Estimating Bicycling and Walking for Planning and Project Development: A Guidebook

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Nanda S. Srinivasan
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This guidebook contains methods and tools for practitioners to estimate bicycling and walking demand as part of regional-, corridor-, or project-level analyses. The methods are sensitive to key planning factors, including bicycle and pedestrian infrastructure, land use and urban design, topography, and sociodemographic characteristics. The planning tools presented in this guidebook include some entirely new methods as well as some existing methods found to have useful properties for particular applications. The tools take advantage of existing data and the capabilities present in GIS methods to create realistic measures of accessibility which are a critical determinant of bicycle, pedestrian, and even transit mode choice. The guidebook should be of considerable value to transportation practitioners either directly interested in forecasting bicycling or walking activity levels or accounting for the impact of bicycle or pedestrian activity in support of broader transportation and land use planning issues.

The need for robust methods that can accurately measure bicycle and walking activity has long been recognized, particularly in relation to land use. Many planning agencies are trying to assess the potential for smart growth and other land use options to increase bicycling and walking and reduce motor vehicle use. Existing national data sources document a particular segment of bicycling or walking trips (e.g., U.S. Census Journey-to-Work data) or document all bicycling or walking trips at large-scale geography such as state or aggregations of metropolitan areas (e.g., the National Household Travel Survey or other household travel surveys). However, there was a lack of consistent methods to understand bicycling and walking activity, and relationships to demographic, social, and physical factors were not well understood. Consistent methods and credible data were needed to enhance local and regional planning to evaluate bicycle and pedestrian needs. NCHRP Project 08-78, "Estimating Bicycling and Walking for Planning and Project Development," was conceived to fill this gap. NCHRP Project 08-78 addresses robust methods to accurately estimate bicycle and walking activity, both to account for the role of non-motorized travel in coordinated transportation/land use planning and to support design and prioritization of pedestrian and bicycle facilities and systems.

The research was performed by Richard Kuzmyak of Renaissance Planning Group in association with Fehr & Peers; Keith Lawton Consulting, Inc.; Mark Bradley Research and Consulting; John Bowman Research & Consulting; Richard H. Pratt, Consultant, Inc.; University of Texas at Austin; and NuStats. Information was gathered via literature review and interviews with practitioners. The products of the research include a guidebook for practitioners on a range of methods for estimating bicycling and walking activity and *CRP-CD-148* containing a GIS Walk Accessibility Model, spreadsheets, and the contractor's final report, which documents the research and tools that operationalize the methods described in the guidebook.

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SUMMARY

Estimating Bicycling and Walking for Planning and Project Development: A Guidebook

This guidebook is the product of NCHRP Project 08-78, a multi-year research project tasked with developing improved methods for estimating bicycling and walking for planning and project development. The project was in response to widely acknowledged needs for more robust and responsive analytic tools to support bicycle and pedestrian planning. These needs range from more realistic accounting for non-motorized travel in regional planning to the design of mixed-use communities and multimodal corridors and, ultimately, to the design of efficient and safe non-motorized travel networks and individual facilities.

Despite steadily growing interest in non-motorized travel, not only as serious transportation modes unto themselves but because of the strong supporting role they play in the viability of transit and compact mixed-use development concepts, planning and analysis tools have not kept pace with demand. Although there has been considerable research on key factor relationships, this body of knowledge has not made its way into conventional practice. The goal of NCHRP Project 08-78 was to assess this knowledge, identify major gaps, and attempt to transform key lessons into serviceable planning tools.

Planners and analysts have been seeking ways to address the following issues:

- How to predict whether a person will choose walking or biking as travel mode.
- How important the traveler's sociodemographic characteristics (e.g., age, gender, income, education, and vehicle ownership) are in this decision versus other factors in the environment.
- The relative appeal of walking or biking for particular trip purposes (e.g., travel to work/school versus shopping, personal business, social activities, or recreation).
- The degree to which travelers will choose to travel to a local opportunity by walking or biking versus driving to a more remote opportunity, and the effect of that choice on vehicle trip generation and vehicle miles of travel (VMT).
- The role of non-motorized travel in the viability of compact, mixed-use (smart growth) development designs and transit-oriented development.
- The importance of non-motorized access (at both trip ends) in the viability of transit.
- The influence of non-motorized travel opportunities at the destination end of a trip in determining the mode that will be used for the initial trip (e.g., travel to work, shopping).
- Determining the types and location of improvements to a bicycle or pedestrian network that will produce the greatest overall benefits.

Current analytic options for estimating bicycle or pedestrian travel demand tend to fall into one of the following two categories:

- Regional travel forecasting tools, such as are used by metropolitan planning organizations (MPOs), which are thorough but operate at a level of aggregation (traffic analysis zones [TAZs]) incompatible with the scale of non-motorized travel.

- Facility-demand models, which are constructed to directly explain count-based levels of user activity at intersections or on links through association with descriptive measures of the local environment.

Given that neither group of tools addresses the types of planning and decision-making concerns listed above, NCHRP Project 08-78 was undertaken to provide such information.

A thorough review of research and empirical findings on bicycle and pedestrian travel highlighted the importance of the following characteristics and factor relationships when attempting to explain or forecast non-motorized travel demand:

- Recognizing an obvious but critical *difference between biking and walking:* although both are non-motorized modes and often combined as such in regional models, the distance range (0.7 mile average trip length for walk, 2.3 miles for bike), network needs, user characteristics, and trip purpose types are substantially different between the two modes.
- The relationship between the *built environment* (land use) and *travel network* are extremely important, particularly for walking and biking. Walking and biking demand levels are heavily predicated on the number and variety of opportunities accessible within comfortable travel distance/time envelopes.
- *Acceptable trip distances* vary by trip purpose: travelers seem more willing to travel longer distances for trips to work (about 1 mile for pedestrians, 4 miles for cyclists) than for personal business, shopping, or socializing (0.5 to 0.7 miles for pedestrians, 1.0 to 1.5 miles for cyclists).
- Persons living in more compact, mixed-use settings tend to make more trips as *simple tours* (single-purpose one-stop journeys), while those in automobile-oriented settings make more multi-stop *complex tours;* the choice of walk, bike and transit as modes was found to be much more likely with simple tours.
- The *natural environment* is of much greater consequence to non-motorized travelers than those traveling by automobile or transit: steep hills and topography that causes circuity in travel paths are barriers. Extremes in temperature, precipitation, and hours of daylight affect proclivity to walk or bike.
- *Personal safety* is a major concern to non-motorized travelers, particularly in relation to exposure to motor vehicle traffic. In areas with higher traffic volumes or higher speeds, as in commercial areas, sidewalks and separated paths become more important considerations in the decision to walk or bike.
- *Sociodemographic differences* are observed between motorized and non-motorized travelers, and between pedestrians and cyclists. In general, walking and biking rates peak in the youngest years, and then tail off with advancing age, although this is a trend more common in the United States than in other peer (western) countries. Although a somewhat higher percentage of women over 25 walk than men, male cyclists outnumber females by almost four to one (again a trend highly indigenous to the United States).

Extensive review of these factor relationships suggested a fairly complex set of decisions being made concurrently, involving multiple factors and tradeoffs, with most being highly location specific. To account for these interrelationships in a way that captures their importance to non-motorized travel and to make them accessible to planners as parameters in a planning analysis, a choice-based modeling framework was necessary. Choice-based implies that the travel behavior is the result of logical decision-making in which the traveler chooses rationally from a set of alternative modes and destinations in relation to the purpose of the trip, the array of mode and destination choices available in the particular environment, the sociodemographics of the traveler, and the intangibles of attitudes and preferences that are part of any framework that attempts to quantify human behavior.

The key challenges in devising such an approach were as follows:

- Operating at a spatial scale fine enough to articulate the factors and conditions affecting pedestrian and bicycle travel opportunities and comparison of alternatives.
- Directly accounting for the interplay between the shape of the built environment (e.g., number, type, and mix of activities) and the decision to walk or bike.
- Accounting for the quality and accessibility of the bicycle and pedestrian travel networks, including differences in utility of travel on specific links across the networks based on physical characteristics (e.g., facility type, separation from traffic, crossings, and slope/gradient).
- Representing mode and destination choices from the perspective of the individual traveler, rather than as spatial aggregations of households in traffic analysis zones (TAZs).
- Accounting for destination and mode as simultaneous choices.
- Translating bicycle and pedestrian trip generation into trip flows and assigning those flows to the travel networks to produce estimates of demand at a facility level.

A recurrent theme in the methods developed or adopted by the research team and included in the guidebook is "accessibility." A central premise in a choice-based analytic framework is that alternatives are evaluated in relation to the "utility" they represent to their travelers. Accessibility is an effective measure of utility—it enumerates the opportunities of a particular type (e.g., employment, retail, and health care) available to the traveler by a given mode. What makes accessibility a particularly useful measure is that it reflects both the activities available in the given land use patterns and the ease with which those activities can be reached over the respective modal travel network. Building models around the concept of accessibility provides a solid basis for explaining choice behavior and its inclusion in travel demand models enables planners to investigate both land use and transportation facility factors.

Another element common to the NCHRP Project 08-78 planning methods was the use of geographic information systems (GIS). To measure accessibility for non-motorized travel modes, it is critical to push the level of geospatial resolution to a finer level than is present in TAZ models. The advancement of GIS tools and data has made it possible to create this fine-grained resolution and bring the necessary detail into such planning. Each method in the guidebook relies on GIS to some degree, which may be the principal technological factor enabling the analysis of bicycle and pedestrian behavior.

The planning tools in this guidebook include entirely new methods, as well as existing methods found to have useful properties for particular applications. The tools developed as part of NCHRP Project 08-78 are as follows:

- **Tour-Generation and Mode-Split Models:** In conjunction with the Puget Sound Council of Governments' efforts to develop a new tour-based model structure for the Seattle region, research team members took advantage of new data and tools to develop a set of pedestrian and bicycle models, including a procedure for generating tours (as opposed to trips) by purpose, and a pair of modal-split models that predict walk, bike, transit, and automobile choice for five tour purposes. The variables included in these models provide access to a broad spectrum of sociodemographic, land use, and transportation network characteristics, and accessibility in estimating (separately) bicycle and pedestrian demand, as well as the effect on transit use of non-motorized accessibility. Although immediately suited to use in an activity- or tour-based environment, the methods may also be used to enhance conventional trip-based models, and a *spreadsheet version* of the model (available on *CRP-CD-148*) can be used for simultaneous testing of any of the relationships in the models or for creating sketch-planning tools.

- **GIS-Based Walk-Accessibility Model:** Using data from the Metropolitan Washington (DC) Council of Governments (MWCOG) for Arlington County, VA, the research team developed a method for estimating walk trip generation and mode split that relies exclusively on GIS tools and data. The method uses geospatial overlay and network path-building procedures that are readily available in GIS to calculate measures of accessibility to or from any point by any mode and by type of attraction. The measures are similar to the popular Walk Score, but much more comprehensive in their calculation. By comparing the modal accessibilities, the model can estimate mode split and create walk trip tables by purpose. The current model does not perform network assignment of the walk trips; however, users probably can apply such features in their existing transportation planning software to do so. Because of insufficient data, the current model does not forecast bicycle demand, although the structure will readily accommodate such an enhancement when adequate data are available. This approach offers a new and intuitive way of interpreting modal choice that is responsive to changes in the built environment (land use) or the travel networks such as would occur in corridor or subarea planning, using generally available data and with relative independence from the respective regional travel model.
- **Enhancements to Trip-Based Models:** Research team members also used the Seattle Puget Sound Regional Council (PSRC) data to create a template for systematically enhancing a conventional TAZ/trip-based regional model to improve its sensitivity to land use and non-motorized travel. Advanced statistical methods were used to create enhancements to the Auto Ownership, Trip Generation, Trip Distribution, and mode-choice steps in the existing PSRC regional model. Measures of automobile and non-motorized accessibility play a major role in these enhancements. Although pedestrian and bicycle mode choice are still constrained by the TAZ structure, the methods improve on the current process by introducing a "pre-mode split" step, which first divides trips into intra- versus inter-zonal groups, and then performs a mode-split step specific to those groups. Although the enhanced regional model may not be as fluid as the tour-based or GIS-accessibility approaches in overcoming TAZ aggregation issues, it takes advantage of the new smaller TAZs adopted by many metropolitan planning organizations (MPOs) and provides considerably more sensitivity in existing models.

In addition to the tools developed directly by the NCHRP Project 08-78 research team, other tools, identified from existing practice, were found to merit inclusion in the guidebook. These are as follows:

- **Walk Trip Generation and Flow Models:** The PedContext and MoPeD models developed through the University of Maryland's National Center for Smart Growth offer a method for estimating walking trips and facility volumes at a subarea or neighborhood level. Both methods follow a variation of the four-step process, but operate at a much finer level of spatial resolution–block-size pedestrian analysis zones (PAZs). Both methods generate estimates of pedestrian productions and attractions, create walk trip tables through a trip distribution process, and then assign the walk trips to the local walk network to estimate link and intersection activity levels. The difference in the methods is the degree of detail (e.g., trip purposes, equations, and assignment), with MoPeD being the less detailed of the two. Also, MoPeD uses open-source software, while PedContext is not fully open-source. The limitation of both tools is that they only generate walk trips and do not estimate effects on overall trip generation and mode choice—unlike the new GIS Walk-Accessibility model.
- **Portland Pedestrian Model:** A third (and fairly recent) pedestrian demand estimation model is included in the guidebook because it is an interesting hybrid of the PedContext/

MoPeD models and the Seattle trip-based model enhancements. The procedure was developed by Portland State University for Metro, the Portland, Oregon, MPO, to improve the pedestrian mode-choice capabilities in Metro's existing trip-based model. The resulting procedure can either be used as an enhancement to the regional model or a stand-alone pedestrian planning tool. This model also uses PAZs as the analysis unit and estimates walk trip productions by purpose for each PAZ. Productions are not converted to trips through conventional trip distribution, but through use of Metro's destination choice model. The trip tables thus formed can be reconstituted and used to adjust the motorized trip tables generated at the TAZ level. In addition to accessibility, a key role in trip generation is a "pedestrian index of the environment" (PIE) which shows good sensitivity in differentiating areas by their land use and accessibility characteristics relevant to walking.

- **Facility Demand:** Two very different types of models are presented in this category: route choice and direct demand.

  The *route choice* models apply solely to bicycle use and consist of tools developed by the San Francisco County Transportation Authority and Portland State University, both using GPS data collection methods to track bicycle trip-making. These data were then analyzed to determine the importance of factors such as type of facility, slope/gradient, directness, and exposure to traffic. Neither method predicts overall bicycle travel demand, but both methods offer insight on how travelers value these physical characteristics when choosing a route—information that is important in network design and in calculating accessibility.

  The *direct demand* models predict walk or bike facility use and volumes based on observed counts and context-driven regression models. The examples presented are taken from the City of Santa Monica (developed by Fehr and Peers) and San Diego, the result of the Caltrans-sponsored Seamless Travel Study performed by Alta Planning & Design and the University of California at Berkeley's Traffic Safety Center.

  Network simulation was reviewed in the form of the Space Syntax model, but is not included in the recommended tools because it is proprietary and, hence, it was also difficult to be precise about how the models work. However, the approach is described in the guidebook and in the final report, including example applications in Oakland, California (pedestrian) and Cambridge, Massachusetts (bicycle) for those wishing to pursue this approach further.

The guidebook describes each model in sufficient detail to convey a basic understanding of structure, key characteristics and variable relationships, strengths, and appropriate uses. Users then have guidance on comparing and choosing among the methods in relation to respective planning application needs and available resources. For the three new methods, step-by-step instructions are provided on how to adapt and use the tools, with options ranging from replication with local data to selective application with existing tools, and even use of elasticities for factoring and sketch-planning approaches.

The two special *spreadsheet versions of the tour-based and the walk-accessibility models* (available on *CRP-CD-148*) are expected to be among the most popular products of the research and the guidebook. The tour-based model spreadsheet allows the user to perform sensitivity analyses of a wide range of variables found to affect pedestrian and bicycle demand, including the following:

- Traveler characteristics: age, gender, work/student status, income, vehicle ownership and competition, children.
- Accessibility: attractions of a given type (employment, schools, retail, food service, entertainment/recreation) within 1 mile (walk), 2 miles (bike) or regionally (all modes).
- Land use: household or employment density, mix of uses (entropy), intersection density, transit stop density, distance to nearest transit stop.

- Transportation: mode-specific network distance/travel time for walk & bike, slope/gradient, sidewalk coverage, Class 1 or Class 2 bikeway coverage and directional efficiency (turns per mile, one-way streets), auto travel time and parking cost, transit in and out-of-vehicle time and fare.

Base data are provided for each of the models in the spreadsheet, allowing the user to test assumptions involving any of the above variables—individually or in any simultaneous combination—and instantly see the effect on trip (tour) generation and mode-split for any of five different trip purposes.

The walk-accessibility model spreadsheet also provides ready access for various users and use applications, with sample data and scenarios supplied. To apply the spreadsheet to one's own situation, however, will require technical ability to create the various relationships in GIS, as well as access to basic land use and transportation network information. None of these skills or data requirements is outside what might be expected in a modern planning agency. Individual or small agency users will either need to possess the skills and data to set up the model or will need to collaborate with a larger planning entity (e.g., an MPO) to assist with some of the technical procedures.

The guidebook is more limited in its accommodation of bicycle travel. The Seattle tour-based model includes bicycle as a separate mode throughout its structure and thus provides access to variables important to bicycle planning practitioners (e.g., transportation facility characteristics and network performance). The Seattle-derived trip-based model enhancements methods also incorporate bike throughout their structure, albeit at a TAZ level of aggregation, but they provide practical utility for a range of analytic uses and users. The other models featured in the guidebook are limited to pedestrian travel, either by original design or limitations in data. The walk-accessibility model developed from Arlington, Virginia, data could incorporate bicycle as a discrete modal choice, but would require a larger and more diverse sample of bicycle trips from travel surveys than was available to the research team.

It is hoped that this guidebook will provide major new capabilities to the planning and practitioner community, not only those specifically involved in bicycle and pedestrian planning but for land use/community planning, transit, policy evaluation and project prioritization. It is expected that this field of study will continue to evolve, and with it the capabilities of the modeling tools. This guidebook and the research will help existing practice and establish directions for future enhancement.

CHAPTER 1

Introduction

1.1 Purpose

This guidebook is designed to help transportation and community planners account more effectively for pedestrian and bicycle activity (demand) in plans and projects. As interest in promoting walking and bicycling has increased, so too has the awareness that the tools and data to support good planning and decision-making for these modes are very limiting. This guidebook is the product of NCHRP Project 08-78, which was specifically undertaken to address these deficiencies with more robust tools and methods so as to meet the needs of a growing and diversified body of practitioners and planning applications.

Non-motorized travel has garnered increased attention from the planning profession for various reasons:

- Continued growth in demand for highway travel unmet by expansions in capacity due to persistent funding limitations.
- Efforts to provide a greater number of meaningful transportation choices for more people.
- Concerns about the environmental implications of large-scale personal vehicle use, including greenhouse gas emissions and stormwater runoff from highway facilities.
- Growing interest in building sustainable, livable communities that rely heavily on walkable design.
- Value of walking and biking as "active" transportation modes in combating obesity and related health problems.
- Need for assistance in designing and prioritizing non-motorized transportation facilities.
- Direct relevance of walking and biking as key elements in supporting transit use and development concepts such as smart growth and transit-oriented development.

The tools and data available to address most of these issues have been very limited, both in number and sophistication—this makes it hard to identify the most cost- and demand-effective projects or to compete for funds with other modes. Perhaps more urgent, however, is the need to demonstrate the benefit potential of compact mixed-use development designs, including transit-oriented development, where higher densities require increased walking and biking for both access and circulation—and in effect, allowing these designs to function efficiently by reducing auto demand for travel to, from or within them.

The need for good analytic tools occurs at all geographic scales—from comprehensive state and regional plans and capital programs, to designing effective multimodal corridors, to evaluating alternative community and activity center designs, to evaluating individual bicycle and pedestrian projects. This guidebook offers tools and accompanying guidelines to address these key planning and decision-making concerns, with methods that range from very sophisticated and detailed models to very simple sketch-planning and elasticity techniques. The sections below give more information on what the guidebook contains, how it is structured, and how to use it.

1.2 Overview of Analytic Tools and Gaps

The tools and data available for bicycle and pedestrian planning are less detailed and sophisticated than those developed for motorized travel. Possible reasons for this include

- Highway and transit modes receive more attention because of (1) the scale of public investment involved in their construction and operation and (2) the many associated impacts that must be addressed as a result of the scale of such projects.
- Walking and bicycling are more difficult to model because they are at a different scale and have a much closer relationship with the nuances of land use than motorized modes.

The analytic tools available for bicycle or pedestrian planning fall into one of two broad categories:

- *Comprehensive four-step trip-based travel forecasting models*, such as have long been used for regional transportation planning. Because of their spatial aggregation into TAZs, these models lack the fine granularity necessary to capture the essence of non-motorized travel choice factors. In most cases, these models are used to estimate the total number of non-motorized trips that would be generated for each TAZ (bicycle and pedestrian are often combined), based on population and employment measures. These trips are then assumed to remain within the TAZ in which they originated, and so are effectively removed from further analysis in the destination and mode-choice steps. Hence, the non-motorized modes are never able to compete with motorized modes as travel choices (thereby allowing for modal substitution if there are attractive opportunities within walking or biking distance), which also limits the degree to which changes in land use or walk/bike network accessibility can influence non-motorized travel demand given that the relevant design characteristics would be lost within the aggregation of the zonal geography.

- *Facility demand type models*, which differ from the comprehensive models in being "count" based as opposed to "choice" based. A choice-based model attempts to estimate trip volumes through a series of steps meant to replicate the process of deliberately deciding among travel alternatives, whereas a count-based approach sidesteps that complexity by trying to directly explain the level of activity at a given location through an association with various measures of the local environment. Multiple regression is used to quantify the association, and both respectable R^2 values and good parameter statistics suggest that these models are effective in explaining levels of activity. However, because the models are created with highly aggregated data to represent both the dependent (counts) and independent (explanatory) variables, and the explanatory variables often have little direct "causal" relationship with the activity level, their reliability for forecasting often carries some doubt. Hence, their applicability is limited to the specific area for which they were developed and to the variables included in their structure.

Neither type of model was judged by the NCHRP Project 08-78 review as having the desired capability to link non-motorized travel behavior to the key underlying factors identified in research studies. These factors included the characteristics of the traveler, the shape of the travel environment in terms of the number and types of opportunities that would compel someone to walk or bike, and the degree to which the respective transportation networks provided access to those opportunities. Given the relatively short travel distance range associated with walking—and to a lesser extent, biking—the relationship between environment and behavior is much more elemental than it is with auto travel. Small differences in the composition of the built environment and how non-motorized travelers must interact with motor vehicle traffic have an important impact on the desirability of walking or biking. Designing effective environments or determining the most cost-beneficial facility improvements require the ability to quantify the interrelationship between the two.

The most effective way to quantify this set of relationships is through the measure of "accessibility." The concept of accessibility—the measure of the number and variety of opportunities made available in the given pattern of land use, coupled with the efficiency of the transportation network in reaching these opportunities—is fundamental to any travel decision, but it is particularly central to non-motorized travel. Any effort to improve the capability of bicycle and pedestrian planning tools would need to address the issue of accessibility directly.

How this concept manifests itself in non-motorized travel is presented in Figures 1-1 and 1-2. Figure 1-1 shows the diversity and distribution of land use/employment activities for Arlington County, Virginia—one of the project research test sites—while Figure 1-2 shows the network of travel facilities available to access those opportunities. The task is to merge the information in the two sources into measures that reflect the joint opportunity. If such a conjunction can be made for any point in the travel environment—a household, a work place—it is possible to evaluate each location's modal competitiveness in terms of its comparative accessibilities.

In terms of the relevance for planning tools, the ability to make this simultaneous connection allows planners to work with both halves of the planning equation. As shown in Figure 1-3, planners can affect accessibility by either modifying the location or mix of opportunities in the land use through the numerator (as in Figure 1-1), or enhancing the ability to access those opportunities by reducing travel time to reach them through enhancements to the travel network (as in Figure 1-2).

Steady advances in GIS methods have created new opportunities for building and working with these accessibility relationships. It is now possible to portray the environment in which travel occurs in much greater detail and with more realism. Rather than generalizing land use and travel at the level of TAZs, one can discern activities at a parcel-level of detail. Given that most of the data prepared for GIS manipulation is in the form of layers (represented as polygons, lines, or points), it is possible to share information between these layers through geospatial overlay methods and create relationships. Perhaps just as valuable, tools have been developed for GIS to perform unique analysis with this information (e.g., building a travel network and quantifying the access it provides to activities by building connecting paths).

Research on the relationship between land use and transportation has shown that built environments that feature shorter distances as a result of higher density, more attractive assortment of co-mingled land uses, safe and convenient

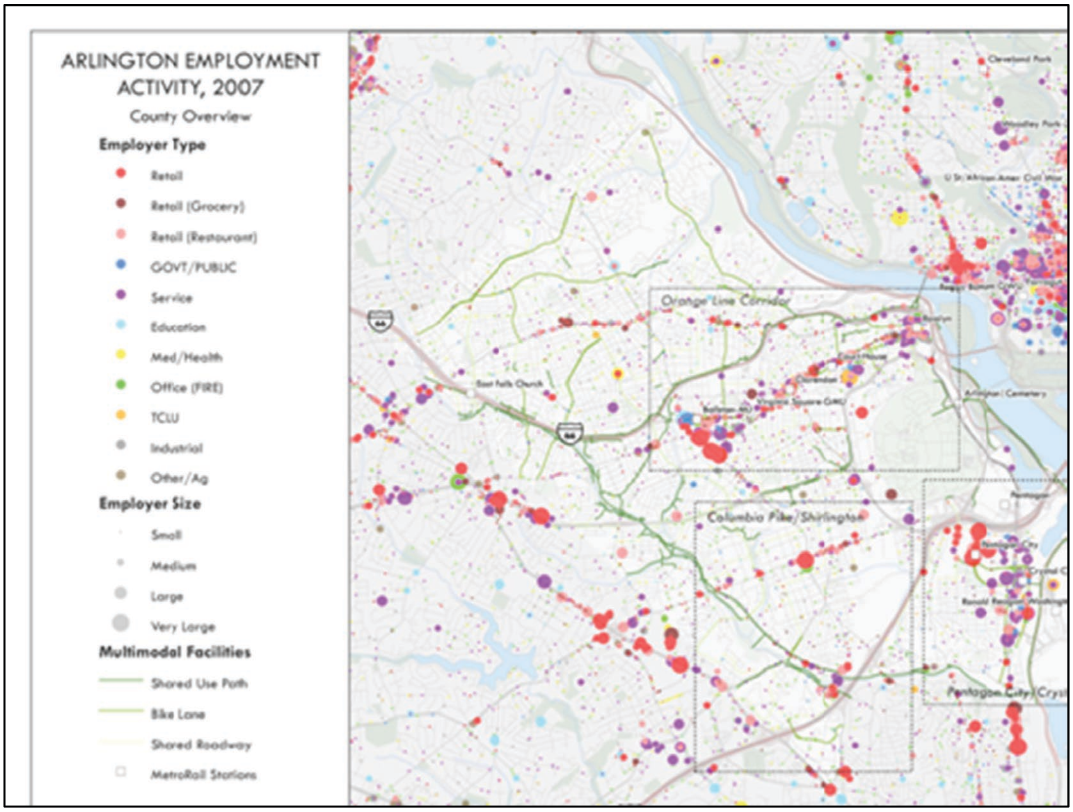


Figure 1-1. Location of employment activity in Arlington County.

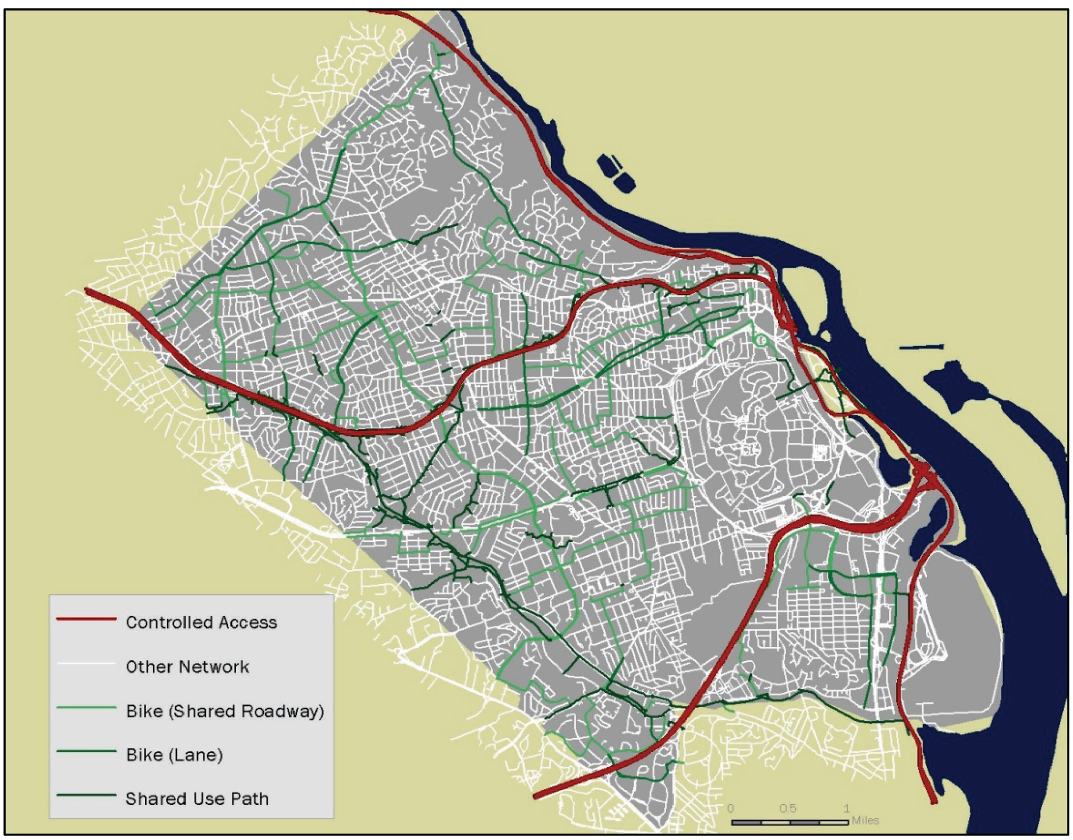


Figure 1-2. Bicycle and pedestrian networks in Arlington County.

Figure 1-3. Relating land use and network capability through accessibility.

facilities for non-motorized travel, and good regional accessibility afforded by transit have much more efficient travel patterns. Households of similar size and similar economic status in such compact, mixed-use areas own fewer cars and make fewer and shorter trips by car than households in suburban, auto-dependent subdivisions. This difference is because more of these trips are made internally, to local destinations, or because access to transit is very convenient. Similar results are seen in employment and activity centers, where employees or visitors are more likely to shop or conduct business internally if they can walk to nearby activities; people are also much more likely to take transit to these areas if they can function without an auto once at the site.

Another capability absent in available tools is user interaction. Historically, transportation models have been highly technical and complex, with little user-friendliness in set up, inserting assumptions, or interpreting output. These models have required unique expertise to set up and run, are particular about the strategies they can analyze, and take long computational periods to return answers. Although better software interfaces have made most models more approachable, increased application of GIS technology has resulted in greater visualization and, in the process, greater accessibility for both modeler and user audiences. It is now possible to visualize the planning environment through aerial maps, 3-D imagery, shadings, or graphics. This allows the user to "see" the planning environment and take part in the design of alternatives. The exercise facilitates better communication of results to stakeholders.

This guidebook presents methods that take maximum advantage of accessibility, visualization, and stakeholder participation.

1.3 Overview of the Research behind the Guidebook

Prior to preparing this guidebook, the NCHRP Project 08-78 research team performed an extensive review of the state of the practice in bicycle and pedestrian planning and demand forecasting methods. This review covered more than 20 years of research studies and reports, both domestic and international. The goal was to learn as much as possible about the factors influencing bicycle and pedestrian travel, including the following:

- Transportation infrastructure characteristics
- Land use and built-environment factors
- Topography
- Weather and climate
- Sociodemographic characteristics

As part of this review, planning tools and research models used to quantify these relationships were evaluated in terms of planning applications they were being used for, their data requirements, and their accuracy and realism. This review made it possible to isolate the factors of importance associated with bicycle and pedestrian travel and provide insights into their relative importance. Many of the studies were limited in important ways, most commonly by focusing on one particular aspect of the demand equation (e.g., bicycle route choice). Although each of these bodies of research helped sharpen the research team's understanding of particular factor relationships, no overarching effort to connect these pieces into a comprehensive framework for modeling non-motorized travel behavior was uncovered. Summaries of this background research and major findings are provided in Chapters 2 and 3 of the guidebook. Readers wishing to benefit more fully from this earlier research are encouraged to consult Appendices 4 through 8 of the Contractor's Final Report, which are available as part of *CRP-CD-148*.

Given the absence of a template connecting the identified key relationships, the research team sought to capture these relationships. This research was conducted in two different venues—Seattle and Washington, DC—taking advantage of what were judged the best combinations of available travel survey data, the ability to relate this information to walkable/bikeable environments, and excellent GIS tools and geospatial databases. Although the two research efforts used different methods, both were directly tied to the importance of accessibility, for both motorized and non-motorized modes.

The Tour-based Bicycle and Pedestrian Model developed in Seattle and the GIS-based Walk-Accessibility Model developed in the Arlington County, Virginia, portion of the Washington DC metro area, are new tools that should create opportunities for planning practitioners—both tools focused primarily on bicycle/pedestrian issues, as well as those more involved with comprehensive planning, land use, and multimodal transportation analysis. Both models use a choice-based structure to estimate trip generation and modal choice, but they do so in different ways. The Seattle approach uses the highly disaggregate methods employed in activity/tour-based modeling, which brings the choice to the level of the individual and articulates land use and network relationships at the parcel level of detail. Accessibilities are computed using the actual networks. The Arlington approach also uses the actual networks to compute accessibility to activities, but relies on GIS tools to create the paths and make the connections with the land use opportunities. A cumulative walk-accessibility score—similar to Walk Score—is used to estimate the likelihood of walking for a particular trip purpose from (or to) any potential location. Both methods produce walk trip tables, which can be assigned to a transportation network, although neither tool currently includes an assignment procedure. It is expected that these routines can be found in the conventional transportation planning models or software available and in use at most MPOs and local planning agencies.

Because these models are the major new tools coming out of NCHRP Project 08-78, the guidebook presents them in greater detail than some of the other tools included as options. Moreover, to encourage maximum accessibility to these two new tools, special spreadsheet versions have been developed and included with the guidebook. These spreadsheet models are intended to build familiarity with the tools and a better understanding of the key relationships and their sensitivities. Sample data are provided with each model, along with detailed instructions on how to set up, use, and interpret the findings. Both spreadsheet tools can serve as sketch-planning models or in factoring estimates (in lieu of elasticities) from other models that do not have the same sensitivities.

Other tools deemed to have merit for use in bicycle and pedestrian planning have been included, along with guidelines on their use. These tools include the following:

- A comprehensive set of enhancement procedures for use in modifying an existing four-step trip-based model to improve its sensitivity to land use, accessibility, and non-motorized travel. These enhancements were developed as part of the Seattle-based research.
- Pre-existing pedestrian planning tools—PedContext and MoPeD—that offer special capabilities for estimating pedestrian travel in relation to land use and accessibility, at a pedestrian scale of spatial resolution. These tools also can assign walk trips to travel networks and estimate usage levels on facilities.
- Bicycle route choice models that quantify the relative value of the characteristics of a bicycle travel network in guiding choice of route; while these models do not predict mode or destination choice, they provide important insights that aid in effective network design and in gauging the accessibility of a path or network in reaching desired opportunities for choice modeling.
- An introduction to direct demand models used for directly estimating bike or pedestrian facility demand, with examples taken from applications in Santa Monica and San Diego.

1.4 Content of the Guidebook

The guidebook is organized as follows:

- **Chapter 2, Fast Facts About Walking and Bicycling:** This chapter provides basic parameters on walking and bicycling, such as trip rates, trip distance and travel time distributions, comparative average distances and travel times across trip purposes, and correspondence of bike and walk trip rates with user characteristics (e.g., gender, income, auto ownership, education, and race/ethnicity). Most of this information is from a single source, the 2009 National Household Travel Survey, to ensure consistency among the various relationships.
- **Chapter 3, Factors Affecting Walking and Biking:** This chapter summarizes key factors that affect bicycle and pedestrian trip-making, including relationships with land use, facilities, natural environment, sociodemographic factors, and attitudes and perceptions. These factors are presented separately for walking and bicycling.
- **Chapter 4, Best-Practice Methods for Estimating Bicycle and Pedestrian Demand:** This chapter discusses each model or approach included in the recommended tools. This chapter familiarizes the reader with each method, the purpose behind its development, and special features or capabilities that may interest the reader. Full detail on the tools is provided in the appendices to the Contractor's Final Report (project-developed methods) or links to key source documents for other recommended methods.
- **Chapter 5, Application of Methods:** This chapter provides users with various tips, displays, and organizational strategies aimed at selecting and using the assembled tools. Tables comparing the key characteristics and features of each tool are provided; these are accompanied by individual model fact sheets to collect information in a single place when focusing on the given tool. Advantages and disadvantages associated with each tool are presented so as to help in the selection process. This descriptive and comparison information is followed by guidelines on ways to adapt and use each tool, along with caveats to be aware of. The level of detail in this section is greatest for the two new tools, the Tour-Based (Seattle) and the walk-accessibility (Arlington) model because they are new and different and are the major offerings from the NCHRP Project 08-78 research project. The custom spreadsheets developed for both of these tools are presented in detail.
- **Appendixes:** Individual appendixes contain the full model results and related discussion and elasticities (where available) for each of the recommended tools.

1.5 How to Use the Guidebook

Users will benefit most from this guidebook if they take time to become familiar with the overall content and organization, beginning with the accessibility concepts highlighted in this chapter. The guidebook is more than a set of tools and instructions on how to use them: it provides an understanding of the key relationships, how they affect non-motorized travel behavior, and how these tools can be used to do a better job of including such information in the analysis. The guidebook demonstrates (1) how land use and transportation network shape and coverage combine to define accessibility, (2) that accessibility is the key factor in understanding walk/bike travel, and (3) effective land use and network strategies improve accessibility.

This guidebook summarizes the information compiled on the tools, explanation of their development, and the findings of the earlier research. For many users, the guidebook's level of information will be more than sufficient; those wishing to deepen their understanding are encouraged to consult the Contractor's Final Report and its appendices. In addition to providing an overview of the preliminary (Phase I) research, the Contractor's Final Report provides an overview and assessment of data sources and offers recommendations for future research.

Ideally, users will review Chapters 2 and 3 for Fast Facts and Key Factors. This will provide a good overview of bicycle and pedestrian travel and serve as a basis for understanding the reasons behind the development or structure of the various tools and recommendations for their use. Again, the background research on these issues is documented in much greater detail in the Contractor's Final Report.

The key operative sections of the guidebook are Chapters 4 and 5. Chapter 4 provides an overview of each of the tools, in enough depth to communicate purpose, construction, and level of complexity. Review of Chapter 4 is recommended before using the guide in Chapter 5. Chapter 4 will be of continuing value as reference when using Chapter 5, when more information will be wanted on specific attributes of models.

Chapter 5 contains aids to help understand the tools and compare them on various criteria, including intended geographic scale, type of application, data requirements, and key output metrics. This information, along with the accompanying narrative, should help users select the most appropriate tool or tools for their applications. The remainder of Chapter 5 details how to apply the various tools.

Equations, elasticities, and key details of models (to the extent of availability) are packaged into separate referenced technical appendices, by model.

A special supplement to this guidebook may be found in the customized spreadsheet versions of the two new models created by the NCHRP project—the Seattle-derived tour-based model and the Arlington-based walk-accessibility model. The user will find these tools useful, particularly for sensitivity testing and creative application to individual planning tasks.

Users who want to replicate or emulate a given technique have access to detailed model development reports on each of the tools. For the Seattle tour-based, Arlington Walk-Accessibility, and trip-based model enhancements, documentation is provided as Appendices 1 through 3, respectively, of the Contractor's Final Report. For all other models, web citations are provided.

CHAPTER 2

Fast Facts about Walking and Bicycling

Perhaps the best place to start when approaching bicycle and pedestrian planning is to gain an understanding of the basic parameters of bicycle and pedestrian travel:

- How much do people walk or bike?
- How far do they travel?
- Why do they travel?
- Which segments of the population walk or bike the most?

Below are basic statistics on walking and biking in the United States; unless otherwise noted, these are taken from the most recent National Household Travel Survey (NHTS), conducted in 2009. These profiles are summarized in the guidebook in order to provide users with a quick basic understanding. Readers wanting more detail on these relationships should consult Appendix 4 of the Contractor's Final Report.

2.1 Walking and Bicycling Activity Levels

In terms of overall pedestrian and bicycle activity

- U.S. households generated 48.6 billion annual walking trips and 4.1 billion annual bicycle trips in 2009. Table 2-1 illustrates the frequency of walking and biking on a weekly basis.
- On average, 68% of all people made at least one walking trip during the past week, and 24% averaged at least one per day. However, this implies that a substantial proportion – 32% – did not make even one walking trip in the previous week. For those making at least one trip, the average number of trips made per week is 4.8; for all travelers, the average is 3.2.
- Activity levels for bicycling are much less: 87% of all people made no trips by bicycle in the previous week, and only 2% averaged one or more trips per day. For those making at least one bicycle trip, the average number of trips made is 3.1; for all travelers, the average is only 0.4.
- In terms of mode share, walking accounts for 11.8% of all daily person trips, and bike accounts for slightly more than 1 percent.
- Of the 11.8% of overall trips made by walking, 2.5% were specifically for accessing transit, accounting for 15.6% of all walk trips. Unfortunately, equivalent survey information on bicycle access to transit was insufficient to allow an estimate of its magnitude.

Trends over Time

Table 2-2 shows that rates of walking and bicycling have held fairly steady over the 30-plus years that the NHTS has included them as modes in the survey. The percentage of trips made by walking in 1977 *exclusive of trips to access transit* was 9.3% (walk access trips were blended into the transit trip in the earlier surveys) and stands at 8.7% in 2009. Bicycle use suggests a slight increase, from 0.7% in 1977 to about 1% in 2009.

Focusing on use of walk or bicycle for travel to work, walking has fallen from 7.4% of all trips in the 1970 Census Journey to Work (JTW) to 2.9% in the 2000 Census JTW. Because the Census ceased collecting JTW data after the 2000 decennial Census, the 2009 NHTS provides the most recent estimate, suggesting that the share is still about 2.9%. Bicycling to work was measured at 0.5% of all trips in the 1980 Census JTW, and 0.4% in the 2000 JTW. However, the 2009 NHTS places the bicycle share at 0.9%, which—although not a large number and taken from a different data source—may reflect an increase in the use of biking for travel to work.

Use of bicycle or walking for travel to school (children under 18) shows a pronounced downward trend for walking, from 22.5% in 1977 to 9.5% in 2009, but only a 0.3 percentage point decline for bicycle use over the same period (Table 2-3).

2.2 The Role of Distance in Non-Motorized Travel

Distance is a limiting factor for travel by any mode, but is much more so for non-motorized modes, particularly for walking. The average one-way distance for all walk trips in the

Table 2-1. Percent of travelers by number of walk or bike trips made in past week.

Number Trips Made Last Week	Walk	Bike
None	32%	87%
1	6	4
2	10	3
3	10	2
4	6	1
5	8	1
6	3	0.4
7	11	1
8+	13	0.8
Avg for those making at least 1 trip	4.8	3.1
Avg for all travelers	3.2	0.4

NHTS is 0.7 miles (and 15 minutes of travel time); for bike travel, average one-way distance is 2.3 miles (19.4 minutes of travel time).

Many factors affect how far or how long people are willing to walk or bike, such as the purpose of the trip, the quality of attractions to be reached, how easily and directly trip ends can be reached over the travel network; characteristics of the individual traveler (e.g., age, income, gender, and driver's license), the presence of hills, difficult crossings, and concerns about safety; and even such factors as weather and daylight/darkness. The importance of these factors is explored in greater detail in Chapter 3.

A key relationship derived from the study of non-motorized travel behavior is that the value (or utility) of a potential destination not only declines with greater distance, but *does so at a non-linear rate of decay*, constituting what is referred to as a distance-decay rate. The relationship that best reflects the decline in utility is the negative exponential of distance—or travel time—where the initial fall off is very steep and then tapers off.

Using readily available data from the Metropolitan Washington Council of Governments 2007/08 regional travel survey (done as part of the NHTS), these relationships can be clearly illustrated. Figures 2-1 and 2-2 show the pattern of decline in walking trips in relation to trip distance and travel time, while Figures 2-3 and 2-4 show the same relationships for bicycle trips.

These figures reveal the following:

- Walk trips are often short: 25% of all walk trips are 0.1 mile or less, half are 0.3 miles or less, and three-quarters

Table 2-2. Trends in bicycling, walking, and transit mode shares, 1969–2009.

Travel Mode	1969/70	1977	1980	1983	1990	1995	2000/01	2009
All trip purposes (Source: NPTS/NHTS Surveys)								
Bicycle	n/a	0.7%	—	0.8%	0.7%	0.9%	0.9%	1.0%
Walk only	n/a	9.3	—	8.5	7.2	5.4	8.6[a]	8.7[a]
Transit[b]	3.2%	2.6	—	2.2	2.0	1.8	1.6	1.9
Work purpose trips (Source: Decennial Census Journey to Work)								
Bicycle	n/a	—	0.5%	—	0.4%	—	0.4%	0.9%
Walk only	7.4%	—	5.6	—	3.9	—	2.9	2.9
Transit	8.9	—	6.4	—	5.3	—	4.7	4.0

Source: Data for work trip purpose calculated from decennial Census Journey to Work for years 1970, 1980, 1990 and 2000. The 2009 values have been estimated using the 2009 NHTS
Notes: a. Increase reflects new efforts to capture previously unreported walk trips.
b. Transit shares are included as an approximation of the substantive walks that occur in connection with access to transit.

Table 2-3. Bicycle and walking mode shares for child transportation to school, 1969–2009.

Travel Mode	1969	1977	1983	1990	1995	2001	2009
Bicycle	n/a	1.0%	0.5%	1.0%	1.1%	0.8%	0.7%
Walk	n/a	22.5	14.5	18.2	10.6	12.1	9.5
Total NMT	40.7%	23.5%	15.0%	19.2%	11.7%	12.9%	10.2%

Source: NPTS results for 1969, 1977, 1983, 1990, and 1995; and NHTS results for 2001 and 2009; all except 2009 as reported in Moudon, Stewart, and Lin (2010).
Notes: Includes children ages 5 to 18.

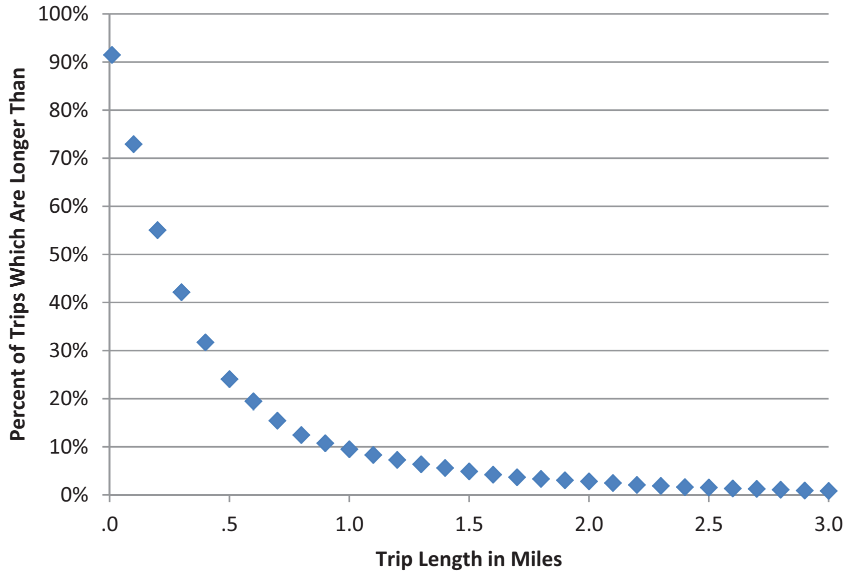


Figure 2-1. Walk trips by distance (2007/08 MWCOG Regional Travel Survey).

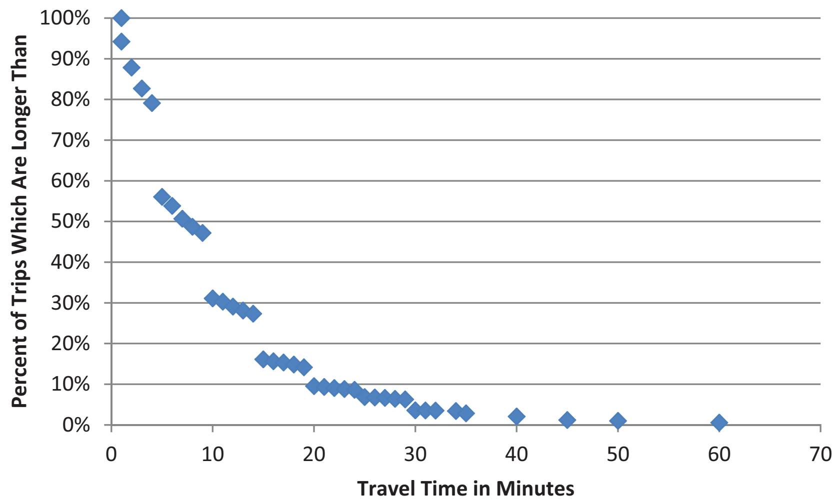


Figure 2-2. Walk trips by travel time (2007/08 MWCOG Regional Travel Survey).

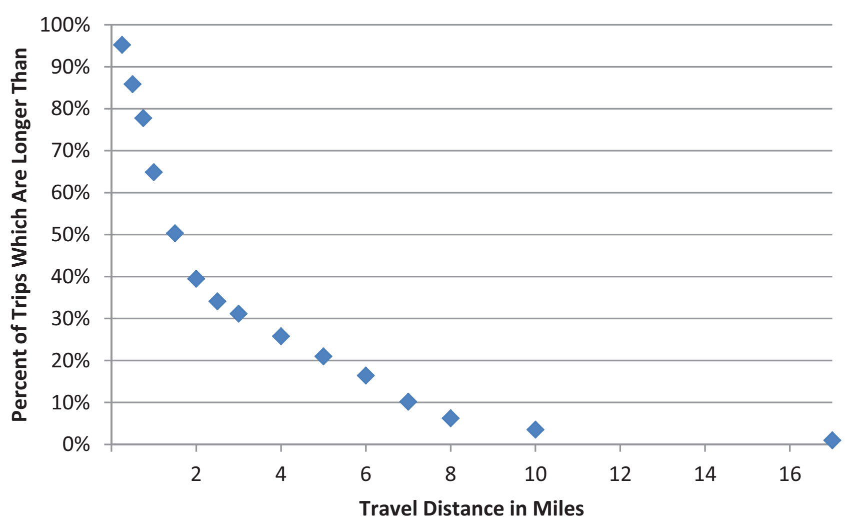


Figure 2-3. Bicycle trips by distance (2007/08 MWCOG Regional Travel Survey).

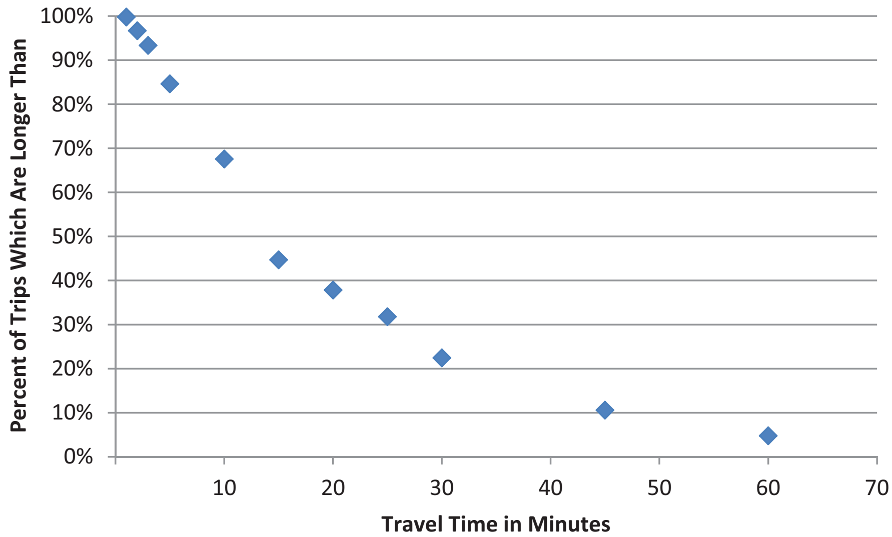


Figure 2-4. Bicycle trips by travel time (2007/08 MWCOG Regional Travel Survey).

are one-half mile or less. Overall, 90% of all walk trips are 1 mile or less.

- For bicycle trips, 25% are 0.8 miles or less, 50% are 1.7 miles or less, and 75% are 4 miles or less. Overall, 90% of bicycle trips are 8 miles or less.
- Although the differences in distance coverage are not surprising given a roughly 3-to-1 speed advantage for bicycle travel over walking, cyclists are willing to expend additional travel time: 25% of walk trips are less than 3 minutes in duration, compared to 10 minutes for bike; 50% are up to 8 minutes compared to 15 minutes for bike; and 75% are up to 15 minutes compared to 30 minutes for bike. When 90% of all trips are considered, up to 20 minutes are invested for walk trips versus 60 minutes for bike trips.

Apparently cyclists not only travel farther, but are willing to commit more time to their travel than pedestrians. However, before any strong conclusions can be taken from this set of comparisons it must be recognized that these distributions do not control for trip purpose, the relationships with which are explored in the following section.

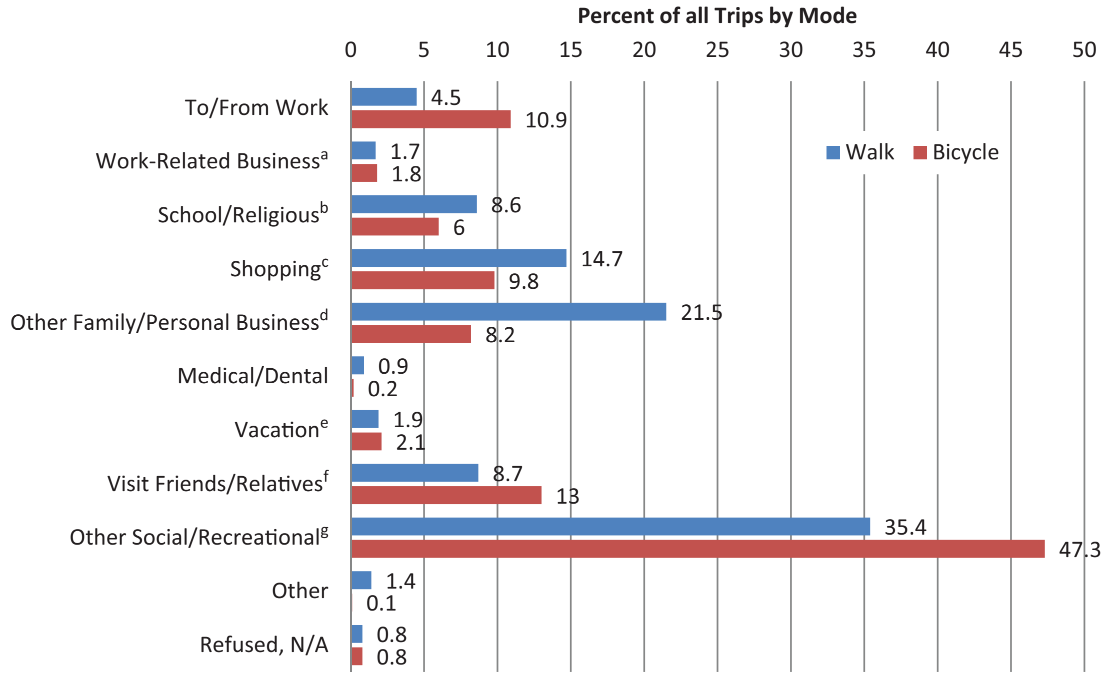
2.3 Walking and Biking by Trip Purpose

Figure 2-6 shows the popularity of walking or biking for particular trip purposes. The most common purpose for walking or biking is "Other Social/Recreational" travel, which accounts for almost half (47.3%) of all bike trips and 35.4% of all walk trips. After Other Social/Recreational travel, the most frequent purposes for walking are Other Family/Personal Business (21.5%), Shopping (14.7%), Visiting Friends & Relatives (8.7%), and School/Religious (8.6%). Travel To/From Work accounts for only 4.5% of all walk trips. The most popular trips for biking after Other Social/Recreational are Visiting Friends & Relatives (13%), travel to Work (10.9%), Shopping (9.8%), Other Family/Personal Business (8.2%), and School/Religious (6%).

Before these relationships are used to assess the potential for walking or biking in a plan or project, the following qualifications should be considered:

First, the trip purpose definitions established by NHTS and used in these figures might be misleading in important ways. They attempt to characterize typical travel activity purposes, but several are a roll-up of many sub-purposes presumed to be related. In the notes for Figure 2-5, the assumptions of what is included in each primary purpose definition are listed. Particularly in the case of Other Social/Recreational and Other Family/Personal Business, various activities are contained in each and some similar activities (e.g., dining out). For both of these purpose groups, it is difficult to distinguish between travel purely for exercise/recreation and travel that has a utilitarian purpose. For example, "recreation/exercise" is included under Social/Recreational, but it may either consist of traveling to a "place" for exercise (e.g., gym or sports facility) or the travel by walking or biking is itself the exercise medium. Similarly, under Family/Personal Business, pet care (primarily dog walking) accounts for almost one-third of all walk trips in this major category.

Second, the profile suggested by the walk and bicycle use patterns in Figure 2-5 is effectively a "snapshot" of how these modes are being used in the United States today. The finding that a fairly high share of domestic walking and biking trips are for recreation and exercise stands in sharp contrast to the experience in Europe, where walking and bicycling for utili-



Source: 2009 NHTS
Notes:
a. Work-related business: Attend business meeting; other work-related activity; return to work
b. School/Religious: To & from school, school related; religious activity; school/religious activity
c. Shopping: Shopping/errands; buy groceries, clothing, hardware; buy gas for car
d. Other Family/Personal Business: Includes day care; transport someone/something; acquire personal or professional services; pet care/dog walk, attend civic meeting/event; get/eat meals/coffee/ snacks; attend social event, wedding/funeral
e. Vacation: Formal vacation; rest and relaxation
f. Visit Friends & Relatives: Purely visitation
g. Other Social/Recreational: Includes social/recreational, exercise (including walking and jogging), play sports, go out for entertainment,visit public place, eat meal, social event, get/eat meal, coffee/snacks

Figure 2-5. Frequency of walk or bicycle trips by trip purpose.

tarian purposes is much more common. Although exercise and recreation are certainly important in relation to health benefits, the market for increasing non-motorized travel in the United States is more likely to come from daily family and personal needs.

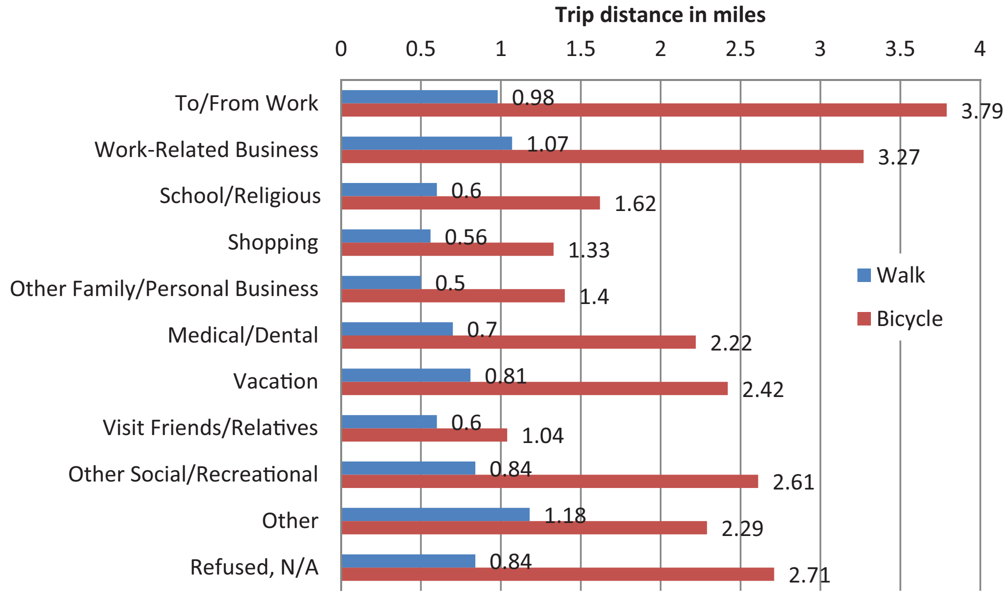
Figure 2-6 illustrates how trips for these various purposes vary by average trip length. The longest trips for both walking and cycling are those for travel to work and work-related business. The shortest trips are those for shopping, family/personal business, and visiting friends and relatives. The Other Social/Recreational category has above-average trip lengths for both modes, a result that may be driven by the high proportion of recreation/exercise trips in this category.

2.4 Who Walks and Bikes?

The NHTS also provides information to characterize the types of people who currently walk or bicycle. Matching pedestrian/bicycle trip-making from the survey with the characteristics of the individuals making those trips begins to convey a sense of the characteristics (e.g., age, gender, income, vehicle ownership, education, and race/ethnicity) associated with the walking and biking populations. However, these profiles represent a snapshot of non-motorized travel in the United States today, but different policies and trends may result in very different profiles of users in the future.

With these points in mind, the following characteristics describe current non-motorized travelers:

- **Age:** As seen in Figure 2-7, the highest rates of walking and biking occur among children, aged 5 to 15, most of whom are not permitted to drive until age 16. Among walkers, the next most active age group is adults aged 25 to 34 years. Walking rates then remain stable until age 65 and then decline. Walking to transit peaks in the 16 to 24 year age group, and then steadily declines. For biking among adults, rates remain fairly stable across all age groups, and then decline after age 55.
- **Gender:** Figure 2-7 shows that differences in gender are most pronounced for bicycling, where males are two to four times more likely to make a bicycle trip than females in all age



Source: 2009 NHTS

Figure 2-6. Average trip length by purpose.

groups. For walking, males walk at higher rates in the youngest age groups – 5 to 15, and 16 to 24 – while females walk at similar or slightly higher rates in all other age groups; a similar relationship is seen in the use of walking to access transit.

- **Income:** Walking appears to be linked to income. Figure 2-8 shows that travelers in the lowest income category make 16.9% of their trips by walking and another 4.8% of their trips to access transit. This share declines to 8.9% for people with incomes between $40,000 and $99,000, and then rises with incomes more than $100,000. Bicycling is more consistent across income classes, with the highest rate of 1.3% in the $20,000 to $39,000 class, declining to 0.9% in the $75,000 to $99,000 range, and 1.1% for all other groups.
- **Vehicle Ownership:** The number of vehicles owned by a household and the availability of those vehicles to household drivers strongly impact rates of walking, although the impacts on biking are much less. Figure 2-9 states that in households that do not own any vehicles, 41% of daily trips

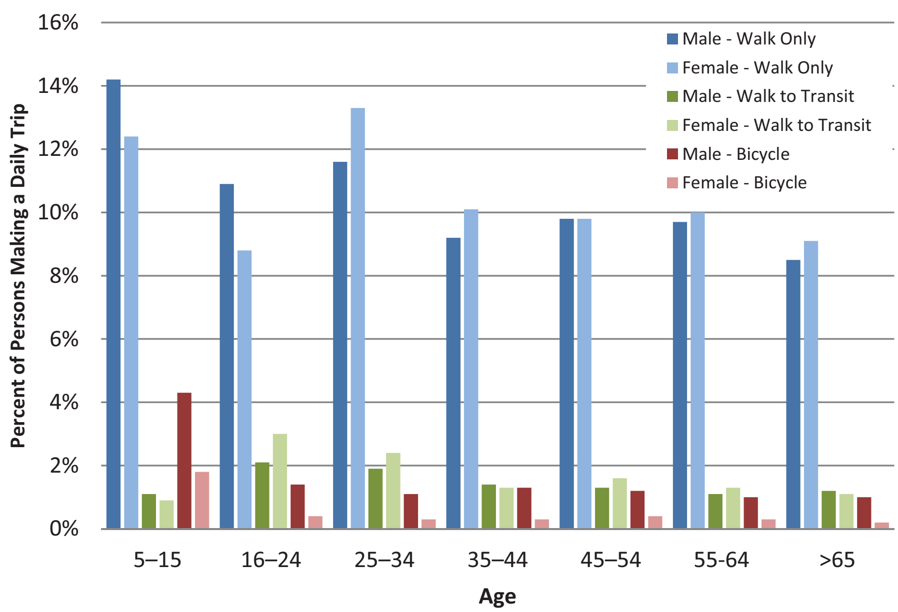
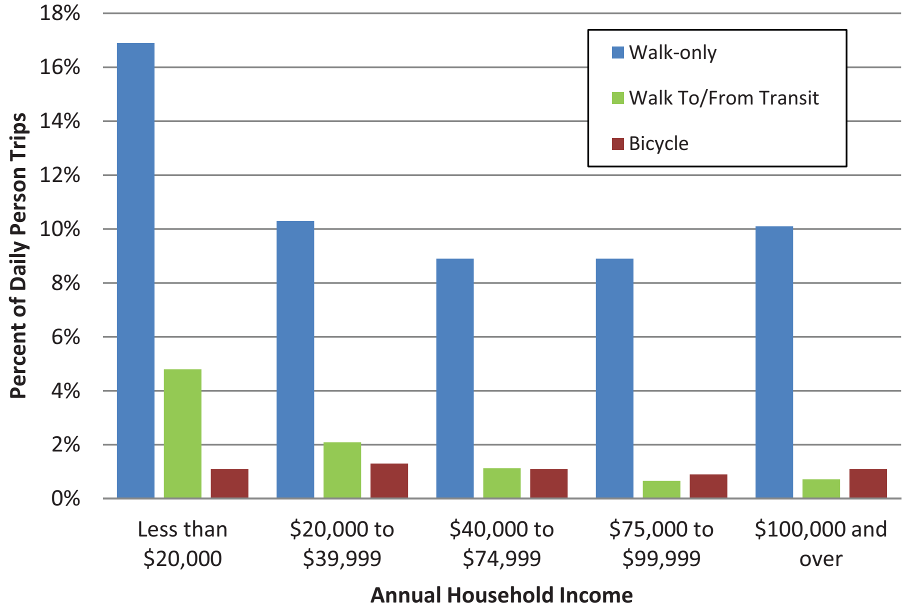


Figure 2-7. Percentage of daily trips made by walking or bicycle by age and gender.



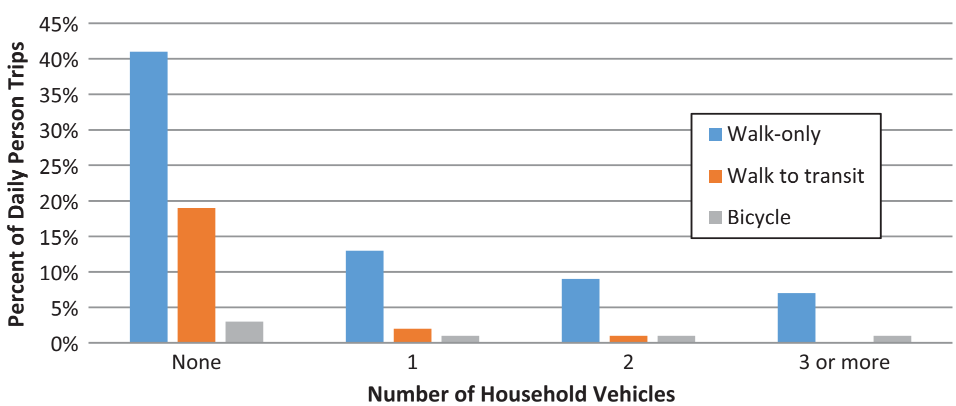
Source: 2009 NHTS

Figure 2-8. Percentage of daily person trips by mode and income.

are made by walking, 9% by walking to transit and 3% by bicycle. If only one vehicle is owned, the walk trip rate drops to 13%, walk to transit drops to 2%, and bike drops to 1%. If more than two vehicles are owned, the walk rate drops to 7%, while the bike rate remains at 1%.

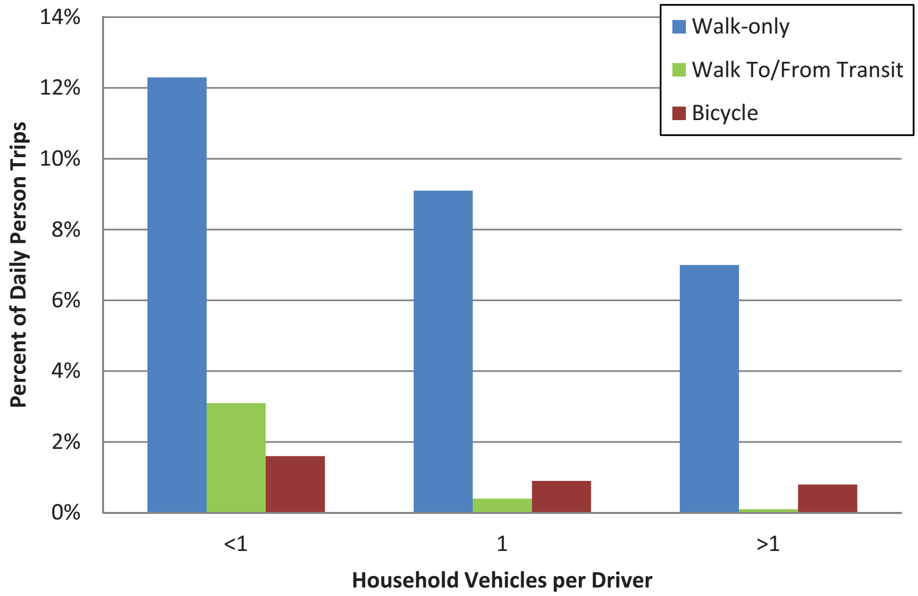
- **Vehicle Demand**: If one accounts for the *availability* of vehicles in terms of vehicles per household driver, Figure 2-10 shows that households with fewer vehicles than drivers average 12.3% of their trips by walking and 1.6% by bicycle, whereas when the number of vehicles equals or exceeds the number of drivers, the walk rate drops to 7% and bicycle rate drops to 0.8%. The decline of rates of walk to transit is even more precipitous: from 3.1% where drivers outnumber vehicles to 0.1% when there are more vehicles than drivers.
- **Education:** As seen in Figure 2-11, the highest rates of walking are among people who did not finish high school (16.7%) (which includes trips to transit), while the lowest rates are for those with either a high school diploma or who have competed some college (about 10%), after which the rates increase to 11.2% for those who have attained a bachelor's degree, and about 14% for those with post-graduate education. A similar relationship exists for bicycle use across the five education categories, though at much lower rates.

For more detail on these and other relationships describing the characteristics of persons who walk or bicycle, please consult Appendix 4 of the Contractor's Final Report.



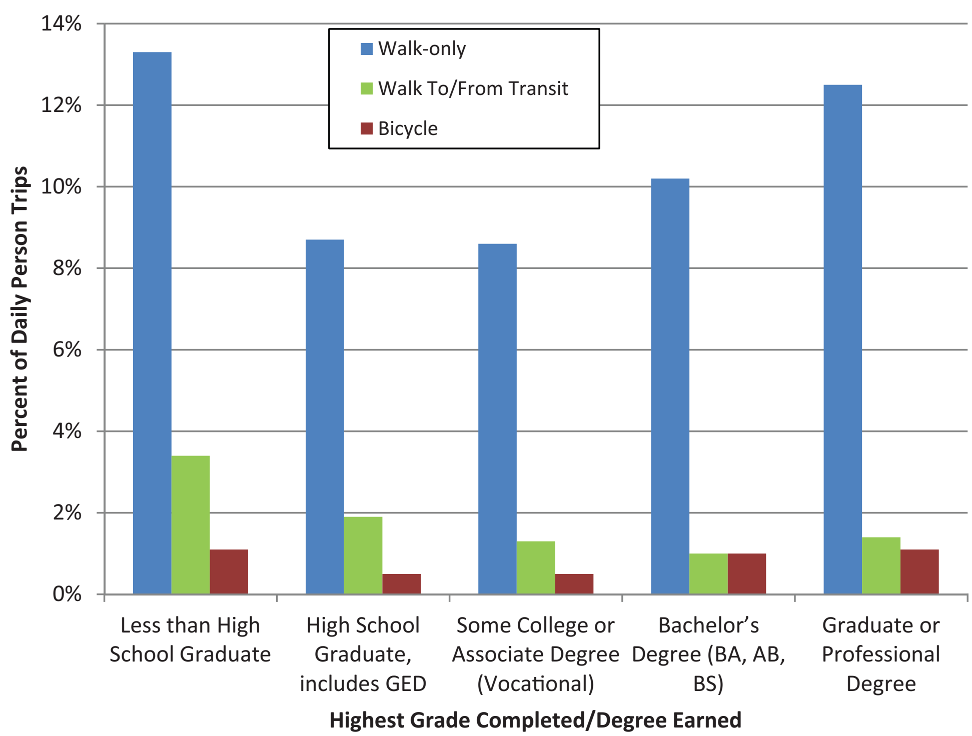
Source: 2009 NHTS

Figure 2-9. Percent of daily trips made by walking or biking by number of household vehicles owned.



Source: 2009 NHTS

Figure 2-10. Percentage of daily person trips by mode and household vehicle availability.



Source: 2009 NHTS

Figure 2-11. Percentage of daily person trips by mode and education level.

CHAPTER 3

Factors Affecting Walking and Biking

3.1 Overview

Chapter 2 provided an overview of the current status of walking and bicycling in the United States: who walks and bikes, how frequently, how far, and for what purposes. This chapter provides insights on the many factors found to influence walking and bicycling behavior, from the choice of mode itself to the decision of whether to travel, where to travel and what route to take. These factors include

- Land use and the built environment
- Number, type, coverage and connectivity of facilities
- Natural environment (topography, climate/weather)
- Sociodemographic factors
- Perceptions and attitudes

Walking and biking are much more context-sensitive than motorized travel modes, particularly auto, so factors such as these can have an important impact on the travel decision. People considering making a trip by auto probably give little thought to whether they will have to travel uphill, if it is raining or the temperature is uncomfortably hot or cold, whether it is day or night, or if they have to cross a major street or highway. In contrast, because walking and bicycling involve physical effort and exposure, these factors matter—particularly for travelers whose decision to walk or bike may be at the margin.

Although these contextual factors matter, not all factors carry the same weight in the travel decision, and the importance will vary from person to person and with the trip purpose being served. For example, if a person is walking or biking for fun or exercise, the presence of a sidewalk or dedicated bike path, or even weather or topography, may not be of central importance. On the other hand, if the trip has a utilitarian purpose—work, school, visiting a doctor—then factors like distance, convenience, and safety become more relevant to the decision to walk or bike. To further complicate matters, many of the factors carry different importance to different types of individuals. For example, young and athletic cyclists are found to have fewer reservations about riding in proximity to vehicle traffic or having to negotiate hills than cyclists who are less experienced or fit. However, the regular cyclists are also likely to be more concerned about the efficiency of their trip, in terms of directness and sustainable speed, where the infrequent riders are more likely to add time or distance to their trip in order to feel comfortable. There is also the issue of whether the factor is part of the primary decision of whether to walk or bike or whether it merely affects the choice of route or destination.

NCHRP Project 08-78 reviewed extensive prior research efforts to identify and quantify the importance of these factors, for the purpose of informing the development of new bicycle/pedestrian planning tools. The magnitude and diversity of these research studies precludes their unabridged inclusion in this guidebook; however, users are encouraged to consult Appendices 5 and 6 of the Contractor's Final Report for more information.

3.2 Insights from International Experience

If this guidebook has one overriding objective, it is to encourage planners and analysts to consider the potential for walking and biking as broadly as possible. Although we argue that context matters with non-motorized travel, there is a tendency to use those factors as a way to gage—and even "cap"—walking or biking potentials. For example, one may associate walking with people of limited economic means, or biking with young people who enjoy exercise. Although such tendencies are seen in the data presented in Chapter 2, there is no reason to believe that the popularity of walking or biking could not be enjoyed by other sociodemographic segments, given the right circumstances.

Western Europe provides challenges to stereotypes about walking and biking. Although high rates of biking and walking in Asia and third-world countries may be explained by economic and technologic differences, the large differences between walk and bike rates in the United States versus other modern western nations, including most of Europe and even Canada, are not as easily explained. A 2008 study motivated by negative health and obesity trends in the United States compared walking and biking rates in the United States with a large sample of western countries, with the findings summarized in Figure 3-1 (Basset, et al., 2008).

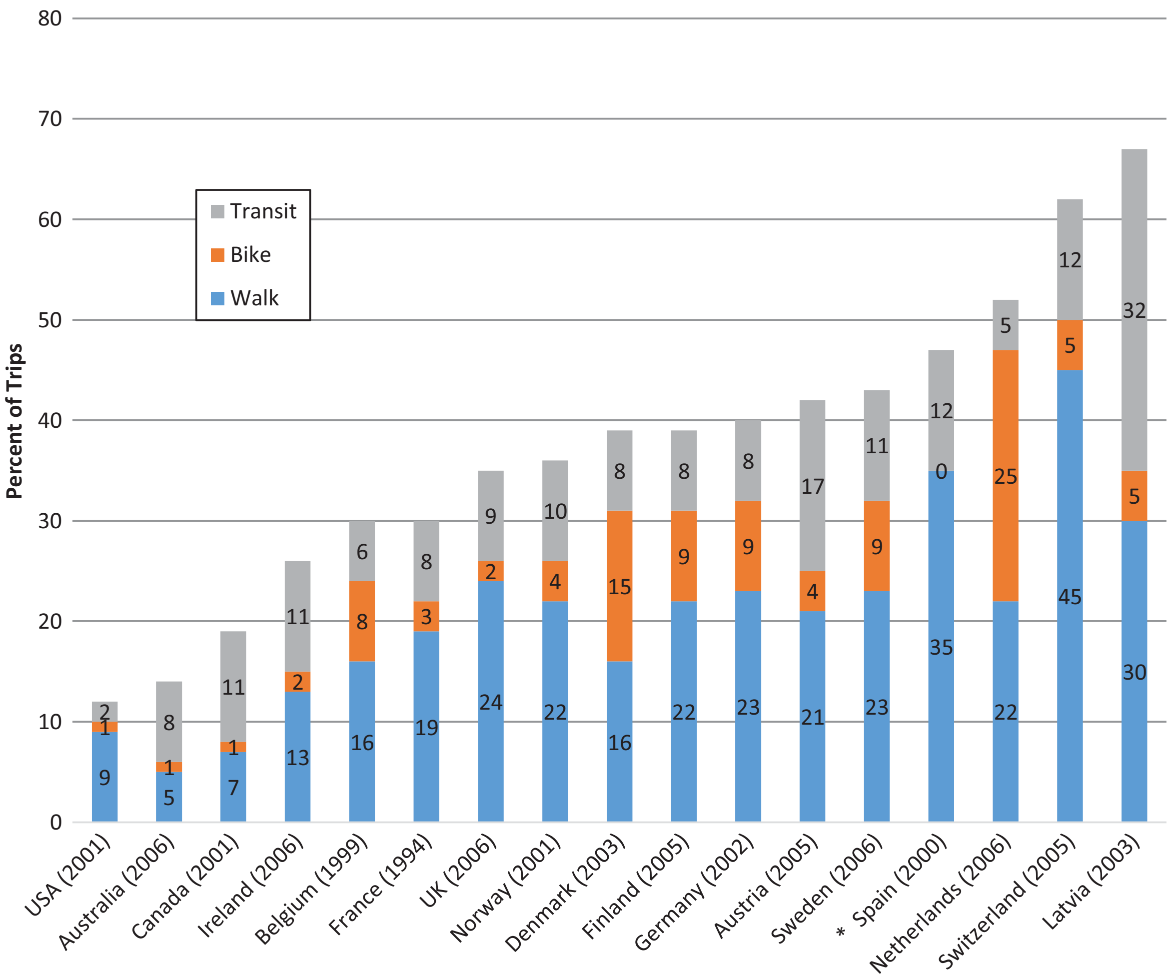
The combined walking and biking rate in the United States of 10% contrasts strongly with rates of 26% in the United Kingdom, 22% in France, 32% in Germany, and 35% in Spain – even without considering countries like the Netherlands or Denmark, which are often regarded as having a unique culture. Issues of inclement weather and difficult topography also challenge travelers in many of these areas, yet they walk and bike at consistently higher rates than in the U.S.

Higher rates of transit use in most of these countries can also be attributed to urban design and facility networks that support non-motorized access to transit. Similarly, destination areas served by transit are more likely to draw ridership if the areas are pedestrian or bicycle friendly.

The Basset study found that, although walking is the most common leisure-time physical activity in the United States and Europe, Europeans walk much more for shopping, commuting, school trips, and so forth. Short trips in Europe are often made by walking, but in the United States they are usually made by automobile, which is used for 55% of trips that are about 0.5 km in length, 85% of trips that are 1 km in length, and 90% of trips longer than 1 km. Moreover, rates of walking in European countries actually increase with age through age 65, and biking rates stay roughly steady with age, while both decline with age in the United States.

The principal differences between the United States and its peers seem to be as follows:

- More compact, mixed-use cities and urban areas with smaller footprints that provide high proximity and shorter trips



Note * : Separate walk and bike rates were not reported for Spain; the shown rate is a combined rate.

Source: Recreated from Figure 1 in Basset, Pucher, Buehler, Thompson and Crouter. "Walking, Cycling and Obesity Rates in Europe, North America and Australia." Journals of Physical Activity and Health, 2008, 5, 795-814 by permission from publisher (Human Kinetics).

Figure 3-1. Percentage of trips taken by walking, biking and public transit by country.

- Well-established, efficient transit systems coupled with pronounced efforts to maximize walk and bike access
- Ubiquitous, high-quality, and well-connected bicycle and pedestrian networks and facilities
- Pedestrian and bicycle-friendly policies to manage vehicular traffic in high-demand areas
- Higher costs of owning, operating, and parking a motor vehicle

If the differences between the United States and its peers on these attributes were reduced, more U.S. travelers would have attractive non-driving opportunities, in which case walking and biking rates would be expected to increase accordingly.

3.3 Land Use and the Built Environment

The European comparison suggests that the shape of the built environment may be fundamental in shaping walking and biking behavior, and hence provide clues as to what these design characteristics are. The impact of land use and urban design on travel behavior has been heavily studied, and the research has established a strong set of statistical relationship between the so-called built environment and travel behavior. These attributes have come to be known as the "Ds" as follows:

- Density: Of population or employment
- Diversity: Variety of different land uses (mix) and their proportional balance (entropy)
- Design: Orientation between development and people, enabling efficient pedestrian access (e.g., existence of pedestrian facilities, frequency of safe crossings, intersection types and density, and building setbacks and curb cuts)
- Distance to Transit: Nearest stop for particular services, stop density
- Destinations: Access to regional opportunities, usually by transit

Researchers have attempted to quantify the importance of these characteristics using regression models to help explain auto ownership, choice of mode, and VMT. Some of these research models have included walking as a mode but not bicycling, or have combined walking and biking into a single non-motorized mode, which is not particularly meaningful.

Ewing and Cervero in their 2010 *Meta Analysis* tried to discern the impacts of the Ds on travel behavior. The researchers reviewed more than 50 studies using Ds methods and attempted to synthesize average elasticities that reflect the level of impact of the particular variables on travel demand, including walk trips. These elasticities are derived from the coefficients estimated through regression and represent the percentage change that would be predicted in the dependent variable (number of walk trips in this case) in response to a 1% change in the particular independent variable. Table 3-1 presents estimates of demand elasticities for walking derived through this synthesis.

To illustrate the meaning of the elasticities, a 1% increase in the level of residential density would be expected to lead to a 0.07 increase in the number of walking trips. Table 3-1 suggests that the factors having most impact on walking are intersection density (0.39), distance to the nearest store (0.25), jobs/housing balance (0.19), mix entropy and jobs within 1 mile (both 0.15), and distance to transit (0.14). These elasticities are not necessarily additive; it would be incorrect to assume that, if each of the variables listed in Table 3-1 were increased by 1%, the number of walk trips would increase by 1.39% (sum of all the elasticities). This is because (1) many of the measures are interrelated, so that changing one would also affect one or more of the others, and (2) the coefficients in the models from which the elasticities were derived depend on each other and the specification of the model. A better approach would be to apply the original equation to allow for these interactions, or to use the tour-based model spreadsheet developed as part of NCHRP Project 08-78 and presented in Chapter 5.

Although transportation planners generally treat travel as occurring in the form of individual "trips," travel is more

Table 3-1. Weighted average elasticities of walking in relation to built-environment factors.

"D" Variable	Measure	Elasticity
Density	Residential density	0.07
	Employment Density	0.04
	Commercial FAR	0.07
Diversity	Mix entropy	0.15
	Jobs/housing balance	0.19
	Distance to nearest store	0.25
Design	Intersection density	0.39
	Percent 4-way intersections	-0.06
	Distance to nearest transit stop	0.14
Destination Accessibility	Jobs within 1 mile	0.15

Source: Ewing & Cervero, Meta Analysis (2010) realistically viewed as combinations of trips that constitute complete "tours," beginning and ending at the same point. A tour that begins at home, goes to a location such as work, and then returns home without intermediate stops is known as a "simple" (home-based) tour. In contrast, tours that involve more than one stop and purpose are called "complex" tours. The difference is relevant because research shows that travelers in more compact, mixed-use environments (with high values of the Ds) are much more likely to make their trips as simple tours, apparently taking advantage of convenient proximity to venture out multiple times for various purposes. In contrast, travelers in areas without such proximity tend to group trips into multi-stop tours in order to increase efficiency. The same research also shows that trips by walking, biking and transit are much more likely to be made as simple tours, whereas complex tours are much more likely to be made by auto. These relationships are evident in the models developed for the project in Seattle and presented in Chapters 4 (Section 4.3) and 5.

Figure 3-2 summarizes how land use and built-environment factors affected non-motorized travel, first for walking and then for bicycling. These factors were identified in the earlier NCHRP Project 08-78 research and are provided in much greater detail in Appendices 5 and 6 of the Contractor's Final Report.

There has been much less research dealing with the effects of land use on bicycle demand than on walking, although substantial evidence indicates that biking levels are also higher in areas that are more compact, have mixed uses, and feature well-connected non-motorized networks. The many studies of Pucher, et al. (1997, 2003, 2006, 2008a & b), which compare biking in the United States and Europe (as well as other areas of the globe), indicate that over two-thirds of all bike trips in Europe are for utilitarian purposes, versus almost half (47.3%) of all bike trips in the United States being made for social or recreational purposes. The difference between the two environments shows up in attractive destinations within reasonable distance, direct and efficient connection via the networks, and minimal conflict with motor vehicles. The links among urban densities, shorter trips, and greater use of bike for utilitarian purposes was also found in Baltes' 1996 study of biking in 284 U.S. MSAs, and Dill and Voros' (2007) survey of Portland cyclists.

Although the aforementioned research suggests an important role for land use and accessibility in projecting walk and bike travel, the limitations in existing research provided motivation to sharpen this relationship in the new methods developed under NCHRP Project 08-78. The walk-accessibility approached developed for Arlington, Virginia, demonstrated a clear relationship between high rates of walking, biking, and transit use to destinations with high walk-accessibility, implying a high number of opportunities available within walking distance. This research also ascertained that bicycle travel does not favor high-density destinations as much as walking, seemingly because of the likelihood of greater conflicts with traffic and fewer safe path alternatives. Also, for short trips in dense areas, walking may

Land Use & Built Environment	
WALKING	➢ Areas with higher densities, compact pedestrian-oriented design, and a mix of uses have higher rates of walking – particularly for utilitarian purposes (Lawrence Frank & Co., 2008; Kockelman, 1996; Kuzmyak, et al., 2010). ➢ Density, per se, is less important than the mix of uses and the connectivity provided by the street network (small blocks and gridiron shape) (Ewing & Cervero, 2010). ➢ Proximity to transit and the regional accessibility afforded by transit also reduce auto reliance and encourage walking, both to access transit and overall (Parsons Brinckerhoff, 1996; Cambridge Systematics, 2002). ➢ Compact, mixed-use design at employment or commercial centers encourages access by modes other than driving, and substitution of walking to secondary destinations (NCHRP 8-78 Arlington research, 2012). ➢ Visually interesting and attractive landscaping and building features encourage walking (Cambridge Systematics, 1994).
BICYCLING	➢ Densities somewhat less important than with walking; network connectivity measures more important (NCHRP 8-78 Arlington research, 2012). ➢ Compact form contributes to shorter distances, which is associated with more utilitarian biking (Dill & Voros, 2007). ➢ Convenient and secure bike parking important (Hunt & Abraham, 2006).

Figure 3-2. Land use factors affecting walking and biking.

Facilities	
WALKING	➢ Less than half of all walking (45%) takes place on sidewalks (NHTSA/BTS National Survey, 2002). ➢ Connectivity and directness (shortest path) are important – a 12% increase over the shortest distance path is enough to induce shortcutting (Moudon, et al., 2007). ➢ Sidewalks are much more important in commercial areas than in residential areas, owing to differences in traffic volumes and speeds (Cao, et al., 2006; Handy, et al., 1998). ➢ Shorter blocks and four-way intersections enable more frequent, efficient and safer crossings, which encourages walking. Signalization is the most important crossing treatment, particularly in high traffic areas (Boarnet, et al., 2005). ➢ Grade-separated pedestrian crossings (overpass or underpass) are not popular, and are not well used if they add 25 to 50% additional time to the crossing (Zegeer, 1998).
BICYCLING	➢ Shortest distance and minimizing exposure to traffic are top considerations; shortest distance slightly more important (Dill & Gliebe, 2008; Dill, 2009; Menghini, et al., 2009). ➢ Safety (from traffic) a bigger concern for non-regular/inexperienced cyclists; travel time more important to experienced cyclists and those making commute trips (Dill, 2009; Hunt & Abraham, 2006). ➢ Dedicated facilities—off-road bike paths, on-road bike lanes, and bike boulevards (traffic-calmed routes through residential communities) are all preferred to riding in mixed traffic (Dill, 2009). Riders will travel extra distance or time to use a high-quality facility, with the amount of tradeoff depending on the trip purpose (utilitarian versus recreational) and rider experience (Stinson & Bhat, 2004; Hunt & Abraham, 2006). ➢ Number of intersections with traffic control and number of turns per mile reduces desirability of a given route; however, traffic signals are welcomed for crossing or turning at a busy intersection (Broach, Gliebe & Dill, 2009[1]; Aultman-Hall, et al., 1997; Menghini, 2009; Stinson & Bhat, 2004). ➢ Experienced cyclists prefer smooth pavement for maximum speed & comfort (Stinson & Bhat, 2004). ➢ Steep grades are a bigger deterrent to cyclists than to pedestrians (Cervero and Duncan, 2003). ➢ Secure parking at destination was valued at 8.5 to 26.5 minutes of travel time to riders in Calgary and Edmonton (Abraham et al., 2001; Hunt & Abraham, 2006).

Figure 3-3. Facility-related factors affecting walking and biking.

be preferred to biking because of the extra burden of finding secure bicycle parking.

3.4 Facilities

The largest body of research on pedestrian and bicycle travel behavior has been in relation to facilities and their various characteristics, such as:

- Type of facility
- Safety in relation to traffic
- Steep grades
- Difficult crossings

[1]Also see: Joseph Broach, Jennifer Dill, and John Gliebe, “Where Do Cyclists’ Ride? A Route Choice Model Developed with Revealed Preference GPS Data,” Transportation Research-Part A, 46: 1730–1740, 2012.

The planning needs motivating these studies are as follows:

- Understanding facility characteristics in relation to choice of route for bicycling
- Ascertaining the comparative value of different types of bicycle facilities (on- versus off-road)
- Projecting demand for a new bicycle facility or mixed-use trail
- Projecting pedestrian volumes at intersections in relation to intersection design, signal timing and traffic management

Figure 3-3 summarizes findings from these research studies that highlight the key relationships between facility-related factors and non-motorized travel. For either mode, the top consideration is shortest distance or travel time afforded by the given network. From that baseline standard, the next most important consideration is safety in relation to exposure to vehicle traffic. For pedestrians, this concern is manifest in having sidewalks and frequent safe crossings where vehicle travel volumes and/or speeds are high. Pedestrians are also averse to traveling in close proximity to speeding vehicle travel when walking along a busy street or highway. That said, while pedestrians find security in sidewalks, this concern appears to be scaled to the level of threat posed by vehicle traffic; sidewalks are highly desired in busy commercial areas, but are not regarded as essential in all residential areas. In fact, more than half of all walking does not occur on sidewalks.

Examination of the data on biking also confirms the importance of networks with good coverage and connectivity that enable efficient point-to-point travel. However, because cyclists are more often sharing the street network with motor vehicles, concerns about safety are more immediate. Thus, attempting to provide cyclists with a safe and efficient network is a goal patterned after the apparent success of such efforts in Europe. Because riding on sidewalks is neither efficient for cyclists nor safe for pedestrians, bike facilities generally fall into the categories of

- Marked lanes on mixed-use streets and roads
- On-road (or immediately parallel) bike lanes physically separated from the vehicle right-of-way (cycle tracks)
- Separate off-road paths and trails
- Marked routes (bike boulevards) through suburban neighborhoods and low-volume streets

The many studies reviewed agree that cyclists prefer these dedicated facilities to sharing the road with high traffic activity, and they will decide consciously to add time or distance to their shortest distance trip in order to take advantage of such facilities. The degree to which riders prefer and use these facilities depends on the type of trip, the type of rider, and the type of facility. In general, on-road paths are preferred by regular/experienced cyclists, who are typically traveling to work or for some other utilitarian purpose, while off-road paths are preferred by infrequent/less experienced cyclists, who hold safety in higher regard than travel time. The referenced research studies have gone into considerable detail in quantifying these cross-relationships as to the value attached to the various options by the different rider types and trip purpose categories. The research in NCHRP Project 08-78 has attempted to take these factors into account in the new models that have been developed.

Perhaps one of the most robust studies of the importance of facilities-related factors to bike use (route choice in particular) was a GPS-based survey of bike travelers in Portland, Oregon. The survey found that bike travelers making utilitarian trips for work, school, shopping, or personal business ranked minimum distance as their top criteria, followed by avoiding traffic, ability to use an on-road bike lane, minimal intersection delays, taking a signed route, using an off-road path, and lastly, avoiding hills. People using bicycles for social and recreational travel made safety their top preference over minimum distance, while those biking purely for exercise had minimizing distance as their next to last concern; these people also preferred use of off-road paths.

3.5 Factors Related to the Natural Environment

The natural environment can pose numerous challenges to walking and biking. Among the factors identified by research are the following:

- Climate
- Extremes of temperature
- Precipitation
- Darkness
- Topography

Figure 3-4 summarizes what is known about these factor relationships with walking and biking. What the studies suggest is that most of these factors (excluding topography, which was essentially discussed in relation to facilities) are transient in their effects. In other words, there may be an impact on behavior when the particular event is occurring, but the event is not considered "normal" time. For example, a period of extended unusually high temperatures and humidity might affect normal levels of walking and biking, but probably will not be a sustained effect, and normal behavior will return when conditions return to normal. The gray area here would seem to be in the duration of the event(s), and whether it is an anomaly or sufficiently predictable that it defines the area's "climate." In such cases, climate could act to set an overall expectation of conditions and behavioral norms. For example, it might be fair to assume that levels of biking and walking in Phoenix – where summer temperatures routinely exceed 100°F – would be less due to this extreme, and at least one cross-sectional study has confirmed that non-motorized travel in Sun Belt cities is lower than in the more temperate climates. However, one also observes that places like Minneapolis and Chicago with extended cold and snowy winters, also have some of the highest walking and biking rates in the country. The most likely explanation for this conundrum may be the design of the respective cities, where the older northern cities have more compact, mixed-use environments that support walking and biking.

Appendices 5 and 6 of the Contractor's Final Report supply much more information on this topic gleaned from prior studies. Efforts to include temperature and precipitation variables in the new models created by the project did not yield consistent or significant results. Topography, however, did prove significant and is included in the models as a variable.

Natural Environment	
WALKING	➢ Climate: Regions of the United States with extended hot and/or humid summers have walk rates less than half those in more temperate regions; however, this finding may be more associated with Sun Belt cities that are younger and have been shaped around the automobile (Pucher & Renne, 2003). ➢ Temperature: Extreme high temperatures are more of a deterrent than cold temperatures (Schneider, et al., 2009). ➢ Weather: Precipitation is more influential than temperature for walking (Schneider, et al., 2009). ➢ Precipitation: The potential for rain is more of a deterrent than the amount of rain itself (Nankervis, 1999). ➢ Darkness: A significant deterrent to walking, but less than with biking; more of an issue in crime-prone areas (Cervero and Duncan, 2003). ➢ Topography: Steep slopes are a deterrent to walking, though not as much for walking as for biking. Slope is more important as a factor for work-related trips than for discretionary (Cervero and Duncan, 2003).
BICYCLING	➢ Climate: Areas with cold winters may see a 50% reduction in bike activity levels; areas that are both cold and snowy may see an 80% decline. Effects of hot/humid climate not as well studied (Pratt, et al., 2012). ➢ Temperature: Ridership generally increases with temperatures up to 90º F; effect of humidity believed important but not well studied (Lewin, 2011). ➢ Weather: Biggest impact of weather extremes is on recreational riders (Lewin, 2011). ➢ Precipitation: Precipitation is more influential than temperature for biking (Lewin, 2011). ➢ Darkness: Measured to be five times more important to cyclists than pedestrians (Cervero and Duncan, 2003). ➢ Topography: Hills and steep grades discourage bike use or choice of destination or route. Cyclists are more sensitive to steep grades than pedestrians. Experienced riders are more tolerant of grades (Cervero and Duncan, 2003).

Figure 3-4. Environmental factors affecting walking and biking.

3.6 Sociodemographic Factors

Chapter 2 presented information on the types of people who walk and bike. The discussion in this chapter attempts to look more deeply into how certain characteristics are more associated with particular behavioral patterns or needs. The real question to the planner in using this information, however, is in whether the result is used to reduce the estimate of demand because particular demographics have not walked or biked in the past because of such factors, or if by understanding which factors are particularly important to these groups, whether facilities, plans, or improvements can be designed that address these particular concerns. Figure 3-5 summarizes these factors.

For example, the NHTS survey data indicate that men are much more likely to be regular bikers than women – both for utilitarian and recreational travel. In terms of walking, men and women are equally likely to walk to work, but they are less likely than women to walk for recreation/exercise and to reach transit. Walking and biking rates decline with age and with higher income, though more in-depth studies of the behavioral differences indicate that women and older riders are much more concerned about the safety and security offered by the land use setting and the travel networks. If it is an objective to encourage more people across a broader sociodemographic spectrum to bicycle, then factors such as these should be carefully considered in the design of both communities and facilities.

Similarly, when factors such as age, income, education, vehicle ownership, and ethnicity are examined, the possibility that these trends seen in domestic travel data may be intertwined with others must be considered, raising the question of which effect is dominating. In the case of age, both walking and biking decline with age, although in Europe the trends are more constant and, in fact, may increase with age above 65. In the United States, the behavior studies show that walking and biking for utilitarian purposes are highest for younger travelers, while the rates for exercise and recreation are highest among older people. Similar trends are seen in relation to income and ethnicity, with minorities more likely to walk or

Sociodemographic Factors	
WALKING	➢ Gender: Men and women are equally likely to walk to work (2001 NHTS); Men are 13% less likely to walk for recreation/exercise or to access transit. Rates of walk to work are similar, and no difference in average trip distance (Agrawal & Schimek, 2007). ➢ Age: Rates decline with age; persons 65 and older are 25% less likely than average to walk for utilitarian purposes, but 39% more likely to walk for recreation or exercise (Pucher & Dijkstra, 2003). ➢ Income: Walking for utilitarian purposes declines by 40% once income exceeds $30k, while walking for recreation or exercise increases steadily as income exceeds $30k (Agrawal & Schimek, 2007). ➢ Vehicle Ownership: Walk shares are 3.5 times higher for zero-car households than single-car households; persons in households where number of drivers exceed number of vehicles average a 12.3% walk share, compared to 7% where vehicles outnumber drivers (Agrawal & Schimek, 2007). ➢ Education: Rates of walking for both utilitarian and recreational purposes increase with higher levels of educational attainment (Agrawal & Schimek, 2007). ➢ Ethnicity: All minorities engage in more utilitarian walking than whites or Asians, while the reverse is true for recreational walking (Agrawal & Schimek, 2007).
BICYCLING	➢ Gender: Men are 2 to 3 times more likely to be regular cyclists (NCHRP 552, 2006; Moudon, et al., 2007; Dill & Voros, 2007). Non-commuting cyclists 50% more likely to be male (Stinson & Bhat, 2004). ➢ Age: Rates decline with age; the highest rates being for young to middle aged (Moudon, et al., 2007; Dill & Voros, 2007). ➢ Income: Persons with incomes of $100k and above were much more likely to be regular riders (30%) than those from households with incomes <$35k, though relationships in the other income strata were not systematic (Dill & Voros, 2007). ➢ Vehicle Ownership: 22% of people in households with fewer vehicles than adults are regular riders, versus 19% where vehicles equal or exceed adults (Dill & Voros, 2007). ➢ Education: Having a college degree showed 2.8 greater odds of being a regular cyclist, but was found to be negatively correlated with commute cycling (Sener, Eluru, & Bhat, 2010). ➢ Ethnicity: No firm relationships were found between race/ethnicity and regular bicycle use.

Figure 3-5. Sociodemographic factors affecting walking and biking.

bike for non-discretionary travel, and whites doing so more for social/recreational (discretionary) travel. The key question is in whether this behavior is attributable to the sociodemographic characteristics. For example, are people who are older and more financially secure less likely to walk or bike because they do not have to, or is it because when they have those characteristics in America they most likely live in suburbs, where walking or biking opportunities for non-recreational travel are very limited or non-existent? Those households are also likely to have more vehicles and more drivers.

Most of the travel models developed by NCHRP Project 08-78 have taken these factors into account, and in most cases are included in the model structure. The tour-based models explicitly differentiate among male and female riders and work and non-work travel when identifying optimal bicycle paths for these populations. Planning professionals need to apply relationships like those in Figure 3-5 judiciously and question how much the sociodemographic factors are responsible for the choice. This is why accounting for these factors simultaneously with the variables associated with the transportation and land use setting using well-specified choice-based models is the preferred approach.

3.7 Attitudes and Perceptions

This final category of factors is closely related to the previous category, in that it involves "human factors" involved in travel decision-making. Although these factors may be tied to various sociodemographic subgroups, there are broader issues about how these potential travelers "feel" about their choices as opposed to the physical realities that may be present.

Figure 3-6 presents results obtained from a 2002 National Survey of Bicycle and Pedestrian Attitudes and Behavior conducted by the U.S. DOT. This survey explored why people do not walk or bicycle more often. In reviewing the responses, the most common reasons given seem to have little to do with see-

Attitudes and Perceptions	
WALKING	➢ Primary reasons for not walking: Health or disability (24.5%), weather related (22%), too busy (18.8%) (National Survey of Bicycle and Pedestrian Attitudes and Behaviors, 2002). ➢ Minor reasons for not walking: Other transportation is faster (4%), do not like to walk (3.5%), no safe place to walk (3%), own a vehicle and prefer to drive (2.5%) (National Survey of Bicycle and Pedestrian Attitudes and Behaviors, 2002). In this response, no safe place to walk is more tied to having a sidewalk than the overall fear of traffic exposure or security (see below). ➢ Safety: Presence of traffic control devices and safe vehicle speeds ranked 2^{nd} and 3^{rd} after shortest distance (Weinstein and Schinek, 2005). ➢ Security: The elderly, minorities, and women are most likely to curtail walk travel due to concerns about personal safety, particularly after dark (Committee on Physical Activity, Health and Transportation, 2005).
BICYCLING	➢ Safety appears to be the overriding factor influencing attitudes toward and willingness to travel by bicycle: All riders are apprehensive about riding in motor vehicle traffic, and will deviate from the shortest route to avoid streets with heavy traffic; regular/experienced riders may be less concerned about traffic safety than infrequent/inexperience riders, but they still demonstrate preference for routes/facilities that buffer them from traffic (Dill & Gliebe, 2008; Hunt & Abraham, 2006; Krizek/NCHRP 552, 2006; Sener & Bhat, 2010)

Figure 3-6. Attitudinal and perceptual factors affecting walking and biking.

ing walking or biking as inferior or irrelevant modes, or even concerns about safety. The primary reasons given seemed to have more to do with health or weather, or even simply lack of interest or time. Much less common answers had to do with age, having a safe place to walk or bike, or preferring to drive. Upon review of the other research experience presented herein, it seems hard to accept these findings as realistic when concerns about safety and security seem paramount in the empirical studies. Those empirical studies suggest that one or more of the following explanations may provide insight on the responses received in the survey:

- For many people, walking is not a realistic mode for anything but exercise or recreation, because they are not within reasonable access of opportunities or activities important to personal or household business.
- Although bicycling offers a wider range than walking in terms of opportunities, potential users still face the concerns of directness and safety. Except for recreational biking, paths to relevant opportunities are likely to be circuitous and/or require the user to vie with vehicle traffic on shared roads or at crossings. The research shows that only the more experienced and determined individual will travel by bicycle under these circumstances.

These questions bring to the fore the concept of self-selection and the relevance it has in describing these behavioral traits. Are certain types of people inherently disposed to particular lifestyles that greatly determine how they will choose to travel? The argument is that people who like living in urban settings are also comfortable with traveling by transit, walking, or bicycle, while those who prefer more subdued, residential settings also prefer the lifestyle that goes with that setting, including accomplishing travel needs via personal vehicle. The argument further suggests that simply creating urban places and walkable environments will not induce those who do not embrace that lifestyle to begin to walk, bike, or use transit, i.e., that their preferences are determined by a behavioral cohort that will not change, even in a very different environment.

Amid growing evidence of retirees and empty-nesters opting for urban condominium living in order to have less home maintenance and be less car dependent and of millennials and couples without children preferring an urban setting for its convenience, vitality, and range of opportunities, there has been cause for debate. How widespread or sustained these trends is uncertain, but it leaves the dilemma of "nature or nurture" in the question of opportunity and propensity to walk or bike, or use either mode to better use transit.

Although the self-selection argument has had considerable support, particularly in academic circles, and resulted in many studies to try to quantify the magnitude of the effect, most studies appear to show that the environment factors (land use and transportation alternatives) are as or more important in predicting behavior than an embedded pro/anti mode attitude. The interested reader is urged to consult the body of experience on this topic referenced in Appendix 7 of the Contractor's Final Report.

CHAPTER 4

Best-Practice Methods for Estimating Bicycle and Pedestrian Demand

4.1 Identification of Planning Needs and Assessment of Available Tools

The goal of NCHRP Project 08-78 has been to provide planners and analysts needing to estimate the demand for bicycle or pedestrian travel with (1) a better understanding of the key underlying relationships and (2) planning tools that put those relationships to work. Planning needs involving bicycle and pedestrian travel are wide ranging, from representing non-motorized travel activity levels and impacts in regional plans to estimating demand for an individual facility. In general, it is helpful to organize these needs in relation to geographic scale:

- **Regional Planning Scale:** Exemplary of the plans and analyses performed by MPOs, particularly in relation to long-range regional transportation plan (RTP) updates or supporting areawide policy or investment analyses. Non-motorized planning needs include
  - Projecting areawide bicycle and pedestrian activity levels
  - Accounting for bicycle and pedestrian access in estimating transit use
  - Effects of bicycle/pedestrian mode choice on the demand for auto travel and subsequent impact on congestion and VMT
  - Impacts of bicycle/pedestrian travel on effectiveness of compact mixed-use development (i.e., smart growth), and the converse
  - Use in regional visioning or scenario planning.
- **Corridor and Subarea Analysis Scale:** To support analysis of travel in corridors, activity centers, neighborhoods, or transit-oriented development (TOD) plans where success of a modal investment, viability of a local land use plan, or the magnitude of traffic impacts are closely tied to the interaction between the corresponding transportation and land use plans. These analyses may be part of local comprehensive or master planning and involve stakeholders from the local planning, zoning, transportation, development, and residential communities. Visualization and the ability to support interaction are important needs, as is the degree to which walking and biking support local trip-making and circulation and access to transit.
- **Facility Demand and Project Development Scale:** For project (facility) planning, it is important to (1) gage the impact of improvements in accessibility provided by the respective networks on walking and bicycling activity levels, (2) evaluate priorities for the most effective improvements, and (3) account for the corroborative effects of the built environment.

In addition to the geographic scaling that differentiates these categories, there is an alignment with the types of entities who would be performing the analysis, the types of questions being asked, accuracy needs, response time, and the tools and expertise available. Table 4-1 characterizes these different audiences and the tools they are using.

NCHRP Project 08-78 evaluated numerous existing tools and methods developed in relation to bicycle and pedestrian travel. The goal was to identify those tools that reflected the best existing practice in addressing the three categories of application needs above. Table 4-2 provides an overview of the range of tools evaluated, along with noteworthy examples of each. In some cases, the methods are free-standing tools; in other cases, they are enhancements or supporting techniques for existing tools. Some of these examples fall into the category of "research models," developed mainly to investigate and quantify key relationships, although the models themselves are generally not suitable as planning tools.

In relation to **Regional Planning**, standard practice consists of the traditional four-step trip-based regional forecasting models, which rely on TAZs as their geospatial structure when estimating trip generation, destination, and modal choice. These methods have difficulty representing non-motorized

Table 4-1. Framework for relating planning needs to applications and user characteristics.

Scope	Regional	Corridor/Subarea	Project/Facility
Geographic scale	Region Local (county, large municipality)	Multimodal corridor; Transit line/node; Activity center; Neighborhood	Development site; Travel network link; Intersection
Agency	MPO, County Planning City Planning	MPO, County, Municipality, Transit Agency	County/Municipality; Developer;
Practitioner type	Transportation planner Travel modeler; Bike/Ped planner	Transportation planner; Bike/ped planner Traffic engineer	Bike/ped planner Traffic engineer
Key Questions	Walk/bike travel levels; Access to transit; Mode choice, VMT; Land Use viability	Access to transit Person/vehicle conflicts Network coverage & connectivity	Network coverage & continuity; Safety; Link demand levels
Resources	Computer tools & expertise; GIS tools/data; Travel survey & other specialized data	Computer tools & expertise; GIS tools/data; Travel survey & other specialized data	Simple methods: Maps & Counts Advanced methods: GIS tools/ data; Travel survey & other specialized data
Current tools	Regional models (trip based or activity based); Scenario planning tools w/ land use sensitivity	Regional models; Scenario planning tools Planning standards	Direct demand models; Planning standards; Professional judgment; Factoring methods

travel demand, largely because of coarse scale of analysis attributable to the TAZ aggregation of land use. If these models are used to account for non-motorized travel, it is typically limited to the trip generation step; non-motorized trip productions and attractions are estimated, but they are then removed from the remainder of the analysis, which focuses on motor vehicle trips.

Three types of efforts have been made to improve the sensitivity of these widely used transportation planning models to land use and non-motorized travel:

- **Enhancements:** Various types of enhancements to the steps of the modeling, including sensitizing trip generation to land use factors, reducing the size of TAZs, and taking advantage of the smaller zones to try to carry non-motorized trips further into destination choice and mode split. *(A similar approach developed under NCHRP Project 08-78 is presented as one of the recommended methods.)*
- **Post Processors:** Development of ancillary models that use GIS methods to reflect differences in land use at a much finer level of geography (parcels or grid cells); these models are then used to modify preliminary results from the trip-based model.
- **Microsimulation:** A new class of activity- or tour-based models developed using parcel or point-level information instead of TAZs to more closely associate travel choices with the adjacent (as well as regional) transportation and land use characteristics. The finer scale makes it possible to directly incorporate walking and biking as modes. *(One of the new methods developed by the NCHRP 08-78 project takes advantage of such a tour-based structure.)*

Most of the reviewed methods fall into the category of **facility-demand** estimation tools. Because the regional modeling tools are not easily accessed or understood by many practitioners, nor realistically represent non-motorized travel, practitioners needing answers for planning bicycle or pedestrian systems have been obliged to develop their own tools. Tools in this category include

- **Factoring and sketch-planning methods** that estimate demand by projecting from a similar project or situation, relying on mode-choice information from Census Journey-to-Work statistics, or using various rules of thumb to relate bike/pedestrian use levels to existing or new population or activity levels.
- **Direct demand models**, which are among the newest and most widely used tools in this genre, developed using regression models to explain demand levels as recorded in counts as a function of measured characteristics of the adjacent environment (e.g., population, employment by type, major generators, and facility proportions).

Table 4-2. Overview of existing tools and methods for non-motorized planning.

Application Category/Approach	Examples
Regional Planning	
Trip generation: trip generation augmented by special models that estimate non-motorized productions based on density, land use mix, accessibility, and/or urban design	Atlanta (ARC), Austin (CAMPO), Portland (Metro), Durham, NC; Buffalo
Auto ownership: context-enhanced auto ownership as input to non-motorized trip production	Atlanta (ARC), Austin (CAMPO), Portland (Metro), Los Angeles (SCAG)
Destination choice: separate models to forecast trip generation for inter and intrazonal trips based on land use/accessibility context factors	Buffalo, Durham
Mode choice: Special context-sensitive models to estimate non-motorized mode split for intrazonal trips	Buffalo, Durham
Activity/Tour-based models: projected replacement to trip-based models, spatial resolution reduced to parcel level and individual travelers – remove TAZ aggregation bias in clarifying non-motorized mode use; travel treated as simple versus complex tours which impact mode choice	Edmonton Transport Analysis Model; San Francisco (SFCTA), Sacramento (SACOG), many under development
Corridor, Subarea and TOD Planning	
Scenario Planning Tools: Estimation of non-motorized travel and VMT reduction in relation to alternative land use and transportation investment scenarios	US EPA Index 4D method (2001); Frank & Co. I-PLACES (2008); Ewing, et al.—MXD model (2010); Kuzmyak, et al.—Local Sustainability Planning Model (2010)
Walk Trip Models: Models that resemble four-step regional approach, but employ "pedestrian" zones instead of TAZs; create trip tables and assign to facilities	PedContext – Maryland State Highway Administration and Univ of MD Nat Center for Smart Growth (2004/08); Clifton—MoPeD Model (2008)
Facility Planning	
Factoring and sketch-planning methods: attempt to predict facility-demand levels based on peer comparisons, application of trip generation rates to sociodemographic data, association with other related data/trends, proximity rules, etc.	Lewis & Kirk (1997); Wigan, et al. (1998); Goldsmith (1997); Ercolano, et al. (1997); Clark (1997); Krizek, et al. (2006)
Direct Demand: Project bicycle or pedestrian volumes based on counts related to various context and facility factors through regression models	Ashley & Banister (1989); Parkin & Wardman (2008); U.C. Berkeley—Seamless Travel (2010); Schneider, et al.—Alameda (2009); Liu & Griswold (2008); Fehr & Peers—Santa Monica (2010)
Aggregate demand: Seek to quantify relationship between overall demand (e.g., annual regional bike trips) and underlying factors, often as a way of gauging importance of infrastructure types and extents	Baltes (1996); Dill & Carr (2003); Buehler and Pucher (2011); Nelson & Allen (1997)
Route or path choice: Methods that try to account for the characteristics of a transportation network or its users in determining route choice, and for identifying network improvement priorities	Hunt & Abraham (2006); Krizek (2006); Menghini, et al. (2009); Dill & Gliebe (2008); Hood, et al. (2011); Space Syntax—Raford and Ragland, Oakland pedestrian master plan (2003); McCahill & Garrick—Cambridge MA bike network (2008)

Also among the tools in this genre that provide valuable insights on factor relationships but lack the structure to serve as complete or practical planning tools are

- **Aggregate demand** methods that attempt to explain regional (or similar large area) activity levels of walking or biking based on aggregate population, employment, density, facility mileage, and even climate factors.
- **Route choice models** that focus on the factors that affect choice of route. These models have their greatest value in quantifying the degree to which particular features (e.g., type facility, hilliness, and so forth) affect the utility and selection of a link or path.

Tools for the middle of the planning spectrum, **Corridor and Subarea** planning, were found to be the leanest of the offerings in the existing body of methods or focus of research. NCHRP Project 08-78 found that planning at this level is either done with a focused application of the respective regional model (albeit lacking sensitivity to land use and non-motorized travel), or without analytic tools and relying instead on trip generation rates and traffic level of service standards.

Two variations on the focused regional model approach are

- **Scenario Planning** tools, such as Envision Plus, Urban Footprint, I-PLACES, and EPA's Smart Growth Index, rely heavily on GIS to depict alternative land use and transportation configurations and estimate their effect on travel behavior. These tools may be used independently for local planning, or in tandem with the respective regional model for larger area assessments. *(These tools served as a basis for NCHRP Project 08-78's design and testing of a GIS-based accessibility approach, which expands the capability of these existing tools in important ways, particularly in relation to non-motorized travel).*
- **Walk Trip Models:** Two models were found to have interesting capability and relevance for this subarea level of analysis: PedContext and its sequel, the Model of Pedestrian Demand, or MoPeD. These models estimate pedestrian travel (only) in relation to land use and transportation network features. Both methods are similar to the four-step process, but operate at a much finer level of detail—PAZs—which are roughly the scale of a city block. Both perform trip generation (for walk trips only), create trip tables, and assign the trips to the local walk network to produce link-level and intersection-level activity estimates. The principal difference between the two methods is the degree of detail and rigor applied, with MoPeD being the less detailed of the two.

Table 4-2 provides referenced examples for each type of tool or procedure. These and similar examples are documented in greater detail in Appendix 7 of the Contractor's Final Report.

4.2 Addressing the Gaps

The review and evaluation of the existing tools corroborated initial perceptions that the current methods fell short in being able to address the range of planning and decision-making needs. In general, an overall paradigm to explain bicycle and pedestrian travel decisions in relation to travel demand theory and in consideration of the mode-specific factors of importance identified in the research is lacking.

This paradigm should attempt to account for the following elements:

- Sociodemographic characteristics of the traveler and the traveler's household
- Trip purpose
- Access to purpose-specific activities by each mode, as afforded by the patterns of land use and the design of the transportation network providing connectivity with those opportunities

A model that includes such a structure is said to be "choice-based," meaning that each of the factors enabling the individual to choose from among his/her destination or modal options is part of predicting their behavior. This choice is generally determined as a probability that the traveler will pick alternative A over alternative B, C, or D based on their comparative advantages (utilities) and how those elements are weighed in importance by the particular type of individual.

Although the regional models are regarded as choice-based, they neither include all of the relevant modes in the set of choices nor provide the detail to properly calculate the utility for the non-motorized choices (i.e., land use attractions and facilities relevant for walk or bicycle travel). At the other end of the spectrum are the facility-demand models, which are not choice based. Rather, a set of descriptive environmental context variables are used to explain variations in usage levels (through activity counts) across a sample of sites; however, the counts—and hence the explanatory models—do not reveal behavioral motivation, in terms of traveler characteristics, trip purpose, origin-destination, or available alternatives.

This dichotomy creates a dilemma with regard to designing the best user tools. Ideally, a choice-based approach should be used for most bicycle-pedestrian planning assessments. As characterized in Figure 4-1, the choice-based process progresses from trip generation to destination choice, then mode choice, then assignment of trips by mode to the respective network. From the network assignment step it is possible to ascertain facility volumes (link or intersection). Assuming the choices are captured correctly in the respective models, this approach allows for multiple forces to interact toward the final outcome, while providing multiple places for testing planning interventions or other assumptions.

In contrast, the facility-based approach focuses directly on explaining link or intersection counts. Although this approach is much less cumbersome for the planner, it also is considerably less informative as to composition or behavioral motivation underlying the observed volumes.

To improve the overall caliber of bicycle/pedestrian planning tools, project research has focused heavily on forging a satisfactory choice-based approach, both to provide needed illumination about the behavioral relationships in non-motorized travel and, by accounting for those relationships, enabling planners to control for those variables in an analysis. Therefore, most of the tools featured in the guidebook

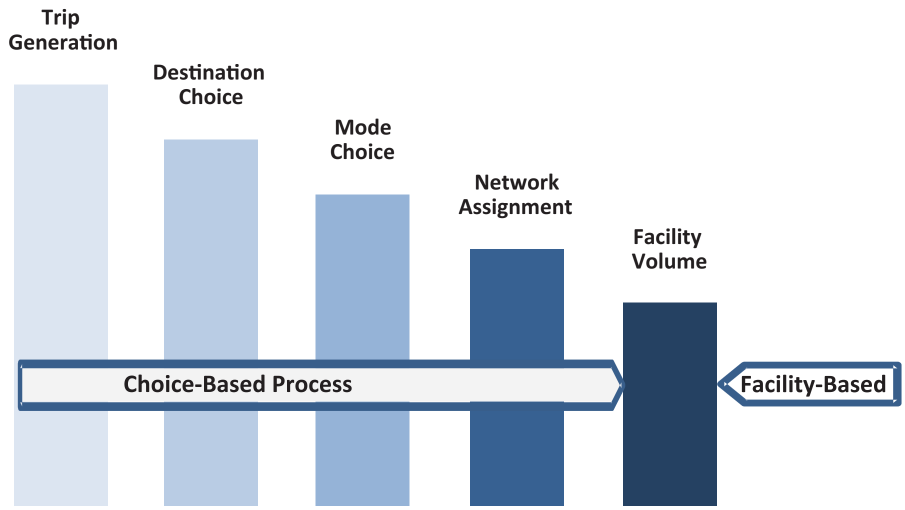


Figure 4-1. Choice-based versus facility-based activity estimation approaches.

will embody some semblance of this holistic, choice-based behavioral structure.

This is not to say that the facility-based methods have no value in bicycle/pedestrian planning. For certain types of analyses (e.g., extrapolating demand from a pre-existing situation in response to incremental changes in local development) facility-based methods may be helpful in supporting localized decisions related to pedestrian connections or intersection crossings, grid traffic management, or additional bike travel. However, because facility-based methods lack a behavioral structure, their use for land use planning, planning for changes to the bike or walk networks as regards connectivity would be limited because they do not incorporate those relationships in their structure.

The following guiding principles have been applied in developing and suggesting methods for bicycle and pedestrian planning and demand estimation:

- The recommended planning tools should stress a choice-based structure.
- The modeling tools developed or brought forward by the project should bring the choice-based option within the ability and resource range of more practitioners.
- The tools should be able to assess the relative importance of land use features versus facility improvements, toward the ideal combination of both.
- To the degree possible, the tools should be applicable in circumstances ranging from full deployment in regional planning to strategic use of the relationships in scenario planning or facility design.
- The choice-based tools and relationships should be able to assist in improving the structure and accuracy of facility-demand tools.

4.3 Introducing the Guidebook Planning Tools

Rather than a single all-purpose model, the guidebook features some tools that may be of particular value to practitioners, depending on the scale of the analysis, the decision being supported, skill level of the user, and available resources. Recommended tools are listed in Table 4-3.

The tools are listed in generally declining order of complexity, which also roughly corresponds to the geographic scale at which they most likely will be applied. The first three tools were all created through research performed under NCHRP Project 08-78, taking advantage of willing local partners, suitable environments for walking and bicycling, and above-average data to support the research. Two of the projects were performed using data from the Puget Sound Regional Council (PSRC) in the Seattle area, while the third focused on Arlington County, VA, using data from the Metropolitan Washington Council of Governments (MWCOG).

Tour-Generation and Mode-Split Models: In conjunction with the Puget Sound Council of Governments' efforts to develop a new tour-based model structure for the Seattle region, research team members took advantage of various new data and tools to develop a set of pedestrian and bicycle models. The set includes a procedure for generating tours (as opposed to trips) by purpose, and a pair of modal-split models that predict walk, bike, transit, and auto choice for five tour purposes. The variables included in these models provide access to a broad spectrum of sociodemographic, land use, transportation network characteristics, and accessibility in estimating (separately) bicycle and pedestrian demand, as well as the effect on transit use of non-motorized accessibility. Although immediately suited to working in an activity- or

Table 4-3. Bicycle/pedestrian planning tools included in guidebook.

Modeling Approach	Source	Characteristics
Tour Generation/ Mode Split	NCHRP 8-78 (Seattle/PSRC data)	Simple/complex tour generation for 8 trip purposes (sociodemographic characteristics, land use, local & regional accessibility) Mode choice (walk, bike, transit, auto) for 5 trip purposes (sociodemographics, land use, local & regional accessibility, Fully detailed walk and bicycle networks, physical attributes affect impedance
GIS-Accessibility Model	NCHRP 8-78 (Arlington, VA/MWCOG data)	Uses GIS layering to create accessibility scores for walk, bike, transit, and auto. Links mode choice with accessibility scores at trip origin and destination Estimates mode share at block level for HBW, HBO, NHB and WBO purposes Builds walk trip table (but does not assign) Highly visual presentation
Trip-Based Model Enhancements	NCHRP 8-78 (Seattle/PSRC data)	Strategic changes to traditional four-step TAZ model to improve sensitivity to land use and non-motorized travel Sensitizes auto ownership and trip generation to land use characteristics Performs pre-mode choice to distinguish inter- versus intrazonal trips Performs mode choice separately for intra zone (drive-alone, shared-ride, walk) and inter-zone (drive, shared-ride, transit, walk, bike) travel
Pedestrian Demand Models	PedContext and MoPeD (Univ. of MD/ Maryland DOT)	Modified four-step approach focused on estimating walk trips Walk trip generation for several purposes at PAZ level Creates walk trip tables, assigns trips to walk network
Bicycle Route Choice Models	San Francisco County Transp. Authority Portland State Univ.	Models built from GPS data to predict choice of route for bicycle riders Quantifies importance of route characteristics (type facility, gradient, directness, traffic exposure)
Facility-Demand Models	Fehr & Peers (Santa Monica)	Separate bicycle and pedestrian direct demand models Predict PM peak hour bicycle demand based on employment density, proximity to bike facilities, land use mix, and intersections Predict PM peak hour walk demand based on employment density, proximity to shopping, PM bus frequency, and traffic speeds

tour-based environment, the methods may also be used to enhance conventional trip-based models, and a spreadsheet version of the model can be used for simultaneous testing of any of the relationships in the models or for creating sketch-planning tools.

GIS-Based Walk-Accessibility Model: Using data from the Metropolitan Washington (DC) Council of Governments (MWCOG) for Arlington County, VA, the research team developed a method for estimating walk trip generation and mode split that relies exclusively on GIS tools and data. The method uses geospatial overlay and network path-building procedures readily available in GIS to calculate measures of accessibility to or from any point by any mode and by type of attraction. By comparing the modal accessibilities, it is possible to estimate mode split and create walk trip tables by purpose. The current model does not perform network assignment of the walk trips, although it is assumed that users can apply such features in their existing transportation planning software to do so. Given insufficient data, the current model does not forecast bicycle demand, although the structure will readily accommodate such an enhancement when adequate data are available. This approach offers a new and intuitive way of interpreting modal choice that is very responsive to changes in the built environment (land use) or the travel networks such as would occur in corridor or subarea planning, using generally available data and with relative independence from the respective regional travel model.

Enhancements to Trip-Based Models: Research team members also worked with the PSRC data in Seattle to create a template for systematically enhancing a conventional TAZ/trip-based regional model to improve its sensitivity to land use and non-motorized travel. Advanced statistical methods were used to create enhancements to the Auto Ownership, Trip Generation, Trip Distribution, and Mode-Choice steps in the existing PSRC regional model. Measures of auto and non-motorized accessibility play a major role in these enhancements. Although pedestrian and bicycle mode choice are still constrained by the TAZ structure, the methods improve on the current process by introducing a "pre-mode-split" step, which first divides trips into intra- versus interzonal groups and then performs a mode-split specific step to those groups. Although the enhanced regional model may not be as fluid as the tour-based or GIS-accessibility approaches in overcoming TAZ aggregation issues, the enhanced regional model takes advantage of the new smaller TAZs adopted by many MPOs and provides considerably more sensitivity in existing models.

Walk Trip Generation and Flow Models: The PedContext and MoPeD models developed and tested in Maryland offer a set of methods for estimating walking trips and creating walk trip tables at a block level. Both methods follow a variation of the four-step process, and both assign the walk trips to the local walk network to estimate link and intersection activity levels. The difference in the methods is the degree of detail each applies at each step, with the MoPeD model being the less detailed of the two. Another tool grouped in this set is a pedestrian model recently produced for Portland Metro that is similar to MoPeD, but which serves more as a support procedure for the regional travel model.

Facility Demand: Two types of models are included in this category: bicycle route choice models (e.g., those developed by the San Francisco County Transportation Authority and Portland State University) and direct demand models which predict walk or bike facility use and volumes based on observed counts and context-driven regression models. A third type of model reviewed falls into the category of "network simulation," and is most exemplified by the Space Syntax model, which estimates network flows using network geometric relationships. This model is presented in discussion which follows, but was not included in the list of recommended tools because (1) it is proprietary, and (2) it was difficult to acquire enough information on the inner workings to be able to fairly evaluate its performance and validity.

The next section provides the user with an overview of each of the tools. The objective is to give enough information on how the tools were developed, their structure, and how they work to establish a basic understanding of what they are and what they do. Chapter 5 then integrates and synthesizes this information to help users distinguish among the tools and determine which to choose for their particular application needs. Users may want to refer to the profiles below in Section 4.4 as they become more involved in looking at the tools and their capabilities. Full documentation for all the models is also provided: for those tools developed directly by NCHRP Project 08-78, Appendices 1 (Seattle Tour-Based Model), 2 (Arlington Walk-Accessibility) and 3 (Trip-based Model Enhancements) of the Contractor's Final Report contain full descriptions of each tool. Citations and website addresses are provided for the other tools.

4.4 Overview of Recommended Guidebook Tools

Tour-Based Approach

The researchers used data and resources from the PSRC in Seattle to create a new set of models that estimate the demand for walking and bicycle travel based on characteristics of the traveler, purpose of the trip, opportunities present in the prevailing land use, and the accessibility provided by the respective travel networks. These models offer important insights into non-motorized travel behavior, in large part because the extremely high level of detail is much more effective in capturing factors that influence walk or bicycle mode choice.

The models were developed using a tour-based model structure. Tour- and activity-based models have gained increased attention from transportation planners and planning agencies for use in regional and even statewide planning. They are different from conventional TAZ-level trip-based models in the following ways:

- **Parcels instead of TAZs:** Analysis is performed at a much finer scale of geospatial resolution, generally working with land use parcels as opposed to TAZs. This allows for much sharper characterization of the travel environment and the factors that affect non-motorized travel.
- **Tours instead of Trips:** Travel is portrayed in the form of complete "tours" rather than a series of individual "trips." This is more reflective of how travel actually occurs (i.e., with one or more purposes accomplished before completing a "round trip") and has an important bearing on mode use. Travelers in more urban, mixed-use environments make more journeys as *simple* out-and-back tours, while journeys in lower density/separated land use settings more

commonly occur as multi-stop *complex* tours, for efficiency. The multi-stop tours are generally made by auto, while simple tours are more likely to be made by walking, biking, or transit.

- **Individuals instead of Households:** Tour or activity-based models focus on the travel of individuals, rather than aggregate households. This allows inclusion of key socio-demographic factors such as age, gender, driver status, and employment/student status, along with household composition (income, size, and vehicle ownership). These factors have been found to be fairly important in explaining non-motorized travel behavior tendencies.

As with most of the guidebook tools, *accessibility*—the measure of the opportunities that can be reached with the land use patterns and modal options at hand—is a central theme in this approach. Determining accessibility for non-motorized modes is more challenging than with auto, given the need to perform the assessment at a much finer geographic level and the importance of physical factors in gauging the performance of the travel networks. The Seattle approach used the following steps to measure accessibility:

- **Explicit Networks:** Travel distance and time are particularly important factors in the non-motorized travel decision. All else being equal, people considering a walk or bicycle trip rank straight line distance as the number one factor in assessing their travel options, which is heavily determined by the coverage and connectivity of the respective travel network. However, cyclists and pedestrians are also highly sensitive to personal safety, and so will prefer routes with less exposure to vehicle traffic, even if they involve longer distances; steep hills are a similar discouragement. To ensure that the tour models accurately reflected these sensitivities, considerable care was devoted to mapping and quantifying the various attributes of the bicycle and pedestrian networks. The result is a sharper depiction of the service characteristics provided by the respective network when calculating the statistical relationships.
- **Buffering Walk and Bike Opportunities:** Accessibility to opportunities by walk and bicycle from each potential trip origin or destination was estimated using a buffering process, which sums the number of opportunities within a "reasonable" distance (1 mile for walk, 2 miles for bike), with each opportunity discounted by its respective over-the-network distance (not travel time because that information was not available for walk/bike). The effect of longer distances making far-away destinations less desirable is represented through a logistic distance-decay relationship, as illustrated in Figure 4-2. These curves were plotted using data from the regional household travel survey. The flat portions at the beginning of each curve imply that distance is not important for the first block or two, but then utility falls off rapidly with longer distance.
- **Competing Opportunities:** Travelers who have autos or transit service available make tradeoffs in choosing between travel to a nearby destination by walking or biking or making a vehicle trip to a more remote location. This competition is measured through a comparison of local and regional accessibility, with the latter accounting for *all* opportunities, regardless of distance, by all modes. In the tour-based model, regional accessibility is represented through a *logsum* measure, which is a summation of the accessibilities of auto driver, shared-ride, transit, and bicycle weighted by modal share as taken from the denominator of the mode/destination choice model. More details on the composition of this measure are provided in the model documentation.

With this "dual accessibility" structure, the models can be used when attempting to ascertain how walking or biking

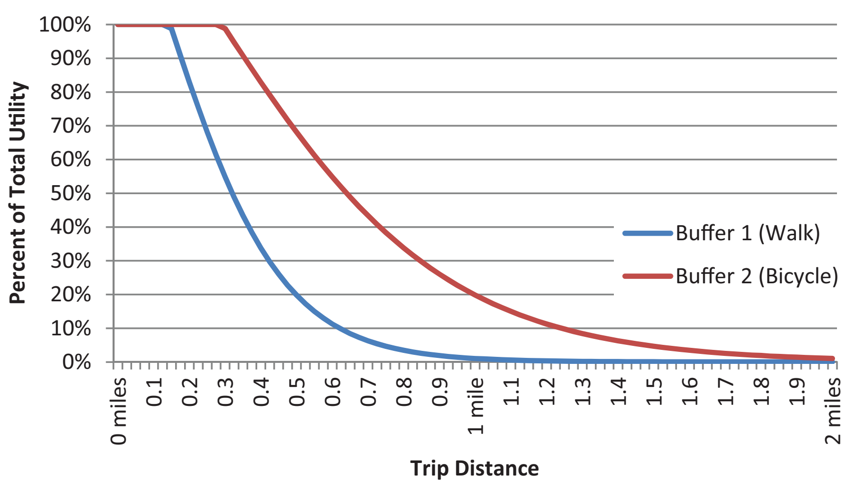


Figure 4-2. Logistic travel decay rates by distance.

would benefit from improvements in local land use or network coverage that directly improve local accessibility, or from changes that might occur regionally (e.g., new highway or transit line, congestion delay, or changes in fuel prices) that would affect the desirability of longer trips by driving or transit.

Two types of predictive models were developed for bike/pedestrian analysis:

- **Tour Generation:** A model that predicts the number of daily tours that a given individual will generate, the travel purpose of the tour, and whether the tour will be simple or complex.
- **Mode Choice:** A set of models predicting choice of mode (walking, bicycle, transit, or auto) for different trip purposes (home-based work, home-based school, home-based recreational, home-based other, and work-based other). Two different mode-choice model formats were developed:
  - **Origin-Destination**—incorporates information on land use, network, and accessibility at both origin and destination, as well as origin-destination travel time and/or cost; using this version of the model is appropriate when the location of the trip destination is known (e.g., a work or school trip).
  - **Origin Only**—includes information on land use, network, and accessibility at the origin end only; using this version is appropriate when the location of the destination is unknown (e.g., a shopping or personal business trip).

A quick overview of the models, the variables they contain, and how they work are presented below. Guidelines on how to apply the models for planning are provided in Chapter 5, including introduction to a spreadsheet version of the combined model set which accompanies the guidebook. Detailed specifications for each model (e.g., coefficients, estimation statistics, and sample size) are presented in Table A-1 (Appendix A) of the guidebook. Full documentation describing development of the models and preparation of the data is provided as Appendix 1 to the Contractor's Final Report.

In a full application, the Seattle tour-based models follow a sequence in which the number and type of tours are first estimated for a given individual. The tours are then processed by one of the mode-choice models to estimate the probability of traveling by walking, bicycle, transit or auto for each tour purpose. A simplified portrayal of the tour generation/complexity model is shown in Figure 4-3, illustrating the following steps:

- **Number of Tours:** The first step estimates the likelihood (probability) that the person will make any tours at all on the given day, and then whether they will make a second, third, or fourth tour on the same day.
- **Tour Complexity:** The next calculation is in whether the tour will be simple or complex; this is not a yes/no answer, but again a probability that separates the given tour into a simple and complex portion.
- **Tours by Purpose:** The third step is to determine the purpose of the tour. The model predicts travel for work, school, escort, personal business, shopping, eating a meal, and social/recreational. If a home-based work tour is made, a separate tour generation model estimates the number and type of work-based tours that will be made (followed by mode split).

The tour-generation model is applied to the population of potential travelers, typically represented through a synthetic population (a specially drawn demographically representative sample meant to represent the overall population). The estimated tours are then assigned to travel modes, using either of the two mode-choice models (origin-only information or both origin and destination). A simplified presentation of the origin-only mode-choice model is shown in Table 4-4, and the origin-destination model is shown in Table 4-5.

The tables show the estimated coefficients used to compute the modal shares for each tour purpose. The previous separate tour generation models for home-based shopping, eating a meal, and personal business have been collapsed to a single home-based other model for mode-choice purposes. Different variables come into play for any given mode, depending on the trip purpose, and walk and bike modes use different specifications for the buffer measures, with Buffer 1 reflecting the range for walk trips (including walk access to transit) and Buffer 2 addressing bicycle.

Table 4-6 summarizes the variables contained in these models. Planners can use these relationships in various ways, from building their own models to enhancing existing models, post-processing model results, or creating sketch-planning models for sensitivity testing or project comparisons. Suggestions for use, along with an interactive spreadsheet version of the models, are provided in Section 5.4 of Chapter 5. Elasticities for the mode-choice models are provided in Section 5.3.

GIS-Based Walk-Accessibility Approach

The other original research conducted by the NCHRP Project 08-78 team focused on developing a direct *accessibility* approach that would take maximum advantage of the capabilities offered by modern GIS tools and data. Although the tour-based approach developed in Seattle is an effort to expand the limits of what is currently possible in regional-scale models, the GIS-based accessibility seeks to create something much simpler and more intuitive in concept that might be accessible to many users and a range of applications.

Likelihood of No More Tours	
Low income HH	0.449
High income HH	-0.0743
Male	0.0834
Age < 30	0.42
Age > 50	0.0414
Zero car HH	0.552
Car competition HH	0.138
Origin entropy	0.0803
Origin average rise	6.18
Origin CL I bike path fraction	-0.349
Origin distance to transit	0.0669
Make a second tour (constant)	2.56
Make a third tour (constant)	3.39
Make a fourth tour (constant)	3.78

(if coefficient is positive (+), increases in that variable discourage additional travel)

Likelihood of Complex Tour	
Origin composite logsum	0.0347
Origin entropy	-0.201
Full-time worker	-0.349
Part-time worker	-0.251
Retired	0.229
Student	-0.425

Tour Purpose	Work	School	Escort	Pers Business	Shopping	Meal	Social-Recreat
Constant	-2.66	-3.58	-2.46	-0.715	-1.35	-2.31	-2.84
Buffer 2 Activity (purpose specific)	0.0724	0.0559	0.0804	0.0687	0.12	0.0491	0.183
Purpose-specific logsum			0.103	0.0151	0.0542	0.144	0.0669
Complex tour interaction constant	0.0687	-0.66	-0.066	-0.798	-0.458	-0.809	-1.04
Full time worker	3.02	-0.426	-1.48	-1.08	-1.11	-0.635	-0.998
Part time worker	3.03	1.4	0.16	0.0792	0.0749	-0.0344	0.154
Retired	-0.798	-1.23	-0.739	-0.252	-0.486	-0.24	-0.373
High School/Univ Student	1.75	4.93	-0.47	-0.129	-0.354	-0.223	0.247
Child age 5-15	-4.13	4.29	-1.28	-1.32	-1.74	-0.939	-0.684
Kids in Household	0.231	0.347	2.01	0.36	0.336	0.0936	0.247

Buffer 2 Activity definitions:

Work = total employment
School = relevant school enrollment
Escort = households + grade school students (if HH has school age kids)
Personal Business = service + medical employment
Shopping = retail employment
Meal = food service employment
Soc/Rec = households + service employment

Figure 4-3. Tour generation/complexity calculations (shown values are coefficients, not elasticities).

Planners as well as non-planners are familiar with Walk Score, the internet application that attempts to quantify the level of walkability for any given place on a scale of 1 to 100. This statistic is widely used to assess the richness of access to local activities and is even employed by the real estate industry as an added-value attribute when marketing properties. Although the NCHRP project did not set out to replicate Walk Score, the research showed that similar types of measures, if properly constructed and interpreted, could provide the basis for a practical and fairly accurate procedure for bicycle and pedestrian planning.

Although early uses of GIS focused on its rich mapping capabilities, its true value is the ability to perform complex mathematical tasks using geospatial overlay methods to exchange information among multiple layers. From a transportation perspective, this makes it possible to overlay the coverage and service provided by transportation networks in one layer onto the characteristics of the corresponding land use environment, leading to very realistic measures of connection between the two.

For reasons of data quality, tools, and a highly diverse transportation/land use setting, the accessibility analysis

Table 4-4. Tour mode choice models with origin-only information (shown values are estimated coefficients, not elasticities).

	Home-Based Work				Home-Based School				Home-Based Social/Rec				Home-Based Other				Work-Based			
	Walk	Bike	Transit	Auto	Walk	Bike	Transit	Auto	Walk	Bike	Transit	Auto	Walk	Bike	Transit	Auto	Walk	Bike	Transit	Auto
Constant	-7.31	-3.61	-3.78		-3.82	-7.69	-2.94		-2.92	-4.84	-5.78		-3.03	-6	-8.5		-3.49	-3.49	-0.986	
Income < $25k			0.379		1.14		2.38						-0.647		0.813					
Income > $100k	-0.546				-0.42								-0.256		-1.81					
Male	0.337	0.676			0.32	0.711				1.96				0.72						
Age <35		-1.38							-0.412		1.25		-0.26							
Age > 50		-0.833								-0.991	2.17		-0.486	-0.338						
Zero car HH				-4.69				-5				-3.09				-3.6				
Adults > Cars				-1.21				-1.16				-0.799				-0.417				
Buffer 1 attractions for purpose	0.403				0.423				0.262				0.36							
Buffer 2 attractions for purpose						0.22														
Mode/destination logsum with zero cars	0.245					0.289			0.0922						0.355		0.699			
Mode/destination logsum with full car own				0.154								0.0944				0.04				
Buffer 1 household density													0.00026							
Buffer 1 net intersection density	0.0043		0.00007								0.00048		0.0101		0.00014					
Buffer 2 net intersection density		0.0087												0.0127						
Buffer 1 average fraction rise									-29.2				-35.5							
Buffer 2 average fraction rise		-62.6				-31.4								-92.5						
Buffer 2 fraction Class 1 bike path		2.4				3.15														
Buffer 1 percent no sidewalk	-1.04						-1.38		-0.769		-2.96		-1.12				-1.6		-3.89	
Buffer 1 transit stops			0.737				0.291				0.121				0.296				0.312	
Buffer 1 mixed use index			0.716						0.454						1.36		0.791		0.559	
Walked to work																				
Bike to work																		2		
Transit to work																			0.574	
Car to work																				1.67
Tour Complexity	-1.45	-1.08	-0.781		-2.21	-2.18	-0.314		-1.33	-0.628	0.693		-1.3	-1.59	-0.361		-1.61	-2	-0.677	

Table 4-5. Tour mode-choice models with both origin and destination information (shown values are estimated coefficients, not elasticities).

	Home-Based Work				Home-Based School				Home-Based Social/Rec				Home-Based Other				Work-Based			
	Walk	Bike	Transit	Auto	Walk	Bike	Transit	Auto	Walk	Bike	Transit	Auto	Walk	Bike	Transit	Auto	Walk	Bike	Transit	Auto
Constant	1.07	-2.92	-4.74		0.91	-4.12	-1.6		2.96	-4.53	-3.15		1.81	-3.74	-5.61		3.34	-8.82	-8.05	
Income < $25k	0.863		0.961		0.36		3.02		0.0615				-0.702		0.468					
Income > $100k	-0.412		-0.447		-0.669		-0.0075		-0.498		-1.15		-0.121		-1.57					
Male	0.534	0.859	0.186		0.578	1.71	0.0012		0.0356	2.05	-0.325		0.119	0.842	-0.215				1.16	
Age <35		-1.45	0.398							-0.36	-0.0084			-0.285	-0.458				2.25	
Age > 50		-0.863								-1.26				-0.518						
Zero car HH				-4.7				-5				-3.32				-4.32				-10
Adults > Cars				-1.4				-1.27				-0.976				-0.633				0
Route choice generalized distance		-0.113				-0.277				-0.0874				-0.276				-0.331		
Distance (over network)	-0.942				-1.45				-1.6				-1.87				-1.88			
Pct Class 1 path																				
Pct Class 2 path																				
Fraction wrong way																				
Turns/mile																				
Fraction rise																				
Dest - Buffer 1 Tot Emp	3.80E-05		2.70E-05																	
Dest - Buffer 2 Tot Emp																				
Dest - Buffer 2 Emp Density		3.70E-07																		
Orig+Dest Buffer 1 Avg Intersection Density													0.005				0.0111			
Orig Buffer 1 Intersect Density			1.50E-04																	
Orig Buffer 2 Intersect Density		0.0061																		
Orig+Dest Buffer 2 avg Fraction Class 1 Path		4.97				3.01														
Orig+Dest Buffer 1 Avg Fraction Rise	-61.3				-9.85				-15.6											
Orig Buffer 1 Fraction Rise													-36.2							
Orig Buffer 2 Avg Fraction Rise		-77.8																		
Orig Buffer 1 Transit stops			0.539				-0.334				-0.608				0.214					
Dest Buffer 1 Transit Stops			0.179				0.268				0.825				0.606				1.73	
Orig Buffer 1 Pct. No Sidewalk	-0.84						-0.715		-1.07				-1.44							
Dest Buffer 1 Pct. No Sidewalk							-0.872				-4.26									
Walked to work																	10			
Bike to work																		10		
Transit to work																			0.224	
Car to work																				2.3
Complex Multi-stop Tour	-1.24	-0.782	-0.501		-2.55	-2.25	-0.785		-2.14	-1.61	5.00E-15		-1.51	-1.95	-0.647		-2.71	-2	-1.5	
In-vehicle time			-0.01	-0.02			-0.01	-0.02			-0.01	-0.02			-0.01	-0.02			-0.01	-0.02
Wait time			-0.02				-0.02				-0.02				-0.02				-0.02	
Fare			-0.2				-0.2				-0.2				-0.2				-0.2	
Dest Parking Cost				-0.06				-0.06				-0.06				-0.06				-0.06

Table 4-6. Variables included in Seattle tour-based models.

	Sociodemographic	Land Use/Accessibility	Transportation/Network Characteristics
Tour Generation & Complexity	Gender Age Work/Student status Income Car ownership/ competition Children in HH	Land use mix (entropy) Purpose-specific buffer activity Purpose-specific logsum Intersection density Distance to transit stop	Gradient Class I or II bike path
Mode Choice (origin only)	Gender Age Income Car ownership/ competition	Land use mix (entropy) Household density Purpose-specific buffer activity Mode/destination logsum Intersection density Transit stop density	Gradient Percent Class 1 bike facilities Percent no sidewalks
Mode Choice (origin-destination)	Gender Age Income Car ownership/ competition	Land use mix (entropy) Employment density Purpose-specific buffer activity Mode/destination logsum Intersection density Transit stop density	Trip Distance Gradient Percent Class I & II bike facilities Percent wrong way Turns per mile Percent no sidewalks Auto & transit travel time Auto & transit cost

focused on Arlington County, VA. Given that Arlington is part of the Washington, DC, region, its selection provided access to the resources of both the County and the MWCOG, including a recent (2008) regional household travel survey with excellent coverage in Arlington.

The following data and tools were used to create the accessibility relationships that formed the basis for the eventual walk-accessibility model:

- A regional employment database prepared by Dun & Bradstreet and accessed through MWCOG, providing information on the type (4-digit NAICs code), size, and point location of all employers; this information was used to represent trip attractions.
- A complete-streets transportation network developed by NAVTEQ and accessed through MWCOG; the base network was enhanced to include any missing bicycle or pedestrian links; GTFS data were used to represent the transit network.
- Complete information on 9,100 trips from the regional travel survey having at least one trip end in Arlington County.

By knowing the block-face location of each of the 9,100 trips (both origin and destination), it was possible to estimate accessibility for all modes (i.e., walk, bicycle, auto, and transit) using the respective travel networks in conjunction with the Dun & Bradstreet data. This was done by using the Network Analyst program within ArcGIS to ascertain the shortest time path between the respective trip end and each opportunity represented in Dun & Bradstreet, using the actual network for that mode. Individual opportunities were discounted by the amount of travel time required to reach them, applying a logarithmic time-decay relationship similar to the approach used in Seattle but with the values drawn from distributions of the Arlington trip data. The discounted opportunities were then summed into a total accessibility value for each mode.

A strong relationship was identified between the calculated walk-accessibility score at either the trip origin or destination and the mode which was used for the trip as recorded in the travel survey data. These relationships are illustrated in the graphs of Figures 4-4 for home-based work travel and 4-5 for home-based non-work travel. The figures illustrate the percentage of trips made by auto, transit, and walking for different levels of walk-accessibility, ranging from under 200 to over 1200, with both walk share and transit share increasing directly with higher values of walk-accessibility. There were too few bicycle trip observations in the survey data to enable inclusion of bicycle as one of the primary modes, although the accessibility approach appears suitable for bike travel.

The black curves in the figures represent the plotted data, while the red curves are those fitted by to the data by Excel. The mathematical functions describing the fitted curves are

Home Based Work (HBW) Origin

Walk Score

	100	300	500	700	900	1100	1300	All
Auto	685	68	24	16	25	8	30	856
Transit	260	57	23	16	25	14	30	425
Walk	12	7	3	4	12	3	6	47
	957	132	50	36	62	25	66	1,328

Mode Shares

	100	300	500	700	900	1100	1300	All
Auto	72%	52%	48%	44%	40%	32%	45%	64%
Transit	27%	43%	46%	44%	40%	56%	45%	32%
Walk	1%	5%	6%	11%	19%	12%	9%	4%

Home Based Work (HBW) Destination

Walk Score

	100	300	500	700	900	1100	1300	All
Auto	237	97	61	55	43	37	326	856
Transit	54	16	7	19	18	10	307	431
Walk	6	5	3	6	7	4	16	47
	297	118	71	80	68	51	649	1,334

Walk Score

Mode Shares

	100	300	500	700	900	1100	1300	All
Auto	80%	82%	86%	69%	63%	73%	50%	64%
Transit	18%	14%	10%	24%	26%	20%	47%	32%
Walk	2%	4%	4%	8%	10%	8%	2%	4%

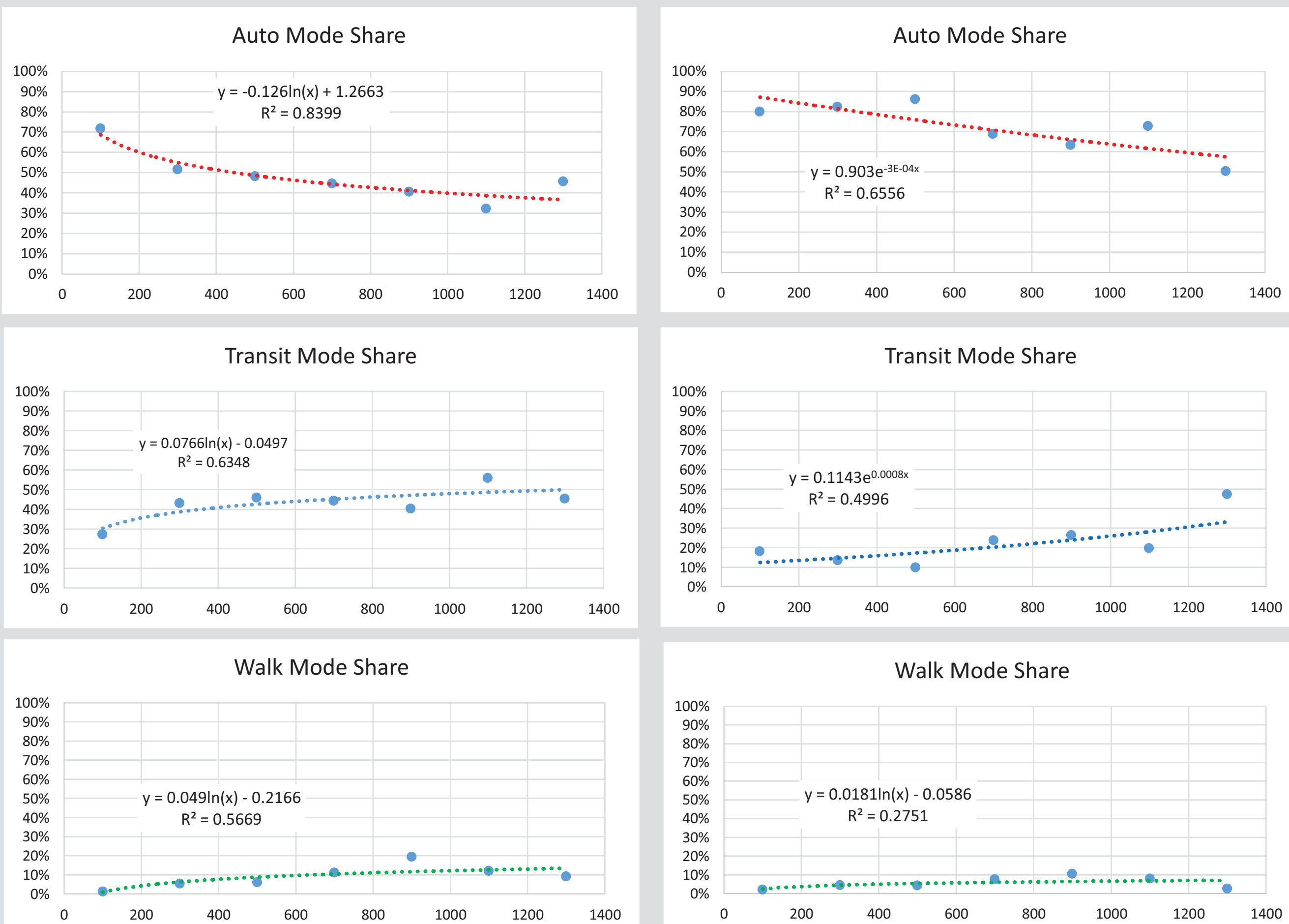


Figure 4-4. Mode choice in relation to walk-accessibility score—home-based work travel.

Home Based Non-Work (HBW) Origin

Walk Score	100	300	500	700	900	1100	1300	All
Auto	1,342	134	42	39	47	10	43	1,657
Transit	68	18	8	5	6	8	16	129
Walk	146	28	14	22	30	4	30	274
	1,556	**180**	**64**	**66**	**83**	**22**	**89**	2,060

Mode Shares	100	300	500	700	900	1100	1300	All
Auto	86%	74%	66%	59%	57%	45%	48%	80%
Transit	4%	10%	13%	8%	7%	36%	18%	6%
Walk	9%	16%	22%	33%	36%	18%	34%	13%

Home Based Non-Work (HBW) Destination

Walk Score

Walk Score	100	300	500	700	900	1100	1300	All
Auto	777	331	153	87	95	40	174	1,657
Transit	16	12	9	6	17	3	66	129
Walk	111	57	20	14	21	7	44	274
	904	**400**	**182**	**107**	**133**	**50**	**284**	2,060

Mode Shares	100	300	500	700	900	1100	1300	All
Auto	86%	83%	84%	81%	71%	80%	61%	80%
Transit	2%	3%	5%	6%	13%	6%	23%	6%
Walk	12%	14%	11%	13%	16%	14%	15%	13%

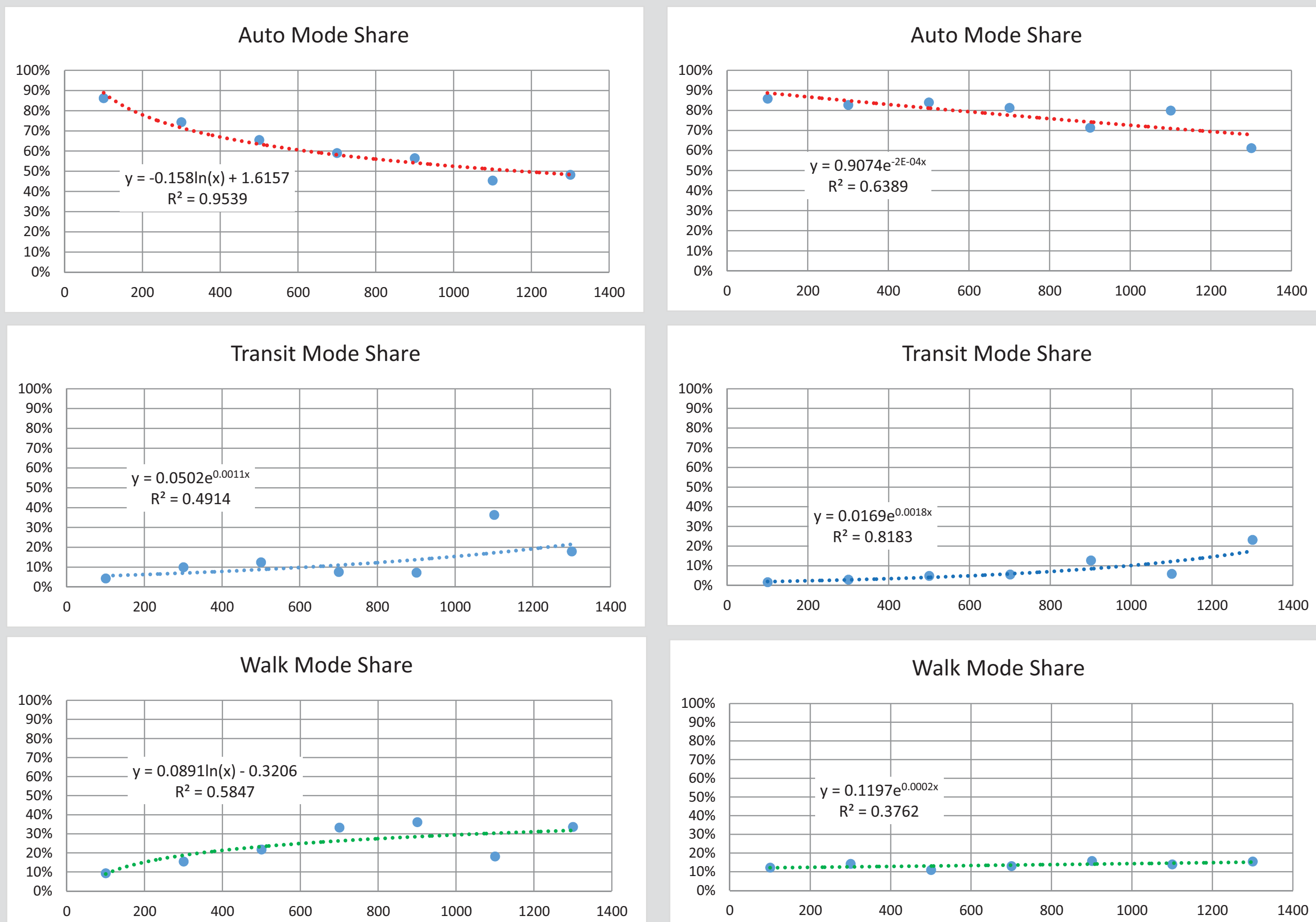


Figure 4-5. Mode choice in relation to walk-accessibility score—home-based non-work travel.

also shown in each graph, illustrating both a logarithmic relationship in each curve and a high R^2 value reflecting goodness of fit.

Table 4-7 shows that projected walk mode split for home-based work trips increases from about 1% at the lowest walk-accessibility level at the origin to 14% at the highest accessibility location, while transit share also increases from 30% to 50% and auto share declines from 65% to 35%; at the destination end, the increase in walk share is somewhat less (3% to 9%), while transit again increases by 20 percentage points and auto declines by 25 percentage points. For non-work travel, walk shares are higher overall and the increase with improvements in walk-accessibility are greater, particularly at the origin end: Walk share increases by 22 percentage points and transit increases by 16 percentage points, while auto declines by 40 percentage points; at the destination end the effect is not quite as dramatic, with auto share dropping by only 18 percentage points while walk increases by only 3 percentage points and transit increases by 12 percentage points.

Table 4-7. Mode split for HBW and HBO trips in relation to walk-accessibility score at origin and destination.

WALC Score	HBW Origin			HBW Destination		
	Auto	Transit	Walk	Auto	Transit	Walk
<200	65%	30%	1%	85%	10%	3%
200	55%	37%	5%	79%	17%	5%
400	50%	43%	8%	70%	21%	6%
600	43%	45%	10%	67%	24%	7%
800	40%	47%	11%	65%	27%	7%
1000	38%	48%	13%	62%	29%	8%
>1200	35%	50%	14%	60%	30%	9%
WALC Score	**HBO Origin**			**HBO Destination**		
	Auto	**Transit**	**Walk**	**Auto**	**Transit**	**Walk**
<200	88%	2%	10%	88%	1%	12%
200	75%	8%	17%	81%	3%	13%
400	65%	12%	23%	79%	8%	14%
600	59%	15%	26%	76%	10%	14%
800	54%	16%	29%	74%	11%	15%
1000	51%	18%	31%	72%	12%	15%
>1200	48%	18%	32%	70%	13%	15%

Perhaps as important as the effect of walk-accessibility on walk mode share is the effect that higher walk-accessibility has on transit share, particularly at the destination end. This may be due simply to destinations being more walk accessible to transit users, but may also provide evidence that travelers are more likely to use transit if they do not have to be dependent on personal vehicles once they reach their primary destinations.

The relationship between the walk-accessibility score and the patterns of land use is shown in Figure 4-6, which uses color-shading to represent the level of walk-accessibility for each of the MWCOG survey trip ends. The map shows clear patterns between the level of walk-accessibility and location in Arlington County, particularly highlighting the areas of high walkability along the Orange Line (Rosslyn-Ballston) corridor, in Crystal/Pentagon City, and in Washington, DC.

When applying the walk-accessibility model, the basis shifts from the survey trip ends which were used to calibrate the models, to census blocks. The user defines the "study area" of interest, as well as the surrounding walk shed of opportunities that can be reached by walking from the study area. The census blocks for the walkshed are identified, and their centroids become the reference points for model application. Walk-accessibility scores are computed for each block by accumulating the opportunities present in each block in the walkshed as represented by their employment or population, discounted by the network travel time between the respective blocks.

This approach—both calibration of the base model and its application to a block-specified study area—has been compiled into a custom spreadsheet program provided with the guidebook. Step-by-step instructions on its structure and use are provided in Section 5.4, illustrating how the model may be used for trip generation, distribution, and mode-split analysis. As part of the presentation, the model is applied to an actual setting in the Shirlington area of south Arlington County, where changes are made to both existing land use and the networks, and the results run through the model to exhibit

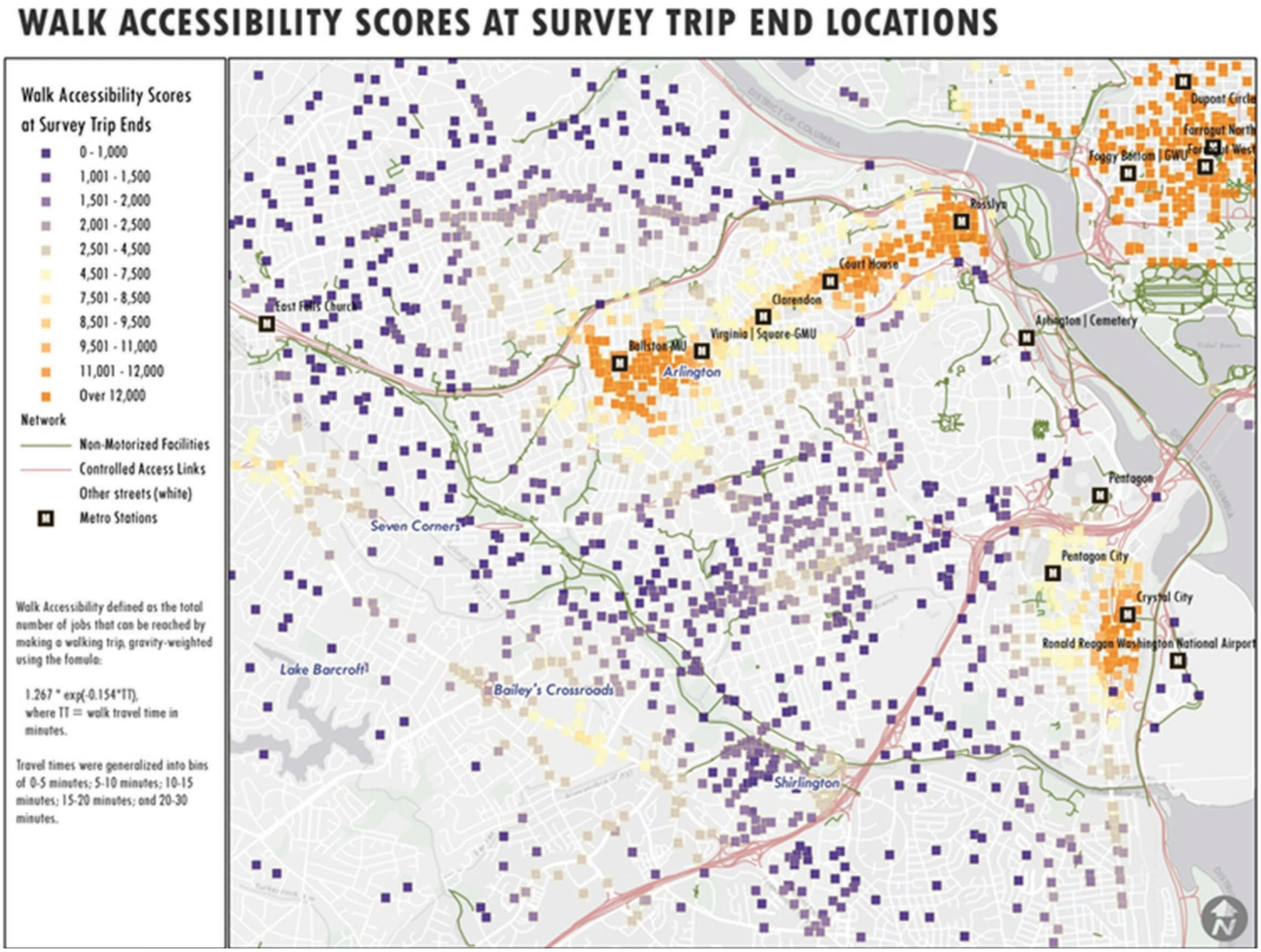


Figure 4-6. Walk-accessibility scores—illustrative values in Arlington County.

changes in overall walking levels—by origin-destination block pair and by trip purpose. A complete documentation of the development of the walk-accessibility model is also provided as Appendix 2 of the Contractor's Final Report.

Strategic Enhancements to TAZ Trip-Based Models

The two techniques presented in the preceding sections represent new approaches to the analysis of pedestrian and bicycle travel demand. They will offer assistance in not only non-motorized travel demand analysis, but how the principles of accessibility are used to understand bicycle and pedestrian demand and how the demand can be influenced by changes to land use and the transportation networks.

Many planners—particularly those in metropolitan or local planning agencies—may also be seeking near-term options for improving the capability of their existing regional forecasting models to do a better job of accounting for non-motorized travel. For this reason, a third research approach was developed by NCHRP Project 08-78 to identify how conventional trip-based models might be enhanced to improve their sensitivity to land use and non-motorized travel. This research also took advantage of the special data resources developed in the Seattle area and used by the tour-based modeling team.

Enhancing trip-based models, particularly to improve their sensitivity to differences in land use and accessibility factors, is not a new concept. The background research identified and reported on some such efforts, some of which were referenced in Table 4-2 (e.g., Durham and Buffalo) and can be reviewed in greater detail in Appendix 7 of the Contractor's Final Report. The approach developed by NCHRP Project 08-78 incorporates some similar methods, particularly in trying to bring walking and biking further along in the modeling than trip generation. However, there was also a deliberate effort to sensitize as many of the steps in the process to important land use effects as possible.

The primary limitation posed by most trip-based models when trying to analyze non-motorized travel is the aggregation inherent in the use of TAZs. Although this may be an acceptable simplification of detail when analyzing vehicle travel, it eliminates the very detail necessary to understand non-motorized travel. This detail applies to (1) the level and mix of activity within reasonable travel distance by walking or biking and (2) the accessibility provided by the respective transportation networks.

Recently, many MPOs have updated their models using a finer-grained system of TAZs. This shift has resulted in zones now more the size of a census block group than a Census Tract, increasing the number of zones overall by a factor of 3 or 4 to 1. Although smaller, the block-group-sized zones are still much larger than the parcels, blocks, or walkable buffers featured in the previous two methods. However, the downsizing provides more resolution and also opens the opportunity for including non-motorized modes in the trip distribution and mode-choice steps of the model. (The large scale of previous TAZs allowed the assumption that most non-motorized trips would remain within the TAZ in which they originated.)

Figure 4-7 illustrates the standard four-step modeling process, depicting how non-motorized travel is generally accounted for and shows where the NCHRP Project 08-78 enhancements were targeted. The boxes in the Enhanced Approach highlight those steps where new relationships were developed, largely by drawing on the rich database of land use characteristics developed by PSRC using parcel buffering methods.

The database of available land use (also presented as *built environment*, or BE) measures included the following

- Number of persons and households (¼ mile buffer);
- Employment (# jobs) by type (¼ mile buffer);
- Parking supply: daily and hourly paid spaces, free off-street spaces (¼ mile buffer);
- Parking cost: average daily or hourly cost (¼ mile buffer);
- Street grid: # of dead ends, 3-way and 4+ way intersections (½ mile buffer);
- Distance to transit: nearest express bus stop, local bus stop (miles);
- Bus stop density: number of express, local stops (¼ mile); and
- General home location indicator: urban, suburban or rural.

In addition, two key measures of accessibility were developed (for each TAZ) and had important roles in the new models:

- Single-occupant vehicle accessibility index (SOV AI): created from the logsum (denominator) of the destination choice model, based on network distance to destination, distance (destination) to the central business district (CBD), travel time, and log of jobs at the destination.
- Non-motorized accessibility index (NMT AI): similar to the SOV AI as a logsum value, based on network distance to destination, land use mix at destination, and log of jobs at the destination.

The following deficiencies were targeted, along with a description of the approach used to enhance the process. (The actual models are too voluminous to present here, but are available for viewing, along with the corresponding elasticity estimates in Table A-2 in Appendix A.) Figure 4-8 illustrates where in the process the enhancements were made and what variables were used in each.

Vehicle Ownership: Although vehicle ownership is not one of the official steps in the four-step model, it has an important role in both trip generation and in mode choice (in many models). Because research shows that households residing in settings more transit and walk friendly own fewer vehicles, more

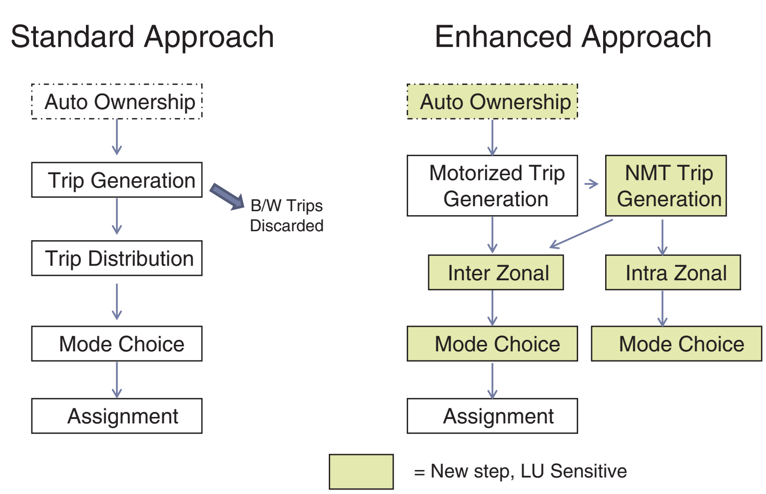


Figure 4-7. Modifications to four-step trip-based model to improve non-motorized travel estimation.

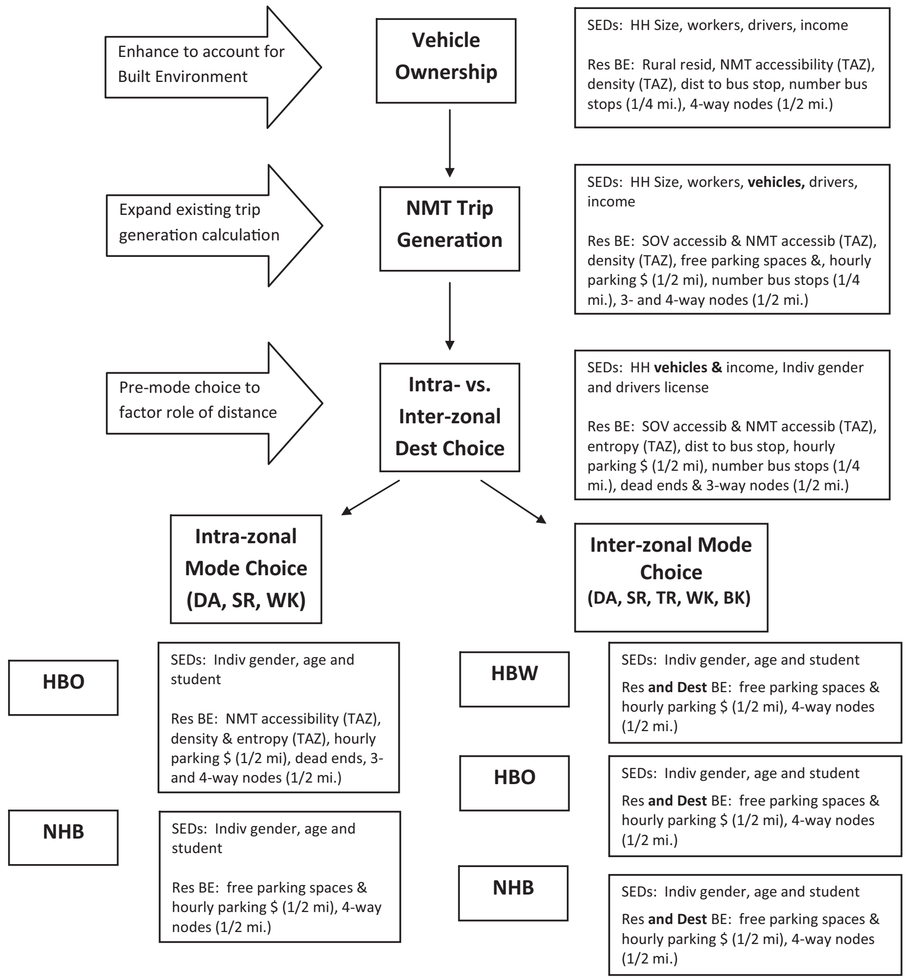


Figure 4-8. Sociodemographic (SED) and built environment (BE) variables used to enhance Seattle trip-based model.

regional models are beginning to incorporate context factors when predicting household vehicle ownership (see Atlanta, Austin, Los Angeles, and Portland examples in Table 4-2).

The Seattle research developed (1) a new vehicle ownership model using a Poisson regression approach (well suited for modeling "counts") to predict the number of household vehicles based on household sociodemographic characteristics (number of members, workers, drivers and income) and (2) the following land use context measures:

- Rural home location
- Non-motorized mode accessibility index
- Distance to nearest bus stop and bus stop density
- Home TAZ population density
- 4-way intersection density.

Non-Motorized Trip (NMT) Generation: Most trip-based models have improved their procedures for estimating trip productions and attractions, moving from simple cross-classification procedures to models more tied to important context factors. Examples were listed earlier in Table 4-2 (Atlanta; Austin; Portland; Durham, NC; and Buffalo). However, even the best of these models still makes a rough estimate of NMT productions by trip purpose and then removes those trips from consideration in the remaining steps of the modeling. The Buffalo approach (Wang, et al., 2010) is an exception and has similarities to the approach used in Seattle.

For Seattle, the research team used a two-step approach using a binary logit model to first predict whether a household would make any NMT trips at all, followed by a negative binomial model that then predicted the number of NMT trips for households that make them. Both models incorporate land use variables, including parking availability and cost, intersection density, home TAZ density, bus stop density, and both auto and NMT accessibility indices for the home TAZ. The two-step approach was used in lieu of calculating NMT productions as part of the base trip generation process, which was left to focus on motorized trip generation.

Intra- Versus Interzonal Destination Choice: The typical trip-based model does not carry non-motorized trips beyond trip generation. With the downsizing of TAZs, greater opportunity exists to begin to include non-motorized trips into the destination choice and mode-choice determinations. To exploit this opportunity, the Seattle research inserted a procedure to predict whether non-motorized trips would be made to destinations in the same zone as the origin (intrazonal) or to other zones (interzonal). The new model predicts whether an NMT trip production will travel to a destination within the origin zone or to another using a binary logit model incorporating sociodemographic characteristics (i.e., vehicle, income, drivers, and gender), an array of land use measures (i.e., SOV and NMT AI indices, land use mix, distance to bus stop, bus stop density, dead ends and 3-way intersections, and parking price), and trip purpose (commute) and time of day (i.e., mid-day, PM peak, evening). The earlier mentioned Buffalo study uses a similar approach.

Mode Choice: Non-motorized modes typically do not progress to the mode-choice step, but with the separation into intrazonal and interzonal trip types this becomes possible. Because of very low bike and transit shares, the intrazonal model includes only three modes: drive-alone, shared-ride, and walking. The interzonal model has a similar specification, but includes five modes (i.e., drive-alone, shared-ride, walking, transit, and bicycling). Both interzonal and intrazonal models include individual models for home-based work, home-based other, and non-home-based travel. Key land use context variables in the intrazonal mode-choice models were NMT Accessibility, intersection density, land use mix, density, and parking availability and price. For interzonal, the key context variables were SOV accessibility at the origin and both NMT and SOV accessibility at the destination; density at both origin and destination; intersection type and density at both origin and destination; bus stop density at origin and destination; and land use mix at the destination.

Destination Choice models for interzonal home-based work, home-based other, and non-home-based trips were estimated using a multinomial logit approach, with the weighted logsums across the five modal alternatives (aggregate accessibility) serving as key explanatory variables along with intersections, density, land use mix, distance to transit and transit stop density, and parking availability. The importance of the land use variables was further articulated in relation to key demographic segments (i.e., gender, senior citizen, income, and licensed driver).

These enhancements and the methods used to create them will be useful for planners and agencies that want to make near-term improvements to existing trip-based models. The equations and elasticities are provided in Chapter 5 to assist users who wish to explore these methods further. As with any of the models offered by this research, however, important caveats should be observed in working with these tools:

- The model coefficients and elasticities were derived using data from Seattle, and so should be used with caution in terms of direct transferability.
- When calculating the non-motorized accessibility measure, walk and bike are combined into a single mode, which may exaggerate the level of accessibility, given the longer range of bicycle travel.
- Although reduced TAZ size was an important factor enabling this analysis, the research models do not directly account for TAZ size in the models or measures, when it is likely that zone size could be an important contributing factor in determining the extent to which a trip is intra- versus interzonal.

Despite these caveats, practitioners working with trip-based models may wish to build on or emulate this approach.

Pedestrian Trip Generation and Flow Models

The NCHRP Project 08-78 research team reviewed existing models that estimate pedestrian trip generation and assign those trips to facilities. Although they are not full choice-based models in the sense of deriving walk trips from a comprehensive trip generation and mode-split process, they do offer an approach that employs accessibility principles to account for the combined effects of land use and network connectivity.

Two models in this group—MoPeD and PedContext—have common lineage. The original model was the PedContext tool, developed under contract for the Maryland Department of Transportation (State Highway Administration) by the University of Maryland for estimating pedestrian flows to support safety analyses (Urbitran Associates, 2004). http://smartgrowth.umd.edu/assets/cliftondaviesallenraford_2004.pdf

The model was applied and validated in downtown Baltimore and Langley Park in suburban Washington, DC. MoPeD, described next, is a descendent of PedContext, and carries many of its characteristics but at a much reduced level of detail, which may offer a simpler option for some users or applications.

The models have a structure familiar to the four-step transportation models, performing trip generation, distribution, and network assignment. However, these models concentrate solely on pedestrian trips and do not attempt mode choice. They also operate at a pedestrian scale of detail, substituting block-size pedestrian analysis zones (PAZs) for TAZs. Neither of these tools addresses bicycle travel, although except for sufficient bicycle data from travel surveys, there appears to be no obvious reason why the structure of either model could not accommodate bike as a mode.

PedContext Model

PedContext is the more detailed of the two pedestrian models. It features a land use allocation step, pedestrian travel generator, a distribution module, and a stochastic assignment procedure to allocate the estimated pedestrian trips to the walk network. The steps in setting up the model are as follows:

- Networks: A detailed street network was created from Census TIGER files, enhanced to account for sidewalk coverage (using aerial data) and characteristics important to walking (i.e., functional class of roadway, speed limits, volumes, and traffic control devices). Each link is assigned nodes at the end points, plus one in the center to serve as a mid-block crossing (i.e., jay-walking) opportunity, subject to various conditions. These nodes are later treated as "load points" when assigning trips to the pedestrian network.
- Land Use Allocation: Parcel-level land use data available through Maryland's "Property View" GIS database was coupled with Census data to reflect land use activity at each block face.
- Trip Generation: Walk trip productions and attractions for seven different trip purposes were estimated for each block face from a set of equations developed using travel survey data from the New York metropolitan area; the trip generation models were distinct in including innovative, purpose-specific land use accessibility measures.
- Trip Distribution: Walk productions and attractions were converted to trips by purpose using a gravity-based trip distribution model in which a distance-decay relationship based on a gamma function was used to calculate the travel time impedance.
- Trip Assignment: The estimated walk trips for each block face were associated with the nodal load points (described above) and then assigned to the sidewalk network by purpose and time of day using the weighted impedances and a stochastic, multi-path assignment algorithm (see Figures 4-9 and 4-10).

The PedContext model was developed using a combination of tools, including ArcGIS and CitiLabs CUBE and VIPER transportation planning software, with specialized routines written by the model development consultant to coordinate the various elements. This model has many features that could make it attractive to pedestrian planners; however, it is not in the public domain. Interested parties can contact the Maryland State Highway Administration or the University of Maryland National Center for Smart Growth for more information on its potential availability and use, either through acquisition of the actual software or by attempting to emulate the methods, which are detailed in Table A-4 of Appendix A.

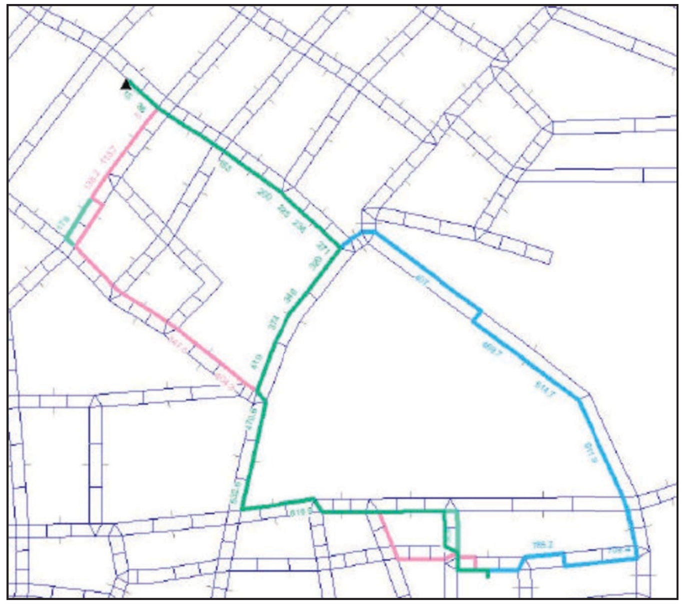


Figure 4-9. PedContext multi-path assignment.

Model of Pedestrian Demand (MoPeD)

The MoPeD model was also developed by the University of Maryland National Center for Smart Growth, as a somewhat less complex and computationally demanding version of the PedContext model, but with an open-source software program. MoPeD also can estimate pedestrian activity levels at intersections at a subarea scale using readily available data in a GIS framework.

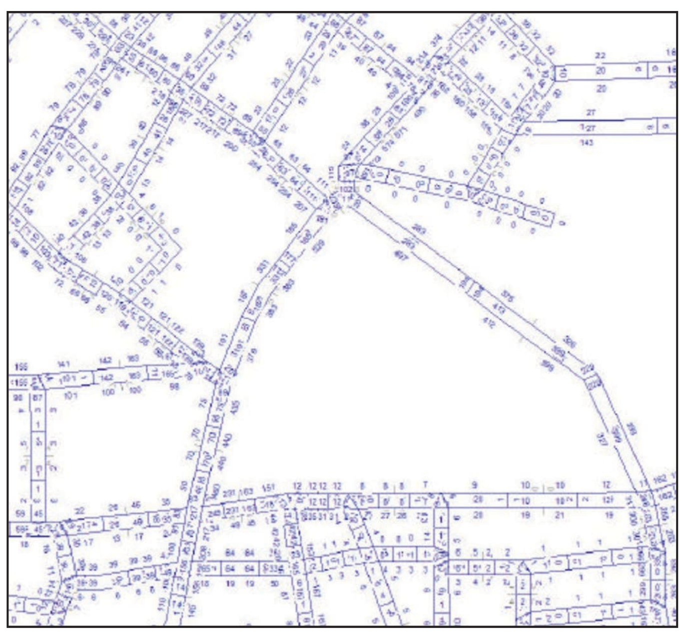


Figure 4-10. Assigned pedestrian volumes.

MoPeD is similar to PedContext in the following ways:

- Census TIGER network line files were enhanced to represent the full pedestrian network, accounting for the connectivity and impedances associated with sidewalks and crosswalks.
- The spatial units of analysis are PAZs, which are in the form of blocks and block faces.
- Like PedContext, MoPeD directly estimates pedestrian trips, rather than deriving them from a mode-choice analysis.

Important differences with PedContext are as follows:

- MoPeD focuses only on home-based and non-home-based walk trips, versus PedContext's inclusion of six purposes.
- Relationships were drawn exclusively from local data, using NHTS add-on travel survey data collected from the Baltimore region.
- Unlike the detailed equations used in PedContext, trip generation is a simpler function of vehicle ownership, street connectivity, residential development, and commercial mix. For non-home-based walk trips, correlated variables were retail, service, and other employment and housing within ¼ mile buffer of the trip end.
- Walking trips were distributed and routed among producing and attracting PAZs via a walk-distance gravity model and shortest-path assignment (i.e., not a detailed stochastic multi-path assignment as in PedContext).
- MoPeD runs on a GIS platform with open-source analysis routines intended for use by planners and analysts without proficiency in regional travel models.

Both MoPeD and PedContext can be used for various planning purposes, to estimate walking under different land use and pedestrian network configurations. They support impact analysis of new or infill development and changes to the pedestrian network (e.g., adding sidewalks, improving connectivity, or removing access).

The features in MoPeD for creating and editing networks, processing land use and population and employment data into block-size units, and performing trip generation, distribution, and assignment are complete and well documented. Many bike/pedestrian and land use planners may find this model useful (see http://kellyjclifton.com/MoPeD/DemandModelProtocol07_08.pdf).

Figure 4-11 illustrates the Baltimore City study area to which MoPeD was applied and the estimated 24-hour pedestrian counts by intersection.

Portland Pedestrian Model

A third pedestrian demand estimation model is included here—because of its lineage with PedContext and MoPeD and because it offers another potentially useful approach for enhancing the capabilities of regional trip-based models. Researchers at Portland State University (PSU) were contracted by the regional MPO, Metro, to develop a procedure to improve the pedestrian mode-choice capabilities in Metro's existing trip-based model. The lead researcher also led development of the MoPeD model at the University of Maryland. The resulting procedure can either be used as an enhancement to the regional model or as a stand-alone pedestrian planning tool.

Like MoPeD, the Portland pedestrian model approach uses PAZs as the analysis unit. The Portland PAZs were formed by disaggregating the regional TAZ system into 1.6 acre (264 × 264 feet) grid cells. The steps in the modeling procedure are pictured in Figure 4-12.

The procedure first estimates total person trip generation for each PAZ, using Metro's existing trip generation procedure. Metro estimates only trip productions, because attractions are identified through a destination choice model.

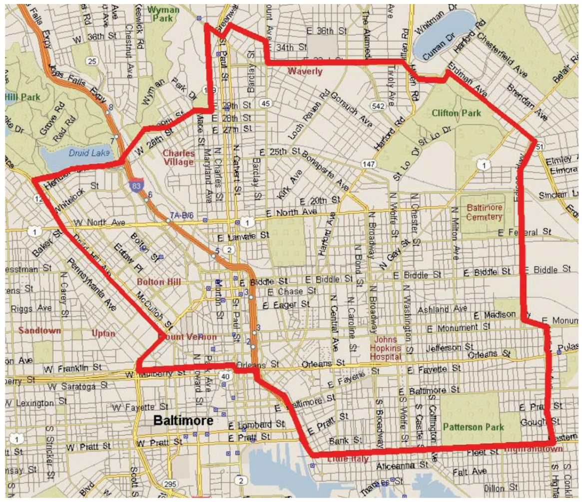
Next, a set of binary logit walk models is used to separate the estimated trip productions into walk and non-walk for three purposes: home-based work, home-based other, and non-home-based. An important variable in these equations is a pedestrian index of the environment (PIE), a weighted sum of six different contextual variables.

Metro developed its "Context Tool" to represent land use and other urban form contextual variables in its regional model. The standard Context Tool consists of the following measures:

- Bicycle Access—Density of bicycle network links within a 1-mile radius, weighted by classification (e.g., off-street paths/trails, main bikeways, bike lanes, low/moderate/high traffic streets with no bicycle facilities).
- Block Size—Block-size density within a ¼ mile radius.
- Activity Density—Population and employment density within a ¼-mile radius.
- Sidewalk Density—The percentage of road segments with sidewalks, weighted by continuity, within a ¼-mile radius.
- Transit Access—The density of bus, light rail, and commuter rail stops, weighted by service frequency, within a ¼-mile radius.
- Urban Living Infrastructure—Grocery stores, cafes, restaurants, clothing and other retail stores, schools, dry cleaners, and entertainment venues within a ¼-mile radius.

Compiling all the measures into a single index proved an effective strategy for overcoming multicollinearity problems when using these variables. Developers of the pedestrian model augmented the standard Context Tool by applying weights to the individual components to reflect their differential importance in impacting the walk decision. Binary logit models were used to establish the importance levels presented in Table 4-8. The analysis determined activity density

Boundary of Baltimore City Study Area



Predicted Intersection Volumes Using MoPeD Model

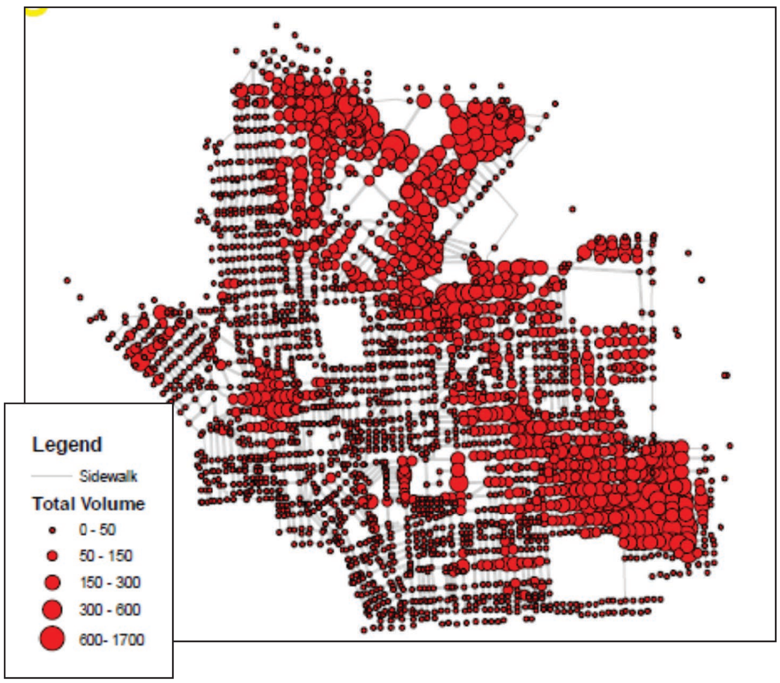


Figure 4-11. Application of MoPeD model in Baltimore City.

to be the highest-weighted attribute, followed by transit access. If each attribute were to realize its maximum value (5) in the given setting, the maximum weighted value would appear as shown in the final column.

The PIE variable was found to be an important indicator of environmental context in the pedestrian mode share model. PIE values for all grid cells in the Portland region demonstrated the highest values in Downtown Portland, followed by other major neighborhood centers, then suburban centers, with the lowest values in isolated industrial, rural, and undeveloped areas. Figure 4-13 shows the values predicted for different areas in the region, accompanied by a picture conveying the "feel" of these areas in relation to the PIE score.

The third step in the pedestrian model process was to match the pedestrian trip productions into origin-destination trips across the study area of PAZs, which was done using Metro's destination choice model instead of distribution. The resulting trip tables (by purpose) were then assigned to facilities in the network, although the current model does not perform that task.

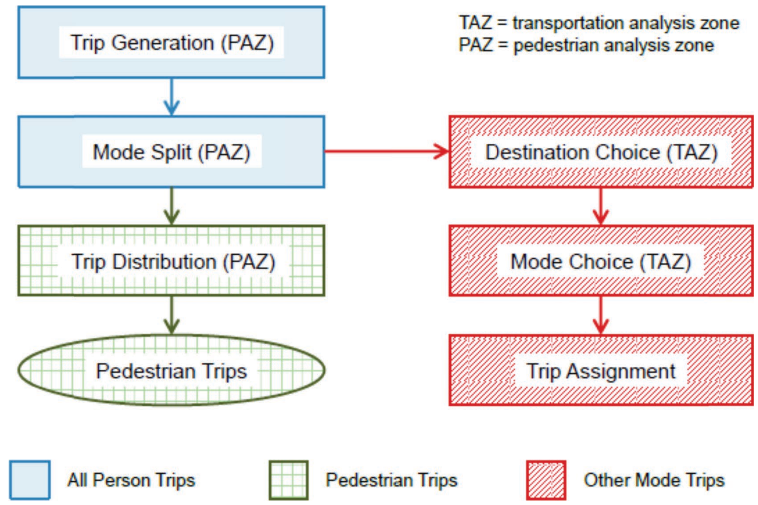


Figure 4-12. Portland pedestrian model.

Once the pedestrian trip tables were determined, non-pedestrian trips could then be aggregated up to the TAZ-level trips and passed to the regional model for further analysis. This is very similar to how the walk-accessibility model developed for Arlington operates.

Facility-Use Estimation Models

This group of tools predicts user volumes or activity levels on bicycle or pedestrian networks for purposes of network design, assessment of sufficiency or potential improvements, or crossing volumes for safety studies. The difference in this group from the PedContext and MoPeD approaches is that they are not fully integrated approaches that estimate demand from a top-down process, but attempt to explain existing activity levels or patterns with characteristics of the existing environment and then project changes in activity based on changes in the context factors.

Three types of tools are included in this category:

- Route choice models,
- Network simulation models, and
- Direct demand models.

Route Choice Models

Bicycle Route Choice

There has been considerable research on quantifying the factors underlying bicyclist choice of route, resulting in insights on how physical factors (e.g., directness, facility type, slope, and traffic exposure) influence choice of route. By quantifying the importance of these characteristics in relation to travel time (or distance), it becomes possible to express the utility of choosing alternative paths based on their packaging of these characteristics.

The best examples of models created for this purpose are those developed by the San Francisco County Transportation Authority (SFCTA) and Portland State University (PSU), which used GPS recording methods to obtain data on actual route selection behavior. This differentiates them from similar research studies that relied exclusively on stated preference information, although those studies (e.g., Hunt and Abraham, Krizek, Menghini in Table 4-2) also provide interesting and useful insights on these values and tradeoffs. Other research can be reviewed in Appendix 7 of the Contractor's Final Report.

The SFCTA model, shown in Table 4-9, accounts for distance, turns, slope, wrong-way links, path size, and proportion of

Table 4-8. Estimated importance weights for PIE index.

Component	Possible Values	Weight	Maximum Weighted Value
Bicycle access	1 to 5	2.808	14.04
Block size	1 to 5	3.086	15.43
Activity density	1 to 5	4.615	23.07
Sidewalk density	1 to 5	2.842	14.21
Transit access	1 to 5	3.529	17.65
Urban living infrastructure	1 to 5	3.120	15.60
Total			100.00

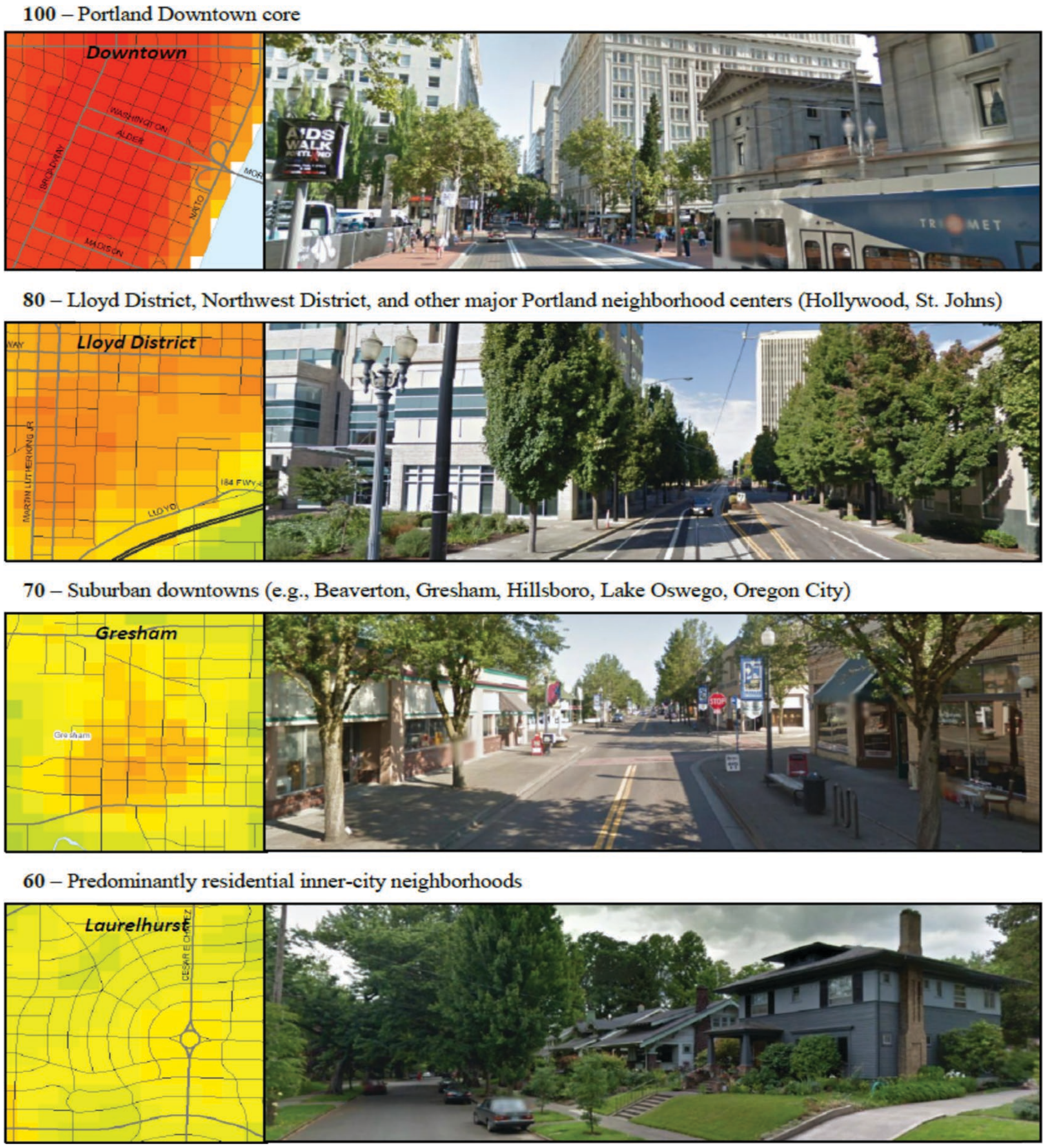


Figure 4-13. Illustration of pedestrian index of environment (PIE) in Portland region.

Class I, II, and III facilities in explaining choice of route. It also accounts for different trip purposes (work versus non-work) and gender in explaining the importance of particular features, which earlier research has shown to be fairly important in understanding bicyclist behavior. Also shown are the marginal rates of substitution (MRS), signifying the relative importance of each characteristic in relation to trip length. For example, the average cyclist would avoid a turn if it costs no more than 0.17 km and will avoid climbing a hill 10 m tall as long as the detour is less than 0.59 km. Similarly, a cyclist will not travel the wrong way down a one-way street unless doing so saves more than four times the distance (or its equivalent in turns or hill climbing) elsewhere. On the other hand, the average cyclist is willing to add a mile on bike lanes in exchange for only ½ mile on ordinary roads.

The PSU model uses similar explanatory variables, but includes a provision to account for the effects of adjacent vehicular traffic volumes, as well as cyclist wait times at crossings. The PSU research obtained information on user type, but these factors were not found to be significant in the estimated models. The full PSU model is presented in Table A-7 of Appendix A, and the relative value of the route characteristics (similar to the SFCTA marginal rates of substitution) is provided in Table 4-10.

In considering use of these models, it is important to be aware of their application limitations. They provide invaluable

Table 4-9. SFCTA bicycle route choice model and marginal rates of substitution.

Attribute	Coefficient	t-stat.
Length (km)	-1.69	-11.8
Turns per km	-0.13	-12.15
Proportion wrong way	-13.5	-19.87
Proportion bike paths	1.89	6.17
Proportion bike lanes	2.15	17.69
Cycling freq. < several per week	1.85	44.94
Proportion bike routes	0.35	3.14
Average upslope (m/100m)	-0.50	-6.35
Female	-0.96	-4.34
Commute	-0.90	-8.21
Path size (log)	1.07	26.38

Number of observations	2.678
Null log-likelihood	-10,006
Final log-likelihood	-7,123
Adjusted rho-square	0.23

Marginal Rate of Substitution (MRS)

MRS of Length on Street for	Value	Units
Turns	0.17	Km/turn
Length wrong way	4.02	None
Length on bike paths	0.57	None
Length on bike lanes	0.49	None
Length on bike routes	0.92	None
Total rise	0.59	km/10 m

information on how these different characteristics are weighed by the traveler by converting those preferences into quantitative factors influencing perceptions of travel time or distance, so, if the planning question is to determine what improvements would make one path better than another, these tools would be directly relevant. However, these tools do not attempt to predict whether a bike trip will be made, which destination will be chosen over another, or whether the bike mode will be chosen over another for that destination.

Network Simulation Models

Another approach used to project route choice is through a spatially-driven network simulation procedure (e.g., Space Syntax). Space Syntax was developed in London in the 1980s and has been widely used in Europe for pedestrian planning. It has been used only marginally in the United States, for at least two reasons: (1) the software is proprietary, hence there is not a lot of freely available information on how it works; and (2) its process is not instantly intuitive to traditional transportation planners. Space Syntax does not cast travel flows in the context of trip generation and distribution in a conventional sense, but uses spatial characteristics and relationships to try to explain how particular paths will be chosen. The underlying assumption is that travel patterns in a network are not necessarily determined by individuals minimizing travel time or distance,

Table 4-10. PSU bicycle route choice model—relative rates of substitution.

Attribute	Distance Value (% distance)	
	Non-Commute	Commute
Turns per mi.	7.4	4.2
Proportion upslope 2-4%	72.3	37.1
Proportion upslope 4-6%	290.4	120.3
Proportion upslope ≥ 6%	1106.6	323.9
Traffic signal exc. right turn (per mi)	3.6	2.1
Stop sign (per mi)	0.9	0.5
Left turn, unsig. AADT 10-20k (per mi)	16.2	9.1
Left turn, unsig. AADT 20k+ (per mi)	43.1	23.1
Unsig. cross AADT ≥ 10k right turn (per mi)	6.7	3.8
Unsig. cross AADT 5 - 10k right turn (per mi)	7.2	4.1
Unsig. cross AADT 10 - 20k right turn (per mi)	10.4	5.9
Unsig. cross AADT 20k+ right turn (per mi)	61.7	32.2
Prop bike boulevard	-17.9	-10.8
Prop bike path	-26.0	-16.0
Prop AADT 10-20k w/o bike lane	22.3	36.8
Prop AADT 20-30k w/o bike lane	137.3	140.0
Prop AADT 30k+ w/o bike lane	619.4	715.7
Bridge w/ bike lane	-29.3	-18.2
Bridge w/ separate bike facility	-44.9	-29.2

but in terms of "transitions" from one space to another. The approach requires coding of a detailed network, which is then treated as a "graph." Topological methods are used to characterize the properties of the network (graph) through such measures as connectivity (number of other nodes that connect to each node), depth (average number of steps between nodes), and integration (ease of access from other nodes). Integration is the key variable, whose formula compares an ideally connected graph with the one in question to determine a measure of accessibility for each node in the network. The quantified measures of accessibility and connectivity are then used to generate movement "potentials," which are then correlated with counts. The correlations are then used to predict volumes on a street-by-street basis for the defined study area.

Illustrative tests of Space Syntax in the United States have occurred in the City of Oakland, CA, for pedestrian planning (Raford and Ragland, 2003) and in relation to bicycle travel in Cambridge, MA (McCahill & Garrick, 2008). In the McCahill & Garrick example, the correlation of Space Syntax measures and observed bicycle volumes in the Cambridge, MA, bicycle network was tested. The "choice" segment indicator was used as the means of predicting relative cyclist volumes on facilities, using road centerline maps in place of the traditional "axial maps," and ArcGIS to compile information on segments from spatial analysis and census statistics. A linear regression was developed to reveal the best correlation between existing bike volume counts at 16 intersections, census population, and employment data to serve as productions and attractions, plus various Space Syntax measures. The researchers determined that the method was useful in predicting bike volumes in a network and could be useful in designing more efficient networks.

In the City of Oakland, Raford and Ragland used Space Syntax to forecast pedestrian volumes for safety analysis in the City's pedestrian master plan. Space Syntax was used to leverage existing count data from a sample of 42 intersections into forecasts of pedestrian volumes at 670 intersections citywide. However, because Space Syntax assumes an even population distribution, the researchers supplemented the model by using Census population and employment data to allow for distortions caused by major generators. Discrepancies in forecasting accuracy (remaining after the adjustments) included a tendency to underestimate volumes on high-volume streets and on streets connecting to three Bay Area Rapid Transit (BART) stations. However, the researchers believed that additional enhancements (e.g., including auto volumes and speeds and using more specific land use characteristics) could help improve accuracy.

Because of the lack of clarity in how Space Syntax works and that it is proprietary, it has not been possible to fully evaluate Space Syntax's capabilities, so it is not included in the best-practice recommendations. However, users can investigate further if the features of the tool seem interesting or useful.

Direct Demand Models

Direct demand models have been the accepted practice for estimating pedestrian or bicycle facility demand for some time. The NCHRP Project 08-78 background review recorded use of these methods back in the 1970s (Benham & Patel, 1977). Their structure is to explain observed levels of bicycle or pedestrian activity on facilities (links) or at intersection (points) as recorded through counts, using a range of factors that describe local context. This is usually done using regression modeling techniques, with the calibrated models then applied back on all or a subset of the sampled system of intersections or links to assess their accuracy in replicating choices.

Variables often used to represent context in these types of models include the following:

- Population or employment densities, sometimes differentiated by type (e.g., populations differentiated by age, gender or income, or employment categorized as office or retail).
- Population or employment activity levels within a nominal buffer distance of ¼ or ½ mile from the intersection.
- Land use mix, measured either through an index (e.g., entropy) or implicitly through corresponding buffered activity levels.
- Characteristics of the facility, including type of bike path and sidewalk existence and sufficiency.
- Interaction with vehicle traffic (e.g., adjacent speeds or volumes, intersection approaches with crosswalks, sidewalk widths, on-road versus off-road bike facilities).
- Transit availability (e.g., transit frequency and stop density).
- Major generators (e.g., proximity to universities, schools, recreation, neighborhood shopping, major transit centers, and civic centers).

Numerous examples of models in this genre are cited in Table 4-2 and documented in Appendix 7 of the Contractor's Final Report under the Aggregate Demand Methods discussion. Because each is unique, it is difficult to name one or two that are exemplary; however, among those that have undergone the most development and had access to the best data resources are the Seamless Travel pedestrian and bicycle models developed by Alta Planning & Design in San Diego (Jones, et al., 2010) and the Santa Monica pedestrian and bicycle demand models (Fehr & Peers, 2010).

Seamless Travel Models

In the Seamless Travel study, pedestrian and bicycle models were developed to predict approach volumes at intersections during the 7 to 9 A.M. period on weekdays. Manual counts from a sample of 80 intersections supported the analysis. Counts were supplemented with traveler intercept surveys at 25 locations to obtain additional data, although the surveys did not identify the type of trip in progress.

The Seamless pedestrian model is of the following form:

$$P_{AM} = 1.555 + 0.723\ ED + 0.526\ PD - 1.09\ R\ (R^2 = 0.516)$$

where
P_{AM} = Morning peak pedestrian count
ED = Employment density within 0.5 mile
PD = Population density within 0.25 mile
R = Presence of retail within 0.5 mile

So the model predicts that A.M. peak-period walk trips will increase in proportion to adjacent employment and population density and decrease in the presence of retail activity. Even though these are probably work-related trips, given the time of day, it is not immediately clear why retail activity would have a negative effect on walk trip levels. Employment density carries a higher coefficient than population density, again presumably related to these being primarily work trips, although the buffer radii are different for population and employment and elasticities were not provided.

The Seamless bicycle model has the following form:

$$B_{AM} = -4.279 + 0.718\ C + 0.438\ ED\ (R^2 = 0.439)$$

where
B_{AM} = Morning peak bike trips
C = Footage of Class I bicycle path within 0.25 mile
ED = Employment density within 0.25 mile

This bicycle model predicts an increase in bike trips based on higher employment density and greater presence of Class 1 bikeways within ¼-mile of the count site.

Santa Monica Models

The pedestrian and bicycle models developed by Fehr & Peers for Santa Monica predict volumes for the 5 to 6 PM peak hour. The pedestrian model has the following form:

$$P_{PM} = 222.18 + 0.00321\ ED + 3.675\ BF_{PM} + 82.695\ SDP - 0.00685\ DO - 5.699\ SL\ (R^2 = 0.584)$$

where
P_{PM} = Evening peak pedestrian volume
ED = Employment density within ⅓ mile
BF_{PM} = PM bus frequency
SDP = Intersection is within shopping district
DO = Distance from ocean
SL = Average speed limit on approaches

This equation predicts that PM peak-period walk trips will increase in proportion to adjacent employment, with higher rates of PM bus service, and if the intersection lies within a shopping district. This equation predicts that PM peak-period walk trips will decline with increased distance from the ocean and with higher adjacent auto speeds. In contrast to the Seamless Travel pedestrian model, this model sees a positive effect from retail proximity, which may be due to a higher proportion of non-work trips occurring during the PM peak.

The Santa Monica bicycle model has the following form:

$$B_{PM} = 1.317 + 0.120\ \text{Ln}\ ED + 1.632\ MXD + 0.431\ BN + 0.523\ INT\text{-}4\ (R^2 = 0.401)$$

where
B_{PM} = Evening peak hour bike trips
Ln ED = Log of employment density within ⅓ mile
MXD = Land use mix within ⅓ mile
BN = Proximity to bike routes (intersection is along a bike route or at the intersection of two bike routes, with higher weighting going to better classes of bike facilities)
INT-4 = Four-legged intersection

This equation predicts an increase in bike trips based on higher employment density, mixed land use, proximity to bike routes, and if the intersection is four-way.

The appeal of these models lies in their simplicity and custom quality. Although not easy to construct, they do not require advanced transportation modeling skills and are fairly easy to understand and apply. Aside from the activity counts, most of the data used to construct the context variables are generally available, and model builders are often resourceful in designing the models to use the data that they have.

The caveat with these models is that they trade directness and simplicity for behavioral structure. In effect, they try to explain/predict an aggregate quantity—activity counts in a particular time period—with factors descriptive of the surrounding environment. What results are relationships that may display strong correlations with the activity variable, but cannot be readily shown to "cause" the behavior represented in the counts (which is itself an amalgam of travel activity).

What the NCHRP Project 08-78 research has shown is that accessibility is the most significant determinant of choice, particularly for non-motorized travel, and representing accessibility requires a deliberate effort to simultaneously account for both the opportunities presented through the land use and the ease and efficiency with which the modal networks connect the traveler with these opportunities. It is difficult to apply this relationship in count-based models given that the modeled intersection or link is neither a trip production nor attraction.

Therefore, this guidebook suggests that use of these models should be judicious in how they are developed and when they are used. The following guidelines are suggested:

1. None of these models should be construed as transferrable. Their coefficients are unique to how the models have been

specified (variables included) and the specific location for which they were developed. If an existing model presents an appealing structure, the user is advised to re-estimate the model(s) using identical data for the new study area.

2. The user needs to be aware of the uncertainties associated with modeling "count" data. In almost all cases, the models are blind to the travel behavior represented by the counts (e.g., the purpose of the trip, the sociodemographic characteristics of the traveler, the origin-destination of the trip, and the existence of alternatives). Focusing the counts and models on a particular time period (e.g., A.M. weekday peak for work or mid-day weekend for recreation) can narrow the uncertainty as to the types of trips being observed, but, for other time periods, the mix of trips being modeled may be difficult to surmise.
3. Once the models are calibrated, the user should test their reliability in predicting activity at individual locations and overall for the study area. Although most of the models reviewed have R^2 values of 0.5 or better, they may not be particularly accurate at the level of the individual intersection or link. The Seamless Travel study experimented with methods to adjust the base estimates to account for unusual circumstances (that cannot be directly included in the model), and it may prove worthwhile to review and consider emulating these methods (see http://www.altaplanning.com/caltrans+seamless+study.aspx).
4. Be judicious in the types of applications or decisions to be supported by the models. For example, if measures of network connectivity are not included in the model structure, it would be misleading to estimate demand for a new or improved facility without recognizing that some portion of the new demand predicted may simply be a diversion from some other facility. At the same time, a network improvement that contributes to overall network connectivity may well induce new travel on other portions of the network.

Given the above, it is recommended that the direct demand tools be reserved for either quick estimates or screening in advance of more comprehensive analysis, or for incremental extrapolations from an existing situation. Regardless, the forecast effort should be within the bounds of the explanatory variables in the model and not be used for forecasting new demand or changes within a network. For these types of applications, the user is advised to apply one of the earlier choice-based tools (e.g., the GIS-Accessibility, MoPeD, PedContext, or even the Portland Pedestrian model approach).

CHAPTER 5

Application of Methods

5.1 Introduction

This chapter is the core of the Guidebook. It distills all of the theory, empirical factors, and modeling research from the preceding chapters into a set of methods and guidelines to address planning questions related to non-motorized travel demand.

The guidebook contains a set of analytic techniques, constituting a toolbox of options with different capabilities, accuracy potentials, data needs, and technical skill requirements. Although a single all-purpose tool to anchor the guidebook would have been ideal, it was not realistic given the range of planning needs to be served versus the state of the practice (tools and data) from which the project started. Several of the tools in the set—in particular the new tour-generation/mode split and the GIS-accessibility approaches—could become fully integrated, all-purpose models. Such advancement is anticipated beyond the scope of the current project, as familiarity with the tools grows through application and they become integrated within transportation or land use planning software packages.

Until universal tools become available, the collection of tools in this guidebook offer a credible means to address a wide range of planning questions related to bicycle and pedestrian travel behavior and demand. Table 5-1 provides a listing and short description of the tools in the guidebook.

Collectively, these tools can address the following types of planning issues:

- **Land Use:** Evaluate the impact of land use (density, mix, design) on bicycle or pedestrian trip generation and mode choice, as well as assess how increased non-motorized travel activity supports the viability of compact, mixed land use (AKA, smart growth) policies.
- **Facilities:** Plan effective bicycle and pedestrian networks based on (1) maximizing accessibility to opportunities, (2) emphasizing connectivity, and (3) taking account of user preferences regarding facility type, buffering from traffic, steep grades, and efficient crossings.
- **Transit:** Assess the importance of non-motorized access to/from and accessibility (nearby opportunities) on the viability of transit.
- **Travel Markets:** Address the differential demand for walking and biking across different trip purposes.
- **Traveler Characteristics:** Account for sociodemographic differentials when assessing bike/pedestrian demand potential simultaneous with the accounting for quality of bike/pedestrian opportunity afforded by both the travel network and the built environment which it serves.
- **Scenario Planning and Visioning:** Support interactive land use and transportation planning among diverse stakeholders at the regional, corridor, subarea, neighborhood, or project level.

The rest of this chapter will (1) guide the practitioner in understanding the capabilities of the individual tools, (2) help in determining which tool or tools to select for a particular application need, and (3) provide step-by-step guidance in accessing and using the selected technique. The material is organized into the following sections:

- **Section 5.2—Comparison of Tool Properties and Capabilities:** The properties and characteristics of the suite of recommended tools are displayed in tables to provide a quick visual understanding of key properties and characteristics, alone and in relation to one another.
- **Section 5.3—Individual Tool Profiles:** This section reorganizes the model information presented in the Section 5.2 tables into the form of individual model profiles, where all of the information for the given tool is condensed into a single fact sheet.
- **Section 5.4—Guidelines for Model Selection:** This section provides suggestions and protocols on how to select the right tool or tools from the listings in Sections 5.2 and 5.3, followed by general guidelines on how to use the tools for planning and analysis.

Table 5-1. Summary of NCHRP 8-78 guidebook bicycle/pedestrian planning tools.

Modeling Approach	Source	Characteristics
Tour Generation/ Mode Split	NCHRP 8-78 (Seattle/PSRC data)	Simple/complex tour generation for 8 trip purposes (sociodemographic characteristics, land use, local & regional accessibility) Mode choice (walk, bike, transit, auto) for 5 trip purposes (sociodemographics, land use, local & regional accessibility, Fully detailed walk and bicycle networks, physical attributes affect impedance
GIS-Accessibility Model	NCHRP 8-78 (Arlington, VA/MWCOG data)	Uses GIS layering to create accessibility scores for walk, bike, transit, and auto. Links mode choice with accessibility scores at trip origin and destination Estimates mode share at block level for HBW, HBO, NHB and WBO purposes Builds walk trip table (but does not assign) Highly visual presentation
Trip-Based Model Enhancements	NCHRP 8-78 (Seattle/PSRC data)	Strategic changes to traditional four-step TAZ model to improve sensitivity to land use and non-motorized travel Sensitizes auto ownership and trip generation to land use characteristics Performs pre-mode choice to distinguish inter- versus intrazonal trips Performs mode choice separately for intra zone (drive-alone, shared-ride, walk) and inter-zone (drive, shared-ride, transit, walk, bike) travel
Pedestrian Demand Models	PedContext and MoPeD (Univ. of MD/ Maryland DOT) Portland Pedestrian Model (PSU)	Modified four-step approach focused on estimating walk trips Walk trip generation for several purposes at PAZ level Creates walk trip tables, assigns trips to walk network
Bicycle Route Choice Models	San Francisco County Transp. Authority; Portland State Univ.	Models built from GPS-recorded trip data to predict choice of route for bicycle riders Quantifies importance of route characteristics (type facility, gradient, directness, traffic exposure)
Facility-Demand Models	Santa Monica Bicycle and Pedestrian Models (Fehr & Peers) Seamless Travel Bicycle and Pedestrian Models (Alta Planning & UC Berkeley)	Separate bicycle and pedestrian direct demand models Predict PM peak hour bicycle demand based on employment density, proximity to bike facilities, land use mix, and intersections Predict PM peak hour walk demand based on employment density, proximity to shopping, PM bus frequency, and traffic speeds

- **Section 5.5—Guidelines for Use:** This section provides step-by-step guidance for applying each of the tools. The appendixes to the Guidebook contain all key equations, elasticities where available, and calibration statistics.

5.2 Comparison of Tool Properties and Capabilities

This section presents summary information on the properties and characteristics of each of the methods, portrayed in table format to facilitate comparison across tools. Tables provide the following information:

- **Table 5-2: Model Type and Geographic Scale:** Cites the form and distinguishing characteristics of each tool, the level of aggregation at which it operates, and the most suitable geographic scales for its application.
- **Table 5-3: Modeling Steps Impacted:** Lists the modeling steps or elements exercised by the model (e.g., auto ownership, trip generation, distribution, mode choice, time of day and assignment, as well as trip purpose definitions and use of accessibility relationships).
- **Table 5-4: Planning Applications:** Suggests suitability for use in a set of 11 illustrative planning applications. Suitability is denoted as being *directly* applicable (D), having

Table 5-2. Model type and geographic scale.

	Disaggregate Tour-based (Seattle)	GIS-Based Accessibility (Arlington)	Enhanced Trip-Based (Seattle)	Pedestrian Model (Portland)	Walk Models (PedContext & MoPeD)	Bike Route Choice (SFCTA/PSU)	Direct Demand (Various)
Model Type	Compr. Tour Generation, Mode Choice	Full GIS-based Compr. Trip Generation, Mode Choice, Distribution	Trip Gen, Inter versus Intra- Zonal Distribution, Mode Choice	Context Based Index Method For Walk Trip Generation	Walk Trip Generation, Distribution, Assignment	Explain Route Choice from Path Attributes	Explain bike or walk link or intersection counts through regression with context measures
Aggregation Level	Parcel	Block	TAZ	PAZ	PAZ	Link	Intersection or Link
Geographic Scale							
Regional	Y		Y	Y			
Corridor	Y	Y	Y	Y	Y	Y	
Subarea	Y	Y	Y	Y	Y	Y	Y
Project Site	Y*	Y	Y*	Y*	Y		Y
Facility/Point	Y*	Y*	Y*	Y*	Y		Y

* = Model outputs may be used for assignment in host model (given availability of a non-motorized network)

a significant *assisting* role but probably unable to perform the entire task alone (A), having a *partial* but potentially useful role (P), or having *no* obvious role (N).

- **Table 5-5: Key Indicators:** Lists the principal output measures and performance metrics generated by the respective model to support the planning applications in Table 5-4.
- **Table 5-6: Variable Sensitivities:** Presents the generic types of factors (e.g., sociodemographics, land use, and transportation network) and specific variables in those categories to which the models are sensitive.
- **Table 5-7: Data Requirements:** Summarizes the various types and sources of data needed by the respective tools for development, transfer, or validation.

Table 5-3. Modeling steps impacted.

	Disaggregate Tour-based (Seattle)	GIS-Based Accessibility (Arlington)	Enhanced Trip-Based (Seattle)	Pedestrian Model (Portland)	4-Step Walk Model (PedContext)	4-Step Walk Model (MoPeD)	Bike Route Choice (SFCTA/PSU)	Direct Demand (Various)
Auto Ownership	Y	N	Y	N	N	Y	N	N
Accessibility	Y	Y	Y	Y	Y	Y	Y[1]	Y[2]
Trip/tour Generation	Y	Y	Y(W, B)	Y(W)	Y(W)	Y(W)	N	N
Trip/Tour Purpose	Y	Y	Y	Y	Y	Y	Y	N
Distribution/Trip Tables	N	Y	N	N	Y	Y	N	N
Mode Choice	Y	Y	Y	Y (W, NW)	N	N	N	Y
Time of Day	N	N	N	N	Y	N	N	Y
Non-Motorized Definition	W, B	W	W, B	W	W	W	B	W, B
Assignment/Facil Volumes	N	N	N	N	Y	Y	Y	Y

Notes:

1 Assist in valuing travel time/distance

2 Aggregate

W, B = Walk, Bike W, NW = Work, Non-work

Table 5-4. Planning applications.

	Disaggregate Tour-based (Seattle)	GIS-Based Accessibility (Arlington)	Enhanced Trip-Based (Seattle)	Pedestrian Model (Portland)	4-Step Walk Model (PedContext)	4-Step Walk Model (MoPeD)	Bike Route Choice (SFCTA/PSU)	Direct Demand (Various)
Regional Plan Development	D	A	D	A	A	A	P	P
Scenario Planning/ Visioning	D	D	A	A	A	A	P	P
Land Use/Smart Growth/TOD	D	D	A	A	A	A	P	P
Multimodal Corridor Studies	D	D	A	P	A	A	A	P
Transit Planning	A	A	A	P	A	A	A	A
Multimodal Accessi-bility & Equity	D	D	A	A	A	A	A	A
Local Comp or Master Plans	D	D	A	A	D	D	A	P
Site Planning & Traffic Impact Mitigation	A*	A*	A	A	D	D	A	P
Bicycle or Pedestrian Facility Planning	A*	A*	P	A*	D	D	D	A
NMT Facility Prioritization	A*	A*	P	A*	D	D	A	A
Intersection Activity Levels for Safety Analysis	A*	A*	N	A*	D	D	A	D

Applicability Codes:
D = Direct role
A = Key assisting role
P = Partial role, can contribute
N = Not an obvious role

Notes:
* – Needs to be accompanied by assignment program

Table 5-5. Key indicators.

Indicators	Disaggregate Tour-based (Seattle)	GIS-Based Accessibility (Arlington)	Enhanced Trip-Based (Seattle)	Pedestrian Model (Portland)	4-Step Walk Model (PedContext)	4-Step Walk Model (MoPeD)	Bike Route Choice (SFCTA/PSU)	Direct Demand (Various)
Mode Split (shares)	Y	Y	Y	Y	N	N	N	N
Vehicle Trips	Y	Y	Y	N	N	N	N	N
Transit Trips	Y	Y	Y	N	N	N	N	N
Bike Trips	Y	N	Y	N	N	N	N	Y
Walk Trips	Y	Y	Y	Y	Y	Y	N	Y
VMT	N	N	N	N	N	N	N	N
Bike Link Volumes	N[1]	N	N	N	N	N	Y	Y
Ped Link Volumes	N[1]	N[1]	N	N	Y	Y	N	Y
Walk Intersection Volumes	N[1]	N[1]	N	N	Y	Y	N	Y

Notes:
1 – Would need to be coupled with route assignment model

Table 5-6. Variable sensitivities.

	Disaggregate Tour-based (Seattle)	GIS-Based Accessibility (Arlington)	Enhanced Trip-Based (Seattle)	Pedestrian Model (Portland)	4-Step Walk Model (PedContext)	4-Step Walk Model (MoPeD)	Bike Route Choice (SFCTA/PSU)	Direct Demand (Various)
Sociodemographic	Age, Gender, F/PT Worker, Student, Retired, Income, Auto Ownership	HHs by Auto Ownership (trip gen)	HH size, Workers, Drivers, Income, Age/Gender, Employed	HH size, Autos Income, Workers, Age Head, Children	Income', HH size, age, workers, children, autos	Block-level Households & Employment by type, DUs, Auto Ownership	Gender, Commuter (SFCTA only)	Varies: e.g., 0-vehicle HHs; density of persons < 18
Local Accessibility	Purpose-specific buffered activity for W,B	Purpose-specific activity sums for W, B	NMT Accessibility Index	Buffered Pop &Emp	Block-level walk-accessibility to MFDUs, Total or Retail Emp	Block to block network distance, exponential decay	None	Proximity to major generators & attractors
Regional Accessibility	General and purpose-specific logsums	Purpose-specific activity sums for Auto, Transit	SOV Accessibility Index	None	None	None	None	Generally not included
Built-Environment Characteristics	Pop & Emp densities, Entropy, Intersections, Transit stops	Number Establishments or Employees by 4-digit NAICS within walking range	Pop & Emp densities; Intersections; Transit proxim; Parking Supply & $; Home loc indicator	Pop & Emp densities, Transit proximity, Urban Infrstruct	Block level Pop, Dwelling units (SF, MF); Floor area; Emp by type	Pop & Emp densities, Intersection density	None	Pop & Emp Density, LU mix, intersections, transit proximity & availability,
Impedance	Logistic decay of travel distance	Logarithmic decay of travel time	Logistic decay of travel distance	None	Gamma decay of travel time	Exponential decay of walk network distance	Imputed by individual factor values	None
Walk Facility Characteristics	Sidewalk coverage; traffic speed	Shortest time path; crossings	None	Sidewalk density, block size	Sidewalk "Quality". Crossings; Traffic vols & speed	Road layer converted to sidewalk network with crossings	None	Intersection design, traffic, signalization, facility type,
Bicycle Facility Characteristics	Average rise, Cl I or II Paths, Wrong-way %, Turns per mile	Shortest time path; crossings	None	Included in pedestrian environment (PIE) index	None	None	Facility type, slope, turns, wrong way, crossing AADT	Facility type, nearness, proximity to traffic, turns & crossings

W, B = Walk, Bike

Table 5-7. Data requirements.

	Disaggregate Tour-based (Seattle)	GIS-Based Accessibility (Arlington)	Enhanced Trip-Based (Seattle)	Pedestrian Model (Portland)	4-Step Walk Model (PedContext)	4-Step Walk Model (MoPeD)	Bike Route Choice (SFCTA/PSU)	Direct Demand (Various)
Travel Survey	Y[1]	Y[1]	Y[1]	N	Y[1]	Y[1]	Y[6]	N
Parcel-level Land Use	Y	Y[1]	Y[1]	N	N[5]	Y[1]	N	N
Census population & employment	Y	Y[2]	Y	Y	Y	Y	N	Y
Transit system & stop locations	Y	N[4]	Y	Y[7]	N	N	N	Y
All streets network (GIS)	Y	Y	Y	Y	Y	Y	Y	Y
Regional TAZ data & travel skims	Y	N	Y	N	N	N	N	N
Walk link characteristics	Y[8]	N	N	Y	Y	Y	N	Y
Bike Link characteristics	Y[9]	N	N	Y	N	N	Y	Y
Crossings and intersection location & characteristics	Y	N	N	N	Y	Y	Y	Y
Activity counts	N	N	N	Y[3]	Y[3]	Y[3]	Y	Y

Notes:

1 – Needed for model calibration or transfer
2 – Need for application
3 – Need for validation
4 – Only if calculating transit accessibility
5 – Block-level data is sufficient
6 – GPS rider data
7 – Stops only
8 – Sidewalk coverage, speed limits
9 – Grade, facil type, turns, wrong way

5.3 Individual Tool Profiles

This section condenses and supplements the information presented in the preceding tables into a separate fact sheet, or profile, for each method. The profiles describe the strengths and weakness of each technique, which should help users when selecting methods.

Tour-Generation and Mode-Choice Models

Description:

This tool uses a highly disaggregated modeling approach—individual tour generation and mode choice at the parcel level—to account for the many factors that affect bicycle and pedestrian travel choice, particularly land use and network connectivity through measures of both local and regional accessibility. The tool offers insights on the importance of particular bicycle and pedestrian network characteristics in valuing travel time, which is critical for measuring accessibility and when designing effective network enhancements. The procedure may be applied in full tour-based form (proper model platform required), or used to enhance existing tour or trip-based models, either through application of the full models, individual elasticities, or the custom spreadsheet provided with the guidebook.

Geographic Scale:

☑ Regional ☑ Corridor ☑ Subarea ☐ Project/Site ☐ Facility/Point

Planning Applications:

☑ Scenario Planning	☑ Smart Growth/TOD	☑ Transit
☑ Comp/Master Plans	☑ Traffic Impact Mitigation	☐ NMT Facility Planning
☐ Safety Analysis	☑ Equity	

Forecasting Elements:

☐ Auto Ownership	☑ Trip Generation	☐ Distribution
☑ Mode Choice	☐ Assignment	

Indicators and Metrics:

☑ Mode Shares	☑ Walk Trips	☑ Bike Trips
☑ Vehicle Trips	☑ Transit Trips	☑ VMT
☐ Walk Link Volumes	☐ Bike Link Volumes	☐ Intersection Volumes

Trip Purposes

☑ Work	☑ School	☑ Other
☑ Recreation	☑ Work-based	☐ Non-home-based

Model Relationships and Sensitivity:

Land Use:	☑ High	☐ Medium	☐ Low
Non-Motorized Network:	☑ High	☐ Medium	☐ Low
Accessibility:	☑ High	☐ Medium	☐ Low
Sociodemographics:	☑ High	☐ Medium	☐ Low

Data Requirements:

- ☑ Travel Surveys
- ☑ Census Population & Employment
- ☑ Walk Link Characteristics[2]
- ☑ Transit Stop Locations
- ☑ Parcel-Level Land Use
- ☑ All-Streets Network in GIS format
- ☑ Bike Link Characteristics[3]
- ☑ Regional Model TAZ data & Skims (for accessibilities)

Tools & Expertise:

- ☑ Travel Modeling
- ☑ GIS Tools & Expertise
- ☑ Data Management

Strengths

- Highly insightful into the choice of travel modes based on travelers' assessment of local and regional opportunities and benefits and traveler/household needs (e.g., combining trips or chauffeuring passengers).
- Deals directly with land use and network accessibility, at both the communitywide and regional level.
- Distinguishes between traveler choice of simple versus complex tours, which are predicated on local land use and which have strong implications for mode choice for specific trip purposes (work, school, shop, work-based, and other).
- Captures important physical attributes of bicycle or pedestrian networks that affect accessibility, (e.g., directness and trip length, slope, presence of sidewalks and Class I and Class II bikeways, and concentrations of population and employment).
- Accounts for traveler socioeconomic factors (e.g., gender, work status, household size and composition, income, and vehicle availability).

Weaknesses

- Complete replication of the methods would require substantial resources in terms of data availability, analytic expertise, software and (potentially) hardware investment, and so would be most appropriate for areas that already have or are contemplating an activity or tour-based model platform. However, transfers and partial applications may be done with considerably less effort.
- The best application works within a tour- or activity-based model environment, based on definitional issues distinguishing tours from trips; however, this problem can be overcome with some simplification of assumptions.
- Ideal application would require development and use of a synthetic population of individuals, given that the models are most relevant when applied to individuals as opposed to households (important individual characteristics are lost) or zones (aggregation affects accuracy).
- To obtain estimates of area-specific or facility-specific use, additional tools are required for destination choice and route choice, coupled with validation of the resulting estimates.

GIS-Accessibility Tool

Description:

This tool relies almost entirely on GIS tools and data to create relationships between land use activity, accessibility to opportunities defined by the shape and service of the transportation networks, and mode choice. The tool focuses on a walk-accessibility score—similar to, but more informed than, the Walk Score program on the internet—to estimate walk potential and mode choice. Block-level walk trip tables are created, which can be assigned to a network (feature not included).

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[2] Sidewalk coverage; speed range of adjacent traffic

[3] Class I or II bike lane; elevation gain, number of turns, fraction wrong way

Geographic Scale:

☐ Regional ☑ Corridor ☑ Subarea ☑ Project/Site ☐ Facility/Point

Planning Applications:

☑ Scenario Planning
☑ Comp/Master Plans
☐ Safety Analysis
☑ Smart Growth/TOD
☑ Traffic Impact Mitigation
☑ Equity
☑ Transit
☑ NMT Facility Planning

Forecasting Elements:

☐ Auto Ownership
☑ Mode Choice
☑ Trip Generation
☐ Assignment
☑ Distribution

Indicators and Metrics:

☑ Mode Shares
☐ Vehicle Trips
☐ Walk Link Volumes
☑ Walk Trips
☐ Transit Trips
☐ Bike Link Volumes
☐ Bike Trips
☐ VMT
☐ Intersection Volumes

Trip Purposes

☑ Work
☐ Recreation
☐ School
☑ Work-based
☑ Other
☑ Non-home-based

Model Relationships and Sensitivity:

Land Use:	☑ High	☐ Medium	☐ Low
Non-Motorized Network:	☑ High	☐ Medium	☐ Low
Accessibility:	☑ High	☐ Medium	☐ Low
Sociodemographics:	☐ High	☑ Medium[4]	☐ Low

Data Requirements:

☑ Travel Surveys
☑ Census Population & Employment
☐ Walk Link Characteristics
☐ Transit Stop Locations
☑ Parcel-Level Land Use[5]
☑ All-Streets Network in GIS format
☐ Bike Link Characteristics
☐ Regional Model TAZ data & Skims (for accessibilities)

Tools & Expertise:

☑ Travel Modeling ☑ GIS Tools & Expertise ☑ Spreadsheet Mechanics

Strengths

- GIS approach in many ways is more intuitive and realistic than working with TAZ-based travel models; it accomplishes through geospatial relationships what requires considerable coding and computation in conventional models.
- Calibration requires travel survey and GIS network data, but once calibrated, typical application is at a much simpler block level.

[4] Trip generation only at present, not mode choice
[5] Uses Dun & Bradstreet employment data for model calibration (employer by NAICs code, number employees, and latitude/longitude location)

- Accessibility framework implicitly and simultaneously accounts for both land use and network coverage/quality factors; provides a natural platform for collaborative community planning.
- Separately accounts for four trip purposes: home-based work, home-based non-work travel, work-based, and non-home-based travel.
- Both origin and destination accessibilities are considered when calculating mode-split.
- Requires GIS tools and knowledge, but requirements are fairly standard.
- Spreadsheet version of model provided with test data and examples.

Weaknesses

- Estimates walk travel only, not bike.
- Does not account for sociodemographics directly in mode choice, but indirectly through trip generation.
- Does not account for link characteristics (e.g., facility type or gradient), although these could be easily added to the calculation of link impedance.
- Uses trip generation equations from MPO model to estimate total person trip generation, from which walk trips are then extracted/estimated.
- Generates walk trip tables but does not include an internal assignment program to estimate facility volumes (access to external program required for this step).

Seattle Enhancements to Trip-Based Model

Description:

This approach illustrates how sensitivity in traditional TAZ-level trip-based models can be strategically enhanced by introduction of land use and accessibility measures at the auto ownership, trip generation, and mode split steps. Instead of being discarded following trip generation, non-motorized trips are taken forward into mode-choice analysis by separation into groupings of intrazonal and interzonal trip types.

Geographic Scale:

☑ Regional ☑ Corridor ☑ Subarea ☐ Project/Site ☐ Facility/Point

Planning Applications:

☑ Scenario Planning
☑ Comp/Master Plans
☐ Safety Analysis
☑ Smart Growth/TOD
☑ Traffic Impact Mitigation
☑ Equity
☐ Transit
☐ NMT Facility Planning

Forecasting Elements:

☑ Auto Ownership
☑ Mode Choice
☑ Trip Generation
☐ Assignment
☑ Distribution

Indicators and Metrics:

☑ Mode Shares
☑ Vehicle Trips
☐ Walk Link Volumes
☑ Walk Trips
☑ Transit Trips
☐ Bike Link Volumes
☑ Bike Trips
☑ VMT
☐ Intersection Volumes

Trip Purposes

☑ Work
☐ Recreation
☐ School
☐ Work-based
☑ Other
☑ Non-home-based

Model Relationships and Sensitivity:

Land Use:	☐ High	☑ Medium	☐ Low
Non-Motorized Network:	☐ High	☑ Medium	☐ Low
Accessibility:	☐ High	☑ Medium	☐ Low
Sociodemographics:	☐ High	☑ Medium	☐ Low

Data Requirements:

☑ Travel Surveys
☑ Census Population & Employment
☐ Walk Link Characteristics
☑ Transit Stop Locations
☑ Parcel-Level Land Use
☑ All-Streets Network in GIS format
☐ Bike Link Characteristics
☑ Regional Model TAZ data & Skims (for accessibilities)

Tools & Expertise:

☑ Travel Modeling
☑ GIS Tools & Expertise
☑ Data Management

Strengths

- Can be emulated for most urban area models in the United States. About 90% of MPOs employ trip-based as opposed to activity-based models.
- Emulates a full travel decision process: vehicle ownership, trip generation, destination choice, and mode choice.
- Estimates are sensitive to traveler demographics, including age, gender, income, and auto availability.
- Mode choice and destination choice estimates are sensitive to localized built-environment factors at trip origin and destination, including development density, land use mix, local street connectivity, and transit availability.
- Allows travel route assignment and facility-use estimates (but only for motorized modes and only for interzonal travel).

Weaknesses

- Effects of TAZ size on key relationships (accessibility, intra- versus interzonal trip-making) not controlled for.
- Requires an extensive regionwide geospatial database with parcel-based land use activity, local streets and paths, parking supply and cost, and bus stops.
- The equations presented in the guidebook are not directly transferrable to other regions, because they are implicitly tied to the zone size and structure of the Seattle region. Developing models of this type for another region would require including a zone-size variable in the equations, such as acreage or total population and employment.
- Cannot report full effect of land use mix and trip destination employment density on travel by mode because of the way the effects are subdivided in the model.
- Obtaining estimates of area-specific or facility-specific use requires additional tools for intrazonal destination choice and route choice, followed by count-based model validation.

Portland Pedestrian Model Enhancement

Description:

This is not so much a stand-alone tool as a creative enhancement for a trip-based model to improve its sensitivity for pedestrian analysis. The enhancement estimates pedestrian trip generation at a block level through a combination of buffered land use and transportation system variables into a pedestrian index of the environment (PIE).

Geographic Scale:

☑ Regional ☑ Corridor ☑ Subarea ☐ Project/Site ☐ Facility/Point

Planning Applications:

☑ Scenario Planning
☑ Comp/Master Plans
☐ Safety Analysis
☑ Smart Growth/TOD
☐ Traffic Impact Mitigation
☐ Equity
☐ Transit
☐ NMT Facility Planning

Forecasting Elements:

☐ Auto Ownership
☑ Mode Choice
☑ Trip Generation
☐ Assignment
☐ Distribution

Indicators and Metrics:

☐ Mode Shares
☐ Vehicle Trips
☐ Walk Link Volumes
☑ Walk Trips
☐ Transit Trips
☐ Bike Link Volumes
☐ Bike Trips
☐ VMT
☐ Intersection Volumes

Trip Purposes

☑ Work
☐ Recreation
☐ School
☐ Work-based
☑ Other
☑ Non-home-based

Model Relationships and Sensitivity:

Land Use:	☐ High	☑ Medium	☐ Low
Non-Motorized Network:	☐ High	☐ Medium	☑ Low
Accessibility:	☐ High	☐ Medium	☑ Low
Sociodemographics:	☐ High	☑ Medium	☐ Low

Data Requirements:

☑ Travel Surveys
☑ Census Population & Employment
☑ Walk Link Characteristics
☐ Transit Stop Locations
☑ Activity Counts
☐ Parcel-Level Land Use
☐ All-Streets Network in GIS format
☐ Bike Link Characteristics
☐ Regional Model TAZ data & Skims

Tools & Expertise:

☐ Travel Modeling ☐ GIS Tools & Expertise ☑ Data Management

Strengths

- Brings scale of analysis to a block level of detail.
- Pedestrian trip estimates can be used directly for scenario purposes or combined with regional model outputs to compute/adjust mode split.
- Can operate independently of regional model, but operates well to serve it with pedestrian information.
- Accounts for interactions among built-environment variables as revealed through correlations to choice of walking mode (Portland case) accounting for block size and sidewalk density, transit access, population and employment density and concentrations of grocery stores, restaurants, retail stores, services, and schools.

Weaknesses

- Does not predict bicycle trips.
- Deals only with walk (versus non-walk) trip generation.
- Does not directly create a walk trip table or assign to facilities.

Model of Pedestrian Demand (MoPeD)

Description:

MoPeD is a method for estimating pedestrian trip generation at a block level, creating trip tables, and assigning those trips to a grid. It is a simplified four-step process for walk travel that offers good spatial resolution, incorporation of land use and network accessibility factors, and the ability to exercise those factors in assessments of changes in land use or network needs/improvements.

Geographic Scale:

☐ Regional ☑ Corridor ☑ Subarea ☑ Project/Site ☐ Facility/Point

Planning Applications:

☑ Scenario Planning	☑ Smart Growth/TOD	☐ Transit
☑ Comp/Master Plans	☐ Traffic Impact Mitigation	☑ NMT Facility Planning
☑ Safety Analysis	☐ Equity	

Forecasting Elements:

☐ Auto Ownership	☑ Trip Generation	☑ Distribution
☐ Mode Choice	☑ Assignment	

Indicators and Metrics:

☐ Mode Shares	☑ Walk Trips	☐ Bike Trips
☐ Vehicle Trips	☐ Transit Trips	☐ VMT
☑ Walk Link Volumes	☐ Bike Link Volumes	☑ Intersection Volumes

Trip Purposes

☑ Work	☐ School	☐ Other
☐ Recreation	☐ Work-based	☑ Non-home-based

Model Relationships and Sensitivity:

Land Use:	☐ High	☑ Medium	☐ Low
Non-Motorized Network:	☐ High	☑ Medium	☐ Low
Accessibility:	☐ High	☑ Medium	☐ Low
Sociodemographics:	☐ High	☑ Medium	☐ Low

Data Requirements:

☐ Travel Surveys	☑ Parcel-Level Land Use
☑ Census Population & Employment	☑ All-Streets Network in GIS format
	☑ Bike Link Characteristics
☑ Walk Link Characteristics	☑ Regional Model TAZ data & Skims (for accessibilities)
☑ Transit Stop Locations	

Tools & Expertise:

☑ Travel Modeling ☑ GIS Tools & Expertise ☑ Statistical Analysis skills

Strengths

- Similar in structure to four-step regional models, but functions at pedestrian scale of geospatial analysis using block-size PAZs.
- Can focus in detail on the neighborhood of interest.
- Accounts for sociodemographic characteristics (at block level) (e.g., household vehicle ownership, head of household age, and household size and income).
- Performs facility-use assignments and estimates 24-hour pedestrian volumes on sidewalks and intersections.
- GIS platform and open-source analysis routines make the method more available to planners and analysts without proficiency in regional travel models.

Weaknesses

- Estimates walk trips only, not bike.
- Does not account for regional accessibility effects in competing for local walk trips; auto or transit not factored in as alternative choices.
- Accessibility is based on spatial buffering of blocks, not parcels, and is not network path based.
- Assignment process is based on shortest-path all-or-nothing rule; does not account for path characteristics.
- Land use influences limited to block-level households and dwelling units, employment mix (retail, service, other) and intersection density.

Maryland PedContext Model

Description:

This tool was a precursor to MoPeD and is much more detailed (and demanding) in each of its steps in estimating walk travel generation and the distribution of walk trips to a network. However, it offers a much higher level of precision in interpreting land use, network characteristics, and accessibility, and potentially a higher level of accuracy of the facility volume estimates.

Geographic Scale:

☐ Regional ☑ Corridor ☑ Subarea ☑ Project/Site ☐ Facility/Point

Planning Applications:

☑ Scenario Planning ☑ Smart Growth/TOD ☑ Transit
☑ Comp/Master Plans ☐ Traffic Impact Mitigation ☑ NMT Facility Planning
☑ Safety Analysis ☐ Equity

Forecasting Elements:

☐ Auto Ownership ☑ Trip Generation ☑ Distribution
☐ Mode Choice ☑ Assignment

Indicators and Metrics:

☐ Mode Shares ☑ Walk Trips ☐ Bike Trips
☐ Vehicle Trips ☐ Transit Trips ☐ VMT
☑ Walk Link Volumes ☐ Bike Link Volumes ☑ Intersection Volumes

Trip Purposes

☑ Work	☐ School	☑ Other
☑ Recreation	☐ Work-based	☑ Non-home-based

Model Relationships and Sensitivity:

Land Use:	☐ High	☑ Medium	☐ Low
Non-Motorized Network:	☑ High	☐ Medium	☐ Low
Accessibility:	☐ High	☑ Medium	☐ Low
Sociodemographics:	☐ High	☐ Medium	☑ Low

Data Requirements:

☐ Travel Surveys	☐ Parcel-Level Land Use
☑ Census Population & Employment	☑ All-Streets Network in GIS format
☑ Walk Link Characteristics	☐ Bike Link Characteristics
☐ Transit Stop Locations	☐ Regional Model TAZ data & Skims
☑ Facility activity counts	

Tools & Expertise:

☑ Travel Modeling ☑ GIS Tools & Expertise ☑ Data Management

Strengths

- Replicates much of the familiar four-step process, but specifically at the pedestrian scale.
- Land use and trip generation represented at block-level geography.
- Highly detailed treatment of walk network using GIS, creative enhancements to quantify utility of sidewalks and crossings.
- Extensive use of walk-accessibility measures in walk trip generation.
- Accessibility measures are calculated using actual network travel times.
- Trips for six different trip purposes (both home and non-home-based).
- Trip distribution using different (locally derived) impedance functions for each trip purpose.
- Uses a stochastic (iterative) multi-path network assignment process (using weighted impedances) to estimate 24-hour pedestrian volumes by link and intersection.

Weaknesses

- Although PedContext uses commonly available software (e.g., ArcView GIS and the Citilabs CUBE and VIPER programs), the custom package includes processing innovations that are proprietary (at present) to the PedContext software. However, each of the steps is well explained in the documentation and can likely be emulated if the user chooses not to acquire the PedContext software.
- Deals only with walk trips, and does not account for role of regional accessibility in competition for other modes/destinations.
- Requires a reasonable understanding of network development and assignment protocols to most easily begin to emulate or use.
- The detail in land use relationships is aggregated at the block level, though given the small size of the blocks, this may be sufficient for most applications.

Bicycle Route Choice Models

Description:

These two tools (SFCTA and Portland) both used GPS methods to compile route choice data on a large sample of bicycle trips, which were then used to develop models of route choice incorporating such attributes as directness, facility type (sidewalk and Class I, II, III bike paths), gradient, turns, and traffic exposure. The results can be used to assign value to these attributes in facility planning or to inform full-scale planning models with measures of weighted travel impedance.

Geographic Scale:

☐ Regional ☑ Corridor ☑ Subarea ☑ Project/Site ☑ Facility/Point

Planning Applications:

☑ Scenario Planning
☑ Comp/Master Plans
☑ Safety Analysis
☐ Smart Growth/TOD
☐ Traffic Impact Mitigation
☐ Equity
☐ Transit
☑ NMT Facility Planning

Forecasting Elements:

☐ Auto Ownership
☐ Mode Choice
☐ Trip Generation
☑ Assignment
☐ Distribution

Indicators and Metrics:

☐ Mode Shares
☐ Vehicle Trips
☐ Walk Link Volumes
☐ Walk Trips
☐ Transit Trips
☑ Bike Link Volumes
☐ Bike Trips
☐ VMT
☑ Intersection Volumes

Trip Purposes

☑ Work
☐ Recreation
☐ School
☐ Work-based
☑ Other
☐ Non-home-based

Model Relationships and Sensitivity:

Land Use:	☐ High	☐ Medium	☑ Low
Non-Motorized Network:	☑ High	☐ Medium	☐ Low
Accessibility:	☐ High	☐ Medium	☑ Low
Sociodemographics:	☐ High	☑ Medium	☐ Low

Data Requirements:

☑ Travel Surveys (GPS)[6]
☐ Census Population & Employment
☐ Walk Link Characteristics
☐ Transit Stop Locations
☑ Activity Counts
☐ Parcel-Level Land Use
☑ All-Streets Network in GIS format
☑ Bike Link Characteristics
☐ Regional Model TAZ data & Skims

Tools & Expertise:

☑ Travel Modeling ☑ GIS Tools & Expertise ☑ Statistical Analysis skills

[6] Required only to supply the data for model calibration, not for application

Strengths

- Not of great direct value as a planning tool, but for the unique relationships it supplies on valuation of facility and network design features
- Quantifies values of physical attributes of alternative routes using actual (revealed preference) data on observed trip-making
- Weights calculated in relation to route choice can be used for facility/network design or comparing project improvement alternatives
- Weighted attributes can be used to sensitize travel impedances to reflect importance of path characteristics on value of travel time (procedure was used to develop bike network skims for Seattle Tour-based model)

Weaknesses

- Deals with bicycle only.
- Deals only with route choice and not with overall choice of bicycle as mode, nor choice of destination in relation to bicycle accessibility.
- Does not predict facility volumes.

Direct Demand Facility Volume Models

Description:

This class of tools includes many examples, most of which are custom-developed for a particular site and planning question. The tools are designed to forecast demand levels for walk or bike at a point or intersection level, usually to support traffic safety studies, although they are also used to evaluate and prioritize projects.

Geographic Scale:

☐ Regional ☑ Corridor ☑ Subarea ☑ Project/Site ☐ Facility/Point

Planning Applications:

☐ Scenario Planning	☑ Smart Growth/TOD	☐ Transit
☑ Comp/Master Plans	☐ Traffic Impact Mitigation	☑ NMT Facility Planning
☑ Safety Analysis	☐ Equity	

Forecasting Elements:

☐ Auto Ownership	☑ Trip Generation	☐ Distribution
☐ Mode Choice	☑ Assignment	

Indicators and Metrics:

☐ Mode Shares	☐ Walk Trips	☐ Bike Trips
☐ Vehicle Trips	☐ Transit Trips	☐ VMT
☑ Walk Link Volumes	☑ Bike Link Volumes	☑ Intersection Volumes

Trip Purposes (generally not determined)

☐ Work	☐ School	☐ Other
☐ Recreation	☐ Work-based	☐ Non-home-based

Model Relationships and Sensitivity:

Land Use:	☐ High	☑ Medium	☐ Low
Non-Motorized Network:	☐ High	☐ Medium	☑ Low
Accessibility:	☐ High	☐ Medium	☑ Low
Sociodemographics:	☐ High	☐ Medium	☑ Low

Data Requirements:

☐ Travel Surveys
☑ Census Population & Employment
☑ Walk Link Characteristics
☑ Transit Stop Locations
☑ Activity Counts
☐ Parcel-Level Land Use
☐ All-Streets Network in GIS format
☑ Bike Link Characteristics
☐ Regional Model TAZ data & Skims

Tools & Expertise:

☐ Travel Modeling
☑ Statistical Analysis and Spreadsheet Skills
☐ GIS Tools & Expertise

Strengths

- Convenient method for estimating the impact of an individual investment or accessibility improvement along a specific corridor or neighborhood, such as a Complete Street project, on usage levels.
- Avoids complexity and coarseness associated with TAZ trip-based models; does not require traditional transportation modeling skills to develop or apply.
- Provides a way of gauging effects of residential and non-residential development projects on pedestrian and bicycle activity levels and capacity needs.
- Based on observed local walking and biking behavior rather than on self-reported travel (surveys).
- Provides estimates of activity for specific time periods (e.g., A.M. peak or weekend).

Weaknesses

- Does not systematically link activity levels to elements of the decision-making process (trip generation, mode or destination choice) but rather through correlation with environmental factors believed to be causal (development levels, major generators, transit activity/use levels, population or employment subgroups)
- Generally does not account for characteristics of the traveler or trip (e.g., socioeconomic factors, trip purpose, origin or destination); the models generally attempt to project usage levels based on correlative relationships
- Does not directly account for network accessibility characteristics in ascertaining the absolute or relative value of individual link or intersection improvements, although this is a potential enhancement that should be given further study.

5.4 Guidelines and Suggestions for Model Selection and Use

This section provides assistance in how to decide which of the various tools to use for a particular planning application, along with suggestions, caveats, and protocols to take into consideration when adapting or applying the given tool. Topics discussed include the following:

- How to compare the capabilities of the guidebook tools, in relation to a choice-based behavioral framework,
- Selecting the best approach for a particular geographic scale,
- Trading off accuracy needs versus complexity and effort,
- Ways to use the tools, and
- Validation guidelines.

Varied Tools for Varied Needs and Capabilities

The user should view the tools in this guidebook as a hierarchy, beginning with the most comprehensive and tending to the most specific and focused—and potentially limited. Each comes with tradeoffs, articulated in the Strengths and Weaknesses assessment in the preceding model profiles. The more comprehensive tools will probably require more effort and expertise, but for particular planning or policy questions, they may be the only way to effectively address those issues. At the same time, some users will want to get as quickly as possible to an answer—perhaps to support an impending or preliminary decision—who have neither the time nor resources for a full analysis and will want a simpler approach.

To the extent possible, users should attempt to use one of the more comprehensive choice-based tools because of the demonstrated role of accessibility and how these tools coordinate land use and network relationships to employ accessibility considerations. If the tools at the top of the menu (tour-based or GIS-accessibility approach) cannot be used, then the next priority would be the model enhancement (trip-based enhancements or Portland pedestrian model) or the four-step pedestrian models (PedContext or MoPeD), which have a choice-based structure but may be easier to implement for some users. The facility demand (i.e., direct demand) tools can offer important convenience and utility to users, but their use should be confined to screening or preliminary analyses until such time as a more complete model may be brought to bear. An alternative to the direct demand methods may be to use either elasticity relationships from the choice-based models or strategically apply the special spreadsheet version of the tour-based model (presented in detail in Section 5.5).

Despite the recommendation to use the comprehensive choice-based tools, several of these may not currently have the structure to perform a complete analysis, particularly if the ultimate goal is to estimate facility volumes for project planning or safety studies. In particular, neither the tour-based nor the GIS-accessibility methods currently allow the user to estimate link volumes of walk or bike trips. This is because neither is a stand-alone model in its current form; however, both support development of trip tables that can subsequently be assigned using standard distribution and assignment routines in a conventional transportation modeling package like CUBE or TransCAD. The PedContext and MoPeD tools already incorporate trip assignment in their design, although the MoPeD assignment process is somewhat simplistic and could be enhanced if desired.

To help assimilate the model characteristics information presented in the preceding tables and profiles, Figure 5-1 highlights the differences and relative strengths of the methods. The figure shows the seven tools aligned in relation to the steps that generally constitute a choice-based travel demand forecasting process. A comprehensive choice-based model would account for all dimensions of choice from trip generation to choice of mode, distribution/destination choice, assignment of trips to the travel network, leading finally to estimates of the number of trips at a given location at a given time.

A white box in Figure 5-1 indicates that the model currently performs this function directly; a shaded box indicates that the model could be used to support the step, but does not currently include the step in its own structure. The absence of a box indicates that the model was not designed or intended to address that aspect of the analytic process.

Using this means of comparison, the guidebook tools may be differentiated as follows:

- **Tour-Based Generation and Mode-Split Model:** This model performs trip (tour) generation and mode split in major detail, covering multiple purposes and four modes (walk, bike, transit, and auto). The model provides access to previously unquantified relationships among land use, network accessibility, and sociodemographics in explaining the decision to walk, bike, take transit, or travel by auto. The procedure could be replicated as a stand-alone model, but has greater immediate utility as a set of equations that can be used to replace or revamp these functions in existing models. Hence, the procedure does not include the steps of distribution and assignment, which could be performed using those program utilities within the host model software.
- **GIS Walk Accessibility Model:** Although this model is unusual because of its GIS orientation, its application steps are similar to a choice-based model. It performs overall person trip generation by purpose and then computes mode split. It performs distribution of walk trips (only) at a block level, but can transform the created walk trip

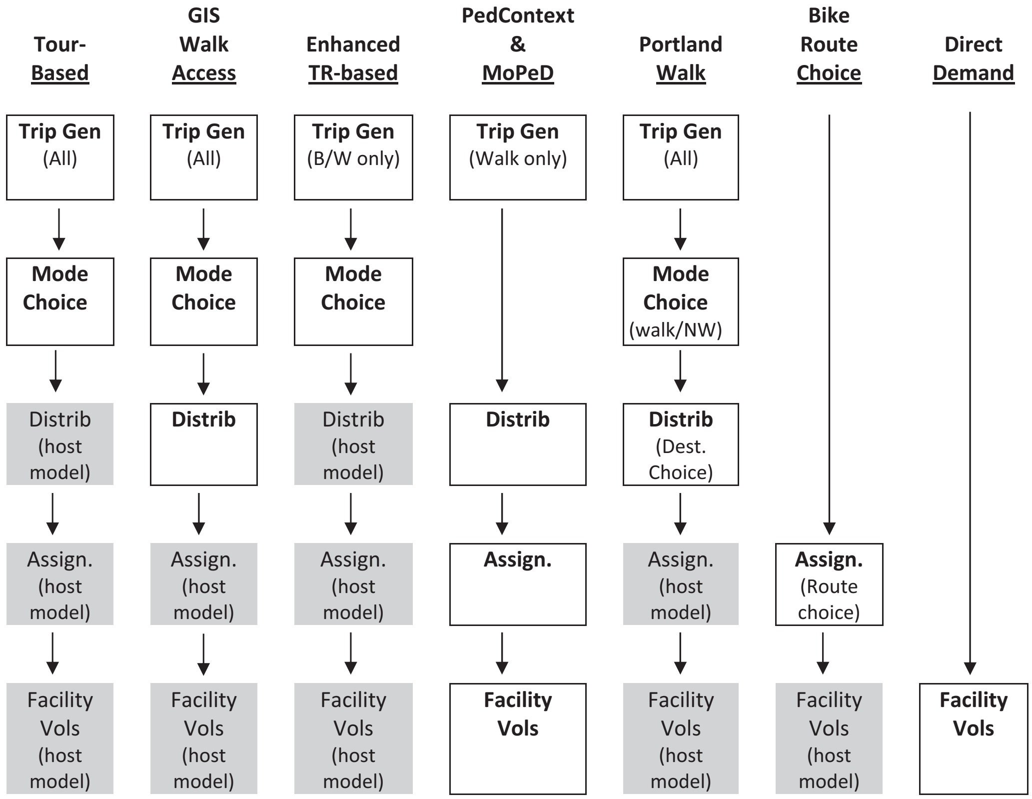


Figure 5-1. Modeling steps addressed by guidebook tools.

tables to the TAZ level, at which point they can be used to adjust mode split for the other modes. The model does not perform assignment of walk trips, although it provides the trip tables and network information to support that procedure. The current packaging of the model is in an enhanced Excel workbook, though it is highly amenable to being integrated within a GIS scenario planning model.

- **Trip-Based Model Enhancements:** This tool is not a stand-alone model, but a set of procedures and sample equations for improving the sensitivity of existing trip-based models. The enhancements affect trip generation (which is performed only for walk and bicycle) and mode choice. Given that the approach was designed to function in a TAZ environment, the strategy for including non-motorized travel in mode split focuses on separating the non-motorized trips into intrazonal and interzonal categories, with intrazonal trips offered the options of walk, auto driver or passenger, while for interzonal trips the options also include bicycle and transit. Interzonal motorized trips are then taken forward into distribution and assignment using the host model's existing programs.
- **Portland Walk Model:** Like the trip-based model enhancements approach, this tool can be used to improve the estimation of walk trips for a regional TAZ-based model or can be used as a stand-alone model. Its advantage is that its assessments are performed at a much finer geospatial scale (1.6 acre blocks versus TAZs). Trip generation consists only of productions, which are then mated with attractions to create trips using a destination choice model contained in the MPO's host model. Productions are estimated for all trips and then split into walk and non-walk with a mode-choice model prior to destination choice. Users who do not employ destination choice models for trip distribution may have difficulty applying this approach without customization.
- **PedContext and MoPeD Walk Trip Models:** These are the most "complete" tools in the group, in the sense of taking the process from trip generation to assignment, and in the case of PedContext, allocating trips to totals (facility volumes) at crossings and key nodes. The limitation is that trip generation is done only for walk trips, although, as with the GIS walk accessibility and Portland walk models, the resultant walk trip tables could be re-aggregated to TAZs and used to adjust TAZ mode splits for the other modes. PedContext is considerably more detailed than MoPeD, both in trip generation and distribution, offering an important tradeoff between complexity and accuracy. The GIS walk accessibility model might be used as an alternative to provide the estimate of walk trips for distribution and assignment in these models.

- **Bike Route Choice Models:** These may be the most application-specific tools in that they are not designed to estimate demand, but mainly to inform route selection for cycle trips. As bicycle demand is sensitive to conditions associated with the travel network—directness, connectivity, safety, and hills—and these sensitivities vary by type of traveler and trip purpose, accurately representing these preferences is key to modeling bike travel. The coefficients of the two models in this group (SFCTA and Portland State) can be used to create more accurate measures of travel time or distance reflecting user values for facility attributes.
- **Direct Demand Models:** Reflective of their name, these models deal directly with the task of estimating walk or bike activity levels on a given facility or at an intersection. The estimates are generated through a set of regression-derived relationships between observed counts and measures of context of the adjacent area served. This is not intended to be a top-down process as with the choice-based models. Accordingly, these models may lack sensitivity to some of the important interrelationships among land use, network accessibility, and sociodemographics that the choice-based methods attempt to capture. Their simplicity, however, makes them attractive for use in particular situations.

Model Selection Criteria

The following criteria can be used to decide what model or models to use:

- **Analysis objectives**—What tasks are you trying to perform and what answers will you require? The tables provide information to help in this process, ranging from geographic scale and type of application (Table 5-2 and 5-4), to key metrics or indicators desired (Table 5-5), or particular variables for which sensitivity is desired (Table 5-6).
- **Resources**—What data, computer tools, and expertise will you need to use the particular method, or conversely, what tools can you reasonably apply given your existing or achievable resources? Table 5-8 summarizes these needs. It may be possible to apply variations of most of the tools using simplified assumptions or borrowing from the tools in part (e.g., through elasticity relationships).
- **Accuracy tolerance/confidence level**—How much is riding on the answer? This is not necessarily an easy question, because "accuracy" may be viewed differently in different situations. For example, if the answer supports a major investment or program initiative that has expensive, long-term consequences (e.g., the remake of a downtown or a large new development project), the analysis should attempt to account for the complex interrelationships of land use, network accessibility, and sociodemographics. This would imply reliance on the more elegant choice-based models in the list. On the other hand, if the issue is estimating intersection volumes to assist in safety studies, less comprehensive methods may serve just as well—or better—in projecting incremental changes in demand from incremental changes in the context descriptor variables. Indeed, the more complex choice-based models excel in tying demand to known behavioral factors, but may be less precise in forecasting hourly link or intersection volumes, while the less comprehensive facility models generally provide good correspondence with current counts but leave questions about predictive value in the case of more fundamental planning changes.

Choosing an Approach—Analytic Objectives

Table 5-8 offers a guide to selecting the appropriate tool to best serve the Analytic Objective criteria, which in this case

Table 5-8. Recommended approaches for different analytic objectives.

Scale of Analysis	Best	Good	Acceptable
Regional	Tour-based	GIS Accessibility Trip-based Enhan. Portland Ped Model	Tour-based Elasticities or Spreadsheet
Corridor	Tour-based	GIS Accessibility Portland Ped Model	Trip-based Enhan. Tour-based Elasticities or Spreadsheet
Subarea	GIS Accessibility	PedContext Portland Ped Model	MoPeD Direct Demand Tour-based Elasticities or Spreadsheet
Project/Site	GIS Accessibility PedContext	MoPeD Tour-based Elasticities or Spreadsheet	Direct Demand

is represented by geographic scale. The scale has much to say about the appropriate level of detail and coverage that must be provided by the approach. So for example, at a *regional* level of analysis, issues are likely to concern projected levels, locations and type of growth, investments in transportation facilities, and impacts on overall mode split, VMT and congestion. For such analysis, the tour-based methods—alone or applied as modifications within existing trip-based models—offer the most sweeping combination of coverage and detail to process these relationships. The GIS-accessibility approach would provide excellent detail, but would probably have to be applied in multiple locations, and the effects then translated to the regional model for overall effects. It could, however, play a vital role in regional visioning in support of regional plan development. The trip-based enhancements support region-level analysis, but are rated as "good" because the TAZ-level relationships would not be as incisive as the tour-based or GIS-accessibility models. The Portland pedestrian model was created to enhance the regional model, but is not as incisive as the tour-based or GIS-accessibility models. An "acceptable" approach for regional analysis would also be to use the elasticities from the tour-based models to enhance existing model relationships or the special spreadsheet version of the tour-based model.

At the *corridor* level, the scale of analysis would suggest the same suite of tools in the best, good, and acceptable ratings. The exception would be a downgrading in the trip-based model enhancements methods, given that their TAZ resolution would be less sensitive in addressing analysis issues at this finer geographic scale; the trip-based enhancements are not seen as being acceptable below the corridor scale.

The GIS-accessibility approach was largely designed for the *subarea* scale of analysis and so is recommended as the best possible tool for applications in this category, which would include comprehensive plans, scenario planning, TOD and smart growth, and non-motorized network planning. The PedContext and Portland pedestrian models would also be very useful in this category, although perhaps less sensitive to the intricacies of accessibility than the GIS-accessibility tool. None of the three tools currently addresses bicycle travel; the spreadsheet version of the tour-based model could be useful in this regard. MoPeD is listed as an acceptable approach for the subarea model, mainly because its estimation of demand is more simplistic than the other tools, although it does offer creation of a trip table and assignment to a network, which is currently not possible without supplemental tools in the GIS-accessibility or Portland pedestrian models.

Finally at the *project/site* level, the GIS-accessibility and PedContext models are seen as the best tools for estimating facility demand, given that they are choice based and take direct account of accessibility. The GIS-accessibility tool is constrained by its lack of an assignment routine, but this can be remedied through application of a conventional assignment method or emulation of the procedure in PedContext. MoPeD is regarded as a good technique for this application, although its assignment routine should be reviewed and enhanced if possible. The direct demand models—which are most commonly used for this application—are rated as only "acceptable" practice given their aggregate structure.

Choosing an Approach—Accuracy Versus Complexity

An important issue when choosing the right modeling approach is deciding between the accuracy level desired in the measures of performance and the amount of complexity involved in using the particular approach. Figure 5-2 provides an overview of the general level of accuracy achievable (expected reliability of the prediction) with each of the guidebook methods, along with a sense of the level of effort associated with development and use of the tool. Comments associated with each rating may vary depending on the resources available and how the model is to be used.

How to Use the Models

The self-assessment of objectives, resources, and tolerances will enable the user to choose among four general approaches to using the models presented in the guidebook. Choices are as follows:

- **Adopt/Adapt**—"Borrow" the models presented in the toolkit, but in conjunction with a process for calibration and validation to local conditions. Detailed instructions to guide adaptation are provided for the tour-based and GIS-accessibility models.
- **Emulate/Create**—If the most appropriate model cannot be adapted to replicate local travel behavior surveys and match local empirical use data, create a similar local model by emulating the procedures described in the preceding chapter with local data.
- **Selective Enhancement**—Several models in the compendium embody relationships not found in other conventional models and may be used to either attempt enhancements within existing model steps or to add or adjust particular variable relationships. This should be done with caution, however, with sensitivity testing to determine whether or not the effect on results falls within reasonable limits.
- **Pivot**—For quick analysis of limited changes within limited ranges and to produce general and relative findings within relatively relaxed accuracy tolerances, consider applying the elasticities generated by the various models or—in particular—using the special spreadsheet version of the tour-based model.

Tour Generation & Mode Split
Highest level of detail and accuracy of any method, very high data and experience required if develop from scratch. Much less demanding if use to modify existing model or use elasticities/spreadsheet.

GIS Accessibility
Not as demanding of data and modeling expertise as tour-based approach, but does require abilities with GIS data and tools. Accessibility approach and fine resolution of GIS provides high sensitivity.

Trip-Based Model Enhancements
Not as accurate as the previous two methods because of TAZ aggregation, but may be very convenient/serviceable way of using existing models. Data needs and statistical skills to develop may be non-trivial.

Portland Pedestrian Model
Similar to trip-based model enhancements, but slightly more accurate since work at finer spatial level. Representation of context through PIE index is useful, but not robust. Should not be difficult to develop.

PedContext Model
Rigorous model which should be fairly accurate. Limitation is in not considering overall trip generation and mode split. Model estimation may represent above-average level of effort and data.

MoPeD Model
Good choice-based model structure, accuracy limited only by specification of models and assignment routine. Should not be difficult to develop, enhance or apply with moderate GIS data and skills.

Bicycle Route Choice Models (e.g., SFCTA or PSU)
Difficult to type, since these are not complete models but deal only with route choice aspect and only for bike. Are somewhat difficult to develop (GPS survey/data), although template exists. Accurate for their intended use.

Direct Demand Models (e.g., Santa Monica Bicycle/Pedestrian)
Requires statistical skills to develop, count and context data to support model estimation. Not particularly difficult to apply. Accuracy limited because of aggregate structure.

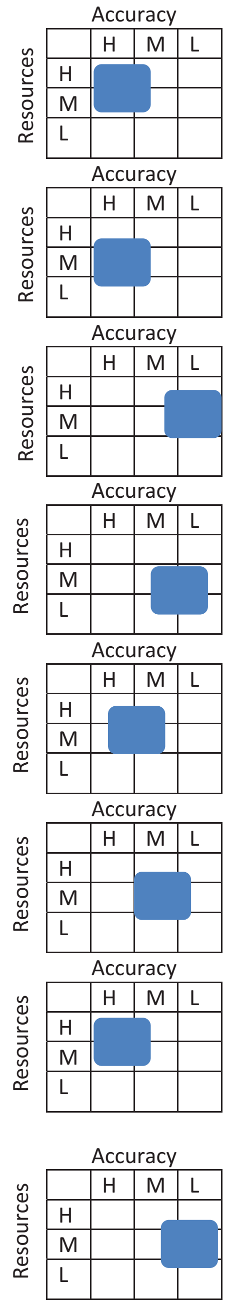


Figure 5-2. Accuracy versus resource requirements for guidebook tools.

Adopting one of the models presented here without local adaptation should only be done if the study community is reasonably similar to those in the examples with respect to the following:

- Similarity of land use and infrastructure landscape based on regional and community descriptors such as topography, weather, sprawl characteristics, highway and transit infrastructure (e.g., lane miles per capita, or fixed-route miles and total transit revenue miles and per capita), and completeness of local street and path networks.
- Similarity of the community with respect to socio-economics and demographics, presence in the community of unique travel generators such as colleges, major recreational or entertainment/social venues, and car culture (possibly exhibited in the region's Census journey-to-work model shares).

All models should be used with proper caution. They are simply equations correlating particular variables that seem to explain an important behavior or result, and the underlying assumption is that there is a causal relationship between the explanatory (independent) variables and the variable of interest. There is generally no way to confirm this causality, so look to these equations to statistically "infer" that a particular result will occur if the included variables are changed. Confidence in this approach is measured in three ways: (1) by a plausible structure in terms of the relationships reflected in the model, (2) through statistics reflecting the goodness of fit of the model and the individual variables, and (3) ultimately testing its predictive ability against observed behavior.

The models in this guidebook are of two different types. The more comprehensive models attempt to predict behavior from an integrated structure that accounts for the individual, the setting, and the alternatives. Their primary output is an estimate of mode choice and trips by mode. Their validity is primarily shown in their ability to predict these choices. The other type of model attempts to directly predict activity levels, generally with a fairly aggregate level of context factors which show high correlation, but which may or may not be explanatory. Validation of these models is generally seen in their ability to reproduce the volumes measured in actual counts.

Neither of these tests is entirely satisfactory, given that the choice-based models often do not attempt to predict point-level usage values, while the simpler context models may replicate counts adequately but not be able to show reasonable sensitivity to important decision-oriented variables. Two general rules should be applied when adopting and adapting the two types of models:

- Facility-demand models should always be derived specifically for local conditions. Such direct demand models are heavily customized to a specific array of local conditions, including unique trip generators, sociodemographics, and modal culture.
- Choice models (including disaggregate tour-based, GIS-based accessibility, enhanced 4-step, and trip-based disaggregate) should always be tested against local facility-use data if their use is extended to facility-demand estimation.

A possible strategy when confronting this dilemma is to consider the choice-based and use-based models as valuable complements to one another. Direct demand (use-based) models can help address the problem of underrepresentation of walk and bike trips in travel surveys, as well as the fact that most pedestrian and cyclist destination and route choice models are relatively unproven. Direct demand models can also be strategically useful for helping validate choice models such as the tour-based, trip-based, and geospatial models, which fall into the comprehensive choice-based category. This symbiosis is likely to become more important as walking and cycling models begin to be held to the same performance standards as other transportation models for other modes. Such additional requirements can be expected to accompany uses of models for facility-specific improvement proposals and impact assessments and to justify potentially controversial policy decisions and expenditures.

Figure 5-3 illustrates how these two classes of models might be integrated and thereby strengthened; Figure 5-4 profiles how they might be used for cross calibration and validation.

5.5 Guidelines for Use

Tour-Generation and Mode-Choice Approach

This approach was designed to

- Use the most advanced current methods in travel demand modeling (activity-based (AB) and tour-based (TB) structures) to try to capture the scale and nuance of non-motorized travel.
- Work with parcel/point-level or block-level data instead of zonal aggregations.
- Account for the practice of grouping trips into home-based and work-based tours—simple and complex—which are strongly influenced by land use and transportation accessibility and is an important determinant in choice of mode.
- Help the following types of users in the following situations:
  - Those who are developing or thinking of developing an AB or TB modeling platform to replace an existing trip-based model,
  - Those who have an existing AB or TB model and wish to enhance its capability to address non-motorized travel,

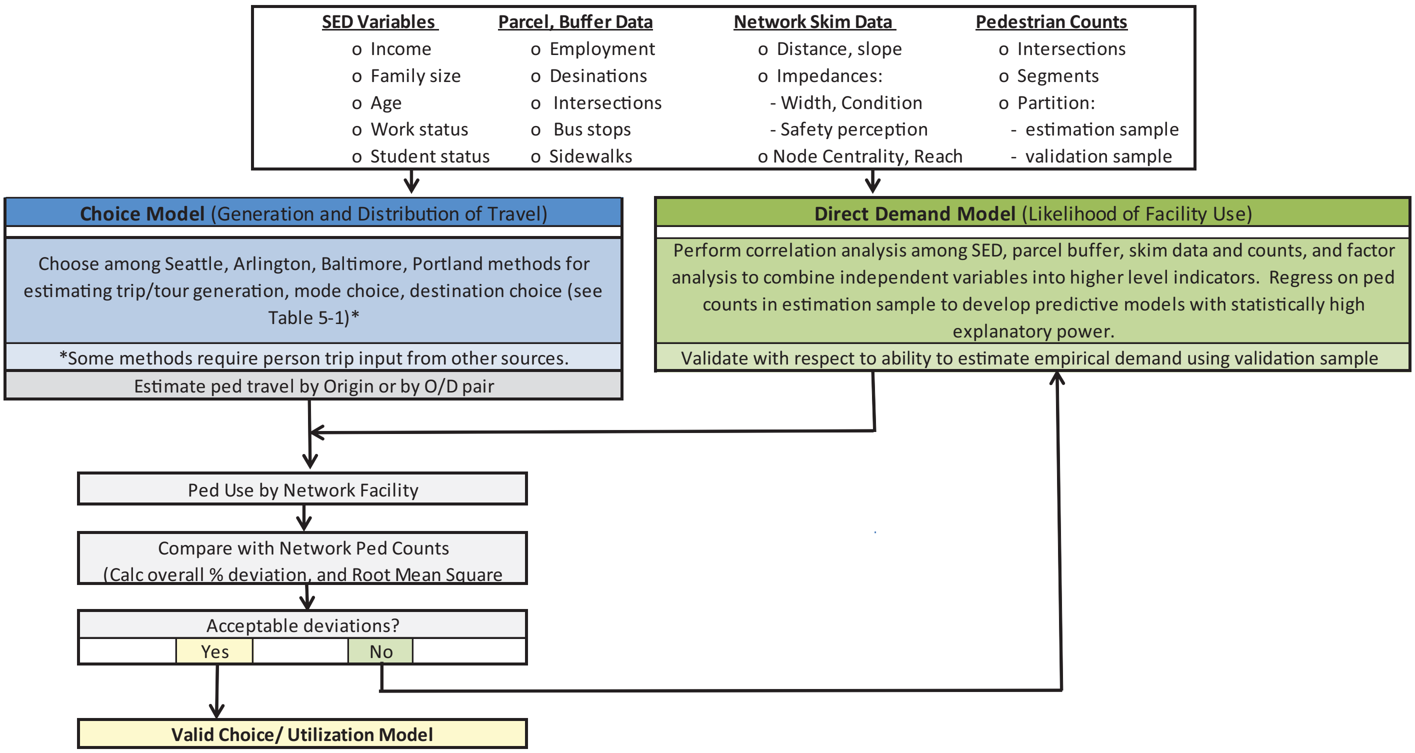


Figure 5-3. Integration of direct demand and choice models.

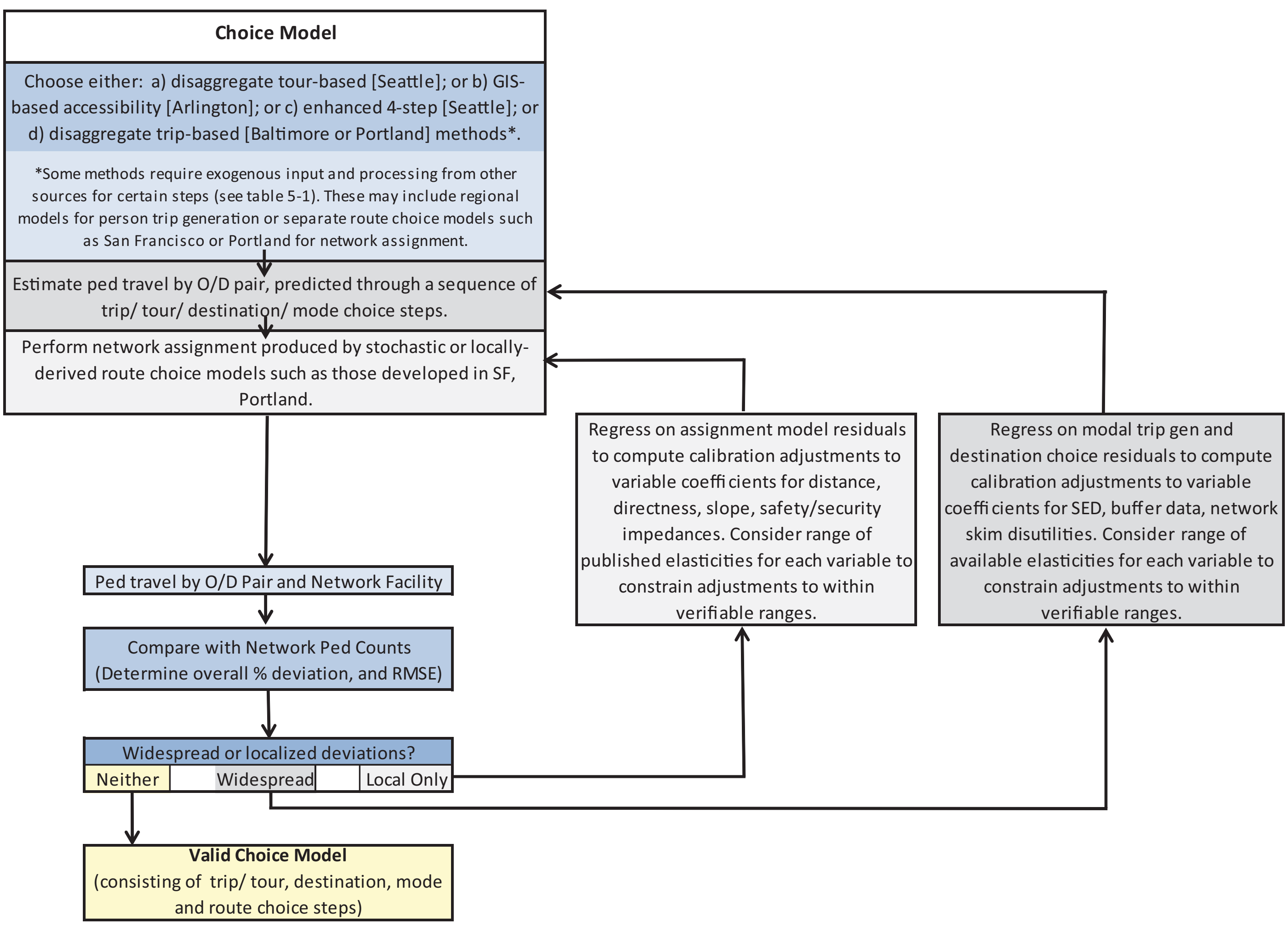


Figure 5-4. Calibration and validation of walk choice models.

- Trip-based model users who wish to enhance their models for bike-pedestrian analysis, and
- Persons seeking better understanding or key relationships between land use, network accessibility, and bicycle or pedestrian demand for policy or educational purposes.

Scale of analysis

- This approach would be most readily applied at a regional level of analysis. Such use would be easiest for those with existing AB/TB models in place or under development, although the methods can also be extended to trip-based models if appropriate steps are taken.
- Another common application would be within a corridor or subarea, in which case the study area would be treated as a "window" in the modeled region, with provision to maintain SED and trip flow consistency between study area and the remaining region.
- Finer level site or project-level analyses may be possible using the starting conditions provided by the land use/scenario base developed above.
- Sketch-planning analyses can be performed through use of elasticities or the special spreadsheet model.

Data, tools, and expertise needed

- If developing or enhancing an AB/TB model and wishing to emulate the approach used with the Seattle/Puget Sound data for estimating bicycle and pedestrian demand:
  - Travel survey data with full household and individual sociodemographic characteristics plus information on the purpose and mode for each trip and latitude/longitude location for each trip end. The survey should include walking and bicycle trips. (If estimating new models, larger samples will generally be required than are needed to transfer and recalibrate models first estimated elsewhere.)
  - A synthetic population of households/individuals, controlled to match Census/ACS population distributions at an appropriate spatial scale (e.g., Census block groups).
  - Parcel-level or block-level land use information in geospatial format.
  - An all-streets network in GIS format, enhanced to include all bicycle and pedestrian facilities, and with link-level information on characteristics (e.g., facility type and grade) used to create weighted impedances for each link.
  - Buffered measures of accessibility, land use characteristics, street grid, and transit access for each parcel (for walking and biking using respective networks). Such measures are typically calculated in a GIS or similar spatial programming tool.
  - Regional accessibility as measured through composite (logsum) measures across possible modes and destinations (mainly influenced by the times and costs for the auto and transit modes).
  - High-level expertise with AB/TB models and GIS.
- If attempting to apply the tour-based approach within existing an AB/TB or trip-based model (using new mode choice models to augment trip tables):
  - Parcel-level or block-level land use data (as above).
  - A synthetic population of households/individuals (as above).
  - Bike (and pedestrian) networks and skims (as above).
  - Buffered land use and accessibility measures (as above).
  - Composite accessibility measures (logsums, as above).
  - Working familiarity with AB/TB modeling concepts (or senior-level expertise with trip-based models, if that is the platform) GIS modeling tools, data, and skills in their use.
  - Ideally, some survey data and/or count data on walk and bike trips to validate model outcomes.
- If attempting to post-process results from a trip-based model or conduct sketch-planning analysis:
  - Sufficient information to apply either elasticities or the provided spreadsheet model,
  - Bicycle (and pedestrian) networks (with weighted impedances if possible), and
  - The ability to buffer land use and built-environment characteristics with GIS and the corresponding networks.

Suggestions for Adaptation and Use

AB/TB model development or enhancement

Because this topic is technically complex and beyond the general scope of this guidebook, detailed instructions are not included here. Users should refer to Appendix 1 of the Contractor's Final Report for detailed technical documentation on the models and their development process.

In general, incorporation of detailed behavioral responses of cyclists and pedestrians to infrastructure and land use should contain at least the following elements:

- Use of detailed land use data at the parcel/point-level or block-level. Buffering of land use and street network/intersection data around each parcel/point or block, ideally using on-street distances for buffering rather than crow-fly distances.
- Use of a network for the bicycle mode that incorporates designated bicycle facilities, as well as other key factors such as elevation gain.
- Ideally, use of a bicycle route choice model such as those developed for San Francisco or Portland, or, at least, use of a generalized distance function in bike network path-building to select appropriate paths to use in mode choice and other model components.

- Ideally, use of a separate pedestrian network that includes all local street segments and intersections, as well as coding of sidewalks and elevation gain.
- Use of detail on where transit stops are located, in buffer-based measures and, ideally, in defining transit walk access and egress times for each O-D.

Application of TB models to enhance an existing AB/TB or trip-based model

The expectation of users in this category is that they want to take advantage of the new bicycle and pedestrian models developed in the NCHRP research, but do not wish to embark on a comprehensive model development or enhancement process. Rather, their goal is to access the set of relationships captured in those models and supplement those in their existing model. This would involve adaptations of the mode choice and possibly the tour-generation models within the current tour/trip generation, distribution/destination choice and mode-choice model steps.

Application would be more direct in an AB/TB model platform, but with some creativity can be used in a trip-based model. This type of enhancement could be done at a few levels as follows:

Update of origin-destination (O-D) mode-choice models: One of the primary effects of improvements in infrastructure or land use is to attract shorter trips from other modes to walk and/or bike. This can be incorporated into an existing mode-choice model run for trips or tours with known origin and destination, by incorporating some or all of the variables used in the O-D level mode-choice models presented in this report. In general, this would involve the following steps:

1. Select a "basis variable" in both the existing mode-choice model and the one from this report for the corresponding tour/trip purpose. Walk distance or auto travel time are good candidate variables.
2. Add any new variables that can be supported by the available input data into the model utility functions, giving them the same *relative* coefficient values as in the "transferred" model from this report. So, the coefficient to use in the model will be the basis variable coefficient in the existing model, multiplied by the ratio of the new variable coefficient divided by the basis variable coefficient in the transferred model.
3. After all new variables have been added, apply the model to the base year data and (re)calibrate the mode-specific constants so that the mode shares still match any calibration target mode shares (e.g., the shares used to calibrate the original existing mode-choice model).

In general, this type of model update is preferable to applying the elasticities provided later in this section in a post hoc manner. In contrast to estimated model coefficients, elasticities are essentially a model output, rather than an input, and thus are more sensitive to the network supply and competitive balance between the modes specific to the region in which they are derived.

Although the models in this report were estimated at the tour level, they can be used to update either tour-level or trip-level mode-choice models. Although in a behavioral sense it has been seen as superior to model mode choice at the tour level, there is no reason to expect (and no experience in practice) that the *relative* values of the coefficients are markedly different in models estimated at the tour level versus the trip level. These models include variables that may not be available in the local data to apply the model. In addition to specific infrastructure and land use variables, this may also include socioeconomic variables such as age and gender not available in household-level aggregate models. Transferring some variables is likely to be worthwhile, even if some of the variables in these models are not applicable, given that the alternative is to ignore *all* of the variables.

A caveat to this recommendation is that it may not be worthwhile to attempt to update an existing model that uses fairly large zones (e.g., much larger than Census blocks) and/or sparse networks to represent the walk and bike modes. In that case, the data that the models are applied to would be different in scale and accuracy to the data used in estimation and would not be accurate enough to give meaningful or reliable results.

The above discussion assumes that the original mode-choice model already included the walk and bike modes, at least in some rudimentary way. If the original mode-choice model only included motorized modes, it is still possible to use the update procedure outlined above. In that case, however, it will also be necessary to make some adjustment to the trip/tour-generation model process so that it does not exclude non-motorized trips or tours at that earlier stage. (This point is discussed further below.)

Update of origin-only ("pre-") mode-choice models: Some trip-based and TB model systems generate trips across all modes, but then use a two-stage process to represent mode choice. Before distributing trips across destinations, a "pre-mode-choice" model is sometimes used to split the generated trips between the motorized and non-motorized models, and then only the motorized trips are used in the subsequent distribution/destination choice and origin-destination mode-choice models. If one wishes to retain this approach, it is possible to use the "origin-only" versions of the mode-choice models presented in this report and use that model for the corresponding trip/tour purpose, knowing only the socio-demographic characteristics of the traveler (segment) and the characteristics surrounding the residence location. The general transfer/enhancement procedure is the same as that outlined above for the O-D mode-choice models, except in this case there is no ubiquitous variable such as auto travel time to use as the basis variable. If there is no candidate basis variable, the best option may be to simply use this complete model (or at least all of those variables applicable) in place of the existing pre-mode-choice model and calibrate it to the same observed shares to which the existing model was calibrated.

If one maintains (or adopts) the approach of using an origin-only mode-choice model before trip distribution/destination choice, there is still the option of subsequently distributing and assigning the bicycle and/or pedestrian trips to the appropriate network. The attraction variables for distribution/destination choice would be the same as when distributing trips for other modes, but the impedance variable would be mode-specific. For bicycle, the generalized distance along the best path to each possible destination would be an appropriate impedance variable, insofar as it is consistent with the path-specific impedance measures used for path-building in bike trip assignment.

Distribution and assignment models were not estimated with the Seattle tour-generation/mode-choice models, but such models can be estimated and applied in a conventional modeling package such as CUBE or TransCAD. Both friction factors and attraction variables can be adapted to include walk- and bike-specific attributes.

Update of trip or tour-generation models: Compared to mode-choice models, a wide variety of methods are used to generate tours and trips in existing models, ranging from simple cross-classification tables in 4-step trip-based model systems to complex full-day activity pattern models in advanced AB model systems. It is not possible to outline one way of using the NCHRP tour-generation/complexity models that will be applicable in most cases.

Trip generation models in most trip-based models are not sensitive to accessibility effects (i.e., there is no feedback from the mode-choice and distribution models). In many cases, it may be adequate to update the mode choice (and perhaps the distribution models) to better represent walk and bike demand factors and leave the trip generation models unchanged.

Another option, applicable in a trip-based or TB context, may be to use the tour-generation elasticities from this study in a post-processing step to adjust the tours or trips resulting from the generation model. In some regards, this is similar to applying the well-known "5-D's" post-processing approach, except that in this case the elasticities are applied prior to distribution and mode choice and isolate only the tour and trip generation effects. Because the generation effects are typically second-order changes much smaller than the shifts in mode shares or trip distances, incorporating this type of model update is of less importance than updating the other models described above.

For more substantial model updates, it would be possible to attempt to transfer the tour-generation/complexity model from this report. However, this particular model form may be incompatible with the structure of the existing model system. It may be more efficient and useful to use the type of residence-level land use and accessibility measures used in the various Seattle/Puget Sound models in this report as new, additional variables in re-estimating or re-calibrating one's existing tour-generation models.

Post-Processing, Sketch Planning, and Sensitivity Testing

There will be many occasions when users have neither time nor resources to develop a complete modeling structure for analyzing bicycle or pedestrian travel issues or where the level of importance associated with the answer does not justify extensive model development. In this case, sketch-planning or elasticity methods may be used to factor the basic results generated by a trip-based model or to support a sketch-planning analysis of the relative importance of particular attributes or suitability in a given environment. Two approaches exist for this category of user: elasticity methods and an interactive spreadsheet approach developed expressly for this guidebook.

Elasticities

An important product of this research is the calculation of elasticity relationships from the various models. Elasticities are a unit-less quantity that represents the percentage change in the dependent variable in a statistical equation that occurs in response to a percentage change in one of the independent (explanatory) variables, while everything else is held constant. Unlike the estimated coefficients in the model, the elasticity is a pure measure of the impact of the predictive variable that can be compared with the other variables, without controlling for the magnitude of the measure itself. Elasticities may be positive or negative and exhibit a wide range in values, although the most important range lies between 0 and 1. Variables whose elasticity is greater than or equal to 1 (or –1) are said to be "elastic," in that they produce a change in the dependent variable greater than or equal to the change in the variable itself. Conversely, variables whose elasticity is less than 1 or greater than –1 are said to be inelastic, because they produce a change in the dependent variable less than proportionate to the change in the explanatory variable.

Elasticities can be used to help educate users on the relative importance of particular variables, either in model design or project design. Elasticities can also be used to tweak results from conventional models that do not account for such factors or to create sketch-planning models for simpler planning tasks. The Seattle-derived TB model provides elasticities relating mode choice for walk, bike, and even transit to

- Walk and bike accessibility,
- Regional accessibility,

Table 5-9. Tour mode-choice model elasticities.

Model	Home-based Work	Home-based School	Home-based Recreation	Home-based Shop/PB	Work-based
Walk mode choice					
Network distance	-1.07	-1.10	-.97	-.97	-.48
Bike mode choice					
Network distance	-.60	-.65	-.41	-.75	-.47
Bike path distance	-.08	-.02	-.03	-.03	-.02
Bike lane distance	-.07	-.04	-.04	-.04	-.03
Wrong-way distance	-.007	-.002	-.003	-.005	-.008
Turns per mile	-.10	-.10	-.06	-.12	-.10
Average rise	-.29	-.22	-.19	-.27	-.14

- Land use characteristics at origin or destination,
- Walk and bike transportation network characteristics, and
- The effect of the above characteristics on tour complexity (simple or complex), which strongly impacts choice of mode.

The following tables present some of the more important elasticity relationships derived from the Seattle TB research. Table 5-9 presents elasticities demonstrating the importance of network travel distance and path characteristics to walk or bike mode choice for five trip purposes. Key findings are that

- Walk mode share is elastic or nearly elastic with respect to distance for all purposes except work-based travel.
- Although still sensitive to distance, bike is less elastic than walk, with elasticities ranging from a low of –0.41 for home-based recreation to –0.75 for home-based shopping and personal business.
- In addition to bike network distance, other path characteristics influence bike choice, such as the distance for the part of the trip made on a bike path or lane, the portion of the route this is the wrong way, number of turns per mile, or hilliness as measured by the average elevation rise for the trip. Average rise carries much more weight in the bike decision than the other characteristics, running second only to overall distance.

Table 5-10 shows how these elasticities increase with length of trip. The longer the trip, the greater the negative effect on choice of walk or bike. The values shown in the table are for home-based work tours only, but the increasing effect of distance on non-motorized mode choice is reflected in all purposes.

Table 5-11 presents elasticities relating mode choice to land use variables. In general, these elasticities show that

- Walk mode choice increases with higher employment density (work only) and higher intersection density (personal business and work-based), but declines with increases in grade (percent rise) and absence of sidewalks. Walk choice also declines if the tour is complex rather than simple. The highest single sensitivity, –0.77, is in response to grade for work trips.
- Bike mode choice increases with land use entropy and intersection density (all work only), and the intersection density value is almost elastic (0.90). Existence of a Class I bike path is important for both work and school travel, while grade is an extreme negative factor for work trips.

Table 5-10. Elasticities for work tours by distance band.

One-way distance band	All tours	0-1 miles	1-3 miles	3-6 miles	>6 miles
Walk mode choice					
Network distance	-1.07	-.42	-2.37	n/a	n/a
Bike mode choice					
Route distance	-.60	-.12	-.33	-.59	-1.14
Bike path distance	-.08	-.001	-.03	-.07	-.17
Bike lane distance	-.07	-.003	-.02	-.07	-.15
Wrong-way distance	-.007	-.001	-.005	-.008	-.012
Turns per mile	-.10	-.03	-.07	-.10	-.15
Average rise	-.29	-.03	-.15	-.28	-.59

Table 5-11. Mode-choice elasticities in relation to land use characteristics.

Model	Home-based Work	Home-based School	Home-based Recreation	Home-based Shop/Personal Business	Work-based
Walk mode (using walk buffer = 1 mi)					
Destination total employment	.21				
Origin + Destination avg. intersection density				.23	.17
Origin + Destination avg. fraction rise	-.77	-.03	-.11		
Origin only avg. fraction rise				-.16	
Origin only percent no sidewalk	-.18		-.19	-.22	
Complex multi-stop tour	-.20	-.12	-.03	-.05	-.02
Bike mode (using bike buffer = 2 mi)					
Destination mixed-use entropy	.02				
Origin + Destination fraction Class 1 bike path	.37	.31			
Origin intersection density	.90				
Origin avg. fraction rise	-.82				
Complex multi-stop tour	-.32	-.17	-.08	-.16	-.06
Transit mode (using walk buffer = 1 mi)					
Origin transit stop density	.85	.10	.72	0.32	0
Destination transit stop density	.37	.10	.72	1.21	2.09
Destination total employment	.32				
Origin intersection density	.11				
Origin pct. no sidewalks		-.14	-.70		
Destination pct. no sidewalks		-.21			
Complex multi-stop tour	-.20	-.13	.25	-.09	-.07

Bike choice declines ever more significantly than walking when the tour is complex (for all purposes).

- Transit mode choice is affected by transit stop density (in relation to the walk network) at both origin and destination for all trip purposes. Intersection density and employment density are important positive factors for work trips, and absence of sidewalks has a negative effect for school and social/recreational travel. As with both walk and bike, transit choice is also reduced with the decision to make a complex tour.

The elasticities in these tables may be used to pivot from known levels of walking or bicycling to estimate incremental changes resulting from a single variable of influence. For example, using the elasticities in Table 5-10, improving route directness of streets or bike paths that reduces trip distance between homes and workplaces by 10% would be expected to induce a 3.1% increase in the likelihood of making the home-to-work trip by bicycle. A similar change that reduces trip distance between homes and schools by 10% would be expected to lead to a 4.4% increase in the likelihood of making the home-to-school trip by bicycle.

Such pivot analysis should be performed with care, taking account of only one variable change at a time, and accounting for each of the affected trip purposes individually. The degree of change examined should also be relatively small. Users should avoid situations where the change, for example, in distance is more than a 50% increase or decrease. This is because the elasticities above are only stable for incremental changes near the regional mean value of the variable being tested.

Tour-Generation/Mode-Choice Spreadsheet

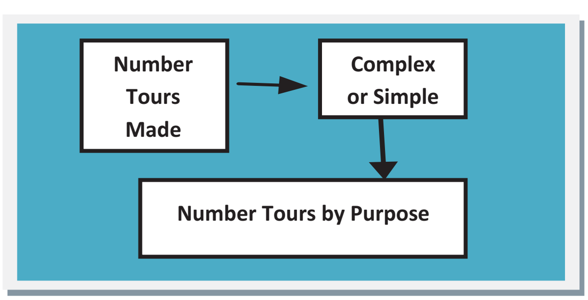
In addition to these simple elasticities, the tour-generation and mode-choice models have been adapted into a spreadsheet created expressly for the guidebook and included on *CRP-CD-148*. Like the elasticities, the spreadsheet has various purposes, from allowing users to interact more dynamically with the relationships to using the relationships to create model enhancements of sketch-planning tools. The value the spreadsheet has over the elasticities is that it allows for testing changes in multiple variables at one time, thereby exposing synergies or conflicts that may exist in those models among key variables. For example, one can test

- Whether network improvements work better or about the same when implemented in conjunction with changes in land use.
- Which travel market segments are most influenced by changes in either land use or network characteristics.

The model is presented as a series of Excel spreadsheets, which includes working versions of both the tour-generation/complexity models and the tour mode-choice models. The file contains the following screens as individual worksheet tabs

- Tour Generation/Complexity by Purpose: Shows the basic structure and estimated coefficients for the tour-generation models.
- Tour-Generation Calculations: Takes the Tour-Generation/Complexity model above and offers it in an interactive, computational format.
- Tour Generation for Work-Based Other Travel.
- Mode-Choice Model: Shows the basic structure and estimated coefficients for the tour mode-choice models, which incorporate four modes and five trip purposes.
- Mode-Choice Calculations: Like the tour-generation model in the second tab, this worksheet contains an interactive, computational version of the mode-choice models.
- Tabulation Sheet: A convenience sheet for storing results of the mode-choice models for later comparison.
- Distance = 0.5 (etc.): To properly assess mode choice across several very different modes, it is necessary to compare the modes on common ground with regard to trip length. Thus, this worksheet has set up the computational version of the mode-choice models to examine mode choice when the average one-way trip distance is 0.5 miles. Subsequent spreadsheets have been similarly set up for one-way trip lengths of 1, 2, 3, 4, and 5 miles.

Tab: Tour Gen Models: There are several ways to work with the spreadsheet. Entering the first tab shows the structure and coefficients estimated for the Tour-Generation/Complexity model. The model has the following overall structure:

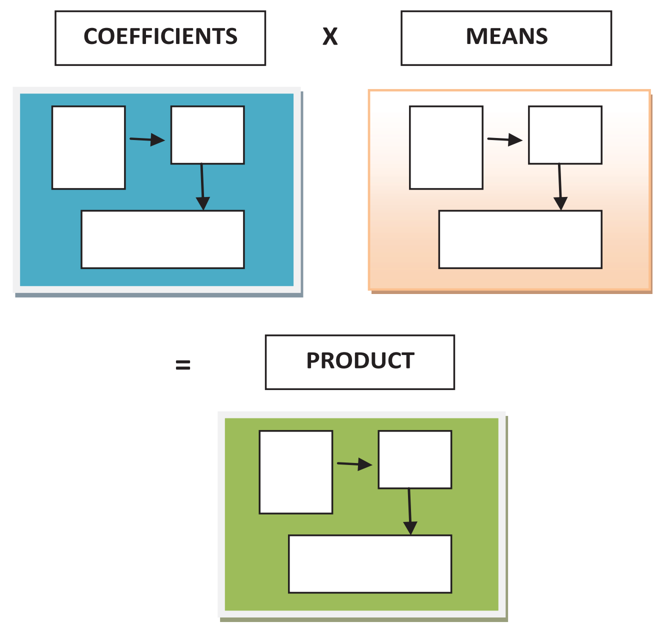


The model first calculates the probability that a tour will be made and then whether a second, third, or fourth tour will be made. A determination is then made as to whether the tour will be simple or complex (multi-stop), which is also a probability calculation. The tour(s) are then allocated to trip purpose, of which the choices are work, school, escort, personal business, shop, and social/recreational. The result of this step is a determination of the total number of simple and complex tours for a given person across the stated trip purposes.

Variable definitions are provided to the right of the page in the spreadsheet.

Tab: Tour Gen Calcs

The second tab in the spreadsheet enables the user to actually use the model. The structure is as shown in the following diagram:



In the first series of boxes at the left side of the worksheet, shaded in blue, are the models just viewed in Tab 1, with the estimated coefficients. The second series of boxes, shaded in peach, are identical in form and contain the "input data" used to run the models. In this case, the means for the sample used to develop the models have been entered as the basis for the test, but this is also where the user would enter his/her assumptions when working with the model. Finally the set of boxes highlighted in green are the product of the coefficients times the means, and thus fuel the calculations.

Under the primary green boxes containing the tour generation, complexity, and purpose computation, the user will find another set of other tables also highlighted in green. These tables are not intended for user access/use—they perform key computations in the overall model. They have been included and annotated to help the user understand and follow what is happening at each step.

Variable definitions are included at the right of the master model spreadsheet in Tab 1.

At the very top of the worksheet is the following summary box:

Primary Effects Summary				
	Test	Base	Net Change	Pct Change
Total Simple Tours	1.1950	1.1950	0.0000	0.00%
Total Complex Tours	0.9234	0.9234	0.0000	0.00%
Total Tours	2.1184	2.1184	0.0000	0.00%
Percent Simple Tours	56.4%	56.4%	0.0%	0.0%

The summary box conveys the number of tours calculated and the proportion that are simple versus complex. A major outcome from this part of the model is in the proportion of tours estimated to be simple one-stop tours (56.4% in this case), because these are the tour types most likely to be made by walking, biking, or transit. The more characteristics an area has that make it "urban," the more likely that projected tours will be simple.

The key variables in the model that reflect the effect of urban design on tour type are the *land use entropy* (in both tour number and complexity equations), the *purpose-specific buffer measures* in the purpose models, and the *logsum measures* in each of the models. In general, higher values of the entropy and purpose-specific buffer measures indicate areas with more "urban" characteristics, while the logsums are more likely to reflect opportunities outside the local area and present a draw for longer distance trips, of which a higher proportion will be in complex tours and hence more likely to be made by auto.

As an illustration of how this worksheet can be used, Table 5-12 is the result of testing different values of Origin Entropy in the model (appears both in Tour Generation and Complexity) to examine sensitivity of both number of tours and the percentage of tours which are simple to level of entropy at the tour origin. The model projects that the overall number of tours *declines* from 2.118 to 2.049 as entropy increases from 0.422 to a maximum of 1.0, while the percentage of tours which are simple i*ncreases* from 56.4 to 59.2%.

The user can attempt any variety of assessments in a similar manner, with the advantage of having the full model active in a spreadsheet being that multiple variables can be tested simultaneously—unlike simple elasticities—thereby realistically accounting for interactions and synergies. To assist the user in testing assumptions, a backup of the original values loaded into the table of means is presented at the bottom of the spreadsheet under the working tables. If the user wishes to restore the input tables to the original values, simply copy the original values in the backup tables to the working tables.

Another illustration of the tour-generation models is to examine the tour-generation rates and distribution by purpose for major sociodemographic travel groups. Table 5-13 conveys total tours generated and breakdown by purpose forecast for ten traveler profiles, exercising combinations of age category, work or student status, and presence of children in the household. Any such combination can be tested by the user and then subjected to different assumptions about the conditions under which the travel decision is being made (entropy, buffer activity, and logsums).

Tab: WB Tour Gen

This tab presents a separate tour-generation model that deals specifically with work-based (WB) tour generation. This calculation is only engaged if the individual traveler made a trip to work in the initial tour-generation analysis. The approach and procedures are otherwise the same, although the variables and coefficients in the models are different.

Tab: Origin-Only MC Model

The next tab contains the set of models that predict mode choice for the estimated tours by purpose and complexity. This particular version incorporates only the land use and travel network characteristics at the trip origin, as opposed to the entire trip (tour), or origin-destination, which is presented later. Although this version of the model is less infor-

Table 5-12. Likelihood of simple or complex TB on origin entropy.

Origin Entropy	Simple Tours	Complex Tours	Total Tours	Percent Simple
0.422	1.195	0.923	2.118	56.4%
0.5	1.197	0.911	2.108	56.8%
0.6	1.201	0.895	2.096	57.3%
0.7	1.204	0.880	2.084	57.8%
0.8	1.208	0.865	2.073	58.3%
0.9	1.211	0.850	2.061	58.8%
1.0	1.214	0.835	2.049	59.2%

Table 5-13. Total daily tours and distribution by purpose for different demographic segments.

Purpose	Adult, FTW, Kids	Adult, FTW, No Kids	Adult, PTW, Kids	Adult, PTW, No Kids	Adult, NW, Kids	Adult, NW, No Kids	HS/Univ Student, NW	HS/Univ Student, PTW	Child, 5-15	Retired, > 50
Work	82.0%	89.4%	52.0%	71.0%	5.9%	12.3%	14.9%	50.4%	0.1%	9.0%
School	0.6%	0.6%	2.3%	2.8%	1.3%	2.4%	70.7%	47.0%	78.6%	1.2%
Escort	9.3%	1.7%	30.2%	6.9%	59.9%	21.2%	2.8%	0.5%	13.8%	16.4%
Pers. Busn.	2.8%	2.7%	5.6%	6.7%	12.1%	22.2%	4.1%	0.7%	2.7%	28.0%
Shop	2.8%	2.8%	5.9%	7.2%	12.6%	23.8%	3.5%	0.6%	1.8%	23.7%
Meal	1.3%	1.7%	1.5%	2.4%	3.7%	8.9%	1.5%	0.2%	1.2%	11.4%
Ent/Rec	1.1%	1.2%	2.2%	3.0%	4.5%	9.2%	2.5%	0.5%	1.9%	10.3%
Total Tours	2.988	2.763	3.272	2.935	2.715	1.988	2.933	3.811	2.643	1.724

mative than the origin-destination version, it has value in the set of tools because of the following:

- There are application situations where the only information available is in relation to the trip origin (travel surveys provide detailed information on the traveler's residence location, but much less on other trip ends). Many of the Density, Diversity, Design, Destinations (4Ds) models that incorporate land use characteristics are limited to residence trip production end only in their specifications.
- Although the destination of a tour for purposes like work or school may be known and made part of the choice computation, for most other trips, the destination is not known and is one of the choices being made along with choice of mode. For these trip purposes, the origin-only model can estimate NMT productions, which then can be distributed to candidate destinations based on relative opportunities.

Separate mode-choice models are presented for five tour purposes: home-based work, home-based school, home-based (social)/recreation, home-based personal business, and work-based other. If one wishes to connect the tours from the tour-generation models to the purposes specified in the mode-choice models, the conversion is as follows:

- Home-based work = home-based work
- Home-based school = home-based school
- Home-based recreation = home-based recreation
- Home-based other = home-based personal business, shopping, meal, and escort
- Work-based other = work-based other

The key "policy" variables that influence choice of mode follow.

For Walking:

- Buffered attractions for the respective purpose (within "walk" Buffer 1)
- Household density in Buffer 1
- Intersection density in Buffer 1
- Percent rise in gradient in Buffer 1
- Percent of facilities with no sidewalks in Buffer 1
- Mode/destination logsum for zero-car households

For Bicycle:

- Buffered attractions for the respective purpose (within "bike" Buffer 2)
- Intersection density in Buffer 2
- Percent rise in gradient in Buffer 2
- Fraction of facilities that are Class 1 bike path in Buffer 2
- Mode/destination logsum for zero-car households

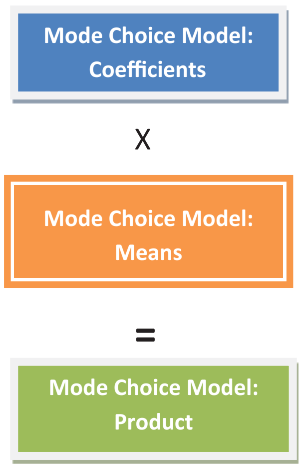
For Transit:

- Intersection density in Buffer 1
- Percent rise in gradient in Buffer 2
- Percent of facilities with no sidewalks in Buffer 1
- Number of transit stops in Buffer 1
- Mixed land use index in Buffer 1
- Mode/destination logsum for zero-car households

The user can modify any or all of these factors (using the orange table) and estimate the effect on mode-split for any trip purpose.

Tab: Variable Defs MC Model

This tab provides a definition of all variables used in either the origin-only or origin-destination mode-choice models.



Tab: Origin-Only MC Model Calcs

As with the tour-generation models, this tab takes the origin-only mode-choice model and arranges it in an interactive version to illustrate calculation and enable user testing. The interactive version of the mode-choice model is presented in a format similar to the tour-generation calculation.

Coefficients in the blue table are applied to the model inputs in the orange table, with the product of the two appearing in the green table. At the bottom of the products (green) table is a summary of the calculated results, indicating the expected mode share for each of the five purposes, distinguished by whether the tour is simple or complex.

Three sets of results are shown in the lines 100 to 102 in the worksheet. One shows the expected mode shares by purpose if the tour is a simple one-stop tour. The simple-tour scenario is communicated by inserting a value of zero for the tour complexity variable in line 61. As expected, the shares of walking, biking, and transit are higher for the simple-tour case than when the tour is complex (specified when the tour complexity value is set to 1). The third set of shares correspond to the percentage of complex tours found in the model calibration sample, which are shown as the default values provided in the table on line 61.

To work with the mode-choice models, enter assumptions in the orange table only. To replace the default values in the orange table at any time, a backup copy is provided at the bottom of the worksheet.

Tab: O-D Mode-Choice Model

This tab introduces the version of the mode-choice models that operate on full origin-destination information. The models are similar in structure to the origin-only models, with four modes and five trip purposes included. The basic structure of the individual models also includes sociodemographic characteristics of the traveler, characteristics of the built environment (household and employment density, purpose-specific activity in the buffer, intersection density, transit proximity, and land use mix), as well regional accessibility represented through logsums. There is also a provision to differentiate between simple and complex tours.

Variables unique to the origin-destination mode-choice models include measures of conditions at the trip destination, measures of trip length (distance and/or distance-related travel time), and characteristics of the journey for bicycle that include relationships for type of bike facility, slope/gradient, turns per mile, and fraction of journey wrong way on directional streets. The inclusion of sidewalk coverage (percent buffer with no sidewalks) also shows important relationship with both walk and transit trip-making. Also, the inclusion of travel time for auto and transit modes, and cost in the form of parking cost and fare, provides an important set of policy variables for analysis with this set of models

Variable definitions are presented in the earlier tab: Variable Defs MC Model.

Tab: O-D Mode-Choice Model Calcs

This tab presents the interactive version of the O-D mode-choice model, following the same structure and format as with the origin-only model. The color coding of the tables—blue, orange, and green—follows the same function and order. To work with the models, direct changes to the value in the orange table. To restore the default values to this table, a backup version has been stored at the bottom of the work sheet.

Because the origin-destination models incorporate trip distance, which greatly improves their explanatory power and application flexibility, an additional burden is placed on the user to be aware of the assumptions related to distance.

The four modes in the mode-choice models operate over different distance ranges. Although the distance range for auto is virtually unlimited, and transit has great range (limited primarily by system coverage), such is not the case for bicycling or walking. The mean distances for each mode from the tours modeled in the travel survey sample are correspondingly different, even for the same trip purpose. Hence, if one were to try to estimate mode shares for the sample of all trips without controlling for distance, the process would be trying to make an apples-versus-oranges comparison.

In the sample calculations shown in this tab, these sample mean values are in fact used, and so the results shown must be regarded as biased because the distances are average, and not for common distance bands. Within the models, certain limits are imposed on trips by the various modes to account for their "availability" as realistic modes. At the bottom of the table of calculations (green "products" table) are shown the available percent. As repeated Table 5-14 below, it can be seen that for work tours, for example, there are 4,483 cases where Auto is available as an alternative, but only 3,664 where Transit is available; 4,414 where Bicycle is available, and only 794 where Walk is available. The reason for the low number for walk trips is that walk trips were not assumed to be viable beyond 5 miles, while transit was not considered viable for very short trips because it cannot be connected to the network.

To account for this effect on the mode-choice calculation, the composite utility values used to calculate the probabilities of selection are reduced by the corresponding "fraction available." Although this correction is not a perfect solution for the mismatch in average travel distances, it produces a more realistic estimate of the potential mode shares (which are shown at the bottom of the table for both simple and complex tours).

The more appropriate way to deal with this phenomenon is to break the choice process down into common distance bands. The computations are then made—more correctly—for similar trip length assumptions. This process plays out in a series of individual interactive worksheets, listed as individual tabs, focused on distance bands of 0 to 1 mile one-way trip distance, 1 to 2 miles, 2 to 3 miles, 3 to 4 miles, 4 to 5 miles, and over 5 miles. The means in the tables for each distance band are reflective of the observations from the calibration sample. This culling of the sample into distance groups does not eliminate the need to account for "available" cases, the adjustments for which are again shown at the bottom of the table of calculations.

Tab: Tabulate Results

This final worksheet provides a common location for the mode-choice estimates made from the different model configurations. These results are placed here manually simply for convenience to the user to study patterns and compare differences; they are not automatically fed by the respective interactive model worksheets. However, if users wish to use this worksheet as a common place to store and reference their own scenario results or create an active link, they should feel free to do so. Table 5-15 shows predicted mode shares by purpose and distance band, illustrating the differences associated with both purpose and simple versus complex tours.

The user is urged to become familiar with this spreadsheet tool and its capabilities. It is anticipated that it will be a powerful tool for sensitivity testing, factoring methods, and sketch-planning approaches.

Guidelines for Use: GIS Walk Accessibility Approach

This approach was designed to

- Quantify the combined effects of land use and travel network level of service on pedestrian travel demand. (This approach is also applicable for bicycle, but insufficient survey data on bike trips prohibited full development.)
- Rely substantially on GIS tools and data to create "accessibility" relationships, which may then be used to explain/forecast non-motorized travel demand.
- Calculate a walk-accessibility score (similar to Walk Score), which then serves as a means for estimating the number and percentage of trips in an area that will be made by walking (versus auto or transit; insufficient data to incorporate bike).
- By changing either the land use (type and location of activities) or the travel network, changes in walk-accessibility can be calculated and converted to changes in number of walk trips and mode-split.
- Walk trip tables can be assigned to the respective walk network in a separate assignment program (not part of this tool).

Scale of analysis

- The characteristics of this tool make it most appropriate for applications at a subarea or site level. The most effective size

Table 5-14. Number and percent of trips available in sample by purpose and mode.

Purpose	Cases	Walk	Bicycle	Transit	Auto
Work	Number Available	794	4414	3664	4483
	Fraction Available	0.1771	0.9846	0.8173	1.00
School	Number Available	757	1220	695	1327
	Fraction Available	0.5705	0.9194	0.5237	1.00
Recreation	Number Available	744	1438	794	1516
	Fraction Available	0.4908	0.9485	0.5237	1.00
Other	Number Available	1326	2432	1457	2567
	Fraction Available	0.5166	0.9474	0.5676	1.00
Work-Based	Number Available	353	430	195	476
	Fraction Available	0.7416	0.9034	0.4097	1.00

Table 5-15. Estimated modes shares by distance, trip purpose and tour complexity.

	Home-Based Work								
Distance	Simple Tour					Complex Tour			
(Rd Trip)	Walk	Bike	Transit	Auto		Walk	Bike	Transit	Auto
0-1 mile	44.6%	8.4%	0.4%	46.6%		20.3%	6.1%	0.4%	73.2%
1-2 miles	13.2%	10.5%	6.0%	70.3%		4.6%	5.8%	4.4%	85.1%
2-3 miles	1.4%	10.0%	7.9%	80.7%		0.5%	5.0%	5.3%	89.2%
3-4 miles	0.0%	8.9%	8.0%	83.1%		0.0%	4.4%	5.2%	90.3%
4-5 miles	0.0%	7.8%	7.5%	84.7%		0.0%	3.9%	4.9%	91.2%
>5 miles	0.0%	2.0%	5.9%	92.1%		0.0%	0.9%	3.7%	95.3%
	Home-Based School								
	Simple Tour					Complex Tour			
0-1 mile	42.9%	3.5%	0.4%	53.2%		5.9%	0.6%	0.3%	93.2%
1-2 miles	7.2%	2.8%	5.7%	84.3%		0.6%	0.3%	3.0%	96.1%
2-3 miles	0.2%	1.5%	8.8%	89.5%		0.0%	0.2%	4.3%	95.5%
3-4 miles	0.0%	0.8%	8.8%	90.4%		0.0%	0.1%	4.3%	95.6%
4-5 miles	0.0%	0.5%	8.2%	91.3%		0.0%	0.1%	3.9%	96.0%
>5 miles	0.0%	0.0%	6.9%	93.1%		0.0%	0.0%	3.3%	96.7%
	Home-Based Social/Rec								
	Simple Tour					Complex Tour			
0-1 mile	71.9%	0.7%	0.1%	27.3%		23.5%	0.4%	0.2%	75.9%
1-2 miles	12.0%	1.9%	2.3%	83.8%		1.6%	0.4%	2.6%	95.4%
2-3 miles	0.4%	1.9%	4.1%	93.6%		0.0%	0.4%	4.1%	95.4%
3-4 miles	0.0%	1.7%	3.5%	94.8%		0.0%	0.3%	3.6%	96.1%
4-5 miles	0.0%	1.5%	3.8%	94.7%		0.0%	0.3%	3.9%	95.8%
>5 miles	0.0%	0.7%	2.4%	97.0%		0.0%	0.1%	2.4%	97.5%
	Home-Based Other								
	Simple Tour					Complex Tour			
0-1 mile	46.2%	1.8%	0.1%	52.0%		16.3%	0.4%	0.0%	83.2%
1-2 miles	3.7%	1.6%	1.0%	93.7%		0.9%	0.2%	0.5%	98.4%
2-3 miles	0.0%	0.9%	1.3%	97.7%		0.0%	0.1%	0.7%	99.2%
3-4 miles	0.0%	0.5%	1.3%	98.3%		0.0%	0.1%	0.7%	99.3%
4-5 miles	0.0%	0.2%	1.1%	98.6%		0.0%	0.0%	0.6%	99.4%
>5 miles	0.0%	0.0%	0.8%	99.2%		0.0%	0.0%	0.4%	99.6%
	Work-Based								
	Simple Tour					Complex Tour			
0-1 mile	91.2%	0.0%	0.0%	8.8%		40.8%	0.0%	0.0%	59.2%
1-2 miles	18.9%	0.0%	1.4%	79.7%		1.5%	0.0%	0.4%	98.1%
2-3 miles	0.3%	0.0%	1.7%	98.1%		0.0%	0.0%	0.4%	99.6%
3-4 miles	0.0%	0.0%	1.8%	98.2%		0.0%	0.0%	0.4%	99.6%
4-5 miles	0.0%	0.0%	1.8%	98.2%		0.0%	0.0%	0.4%	99.6%
>5 miles	0.0%	0.0%	1.4%	98.6%		0.0%	0.0%	0.3%	99.7%

would be an area of about 30 to 40 census blocks, or 3 to 6 TAZs.

- Ideal scale is linked to walk distances—what can be reached within 15–30 minutes of walking time (or about 1–2 miles).
- Larger areas such as corridors may be better addressed if broken into several smaller areas.

Data, tools, and expertise needed

- For initial model calibration: Recent household travel survey data, with trip ends coded to parcel, block face, or other fine-grained geography (for initial model calibration), plus point-level employment data from sources like Dun & Bradstreet or InfoUSA.
- For model application: Census block-level data (population, households, employment [LEHD]). Users can choose other land units, such as parcels, grid cells, or even TAZs (for very coarse analysis), as long as data are available to support walk-accessibility score calculations and trip generation routines. These formulas are customizable within the tool.
- All-streets network obtained through NAVTEQ or TIGER. This may be augmented with non-motorized facilities, centroid connectors (e.g., connecting block centroids to multiple block faces), custom evaluators or other elements to obtain a rich pedestrian analysis network. At a minimum, the all-streets network should be used.
- ArcGIS with Network Analyst and expertise to create paths and overlays. (Network analysis steps take place as independent exercises, the outputs of which may be fed into the tool. The current GIS-accessibility tool is a spreadsheet model and does not perform these GIS operations, although guidelines are provided on the process.)
- Trip generation rates or equations from regional model (defaults are available within the tool, but may not be applicable depending on the land use data to be used in analyses).
- Modal trip tables from regional model (not necessary if mode-split analysis is not required).

Overview of Use

The walk-accessibility model involves both a *setup* and an *applications* phase. A spreadsheet version of the model (WALC TRIPS XL) has been provided with the guidebook, which can be used for composing and evaluating scenarios (see *CRP-CD-148*). Both test data and an application scenario taken from Arlington County, VA, have been provided with the model. Users are encouraged to familiarize themselves with the tool using the pre-loaded data and scenario before attempting to develop the model for their own use.

Basic steps in preparing and applying the model follow. These steps are described generically below and illustrated with a flowchart to create a clear picture of what the model is doing and what is required of the user at each step. Once these basic steps are defined, directions are then provided for replicating the steps with the spreadsheet model.

1. Model Setup

The model setup process is profiled in Figure 5-5. This phase of the tool facilitates the analytical processes described in Chapter 4 to allow users to develop model relationships based on local data, rather than relying on the default relationships derived from Arlington, VA. However, developing local relationships can be computationally intense and time-consuming. Users can skip these steps and apply the default relationships to a local planning problem.

Preparing the model for use in a given area requires developing accessibility relationships, derived from a combination of the following data resources:

- **Local travel survey data** that contains trip-level information on mode, purpose, travel time or distance, and geographic identification of each trip end (exact latitude/longitude, parcel, or block face).
- **Socioeconomic data (SED)** depicting population and employment data at a parcel, block, or other fine geographic level.
- **GIS travel networks** reflecting all streets and potential paths usable by cyclists or pedestrians.

It is necessary to compute modal accessibilities for all modes being considered in the analysis (currently only walk). This is done for each trip end through the following steps:

- First, a **distance-decay relationship** is developed that explains the willingness to travel by the given mode in relation to the travel distance, or more accurately, travel time. This is done by preparing a distribution of trips by travel time for each mode being considered in the analysis (separately by purpose), and then fitting a curve to that relationship (offered by Excel), which mathematically defines the rate at which demand declines as travel time increases (this is usually a represented in a logarithmic relationship, where utility for a destination falls rapidly but then at a slower rate as distance (time) increases).
- **Walk accessibilities:** For each unique trip end, a GIS analyst will ascertain the number of attractions that can be reached from the given trip end reference point by walking along the pedestrian network. The attractions may be population or employment (by type), the location and identity of which are captured from Census block data or proprietary sources like Dun & Bradstreet. Destinations are discounted by their respective impedance (weighted travel time) as measured over the actual network, further discounted by the distance-decay rate, and then summed to a total accessibility "score" for a given location.

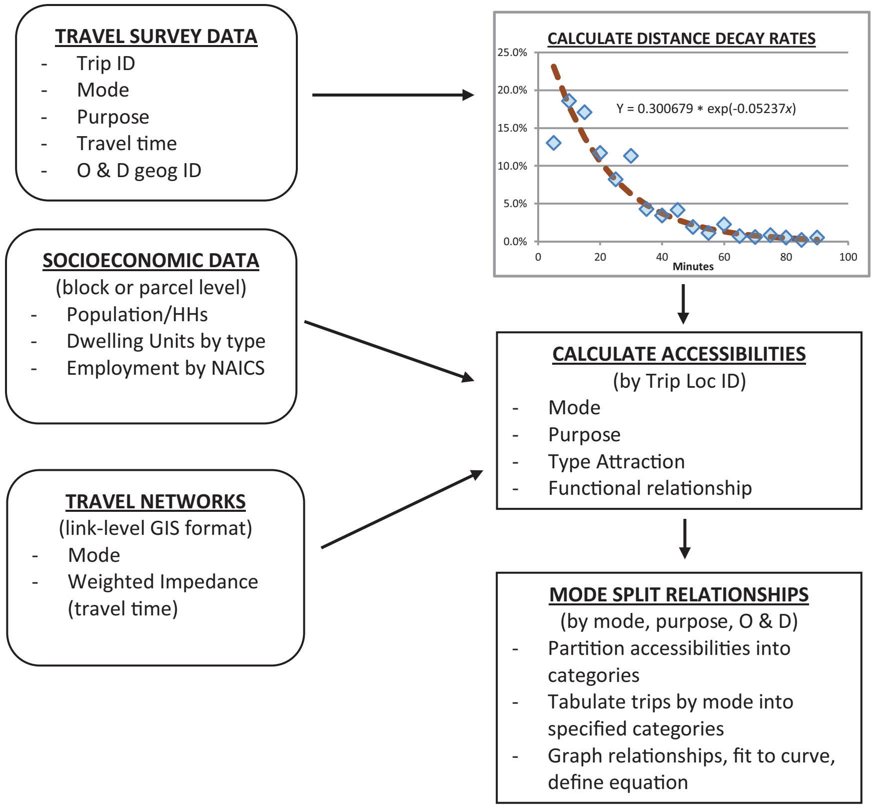


Figure 5-5. Walk-accessibility model setup phase.

Mode-choice relationships are then derived from the accessibility scores. This is done by dividing the overall sample of trips with accessibility information into "categories" (ranges of value) based on the shape of the distribution of the sample (constant increment, constant sample number, number of deviations from the mean). The percentage of trips by mode is then tabulated for each category, by purpose, and for each trip end as an origin and a destination. A curve is fitted to the shape of the distribution of mode share-by-accessibility range, which may then be used to calculate mode split in relation to a given accessibility score that would be generated in a planning scenario. Finding the best fit for these curves is often an iterative process. The analyst should consider the goodness of fit of the curve, the sample sizes created within each accessibility category, and the typical accessibility attributes expected for a given trip purpose and end combination (e.g., the accessibility scores for home-based work origins will often be very different from home-based work destinations).

2. Model Application

Once the model has been set up for the given area, use for analysis may begin. Again, the typical application environment for this method would be a community or subarea of perhaps 1 to 2 square miles, encompassing 4 to 6 TAZs and perhaps 30 to 40 census blocks. Interest in defining such a setting could involve questions related to new development proposals, interest in modifying or testing the performance of the local transportation (especially non-motorized) networks, or transit service or access improvements. The steps in application are as follows, with illustration provided by Figure 5-6:

- **Define Study Area:** The user defines the study area of interest, generally an activity area ranging from one to several TAZs in size. Ideally, the area definition will be consistent with TAZ and census block group boundaries to facilitate sharing of information and later modifying vehicle trip tables to account for changes in mode split. Follow protocols to delineate the "study area" primary area of analysis, the "walkshed" surrounding network of blocks likely to share walk activity (productions and attractions) with the study area, and the "catchment area," the area serving as the spillover for the "walkshed."
- **Create Land Use Data Master File:** Populate the defined system of blocks with SED information from the socioeconomic data file prepared earlier. Record employment by type, population, and households by auto ownership level.

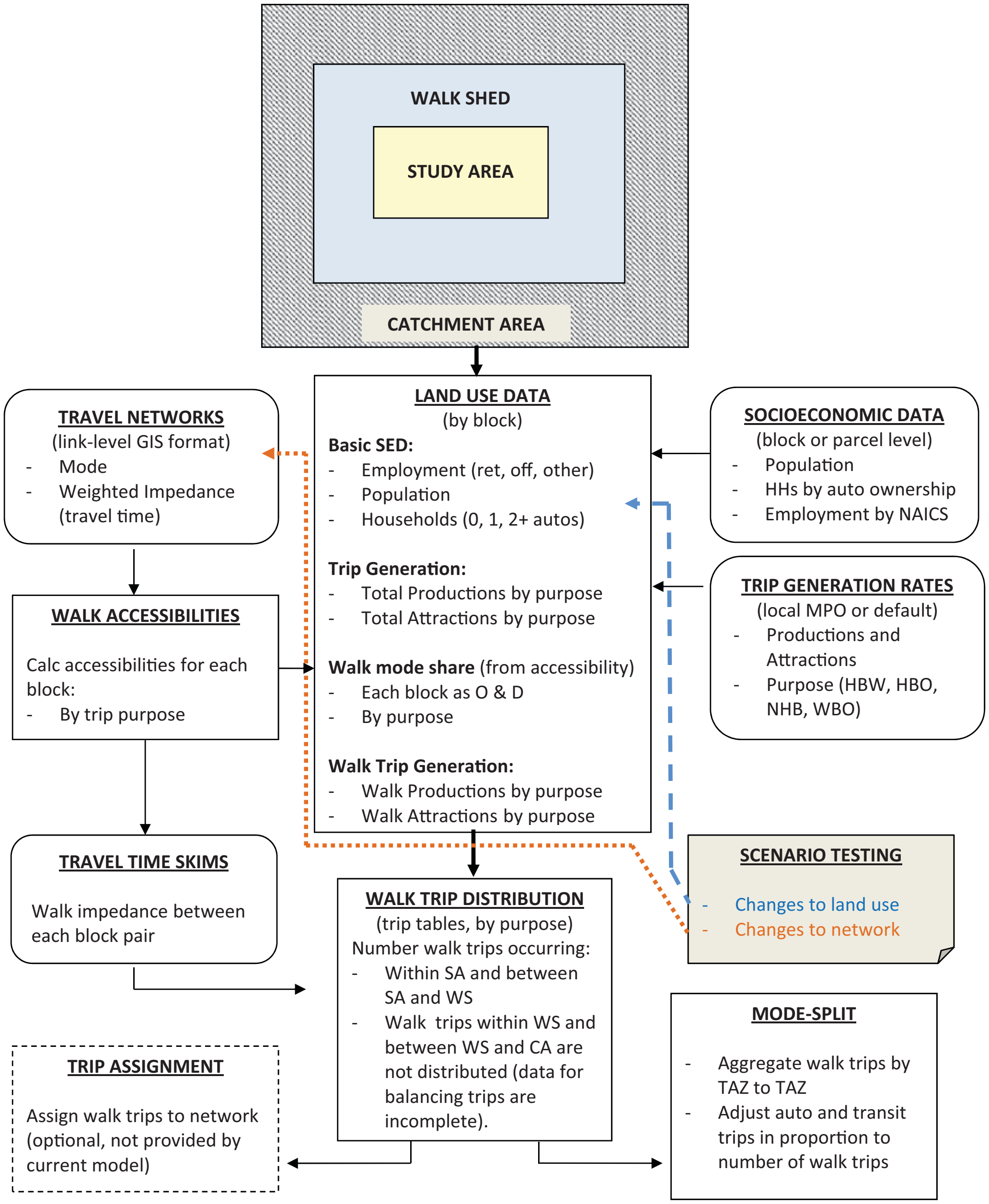


Figure 5-6. Walk-accessibility model—application phase.

- **Trip Generation:** Estimate total productions and attractions for each block in the sample using either trip generation rates obtained from the local MPO model or default values provided.
- **Walk-accessibility:** Using network analysis methods, calculate walk travel times between land units (e.g., parcels or blocks) in the analysis area. For this analysis, land units in the study area and walkshed should be included as origins; all land units, including those in the catchment area, should be included as destinations. This is done off line by a GIS analyst using provided protocols and the information in the walk network and the SED information for each block. Walk travel time skims are then used to support the calculation of walk-accessibility scores in the scenario analyses (a routine for the latter is included in the model).
- **Walk Trip Productions and Attractions:** Walk mode shares are calculated for each block based on the walk-accessibility score and the mode-choice relationships developed during model setup. This is done for each trip purpose (home-based work, home-based other, work-based other, and non-home-based) and for the block as an origin or destination. These shares are then used to determine the portion of total person trip productions and attractions expected to be made by walking.

- **Create Walk Trip Table:** A block-level walk trip table can be formed by performing trip distribution on the walk productions and attractions and the travel time skims (a procedure is provided in the model). This is done for each purpose.
- **Walk Trip Assignment:** This walk trip table could be "assigned" to the walk network to assess facility-demand volumes, although given that there are trip tables for four different trip purposes, the tables would have to be combined into a single trip table for a given time of day in order to be able to perform a credible assignment. An assignment procedure is not provided in the model, but one is suggested in the Ped Context model featured as another tool; users with conventional transportation planning software, such as TP+, can probably use such utilities in those programs.
- **Impact on Auto and Transit Trips:** The effect on trips by other modes can be determined by subtracting the walk trips from the corresponding auto and transit trip tables produced by the MPO travel model. To do this it is necessary to aggregate the block-level walk trip table to a TAZ level and then reduce the trips by auto and transit for the same origins and destinations. The model provides help with this translation between blocks and TAZs.
- **Scenario Testing:** To evaluate changes in land use or network coverage/connectivity, the user enters changes in the boxes highlighted in Figure 5-6. The user can specify various land use and network scenarios (e.g., existing and several proposed futures). For land use changes, revised population or employment assumptions would be communicated to the appropriate census blocks in the study area, as indicted by the line. For network changes, new or modified link information would be related to the computerized network file as indicated by the line. New accessibilities would then be computed for each land use/network combination, and the rest of the steps in the flowchart repeated.

Use of Spreadsheet Model

The walk-accessibility model is offered in the form of an Excel spreadsheet (*CRP-CD-148*) to enable the largest number of users to access and use it. In spreadsheet form, the workings and interrelationships of the model are also made more transparent. Access to GIS data and basic skills in performing network analysis in GIS are required because of the emphasis of the approach on accessibility, which is a very spatial commodity. Eventually, it will probably be more effective to package the model in a GIS-friendly planning model, such as Community Viz, where the user can make more direct use of the file management utilities and gain the benefit of GIS visualization capabilities. Such treatment would also offer more interaction among stakeholders during the planning process.

A user's guide is presented below as Exhibit 5-1, to aid readers in understanding and applying the WALC TRIPS XL model.

Exhibit 5-1. WALC TRIPS XL User's Guide

The WALC TRIPS XL model opens with the following master screen as shown in Figure 5-7. The screen partitions the processes of the model into four basic parts:

- The left side of the screen contains directions on model setup, with press button access to the respective sheets and tables inside the spreadsheet.
- The top left of the screen deals with input of required data to set up the model, while the bottom left accesses steps in processing that data into the necessary relationships.
- The right side of the screen deals with model application and scenario testing.
- The top right of the screen helps to manage input of data for the selected subarea, while the bottom right provides help with processing the data and running scenarios.

Model Setup:

The model setup steps assist users in developing custom relationships for model application. Analysts using the default relationships can skip these steps and move directly to the model application track.

Travel Survey Data

Following the generic steps discussed in the preceding section, the user enters the necessary travel survey data for the area or region under study. A visual of this screen and its counterpart (Location Accessibility Data) is shown as Figure 5-8. The model is designed to read the data fields shown from the source travel survey host file, assuming that they are of the same format. Guidance on importing data—including content, organization, and formatting

(continued on page 101)

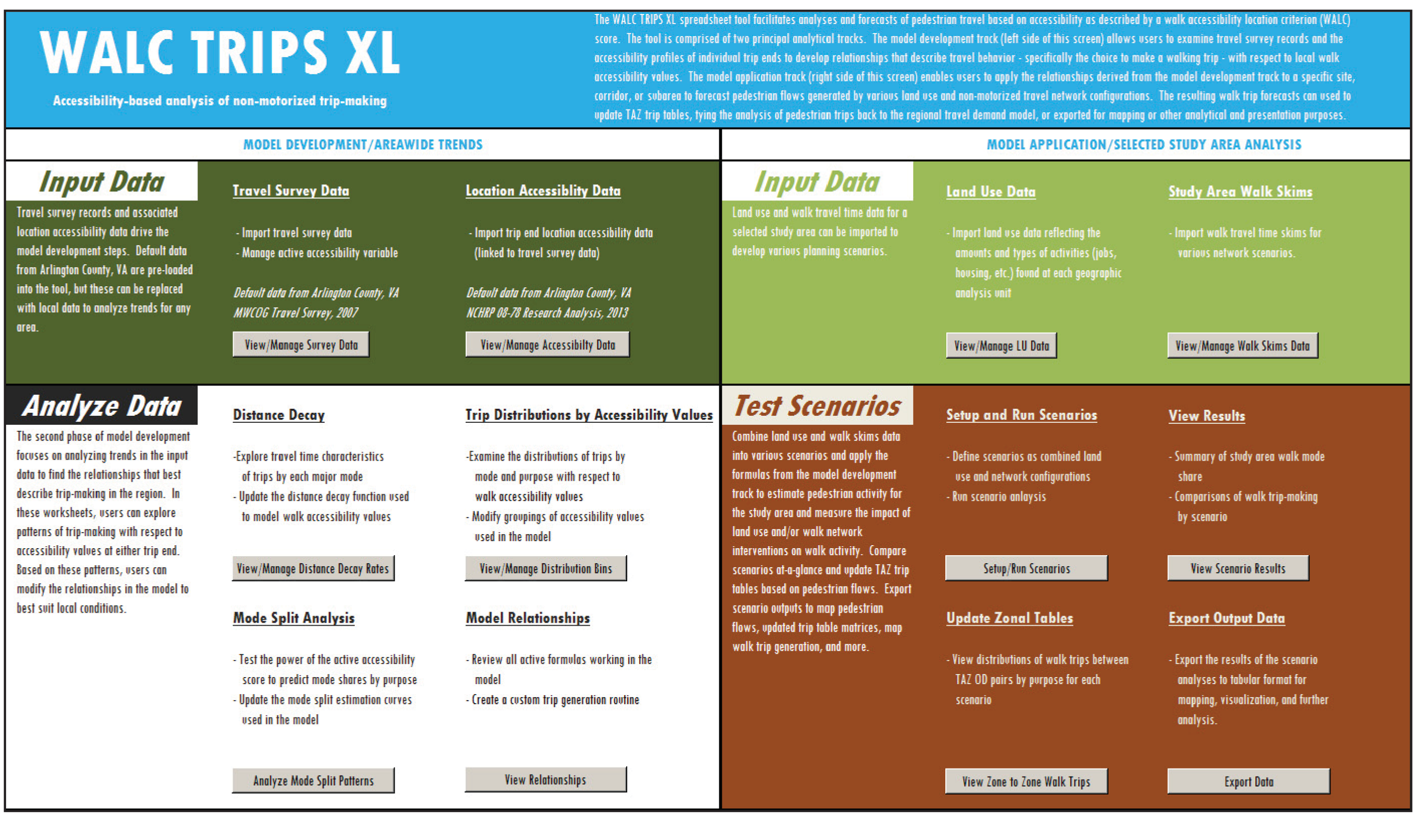
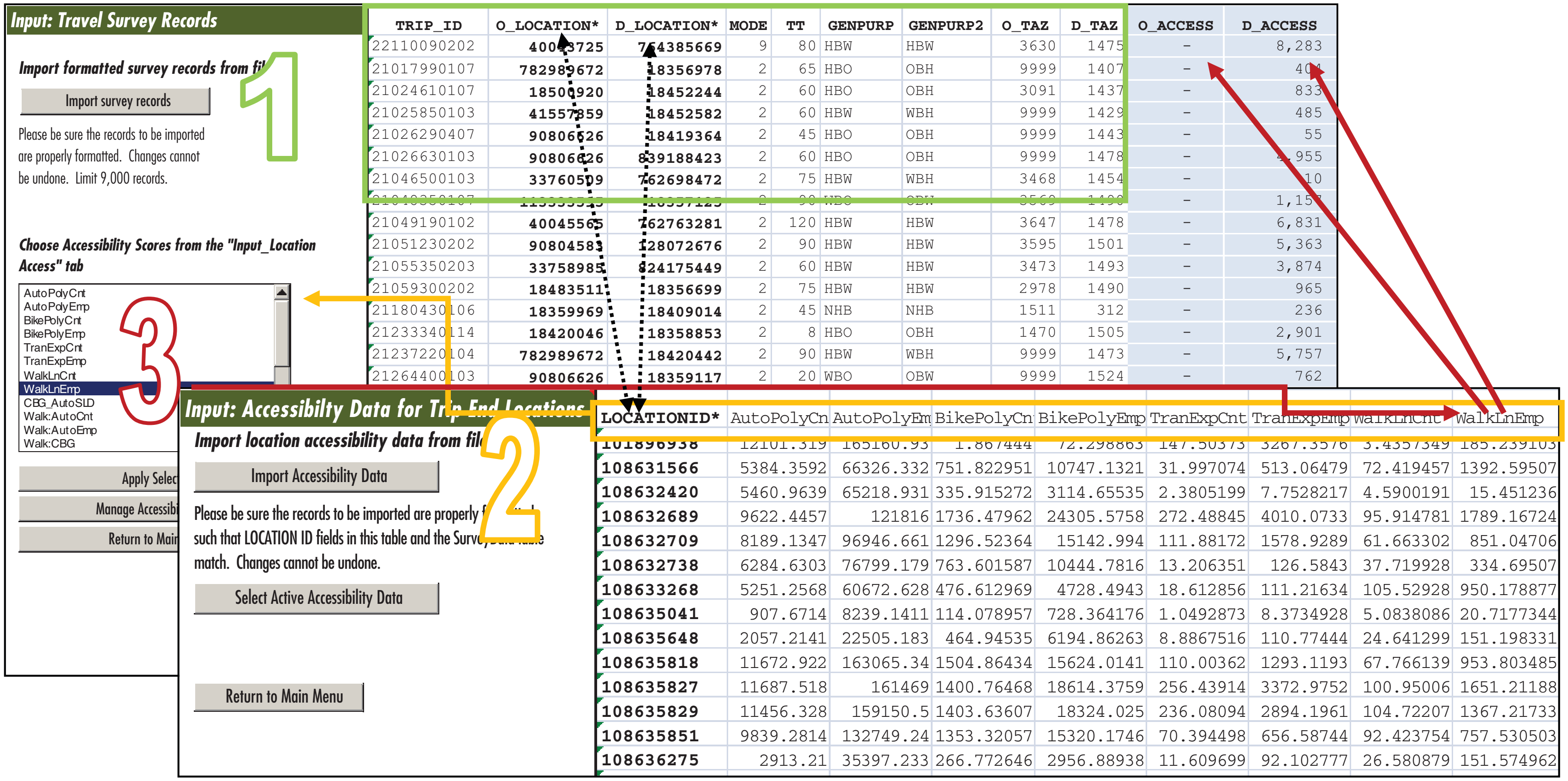


Figure 5-7. WALC TRIPS XL master screen.



1. Use the “Import Survey Records” function to populate the white-shaded columns to the right with local travel survey data. Make sure the data are properly organized and formatted.
2. Use the “Import Accessibility Data” function to load accessibility scores associated with each trip end location. The field headings from the loaded data will appear in the menu on the Travel Survey Records page.
3. Select an accessibility heading from the list and click on “Apply Selected” to activate that field as the accessibility score for further analysis. The blue-shaded fields will look up (see black dashed lines) the accessibility values associated with the origin and destination of each survey trip record.

Figure 5-8. Import travel survey and trip end accessibility data.

Exhibit 5-1. (Continued)

requirements—is provided within the tool. Up to 9,000 trip records can be accepted. The blue-shaded columns on the far right of the table are the accessibility values computed for the corresponding trip ends—origin and destination for each trip. The menu on the bottom left allows the user to access this information from a separate file, wherein any number of accessibility measures may have been calculated by a GIS analyst for the study in response to requests from the project planner. This allows analysts to experiment with various constructions of the accessibility calculation (e.g., focusing on retail employment versus total employment) seamlessly when developing model relationships.

Location Accessibility Data

Using the trip end geographic identification information in the trip file, accessibilities are calculated in an off-line GIS process, which overlays the transportation network onto a layer of trip attractions and computes an accessibility score for the given mode and trip purpose. Those results are stored in this file of the spreadsheet and can be called on in the previous Travel Survey Data file and merged with the respective trip data. The annotations describe the interrelated workings of this page with the Travel Survey Data page.

Distance Decay

To calculate the accessibility scores, it is first necessary to determine distance-decay rates. A separate spreadsheet process for this task is accessed from the main menu under **Analyze Data—Decay Rates** (or using spreadsheet tab). The rates should then be used in calculating accessibilities. To support this procedure, as shown in Figure 5-9, the model pulls up the trips by mode and distance information from the Travel Survey database and posts the information as a table of the distributions for each mode. The model then allows the user to graph any of these distributions and fit a curve that best characterizes the shape of the distribution (log, linear, exponential, power, and binomial functions are offered). Generally, the curve with the highest R^2 is selected, and its mathematical function saved to a file under the tab "Relationships." The saved formula will be used in the model application steps later.

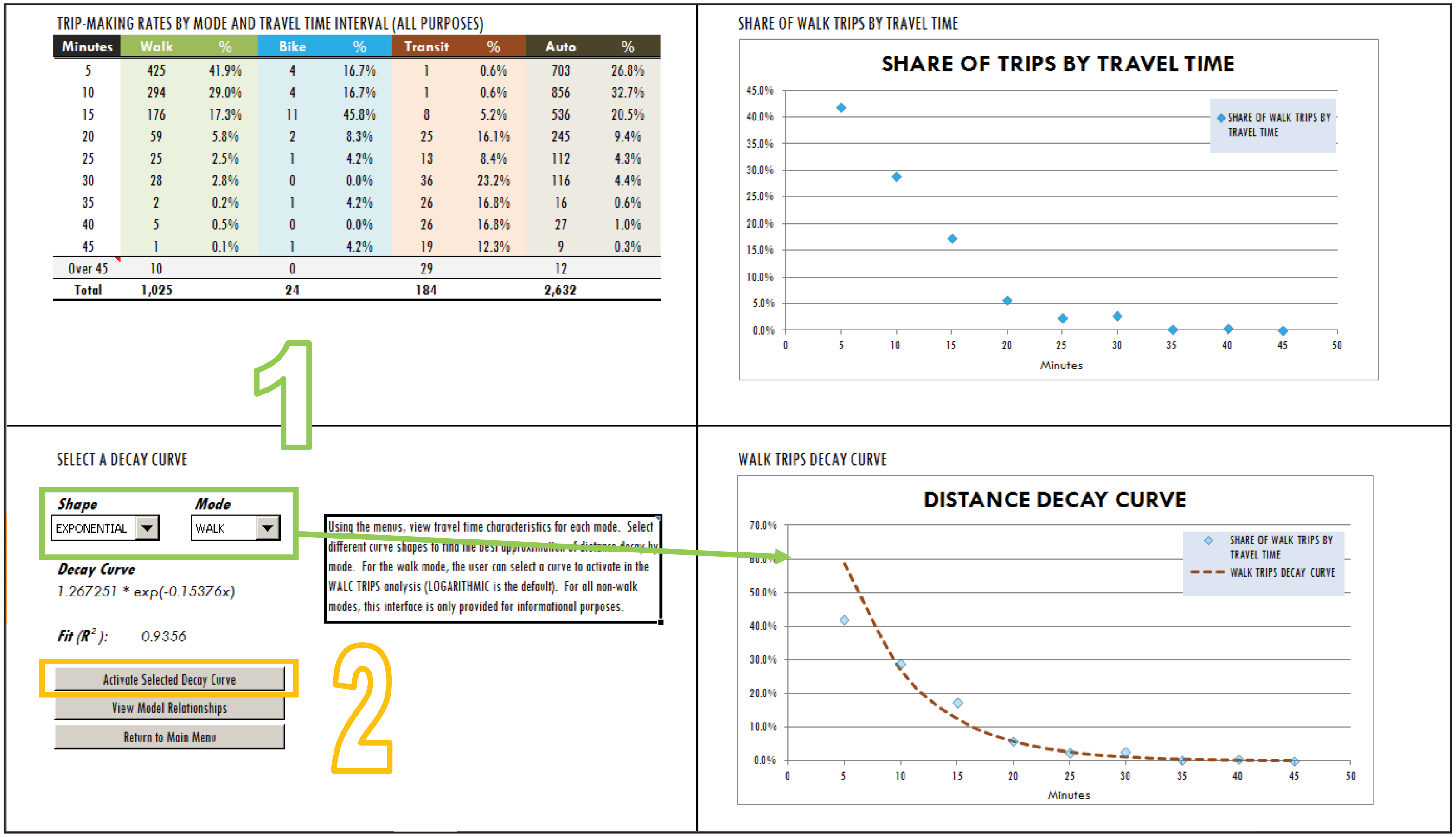
Setup Distributions

This screen (Figure 5-10) takes the calculated accessibilities and provides a visual basis for dividing the data into categories. These categories create "bins" for approximating modal shares in the next step.

In the sample of trips each trip represents an observation, and that observation corresponds to a given mode—auto, transit, walk, or bicycle. The principal assumption behind this model is that choice of walk mode is directly related to the walk-accessibility score, both at origin and destination. However, to determine walk "mode share," it is necessary to compare the number of walk trips made in a given walk-accessibility "range" with the number of trips made by all modes within the same range.

This screen provides the user with statistical information on the distribution of all trips by walk-accessibility. By examining the shape of this distribution, the user can select a set of accessibility ranges that best subdivides the data for comparing differences in mode shares. There is a space at the bottom of the worksheet to specify the range categories for this sorting process. Eleven categories are required, ten of which will be active in the mode-split analysis (the eleventh category, representing the highest accessibility band is assumed to house outlier values). Users can either use the statistical breaks shown in the top of the worksheet by clicking on the "apply standard deviation breaks" button or enter their own category markers that they believe are more appropriate. Generally, the manual breaks will yield better results, and users are encouraged to work among the "Setup Distributions," "View Distributions," and "Mode Split" tabs to find the distribution breaks that best describe walk trip-making by purpose and end.

(continued on page 104)



TRIP-MAKING RATES BY MODE AND TRAVEL TIME INTERVAL (ALL PURPOSES)

Minutes	Walk	%	Bike	%	Transit	%	Auto	%
5	425	41.9%	4	16.7%	1	0.6%	703	26.8%
10	294	29.0%	4	16.7%	1	0.6%	856	32.7%
15	176	17.3%	11	45.8%	8	5.2%	536	20.5%
20	59	5.8%	2	8.3%	25	16.1%	245	9.4%
25	25	2.5%	1	4.2%	13	8.4%	112	4.3%
30	28	2.8%	0	0.0%	36	23.2%	116	4.4%
35	2	0.2%	1	4.2%	26	16.8%	16	0.6%
40	5	0.5%	0	0.0%	26	16.8%	27	1.0%
45	1	0.1%	1	4.2%	19	12.3%	9	0.3%
Over 45	10		0		29		12	
Total	1,025		24		184		2,632	

1. Use the menus to view distance decay patterns by mode and experiment with different decay curves.
2. For walk trips, click on the “Activate Selected Decay Curve” button to use the current decay formula in the WALC TRIPS XL model.

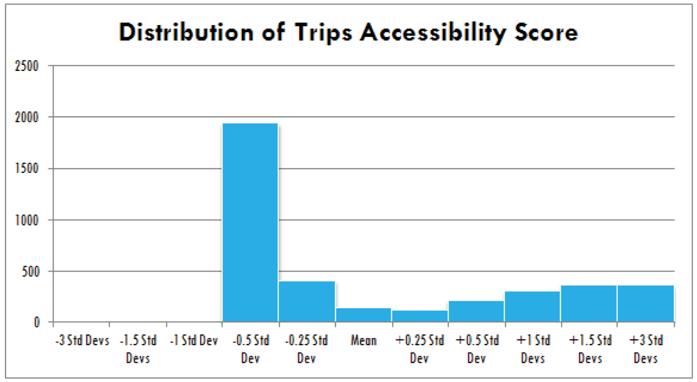
Figure 5-9. Calculation of distance (travel time) decay rate.

Display Accessibility Score Distributions for . . .

Origins

Descriptive Statistics for All Trip Origins

Mean	5,402
Standard Deviation	5,473
Minimum Value	0
Lower Quartile	1,305
Median	2,643
Upper Quartile	8,809
Maximum Value	22,189



1

Establish Breaks for Modal Analysis

Use the information above describing the distribution of all trips from the survey data in terms of their accessibility values to develop bins of accessibility scores that will be used to depict the distribution of trips by mode and purpose in the next tab.

View Distributions

2

Define based on all trips data:

Use Standard Deviation Breaks

Apply Std Dev Breaks

Or manually classify by entering data into the table . . .

Accessibility Bins
1000
1500
2000
2500
4500
7500
8500
9500
11000
12000
23000

Scratch Workspace

	HBWP	HBWA	HBOP	HBOA	WBOP	WBOA	NHBP	N
	1000	2000	1000	1000	2000	2000	2000	2000
	1500	3000	1500	1500	4000	4000	4000	4000
	2000	4000	2000	2000	7500	8000	6000	6000
	2500	6000	3000	3000	10000	11000	8000	8000
	4500	10000	5000	5000	12000	12000	10000	10000
	7500	10667	7000	7000	13500	13000	12000	12000
	8500	11333	8500	8500	15000	15000	14000	14000
	9500	12000	10000	12000	17000	17000	16000	16000
	11000	13000	12000	15000	18000	18000	18000	18000
	12000	14000	15000	21000	19000	19000	19000	19000
	23000	23000	23000	23000	23000	23000	23000	23000

1. The distribution of accessibility scores is plotted in the chart with descriptive statistics provided to inform the user about the general accessibility profile of the region.
2. The user defines accessibility "bins," ranges within which patterns of walk trip-making are similar. Different bins can be setup for different trip purposes and trip ends, allowing users to explore the ranges that are most appropriate for a given purpose/end combination. Although only one set of bins can be active at any one time, the breaks for different purposes and ends can be stored in the scratch workspace provided for reference.

Figure 5-10. Setup distributions.

Exhibit 5-1. (Continued)

View Distributions

The results of the binning process can then be viewed in the View Distributions screen, which provides the selected distributions in both tabular and graphic format, by origin or destination, trip purpose, and mode. Users can select a specific distribution of interest (e.g., HBW walk trips based on origin accessibility scores) to quickly zoom to that distribution in a new window.

Mode Split

The binned trip data from the Distributions task are then analyzed in the Mode Split screen to establish a relationship between accessibility level and mode share. The mode shares for each accessibility group are plotted and fitted to a curve, similar to the distance-decay procedure earlier. The interface is virtually the same as the Decay screen, except that users can look at a particular trip purpose and trip end when analyzing mode-split patterns. For each purpose and end, the curve that best describes the walk mode share can be saved to the "Model Relationships" page to activate the local accessibility relationship in the model application stages.

Relationships

This sheet serves as a common storage site for all computed relationships, including the Distance-Decay functions, Mode Split, and also Trip Generation. These trip generation rates are used later in the model application process. The default rates shown in Figure 5-11 have been taken from the MWCOG travel model; however, the user is encouraged to acquire equivalent rates for the local analysis area.

Model Application:

The right side of the model intro screen guides the application of the WALC TRIPS XL model, beginning with specification of the study area geography. For illustration, an example of an application performed on data for the Shirlington area of Arlington County is included on *CRP-CD-148* with the model.

Input Land Use Data

Activating this tab off the main menu brings the user to a table for entry of the land use data for the area that will be placed under study. The interface is similar to the import pages of the model setup phase. The land use data will be in the spatial form of census blocks in the example, although users may select alternative small-scale geographies for which they have data when running their own applications. The model is set up to read in a prepared file, to which the user applies a name corresponding to the land use scenario (e.g., "existing"). Guidance is provided within the tool about the content, organization, and format of imported data. Generally, there will be one land use file that describes base conditions, and then one or more scenario files (up to five files total in current version). There are 494 census blocks making up the example analysis area (41 TAZs), including the "catchment area."

Input Study Area Walk Skims

The set of census blocks that define the study area and walkshed area serve as both potential origins and destinations, while blocks in the catchment area are included as destinations only. To quantify the ease of travel among all potential walk trip pairings, the walk network is superimposed on the census block geography, and network analysis procedures are used to define the shortest travel time path between all pairs. These are saved as a travel time skim matrix. The analysis should be rerun for all networks to be analyzed. For example, if a new shared-use path facility is planned, the network analysis should be run in the base condition (without the new path) and in the plan

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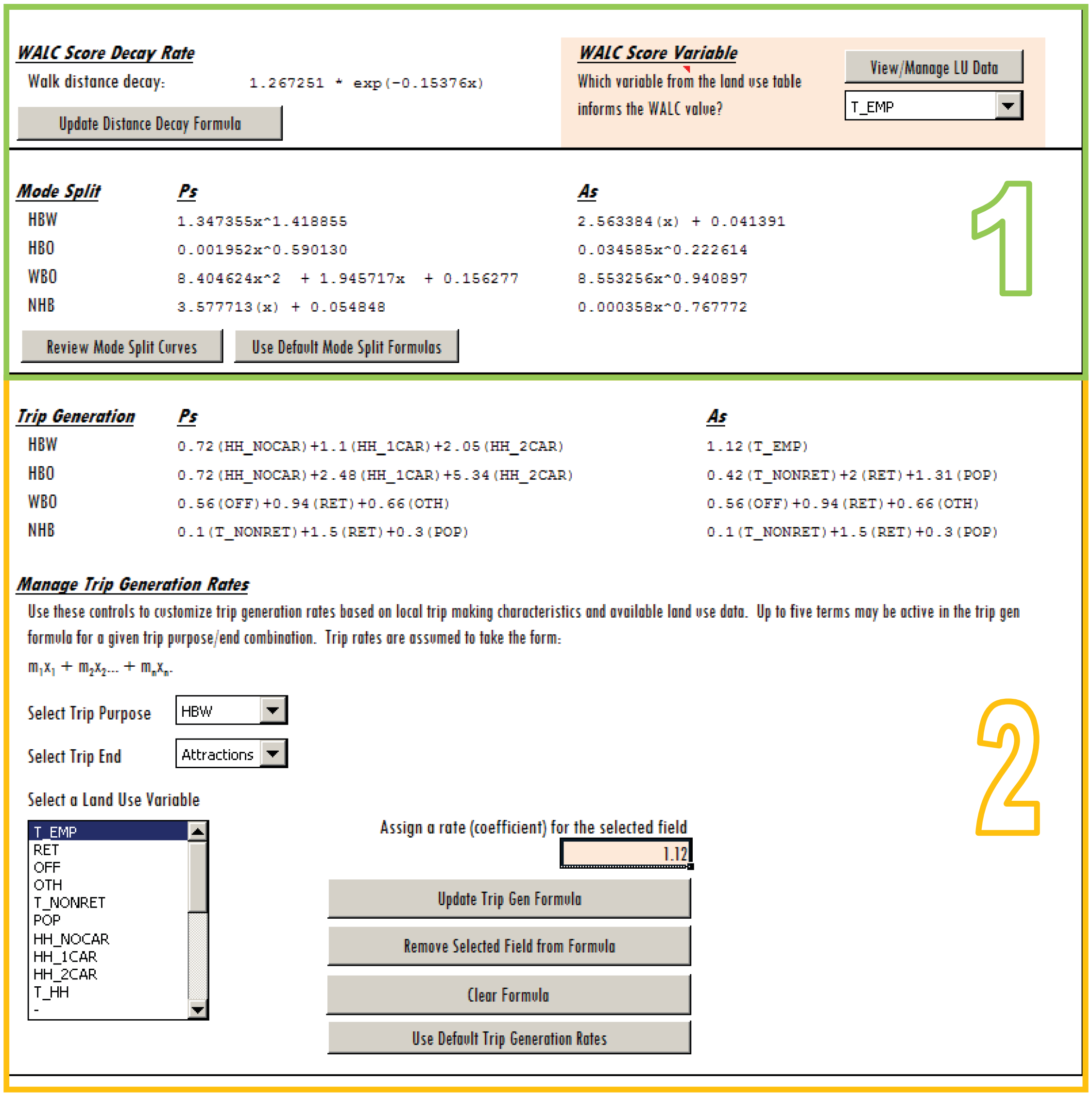


1. Review model relationships as defined through the model setup steps.
2. Manage trip generation formulas. The field headings in the list are read from the Land Use Data page in the model application phase. Users should take care to provide data in the format shown here when using the default relationships in the model application steps.

Figure 5-11. Model relationships.

Exhibit 5-1. (Continued)

condition (with the path added to the network). This will produce two different walk time matrices that can be imported as "network scenarios" in the WALC TRIPS XL model. As with the Land Use input step, the model anticipates access to and incorporation of these files from an external source, and multiple (up to 5) network scenarios can be defined.

Specify and Run Scenarios

This screen (Figure 5-12) is where the user specifies the land use and travel network conditions that will be run through the model as scenarios. For illustration, the screen is showing use of the base land use and base travel network to create an estimate of current conditions. To assess alternative scenarios, the user pairs any of the stored land use and network configurations using the features in the spreadsheet and the model calculates the new results. Up to ten combined land use and transportation scenarios may be defined.

Summary of Results

Each of the model runs of individual scenarios is stored at a summary level in the Scenario Results screen. The contents of this screen are shown in Figure 5-13 and include a summary of the average WALC accessibility value for

(continued on page 108)

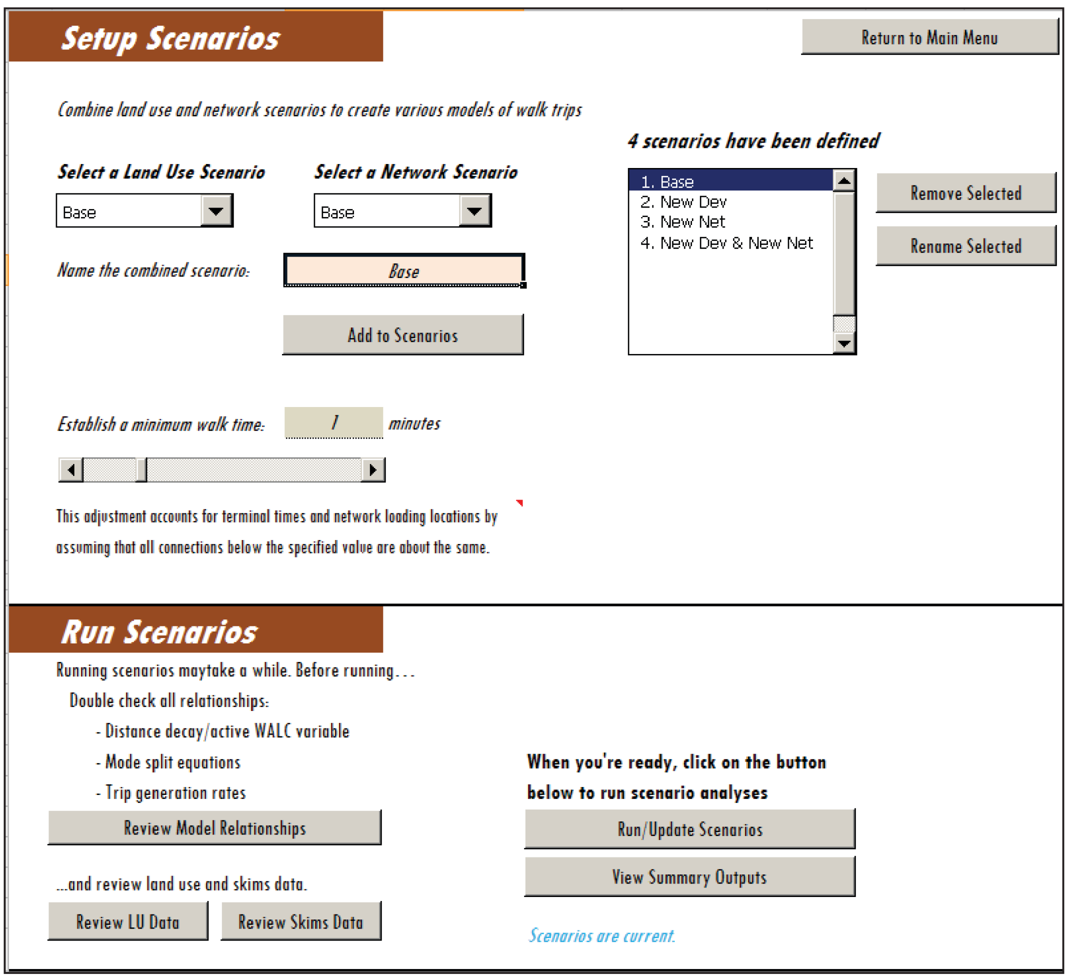
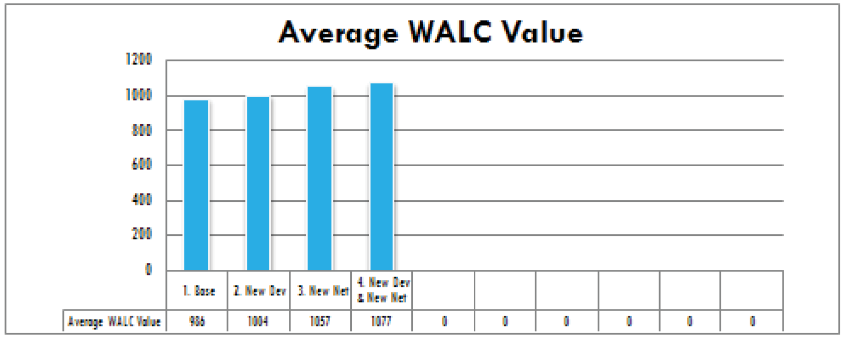


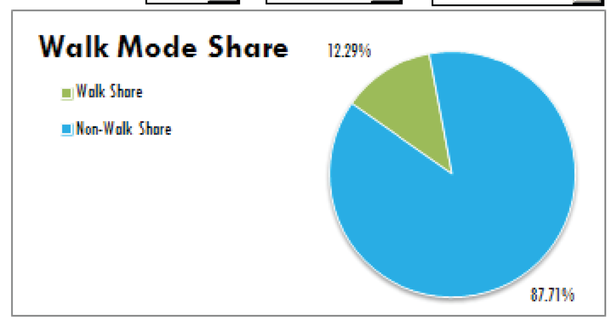
Figure 5-12. Scenario setup screen.

Average WALC Value	
1. Base	986
2. New Dev	1004
3. New Net	1057
4. New Dev & New Net	1077



	Productions				Attractions			
Average Walk Mode Share	HBW	HBO	WBO	NHB	HBW	HBO	WBO	NHB
1. Base	3.39%	11.21%	19.99%	10.28%	9.33%	15.74%	10.97%	8.53%
2. New Dev	3.45%	11.31%	20.02%	10.35%	9.37%	15.80%	11.04%	8.64%
3. New Net	4.05%	12.15%	20.49%	11.01%	9.85%	16.23%	12.07%	9.55%
4. New Dev & New Net	4.15%	12.29%	20.55%	11.12%	9.91%	16.31%	12.20%	9.71%

Display results for: Purpose HBO | Trip End Productions | Scenario 4. New Dev & New



	Balanced Trips			
Walk Trips By Purpose	HBW	HBO	WBO	NHB
1. Base	48	1,003	327	399
2. New Dev	52	1,028	344	419
3. New Net	78	1,480	366	467
4. New Dev & New Net	81	1,524	390	490

Display results for: Study Area

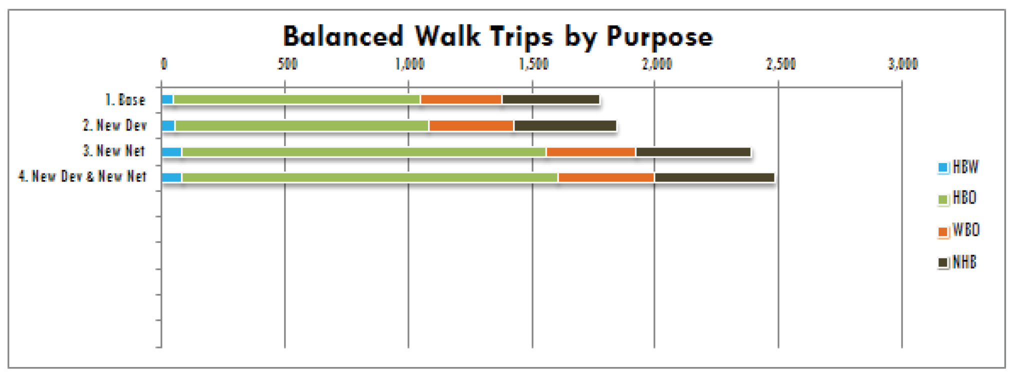


Figure 5-13. Summary of results.

Exhibit 5-1. (Continued)

the scenario, the number of walk productions and attractions by trip purpose, and the number of complete trips by purpose (distribution of Ps and As using the skims). Trips can be displayed for the study area only or the study area plus the surrounding walkshed.

Update TAZ Trip Tables

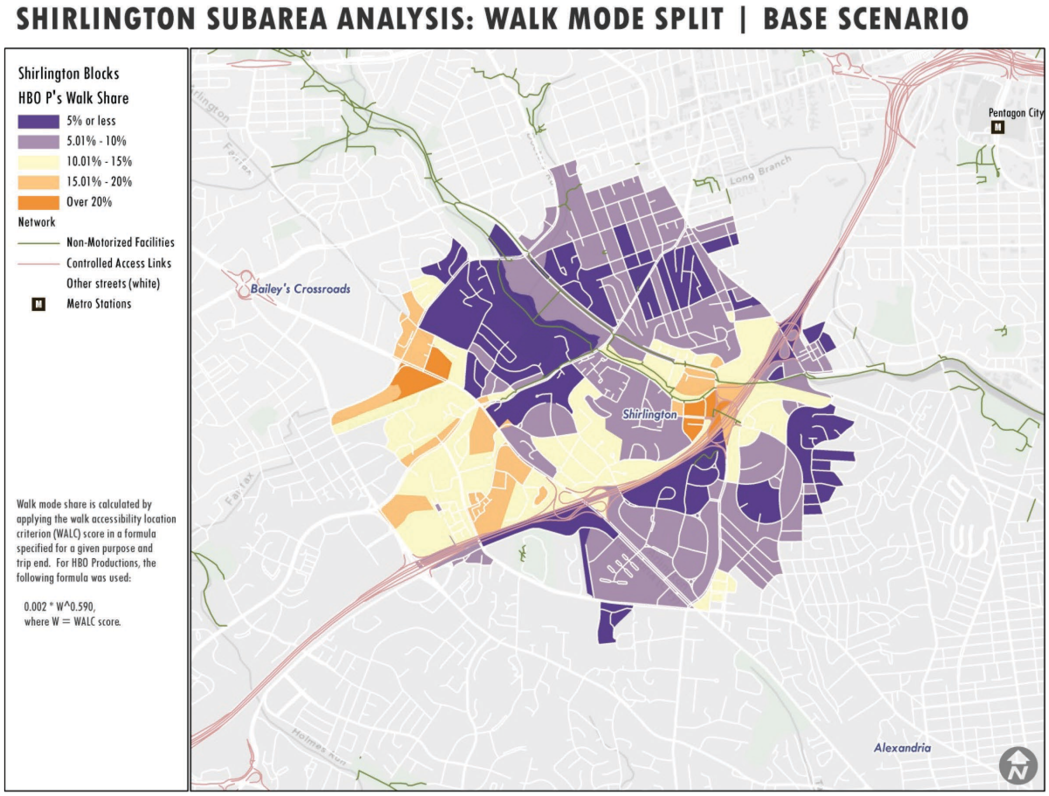
Users can use the update TAZ trip table routine to assemble the distributed walk trips (block to block flows) into estimates of pedestrian flows between TAZ pairs.

Export Output Data

Users can use the Export Output interface to export the results of the scenario analyses to tabular formats that can be used for additional analysis, mapping, and visualization. Figures 5-14 through 5-16 provide examples of the exported outputs for the Shirlington study area (the "combo" scenario represents a new development plus new network links, or Scenario 4 from Figure 5-13).

Figure 5-14 portrays the walk mode share estimates for HBO trips under two scenarios. Other "land unit level" outputs include the WALC score at each land unit (e.g., parcel or block), total trips generated at each land unit by purpose, and unbalanced walk productions and attractions generated by each land unit by purpose.

Figure 5-15 shows the "skim level" outputs. The exported table can be joined to lines that represent the point-to-point flows between each potential O-D pair in the land unit fabric. The joined data can then be referenced to map desire lines for pedestrian travel. In Figure 5-15, thicker lines represent larger numbers of pedestrian trips, and the arrows indicate the direction of travel (arrows point to the "destination" end of the O-D pair). In this way, users can represent the results of the WALC TRIPS XL spreadsheet's trip distribution routine, which are also used to develop the TAZ trip tables shown in Figure 5-16. The trip tables are shown as they appear in the WALC TRIPS XL interface; however, they can also be exported to an unformatted matrix for additional work, such as updating trip tables in the regional travel demand model or mapping walk trip productions at TAZ origins.



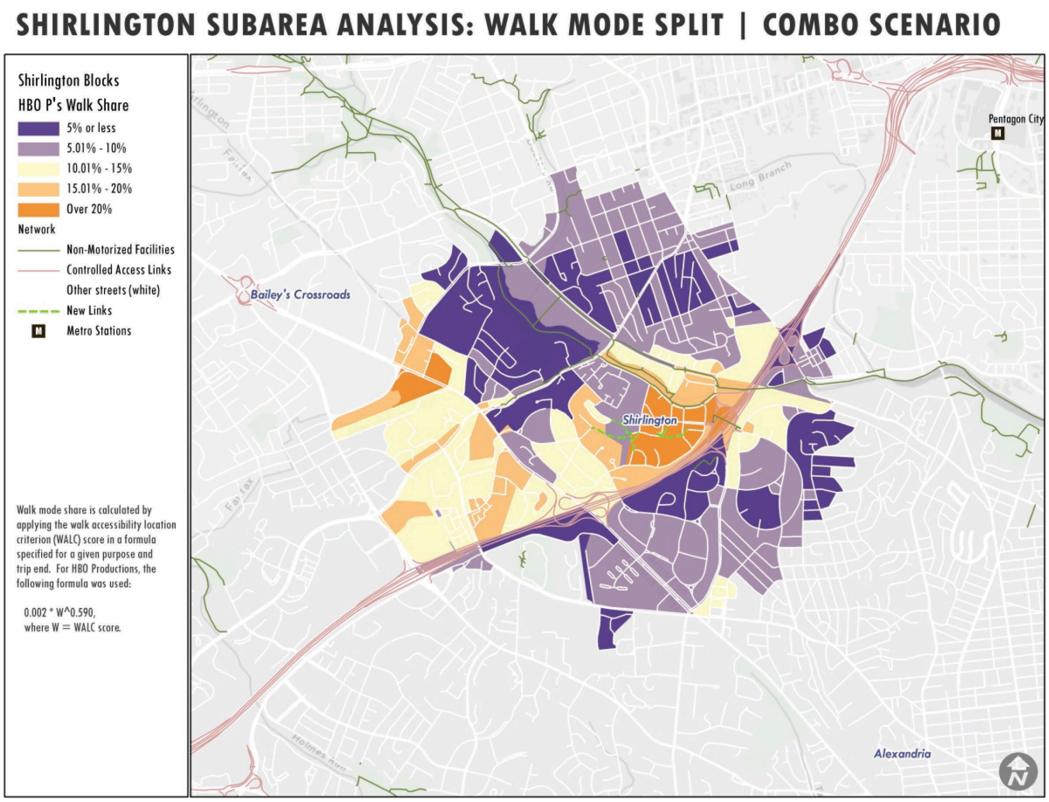


Figure 5-14. Example study area outputs mapped to census blocks: walk mode split.

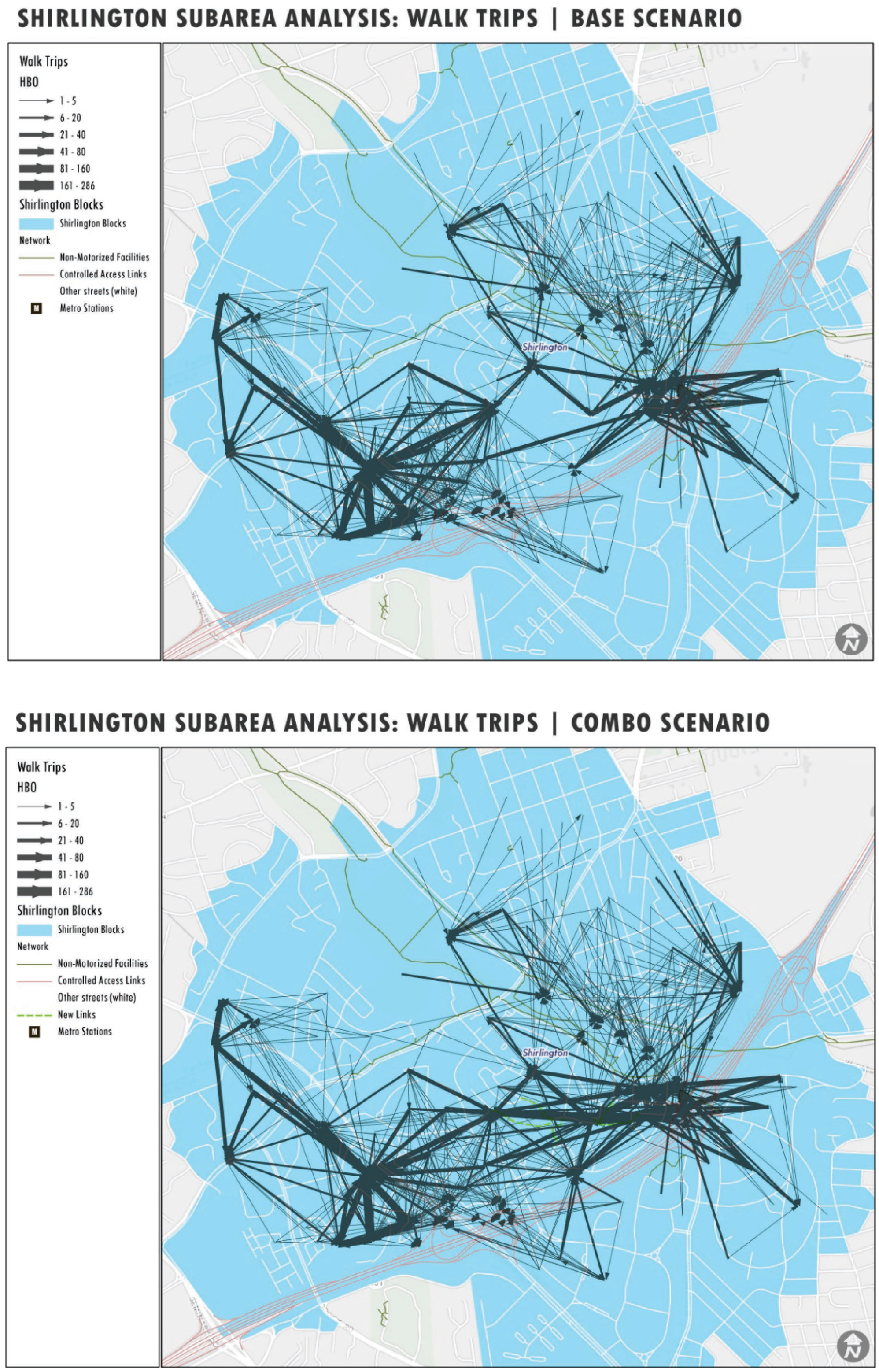
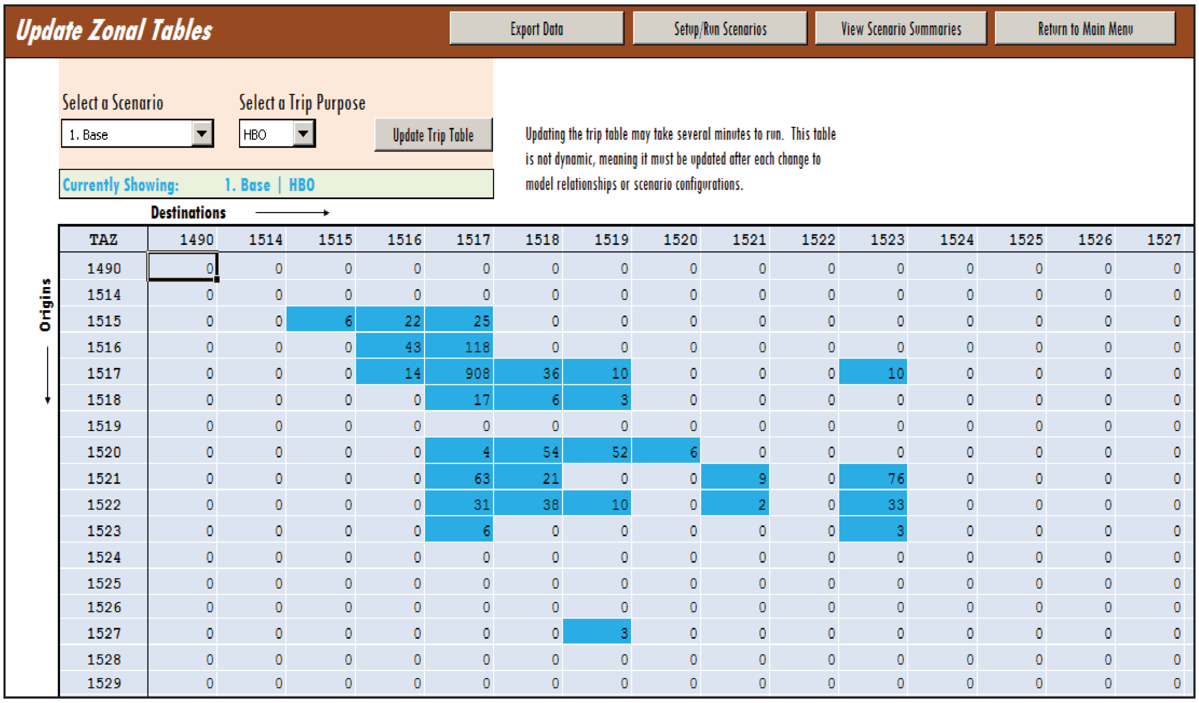
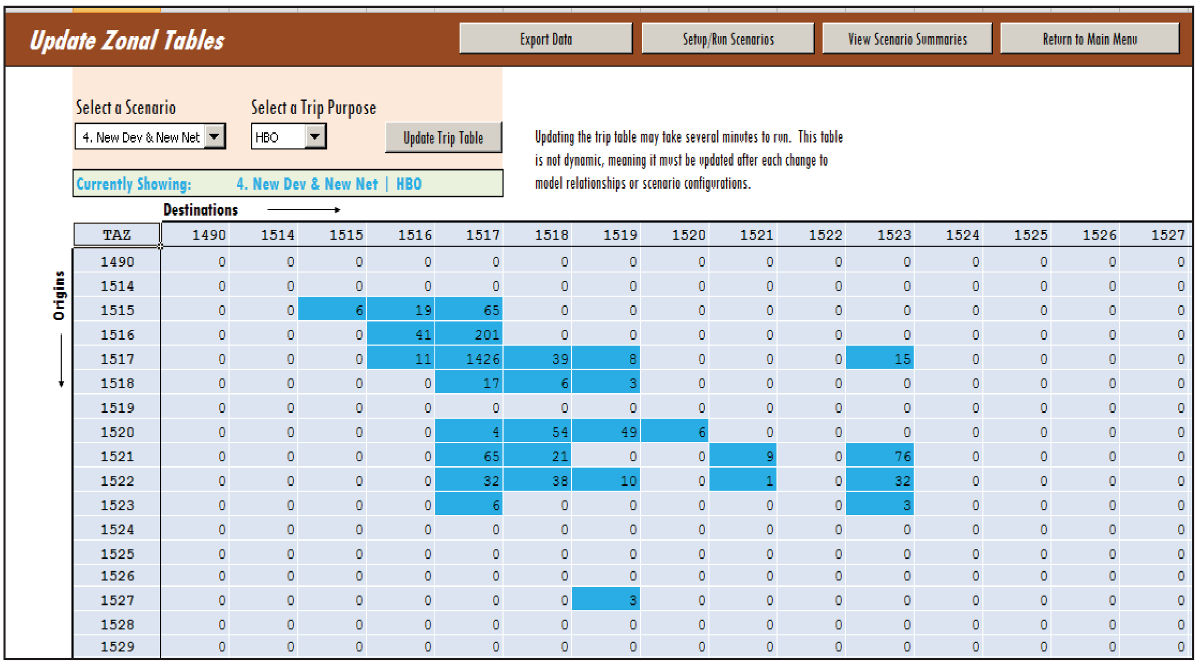


Figure 5-15. Example study area outputs mapped to O-D pairs: distributed walk trips.



TAZ	1490	1514	1515	1516	1517	1518	1519	1520	1521	1522	1523	1524	1525	1526	1527
1490	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1514	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1515	0	0	6	22	25	0	0	0	0	0	0	0	0	0	0
1516	0	0	0	43	118	0	0	0	0	0	0	0	0	0	0
1517	0	0	0	14	908	36	10	0	0	0	10	0	0	0	0
1518	0	0	0	0	17	6	3	0	0	0	0	0	0	0	0
1519	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1520	0	0	0	0	4	54	52	6	0	0	0	0	0	0	0
1521	0	0	0	0	63	21	0	0	9	0	76	0	0	0	0
1522	0	0	0	0	31	38	10	0	2	0	33	0	0	0	0
1523	0	0	0	0	6	0	0	0	0	0	3	0	0	0	0
1524	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1525	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1526	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1527	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
1528	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1529	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



TAZ	1490	1514	1515	1516	1517	1518	1519	1520	1521	1522	1523	1524	1525	1526	1527
1490	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1514	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1515	0	0	6	19	65	0	0	0	0	0	0	0	0	0	0
1516	0	0	0	41	201	0	0	0	0	0	0	0	0	0	0
1517	0	0	0	11	1426	39	8	0	0	0	15	0	0	0	0
1518	0	0	0	0	17	6	3	0	0	0	0	0	0	0	0
1519	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1520	0	0	0	0	4	54	49	6	0	0	0	0	0	0	0
1521	0	0	0	0	65	21	0	0	9	0	76	0	0	0	0
1522	0	0	0	0	32	38	10	0	1	0	32	0	0	0	0
1523	0	0	0	0	6	0	0	0	0	0	3	0	0	0	0
1524	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1525	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1526	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1527	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
1528	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1529	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 5-16. Example study area outputs: TAZ trip tables.

Guidelines for Use: Trip-Based Model Enhancements

This approach was designed to

- Provide users of conventional trip-based models with ways of improving the sensitivity of their models to land use and non-motorized travel through selective enhancements
- Take advantage of research on the 4Ds methods to relate land use effects to trip-based TAZ models
- Take advantage of smaller TAZ sizes as trip-based models have been updated to reflect census block group geographic scale and detail
- Take non-motorized travel beyond trip generation into mode split and distribution by performing a pre-mode split separation into intra- and interzonal destination choice
- Assist the following types of user:
  - Those with conventional trip-based models being asked to increase sensitivity to land use and non-motorized travel, but not considering a shift to an AB model
  - Those needing to analyze policies such as smart growth or transit investment and requiring more detail/resolution on land use and non-motorized travel for regional planning, scenario planning, or visioning exercises

Scale of analysis

- It is expected that these enhancements would be made overall to the regional model, given that they involve adjustments in auto ownership, trip generation, distribution, and mode split.
- Modified tools can be used for regional, corridor, or subarea types of analyses.

Data, tools, and expertise needed

- Familiarity with trip-based models and knowledge of their construction, sensitivities and application
- GIS data and skills to develop measures and relationships
- Sufficient statistical analysis skills to replicate the models in the examples or attempt to recalibrate them to local conditions

Suggestions for Adaptation and Use:

Table A-2 of Appendix A contains detailed information on each of the equations, their coefficients and statistical validity, and (for most) elasticities. The relationships addressed include the following:

- Vehicle ownership (model and elasticities)
- NMT generation (model and elasticities)
- Intrazonal versus interzonal trip-making (model and elasticities)
- Intrazonal mode choice for HBW (model and elasticities)
- Intrazonal mode choice for HBO (model and elasticities)
- Intrazonal mode choice for NHB (model and elasticities)
- Interzonal mode choice for HBW (model and elasticities)
- Interzonal mode choice for HBO (model and elasticities)
- Interzonal mode choice for NHB (model and elasticities)
- Destination choice for HBW (models only)
- Destination choice for HBO (models only)
- Destination choice for NHB (models only)

The reader should see the appendixes to the guidebook to view and assess any or all of the models or examine their sensitivities as represented in the elasticities. The reader also can refer to Appendix 3 of the Contractor's Final Report which contains the model report which describes all of the model development and data issues in full detail.

In terms of applying the findings and products of the Seattle model enhancements, the following options are recommended:

- Adoption versus Emulation: The models shown are believed to be sufficiently unique to the Seattle region and the way in which some of the measures were developed (highly detailed parcel-level GIS network buffering) that direct application is not recommended. Instead, it is suggested that the user attempt to recreate the models with their own data. In the process, an effort should be made to make zone size (or area) into a controlled variable.
- Pivot Analyses: The user may wish to examine the elasticities to gain a sense of the relative importance of the many implied relationships. Caution should be applied to the wholesale use of any elasticity presented without consideration of its relationship to other models in the chain of relationships extending from Auto Ownership to Destination Choice because of possible interdependencies with those other models. To err on the side of caution, the elasticities from the Seattle enhancements work should be seen as indicators rather than robust relationships that can be directly transferred to another location without adequate proofing and sensitivity analyses. Hence, the emulation approach is the most strongly recommended of these approaches to use the Seattle model enhancements results.

Guidelines for Use: Portland Pedestrian Model

This approach was designed to

- Enhance the pedestrian sensitivity in a trip-based model; pedestrian trips are estimated, then existing trip tables are adjusted and the remaining steps in the four-step process completed.
- Assess the effects of land uses or transportation system components that are attractors of pedestrian travel (e.g., mixed-used developments or transit stations).

- Provide a relatively quick way of estimating the potential for pedestrian travel without requiring information or assistance from a regional model.
- Create and test the value of an index (PIE) capable of representing the effects of the pedestrian scale built environment on walking propensity.

Scale of analysis

- Most suitable application is at a neighborhood or subarea level (units are PAZs, roughly equivalent to blocks)
- Results can be used to modify regional model predictions of mode split at all levels.

Data, tools, and expertise needed

- Travel survey data
- GIS data and skills to develop built-environment measures
- Sufficient statistical analysis skills to replicate the models in the examples, or attempt to recalibrate them to local conditions

Suggestions for Adaptation and Use

- Adoption versus Emulation: The researchers would not recommend direct use of the Portland Bike Share Model, given that its basic PIE index was developed from fairly site-specific data on built-environment characteristics and then processed and valued through Metro's Context Model. Instead, the researchers would recommend following the steps used to develop the Portland model—as well as how it is used to inform the regional model and adjust pedestrian trips—using local data.
- Pivot Analyses: The model relationships shown in Table A-3 of Appendix A can provide insights into the variables used in the models and their relative importance; however, elasticities have not been developed.

Guidelines for Use: Model of Pedestrian Demand (MoPeD)

This approach was designed to

- Provide estimates of walk activity levels at intersections for safety exposure analysis
- Reflect the role of land use and network coverage in generating and assigning trips

Scale of analysis

- Neighborhood or subarea level
- Analysis is scaled to PAZs, which are about the size of census blocks

Data, tools, and expertise needed

- Parcel and block-level land use data
- GIS data and skills to develop buffered measures of land use
- Familiarity with trip generation, distribution, and assignment routines in four-step models

Suggestions for Adaptation and Use

- The equations developed in this project, presented in Table A-5, address generation and distribution of walk trips.
- The MoPeD project created software to assist in network development, creating PAZs, creating the land use measures, and performing trip generation, distribution and assignment.

It is recommended that users review the background report to gain a better understanding of the nature, strengths, and limitations of the model, to see if it is appropriate to answer their specific questions.

The Maryland PedContext tool, the forerunner of the MoPeD model, offers considerably greater detail, though with potential limitations in acquiring the full model. In this event, it may be preferable to consider accessing and adapting the MoPeD model and enhancing it to begin to provide the additional detail exhibited in the PedContext report.

Guidelines for Use: Maryland PedContext Model

This approach was designed to

- Provide reliable estimates of pedestrian volumes on links and at intersections to support safety analysis
- Incorporate the influence of land use and network accessibility
- Work independently of the regional trip-based model

Scale of analysis

- Neighborhood or subarea
- Block-level geography
- Sidewalk level network detail

Data, tools, and expertise needed

- Familiarity with trip-based models, particularly network preparation, land use allocation, trip generation, distribution, and assignment steps
- GIS data and skills to develop measures and relationships
- Parcel and block-level land use data
- Pedestrian network in GIS format; sidewalk information (observation or aerial photos)
- Counts

Suggestions for Adaptation and Use

- Adaptation/Transfer: The relationships in these models are probably not suitable for direct transfer.
- Replicate/Emulate: The software package can be acquired through the Maryland State Highway Administration. Otherwise, the user can access the report and attempt to replicate the process used to develop PedContext and create their own utility programs to create and manage the models illustrated in Table A-4.
- Pivot: No elasticities are associated with the PedContext work, so there appears to be little opportunity to extract transferrable relationships from the existing models.

Guidelines for Use: Bicycle Route Choice Models

This approach was designed to

- Quantify the importance of particular attributes of a bicycle network in relation to choice of route—using observed behavioral data obtained through GPS recording.
- Help design better bike systems by knowing the value of particular design attributes.
- Discern differences that may be attributable to rider gender or trip purpose.
- Provide additional input to determinations of bike accessibility and mode choice.

Scale of analysis

- Individual route to entire network
- Regional to project level

Data, tools, and expertise needed

- For application, a detailed GIS rendition of bike-relevant travel network, with information on facility type, gradient, directness, crossings/delay, adjacent traffic, and so forth
- To calibrate to a given site, a GPS survey of riders
- To account for gender or purpose, a corresponding supplement to the GPS survey
- Statistical skills to replicate existing models with local data
- Counts

Suggestions for Adaptation and Use

- Adapt/Transfer: The Seattle TB model made direct use of the SFCTA model to develop bike skims weighted by physical attribute and separately for gender and work/nonwork. Transfer should be possible with sensitivity testing against local data.
- Replicate/Emulate: Given that the models (SFCTA and Portland) are available and probably transferable, it may not be necessary to go through a comprehensive replication, which would require a potentially demanding GPS survey. Much depends on how different the new area is and how important it is to establish site-specific parameters.
- Pivot: It is reasonable to use the relationships in Tables 5-16 and 5-17 to condition design criteria for bicycle networks and to provide weights for calculating impedances in networks.

Guidelines for Use: Facility-Use Direct Demand Models

This approach was designed to

- Answer questions about facility use or needs that could not be addressed with traditional trip-based regional models because of limitations related to scale and ad hoc treatment of non-motorized modes.
- Address the need for estimates of walk activity on links and at intersections for safety analysis and design.
- Address the need for estimates of bicycle activity to support questions on bike network design and to support decisions on facility needs.
- Provide a better connection between the context of the given built environment and non-motorized travel behavior and demand.

Scale of analysis

- Subarea or corridor; potentially an individual site or project facility
- Number of trips at particular locations, generally for specific day of week/time of day period

Data, tools, and expertise needed

- High-level GIS data on land use and transportation networks
- GIS data and skills to develop measures
- Sufficient statistical analysis skills to create new models or replicate the models in examples

Suggestions for Adaptation and Use

Given the many tools that fall into this category, there is no one "best practice" example. However, the Santa Monica

Table 5-16. SFCTA Model—marginal rates of substitution.

MRS of Length on street for	Value	Units
Turns	0.17	km/turn
Length wrong way	4.02	None
Length on bike paths	0.57	None
Length on bike lanes	0.49	None
Length on bike routes	0.92	None
Total rise	0.59	km/10 m

Table 5-17. Portland bike route choice model—relative attribute values.

Attribute	Distance value (% dist)	
	Non-commute	Commute
Turns (/mi)	7.4	4.2
Prop. upslope 2-4 %	72.3	37.1
Prop. upslope 4-6 %	290.4	120.3
Prop. upslope >= 6 %	1106.6	323.9
Traffic signal exc. right turns (/mi)	3.6	2.1
Stop sign (/mi)	0.9	0.5
Left turn, unsig., AADT 10-20k (/mi)	16.2	9.1
Left turn, unsig., AADT 20k+ (/mi)	43.1	23.1
Unsig. cross AADT >= 10k right turn (/mi)	6.7	3.8
Unsig. cross AADT 5-10k exc. right turn (/mi)	7.2	4.1
Unsig. cross AADT 10-20k exc. right turn (/mi)	10.4	5.9
Unsig. cross AADT 20k+ exc. right turn (/mi)	61.7	32.2
Prop. bike boulevard	-17.9	-10.8
Prop. bike path	-26.0	-16.0
Prop. AADT 10-20k w/o bike lane	22.3	36.8
Prop. AADT 20-30k w/o bike lane	137.3	140.0
Prop. AADT 30k+ w/o bike lane	619.4	715.7
Bridge w/ bike lane	-29.3	-18.2
Bridge w/ sep. bike facility	-44.9	-29.2

model reviewed in Chapter 4 and included in the list of models in the toolkit as representative of this class of tools, is a good example. Table A-8 contains a summary of its equations (walk and bike models).

Adaptation/Transfer: In general, these models should almost always be developed from scratch for the given site. Because they are linked to local context and activity levels (counts), they do not transfer well from area to area. For this reason, the researchers recommend use of direct demand models only under all four of the following circumstances:

- They are well calibrated to existing conditions within the specific area and on the specific facilities under study,
- They contain variables and variable sensitivities relevant to the decisions for which they will be used (e.g., terrain if an action under consideration is to reroute bike lane classification to streets that involve hills),
- They are not transferred from one region or study area to another, and
- They are subjected to double-ended validation, replicating not only pedestrian or bicycle counts but demographics and choice characteristics from regional traveler surveys.

Replication/Emulation: The user is advised to review any of the documented models in the main report and in particular the subset cited in Chapter 4. The objective should be to find a model approach that seems to be most suited to the local setting, data, and problem being addressed. Criteria would include interest in walk or bike travel; travel market/time of day being addressed; special provision for large or unique generators, such as universities, transit stations/lines, business or commercial districts; and the degree of detail in the available land use, demographic, and network data to support creation of the variables of interest. Any direct demand type model will require high-quality volume count information; this information may need to be supplemented with user surveys if it is desired to account for sociodemographic traits, trip purpose, or origin-destination bearing.

Pivot: As with the limitations for direct transfer, it is unlikely that relationships captured in existing models can be used as elasticities or adjustment factors in other locations; however, one might borrow such relationships from the choice-based or route choice models in the toolkit to help design or sensitize a new model.

A potential function for these models that may grow in importance is in collaboration with choice-based models, such as described at the end of Section 5.3. Corresponding estimates from the two types of models can be used to cross-check and validate each other in a double-ended validation. This process can also be used to identify potential enhancements to either tool that could lead to improved predictive power and accuracy.

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Technical Appendix: Model Summaries

Appendix A: Seattle Tour-Generation and Mode-Choice Models
Appendix B: Enhanced Four-Step Process
Appendix C: Portland Pedestrian Model Enhancement
Appendix D: Baltimore PedContext Model
Appendix E: Baltimore MoPeD Model
Appendix F: Portland Bicycle Route Choice Model
Appendix G: Direct Demand Models

APPENDIX A

Seattle Tour-Generation and Mode-Choice Models[7]

Table A-1. Tour-generation/complexity model estimation results.

		Home-based		Work-based	
	Observations		44066		7686
	Final log (L)		-65530.8		-3177.3
	Rho-squared (0)		0.451		0.847
	Rho-squared (const)		0.236		0.018
	No (more) tours	**Coeff**	**T-stat**	**Coeff**	**T-stat**
N-LowInc	low income household	0.449	7.3	0.2250	0.6
N-HighInc	high income household	-0.0743	-2.6	-0.2394	-3.2
N-Male	Male	0.0834	3.4		
N-AgeUn30	age under 30	0.42	7.8	0.3345	1.9
N-AgeOv50	age over 50	0.0414	1.2		
N-NoCars	no-car household	0.552	6.1	0.504	1.2
N-CarComp	car competition household	0.138	3.8		
N-MixUse4	Buffer 1 mix use entropy measure	0.0803	1.2	-0.757	-3.5
N-IntDens	buffer1 net intersection density			-.00367	-1.4
N-AvgRise	Buffer 2 fraction average rise	6.18	2.8		
N-BikePa1	Buffer2 Class 1 bike path fraction	-0.349	-1.6	-1.821	-2.0
N-BikePa2	Buffer2 Class 2 bike lane fraction			-1.387	-2.5
N-DisTrans	origin distance to transit stop	0.0669	3.9		
N2-SecondT	constant - second tour	2.56	96.0	0.027	0.2
N3-ThirdT	constant - third tour	3.39	83.5	0.027	0.1
N4-FourthT	constant - fourth tour	3.78	54.1	5.0	Const
	Complex (multi-stop) tour	**Coeff**	**T-stat**	**Coeff**	**T-stat**
C-CompLogs	origin composite logsum	0.0347	2.9		
C-MixUse4	origin mix use entropy measure	-0.201	-3.6	.182	0.4
C-FTW	full time worker	-0.349	-6.9		
C-PTW	part time worker	-0.251	-4.4	-0.965	-1.9
C-RETI	Retired	0.229	3.9		
C-STUD	Student	-0.425	-7.2		

(continued on next page)

[7]Bradley, Mark and John Bowman. "Tests of variables explaining propensity for walk and bike trips in the Puget Sound region." Technical Memo for NCHRP Project 8-78 (September 2013).

Table A-1. (Continued).

			Home-based		Work-based
	Work tour	**Coeff**	**T-stat**	**Coeff**	**T-stat**
W-Const	Constant	-2.66	-21.5	-4.91	-20.8
W-Buffer2	Buffer2 total employment	0.0724	6.6		
WC-Complex	Complex tour interaction constant	0.0687	0.5	-0.994	-2.5
W-FTW	Full time worker	3.02	30.4		
W-PTW	Part time worker	3.03	28.1		
W-RET	retired	-0.798	-5.3		
W-DAS	High school/Univ.student	1.75	12.2		
W-CHI	Child age 5-15	-4.13	-5.8		
W-KidsInH	Kids in the household	0.231	6		
	School tour	**Coeff**	**T-stat**	**Coeff**	**T-stat**
S-Const	Constant	-3.58	-17.2	-20.0	Const
S-Buffer2	Buffer2 relevant school enrolment	0.0559	5.2		
SC-Complex	Complex tour interaction constant	-0.66	-4.8		
S-FTW	Full time worker	-0.426	-1.7		
S-PTW	Part time worker	1.4	5.6		
S-RET	Retired	-1.23	-3.3		
S-DAS	High school/Univ.student	4.93	23.2		
S-CHI	Child age 5-15	4.29	19.6		
S-KidsInH	Kids in the household	0.347	3.9		
	Escort tour	**Coeff**	**T-stat**	**Coeff**	**T-stat**
E-Const	Constant	-2.46	-13.5	-7.17	-19.9
E-Buffer2	Buffer2 households + grade school Students (if HH has school age kids)	0.0804	4.5		
E-AggLogs	Escort tour aggregate logsum	0.103	6.1		
EC-Complex	Complex tour interaction constant	-0.066	-0.5	-0.595	-1.0
E-FTW	Full time worker	-1.48	-22.9		
E-PTW	Part time worker	0.16	2.1		
E-RET	Retired	-0.739	-8.6		
E-DAS	High school/Univ.student	-0.47	-4.1		
E-CHI	Child age 5-15	-1.28	-13.5		
E-KidsInH	Kids in the household	2.01	37.9		
	Personal business tour	**Coeff**	**T-stat**	**Coeff**	**T-stat**
P-Const	Constant	-0.715	-3.1	-5.57	-22.1
P-Buffer2	Buffer2 service + medical employ.	0.0687	4.5		
P-AggLogs	Pers. bus. tour aggregate logsum	0.0151	0.7		
PC-Complex	Complex tour interaction constant	-0.798	-6.0	-1.649	-3.5
P-FTW	Full time worker	-1.08	-16.0		
P-PTW	Part time worker	0.0792	0.9		
P-RET	Retired	-0.252	-3.4		
P-DAS	High school/Univ.student	-0.129	-1.1		
P-CHI	Child age 5-15	-1.32	-11.9		
P-KidsInH	Kids in the household	0.36	6.0		

Table A-1. (Continued).

			Home-based		Work-based
	Shopping tour	**Coeff**	**T-stat**	**Coeff**	**T-stat**
H-Const	Constant	-1.35	-5.2	-9.67	-4.6
H-Buffer2	Buffer2 retail employment	0.12	8.5		
H-AggLogs	Shop tour aggregate logsum	0.0542	2.0	0.3735	1.9
HC-Complex	Complex tour interaction constant	-0.458	-3.4	-1.241	-2.7
H-FTW	Full time worker	-1.11	-16.0		
H-PTW	Part time worker	0.0749	0.9		
H-RET	Retired	-0.486	-6.1		
H-DAS	High school/Univ.student	-0.354	-2.7		
H-CHI	Child age 5-15	-1.74	-12.5		
H-KidsInH	Kids in the household	0.336	5.5		
	Meal tour	**Coeff**	**T-stat**	**Coeff**	**T-stat**
M-Const	Constant	-2.31	-14.0	-5.31	-12.4
M-Buffer2	Buffer2 food service employment	0.0491	2.0		
M-AggLogs	Meal tour aggregate logsum	0.144	5.3	0.141	3.0
MC-Complex	Complex tour interaction constant	-0.809	-5.7	-2.58	-6.1
M-FTW	Full time worker	-0.635	-6.9		
M-PTW	Part time worker	-0.0344	-0.3	-1.081	-3.3
M-RET	Retired	-0.24	-2.3		
M-DAS	High school/Univ.student	-0.223	-1.2		
M-CHI	Child age 5-15	-0.939	-6.1		
M-KidsInH	Kids in the household	0.0936	1.1		
	Recreation tour	**Coeff**	**T-stat**	**Coeff**	**T-stat**
R-Const	Constant	-2.84	-11.8	-10.25	-4.3
R-Buffer2	Buffer2 households + service empl.	0.183	5.4		
R-AggLogs	Recreation tour aggregate logsum	0.0669	2.3	0.319	1.5
RC-Complex	Complex tour interaction constant	-1.04	-7.3	-2.955	-2.7
R-FTW	Full time worker	-0.998	-11.1		
R-PTW	Part time worker	0.154	1.4	-2.0	const
R-RET	Retired	-0.373	-3.7		
R-DAS	High school/Univ.student	0.247	1.7		
R-CHI	Child age 5-15	-0.684	-4.8		
R-KidsInH	Kids in the household	0.247	3.1		

Table A-2. Seattle tour-based mode-choice model estimation results, using only tour origin information.

Model	Home-based Work		Home-based School		Home-based Recreation		Home-based Other		Work-based	
Observations	4509		1344		1531		2571		478	
Final log (L)	-2275.7		-754.8		-745.4		-946.7		-270.6	
Rho-squared (0)	0.636		0.595		0.649		0.734		0.592	
Rho-squared (const)	0.201		0.163		0.147		0.276		0.3	
Walk mode	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**
wk-const	-7.31	-5.8	-3.82	-12.1	-2.92	-2.6	-3.03	-7.8	-3.49	-2.9
wk-incu25			1.14	1.8			-0.647	-2		
wk-inc0100	-0.546	-2.3	-0.42	-2			-0.256	-1.4		
wk-male	0.337	1.8	0.32	1.6						
wk-ageu35					-0.412	-2.3	-0.26	-1.2		
wk-age050							-0.486	-3.1		
wk-buffer1	0.403	4.5	0.423	7.4	0.262	3	0.36	5.4		
wk-nclogsm	0.245	1.7			0.0922	0.9			0.699	6.3
wk-wktowrk										
wk-complex	-1.45	-6.7	-2.21	-6.4	-1.33	-5.5	-1.3	-7	-1.61	-4
wk-omixu41					0.454	1			0.791	1.2
wk-ohhddn1							0.00026	2.6		
wk-ointdn1	0.0043	0.7					0.0101	1.9		
wk-onosid1	-1.04	-2			-0.769	-2.4	-1.12	-2.9	-1.6	-2.1
wk-oavris1					-29.2	-1.6	-35.5	-1.7		
Bike mode	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**
bi-const	-3.61	-6.8	-7.69	-3.5	-4.84	-8.3	-6	-4.9	-3.49	-4.5
bi-male	0.676	3.5	0.711	1.8	1.96	3.6	0.72	1.4		
bi-ageu35	-1.38	-2.9								
bi-age050	-0.833	-3.8			-0.991	-1.8	-0.338	-0.7		
bi-buffer2			0.22	1.5						
bi-nclogsm			0.289	1.3						
bi-bitowrk									2	(*)
bi-complex	-1.08	-5.5	-2.18	-2.9	-0.628	-1.1	-1.59	-2.1	-2	(*)
bi-omixu42										
bi-ohhddn2										
bi-ointdn2	0.0087	9					0.0127	4.4		
bi-opathf2	2.4	1.4	3.15	1						
bi-oavris2	**-62.6**	**-1.9**	**-31.4**	**-0.5**			**-92.5**	**-0.9**		

Table A-2. (Continued).

Model	Home-based Work		Home-based School		Home-based Recreation		Home-based Other		Work-based	
Transit mode	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**
wt-const	-3.78	-8.2	-2.94	-5.9	-5.78	-4.5	-8.5	-9	-0.986	-0.6
wt-owdist	-0.164	-1								
wt-nclogsm							0.355	3.9		
wt-incu25	0.379	1.3	2.38	4.8			0.813	2.2		
wt-inc0100							-1.81	-2.5		
wt-male										
wt-ageu35					1.25	1.4				
wt-age050					2.17	2.8				
wt-trtowrk									0.574	0.8
wt-complex	-0.781	-7.4	-0.314	-1.3	0.693	1.5	-0.361	-1.3	-0.677	-0.8
wt-omixu41	0.716	2.6					1.36	1.8		
wt-ohhddn1										
wt-ointdn1	0.00007	1.2			0.00048	2.2	0.00014	1		
wt-onosid1			-1.38	-2.8	-2.96	-2.4			-3.89	-1.9
wt-ostops1	0.737	7	0.291	2	0.121	0.3	0.296	1.3	0.312	1
Used transit to get to work									**0.487**	**0.7**
Auto mode	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**
ca-fclogsm	0.154	1.4			0.0944	0.7				
ca-nocars	-4.69	-9	-5	(*)	-3.09	-4.6	-3.6	-10.2		
ca-carsltd	-1.21	-12.4	-1.16	-7.1	-0.799	-4.7	-0.417	-2.6		
ca-catowrk									**1.67**	**4.7**

Table A-3. Seattle tour-based mode-choice model estimation results, using origin and destination information.

Model	Home-based Work		Home-based School		Home-based Recreation		Home-based Shop/ PB		Work-based	
Observations	4483		1327		1516		2568		476	
Final log (L)	-4652.4		-1411.1		-1398.8		-2312.9		-372.6	
Rho-squared (0)	0.415		0.403		0.476		0.496		0.563	
Rho-squared (const)	0.156		0.078		0.075		0.152		0.268	
Walk mode	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**
Constant	1.07	2.1	0.91	2.3	2.96	7	1.81	3.8	3.34	4.5
Income under $25K	0.863	1.6	0.36	0.4	0.0615	0.1	-0.702	-1.7		
Income above $100K	-0.412	-1.4	-0.669	-2.8	-0.498	-2.1	-0.121	-0.5		
Male	0.543	2.3	0.578	2.6	0.0356	0.2	0.119	0.6		
Network distance	-0.942	-9.8	-1.45	-9.7	-1.6	-13.4	-1.87	-14.2	-1.88	-7.7
Dest. Buffer 1 total employment	3.80E-05	3.8								
Orig+Dest. Buffer 1 avg. net intersection density							0.005	2	0.0111	3.6
Orig+Dest Buffer 1 avg. fraction rise	-61.3	-3.6	-9.85	-0.7	-15.6	-1				
Origin Buffer 1 avg. fraction rise							-36.2	-1.4		
Origin buffer 1% no sidewalk	-0.84	-1.7			-1.07	-2.7	-1.44	-3		
Walked to work									10	Const?
Complex multi-stop tour	-1.24	-5.9	-2.55	-7.8	-2.14	-9.7	-1.51	-9.9	-2.71	-9.1
Bike mode	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**
Constant	-2.92	-3.9	-4.12	-6.7	-4.53	-7.5	-3.74	-6.4	-8.82	-5
Male	0.859	4.4	1.71	3	2.05	3.6	0.842	1.6		
Age under 35	-1.45	-3			-0.36	-0.8	-0.285	-0.3		
Age over 50	-0.863	-3.9			-1.26	-2.1	-0.518	-0.9		
Route choice generalized distance	-0.113	-9.4	-0.277	-3.7	-0.0874	-2.8	-0.276	-3.6	-0.331	-0.7
Dest. Buffer 2 employment density	3.70E-07	0.1								
Orig/dest Buffer 2 avg fraction Class 1	4.97	3.7	3.01	2.8						

path										
Origin Buffer 2 intersection density	0.0061	4.8								
Origin Buffer 2 avg. fraction rise	-77.8	-2.2								
Biked to work									10	Const
Complex multi-stop tour	-0.782	-4.2	-2.25	-3	-1.61	-2.9	-1.95	-2.6	-2	Const
Transit mode	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**
Constant	-4.74	-13.2	-1.6	-1.6	-3.15	-2.1	-5.61	-6.8	-8.05	-3.1
Income under $25K	0.961	2.6	3.02	4.6			0.468	1		
Income over $100K	-0.447	-3.4	-0.0075	0	-1.15	-1.5	-1.57	-2.1		
Male	0.186	1.6	0.0012	0	-0.325	-0.6	-0.215	-0.6	1.16	1.4
Age under 35	0.398	2			-0.0084	0	-0.458	-0.7	2.25	1.7
In-vehicle time (min)	-0.01	Const	-0.01	Const	-0.01	Const	-0.01	Const	-0.01	Const
Wait time (min)	-0.02	Const	-0.02	Const	-0.02	Const	-0.02	Const	-0.02	Const
Fare ($)	-0.2	Const	-0.2	Const	-0.2	Const	-0.2	Const	-0.2	Const
Origin Buffer 1 transit stops	0.539	5.3	-0.334	-1.6	-0.608	-1.6	0.214	1	0	Const
Destination Buffer 1 transit stops	0.179	1.9	0.268	1.4	0.825	2.7	0.606	2.9	1.73	3
Destination Buffer 1 total employment	2.70E-05	4.9								
Origin Buffer 1 intersection density	1.50E-04	2.2								
Origin buffer 1 pct. no sidewalk			-0.715	-1.1	-4.26	-2.6				
Dest. buffer 1 pct. no sidewalk			-0.872	-1.2						
Used transit to work									0.224	0.3
Complex multi-stop tour	-0.501	-5.6	-0.785	-3.3	5.00E-15	0	-0.647	-2.5	-1.5	-1.9
Auto mode	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**	**Coeff.**	**T-stat**
No cars in the HH	-4.7	-8.7	-5	Const	-3.32	-4.2	-4.32	-10.5	-10	Const
Fewer cars than adults in the HH	-1.4	-12.5	-1.27	-6.9	-0.976	-4.3	-0.633	-3.3		
In-vehicle time (min)	-0.02	Const	-0.02	Const	-0.02	Const	-0.02	Const	-0.02	Const
Destination parking cost ($)	-0.06	Const	-0.06	Const	-0.06	Const	-0.06	Const	-0.06	Const
Used car to get to work									2.3	3.7

APPENDIX B

Enhanced Four-Step Process[8]

Vehicle Ownership

Table B-1A. Household vehicle ownership model results (Poisson).

Variable	Coefficient	t-stat
Household Size	0.179	6.13
Household Number of Workers	0.0382	2.59
Household Number of Licensed Drivers	0.156	4.14
Household Income	1.89E-6	7.02
Rural Home-location Indicator	0.0808	2.44
NMT Accessibility Index of Home TAZ	-0.403	-1.76
Distance to Closest Bus Stop	0.0146	1.51
# of 4-way Intersections – 1/2 mile buffer	-0.000716	-1.61
# of Bus Stops	-0.00697	-3.44
License per Household Member	0.747	6.17
Home TAZ Density	-5.80E-7	-1.30
Constant	-0.488	-2.12
Number of Observations	4,741	
Final Log-likelihood	-6473.0	
McFadden's Pseudo R-square	0.0947	

Table B-1B. Household vehicle ownership model elasticity results.

Variable	Elasticity
Household Size	0.396
Household Number of Workers	0.043
Household Number of Licensed Drivers	0.264
Household Income	0.135
Rural Home Indicator*	0.013
NMT Accessibility Index of Home TAZ	-0.355
Distance to Closest Bus Stop	0.008
# of 4-way Intersections	-0.025
# of Bus Stops	-0.049
Home TAZ Density	-0.008

*Note: The elasticity effect of this indicator variable is computed for a change in the variable from 0 to 1. All other variables are held at sample-mean values.

[8] Kahn, M and K. Kockelman. "Models For Anticipating Non-Motorized Travel Choices, And The Role Of The Built Environment." Annual Meeting of the International Association for Travel Behavior Research, Toronto, Canada.(July 2012).

Table B-2A. Non-motorized trip generation model results (ZINB).

Variable	Coefficient	t-stat
Negative Binomial Model		
Household Size	0.152	3.60
Household Number of Workers	0.132	2.78
Household Number of Vehicles	-0.0978	-2.27
Licenses per Member	-0.276	-1.72
Household Income	1.77E-6	2.75
# of Free Off-street Parking Spaces	-0.000176	-1.48
Hourly Parking Price	0.0484	1.66
# of 4-way Intersections	0.00252	2.32
Home TAZ SOV Accessibility Index	-1.68	-2.84
Home TAZ NMT Accessibility Index	3.44	2.26
Constant	-1.26	-1.23
Alpha	0.612	
Binary Logit Inflation Model		
Household Size	-0.334	-4.54
Household Number of Workers	-0.112	-1.55
Household Number of Vehicles	0.26	3.88
Licenses per Member	0.628	2.10
Hourly Parking Price	0.26	2.80
# of 3-way Intersections	-0.00607	-2.40
# of 4-way Intersections	-0.0117	-5.47
Home TAZ Density	-8.29E-6	-1.68
Home TAZ SOV Accessibility Index	4.57	5.00
Home TAZ NMT Accessibility Index	-7.37	-3.26
# of Bus Stops	-0.0324	-3.46
Constant	4.06	2.61
Number of Observations	4,185	
Number of Zero Observations	3,070	
Final Log-likelihood	-4,225	
McFadden's Adj. R-square	0.079	

Table B-2B. Non-motorized trip generation model elasticities.

Variable	Elasticity
Household Size	0.84
Household Number of Workers	0.24
Household Number of Vehicles	-0.52
Licenses per Member	-0.58
Household Income	0.13
Hourly Parking Price	-0.02
Free Parking Spaces	-0.01
# of 3-way Intersections	-0.01
# of 4-way Intersections	0.36
Home TAZ Density	0.00
Home TAZ Accessibility Index (SOV)	-4.06
Home TAZ Accessibility Index (NMT)	7.31
# of Bus Stops	0.15

Table B-3A. Intrazonal trip-making model results (BL).

Variable	Coefficient	t-stat
Alternative Specific Constant	1.57	3.36
Household Number of Vehicles	-0.0839	-3.85
Household Income	8.71E-7	2.09
Licensed Indicator	-0.366	-7.34
Male Indicator	-0.177	-4.19
Land use mix	2.62	25.38
SOV Accessibility Index	-2.95	-9.73
NMT Accessibility Index	-3.39	-5.06
Distance to Bus Stop	0.0778	3.76
# of Bus Stops - 1/4 mile	0.00596	2.40
# of Dead Ends - 1/2 mile	0.00618	3.39
# of 3-way Intersections - 1/2 mile	0.00604	4.51
Hourly Parking Price - 1/4 mile	-0.0485	-2.08
Commute trip	-2.18	-14.44
Mid-day trip	0.113	2.32
PM Peak trip	-0.0809	-1.39
Night trip	-0.527	-3.32
Number of Observations	42,651	
Final Log-likelihood	-9,151	
Adjusted Rho-squared	0.690	

Note: Base response is choice of a destination that lies outside the origin zone (i.e., interzonal, rather than intrazonal, trip-making).

Table B-3B. Intrazonal trip-making model elasticities.

Variable	Elasticity
Household Number of Vehicles	-0.17
Household Income	0.07
Licensed Indicator	-0.39
Male Indicator	-0.17
Entropy	1.20
SOV Accessibility Index	-2.49
NMT Accessibility Index	-2.89
Distance to Bus Stop	0.03
# of Bus stops - 1/4 mile	0.06
# of Dead Ends - 1/2 mile	0.14
# of 3-way Intersections - 1/2 mile	0.29
Hourly Parking Price - 1/4 mile	-0.02
Commute trip	-1.22
Mid-day trip	0.11
PM Peak trip	-0.08
Night trip	-0.41

Note: The elasticity effect of an indicator variable is computed for a change in the variable from 0 to 1. The different time-period indicators are relative to AM Peak hour.

Table B-4A. Intrazonal HBW mode-choice model results (MNL).

	Drive-Alone		Walk	
Explanatory Variables	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
Alternative Specific Constant	0	-	-84.7	-1.81
Travel Time	-0.472	-1.81	-0.472	-1.81
Age	-	-	-0.108	-1.41
NMT Accessibility Index	-	-	105	1.89
# of Dead Ends	-	-	-0.215	-1.54
N_{obs} = 49 ǁ Final Log-Likelihood= -6.6 ǁ Pseudo R-square=0.7632				

Table B-4B. Intrazonal HBO mode-choice model results (MNL).

	Drive-alone		Shared-ride		Walk	
Explanatory Variables	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
Alternative Specific Constant	0	-	1.53	3.96	-0.503	-0.20
Travel Time	-0.0475	-3.47	-0.0475	-3.47	-0.0475	-3.47
Cost / (Income/member)	-	-	-1.40E-5	-2.68	-9.40E-6	-1.82
Age	-	-	-0.0206	-2.96	-0.0276	-3.77
Male Indicator	-	-	-0.475	-2.31	-0.335	-1.64
Student Indicator	-	-	-	-	-0.482	-2.05
Employed Indicator	-	-	-0.307	-1.45	-0.678	-3.10
Vehicle per Licensed Driver	-	-	-	-	-0.342	-1.89
NMT Accessibility Index	-	-	-	-	3.37	1.26
Land Use Mix	-	-	-	-	-0.408	-1.29
Density	-	-	-	-	-1.40E-6	-2.26
# of Dead Ends	-	-	-	-	-0.0121	-1.79
# of 3-way Intersections	-	-	-	-	0.00870	1.76
# of 4-way Intersections	-	-	-	-	0.0152	4.57
Hourly Parking Price	-	-	-0.00809	-2.00	-	-
# of Free Off-street Parking Spaces	-	-	0.00100	2.54	-	-
N_{obs} = 1,013 ǁ Final Log-Likelihood= -843.2 ǁ Pseudo R-square=0.1238						

Table B-4C. Intrazonal NHB mode-choice model results (MNL).

	Drive-alone		Shared-ride		Walk	
Variables	**Coef.**	**t-stat**	**Coef.**	**t-stat**	**Coef.**	**t-stat**
Alternative Specific Constant	0.000	-	1.465	5.05	0.161	0.53
Travel time	-0.0241	-2.31	-0.0241	-2.31	-0.0241	-2.31
Cost / (Income per member)	-	-	-0.0000107	-3.94	-	-
Age	-	-	-0.0230	-4.85	-0.0189	-4.06
Male Indicator	-	-	0.258	1.82	0.487	3.37
Student Indicator	-	-	-0.732	-3.19	-	-
Employed Indicator	-	-	-0.931	-7.21	-	-
Vehicle per licensed driver	-	-	-	-	-0.388	-2.79
# of 4-way Intersections	-	-	0.00408	1.67	0.0201	9.03
Hourly Parking Price	-	-	-0.00272	-1.98	-	-
# of Free Off-street Parking Spaces	-	-	0.000385	1.85	-	-
N_{obs} = 1,605 ǁ Final Log-Likelihood= -1408.9 ǁ Pseudo R-square= 0.1436						

Table B-5A. Interzonal HBW mode-choice model results (MNL).

	Drive-alone		Shared-ride		Transit		Walk		Bike	
Variables	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Alternative Specific Constant	0	-	-0.744	-0.46	0.0934	0.31	-14.2	-3.62	-3.51	-7.45
Cost / (Income per Member)	-1.22	-4.30	-1.22	-4.30	-1.22	-4.30	-1.22	-4.30	-1.22	-4.30
Travel Time	-0.0229	-14.53	-0.0229	-14.53	-0.0229	-14.53	-0.0229	-14.53	-0.0229	-14.53
Age	-	-	-	-	-0.0103	-2.39	-	-	-0.0150	-2.13
Male Indicator	-	-	-0.434	-4.61	-	-	0.324	1.62	0.954	4.65
Vehicle per Licensed Driver	-	-	-0.525	-4.38	-1.26	-7.85	-1.41	-5.20	-	-
SOV Access. Index (Orig)	-	-	1.80	1.36	-	-	-	-	-	-
Density (Origin)	-	-	-	-	-2.20E-6	-2.08	-	-	-	-
# Dead Ends (Origin)	-	-	-0.0114	-3.66	-	-	0.0138	1.47	-0.0230	-2.33
# 3-way Intersxns. (Origin)	-	-	-	-	-	-	0.0135	2.31	0.0121	2.23
# 4-way Intersxns. (Origin)	-	-	-	-	-0.00459	-2.57	0.0142	4.50	0.00819	2.79
# Free Off-street Parking (Orig)	-	-	-0.000940	-1.97	-	-	-	-	-	-
# of Bus Stops (Origin)	-	-	-	-	0.0192	2.62	-	-	-	-
NMT Access. Index (Dest)	-	-	-	-	-	-	11.9	2.84	-	-
SOV Access. Index (Dest)	-	-	-2.47	-1.76	-	-	-	-	-	-
Land Use Mix (Destination)	-	-	-	-	0.482	1.98	-0.823	-1.82	-	-
Density (Destination)	-	-	4.93E-07	1.38	-	-	-	-	-3.5E-06	-1.47
# 3-way Intersxns (Dest)	-	-	-0.00426	-1.80	-	-	0.0107	2.01	-	-
# 4-way Intersxns (Dest)	-	-	0.00226	1.78	-	-	0.00376	1.80	0.00314	1.84
Hourly Parking Price (Dest)	-	-	0.00106	4.01	-	-	-	-	-	-
# Bus Stops (Dest)	-	-	-	-	0.028	18.38	-	-	-	-
Number of Observations=6,358 || Final Log-Likelihood= -3566.9 || Pseudo R-square=0.6072										

Table B-5B. Mode-choice model results: interzonal home-based other trips (MNL).

	Drive-alone		Shared-ride		Transit		Walk		Bike	
Variables	**Coef.**	**t-stat**	**Coef.**	**t-stat**	**Coef.**	**t-stat**	**Coef.**	**t-stat**	**Coef.**	**t-stat**
Alternative Specific Constant	0	-	1.34	11.56	-4.85	-1.29	-3.29	-1.99	-4.2	-10.09
Cost / (Income per member)	-1.62	-4.33	-1.62	-4.33	-1.62	-4.33	-1.62	-4.33	-1.62	-4.33
Travel time	-0.0506	-23.51	-0.0506	-23.51	-0.0506	-23.51	-0.0506	-23.51	-0.0506	-23.51
Age	-	-	-0.022	-15.35	-0.00651	-1.78	-0.0102	-4.20	-	-
Male Indicator	-	-	-0.147	-3.75	-0.452	-2.57	-	-	0.985	4.98
Student Indicator	-	-	-0.488	-5.97	-	-	-0.267	-2.09	1.08	4.88
Employed Indicator	-	-	-0.149	-3.60	-0.370	-2.00	-	-	0.579	2.64
Vehicle per licensed driver	-	-	-0.252	-5.43	-2.95	-12.81	-0.665	-6.08	-	-
NMT Access. Index (Orig)	-	-	-	-	12.8	3.37	-	-	-	-
Land Use Mix (Origin)	-	-	0.155	1.93	-	-	-	-	0.800	2.02
# of Dead Ends (Origin)	-	-	-	-	-0.0160	-2.04	-0.0072	-1.95	-	-
# 3-way Intersxns. (Origin)	-	-	-0.00210	-2.52	-	-	-	-	-0.00789	-1.76
# 4-way Intersxns. (Origin)	-	-	-	-	-0.00617	-2.22	0.00845	5.49	0.00503	2.15
# Free Off-street Parking (Orig)	-	-	-0.00065	-3.38	-	-	-	-	-	-
NMT Access. Index (Dest)	-	-	-	-	-	-	3.78	2.10	-	-
SOV Access. Index (Dest)	-	-	-	-	-4.95	-1.88	-	-	-	-
Land Use Mix (Destination)	-	-	-	-	-	-	-	-	-0.576	-1.41
Density (Destination)	-	-	-	-	-	-	-1.70E-06	-2.12	-	-
# Dead Ends (Destination)	-	-	-	-	-	-	0.00765	2.06	-0.0227	-2.69
# 4-way Intersxns. (Dest)	-	-	-	-	-	-	0.00283	2.05	-	-
Hourly Parking Price (Dest)	-	-	0.000443	3.23	-	-	-	-	-	-
# Free Off-street Parking (Dest)	-	-	-6.10E-5	-1.57	-	-	-	-	-	-
# Bus Stops (Dest)	-	-	-	-	0.0253	9.22	-	-	-	-
Number of Observations=15,549 || Final Log-Likelihood= -10501.4 || Pseudo R-square=0.484										

Table B-5C. Mode-choice model results: interzonal non-home-based trips (MNL).

	Drive-alone		Shared-ride		Transit		Walk		Bike	
Variables	**Coef.**	**t-stat**	**Coef.**	**t-stat**	**Coef.**	**t-stat**	**Coef.**	**t-stat**	**Coef.**	**t-stat**
Alternative Specific Constant	0	-	-0.497	-0.84	-0.0321	-0.11	-6.39	-3.59	-3.36	-5.24
Cost / (Income per member)	-0.475	-1.57	-0.475	-1.57	-0.475	-1.57	-0.475	-1.57	-0.475	-1.57
Travel time	-0.0505	-23.18	-0.0505	-23.18	-0.0505	-23.18	-0.0505	-23.18	-0.0505	-23.18
Age	-	-	-0.0165	-11.61	-0.0102	-2.56	-0.0144	-6.12	-0.0102	-1.35
Male Indicator	-	-	-0.057	-1.49	-	-	0.379	4.67	0.644	2.46
Student Indicator	-	-	-0.205	-2.65	-	-	-	-	-	-
Employed Indicator	-	-	-1.00	-24.42	0.242	1.51			0.535	1.73
Vehicle per licensed driver	-	-	-0.256	-5.89	-1.41	-7.25	-1.01	-8.96	-0.458	-1.45
NMT Access. Index (Orig)	-	-	-	-	-	-	6.01	3.11	-	-
SOV Access. Index (Orig)	-	-	0.756	1.36	-	-	-	-	-	-
Density (Origin)	-	-	-	-	-	-	-1.80E-6	-2.78	-	-
# Dead Ends (Origin)	-	-	-	-	-	-	-	-	-0.0342	-2.21
# 3-way Intersxns. (Origin)	-	-	-	-	-	-	0.00428	1.95	-	-
# 4-way Intersxns. (Origin)	-	-	-	-	-	-	0.00738	7.07	-	-
# Free Off-street Parkg (Orig)	-	-	-6.50E-5	-2.18	-	-	-	-	-	-
# Bus Stops (Origin)	-	-	-	-	0.0167	8.98	-	-	-	-
SOV Access. Index (Dest)	-	-	1.06	1.85	-	-	-	-	-	-
Density (Destination)	-	-	-2.80E-7	-1.68	-	-	-	-	-	-
# Dead Ends (Destination)	-	-	-	-	-	-	0.00698	1.76	-0.0531	-3.19
# 3-way Intersxns. (Dest)	-	-	-	-	-	-	-	-	0.0142	2.29
# 4-way Intersxns. (Dest)	-	-	-	-	-	-	0.00949	8.95	-	-
# Free Off-street Parkg (Dest)	-	-	-7.90E-5	-2.62	-	-	-	-	-	-
# Bus Stops (Dest)	-	-	-	-	0.012	5.20	-	-	-	-
Number of Observations=17,244 || Final Log-Likelihood = -11528.7 || Pseudo R-square=0.505										

Table B-6A. Percentage change in probability (mode) associated with one st dev. change in explanatory variables for home-based work trips.

Variables	Pr(DA)	Pr(SR)	Pr(TR)	Pr(WK)	Pr(BK)
Age	1.3%	1.3%	-19.1%	1.3%	-27.0%
Male Indicator	1.4%	-18.4%	1.4%	19.3%	63.4%
Student Indicator	-	-	-	-	-
Employed Indicator	-	-	-	-	-
Vehicle per Licensed Driver	5.8%	-24.2%	-52.4%	-56.7%	5.8%
NMT Accessibility Index (Orig)	-	-	-	-	-
SOV Accessibility Index (Orig)	-1.3%	16.5%	-1.3%	-1.3%	-1.3%
Entropy (Origin)	-	-	-	-	-
Density (Origin)	1.1%	1.1%	-16.5%	1.1%	1.1%
# of Dead ends (Origin)	1.2%	-15.7%	1.2%	26.2%	-29.9%
# of 3-way Intersections (Orig)	0.0%	0.0%	0.0%	40.3%	35.5%
# of 4-way Intersections (Orig)	0.8%	0.8%	-12.6%	56.6%	30.0%
Free Parking Spaces (Origin)	1.4%	-17.5%	1.4%	1.4%	1.4%
# of Bus stops (Origin)	-1.2%	-1.2%	18.2%	-1.2%	-1.2%
NMT Accessibility Index (Dest)	0.0%	0.0%	0.0%	111.6%	0.0%
SOV Accessibility Index (Dest)	1.5%	-19.1%	1.5%	1.5%	1.5%
Entropy (Destination)	-0.7%	-0.7%	10.7%	-17.5%	-0.7%
Variables	Pr(DA)	Pr(SR)	Pr(TR)	Pr(WK)	Pr(BK)
# of Dead Ends (Destination)	-	-	-	-	-
# of 3-way Intersections (Dest)	0.7%	-9.5%	0.7%	31.8%	0.7%
# of 4-way Intersections (Dest)	-0.5%	6.7%	-0.5%	11.8%	9.6%
Hourly Parking Price (Dest)	0.0%	0.1%	0.0%	0.0%	0.0%
Free Parking Spaces (Dest)	-	-	-	-	-
# of Bus stops (Dest)	-1.8%	-1.8%	27.5%	-1.8%	-1.8%

Table B-6B. Percentage change in probability (mode) associated with one st dev. change in explanatory variables for home-based non-work trips.

Variables	Pr(DA)	Pr(SR)	Pr(TR)	Pr(WK)	Pr(BK)
Age	23.3%	-23.7%	7.0%	-1.3%	23.3%
Male Indicator	3.7%	-3.7%	-17.3%	3.7%	69.7%
Student Indicator	9.6%	-9.8%	9.6%	-1.5%	68.8%
Employed Indicator	3.7%	-3.7%	-13.7%	3.7%	38.2%
Vehicle per Licensed Driver	8.2%	-7.8%	-83.3%	-29.0%	8.2%
NMT Accessibility Index (Orig)	-0.4%	-0.4%	123.2%	-0.4%	-0.4%
SOV Accessibility Index (Orig)	-	-	-	-	-
Entropy (Origin)	-1.7%	1.8%	-1.7%	-1.7%	17.7%
Density (Origin)	-	-	-	-	-
# of Dead ends (Origin)	0.1%	0.1%	-22.5%	-10.9%	0.1%
# of 3-way Intersections (Orig)	2.6%	-2.7%	2.6%	2.6%	-15.8%
# of 4-way Intersections (Orig)	0.1%	0.1%	-17.4%	30.0%	16.9%
Free Parking Spaces (Origin)	7.0%	-7.2%	7.0%	7.0%	7.0%
# of Bus stops (Origin)	-	-	-	-	-
NMT Accessibility Index (Dest)	0.0%	0.0%	0.0%	26.9%	0.0%
SOV Accessibility Index (Dest)	0.1%	0.1%	-36.5%	0.1%	0.1%
Entropy (Destination)	0.0%	0.0%	0.0%	0.0%	-12.2%
Density (Destination)	0.0%	0.0%	0.0%	-13.8%	0.0%
# of Dead Ends (Destination)	0.0%	0.0%	0.0%	13.0%	-30.5%
# of 3-way Intersections (Dest)	-	-	-	-	-
# of 4-way Intersections (Dest)	0.0%	0.0%	0.0%	9.2%	0.0%
Hourly Parking Price (Dest)	0.0%	0.0%	0.0%	0.0%	0.0%
Free Parking Spaces (Dest)	0.7%	-0.7%	0.7%	0.7%	0.7%
# of Bus stops (Dest)	-0.1%	-0.1%	26.5%	-0.1%	-0.1%

Table B-6C. Percentage change in probability (mode) associated with one st dev. change in explanatory variables for non-home-based trips.

Variables	Pr(DA)	Pr(SR)	Pr(TR)	Pr(WK)	Pr(BK)
Age	13.7%	**-20.6%**	-8.9%	-16.9%	-8.9%
Male Indicator	1.1%	-1.7%	1.1%	22.2%	**39.5%**
Student Indicator	3.2%	-4.9%	3.2%	3.2%	3.2%
Employed Indicator	18.2%	**-28.0%**	**33.3%**	18.2%	**54.1%**
Vehicle per Licensed Driver	6.7%	-9.3%	**-56.3%**	**-43.7%**	**-20.2%**
NMT Accessibility Index (Orig)	0.0%	0.0%	0.0%	**46.0%**	0.0%
SOV Accessibility Index (Orig)	-2.8%	4.2%	-2.8%	-2.8%	-2.8%
Entropy (Origin)	-	-	-	-	-
Density (Origin)	0.0%	0.0%	0.0%	-14.5%	0.0%
# of Dead ends (Origin)	0.0%	0.0%	0.0%	0.0%	**-42.1%**
# of 3-way Intersections (Orig)	0.0%	0.0%	0.0%	11.3%	0.0%
# of 4-way Intersections (Orig)	0.0%	0.0%	0.0%	**25.7%**	0.0%
Free Parking Spaces (Origin)	0.6%	-0.9%	0.6%	0.6%	0.6%
# of Bus stops (Origin)	-0.1%	-0.1%	16.7%	-0.1%	-0.1%
NMT Accessibility Index (Dest)	-	-	-	-	-
SOV Accessibility Index (Dest)	-3.9%	6.0%	-3.9%	-3.9%	-3.9%
Entropy (Destination)	-	-	-	-	-
Density (Destination)	1.0%	-1.5%	1.0%	1.0%	1.0%
# of Dead Ends (Destination)	0.0%	0.0%	0.0%	11.8%	**-57.2%**
# of 3-way Intersections (Dest)	0.0%	0.0%	0.0%	0.0%	**42.8%**
# of 4-way Intersections (Dest)	0.0%	0.0%	0.0%	**34.2%**	0.0%
Hourly Parking Price (Dest)	-	-	-	-	-
Free Parking Spaces (Dest)	0.7%	-1.0%	0.7%	0.7%	0.7%
# of Bus stops (Dest)	-0.1%	-0.1%	11.8%	-0.1%	-0.1%

Table B-7A. Destination choice model results: home-based work trips (MNL).

Variable	Coefficient	t-stat
Hourly Parking Price	-0.095	-1.31
# of Dead Ends	-0.00641	-4.32
# of Bus Stops	0.0148	1.98
Network Distance	-0.195	-12.48
Land Use Mix	-1.67	-3.77
Log of Employment	0.712	9.71
Logsum of Mode-Choice Model	0.395	-27.94
# of 4-way Intersections	-0.00124	-2.24
Density	-2.76E-07	-2.23
Male: Land Use Mix	0.35	2.52
Male: Hourly Parking Price	0.0618	2.78
Male: Distance to Bus Stop	0.3080	4.97
Male: Total Number of Bus Stops	-0.00465	-1.86
Male: Network Distance	0.0486	14.43
Male: Log of Employment	0.0718	2.82
Male: Log of Population	-0.0748	-6.45
Male: Density	-5.82E-07	-3.28
Senior Citizen: Land Use Mix	1.49	3.58
Senior Citizen: Network Distance	-0.0189	-1.84
Senior Citizen: Log of Employment	-0.126	-1.73
Senior Citizen: Density	-1.30E-06	-1.62
High Income: Land Use Mix	-0.350	-2.29
High Income: Distance to Bus Stop	-0.105	-1.49
High Income: # of Bus Stops	0.00182	1.48
High Income: Network Distance	0.0103	2.93
High Income: Log of Employment	0.0667	2.48
High Income: Log of Population	-0.0263	-2.08
Licensed: Land Use Mix	0.750	1.69
Licensed: # of Free Off-street Parking Spaces	-7.46E-05	-3.06
Licensed: Hourly Parking Price	0.136	1.89
Licensed: Distance to Bus Stop	-0.123	-2.03
Licensed: # of Bus Stops	-0.0122	-1.64
Licensed: Network Distance	0.0761	4.93
Licensed: Log of Employment	0.125	1.70
Licensed: Log of Population	0.0484	4.89
Number of Observations	6,615	
Final Log-likelihood	-13,408	
Pseudo R-square	0.4513	

Note: t-stat of mode-choice logsum coefficient calculated with respect to 1.

Table B-7B. Destination choice model results: home-based other trips (MNL).

Variable	Coefficient	t-stat
Hourly Parking Price	-0.0987	-7.57
# of Dead Ends	-0.00793	-7.17
# of 3-way Intersections	0.00562	7.64
Distance to Bus Stop	-0.212	-5.71
Network Distance	-0.358	-52.44
Land Use Mix	-0.659	-4.46
Density	-1.68E-06	-4.61
Log of Employment	0.447	20.38
Logsum of Mode-Choice Model	0.741	-13.53
Distance to CBD	0.0197	9.05
Log of Population	0.119	9.72
Male: Land Use Mix	0.181	1.83
Male: # of Free Off-street Parking Spaces	-8.87E-05	-2.22
Male: Hourly Parking Price	0.0351	2.73
Male: Distance to Bus Stop	0.0860	1.88
Male: Network Distance	0.0221	5.07
Senior Citizen: # of Free Off-street Parking Spaces	7.18E-05	1.37
Senior Citizen: Distance to Bus Stop	0.187	3.44
Senior Citizen: Network Distance	0.0287	5.38
Senior Citizen: Density	6.89E-07	3.07
High Income: Land Use Mix	-0.177	-1.65
High Income: Distance to Bus Stop	0.105	1.90
High Income: Network Distance	-0.00839	-1.65
High Income: Log of Population	-0.0271	-2.66
Licensed: Land Use Mix	0.777	5.12
Licensed: Network Distance	0.137	20.67
Licensed: Log of Employment	0.0424	1.72
Licensed: Log of Population	-0.0708	-5.51
Licensed: Density	7.49E-07	2.04
Number of Observations	15,798	
Final Log-likelihood	-22624	
Pseudo R-square	0.6124	

Note: t-stat of mode-choice logsum coefficient calculated with respect to 1.

Table B-7C. Destination choice model results: non-home-based trips (MNL).

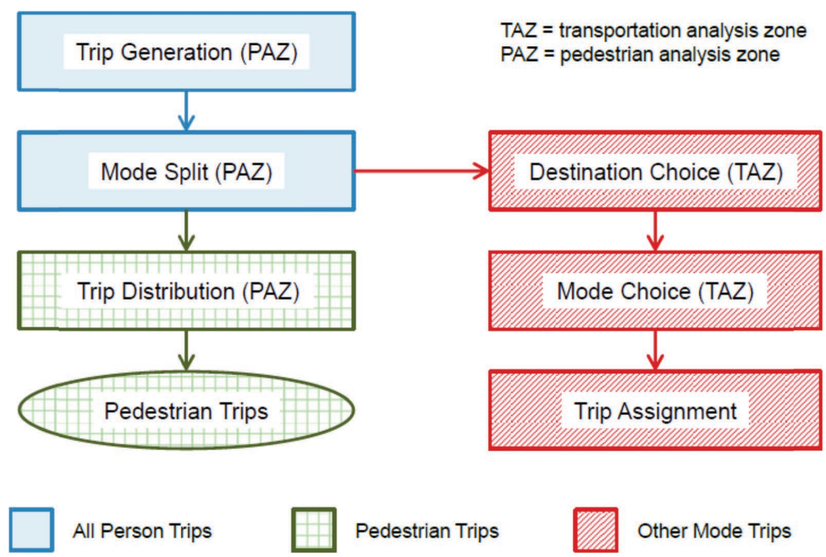
Variable	Coefficient	t-stat
# of Free Off-street Parking Spaces	-0.00016	-2.39
Hourly Parking Price	-0.0575	-4.22
# of Dead Ends	-0.00678	-5.75
# of 3-way Intersections	0.00220	3.04
# of 4-way Intersections	-0.00185	-4.41
Distance to Bus Stop	-0.111	-3.30
Number of Bus Stops	0.00762	5.41
Network Distance	-0.337	-47.97
Land Use Mix	0.377	6.72
Density	-2.71E-06	-6.10
Log of Employment	0.319	14.40
Logsum of Mode-Choice Model	0.580	37.50
Distance to CBD	0.0272	14.68
Log of Population	0.109	7.70
Male: Network Distance	0.0479	14.26
Male: Log of Employment	0.0302	2.01
Male: Log of Population	-0.0473	-5.63
Male: Density	3.14E-07	1.60
Senior Citizen: Land Use Mix	0.847	4.93
Senior Citizen: Hourly Parking Price	-0.0607	-2.01
Senior Citizen: # of Bus Stops	0.00566	1.74
Senior Citizen: Network Distance	-0.0342	-6.11
Senior Citizen: Log of Employment	-0.0732	-2.56
Senior Citizen: Log of Population	0.0180	1.23
High Income: Hourly Parking Price	0.0355	1.94
High Income: Distance to Bus Stop	0.100	1.81
High Income: Total Number of Bus Stops	-0.00378	-1.83
High Income: Log of Population	-0.0530	-6.13
High Income: Density	4.34E-07	2.23
Licensed: # Free Off-street Parking Spaces	0.000142	2.06
Licensed: Network Distance	0.140	20.22
Licensed: Log of Employment	0.189	8.75
Licensed: Log of Population	-0.0426	-3.12
Licensed: Density	1.37E-06	3.30
Number of Observations	17,462	
Final Log-likelihood	-28536	
Pseudo R-square	0.5576	

Note: t-stat of mode-choice logsum coefficient calculated with respect to 1.

APPENDIX C

Portland Pedestrian Model Enhancement[9]

Conceptual Diagram of Approach



[9] Clifton, K. J., et al. IMPROVING THE REPRESENTATION OF THE PEDESTRIAN ENVIRONMENT IN TRAVEL DEMAND MODELS. Phase I Report Oregon Transportation Research and Education Consortium (OTREC) (June 2013)

Table C-1. Metro context tool data sources.

Context Tool layer	Raster creation method	Search radius	Reclassification (1 to 5; low to high)	Data source
Bicycle access	Search radius	1 mile*	Natural breaks	Bike There! map classification
Block size	Search radius	1/4 mile	Natural breaks	Dissolved Metro taxlots, multipart to singlepart features
Access to parks	Path distance**	n/a	Linear distance***	Path distance from access points
People per acre	Search radius	1/4 mile	Natural breaks	Population + Employment
Sidewalk density	Search radius	1/4 mile	Natural breaks	Metro Sidewalk Inventory
Transit access	Search radius	1/4 mile	Natural breaks	TriMet transit stops
Urban Living Infrastructure	Search radius	1/4 mile	Natural breaks	ESRI Business Analyst

* Because of the increased range of bicycles over pedestrian travel, a larger search radius was used to represent accessibility by bike.
** This layer was created based on raster path distance. Raster paths were derived from the Metro streets (minus freeways) and pedestrian paths/trails layers.
*** This layer was classified using quarter-mile increments: 5 = 0 to 1/4 mile; 4 = 1/4 to 1/2 mile; 3 = 1/2 to 3/4 mile; 2 = 3/4 to 1 mile; 1 = greater than 1 mile.

Models were specified for production trip ends. We used production trip ends only because Metro's model generally does not use the trip generation model to calculate trip attractions. Instead, trips are attached to an attraction zone using a logit-based destination choice model with size variables.

Table C-2. Model results.

	HBW Model			HBO Model			NHB Model		
Variable	B	p	OR	B	p	OR	B	p	OR
Traveler characteristics									
Hhsize2	--	--	--	0.191	0.004	1.210	--	--	--
Hhsize3	0.719	0.000	2.052	--	--	--	--	--	--
Hhsize4	--	--	--	--	--	--	--	--	--
Income2	-0.794	0.010	0.452	--	--	--	--	--	--
Income3	--	--	--	--	--	--	--	--	--
Income4	--	--	--	--	--	--	0.270	0.000	1.311
IncomeX	--	--	--	--	--	--	--	--	--
Agecat1	0.957	0.011	2.605	--	--	--	--	--	--
Agecat3	0.343	0.024	1.409	-0.242	0.000	0.785	-0.238	0.002	0.788
Agecat4	--	--	--	--	--	--	-0.330	0.002	0.719
AgecatX	--	--	--	--	--	--	--	--	--
Workers1	--	--	--	0.208	0.003	1.231	--	--	--
Workers2	--	--	--	0.301	0.000	1.352	--	--	--
Workers3	--	--	--	--	--	--	--	--	--
Child1	--	--	--	0.295	0.000	1.343	--	--	--
Child2	0.752	0.000	2.122	0.455	0.000	1.576	--	--	--
Child3	1.121	0.000	3.068	0.479	0.000	1.615	--	--	--
Autos0	1.597	0.000	4.938	1.089	0.000	2.970	1.266	0.000	3.546
Autos2	-0.834	0.000	0.434	-0.463	0.000	0.629	-0.597	0.000	0.551
Autos3	-1.178	0.000	0.308	-0.690	0.000	0.502	-0.757	0.000	0.469
Transportation system variables									
StFwy	--	--	--	-1.093	0.003	0.335	--	--	--
Trail	--	--	--	--	--	--	--	--	--
WA	--	--	--	0.792	0.006	2.208	--	--	--
Built environment characteristics									
PIE	0.036	0.000	1.036	0.043	0.000	1.044	0.051	0.000	1.053
PIE Flag	1.240	0.000	3.457	0.530	0.072	1.699	2.059	0.000	7.835
Trip purpose dummies									
HBshop	--	--	--	-0.145	0.034	0.865	--	--	--
HBrec	--	--	--	0.288	0.000	1.333	--	--	--
HBschool	--	--	--	0.444	0.000	1.558	--	--	--
NHBNW	--	--	--	--	--	--	-0.208	0.002	0.812
Constant	-5.033	0.000	0.007	-4.377	0.000	0.013	-4.883	0.000	0.008
Overall model statistics									
-2 Log likelihood			2,124.57			14,772.66			7,147.62
Nagelkerke R-square			0.151			0.137			0.253
All trip ends			9,949			29,448			17,137
Trip ends removed			1,032			2,998			2,233
Trip ends used			8,917			26,450			14,904
Walk trip ends		#	275			2,490			1,329
		%	3.08%			9.41%			8.92%

APPENDIX D

Baltimore PedContext Model[10]

Walk-Accessibility

Accessibility is a general concept in travel modeling that typically refers to the ability of people to reach various destinations. It measures both the degree of development activity and the travel time needed to get to those activities. It was theorized that accessibility is a primary factor influencing the number of pedestrian trips made. Population and employment density are sometimes used to reflect the closeness of travel opportunities, but given the extremely small size of the TAZs used in this model (i.e., a single block face), density was not a credible measure.

Accessibility is a zone-based measure and can be calculated from a matrix of zone-to-zone travel times and a vector of zonal "opportunities". For the purposes of this study, a fairly conventional definition of accessibility was used:

$$Acc(i) = [Opp(j) * F(i,j)] \text{ (summed across all zones j)}$$

Where:
- Acc(i) = accessibility of zone i
- Opp(j) = opportunities in zone j—generally either employment or households
- F(i,j) = an inverse function of travel time between zones i and j (as time increases, F becomes smaller);

for this purpose, a gamma function is used:

$$F = t_{-1.5} * e_{-0.1t}$$

Where:
- t = walk time between zones i and j, minutes (computed as the distance along the sidewalk at a speed of 3 mph)
- e = base of natural logarithms (2.71828 . . .)

Trip Generation

For each trip purpose, a trip production model of the following type was estimated:

$$TR = ACCMFM_A * ACCEMP_B * ACCRET_C * (D * LOW + E * HIGH)$$

Where:
- TR = trip rate (trips/HH for HB purposes, trips/KSF floor space for NHB purposes)
- ACCMFM = accessibility to MFDUs
- ACCEMP = accessibility to total employment
- ACCRET = accessibility to retail employment
- LOW = low income dummy (= 1 if the zonal average HH income < $41,000, else 0)
- HIGH = high income dummy (= 1 if the zonal average HH income ≥ $41,000, else 0)
- A, B, C, D, E = calibrated coefficients

(Note: for the NHB purposes, the "D" and "E" coefficients were set equal—there is no influence of income)

The models were calibrated using the method of least squares. For each district, the estimated trip rate was compared to the surveyed rate. The coefficients were adjusted so as to minimize the overall sum of the squared error.

[10] Urbitran Associates. *Pedestrian Flow Model for Prototypical Maryland Cities.* Final Report. For Maryland Department of Transportation, Division of Highway Safety Programs, and University of Maryland, National Center for Smart Growth (2004)

Trip Generation Production Model

Purpose	ACCMFM A	ACCEMP B	ACCRET C	Low Inc D	High Inc E	district r^2
Trip Rates per Household						
HB Work	0.0384	0.3655	0.0000	0.0148	0.0148	0.433
HB Pers Bus	0.2396	0.0223	0.0000	0.1578	0.1012	0.445
HB Eat	0.2039	0.0000	0.0212	0.1159	0.0740	0.312
HB Shop	0.3923	0.0000	0.0000	0.0735	0.0735	0.437
HB Leisure	0.2199	0.0000	0.0484	0.1097	0.1013	0.350
HB School	0.1430	0.0000	0.0000	0.0601	0.0347	0.201
Trip Rates per KSF of Total Floor Space						
NHB Work	0.0000	0.8050	0.0000	0.0004	0.0004	0.892
NHB Pers Bus	0.2363	0.3099	0.0000	0.0036	0.0036	0.643
NHB Eat	0.0000	0.0000	0.5948	0.0081	0.0081	0.741
NHB Shop	0.5315	0.0000	0.2370	0.0020	0.0020	0.620
NHB Leisure	0.2547	0.0000	0.2624	0.0055	0.0055	0.358
NHB School	0.3541	0.0000	0.0000	0.0076	0.0076	0.075

Trip Attractions were determined through the following equations:

Trip Distribution

Trip productions and attractions are converted to origin-destination trips through a “gravity model”, which proportions the number of trips between zone i and zone j to the number of trips produced in zone i, the number of trips attracted to zone j, and inversely proportional to the impedance separating the two zones:

$$T_{ij} = P_i * \frac{A_j F_{ij}}{\sum_j A_j F_{ij}}$$

Where:

T_{ij} = trips from zone i to zone j
P_i = trips produced in zone i
A_j = trips attracted to zone j
F_{ij} = impedance function, i to j

And:

$F = a * t_b * e_{gt}$

Where:

F = impedance
t = perceived walk time, minutes
a, b, g = calibrated coefficients
e = base of natural logarithms (2.71828 . . .)

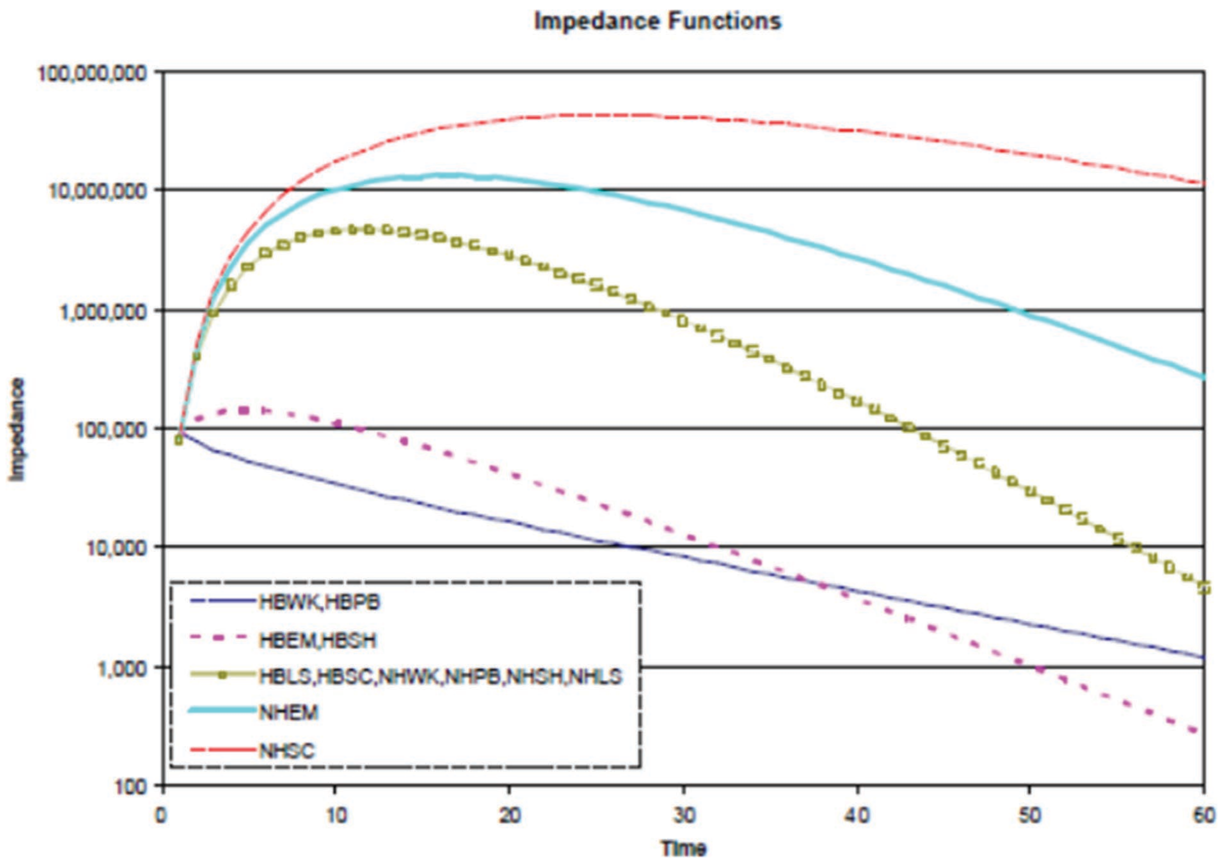
Trip Attraction Equations

Purpose	Equation
HB Work	0.000094 * NONRES
HB Pers Bus	0.000349 * NONRES
HB Eat Meal	0.000226 * (REST_FAST + REST_OTHER)
HB Shop	0.000220 * (AUTO_DLR + STORE_DEPT + STORE_OTHR)
HB Leisure	0.000231 * (HOTEL + REC_PROPSF + REC_MOVIE + REC_MUSEUM + REC_OTHER)
HB School	0.000103 * COM_SCHOOL
NHB Work	0.000128 * NONRES
NHB Pers Bus	0.000164 * NONRES
NHB Eat Meal	0.007683 * (REST_FAST + REST_OTHER)
NHB Shop	0.001935 * (AUTO_DLR + STORE_DEPT + STORE_OTHR)
NHB Leisure	0.003854 * (HOTEL + REC_PROPSF + REC_MOVIE + REC_MUSEUM + REC_OTHER)
NHB School	0.000020 * COM_SCHOOL

Notes:
Variables are as defined in Table 3, plus the following:
NONRES = total non-residential floor space

Distribution Model Coefficients and Results

Purpose	a	b	g	Obs. Avg. Tm.	Est. Avg. Tm.	% Error
HBWK	100,000	-0.2018	-0.0600	23.34	23.16	-0.8%
HBPB	100,000	-0.2018	-0.0600	22.57	22.70	0.6
HBEM	100,000	0.7259	-0.1476	18.77	18.81	0.2
HBSH	100,000	0.6249	-0.1417	18.19	18.04	-0.9
HBLS	100,000	2.5900	-0.2220	20.47	20.54	0.3
HBSC	100,000	2.5910	-0.2034	22.02	21.92	-0.5
NHWK	100,000	2.7580	-0.2225	19.92	19.89	-0.1
NHPB	100,000	2.7571	-0.2405	18.34	18.41	0.4
NHEM	100,000	2.7609	-0.1721	23.81	23.78	-0.1
NHSH	100,000	2.6936	-0.2659	16.05	16.10	0.3
NHLS	100,000	2.6947	-0.2492	18.09	18.05	-0.2
NHSC	100,000	2.7022	-0.1053	33.39	33.36	-0.1



Impedances

The accessibility calculations that underlie the previously described demand model, and the path-finding that underlies the trip assignment model, all are based on travel times and impedances derived from the pedestrian network. Travel (walk) times are computed for each link in the network—sidewalks, intersection crosswalks and mid-block jay walks, doorways / load points, and other types. Then these times are weighted by various factors to produce a set of impedances for each link that govern path-finding. Basic sidewalk walk time is based on walking speed and distance. Average walk speed can be defaulted, or can be specified by the user. The default value for sidewalk walk speed is 3.5 mph. Sidewalk quality factors are applied to modify the walk time to reflect perceived quality. For example, a high-quality sidewalk would receive a quality factor of 1.0, whereas a poor-quality or non-existent sidewalk might receive a quality factor of 2.0. These factors can be set or overridden by the user. Default quality factors are as follows:

Time Factors for Sidewalk Quality

Sidewalk Quality	Time Factor
High quality	1.0
Marginal quality	1.3
Poor quality	2.0
On-street walk	1.7
Other walkway types	1.0

Default Sidewalk Types for Street Facility Types:

Freeway	None
Arterial	Marginal
Collector	High
Local	High
Alleyway	On-Street
Other	Marginal

At intersection crosswalks and mid-block jay walks, basic crosswalk times are based on walking speed (specified separately and typically faster than sidewalk walk speed), distance based on street width, and step-off conditions. Additional time is added to account for wait times for gaps in uninterrupted traffic (a function of the traffic volume), and wait times at signals (a function of signal timing and pedestrian phasing). Default crossing time parameters are shown below:

Crosswalk Time Parameters

Parameter	Value
Crosswalk Walk Speed	4.5 mph
Reaction/Step-off Time	1.0 sec
Speed Risk Allowance	0.05 sec/mph
Crossing time factor if Pedestrian Phase at Signal	0.6
Crossing time factor if Pedestrian Actuation at Signal	0.8

Further adjustments are applied to increase walk time to account for crossing risk. Jay walks, for example, are riskier than intersection crossings. High traffic speeds are more risky than low speed streets. These risk factors and acceptable gap times are computed based on the facility type, speed, and volume. Adopted defaults are shown below:

Street Volume and Speed Defaults

		Traffic Volume (Veh/hour/lane)	
Facility Type	Speed (mph)	Peak	Off-Peak
Freeway	60	1,200	850
Arterial	45	900	600
Collector	35	350	200
Local-1	25	150	80
Local-2	15	0	0
Local-3	15	0	0
Alleyway	15	0	0
Other	15	0	0

Network Assignment

Pedestrian trips from each block face to all other block faces are estimated by the pedestrian travel demand model. Paths are then found through the pedestrian network according to the above travel impedances, and the pedestrian trips are assigned to those paths.

While moving from the same origin to the same destination, a group of pedestrians will use various paths—some efficient with respect to time or impedance, some not so. To emulate this phenomenon the assignment method needs to find multiple paths from each origin to each destination and to proportionally load the trips along those paths.

Because the pedestrian network built by this model contains a multitude of short links that prevent alternative paths from being qualified and assigned, it was concluded that standard stochastic assignment methods could not be used for this pedestrian model. An alternative approach—the Pseudo-Stochastic Network Impedance Model—was deemed more able to deal with specialized traffic assignment issues. This construct uses an iterative path-finding and assignment process, but randomly perturbates the link impedances before finding paths to emulate the random ways in which users perceive or react to actual impedances. After several iterations with these perturbated times, a family of paths was generated for each origin-to-destination movement that were found to be a reasonable representation of multi-path assignment.

The implementation of this model in TP+ found nine separate sets of perturbated paths for each origin-to-destination movement. These sets are developed as three random variants (A through C) of three levels of perturbation (1 through 3). Each trip purpose follows a perturbation level as shown below.

Trip Purposes and Path Perturbation Levels

Trip Purpose	Perturbation Level	Perturbation Assignment Sets
HB Work	Minimum	1A,1B,1C
HB Personal Business	Medium	2A,2B,2C
HB Eat Meal	Maximum	3A,3B,3C
HB Shop	Maximum	3A,3B,3C
HB Leisure	Maximum	3A,3B,3C
HB School	Maximum	3A,3B,3C
NHB Work	Minimum	1A,1B,1C
NHB Personal Business	Medium	2A,2B,2C
NHB Eat Meal	Maximum	3A,3B,3C
NHB Shop	Maximum	3A,3B,3C
NHB Leisure	Maximum	3A,3B,3C
NHB School	Minimum	1A,1B,1C

A path set with minimum perturbation, used by such trip purposes as walking to work, is essentially the minimum path, and typically results in minor variations to jaywalk instead of using intersection crosswalks. A set with maximum perturbation, used by such trip purposes as leisure, will show a high level of variation and can typically result in going entirely around a block or finding another street to walk on.

The variations in travel impedances that comprise these perturbations are computed in one of two ways that can be selected by the user: Either the overall total impedance on a link can be perturbated, or the individual components of travel time (walk time, crossing time, crossing wait time, traffic speed penalties) can be perturbated. It appears that the individual component approach is more sensitive and delivers more appropriate paths, but further experimentation is needed in this regard.

The median values of each component, and of the total overall impedance, are computed using the defaults described above or user data if provided. Then for each of the nine impedance sets (1A through 3C in the preceding table) the values are randomly varied, using a normal distribution with standard deviations that can be specified by the user. Suggested standard deviations that have been defined through practice are shown below.

Trip Assignment Set Weights

Perturbation Set (Purpose)	A	B	C
(1) Minimum (WK, SC)	0.40	0.30	030
(2) Medium (PB)	0.35	0.35	0.30
(3) Maximum (EM, SH, LS)	0.35	0.35	0.35

Standard Deviations Used For Perturbation Levels

	Standard Deviation		
Travel Time Component	Minimum Perturbation (1A, 1B, 1C)	Medium Perturbation (2A, 2B, 2C)	Maximum Perturbation (3A, 3B, 3C0
Overall Impedance	0.1	0.2	0.3
Weighted Sidewalk Time	0.3	0.5	0.5
Sidewalk Quality	0.2	0.6	0.6
Street Crossing Time	0.4	0.8	0.8
Sidewalk Quality	0.2	0.5	0.8

The matrix containing 24-hour pedestrian trips is assigned to the pedestrian network using the TP+ program HWYLOAD. One iteration of all-or-nothing assignment is used, with each trip purpose set assigned according to the three perturbated impedances comprising each set as shown in the table of standard deviations above. Each set is then weighted with the following fractions. For any set (minimum, medium, or maximum), the fractions sum to 1.00.

The product of this step is a loaded network containing estimated 24-hour pedestrian volumes on all links in the network: sidewalks, intersection crosswalks, jay walks, and door links/load points.

APPENDIX E

Baltimore MoPeD Model[11]

Trip Generation

Attractions and Productions for HB Walk Trips

HB Walk (Walk trips/PAZ) = [exp (−1.034232 − 0.9455401 * vehicle ownership + 2.371351 * street connectivity + 0.0070639 * percent commercial + 0.0001527 * residential dwelling units)] * total dwelling units in PAZ

Attractions and Productions for Non-HB Walk Trips

Total NHB Productions (Total trips/PAZ) = 0.798 * Other Employment + 2.984 * Retail Employment + 0.916 * Service Employment + 0.707 * Total Households

Note: all variables are calculated at the PAZ level

Convert All Trip productions to Walk Trip productions

Prob (Walk trip) = exp (UWalk)/(1+ exp(UWalk))
Where, UWalk = −4.286918 + 3.041807 * Connectivity + 0.0051575 * percent commercial

Note: variables in this model are calculated at the ¼ mile buffer of the trip end.

Total NHB Attractions (Total trips/PAZ) = 0.636 * Other Employment + 3.194 * Retail Employment + 0.730 * Service Employment + 0.803 * Total Households

Note: all of the variables are calculated at the PAZ level

Convert All Trip attractions to Walk Trip attractions

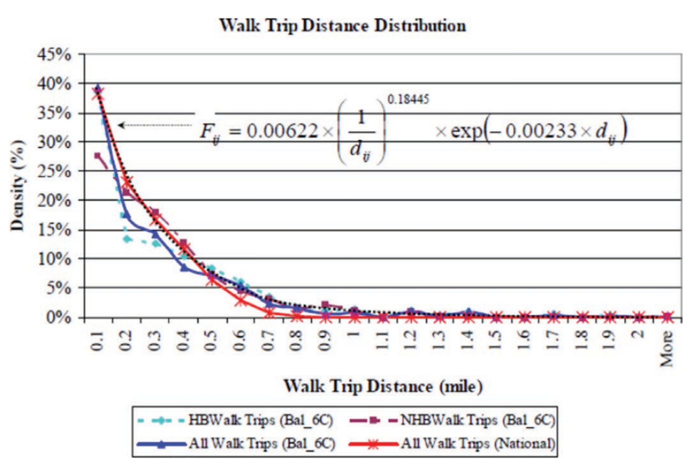
Prob (Walk trip) = exp (UWalk)/(1+ exp(UWalk))

Where, UWalk = −4.286918 + 3.041807 * Connectivity + 0.0051575 * percent commercial

Note: variables in this model are calculated at the ¼ mile buffer of the trip end.

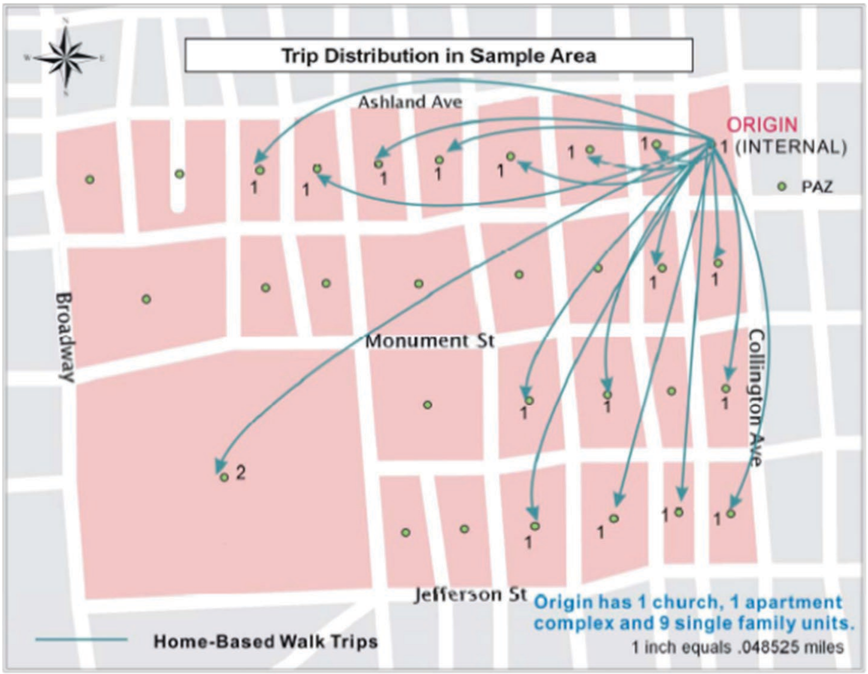
Trip Distribution

$$T_{ij} = P_i \left[\frac{A_j F_{ij} K_{ij}}{\sum_j A_j F_{ij} K_{ij}} \right]$$

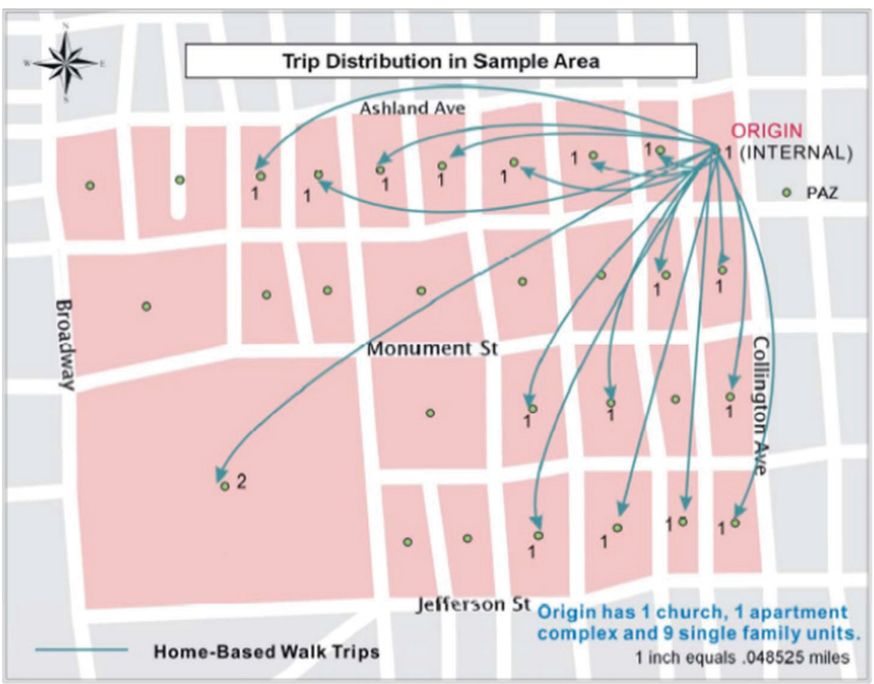


[11] Clifton, K. J., et al. Pedestrian Demand Model & Crash Protocol. Maryland Department of Transportation, State Highway Administration (June, 2008)

Trip Distribution—Home-Based Walk Trips



Trip Distribution—Non-Home-Based Walk Trips



Variables Used in Model Estimation

Variable	Definition	Mean	S. D.
Traveler characteristics			
Hhsize2	Household size was 2 people (binary)	0.31	0.46
Hhsize3	Household size was 3 people (binary)	0.18	0.39
Hhsize4	Household size was 4 or more people (binary)	0.40	0.49
Income2	Household income was $25,000 to $34,999 (binary)	0.05	0.21
Income3	Household income was $35,000 to $74,999 (binary)	0.30	0.46
Income4	Household income was $75,000 or more (binary)	0.52	0.50
IncomeX	Household income was not reported (binary)	0.06	0.25
Agecat1	Age of the head of the household was 0 to 25 (binary)	0.01	0.10
Agecat3	Age of the head of the household was 56 to 65 (binary)	0.22	0.42
Agecat4	Age of the head of the household was 66 or greater (binary)	0.13	0.34
AgecatX	Age of the head of the household was not reported (binary)	0.02	0.12
Workers1	Number of workers in the household was 1 (binary)	0.31	0.46
Workers2	Number of workers in the household was 2 (binary)	0.51	0.50
Workers3	Number of workers in the household was 3 or more (binary)	0.10	0.30
Child1	Number of children in the household was 1 (binary)	0.15	0.36
Child2	Number of children in the household was 2 (binary)	0.20	0.40
Child3	Number of children in the household was 3 or more (binary)	0.10	0.30
Autos0	Household members owned/leased 0 vehicles (binary)	0.03	0.16
Autos2	Household members owned/leased 2 vehicles (binary)	0.46	0.50
Autos3	Household members owned/leased 3 or more vehicles (binary)	0.31	0.46
Transportation system variables			
StFwy	Length (miles) of freeways within an eighth-mile of the trip end	0.02	0.09
Trail	Length (miles) of trails within a quarter-mile of the trip end	0.96	1.26
WA	Trip was located in Washington (binary)	0.25	0.44
Built environment characteristics			
PIE	Weighted sum of Context Tool data	33.98	25.30
PIE Flag	Trip was located outside of PIE extents (binary)	0.27	0.45
Trip purpose dummies			
HBshop	Home-based shopping trip purpose (binary)	0.09	0.29
HBrec	Home-based recreation trip purpose (binary)	0.11	0.31
HBschool	Home-based school trip purpose (binary)	0.09	0.29
NHBNW	Non-home-based non-work trip purpose (binary)	0.18	0.39

APPENDIX F

Portland Bicycle Route Choice Model[12]

Table F-1. Variable descriptions.

Variable	Description	Mean	Present in proportion alts (n=29,090)
Bridge w/ bike lane	bridge with on-street bike lane	dummy variable	0.05
Bridge w/ sep. facility	bridge with improved, separated bike facility	dummy variable	0.22
Prop. upslope 2-4%	Proportion of route along links with average upslope (gain/length) of 2-4%	0.10	0.90
Prop. upslope 4-6%	Proportion of route along links with average upslope (gain/length) of 4-6%	0.03	0.70
Prop. upslope 6%+	Proportion of route along links with average upslope (gain/length) of 6%+	0.02	0.68
Distance (mi)	distance of route in miles	4.48	1.00
Path size (0-1, 1=unique)	path size (see section 4 for formula)	0.31	1.00
Left turn, unsig., AADT 10-20k (/mi)	left turn without traffic signal and parallel traffic volume 10,000-20,000 per day	0.11	0.36
Left turn, unsig., AADT 20k+ (/km)	left turn without traffic signal and parallel traffic volume 20,000+ per day	0.08	0.18
Prop. bike boulevard	proportion of route on designated bicycle boulevard (improved neighborhood bikeway with traffic calming, diversion, and enhanced right of way)	0.10	0.53
Prop. bike path	proportion of route on off-street, regional bike path (i.e. not minor park paths, sidewalks, etc.)	0.04	0.41
Prop. AADT 10-20k w/o bike lane	proportion of route on streets with traffic volume 10,000-20,000 per day without a bike lane	0.08	0.73
Prop. AADT 20-30k w/o bike lane	proportion of route on streets with traffic volume 20,000-30,000 per day without a bike lane	0.04	0.46
Prop. AADT 30k+ w/o bike lane	proportion of route on streets with traffic volume 30,000+ per day without a bike lane	0.02	0.26
Traffic signal exc. right turns (/mi)	left turns and straight movements through traffic signals per mile	1.84	0.90
Stop signs (/mi)	turns or straight movements through stop signs per mile	3.12	0.95
Turns (/mi)	left and right turns per mile	3.64	1.00

(continued on next page)

[12] Joseph Broach, Jennifer Dill, and John Gliebe, "Where Do Cyclists' Ride? A Route Choice Model Developed with Revealed Preference GPS Data," *Transportation Research-Part A.* 46: 1730–1740, 2012.

Table F-1. (Continued).

Variable	Description	Mean	Present in proportion alts (n=29,090)
Unsig. cross AADT 10k+ right turns (/mi)	right turns at unsignalized intersections with cross traffic volume 10,000+ per day	0.16	0.44
Unsig. cross AADT 5-10k exc. right turns (/mi)	left turns and through movements at unsignalized intersections with cross traffic volume 10,000-20,000 per day	0.56	0.72
Unsig. cross AADT 10-20k exc. right turns (/mi)	left turns and through movements at unsignalized intersections with cross traffic volume 10,000-20,000 per day	0.42	0.72
Unsig. cross AADT 20k+ exc. right turns (/mi)	left turns and through movements at unsignalized intersections with cross traffic volume 20,000+ per day	0.16	0.52

Table F-2. Portland bicycle route choice model estimation results.

Variable	Est. coeff.	t-stat
Ln(distance)	-5.22	*-10.9*
Ln(distance) * commute	-3.76	*-5.14*
Turns (/mi)	-0.371	*-15.4*
Prop. upslope 2-4 %	-2.85	*-4.57*
Prop. upslope 4-6 %	-7.11	*-6.11*
Prop. upslope >= 6 %	-13.0	*-8.57*
Traffic signal exc. right turns (/mi)	-0.186	*-5.73*
Stop sign (/mi)	-0.0483	*-2.10*
Left turn, unsig., AADT 10-20k (/mi)	-0.782	*-4.19*
Left turn, unsig., AADT 20k+ (/mi)	-1.87	*-4.70*
Unsig. cross AADT >= 10k right turn (/mi)	-0.338	*-2.32*
Unsig. cross AADT 5-10k exc. right turn (/mi)	-0.363	*-5.39*
Unsig. cross AADT 10-20k exc. right turn (/mi)	-0.516	*-5.39*
Unsig. cross AADT 20k+ exc. right turn (/mi)	-2.51	*-11.5*
Prop. bike boulevard	1.03	*5.17*
Prop. bike path	1.57	*4.64*
Prop. AADT 10-20k w/o bike lane	-1.05	*-3.02*
Prop. AADT 10-20k w/o bike lane * commute	-1.77	*-2.28*
Prop. AADT 20-30k w/o bike lane	-4.51	*-6.04*
Prop. AADT 20-30k w/o bike lane * commute	-3.37	*-2.24*
Prop. AADT 30k+ w/o bike lane	-10.3	*-4.67*
Prop. AADT 30k+ w/o bike lane * commute	-8.59	*-1.96*
Bridge w/ bike lane	1.81	*-4.71*
Bridge w/ sep. bike facility	3.11	*-4.96*
Ln(path size)	1.81	*20.78*
Number of observations	1,449	
Null log-likelihood	-4058.7	
Final log-likelihood	-3020.0	
Rho-square	0.256	

Table F-3. Relative attribute values.

Attribute	Distance value (% dist)	
	Non-commute	Commute
Turns (/mi)	7.4	4.2
Prop. upslope 2-4 %	72.3	37.1
Prop. upslope 4-6 %	290.4	120.3
Prop. upslope >= 6 %	1106.6	323.9
Traffic signal exc. right turns (/mi)	3.6	2.1
Stop sign (/mi)	0.9	0.5
Left turn, unsig., AADT 10-20k (/mi)	16.2	9.1
Left turn, unsig., AADT 20k+ (/mi)	43.1	23.1
Unsig. cross AADT >= 10k right turn (/mi)	6.7	3.8
Unsig. cross AADT 5-10k exc. right turn (/mi)	7.2	4.1
Unsig. cross AADT 10-20k exc. right turn (/mi)	10.4	5.9
Unsig. cross AADT 20k+ exc. right turn (/mi)	61.7	32.2
Prop. bike boulevard	-17.9	-10.8
Prop. bike path	-26.0	-16.0
Prop. AADT 10-20k w/o bike lane	22.3	36.8
Prop. AADT 20-30k w/o bike lane	137.3	140.0
Prop. AADT 30k+ w/o bike lane	619.4	715.7
Bridge w/ bike lane	-29.3	-18.2
Bridge w/ sep. bike facility	-44.9	-29.2

APPENDIX G

Direct Demand Models

Santa Monica Bicycle and Pedestrian Intersection Volume Models[13]

Pedestrian Volumes 5-6pm: regression model			
	Significance	**Coefficient**	**Std. Coefficient**
Employment Density [1]	0	3.217e-3	0.399
PM Bus Frequency[2]	0.001	3.675	0.294
Neighborhood Shopping District Proximity[3]	0.002	82.695	0.267
Distance from Ocean	0.043	-6.855e-3	-0.176
Average Speed Limit Approaches [4]	0.123	-5.699	-0.129
Constant		222.18	--
R-square	0.584		

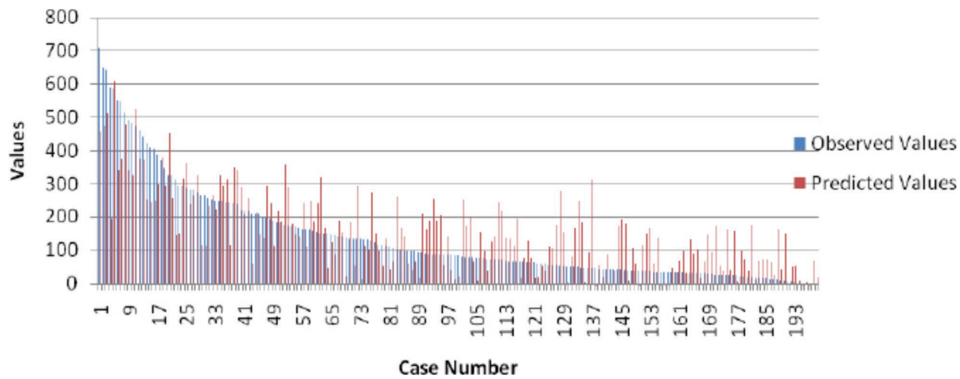
1 – Employment within 1/3 mile of intersection
2 – Frequency of bus arrivals at stops closest to study intersections (giving frequently served intersections a higher rating)
3 – Intersections within local shopping districts
4 – Average speed limits of streets approaching intersections

Square root of 5-6pm bike volumes: regression model			
	Significance	**Coefficient**	**Std. Coefficient**
Employment Density[1] (log scale)	0.171	0.120	0.134
Land Use Mix[2]	0.001	1.632	0.317
Bike Network[3]	0.000	0.431	0.397
4-leg intersection[4]	0.133	0.523	0.123
Constant		1.317	--
R-square	0.401		

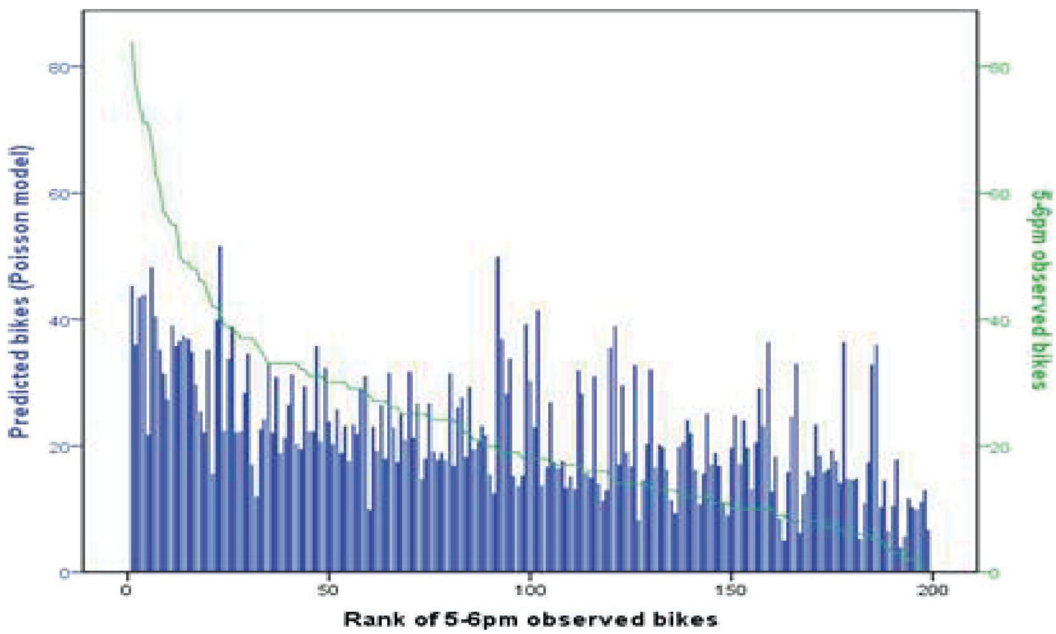
1 – Employment within 1/3 mile of intersection
2 -- Index (unit-less score) based on mix of land uses
3 -- Value based on a composite of proximity to bike routes with higher weighting going to better classes of bike facilities
4 – Subject intersection is/is not four-way

[13] Fehr & Peers. *Santa Monica Pedestrian and Bicycle Forecasting Model Report.* City of Santa Monica, CA (2010)

Observed versus Predicted Pedestrian Volumes



Observed versus Predicted Bicycle Volumes



Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
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
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
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