us that older individuals have higher odds of choosing the better quality facility. Also, individuals whose household size is greater than two have lower odds of choosing the better quality, longer travel time facility. This may be because these individuals have higher constraints on their time than individuals who live in single or two person households.

The estimates of a linear utility model can be used to determine the value of an off-road facility, a bike lane facility and a facility with no parking in terms of the time cost of travel. These are derived using the marginal rate of substitution between each of the facility features and travel time (Table 22). These values are derived based on SP questions that have a 20-minute base travel time, and should be interpreted as such. Accordingly, a bike lane improvement is valued at 16.3 minutes, a no parking improvement is valued at 8.9 minutes and an off-road improvement is valued at 5.2 minutes. This is to say, keeping utility at the same level, one can exchange the off-road improvement for 5.2 minutes of travel time, a bike lane for 16.3 minutes of travel time and a no parking improvement for 8.9 minutes of travel time. This says that the most value is attached to having a designated bike lane. While having an off-road facility would certainly increase the utility of the individual, most of the gains of an off-road facility seem to be derived from the fact that such facilities provide a designated bike lane. The absence of parking is also valued more than taking the facility off-road.

An alternate specification of the model looks at time as a dependent variable and features of the facility as independent variables along with demographic covariates. This specification also employs a mixed models approach to account for the repeated measurements taken over the same subject. The dependent variable is the switching point travel time minus the base facility travel time. This approach yields similar patterns in the order of valuation of the different attributes of the facilities and the expected directions of the parameter estimates. A side by side comparison of the two model coefficients is not possible; however, we can compare the values derived for different facility pairs based on our logit model and the linear model (Table 23). This is given in Table 24 and Figure 19. As can be seen, most comparisons are very close to one another in magnitude. As Figure 19 shows, the results derived from the logit model more closely replicate what is observed in the raw data, even though that is not always the case across the nine comparisons.

The overall assessment of the models suggests that designated bike lanes seem to be what are desired the most. It is also important to consider that both the linear and logit models found no evidence against the possibility that preferences between cyclists and non-cyclists are the same. This is encouraging in many respects, because it avoids the dilemma of which interest to serve. The policy implication is that by addressing this common preference, we can ensure cyclists receive the facilities they prefer and non-cyclists get the facilities that they could at least consider as a viable alternative.

CONCLUSION

This appendix analyzes preferences for different cycling facilities using a computer-based adaptive stated preference survey with first person videos. Using the survey on 168 randomly recruited individuals, we derive the values that users attach to different cycling facility features and expose which are most important. The choice data were collected based on individual preferences between different

TABLE 19 Mean additional travel time between facility pairs and confidence interval of the bootstrapped distribution of the mean

Fac1	Fac2	Original Mean	Bias	Standard Error	Normal 95% CI	Percentile 95% CI
Combined Data						
A	B	14.21	0.0223	0.962	(12.30, 16.08)	(12.41, 16.17)
A	C	16.00	0.0136	0.964	(14.10, 17.88)	(14.16, 17.92)
A	D	18.46	-0.0160	0.984	(16.55, 20.41)	(16.58, 20.40)
A	E	23.14	-0.0051	0.939	(21.30, 24.98)	(21.26, 24.94)
B	C	10.13	0.0092	0.973	(8.21, 12.03)	(8.25, 12.06)
B	D	13.73	-0.0008	0.957	(11.85, 15.61)	(11.90, 15.62)
B	E	20.87	0.0245	0.956	(18.97, 22.72)	(19.09, 22.84)
C	E	19.65	-0.0033	0.950	(17.79, 21.51)	(17.79, 21.49)
D	E	18.25	0.0211	1.002	(16.27, 20.20)	(16.35, 20.22)
Winter Data						
Fac1	Fac2	Original Mean	Bias	Standard Error	Normal 95% CI	Percentile 95% CI
A	B	15.33	0.0208	1.335	(12.69, 17.92)	(12.78, 18.00)
A	C	13.69	0.0339	1.327	(11.06, 16.26)	(11.21, 16.40)
A	D	17.57	-0.0252	1.344	(14.96, 20.23)	(14.99, 20.19)
A	E	20.66	-0.0025	1.319	(18.08, 23.25)	(18.16, 23.28)
B	C	6.17	-0.0064	1.197	(3.83, 8.52)	(3.97, 8.57)
B	D	10.86	-0.0244	1.180	(8.57, 13.19)	(8.58, 13.25)
B	E	17.45	-0.0101	1.248	(15.02, 19.91)	(15.02, 19.91)
C	E	17.39	-0.0097	1.264	(14.92, 19.87)	(14.98, 19.92)
D	E	15.72	0.0074	1.270	(13.22, 18.20)	(13.22, 18.22)
Summer Data						
Fac1	Fac2	Original Mean	Bias	Standard Error	Normal 95% CI	Percentile 95% CI
A	B	13.04	-0.0051	1.338	(10.43, 15.67)	(10.49, 15.74)
A	C	18.43	0.0146	1.353	(15.76, 21.07)	(15.84, 21.16)
A	D	19.40	0.0079	1.434	(16.58, 22.20)	(16.58, 22.25)
A	E	25.73	-0.0071	1.292	(23.21, 28.27)	(23.18, 28.27)
B	C	14.28	0.0154	1.397	(11.53, 17.01)	(11.63, 17.10)
B	D	16.75	-0.0128	1.481	(13.86, 19.66)	(13.89, 19.68)
B	E	24.46	-0.0072	1.332	(21.85, 27.07)	(21.78, 27.06)
C	E	22.03	0.0013	1.403	(19.27, 24.77)	(19.30, 24.82)
D	E	20.92	-0.0055	1.485	(18.01, 23.83)	(17.96, 23.82)

TABLE 20 Coding for facility features

Facility	O	B	P
A (Off-road)	1	1	1
B (Bike lane, No parking)	0	1	1
C (Bike lane, on-street parking)	0	1	0
D (In traffic, No parking)	0	0	1
E (In traffic, on-street parking)	0	0	0

TABLE 21 Logit model

Random effects:

Group	Variance	Std.Dev.
subject	1.550	1.245

Fixed effects:

Variable	Description	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)		–0.620	0.472	–1.315	0.1885	
W	Season (1 = winter, 0 = summer)	–0.627	0.207	–3.028	0.0025	* *
T	Travel time	–0.051	0.004	–12.685	0.0000	* * *
O	Offroad Improvement?	0.264	0.060	4.386	0.0000	* * *
P	Parking Improvement?	0.456	0.065	7.067	0.0000	* * *
B	Bikelane Improvement?	0.831	0.067	12.475	0.0000	* * *
A	Age	0.021	0.010	2.126	0.0335	*
S	Sex (1 = M, 0 = F)	–0.350	0.223	–1.567	0.1171	
I	Income	0.005	0.003	1.584	0.1132	
H	HHsize (if>2, 0 otherwise)	–0.594	0.229	–2.589		* *
C	Cyclist (1 = atleast summer, 0 = No)	–0.133	0.253	–0.524	0.6003	

TABLE 22 Time values of facility attributes

Attribute	Marginal Rate of Substitution (minutes)
O – Off street improvement	5.20
P – Parking improvement	8.98
B – Bike lane improvement	16.36

TABLE 23 Linear model

Random Effects

	(Intercept)	Residual
StdDev:	8.98	8.01

Fixed effects:

	Description		Value	Std. Error	t-stat	p-value	
(Intercept)			7.24	3.377	2.143	0.032	
W	Season Winter?	Yes=1 No=0	–4.13	1.485	–2.782	0.006	* * *
O	Offroad Improvement?	Yes=1 No=0	2.38	0.429	5.540	0.000	* * *
P	Parking Improvement?	Yes=1 No=0	3.50	0.456	7.673	0.000	* * *
B	Bikelane Improvement?	Yes=1 No=0	5.98	0.456	13.127	0.000	* *
A	Age	Yes=1 No=0	0.15	0.071	2.092	0.038	*
S	Sex	Male=1 Female=0	–3.36	1.604	2.093	0.038	*
I	Inc/1000		0.03	0.021	1.475	0.142	
H	Household Size	>2=1 ≤2=0	–3.75	1.645	–2.278	0.024	*
C	Summer cyclist?	Yes=1 No=0	–2.22	1.818	–1.221	0.224	

Significance ***0.001 **0.01 *0.05 +0.1

TABLE 24 Comparison of travel time values between facilities using the linear model and the logit model

Comparison	Facility 1	Facility 2	Logit	Linear	Mean (raw data)
1	A	B	5.2	9.6	13.0
2	A	C	14.2	13.1	18.4
3	A	D	21.6	15.6	19.4
4	A	E	30.5	19.1	25.7
5	B	C	9.0	10.7	14.3
6	B	D	16.4	13.2	16.7
7	B	E	25.3	16.7	24.5
8	C	E	16.4	13.2	22.0
9	D	E	9.0	13.2	20.9

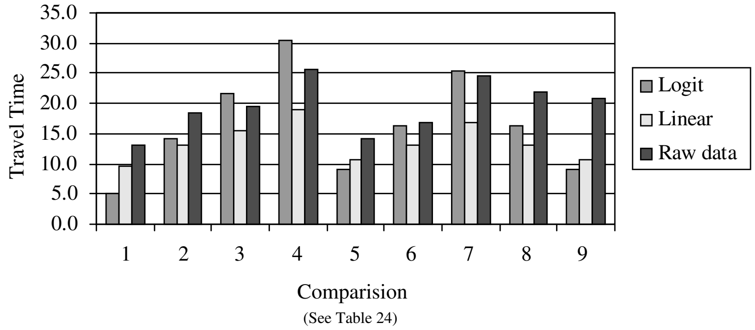


Figure 19. Comparison of the estimates of the additional time willing to travel between facility pairs based on logit model, linear model, and the raw data.

facilities having different travel times, but the same origin and destination. From the raw data we have demonstrated that a hierarchy exists between the facilities considered, and we have extracted a measure of how many additional minutes an individual is willing to expend on an alternate facility if it were available and provided certain features that were not available on the base facility. The data were then used to fit a random parameter logit model using a utility maximizing framework. A linear model was also estimated and compared with the results from the mixed logit model. The results show that users are willing to pay the highest price for designated bike lanes, followed by the absence of parking on the street and by taking a bike lane facility off-road. In addition, we are able to extract certain individual characteristics that are indicative of preferences such as age and household structure and make loose connections with sex and household income. Such an understanding can be incorporated into the planning process to help planners make appropriate recommendations and investment decisions in developing bicycle facilities that are more appealing to the public.

APPENDIX E

USER HEALTH BENEFITS

The benefits of physical activity in enhancing overall health are well established. Physical activity reduces the risk of chronic diseases including coronary heart disease (*170, 205–209*), hypertension (*210*), Type II (non-insulin dependent) diabetes mellitus (*211, 212*), osteoporosis (*213, 214*), cancer (*215–217*) and mental illness (*95, 218–220*). Inversely, reduced levels of physical activity are also associated with mortality rates in general (*221–223*).

The task of attaching monetary amounts to levels of physical activity is a more challenging endeavor. One attempt to this general inquiry has been completed by Wang et al. (*93*) who derived cost-effectiveness measures of bicycle/pedestrian trails by dividing the costs of trail development and maintenance by selected physical activity-related outcomes of the trails (e.g., number of trail users). The average annual cost for persons becoming more physically active was found to be $98; the cost was $142 for persons who are active for general health, and $884 for persons who are active for weight loss.

Estimating the effect of physical activity on direct medical costs is a strategy more often employed, though considerably less straightforward. Part of the reason for ambiguity in this line of research is that an unsettled question looms as to how much physical activity is required to realize certain health benefits (i.e., what is the elasticity?) (*88, 94, 95*). In the field of public health, this matter is often approached from the perspective of dose-response relationships. The aim is to learn what change in amount, intensity, or duration of exposure (in this case, cycling) is associated with a change in risk of a specified outcome (in this case, cost of health care).

Existing literature examining relationships between levels of physical activity and health costs varies considerably in methodology and scope. The majority of existing studies pursue a dichotomized approach, separating respondents into two classes: those that satisfy the accepted “dose” of 30 minutes per day for five days and those who do not. In this first group of studies, there are at least five statewide reports whose methodology and assumptions are relatively general in nature. In most cases, estimates are derived from an aggregation of medical expenditures that can in some form be traced back to physical inactivity. For example, a study commissioned by the Michigan Fitness Foundation (*96*) concentrated on the economic costs to the residents of Michigan. The authors used estimates (acknowledged to be conservative) to derive direct costs (e.g., medical care, workers’ compensation, lost productivity) and indirect costs (e.g., inefficiencies associated with replacement workers). The final amount totaled $8.9 billion in 2003 ($1,175 per resident). A 2002 report from the Minnesota Department of Health (*97*) estimates that in 2000, $495 million was spent treating diseases and conditions that would be avoided if all Minnesotans were physically active. This amount converts to over $100 per resident. Additional reports claim that too little physical activity was responsible for an estimated $84.5 million ($19 per capita) in hospital charges in Washington State (*98*), $104 million ($78 per capita) in South Carolina (*99*), and $477 million in hospital charges in Georgia ($79 per capita) (*100*).

These reports from various state agencies are complemented with more academically oriented research. For example, Colditz (*101*) reviewed past literature on the economic costs of inactivity and concluded that the direct costs for those individuals reporting lack of physical activity was estimated to average approximately $128 per person. A separate analysis by Pratt et al. (*102*) analyzed a stratified sample of 35,000 Americans from the 1987 national Medical Expenditures Survey. Examining the direct medical costs of men and women who reported physical activity versus those who did not reveals that the mean net annual benefit of physical activity was $330 per person in 1987 dollars. An alternative method used a cost-of-illness approach to attribute a proportion of medical and pharmacy costs for specific diseases to physical inactivity in 2001 (*97*). The authors first identified medical conditions associated with physical inactivity and then collected claims data related to those conditions from approximately 1.6 million patients 16 and older from a large, Midwest health plan. While the resulting conditions from lack of physical inactivity include depression, colon cancer, heart disease, osteoporosis, and stroke, the results from this study conclude that claims costs at the health plan attributable to physical inactivity translates to $57 per member. One challenge of these analyses is the decision regarding whether or not to include diseases causally related to obesity or not. The Garrett paper did not, which may account for the lower estimates of cost of inactivity per person.

A different approach than the dichotomized strategy estimates the impact of different modifiable health risk behaviors and measures their impact on health care expenditures. After gathering information from more than 61,500 employees of six employers gathered over a five-year study period, Goetzel et al. (*87*) focused on a cohort of just over 46,000 employees, one-third of whom were considered to be sedentary (or inactive). The analysis found that a “risk-free” individual incurred approximately $1,166 in average annual medical expenditures while those with poor health habits had average annual medical expenditures of more than $3,800. Thus, they estimated the per-capita annual impact of poor exercise habits to be approximately $172. Pronk et al. (*89*) also identify the relationship between modifiable health risks and short-term health care charges. This research surveyed a random sample of 5,689 adults aged 40 years or older enrolled in a Minnesota health plan. Multivariate analysis on the modifiable health risks (diabetes, heart disease, body mass index, physical activity and smoking status) concluded that an additional day of physical activity (above zero) would yield a 4.7 percent reduction in charges (or a $27.99 reduction). The overarching result of the study is that obesity costs approximately $135 per member per year, and those with low fitness (inactivity) cost approximately $176 per member per year.

From this discussion, a couple of matters stand out with respect to understanding such relationships and ultimately informing applicable methods. First, annual per capita cost savings vary between $19 and $1,175 with a median value of $128 (see Table 25). Second,

TABLE 25 Estimated annual per capita cost savings (direct and/or indirect) of physical activity (*103*)

Study/Agency	Per Capita Cost Savings ($)
Washington State Department of Health	19
Garrett et al.	57
South Carolina Department of Health	78
Georgia Department of Human Resources	79
Colditz (1999)	92
Minnesota Department of Health	>100
Goetz et al.	172
Pronk et al.	176
Pratt	330
Michigan Fitness Foundation	1,175

some studies are disaggregate in nature and estimate costs by in-patient, outpatient, and pharmacy claims; others compare average healthcare expenditures of physically active versus inactive individuals. Third, some use a dichotomized approach to operationalize physically active individuals while others employ a modifiable health risks approach and do so in a relatively continuous scale. The studies are difficult to compare because some include different conditions, outpatient and pharmacy costs, and actual paid amounts rather than charges. Nonetheless, existing literature provides adequate, though developing, methodologies for estimating the public health impact of bicycle facilities in terms of economic impacts.

APPENDIX F

USER SAFETY BENEFITS

The prevailing argument is that enhanced facilities—bike lanes, bikeways and special intersection modifications—improve cyclist safety (*83*). This claim, however, is the source of a rich controversy within the literature as evidenced by the debate between Forester (*57*) and Pucher (*58*). Part of the controversy around this topic is fueled by differences between what cyclists state they prefer (i.e., their perception) and what studies with collision data actually reveal.

It is widely acknowledged that increased perception of safety is important to encourage cycling as a means of transportation and recreation (*51, 110*). Subsequently, providing separated bicycle facilities along roadways is mentioned as a key ingredient in increased perception of safety according to the burgeoning literature related to bicycle related stress factors (*111*), bicycle interaction hazard scores (*112*), relative danger index (*113*), compatibility indexes (*114*).

Existing literature on the safety of bicycle facilities usually considers one of three outcome measures: the number of fatalities, the number of crashes, and perceived levels of comfort for the cyclist. Key explanatory variables behind these outcome measures are myriad and complex to identify. For example, the overwhelming majority of bicycle crashes resulting in fatalities are caused by collisions with motor vehicles (*104*). Less severe crashes tend to occur at intersections or at locations where motor vehicles and bicycles come in contact with each other (*105*); it is further suggested that crashes are caused by differing expectations between auto drivers and bicyclists (*106*). However, there is increasing evidence to suggest that some bicycle crashes do not involve any other party (*107, 108*); this is especially true for children (*109*).

The degree to which perception of safety translates into actual increased safety, however, is still debated. It proves difficult to translate perceived measures of safety into quantifiable or economic estimates. Additional confounding factors are that prevailing guidelines recommend a variety of solutions. For example recent research suggests that both bicycle lanes and wide curb lanes can and should be used to improve riding conditions and safety for bicyclists (http://www.fhwa.dot.gov/tfhrc/safety/pubs/99035/intro.htm).

In the end, bicycle safety data are difficult to analyze, mostly because bicycle trip data (and thus accident probability per trip) are hard to uncover. As more research and conclusive findings become available, it will likely be possible to understand the safety benefits of bicycle facilities in more detail—at such time, a model could then be developed and incorporated into the guidelines.

APPENDIX G

RECREATION AND REDUCED AUTO USE BENEFITS

The material in this appendix is adapted from a longer report on the benefits of bicycling in Minnesota (*224*).

USER BENEFITS: HEALTH AND RECREATION

In general people bicycle because they enjoy the activity and the improved sense of well-being and health that comes from it. There is value in this, although it is not reflected in any monetary transaction. An improved bicycling environment will make riding more enjoyable when it is done, and will likely increase the frequency with which it is done; both factors will increase the overall size of this benefit.

Our concern here is with the non-monetary benefits derived from user enjoyment of bicycling and its effects, including health. By this we mean simply the greater sense of well-being that comes from being healthy rather than sick. There are also monetary benefits of better health such as reduced medical costs and less missed work; these are discussed later as societal benefits.

It is hard to place a value on recreation and on improved health separately. One approach to dealing with both these issues is to treat them jointly. This approach would assume that the individual who chooses to ride a bike derives some personal non-financial benefits from doing so, in terms of better health and general enjoyment, but does not try to disentangle this bundle of benefits into its components, instead simply comparing the overall size of the bundle to the costs of participating in the activity. For any person who participates in the activity, the bundle of benefits must exceed the time, money, or other costs of participation. Estimates of non-monetary value then reflect this entire bundle rather than any individual component of it.

While there is a monetary cost to owning and maintaining a bike, the apparent cost of any given ride is generally very low. The larger cost of riding is the value of the time that it takes. If one supposes, as is common in transportation work, that the average person values time at about $10/hr, then the typical hour bike ride, including some preparation and cleanup time, must be generating at least $10 in non-monetary benefits to justify the time taken. Since the total benefits must *exceed* the total costs to justify the activity, the total benefits are certainly higher than this.

Three methods for estimating the value of recreational activities and facilities have been informally sanctioned by the federal government in the form of guidelines for their application. All tend to yield similar results. Perhaps the most relevant for this situation is the "travel cost" approach. Very briefly, the idea of this is to measure and value the time spent accessing the activity, and to value the *net* benefits of the activity as being at least this value. That is, the total benefits of participation, minus the costs incurred by participating, must be greater than the cost of accessing the activity in the first place. A person who makes a two-hour round trip to get to a bike trail, at $10 per hour, must place a net value on the bike ride itself of at least $20.

A wide variety of studies of outdoor recreational activities (non-bicycling) generated typical values of about $40 per day in 2004 dollars (*245*). If a typical day of recreation is about 4 hours, this would be about $10/hour. Note that this is an estimate of the *net* benefits, above and beyond the value of the time taken by the activity itself. This estimate is also in line with a recent study of urban trails in Indianapolis, which used the travel cost method to find typical implied values per trip of about $7 to $20 (*246*).

AUTO SUBSTITUTION BENEFITS

This section discusses three categories of benefits related to auto substitution: lower transportation costs for bicyclists, reduced governmental and infrastructure costs, and reducing problems associated with automobile use. Although our work leads us to conclude that these benefits are relatively small, we treat them at some length here because they are generally considered to be of great importance in the bicycle advocacy literature. Because of this we felt that it was important to explain in some depth our reasons for considering these benefits to be of only minor significance.

The arguments for these benefits, and calculations of their sizes, are summarized in the work of Litman (*225*); his discussion is generally representative of other work in this area. All of these benefits ultimately rely on some assumption of bicycle travel substituting for car travel, with correspondingly reduced costs of some type. There are two broad issues that impact the potential size of benefits from this source.

The first is that the fraction of total bicycling that is actually replacing a driving trip is probably very small. All sources agree that more than half of all riding is recreational or fitness-oriented; these rides almost certainly are not substituting for a driving trip, and may even be creating extra driving if people drive their bikes somewhere else to ride. Even of those trips that are utilitarian in nature, it could be that the trip would have been made by transit, walking, as a car passenger, or not at all if not made by bike. Evidence from the NPTS suggests that of those people who usually commute to work by bike, only about 40% drive on the days that they do not bike; the others use transit, walk, or ride with someone else.

The second reason that biking probably does not have much impact on broader transportation problems is that there is so little of it relative to the amount of driving. Total daily miles of travel by bike in a typical city are perhaps 0.25% of daily vehicle miles of travel by cars. This will certainly have no impact on overall infrastructure needs, and it is hard to imagine that it could have much impact on congestion except possibly in a few isolated situations.

Lower Transportation Costs for Bicyclists

The notion that bicycling reduces transportation costs tends to rely on some combination of two assumptions, each of which is questionable. The first is that a bicycle does not cost very much to operate compared with a car. The second is that the extra time (not to mention inconvenience) that is needed to make trips by bike rather than car is not really a cost. We address each of these in turn.

Litman states that the variable costs of bicycling are 1 cent per mile. These seem low by perhaps a factor of 10 or 20. Parts wear out, or are damaged in crashes. The chain needs to be cleaned and lubricated; the tires need to be inflated. It is impossible to use a bike for 5,000 miles without doing any maintenance on it, as is routinely done with cars. Even if the rider does this work, the time costs of doing it should be counted as a cost of riding. If one rides any significant amount, or uses the bike for utilitarian purposes, then specialized clothing and other equipment will typically also be purchased.

A pair of mid-priced tires, as an example, might cost about $50, and might last about 5,000 miles. This is 1 cent per mile, about the per-mile cost of car tires. Spending three minutes every 100 miles or so to inflate the tires is 50 cents worth of time, or 0.5 cents per mile. The chain should be cleaned every 500 miles at least, at a time cost of about $5, or 1 cent per mile. The occasional tube puncture imposes a monetary and time cost. As with cars, more expensive repairs and tune-ups are sometimes necessary. Expensive bike-specific clothing, a near necessity if one rides very much, wears out after a few hundred miles (and must be laundered in the interim). We are not aware that anyone has really tried to systematically determine these costs, but the author's personal experience does not lead him to believe that he saves money when he rides a bike rather than driving.

Even in terms of fuel, consider that a mile of biking might burn perhaps 50 calories. A dollar would buy roughly somewhere between 100 and 1,000 calories worth of replacement food, depending on the type of food. At 500 calories per dollar, the replacement food is costing 10 cents per mile, a cost that is not really any cheaper than the gas needed to drive a car the same distance. To the possible objection that people enjoy eating but not putting gas in their car, we respond yes, but that benefit is already counted as part of the non-monetary recreational benefits mentioned previously. Here we are talking about monetary costs, and whether it is possible to save money by riding a bike.

The overall variable costs of operating a car (the costs that actually go up as the car is driven more) are about 15 to 20 cents per mile depending on the degree of stop and go traffic conditions (*226*). These costs include fuel, tires, maintenance and repairs, and depreciation. Of these, depreciation is probably the only area where a bike may be cheaper. Overall a bike seems likely to be more expensive for off-peak travel (when cars are cheaper to operate), and even for peak travel the difference seems unlikely to be more than three cents per mile, and likely zero if clothing is included as part of the cost, as we believe it should be. This is substantially less than Litman's estimated savings of 11 to 17 cents per mile.

A second point concerns the time costs of biking versus driving. While there may be isolated situations of extreme congestion where biking is faster, in general there will be a time penalty to riding a bike rather than driving. While Litman argues that since this time penalty is incurred voluntarily it should not be counted as a cost, we contend that this falls into the same category as food. Litman's point is that if someone enjoys riding then the extra time it takes is not really a cost to that person. But again, we are counting this enjoyment value as part of the non-monetary recreational benefits. The fact that there is a compensating benefit does not mean that there is not a cost as well.

Another possible source of user savings is parking, for those commuters who work in areas where parking fees must be paid. This is more likely to be an issue in dense areas, and for those commuters who would drive if they didn't bike. While this could be substantial in some cases, it is location-specific and hence difficult to estimate in a general way.

These results are a small fraction of the level that Litman asserts. We believe that the true value is closer to zero, as we are ignoring the extra time costs usually associated with bicycling and probably underestimating the monetary costs.

Reduced Governmental and Infrastructure Costs

Litman and some advocates argue that bicycling saves costs of roads, parking, and other transportation infrastructure and maintenance. These arguments, however, rely on a confusion of fixed and variable costs. Most state and federal roads are more or less fully funded through fuel taxes and other fees, so that any additional costs created by driving are paid for by taxes on driving. In this sense driving does not create a financial burden on government in general. The exception is local streets and roads, which are often paid for by property taxes and hence could be considered to be "subsidized."

However, philosophically, local streets are paid for by property taxes because their primary purpose is considered to be providing access to property, not transportation (*227*). A person who rides a bike and never drives still needs streets. In any case, the primary cost of streets in most developed areas is for cleaning, snow plowing, and routine maintenance. None of these things will need to be done with any less frequency if bikes are used instead of cars; indeed, they might be even more important for bikes. The need for maintenance arises primarily from weather, the passage of time, and heavy trucks and other equipment, not from cars. The fact that a certain amount of money is spent each year, and a certain number of miles are driven in cars, does not mean that the amount of money would go down if the number of miles driven did. That is, these costs are largely fixed; riding a bike will not save the government money.

Similarly for parking (the governmental or private costs of providing it, not the costs to the user), almost all the cost is the fixed cost of creating the facility in the first place; shifting a trip from car to bike will not change this. In cases where parking is in very short supply, the fact that bicyclists are not taking up spaces may create some convenience for others who are able to park in areas that would otherwise have been full, but the value of this seems unlikely to be large because so few trips are made by bike compared with cars.

One possible exception to this argument would be those cases where costs are incurred to expand streets to alleviate heavy traffic conditions. In this case less traffic could mean eliminating or at least delaying these expenditures. However, as a practical matter, the amount of bike-car replacement is so small that it cannot possibly influence these decisions, even in terms of timing, compared with more important factors such as funding availability, environmental impact issues, and even more significant alternative modes such as transit.

Reducing External Problems Associated with Automobile Use

A final set of minor benefits are those that have to do with reducing external problems associated with automobile use, primarily congestion and air pollution.

Litman claims, citing a Minnesota study (*228*), that urban congestion costs range from 5 to 30 cents per vehicle mile. However, this study was examining primarily the Twin Cities freeway and major arterial network, in the context of understanding how congestion pricing could reduce these costs in part by shifting trips to less congested (but slower) alternate routes. Most of the value of the congestion reduction comes from shifting traffic off of freeways and on to other routes. Once this takes place, the congestion costs are already greatly reduced; further reductions due to shifting from car to bike are limited. The average congestion costs on the non-freeway streets that bikes can use is more in the range of 0 to 5 cents a vehicle mile; the high end is achieved only in a few especially problematic places.

With regard to air pollution, Litman cites sources indicating that average costs of air pollution caused by automobiles are about 5 cents per mile for urban driving and 1 cent per mile for rural (rural emissions cause fewer costs because there are fewer people around to be affected by them).

APPENDIX H

COMMUNITY LIVABILITY BENEFITS

The Value of Bicycle Trail Proximity on Home Purchases

INTRODUCTION

Many cities—through public dialogues, community initiatives, and other land use-transportation policies—are developing strategies to increase the "livability" of their communities. While "livability" is a relatively ambiguous term, there is emerging consensus on the following: the ease by which residents can travel by walking or bicycling represents a critical component of this goal. Communities well endowed with non-motorized infrastructure, either in the form of sidewalks, bicycle paths, or compact and mixed land uses are hypothesized to be more livable than those without. This is an often relied-upon argument used by advocates of bicycle paths or sidewalks.

If livability is a cherished commodity among residents, and one important component of livability includes bicycle paths, then proximity to bicycle paths should be capitalized into the value of home purchases. Documenting this relationship would go a long way for advocates of bicycle facilities who often seek ways to monetize the value of these facilities. Such an endeavor would be especially beneficial since bicycle facilities are non-market goods, making it difficult to attach an economic value to them.

Social or economic benefits can be measured either through stated preferences, in which users are asked to attach a value to non-market goods, or through revealed preferences. The revealed preference approach measures individuals' actual behavior. In this study we measure homebuyers' revealed preferences in the form of hedonic modeling to learn if and how much residents value proximity to bicycle paths. The first part of this paper reviews previous literature on hedonic modeling focusing primarily on the dimension of open space and trails. The second part describes the setting for this work, our data, descriptive statistics, and methodological approach. Part three describes the results of a hedonic regression model, and part four reports on the policy implications and relevant conclusions.

REVIEW OF RELEVANT LITERATURE AND CONCEPTS

Discerning the relative value of non-market goods using hedonic modeling techniques is a method with a long history. Taylor (*229*) used what are now called hedonic techniques to explain the price of cotton with its internal qualities, and later applications by Lancaster (*128*) and Rosen (*129*) standardized the method for consumer products such as houses. An extensive review of this literature (*130*) documents nearly 200 applications that have examined home purchases to estimate values of several home attributes including structural features (e.g., lot size, a home's finished square footage, and number of bedrooms), internal and external features (e.g., fireplaces, air conditioning, garage spaces, and porches), natural environment features (e.g., scenic views), attributes of the neighborhood and location (e.g., crime, golf courses, and trees), public services (e.g., school and infrastructure quality), marketing, and financing.

As the literature describes various methods to assign value to housing characteristics, there exist opportunities to increase the explanatory power of hedonic models. Recent contributions include accessibility, perceived school quality, and measures of environmental amenities. For example, Franklin and Waddell (*230*) used a hedonic model to predict home prices in King County, Washington, as a function of accessibility to four types of activities (Commercial, University, K-12 Schools, and Industrial). In assessing the relationship between public school quality and housing prices, Brasington (*231*) found that proficiency tests, per-pupil spending, and student/teacher ratios most consistently capitalize into the housing market. Earnhart (*232*) combined discrete-choice hedonic analysis with choice-based conjoint analysis to place a value on adjacent environmental amenities such as lakes and forests.

Our application here focuses on the relative impact of bicycle lanes and trails. To the casual observer, bicycle lanes and trails may be considered as a single facility where any type of bicycle trail would have the same attraction. More careful thinking, however, suggests otherwise, especially for different types of bicycle facilities. Consider, for example, the three different types of trails/lanes shown in Figure 20. Some trails are on existing streets (demarcated by paint striping, hereafter "on-street lanes"); some trails are adjacent to existing roadways (hereafter "roadside trails") but are separated by curbs or mild landscaping (these facilities are sometimes referred to as "black sidewalks" because they are nothing more than blacktop in the usual location of sidewalks); other trails are clearly separated from traffic and often within open spaces (hereafter "non roadside trails"). For this last category, it is important to explain and control for the degree to which open space versus the bike trail contained within the open space contribute to a home's value. In many metropolitan areas bike trails and open space share a spatial location and at minimum exhibit similar recreational qualities. On-street lanes or roadside trails are often on or near roads. In some cases they will be on well-used collector streets or trunk highways; in others they may be on neighborhood arterial streets. Home buyers tend to dislike proximity to busy roadways. Much of the attraction of these facilities therefore depends on the design speed of the roadway facility and the average daily traffic. Any research failing to account for any of these factors will misestimate the independent value of bicycle trails.

It is therefore important to consider relevant literature estimating the value of open space. For example, Quang Do (*136*) found that homes abutting golf courses sell for a 7.6 percent premium over others. Other studies include measures of proximity and size of various open spaces (*233, 234*). Geoghegan (*133*) compared the price effects of the amount of permanent and developable open space within a one-mile radius. Smith et al. (*235*) examined the distinction between fixed and adjustable open spaces along a new Interstate highway corridor. Other approaches further disaggregate developable and non-developable open space in terms of ownership type and land cover (*236*). Some studies seek to attach values to views of open space. Benson et al. (*132*) created a series of dummy variables for

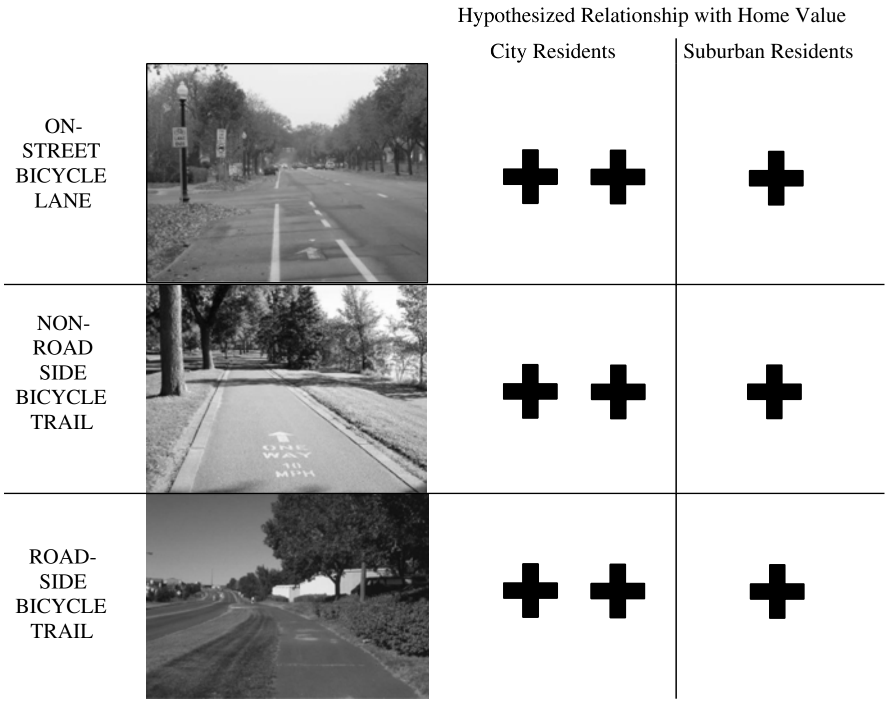


Figure 20. Representative photographs of an on-street bicycle lane, non-roadside trail, and roadside trail, hypothesized relationships.

four different qualities of ocean views, as well as lake and mountain views. Luttik (*135*) combined the vicinity and view approaches, dividing the geography into three levels of proximity.

Anderson and West's work (*131*) is particularly helpful for this specific application. They modeled both proximity and size of six specific open space categories, comparing effects on home prices between the city and suburb. They found that proximity to golf courses, large parks, and lakes has a positive effect on home prices in the city, with no significant results in the suburbs. The effects of open space on home prices also increased with the size of the open space. Proximity to small parks and cemeteries tended to reduce sale prices. To our knowledge, only one application focuses on proximity to bicycle trails. Lindsey (*72*) performed a hedonic analysis of 9,348 home sales, identifying properties falling inside or outside a half-mile buffer around fourteen greenways in Marion County, Indiana. This research found that some greenways have a positive, significant effect on property values while others have no significant effect. A survey in Vancouver found that the majority of realtors perceive little effect of bicycle trails on home values, either positive or negative (*237*). However, two-thirds of respondents also indicated that they would use bicycle trail proximity as a selling point.

Given the novelty of the application presented herein, theory is derived from a combination of sources, including existing published work (described in part above), consumer theory, and anecdotal evidence. Our first underpinning is derived from a local county commissioner who claims that bike facilities—like libraries—are goods everyone appreciates (*238*). Such a claim maps well with the assertions of bicycle trail advocates. Assuming an ability to account for the possible disutility of living on a busy arterial, bicycle facilities—no matter their type—positively contribute to home value. However, this hypothesis needs to be tempered based on the findings of Anderson and West. Their analysis suggests that open spaces and by association, bicycle facilities, may be perceived and valued differently depending on whether they are located in the city or suburbs.

Unlike other attributes which tend to be more universally valued (e.g., home size, number of bathrooms), we hypothesize that trails may be more appreciated by a subset of the population. Households who choose to live in the city are more likely to walk or bike, particularly to work, (*53, 239*) and therefore more likely to value bicycle facilities. Because we specify three different types of facilities with two populations who may value such facilities differently, we present Figure 20 displaying the nature and relative magnitude of our hypothesized relationships.

SETTING AND DATA

Our investigation is based in the Twin Cities (Minnesota) Metropolitan Area which proves to be an almost ideal laboratory for a variety of reasons. First, the Twin Cities boasts an almost unparalleled system of off-street bike paths for a major metropolitan area in the United States, totaling more than 2,722 kilometers (1,692 miles). While not nearly as extensive, striped on-street bike lanes are common as well. The network of on- and off-street trails is accessible to most Twin Citians, with 90 percent of homes within 1,600 meters (one mile) of an off-street trail. In fact, in many communities within the metropolitan area, over 90 percent of the homes have some form of facility within 400 meters (one-quarter mile).

Second, several municipalities and county governments pursue active roles in constructing and maintaining these facilities. The Grand Rounds Parkway in Minneapolis, considered by many to be the crown jewel of parks and recreational trails in Minnesota, con-

TABLE 26 Descriptive statistics of sample

	Variable Name	Description	Mean	Standard Deviation	Median
Environmental Amenities (A)	*Contrnr*	CITY: distance to nearest on-street bicyble lane (meters)	1276.31	947.90	1023.55
	Cnrtrnr	CITY: distance to nearest non-roadside bicycle trail (meters)	799.42	517.82	711.29
	Crstrnr	CITY: distance to nearest roadside bicycle trail (meters)	1293.81	716.20	1219.16
	Sontrnr	SUBURBS: distance to nearest on-street bicycle lane (meters)	1580.51	2240.18	979.82
	Snrtrnr	SUBURBS: distance to nearest non-roadside bicycle trail (meters)	1099.89	1732.29	602.92
	Srstrnr	SUBURBS: distance to nearest roadside bicycle trail (meters)	1359.35	1728.01	911.83
	Cactive	CITY: distance to nearest active open space (meters)	340.15	203.41	315.35
	Cpassive	CITY: distance to nearest passibe open space (meters)	683.10	396.64	633.76
	Cactive	SUBURB: distance to nearest active open space (meters)	569.92	1176.45	290.07
	Spassive	SUBURB: distance to nearest passive open space (meters)	760.73	641.12	613.09
Structural Attributes (S)	*Bedrooms*	Number of bedrooms	3.12	0.91	3.00
	Bathroom	Number of bathrooms	2.14	0.88	2.00
	Homestea	Homestead status	0.86	0.34	1.00
	Age	Age of house	35.88	28.97	27.00
	Lotsize	Size of lot (square meters)	2097.98	8053.17	968.00
	Finished	Finished square feet of floor space	1871.01	908.66	1708.00
	Firepls	Number of fireplaces	0.70	0.76	1.00
	Garagest	Number of garage stalls	1.72	1.02	2.00
Location (L)	*Hwynear*	Distance to nearest major highway (meters)	1672.32	1821.44	1149.58
	Cbdnear	Distance to nearest central business district (meters)	17558.59	10409.61	16374.75
	Busy	Home is on a busy street	0.05	0.21	0.00
Neighborhood Attributes (N)	*mca5_att*	Standardized test score in school district	4760.46	276.78	4836.10
	Pctnonwt	Percent nonwhite in census tract	12.51	14.02	7.82
	Avghhsiz	Persons per household in census tract	2.67	0.40	2.66

sists of 69 km (43 miles) of off-street paved trails along the city's chain of lakes, the Mississippi River, and Minnehaha Creek. Hennepin County, which includes the city of Minneapolis and many of its suburbs, works in cooperation with the Three Rivers Park District to build and maintain the largest network of off-street trails in the metro area (*240*). Many off-street trails in Hennepin and other counties are located on former railroad rights of way for the dual purposes of recreation and preservation of the land for future transit corridors. Other off-street trails in the Twin Cities follow arterial and collector streets. The cities of Chanhassen, Eden Prairie, and Plymouth have extensive networks of these roadside trails, with somewhat smaller networks in Maple Grove, Roseville, Eagan, and Apple Valley. Roseville is the only inner-ring suburb with a substantial network of off-street trails. Third, Twin Citians appear to cherish such trails, particularly in the summer months. For example, Minneapolis ranks among the top in the United States in the percentage of workers commuting by bicycle (*55*).

Consistent with the prevailing literature, our hedonic model assumes a competitive market in which homebuyers are seeking a set of home attributes that can be tied to a location. Locations are defined by structural attributes (S) (including internal and external attributes), neighborhood characteristics (N), location and accessibility (L), and environmental amenities (A). We build an equilibrium hedonic price function on these assumptions, where the market price of a home (P_h) depends on the quantities of its various attributes:

$$P_h = P\left(S, N, L, A\right)$$

The Regional Multiple Listing Services of Minnesota, Inc., (RMLS) maintains home sale data from major real estate brokers in Minnesota. This database includes all home sales in Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington counties in 2001, totaling 35,002[xxii] home sale purchases, including structural attributes of each home. The address of each home was mapped and paired with GIS features for spatial analysis using ArcGIS.

Table 26 lists each variable, its definition, and descriptive statistics. We measure location attributes through simple calculations of linear distance to the nearest central business district (either Minneapolis or St. Paul) (*cbdnear*) and the nearest major highway (*hwynear*). A third location variable (*busy*) indicates the presence of an arterial street fronting the home.

Neighborhood attributes include school district and demographic variables. Standardized test scores capitalize into home sale prices and are an effective measure of perceived school quality (*231*). *Mca5_att* represents the sum of the average math and reading scores achieved by fifth grade students taking the Minnesota Comprehensive Assessment. Scores associated with suburban homes are measured at the school district level, while Minneapolis and St. Paul scores are assigned to elementary school attendance areas. Demographic variables are derived from the 2000 United States Census. We include the percentage of people in the census tract who do not classify themselves as Caucasian (*Pctnonwt*) and the average number of people in each household in the census tract (*Avghhsize*).

MEASURES OF INTEREST AND METHODOLOGY

Measures of Distance to Bicycle Facility

The measures of interest for this application center on bicycle facilities and to a certain extent, open space. Examples of the facilities and trails in this setting are shown in Figure 21. Detailed GIS data allowed us to discern all bike trails in the region, separately identifying

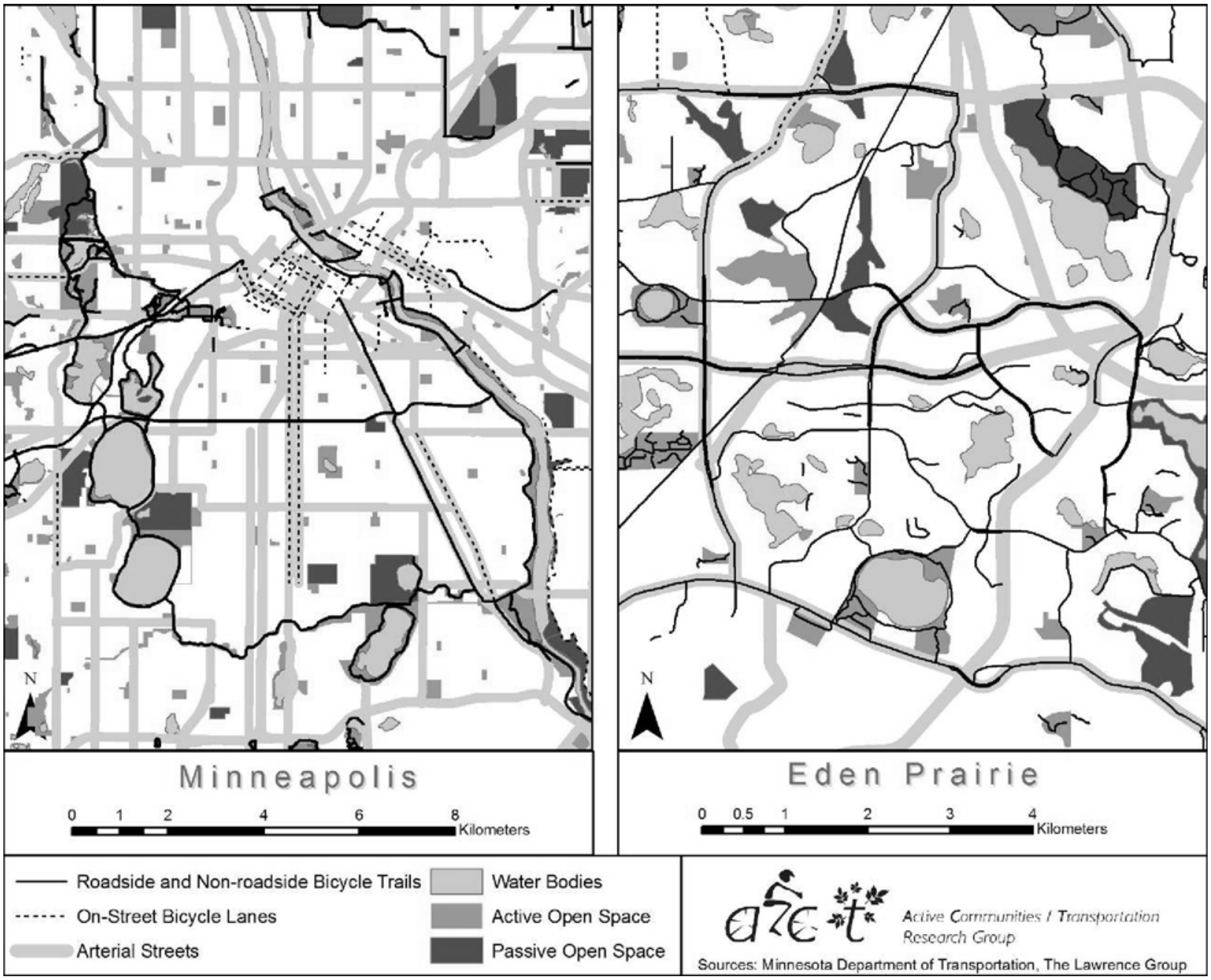


Figure 21. Examples of off-street bicycle trails, on-street bicycle lanes, and open space.

on- and off-street facilities which are distributed across both major open space corridors (e.g., railway lines, rivers, and lakes) and other roadways. We pair the MLS data for every home sale in the seven county study area from 2001 with the location of these trails.

Some on-street and off-street trails are located alongside busy trafficked streets, which is presumably a propelling characteristic for home locations. We therefore divide the off-street layer into roadside and non-roadside trails based on proximity to busy streets. We then calculate distance to the nearest roadside trail, non-roadside trail, and on-street bicycle lane for each home. As previously mentioned, we also measure distance to open space as a central variable, classifying such areas by type: active or passive.[xxiii]

Measures of Density of Bicycle Facilities

Motivated by Anderson and West's (*131*) findings that proximity and size of open space matters, we also theorize it to be important to consider not only the distance to facilities but also the density of trails around a particular home. The overall density (length) of different facilities within a buffer area may also be appreciated by homebuyers. They might value a well-connected system of trails, which are prevalent in many areas throughout the Twin Cities metropolitan area. We therefore calculate the kilometers of trails within buffer distance. See, for example, Figure 22 showing an example home in Minneapolis and how we measured open space and density of bicycle facilities by differing radii of 200, 400, 800, and 1,600 meters.

Interaction Terms

Many of the structural attributes used in this application are universally valued (e.g., home size, number of bathrooms). Several of the spatial attributes employed, however, are hypothesized to vary by segments of the population (urbanites versus suburbanites). Again, this distinction was found by Anderson and West's application for the same region. We therefore generate interaction terms (e.g., city multiplied by independent variable) to measure the attributes that may vary spatially. Doing so allows us to pool the sample of urban and suburban homes, thereby parsimoniously estimating a single model that preserves the integrity of the differing preferences. This single model provides coefficients that describe the effect of common attrib-

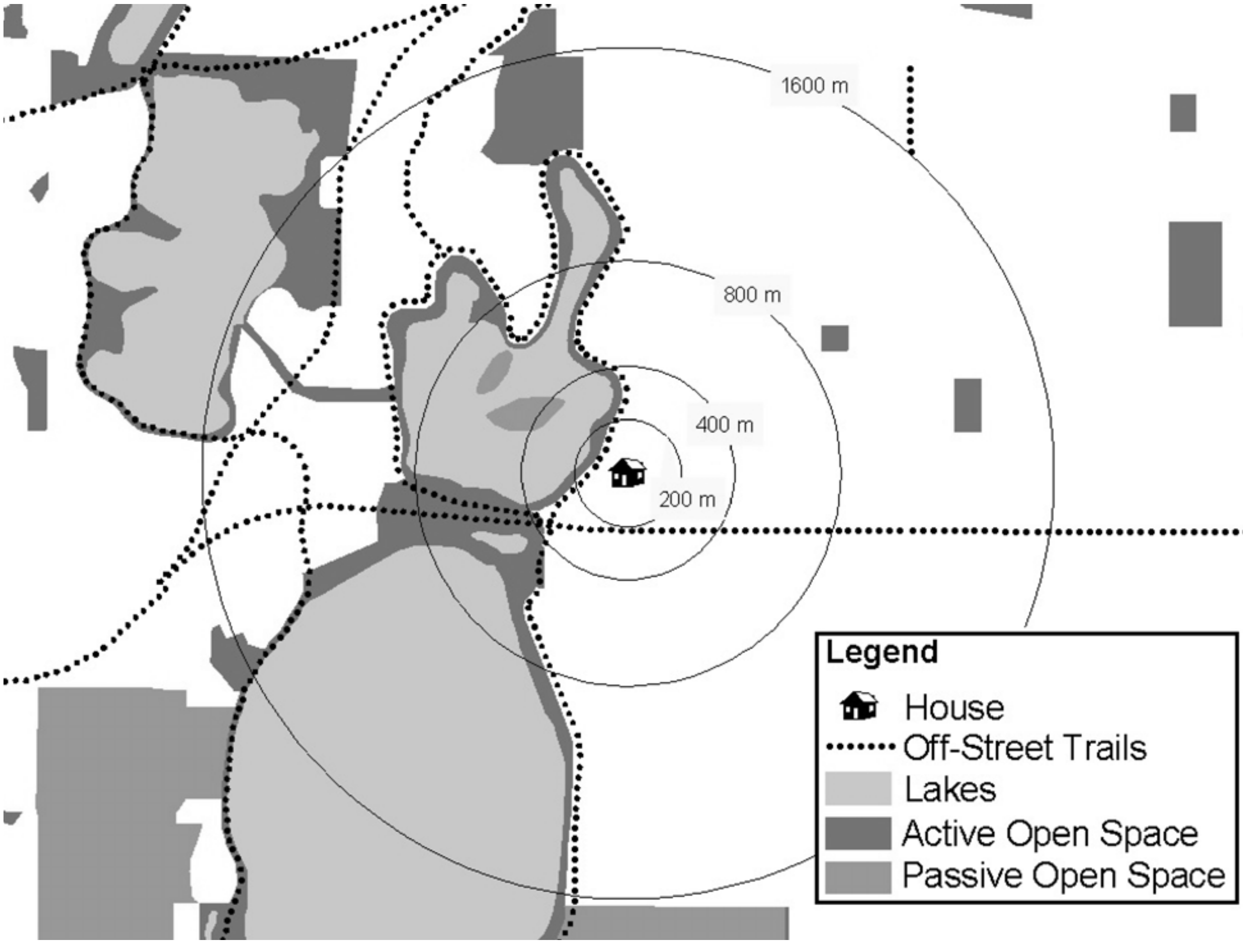


Figure 22. Off-street trails and open space within 200, 400, 800, and 1,600 meters of a Minneapolis house.

utes while producing different coefficients for the spatial attributes that may vary across suburbanites and urbanites.[xxiv]

Fixed Effects

Finally, as with any analysis of this type there are omitted attributes to consider. When estimating phenomena associated with the real estate market this dimension is particularly important. There are likely spatial attributes—not captured by any of our measures—which invariably affect home value. These attributes may include but are not limited to general housing stock of neighboring homes, the reputation effects of different neighborhoods or unobserved characteristics of the neighborhood.

Without fixed effects, variation across all observations in all neighborhoods is used to identify the effect of interest. But given the likely spatial correlation between proximity to bicycle facility with other variables, this effect is susceptible to omitted variable bias. We control for bias introduced by potential omitted variables by using local fixed effects, a dummy variable for each RMLS-defined market area (104 areas in our region). These boundaries mostly follow city limits in suburban areas and divide the central cities into several neighborhoods that closely follow similarly natured real-estate markets. By controlling for fixed effects we are estimating the effect of proximity to a bicycle trail, assuming a household has already decided to locate in one of the 104 MLS areas in the region. While more accurate, this process makes it difficult to identify the impact of bicycle trail proximity because it in effect reduces the variation of the variables of interest. Michaels and Smith (*241*) support this claim, showing that dividing a market into submarkets results in less robust estimates of the effects of hazardous waste site proximity.

RESULTS AND DISCUSSION

Our final model (shown in Table 27) is an OLS regression which determines the effect of bicycle trail proximity on home sale prices. We employ a logged dependent variable and also log transformations of several continuous independent variables, indicated by an *ln* following the variable name. All structural and location variables are statistically significant and have the expected signs. Home values increase with number of bedrooms, bathrooms, lot size, finished square footage, fireplaces, garage stalls, proximity to a central business district, and school quality. Home values decrease with age and percent non-white in the census tract. Similarly, proximity to a freeway has a negative effect on home value, which implies that the disamenity effects of freeways (e.g., noise, pollution) likely outweigh any accessibility benefits within particular neighborhoods. Looking

TABLE 27 Regression results

Variable Name	*Description*	*Coefficient*	*Standard Error*	*t-statistic*	*Effect of 400m Closer*	
Contrln	CITY: distance to nearest on-street bicycle lane (ln)	0.003950	0.002689	1.47		
Cntrln	CITY: distance to nearest non-roadside bicycle trail (ln)	–0.007851	0.003732	–2.1*	$	509.85
Crstrln	CITY: distance to nearest roadside bicycle trail (ln)	0.022772	0.003777	6.03**	$	(2,271.63)
Sonrln	SUBURBS: distance to nearest on-street bicycle lane (ln)	0.003334	0.001272	2.62**	$	(364.02)
Snrtrln	SUBURBS: distance to nearest non-roadside bicycle trail (ln)	0.003858	0.001325	2.91**	$	(239.65)
Srstrln	SUBURBS: distance to nearest roadside bicycle trail (ln)	0.010230	0.001419	7.21**	$	(1,058.73)
Cactive	CITY: distance to nearest active open space (meters)	–0.000024	0.000012	–1.96*		
Cpassive	CITY: distance to nearest passive open space (meters)	–0.000065	0.0000007	–9.08**	$	3,860.35
Cactive	SUBURB: distance to nearest active opn space (meters)	0.000006	0.000001	3.88**	$	(442.80)
Spassive	SUBURB: distance to nearest passive open space (meters)	–0.000028	0.000002	–12.86**	$	2,066.40
Bedrooms	Nubmer of bedrooms	0.033037	0.001570	21.05**		
Bathroom	Number of bathrooms	0.079976	0.002018	39.63**		
Homestea	Homestead status	–0.027259	0.003481	–7.83**		
Ageln	Age of house (ln)	–0.092578	0.001759	–52.65**		
Lotsize	Size of lot (squaremeters)	0.000003	0.000000	21.68**		
Finished	Finished square feet of floor space	0.000168	0.000002	82.14**		
Firepls	Number of fireplaces	0.068749	0.001768	38.89**		
Garagest	Number of garage stalls	0.075257	0.001268	59.37**		
Hwynear	Distance to nearest major highway (meters)	0.000009	0.000001	10.35**	$	(637.20)
Cbdnrln	Distance to nearest central business district (ln)	–0.056065	0.006926	–8.09**	$	9,861.10
Busy	Home is on a busy street	–0.03351	0.005096	–6.54**		
mca5_att	Standardized test score in school district	0.000160	0.000010	15.31**		
Pctnonwt	Percent nonwhite in censu tract	–0.004014	0.000183	–21.99**		
Avghhsiz	Persons per household in census tract	0.038961	0.004481	8.7**		
	Constant	11.314800	0.079957	141.51**		

Number of observations: 35,002
Adjusted R-squared: 07920

** Significant at p<0.01
* Significant at p<0.05

at some of the location and amenity variables reveals a different story. Open space coefficients are generally consistent with Anderson and West's (*131*) findings. Suburbanites value passive open space over active recreational areas. City residents also value lakes and golf courses, but active open space does not affect sale price.

Focusing on the variables of interest in this application, our analysis of bicycle facilities reveals a relatively complex story. It fails to be crisp and clean because we measure three types of facilities for two different populations (urban and suburban). Our discussion separates the findings for city and suburban residents. First, city residents clearly value proximity to non-roadside trails (after controlling for open space). As Minneapolis is well endowed with many off-road facilities and appears to exhibit a relatively high cycling population, this comes as little surprise. The opposite is true for trails alongside busy streets, however, even when controlling for adjacency to the streets themselves. On-street bicycle lanes have no significant effect in the city. The possible reason for this is that in general, the nature of on-street facilities differs considerably between Minneapolis and St. Paul.[xxv]

As in the city, suburban homes near roadside trails sell for less than those further away, even when controlling for busy streets. The same is true for on-street bicycle lanes, for which there was not statistically significant effect in the city. Suburban off-street trails appear to negatively influence home prices, unlike in the city. There are possibly several reasons for this. First, it may be the case that because of decreased cycling use, suburbanites simply do not value access to trails. Such proximity may not even factor into their use or option value of their home purchase locations. Second, counteracting phenomena may be taking place. Some suburbanites may indeed value such trails. However, their preferences may be overshadowed by a combination of the following factors. Some of the suburban trails are along former railway beds. If these property values were formally depressed because of such an externality, such legacy effect may likely still be in effect. Uncertainty surrounding future uses of such corridors, such as commuter rail, could compound any legacy affect. Snowmobiling introduces additional externalities common to exurban trails. Most notable, many suburbanites simply appreciate the seclusion of their settings. Proximity to trails—no matter their character—may be an indication of unwanted people passing by or other symptoms that run counter to factors that prompted their decision. One need only refer to several newspaper headlines (Figure 23) to learn of instances in which suburbanites oppose nearby trails.

Similar analysis employing measures of the density of bicycle facilities did not reveal statistically significant findings in any of the models estimated.

Because the policy variables of interest and the dependent variable are logged, the coefficients can be directly interpreted as elasticities. However, we provide the results of an effect analysis to more concretely estimate values. In Table 27 the last two columns present the effect of moving a median-priced home 400 meters closer to each facility than the median distance, all else constant.[xxvi] We find that in the city, the effect of moving a median-priced home 400 meters closer to a roadside bicycle trail reduces the sale price $2,272. Assuming a home was 400 meters closer to a non-roadside trail would net $510. While all relationships between bicycle facility proximity and home

Lake Sammamish rails-to-trails vision:
'One person's dream, another's nightmare'

7-year property-rights battle grinds on over cross-state pathway for hiking and biking

Trail's Appeal Is Lost on Some

Neighbors: Not in Our Back Yards

By Jennifer Lenhart
Washington Post Staff Writer

A special meeting on Leesburg's long-proposed bicycle-trail network Wednesday attracted more than 150 residents, all of them glad for a gathering devoted solely to airing their views in opposition or support.

ty, one robbery and five arrests for drinking in public. Townwide, the department tracked 104 narcotics violations, 311 citations for destruction of property, 13 robberies and 257 arrests for drinking in public, Price said.

Given that comparison, Price said he decided not to assign two officers exclusively to the trail. "I

Thursday, August 26, 2004 — The Boston Globe — Globe West 9

Friends, foes of Nobscot rail trail take up sides

Supporters say fears unfounded

The Seattle Times, Nov. 1, 2003. P. 1A. Lake Sammamish rails-to-trails vision: 'One person 's dream, another's nightmare.'"
The Boston Globe, Aug. 26, 2004. Globe West P. 9. "Friends, foes of Nobscot rail trail take up sides."
The Washington Post, June 10, 2001. Loudoun Extra P. 5. "Trail's appeal is lost on some; Neighbors: not in our back yards."

Figure 23. Newspaper headlines showing suburban trail opposition.

sale prices are negative in the suburbs, the effect analysis shows significant variation in the magnitude of those relationships. The effects of moving a suburban home 400 meters closer to a roadside bicycle trail is −$1,059 compared with only −$240 for a non-roadside trail.

CONCLUSION AND FUTURE RESEARCH

There are several important implications for our results which confirm the hypothesis that the three types of trails influence home sale prices in different ways. They demonstrate the importance of controlling for bias induced by omitted spatial variables. Such bias is especially relevant for large complex and polycentric housing markets (such as in the Twin Cities, with two CBDs) and in areas where factors that influence home price differ tremendously by neighborhood. We use local neighborhood fixed effects to reduce spatial autocorrelation and also lead to more robust coefficient estimates. Of course, using this methodology—while technically sound and robust—also makes it more difficult to detect the effects of such proximity because we are now comparing homes within MLS areas.

Our results are also able to robustly test for the fact that urbanites and suburbanites perceive and value bicycle facilities differently. The use of interaction terms between city and suburb reveals this difference in preferences between city dwellers and suburbanites. We measure bicycle facilities in different ways. Distance to nearest facility is the measure discussed in detail above. Models that were estimated to examine the role of trail density did not produce statistically significant findings. The comprehensiveness of the Twin Cities' bicycle trails may contribute to a lack in variation among trail densities near homes.

Further refinements would enhance our approach to estimating the value of bicycle facilities. Introducing a stated preference element akin to Earnhart's (*232*) application could yield more robust estimates. Additional stratification of variables would also augment our understanding. We have divided bicycle trails into on-street, roadside and non-roadside facilities in the city and suburbs. Further data collection efforts aimed at identifying other differentiating characteristics among facilities, such as trail width and adjacent land cover, would allow the implementation of a hedonic travel cost model to place a value on such characteristics (*242*).

Assigning future benefits based on a hedonic model presents complications, as new environmental amenities can take years to capitalize into housing prices. Ridell (*243*) shows that cross-sectional studies may underestimate the benefits of these goods, and provides an approach for capturing delayed benefits. In addition to delayed benefits, future benefits also present an opportunity for refining model specification. Shonkweiler's (*244*) methodology accounts for the potential conversion of rural land to urban uses, revealing that this qualitative consideration reduces estimation error.

From a policy perspective, this research produces three important insights. First, type of trail matters. On-street trails and roadside trails may not be as appreciated as many city planners or policy officials think. Second, city residents have different preferences than suburban residents. Third, larger and more pressing factors are likely influencing residential location decisions. Using fixed effects detects such considerations in terms of neighborhood quality and character. Overall, our results suggest that off-street bicycle trails add value to home sale prices in the city, implying a contribution to social livability. No positive or significant relationship, however, is found for other types of facilities in either city or suburb. In fact, bicycle trails exhibit a disutility in suburban settings. This suggests that urban planners and advocates need to be aware of the consequences of providing for bicycle facilities, as the change in welfare is not necessarily positive for all homeowners.

APPENDIX I

FIELD TESTING

An important part of this project's outcome lies in its utility as a tool to assist the local community transportation planning process. Toward this end, the research team conducted field testing of the guidelines before general release to the public. This effort took place in two parallel tracks: one aimed at soliciting comments from the broad cycling community and another focused on communities with strong interest in testing and potentially using the guidelines.

Survey

Through field testing, our aim was to ensure that the guidelines provide a useful and easy-to-use tool that planners, engineers, and policymakers can use for making informed investment decisions. To accurately measure the degree to which the tool met this goal, the research team developed a survey that was distributed to all field testers (see Figure 24). The survey, in Microsoft® Word format, asks a series of questions about the tool's applicability, accuracy, ease of use, "look and feel," and other technical issues. Some questions asked for narrative responses, while others solicited numerical ratings to allow for quantitative analysis.

Track One: Public Testing

After testing the guidelines within the research team, the beta version was released for public field testing through email distribution lists and announcements at research presentations. Potential field testers were asked to apply the online tool to a planned or existing bicycle facility whenever possible, and provide comments using the survey.

The research team solicited field testing from the planning and cycling community through the following efforts:

- A presentation and announcement at the 2005 American Planning Association national conference in San Francisco in March
- A presentation and announcement at the University of Minnesota's 2005 Center for Transportation Studies annual conference in April
- A presentation and announcement at Boise State University's 2005 Community Bicycle Congress in May
- An email invitation to members of the Association of Pedestrian and Bicycle Professionals (APBP)
- An article in the April 22, 2005, edition of *Centerlines,* the newsletter of the National Center for Bicycling and Walking

To augment this "public" field testing track, the research team extended personal invitations to the following select group of bicycle planners and advocates to test and offer comments on the guidelines:

Planners

- Josh Lehman, Massachusetts State Bicycle Coordinator
- Randy Thoreson of the National Parks Service Rivers, Trails, and Conservation Assistance Program, St. Paul
- Tom Huber, State of Wisconsin Bicycle and Pedestrian Coordinator
- Charlotte Claybrooke, State of Washington Bicycle and Pedestrian Coordinator
- Drusilla van Hengel, Mobility Coordinator, City of Santa Barbara
- Paul Magarey, Chair, Australian Bicycle Council

Advocates

- Chuck Ayers, Cascade Bicycle Club
- Louise McGrody, Bicycle Alliance of Washington
- Peg Staeheli, SVR Design Company
- Emily Allen, Seattle Bicycle Advisory Board

These individuals were selected on the basis of referrals or because they represented geographic areas or communities that would likely have good use for the tool.

Active Communities / Transportation Research Group

Field Testing Survey for "Guidelines for Analysis of Investments in Bicycle Facilities (NCHRP Project 07-14)

Thank you for agreeing to pilot test the guidelines created for the above project. Doing so requires four steps.

1. Please familiarize yourself with the guidelines (http://www.bicyclinginfo.org/bikecost/)
2. Envision a possible bicycle facility in your community, or gather data from an existing facility, and apply them to the guidelines.
3. Compare your results with any cost or demand data you may have or evaluate the utility of the data output from the guidelines.
4. Please complete the below survey and provide us with valuable feedback

This form is available at: ________________web site here

APPLICABILITY

Please rate the degree to which any set of guidelines that loosely represent this tool advance the bicycle planning process. Select one...

Now, rate how well you think THIS TOOL serves its intended purpose. Select one...

Did the guidelines meet your expectations? Select one...
If not, in what manner?

In what way do the guidelines help investment decisions?

For each estimated benefit, please rate its ability to help guide facility investments:

Mobility	Select one...
Health	Select one...
Recreation	Select one...
Community Livability	Select one...
Externalities	Select one...

Which benefits do you feel need considerably more attention?

Were there benefits that were not captured by the guidelines?

When calculating facility costs, you were provided the option to enter user-specified values.
Please rate the extent to which this feature was useful: Select one...

Please continue on the next page...

Figure 24. Field testing survey.

Track Two: Active Living By Design Partnership Communities

The second track of field testing focused on a targeted list of bicycle planning professionals with a strong interest in testing and potentially using the guidelines. The goal was to receive detailed and substantive comments from geographically distributed communities where bicycle planning is a priority. Key to this effort was our partnership with Active Living By Design (ALBD), a $16.5 million national program of The Robert Wood Johnson Foundation (RWJF) and part of the University of North Carolina School of Public Health in Chapel Hill. As part of their aim, ALBD is providing $200,000 grants to community-oriented partnerships to develop and implement strategies that increase opportunities for and remove barriers to routine physical activity. Promoting bicycling is an important part of this aim as evidenced by the generous grant recently awarded by the RWJF to the League of American Bicyclists for the Bicycle Friendly Community Campaign. This is a national grassroots effort to increase the number of trips made by bike, promote physical fitness, and make communities more livable. The community partnerships to be selected for funding under ALBD were announced in the fall of 2003. Given that many of these communities have an interest in developing a stronger bicycling infrastructure, and that they have demonstrated a proven level of coordination, we saw these communities as ripe opportunities for field-testing the guidelines. An important consideration is that the chosen communities vary in their bicycling needs, capacities for change, and size. This strategy represents a creative way to mobi-

ACCURACY	
Assuming you are able to compare to existing data:	
What was the total facility cost projected by the guidelines?	$
What was the actual cost of your facility (if known)?	$
If you have cyclist counts for your existing facility, please comment on the accuracy of the guidelines' demand estimates:	
EASE OF USE	
Please rate the guidelines' ease of use a scale of 1 to 10: Select one...	
Please rate the effectiveness of the Bicyclopedia and "i" buttons: Select one...	
How clear were the instructions? Select one...	
What needed to be clearer?	
What improvements would make the guidelines easier to use?	
Please list any data that were difficult to locate (for example, household densities, median home sale price, bicycle commute share):	
BUGS	
Keep in mind that this product is a beta version. Please provide us with detailed description of any errors that you encountered.	

Please continue on the next page...

Figure 24. (Cont.)

lize efforts around our central aim—understanding how to make best use of funds.

The research team recruited three ALBD partnership communities to pilot test the guidelines: Seattle, Somerville, and Chapel Hill. These cities represent a variety of geographic settings, each providing a different bicycle planning context (Table 28).

The combined efforts of tracks 1 and 2 produced responses from the following individuals:

Active Living By Design Partnership Communities

- Steve Winslow, Somerville Massachusetts Bicycle and Pedestrian Coordinator
- David Bonk, Senior Transportation Planner, Town of Chapel Hill
- Gordon Sutherland, Principal Long Range Planner, Town of Chapel Hill
- Ned Conroy, Principal Planner, Puget Sound Regional Council

Solicited Individuals

- Randy Thoreson of the National Parks Service Rivers, Trails, and Conservation Assistance Program, St. Paul
- Tom Huber, State of Wisconsin Bicycle and Pedestrian Coordinator
- Josh Lehman, Massachusetts State Bicycle Coordinator
- Charlotte Claybrooke, State of Washington Bicycle and Pedestrian Coordinator
- Drusilla van Hengel, Mobility Coordinator, City of Santa Barbara

Responses from General Announcements

- Jennifer Toole, Toole Design Group
- Anne Lusk, Harvard School of Public Health
- Jim Coppock, City of Cincinnati
- Heath Maddox, Associate Transportation Planner, City of Berkeley
- Andriana McMullen, Capital Regional District, British Columbia

Internal Research Team

- David Loutzenheiser, Planners Collaborative
- Don Kidston, Planners Collaborative
- Bill Hunter, UNC Highway Safety Research Center
- Libby Thomas, UNC Highway Safety Research Center
- Gary Barnes, Active Communities Transportation (ACT) Research Group, University of Minnesota
- Gavin Poindexter, Active Communities Transportation (ACT) Research Group, University of Minnesota

TABLE 28 Active Living By Design, field testing locations

U.S. Region / Community		*Setting*	*Proposed Project or Specific Facility*
West Coast	Seattle, Washington	Population: 563,000 Five neighborhood project areas are more ethnically diverse than Seattle, with Asians constituting between 12% and 51%, and African Americans representing between 5% and 29% of the population.	A vigorous mapping process in five Seattle neighborhoods will involve neighbors of all ages and ethnicities to make the places they live and work more walkable and bike friendly. An annual neighborhood map will be published, promoting neighborhood assets and promoting the pleasures and benefits of creating a good, safe walking environment.
East Coast	Somerville, Massachusetts	Population: 77,000 More than 50 languages are spoken in this city, which has two distinct faces; the wealthy west, where many professionals moved following the development of the Davis Square subway in 1986; and the east, which retains a largely blue-collar immigrant character with recent arrivals from Central and South America, South Asia, Africa, and the Caribbean.	The project features completing the Somerville Community Path and bringing its physical activity benefits to the lower income communities in East Somerville. Innovative activities include distributing an "Active Living Welcome Package" (including a public transit map) to new residents, conducting physical activity audits in neighborhoods, engaging community members in mapping workshops, and making sure Active Living resources (e.g., bike paths and subway stops) appear correctly on mainstream city maps. In cooperation with realtors, the group will work to allow homebuyers to preview their commute options, based on each house they are considering. Policy change will leverage existing Safe Routes to School efforts, greening projects and master planning work to establish secure, attractive walking corridors. The Somerville Community path runs through a low-income area of high population density, racial and ethnic diversity.
South	Chapel Hill, NC	Population: 50,000 Home of the University of North Carolina—Chapel Hill (UNC); the campus has 26,000 students and 10,000 employees	The partnership will promote active living in neighborhoods, schools, and along a major transportation corridor in Chapel Hill. Specific tactics to promote active living will include: a citizen assessment of environmental supports for active living in a low income neighborhood; Safe Routes to School programming; pedestrian/bicycle/transit assessment of a major town transportation corridor (Airport Road); strengthening transit/active living linkages through bus promotions; and utilizing an existing employer incentive program to promote multi-modal commuting options.

- David Levinson, Associate Professor of Civil Engineering, University of Minnesota

Comments

Comments received via the online survey generally fit four categories. First, several comments pointed out technical bugs in the tool. Second, a substantial number of comments related to ease of use, providing the research team with opportunities to improve the user experience. A third body of comments pointed out specific inaccuracies in methodology, cost estimates, and glossary items. Finally, a number of respondents offered broad methodological comments that could be incorporated into future research.

The following outlines the range of comments that the research team was able to address through changes to the guidelines.

Technical Bugs

- Pressing the “back” button results in an error message.
- In the cost sheet, the numbers in the “Itemized costs” field do not always fit in the allotted space.
- Cost items 4.03 and 4.04 are not calculating correctly.

- Entering median home sale price with a comma ($150,000) results in an error message.
- Entering persons per household with a decimal point (3.2) results in an error message.
- The Community Livability and Externalities benefits do not always appear in the final output page.
- The facility length entered in the cost sheet does not always transfer to the demand and benefits calculations.

Ease of Use

- Include a disclaimer at the beginning of the tool that informs the user about the relative accuracy of the estimates.
- Include an executive summary of the 150-page research report.
- Cost sheet headings should remain static when scrolling down.
- Include instructions on how to use the cost sheet.
- It is unclear which fields in the cost sheet are changeable.
- The heading in the cost sheet called "Base Year" is difficult to understand. It should be called "User-specified unit cost."
- The outputs of the tool should be better formatted and clearly interpreted for the user.

Inaccuracies

- In the glossary, the same photograph is used for bicycle symbol, bicycle arrow, and sharrow.
- Spelling error on Demand Step 1: "Metro are" should be "Metro area."
- Some metro area names on the first input page do not match the metro area names in other parts of the tool.

The following comments for the previous three categories could not be addressed because of technical feasibility and time constraints:

- An option should be provided to save your work partway through the process.
- The option to export the cost sheet to Excel should produce a better-formatted document.
- Users should have the option to use the tool in either metric or English units.

Future Research Possibilities (outside scope of immediate project)

In addition to issues that were impractical to address because of resource constraints, other comments offered ideas that were beyond the research scope of this project but should be considered for future study:

- Costs and benefits should include information about safety in terms of crashes.
- A facility's connection to transit should be considered in the demand model.
- Facility connectivity to schools should be considered in the demand model.
- The manner in which traffic volume, hazards, topography, intersections, and vehicle speed would influence demand.

APPENDIX J

PRIMER ON DESIGNING BICYCLE FACILITIES

When considering, planning, or constructing a bike facility, the first step is to identify the project scope. As more detailed information becomes available on site limitations, construction cost, and funding project impacts, the scope will be refined through the design development process. Basic considerations in defining the scope are facility type (on-street, off-street, equipment), paving, drainage, structures, and design guidelines used to identify dimensions such as width of paths. The following text provides some basics in identifying the project scope.

When developing the cost of on-street bicycle facilities and shared use paths, the user will need to know how to select construction materials, recommend dimensions, and decide on a path surface. The following is a primer for design consideration of bicycle facilities. Pavement design focuses primarily on shared use paths and other off-street facilities. Bicycle facilities on roadways are considered to be a minor part of the structural design of the roadway and are therefore not included as part of the primer. This primer should be used in conjunction with the 1999 AASHTO Guide for the Development of Bicycle Facilities.

On-Street Facility

On-street facilities consist primarily of paved shoulders, wide curb lanes, and bike lanes. All are part of the roadway surface that is also used by motor vehicles. Structural requirements of the road bed including pavement depth are dictated by motor vehicles:

Paved Shoulders

Critical dimensions

- Less than 4 feet (1.2 m): any additional width of paved shoulder is preferred than no facility at all, but below 4 feet a shoulder should not be designated or marked as a bicycle facility
- 4 feet (1.2 m): minimum width to accommodate bicycle travel measurement must be of useable width and should NOT include the gutter pan or any area treated with rumble strips
- 5 feet (1.5 m) or more: minimum width recommended from the face of a guardrail, curb or other barrier

Widths should be increased with higher bicycle use, motor vehicle speeds above 50 mi/hr, and higher percentage of truck and bus traffic.

Wide Outside Lanes

Critical dimensions

- 14 feet (4.2 m): recommended width for wide outside lane width must be useable and measurement should be from the edge line or joint of the gutter pan to the lane line
- 15 feet (4.5 m): preferred where extra space required for maneuvering (e.g., on steep grades) or to keep clear of on-street parking or other obstacles

Continuous stretches of lane 15 feet (4.5 m) or wider may encourage the undesirable operation of two motor vehicles in one lane. Where this much width is available, it is recommended to more seriously consider striping bike lanes or shoulders.

Bicycle Lanes

Critical dimensions

Bicycle lane width

- 4 feet (1.2 m): minimum width of bike lane on roadways with no curb and gutter
- 5 feet (1.5 m): minimum width of bike lane when adjacent to parking, from the face of the curb or guardrail
- 11 feet (3.3 m): shared bike lane and parking area, no curb face
- 12 feet (3.6 m): shared bike lane and parking area with a curb face

Bicycle lane stripe width

- 6-inch (150 mm): solid white line separating bike lane from motor vehicle lane (maybe raised to 8-inches (200 mm) for emphasis)
- 4-inch (100 mm): optional solid white line separating the bike lane from parking spaces

Off-Street Facility (typically shared use paths)

Standards recommend the width be 10 feet or 3 meters for a two-way, shared use path on a separate right of way. Other critical measurements include the following:

- 8 feet (2.4 m) may be used where bicycle traffic is expected to be low at all times, pedestrian use is only occasional, sightlines are good, passing opportunities are provided, and maintenance vehicles will not destroy the edge of the trail
- 12 feet is recommended where substantial use by bicycles, joggers, skaters, and pedestrians is expected, and where grades are steep
- 2 feet of graded area should be maintained adjacent to both sides of the path
- 3 feet of clear distance should be maintained between the edge of the trail and trees, poles, walls, fences, guardrails or other lateral obstructions
- 8 feet of vertical clearance to obstructions should be maintained; rising to 10 feet in tunnels and where maintenance and emergency vehicles must operate

Drainage

The AASHTO Guide recommends a cross slope of 2%. The following are considerations to ensure adequate drainage:

- Slope the trail in one direction rather than having a crown in the middle of the trail
- Provide a smooth surface to prevent ponding and ice formation
- Place a ditch on the upside of a trail constructed on the side of a hill
- Place drainage grates, utility covers, etc., out of the travel path of bicyclists
- Preserve natural ground cover adjacent to the trail to inhibit erosion
- Include price of seeding, mulching, and sodding of slopes, swales, and other erodible areas in the cost

Proper drainage is one of the most important factors affecting pavement performance. Proper drainage entails efficient removal of excess water from the trail. Surface water runoff should be handled using swales, ditches, and sheet flow. Catch basins, drain inlets, culverts and underground piping may also be necessary. These structures should be located off the pavement structure.

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation