

Pedestrians in Regional Travel Demand Forecasting Models: State-of-the-Practice

Patrick A. Singleton (corresponding author)
Department of Civil and Environmental Engineering
Portland State University
PO Box 751 – CEE
Portland, OR 97207-0751
Phone: 412-480-7685
Fax: 503-725-5950
Email: patrick.singleton@pdx.edu

Kelly J. Clifton, PhD
Department of Civil and Environmental Engineering
Portland State University
PO Box 751 – CEE
Portland, OR 97207-0751
Phone: 503-725-2871
Fax: 503-725-5950
Email: kclifton@pdx.edu

Paper # 13-4857

Submitted: August 1, 2012
Revised: November 15, 2012

Submitted for presentation at the 92nd Annual Meeting of the Transportation Research Board
(January 13-17, 2013).

Word count: 6,232 words + (2 tables + 3 figures) * (250 words) = 7,482 total words

1 **ABSTRACT**

2 It has been nearly 25 years since non-motorized modes and non-motorized-specific built
3 environment measures were first included in the regional travel demand models of metropolitan
4 planning organizations (MPOs). Such modeling practices have evolved considerably as data
5 collection and analysis methods improve, decisions-makers demand more policy-responsive
6 tools, and walking and cycling grow in popularity. Many models now explicitly consider the
7 unique characteristics of walking travel, separate from travel by bicycle. As MPOs look to
8 enhance their models' representations of pedestrian travel, the need to understand current and
9 emerging practice is great.

10 This paper presents a comprehensive review of the practice of representing walking in
11 MPO travel models. A review of model documentation determined that – as of mid-2012 – 63%
12 (30) of the 48 largest MPOs included non-motorized travel in their regional models, while 47%
13 (14) of those also distinguished between walk and bicycle modes. The modeling frameworks,
14 model structures, and variables used for pedestrian and non-motorized regional modeling are
15 described and discussed. A survey of MPO staff members revealed barriers to modeling non-
16 motorized travel, including insufficient travel survey records, but also innovations being
17 implemented, including smaller zones and non-motorized network assignment. Finally, best
18 practices in representing pedestrians in regional travel demand forecasting models are presented
19 and possible future advances are discussed.

1 INTRODUCTION

2 MPOs forecasting processes are under pressure to address policy concerns including air quality,
3 public health, climate change, energy and environmental sustainability, and equity. To support
4 such evaluations, many policy-makers demand tools that better represent the interconnected
5 relationships of activities, travel, and land use. MPOs move in this direction by expanding the
6 representation of pedestrian or non-motorized modes in their regional travel demand forecasting
7 models.

8 Pedestrian modeling improvements can make forecasting tools more sensitive to
9 predicting the mode-shift effects of economic changes and policy interventions, such as higher
10 energy prices and smart-growth strategies. Travel models can then be used in the evaluation of
11 long-range regional plans dealing with both transportation investments and land use development
12 scenarios, informing planning decisions at regional and municipal levels. At the same time, a
13 more detailed representation of walking travel behavior assists local planning studies for non-
14 motorized modes, such as predicting the usage of new non-motorized facilities or the mode
15 shares at transit-, bicycle-, and pedestrian-oriented developments.

16 Although the first regional travel models to include non-motorized modes appeared over
17 20 years ago (1, 2), current regional pedestrian modeling practices vary considerably. The
18 challenges non-motorized modelers face include limited quantities and ranges of non-motorized
19 travel behavior data, insufficient modeling resources and expertise, and even lack of decision-
20 maker interest. Many smaller and some larger MPOs still exclude non-motorized travel from
21 their models.

22 At the same time, other MPOs are pushing ahead with advances. Improved computing
23 capabilities in data processing allow for disaggregate analyses of travel behavior at a scale more
24 compatible with walking. Data on walking use and the pedestrian environment are increasingly
25 available, allowing for the development of more detailed models. These advances make
26 modeling pedestrian travel more useful and relevant to a growing field of interested planners,
27 engineers, policy-makers, decision-makers, stakeholders, advocates, and the general public.

28 This paper documents the state-of-the-practice in representing walking in MPO regional
29 travel demand forecasting models. It updates previous studies on the subject (1, 2, 3, 4, 5, 6, 7, 8,
30 9, 10, 11) and is an in-depth companion resource to other recent (12) and on-going efforts, such
31 as NCHRP Project 08-78. The following sections present the results of a comprehensive review
32 of MPO model documentation; describe and discuss modeling frameworks, model structures,
33 and variables; and assess barriers and innovations in representing non-motorized and/or walk
34 travel in regional models.

35 HISTORY

36 Explicit inclusion of non-motorized modes in regional travel demand forecasting models began
37 in the late 1980s and early 1990s. Previously, and in many cases still today, MPO models only
38 included personal-vehicle and transit trip-making; non-motorized trips were excluded. The travel
39 surveys upon which the models were based underreported or did not consider non-motorized
40 travel (5, 13); many surveys in the 1980s only asked for non-motorized home-based work trips
41 (8, 14). A secondary factor was a general lack of interest in non-motorized travel at regional and
42 national levels. This began to change with the Clean Air Act Amendments of 1990 (CAAA) and
43 the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA).

44 The first documented regional travel demand model to include non-motorized travel was
45 developed in 1988 at the Metropolitan Service District (now Metro) of Portland, Oregon (2). In
46

1 preparation for a light-rail expansion project, a 1985 travel survey was used to estimate a binary-
2 logit motorized/non-motorized mode split model for home-based trips, based on trip distance and
3 the relative number of cars and workers per household. Other trip purposes used a static non-
4 motorized mode share (1, 8, 15). In comparison, an ITE study found that as of 1992, none of ten
5 major MPOs included non-motorized modes in their travel demand models (2).

6 Partially in response to ISTEA and CAAA, through the 1990s many large MPOs began
7 incorporating non-motorized or walk and bicycle travel modes into their models. Sacramento
8 followed Portland in 1993 with the first documented use of separate walk and bicycle modes
9 within a mode choice model. By 1997, MPOs in the Baltimore, Chicago, Hampton Roads, Los
10 Angeles, Philadelphia, and San Francisco Bay Area regions either had or were in the late stages
11 of incorporating non-motorized modes into their models.

12 At the same time as non-motorized modes were being added to regional travel models,
13 measures of the pedestrian-level built environment were being developed for use in these revised
14 models. The first documented application of non-motorized-specific built environment measures
15 occurred in 1988 at the Maryland-National Capital Park and Planning Commission. The
16 pedestrian and bicycle friendliness index – a combination of land-use mix, building setback, bus
17 shelters, bicycle infrastructure, and extent of sidewalks – was used in the walk- and bicycle-
18 access-to-transit mode choice utility equations for home-based work trips. However, the model
19 did not consider single-mode non-motorized trips (1, 3).

20 A second influential project – Making the Land Use Transportation Air Quality
21 Connection (LUTRAQ) – occurred during the early-to-mid-1990s at Portland's Metro. The
22 pedestrian environment factor (PEF) it developed was an index of the ease of street crossings,
23 sidewalk continuity, grid street pattern, and terrain to be applied in the pre-mode choice non-
24 motorized split model (15, 16). The PEF or modifications thereof has since been applied in many
25 models around the country, including in the Chicago, Hampton Roads, Miami, Philadelphia,
26 Portland, Sacramento, and Salt Lake City regions. Interestingly, Portland's regional model had
27 discarded the PEF by 2000 in favor of the less subjectively-defined variables of local intersection
28 density and land-use mix (7). Several other MPOs have similarly transitioned from indices to
29 direct measures of the pedestrian environment.

30 Through the mid-2000s, more regions continued to add non-motorized modes to their
31 travel demand forecasting models. A TRB-sponsored study found in 2005 that more than half of
32 large MPOs (54%, N = 35) reported including non-motorized trips in their models (9, 10). A
33 more recent review reported that between half (41-45%, N = 29) and two-thirds (68%, N = 28) of
34 large MPOs have non-motorized travel in their trip-based models, with about half (53%) of those
35 that do including non-motorized trips in the mode choice model (11). This paper, the most
36 comprehensive review of the practice of representing pedestrian and/or non-motorized modes in
37 MPO travel demand forecasting models, provides an update of the practice as of mid-2012.
38 Currently, about 63% of the largest 48 MPOs model non-motorized travel.

39 40 **STUDY METHODOLOGY**

41 To review the state-of-the-practice of representing walk and/or non-motorized modes in MPO
42 travel demand forecasting models, the 48 largest MPOs serving greater than 1,000,000 people (in
43 the 2010 US Census) were selected as the study population (17). Table 1 lists these large MPOs.

44 Model information was obtained and reviewed through a variety of sources, including
45 documentation reports from MPO websites and direct correspondence with modeling staff
46 members. In addition, the authors conducted a brief survey of MPO staff members regarding

1 their models' representation of pedestrians, challenges, and future modeling changes; 29
2 responses were received, a 60% response rate. Results from the analysis of MPO model
3 documentation are presented in the following section; results from the survey of MPO modelers
4 are presented in later sections. Only aspects of full non-motorized or walk trips were
5 investigated; walking as an access/egress mode in multimodal trips was not considered.

6 7 **MODELING FRAMEWORKS, MODEL STRUCTURES, AND VARIABLES**

8 There are several ways in which MPOs represent walk or non-motorized modes in
9 regional travel demand forecasting models. In four-step trip-based models, non-motorized trips
10 can be generated on their own, separated from motorized trips before or after distribution,
11 distinguished from trips of other modes during mode choice, or further segmented into walk and
12 bicycle trips. Calculated non-motorized or walk trips are then output and not used in future
13 modeling stages. Figure 1 graphically represents these different pedestrian modeling
14 frameworks. Table 1 describes the framework classifications and their use among large MPOs.
15 Although these distinctions are based on trip-based model sequences, similar frameworks are
16 used to represent non-motorized or walk travel in tour- and activity-based models (ABMs). At
17 their heart, ABMs use the same model structures as trip-based models; therefore, they can be
18 described analogously.

19 There are also many model structures used to forecast pedestrian or non-motorized travel;
20 most modeling frameworks utilize a single type of model structure. The most common structures
21 are discrete choice models, where the tradeoffs between two or more travel modes are explicitly
22 defined through utility equations: linear combinations of explanatory variables. Discrete choice
23 model structures include binary logit, multinomial logit, and nested logit. Other model structures
24 include percentages, cross-classification, and multiple regression.

25 Just as MPO models use different modeling frameworks and model structures, so is there
26 a range of variables by which walk or non-motorized trips are forecast. These variables can be
27 categorized by what they measure: socioeconomic and demographic characteristics of the
28 traveler, level-of-service characteristics of the trip itself, and characteristics of the environment
29 from, to, or through which the trip occurs. Built environment variables are further categorized
30 according to the "three D's" method: density, diversity, and design (18). The variables used often
31 depend on the modeling framework employed. Full documentation was obtained and reviewed
32 for 26 of the 31 models studied that represent walk and/or non-motorized travel. Table 2 lists,
33 categorizes, and assesses the frequency of variables by modeling framework.

34 35 **Detailed Descriptions of Frameworks, Structures, and Variables**

36 37 *Option 0: Non-Motorized Travel Not Included*

38 Eighteen large MPOs do not include non-motorized modes in their travel demand models. These
39 organizations cannot forecast non-motorized trips using their regional models and thus must
40 develop separate demand forecasting tools if they wish to evaluate walking and cycling policies
41 and projects.

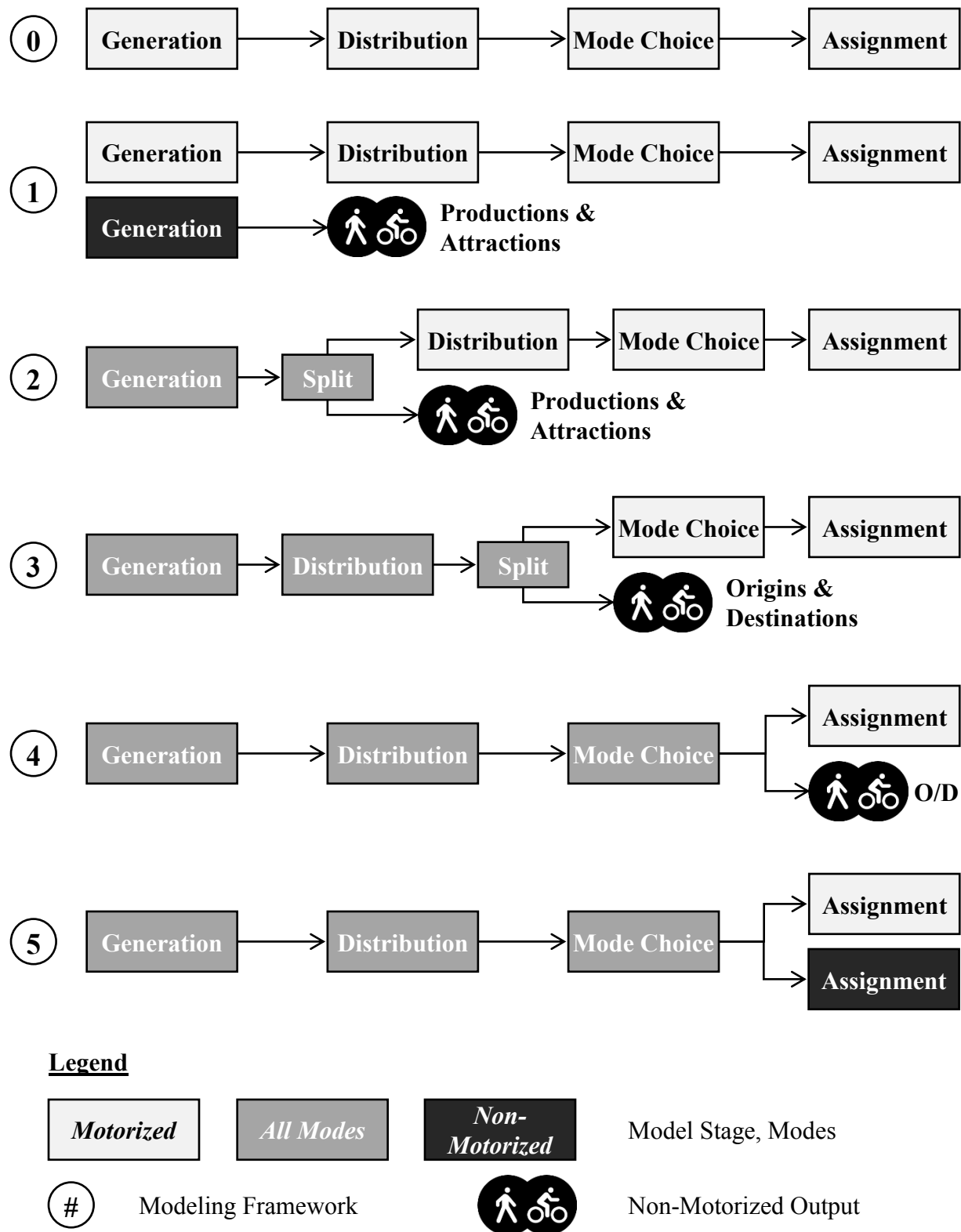


FIGURE 1 Pedestrian modeling frameworks.

1 **TABLE 1 Large MPOs and their Pedestrian Modeling Frameworks**

City, State	Metropolitan Planning Organization	Modeling Framework							
		0 ^a	1 ^b	2 ^c	3 ^d	4A ^e	4B ^f	4C ^g	5 ^h
Atlanta, GA	Atlanta Regional Commission (ARC)	—	—	X	—	—	—	—	—
Austin, TX	Capital Area MPO (CAMPO)	—	—	—	—	—	—	X	—
Baltimore, MD	Baltimore Regional Transportation Board (BRTB)	—	—	X	—	—	—	—	—
Boston, MA	Boston Region MPO	—	—	—	—	X	—	—	—
Buffalo, NY	Greater Buffalo-Niagara Regional Transportation Council (GBNRTC)	—	—	—	—	X	—	—	—
Charlotte, NC	Mecklenburg-Union MPO (MUMPO)	—	—	—	—	—	—	X	—
Chicago, IL	Chicago Metropolitan Agency for Planning (CMAP)	—	—	X	—	—	—	—	—
Cincinnati, OH	Ohio-Kentucky-Indiana Regional COG (OKI)	X	—	—	—	—	—	—	—
Cleveland, OH	Northeast Ohio Areawide Coordinating Agency (NOACA)	—	—	—	—	—	—	X	—
Columbus, OH	Mid-Ohio RPC (MORPC)	—	—	—	—	X ⁱ	—	—	—
Dallas, TX	North Central Texas COG (NCTCOG)	X	—	—	—	—	—	—	—
Denver, CO	Denver Regional COG (DRCOG)	—	—	—	—	—	—	X ⁱ	—
Detroit, MI	Southeast Michigan COG (SEMCOG)	X	—	—	—	—	—	—	—
Fort Lauderdale, FL	Broward MPO	—	—	—	X	—	—	—	—
Houston, TX	Houston-Galveston Area Council (H-GAC)	X	—	—	—	—	—	—	—
Indianapolis, IN	Indianapolis, IN	X	—	—	—	—	—	—	—
Jacksonville, FL	North Florida Transportation Planning Organization (TPO)	X	—	—	—	—	—	—	—
Kansas City, MO	Mid-America Regional Council (MARC)	X	—	—	—	—	—	—	—
Las Vegas, NV	Regional Transportation Commission of Southern Nevada (RTC)	X	—	—	—	—	—	—	—
Los Angeles, CA	Southern California AOG (SCAG)	—	—	—	—	—	—	X	—
Louisville, KY	Kentuckiana Regional Planning and Development Agency (KIPDA)	X	—	—	—	—	—	—	—
Memphis, TN	Memphis Urban Area MPO (MPO)	—	—	—	—	X	—	—	—
Miami, FL	Miami-Dade MPO	—	—	—	X	—	—	—	—
Milwaukee, WI	Southeastern Wisconsin RPC (SEWRPC)	—	X	—	—	—	—	—	—
Minneapolis, MN	Metropolitan Council	—	—	—	—	—	—	X	—
Nashville, TN	Nashville Area MPO	X	—	—	—	—	—	—	—
New Orleans, LA	RPC (RPC)	X	—	—	—	—	—	—	—
New York, NY	New York Metropolitan Transportation Council (NYMTC)	—	—	—	X ⁱ	—	—	—	—
Newark, NJ	North Jersey Transportation Planning Authority (NJTPA)	—	—	X	—	—	—	—	—
Oklahoma City, OK	Association of Central Oklahoma Governments (ACOG)	X	—	—	—	—	—	—	—
Orlando, FL	MetroPlan Orlando	X	—	—	—	—	—	—	—

City, State	Metropolitan Planning Organization	Modeling Framework							
		0 ^a	1 ^b	2 ^c	3 ^d	4A ^e	4B ^f	4C ^g	5 ^h
Philadelphia, PA	Delaware Valley RPC (DVRPC)	—	X	—	—	—	—	—	—
Phoenix, AZ	Maricopa AOG (MAG)	X	—	—	—	—	—	—	—
Pittsburgh, PA	Southwestern Pennsylvania Commission (SPC)	X	—	—	—	—	—	—	—
Portland, OR	Metro	—	—	—	—	—	X	—	—
Providence, RI	Rhode Island State Planning Council	X	—	—	—	—	—	—	—
Raleigh, NC	North Carolina Capital Area MPO (CAMPO)	—	—	—	X	—	—	—	—
Sacramento, CA	Sacramento Area COG (SACOG)	—	—	—	—	—	X ⁱ	—	—
Salt Lake City, UT	Wasatch Front Regional Council (WFRC)	—	—	—	—	—	—	X	—
San Antonio, TX	San Antonio-Bexar County MPO (SA-BC MPO)	—	—	—	—	—	X	—	—
San Diego, CA	San Diego AOG (SANDAG)	—	—	—	—	—	—	X	—
San Francisco Bay Area, CA	Metropolitan Transportation Commission (MTC)	—	—	—	—	—	—	X ⁱ	—
Seattle, WA	Puget Sound Regional Council (PSRC)	—	—	—	—	—	X	—	—
St. Louis, MO	East-West Gateway COG (EWG)	—	—	—	—	—	—	X	—
Tampa, FL	Hillsborough County MPO	X	—	—	—	—	—	—	—
Virginia Beach, VA	Hampton Roads Transportation Planning Organization (HRTPO)	X	—	—	—	—	—	—	—
Washington, DC	National Capital Region Transportation Planning Board (TPB)	—	—	X	—	—	—	—	—
West Palm Beach, FL	Palm Beach MPO	—	—	—	X	—	—	—	—
—	Total Number of Large MPOs	18	2	5	5	4	4	10	0
—	Percentage of all Large MPOs (N=48)	38	4	10	10	8	8	21	0
—	Percentage of MPOs with 1 – 5 (N=30)	—	7	17	17	13	13	33	0

X The MPO uses this modeling framework.

— Not applicable.

^a 0: Does not model non-motorized travel.

^b 1: A cross-classification model to perform separate non-motorized and motorized trip generation processes.

^c 2: A percentage, linear regression, or binary logit model to split non-motorized and motorized trips after trip generation and before trip distribution.

^d 3: A binary logit model to split non-motorized and motorized trips after trip distribution and before mode choice.

^e 4A: A multinomial or nested logit mode choice model with only non-motorized mode.

^f 4B: A multinomial logit mode choice model with walk and bicycle modes but not within a non-motorized nest.

^g 4C: A nested logit mode choice model that considers walk and bicycle modes within a non-motorized nest.

^h 5: A routing process to assign walk and bicycle trips to the network.

ⁱ A tour- or activity-based model.

Acronyms:

AOG: Association of Governments

COG: Council of Governments

MPO: Metropolitan Planning Organization

RPC: Regional Planning Commission

1 **TABLE 2 Variables and their Frequency of Use, by Modeling Framework**

Category Variable	Modeling Framework									
	1		2		3		4A/B/C		5	
	#	(%)	#	(%)	#	(%)	#	(%)	#	(%)
Socioeconomic and Demographic Variables	2	(100)	3	(75)	2	(67)	16	(94)	—	—
Population, Households, and Employment	2	(100)	—	—	—	—	—	—	—	—
Household Income	—	—	1	(25)	2	(67)	5	(29)	—	—
Household Size	1	(50)	—	—	1	(33)	3	(18)	—	—
Vehicle Ownership	2	(100)	—	—	—	—	6	(35)	—	—
Vehicle Sufficiency	—	—	2	(50)	2	(67)	9	(53)	—	—
Traveler Demographics	—	—	—	—	1	(33)	4	(24)	—	—
Density Variables	2	(100)	4	(100)	3	(100)	13	(76)	—	—
Residential Density	—	—	2	(50)	1	(33)	7	(41)	—	—
Employment Density	—	—	2	(50)	1	(33)	8	(47)	—	—
Area Type	2	(100)	4	(100)	3	(100)	8	(47)	—	—
Diversity Variables	—	—	—	—	1	(33)	4	(24)	—	—
Land Use Mix	—	—	—	—	1	(33)	4	(24)	—	—
Design Variables	—	—	2	(50)	2	(67)	6	(35)	—	—
Block Size	—	—	—	—	1	(33)	—	—	—	—
Block Density	—	—	1	(25)	—	—	—	—	—	—
Intersection Density	—	—	1	(25)	—	—	4	(24)	—	—
Non-motorized Path Density	—	—	—	—	1	(33)	—	—	—	—
Network Connectivity	—	—	1	(25)	—	—	—	—	—	—
Network Restrictivity	—	—	1	(25)	—	—	—	—	—	—
Pedestrian Index	—	—	—	—	1	(33)	2	(12)	—	—
Level-of-Service Variables	—	—	—	—	2	(67)	17	(100)	—	—
Trip Distance	—	—	—	—	2	(67)	3	(18)	—	—
Travel Time	—	—	—	—	—	—	14	(82)	—	—
Travel Time Difference	—	—	—	—	1	(33)	—	—	—	—
Accessibility Variables	—	—	1	(25)	1	(33)	—	—	—	—
Tour-Based Variables	—	—	—	—	1	(33)	6	(35)	—	—
# of Documented Models	2	(100)	4	(80)	3 ^a	(100)	17 ^b	(81)	0 ^c	—

2 — None or not applicable

3 ^a One model using modeling framework Option 3 covers three large MPOs.

4 ^b Atlanta's nearly operational ABM is documented here. Although Sacramento and the San Francisco
5 Bay Area have operational ABMs, their trip-based models are also documented here.

6 ^c No large MPOs currently use framework Option 5, which would assign walk trips to the network.

1 *Option 1: Separate Trip Generation Process*

2 One option involves estimating separate trip production and attraction rates for motorized and
3 non-motorized trips, and then only taking the motorized trips through the remaining stages of the
4 travel demand model. Milwaukee and Philadelphia use this modeling framework, but
5 Philadelphia is planning to transition to a different option. This framework is a relatively simple
6 way for an Option 0 MPO to add non-motorized trips without having to re-estimate the
7 remainder of its model. Several MPOs have replaced this framework with more sophisticated
8 approaches because it provides little information about non-motorized travel behavior, has
9 limited policy sensitivity, and cannot represent modal tradeoffs.

10 Both models using Option 1 apply the cross-classification structure, although there is no
11 reason why a different trip generation model structure could not be applied instead. Milwaukee
12 calculates non-motorized trip productions but not attractions, while Philadelphia calculates both.
13 The variables used for non-motorized trip generation are common to cross-classification
14 structures: demographic, socioeconomic, and density-based area type variables. Milwaukee's
15 non-motorized trip rates per household are segmented by household size, vehicle availability,
16 and area type for all purposes. Philadelphia's non-motorized trip rate structures differ based on
17 purpose, but all are also segmented by area type.

18
19 *Option 2: Post-Trip Generation, Pre-Trip Distribution Mode Split*

20 The second option separates non-motorized from motorized trips immediately following
21 generation but prior to distribution. A variety of model structures are used by the five MPOs in
22 this category, including binary logit, multiple regression, and simple estimated mode shares. A
23 few MPOs have moved from percentages or regression to binary logit structures because such
24 discrete choice structures can include more policy-sensitive variables. Nevertheless, because
25 Option 2 occurs before trips are distributed, important level-of-service variables cannot be
26 included. On the other hand, this framework presents a good option for those MPOs that may be
27 unable or unwilling to tackle the calculation of non-motorized network skims.

28 The model structures and variables used in Option 2 range from the basic to the complex.
29 Non-motorized mode shares are used for less dense zones in Washington and for many trip
30 purposes in Baltimore. The binary logit home-based productions model of Baltimore includes
31 area type and vehicle sufficiency: relating the numbers of vehicles and workers. For denser
32 zones, Washington's regression model uses floating population, employment, and street block
33 densities, measured within one mile of the TAZ.

34 Option 2 binary logit models are not limited to basic built environment measures.
35 Newark's trip production mode share models use street network design variables, including
36 intersection density, network connectivity (# intersections / total street distance), and network
37 restrictivity (% roadway network where pedestrians are prohibited). One of the most unique
38 variables, and one that circumvents this stage's lack of level-of-service variables and knowledge
39 of destinations, is the accessibility measure used in Atlanta's binary logit models:

$$Accessibility_{Zone\ i} = \sum_j \frac{Activity_{Zone\ j}}{Distance_{i,j}^2}$$

40 where "activity" could be population, employment, or their sum. Home-based work and
41 shopping trips use employment, home-based school trips use population, and home-based other
42 and non-home-based trips use combined accessibility.

1 *Option 3: Post-Trip Distribution, Pre-Mode Choice Split*

2 The third option calculates non-motorized mode shares after trip distribution; the primary benefit
3 over Option 2 is the use of level-of-service variables. Option 3 is appropriate for MPOs that have
4 insufficient walk and bicycle records and wish to avoid the complication of estimating a full
5 mode choice model. All five MPOs in this category, including New York's tour-based model,
6 apply a binary logit model structure. The three Florida MPOs use one combined model: the
7 Southeast Florida Regional Planning Model (SERPM).

8 These models utilize level-of-service variables in different ways. SERPM uses highway
9 network distance for all trip purposes. Raleigh's highly-specified model uses non-motorized
10 distance for some purposes and a travel time difference measure – non-motorized time minus a
11 weighted average of auto and transit times – for others. Squared distance and travel time terms
12 are also included to attenuate the chance of extremely long non-motorized trips. Instead of
13 distance or time, New York's model has a non-motorized density of attractions variable. It is
14 basically a non-motorized destination choice log-sum:

$$NMDensity_{Zone\ i} = \ln \sum_j \frac{Attractions_{Zone\ j}}{\Psi(Distance_{i,j})}$$

15 where Ψ is a impedance function, accounting for all zones j within three miles.

16 This framework is also conducive to applying unique built environment measures.
17 SERPM is one of the few models to still include a pedestrian index. The “non-motorized
18 friendliness index” is the sum of assessing sidewalk availability (% streets with sidewalks), ease
19 of street crossings (% streets that are easy to cross by pedestrians), and area type on a 0 to 3
20 scale. Raleigh's model takes a different approach with unique design variables, including block
21 size (average block perimeter length) and non-motorized path density (distance of paths / zonal
22 area). A land use mix diversity variable, calculated as

$$LUM = \frac{2 * (People + Jobs) - |People - Jobs|}{Zonal\ Area}$$

23 is also used for some purposes, in addition to the typical socioeconomic and density measures.

24
25 *Option 4: Mode Choice Model*

26 This framework grouping formally includes non-motorized travel modes as options in the mode
27 choice model; structures include multinomial or nested logit discrete choice models. Option 4A
28 keeps walk and bicycle trips lumped into a non-motorized mode, a good option if few bicycle
29 trips are found in the travel survey. Option 4B explicitly includes both walk and bicycle modes,
30 placing them in equal competition in the upper nest of the logit model. Option 4C places walk
31 and bicycle modes within a non-motorized nest for stronger intra-non-motorized mode
32 substitution effects.

33 Most activity-based models fall within this framework. Although ABMs have a
34 sequential process in which trip mode choice is dependent on tour mode choice, they use the
35 same discrete choice model structures as trip-based models. Explanatory variables are also
36 similar, with the addition of person type and tour interaction variables made possible by
37 synthetic populations and tour-based travel representations. In ABMs, trip mode choice models
38 are similar in structure and specification to tour mode choice models, with the addition of
39 hierarchical rules and tour mode variables. Usually, only walk trips are allowed on walk tours,
40 but walk trips may be taken on tours of almost any mode.

In general, the mode choice non-motorized or walk utility equations are simpler than the binary logit equations of Options 2 and 3. A level-of-service variable is included for all trip purposes; although travel time is by far the most common, Memphis and Portland use distance for all purposes and Minneapolis uses generalized cost for some purposes. An advanced practice is to use different travel time coefficients for longer walk trips to reduce their likelihood. The Cleveland, San Francisco Bay Area, and Salt Lake City models attenuate walk trips longer than 1 or 1.5 miles, while Atlanta, Minneapolis, and San Diego distinguish between short, medium, and long duration walk trips.

Relatively few different built environment measures are used in Option 4. Area type dummies are used sparingly, primarily to account for special places like downtowns or university districts/towns. A unique density and diversity mix variable used in Portland and San Diego is:

$$Mix = \ln \left(\frac{Intersections * (Retail\ Employment) * Households}{Intersections + (Retail\ Employment) + Households} \right)$$

where the employment and household variables are normalized to local intersection units by multiplying by the regional averages ($\frac{mean(Employment)}{mean(Intersections)}$ or $\frac{mean(Households)}{mean(Intersections)}$), and all secondary variables are measured within a half-mile of the production zone. Sacramento's and Denver's activity-based models include a similar mixed use density variable, defined as

$$MUD = \frac{0.001 * (Retail + Service\ Employment) * Households}{(Retail + Service\ Employment) + Households}$$

with employment and households measured within a half-mile of the parcel.

Nearly every ABM in this framework uses person and tour variables. Person type dummies include life stage (child, university student, worker, etc.), age, and gender. Tour variables include the number of tour stops and an intrazonal dummy. More complex travel behaviors are accommodated in trip-based models from Cleveland and St. Louis through the use of trip type dummies (intrazonal; direct, complex, and strategic work trips). Standard socioeconomic and demographic variables round out the model specification.

Option 5: Non-motorized Trip Assignment

Although Portland's model and an ABM for the city/county of San Francisco now assign bicycle trips to the network (19, 20), no MPO currently assigns walk trips to the network. This is a logical next step for regional travel demand forecasting models, be they trip- or activity-based. Non-motorized network assignment is discussed in a later section.

Other Considerations

The prevalence of travel time variables necessitates the application of an assumed average travel speed to network distance skims. Most models use an assumed walk speed of 3 mph, but some instead use 2.5 mph; bicycle speeds vary from 7 to 12 mph. When only non-motorized trips are represented, non-motorized speed becomes difficult to define; based on their use of a non-motorized speed in the range of walking speeds, it appears that several MPOs – Boston, Columbus, Memphis, and New York – presume all non-motorized trips to be walk trips.

Another common modeling practice is to prohibit walk and bicycle modes from being available to trips longer than a given distance. Common walk trip limits are 3 or 5 miles; bicycle maximums vary from 6 to 20 miles. Raleigh is one MPO that limits non-motorized trips to 15 miles in length. Note that these limits are different from the walk access-to-transit distance

limits, which are in the range of $\frac{1}{4}$ to 1 mile. An alternate way of discouraging long walk trips is to include an appropriate distance-decreasing impedance function in walk utility equations.

Discussion

The most advanced representations of walking in travel demand forecasting models are Options 4B and 4C. Both frameworks produce origin-destination walk trip tables for each trip purpose. Neither option is necessarily more behaviorally sound; the decision is often based on whether the model estimation process produces theoretically valid nesting coefficients (< 1.0). Additionally, these options are by no means the only ways to model walk and bicycle mode choices. Future mode choice models, especially in regions with high shares of bicycle commuters and/or bike-share programs, might experiment with alternative nesting structures, especially those that put transit and bicycle modes in direct competition.

Tied closely with model frameworks are practices of model specification. It begs the question of which models are better: 1) those with highly-specified equations – like Minneapolis, Newark, or Raleigh – utilizing many variables that differ across purposes; or 2) those with simple equations – like Buffalo, Portland, and Salt Lake City – using the same few key variables throughout. Complex models can utilize a number of different built environment measures that apply to specific modes and purposes and may provide better statistical fits. Conversely, simple models require less data collection, are quicker to estimate and calibrate, and focus on variables of importance; travel behavior literature suggests that socioeconomics and trip level-of-service are stronger influences on mode choice than the built environment (18, 21). Over-specification may lead to more deviations in forecasts or challenges during re-calibration. Under-specification may place more weight on alternative-specific constants, indicating greater unobserved preferences/biases for specific modes.

Mode choice utility equations tend to be simpler than their binary logit counterparts, which may be an artifact of the processes that govern their specification and estimation. Many model changes were premised on the use of revised regional models for air quality conformity or major capital transit projects, such as a Federal Transit Administration New Starts application. Critical New Starts concerns over the calculation of user benefits required the consistency of time and cost coefficients and discouraged complex mode choice model specifications.

The treatment of built environment variables is an important aspect of modeling for pedestrians. Most MPOs have transitioned away from subjectively-defined pedestrian environment indices like the PEF towards more objective design measures like intersection density. Significant disadvantages of indices include imprecise measurements, reproducibility concerns, lack of standardization between regions, and limited policy sensitivity for forecasts due to their step-wise nature. Nevertheless, indices provide some benefits, including representing variables that are impossible to objectively measure or require time-consuming data collection, and grouping explanatory but highly correlated built environment and street-design variables. Newer access or mix variables, such as the one developed for Portland, may provide a middle ground forward for further inclusion of pedestrian environment measures.

While not examined in this paper, walking as a transit access mode has a longer history in travel demand models. Splitting zones into various walk-to-transit sheds, assigning maximum distances/times to centroid connectors, and segmenting walk, wait, and transfer times in utility equations is established practice; nevertheless, improvements are possible. More effective survey design approaches can reduce the underreporting of multimodal trips (14). Additionally, more

behavioral data on walking distances to different transit modes and frequencies can improve practices of representing walking as an access/egress mode.

Finally, some MPOs are adopting more innovative pedestrian modeling practices, including new measures of the pedestrian environment, more disaggregate spatial analysis units, and non-motorized network assignment. Simultaneously, other MPOs face data, resource, and institutional limitations to improving representations of walk travel in their models. These challenges and opportunities are discussed in the following sections.

BARRIERS TO REPRESENTING NON-MOTORIZED AND/OR WALK TRAVEL

To uncover why a third of large MPOs do not include non-motorized travel and another third do not distinguish between walk and bicycle travel in their models, a survey asked lead modelers to select from a list of possible reasons. Figure 2 shows the frequencies of responses (N = 19).

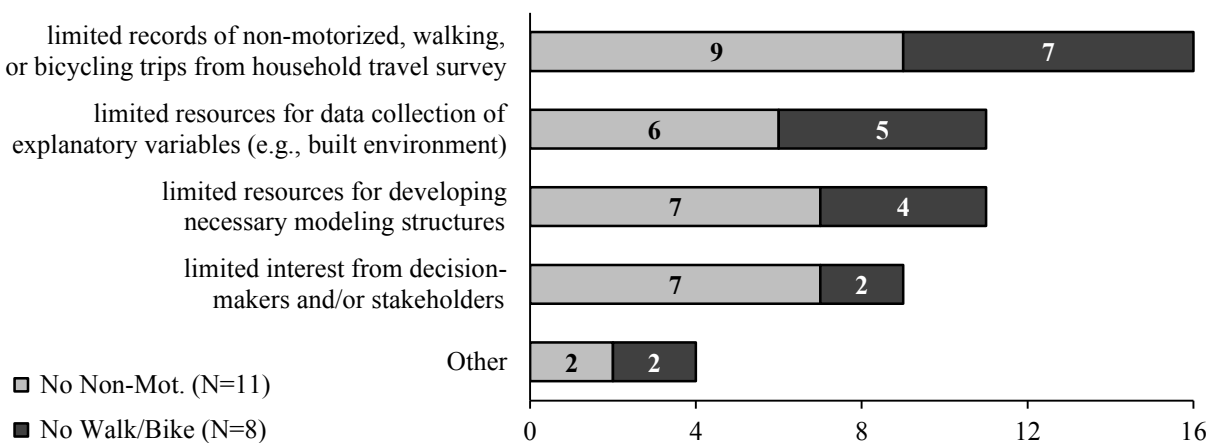


FIGURE 2 Barriers to representing non-motorized and/or walk travel.

Travel Survey Records

Insufficient non-motorized travel survey records is a primary barrier for many MPOs (84%). Household travel surveys must contain a large-enough sample of walk and bicycle trips for each trip purpose from which to estimate statistically-valid models. MPOs that face non-motorized survey record limitations may be able to transfer models/coefficients from other regions, or borrow parameters from national research reports (12). Alternatively, they may supplement walk records with standardized data from the National Household Travel Survey (NHTS) or purchase add-on NHTS samples for their regions. More standardized data collection of regional travel surveys will increase the potential transferability of non-motorized trips (22).

Data Collection Resources

Limited environmental data collection resources also constrain many MPOs (58%). While residential, employment, and intersection densities are simple to calculate, they lack policy-sensitivity and act as proxy variables. Collecting data and forecasting disaggregate and manipulatable pedestrian environment measures for an entire region, while of interest, are still expensive and time-consuming tasks. One MPO responded: “We would like to assemble

1 information on pedestrian environment (e.g. presence/absence of sidewalks, width of sidewalks,
2 landscape/buffer treatments outside the curb, presence/absence of on-street parking lanes, traffic
3 volumes at crossing, etc.) but the cost and difficulty of doing so has so far been prohibitive.”
4

5 **Model Development Resources**

6 Adding non-motorized or walk modes to regional travel models requires a corresponding
7 increase in staff modeling abilities, a challenge for some MPOs (58%). Budgets for model
8 improvement programs are tight, non-motorized modeling is often of lesser importance, and staff
9 members may not feel comfortable developing walk models in-house.
10

11 **Decision-Maker Interest**

12 The time and effort to develop models sensitive to non-motorized policy, planning, and
13 investment decisions will not be expended if decision-makers do not value such characteristics.
14 This survey suggests that some metropolitan transportation planning institutions place little value
15 on regional non-motorized travel modeling (47%); the majority of these MPOs do not include
16 non-motorized travel. If lack of interest is a barrier for some large MPOs, it is likely to be a
17 major barrier for many smaller MPOs.
18

19 **Other Considerations**

20 Other responses followed consistent themes. A common thread mentioned how the large regional
21 zonal and network scales of travel demand models are incompatible with the smaller scale at
22 which non-motorized travel takes place. One MPO modeler said that pedestrian and bicycle
23 infrastructure projects and concerns “are addressed in small funding or by city governance rather
24 [than] the regional planning agency.” Another response suggested that including non-motorized
25 trips is little more than an accounting mechanism to better estimate motorized travel.
26

27 **CURRENT AND FUTURE INNOVATIONS**

28 Regional travel demand forecasting models are rarely static entities. Even while one model
29 version is in use, subsequent versions are typically in development. For example, several
30 activity-based models are now being sequentially adopted, replacing trip-based model
31 components one-at-a-time. In addition, some MPOs are surging ahead with innovative modeling
32 developments, pushing the boundary of best-practice regional travel models. With these thoughts
33 in mind, the survey of MPO modelers also asked all respondents to select from a list of planned
34 modeling changes. Figure 3 shows the frequencies of responses (N = 29).
35

36 **Adding Modes or Modifying the Mode Choice Model**

37 Some MPOs suggested they plan to add walk or non-motorized modes to their regional models
38 (17%) or change the structure of their mode choice models (38%). Four MPOs of the first type
39 do not currently include non-motorized modes, indicating that MPOs are interested in being
40 better able to represent regional walk and bicycle travel.
41

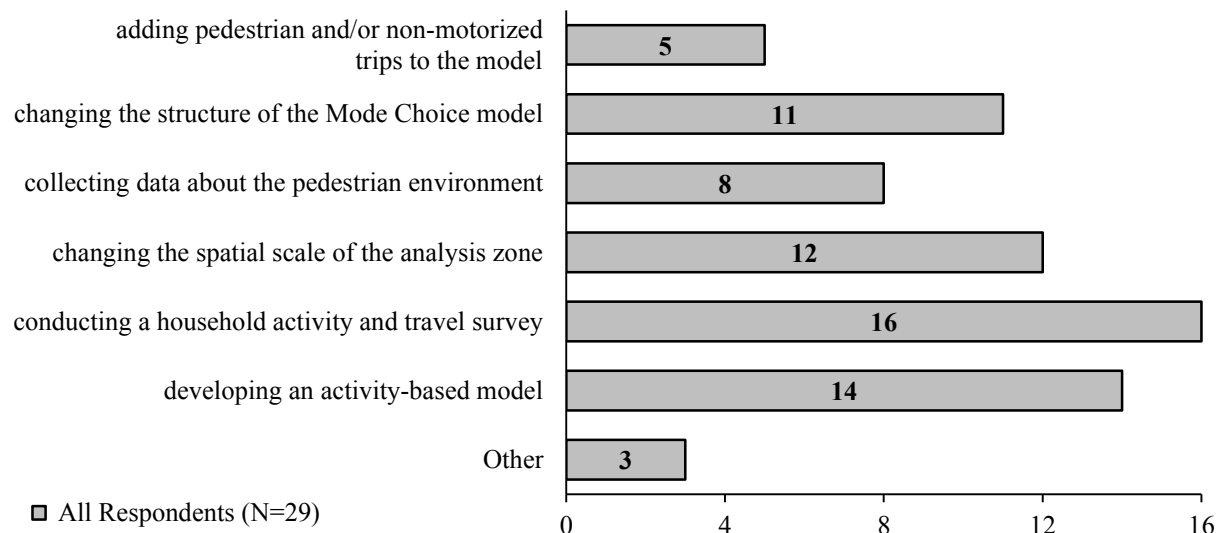


FIGURE 3 Current and future innovations in representing non-motorized and/or walk travel.

Pedestrian Environment Data

Many MPOs plan to collect better pedestrian environment data (28%). For some this means gathering pedestrian facility information to calculate sidewalk availability or street crossing variables. For others this means compiling new measures of the pedestrian-scale street environment (sidewalk width or roadway buffers, among others) or pedestrian-attractive land uses, such as “urban amenity” businesses (23). Design variables need no longer be limited to those that can be calculated using a GIS-based street network.

Smaller Spatial Analysis Units

A number of MPOs reported planning to change their zonal structure (41%), while others have already done so. These smaller spatial analysis units are being used for disaggregate land use and demographic forecasts, walk trip distance estimates, and walk accessibility calculations. Atlanta is in the process of more than doubling the number of zones in its trip-based model to 5,000+. Chicago’s trip-based model has more than 16,000 sub-zones for trip generation. Los Angeles’s trip-based model uses two tiers of nested TAZs, with the lower tier containing over 11,000 zones. San Diego’s trip-based model (and ABM in development) similarly has nearly 5,000 TAZs and over 21,000 master geographic reference areas (MGRAs); non-motorized trips shorter than 1.5 miles use MGRA-to-MGRA network skims. Such TAZ-parcel intermediaries are stepping stones toward the more disaggregate spatial units (parcels) at which synthetic populations are generated in some activity-based models.

Activity-Based Modeling Activities

The most frequently selected responses related to activity-based models. Over half of MPOs indicated conducting activity and travel surveys (55%), while activity-based models are in progress or planned by fourteen (54%); three responding MPOs already use ABMs. It is notable that five MPOs planning ABMs do not currently model non-motorized travel. These results

confirm that an increasing number of regions are turning to activity-based models and tour-based travel frameworks for their travel demand forecasting needs (24). One advantage of ABMs is that the typically-smaller spatial scale is better able to represent the shorter distances over which walk trips occur and the localized nature of the influences on walking travel behavior. Also, tour-based frameworks can allow for a clearer and more realistic representation of modal options and intra-household interactions.

Non-Motorized Network Assignment

Although not a survey question, this study found two regions (Portland and San Francisco) that have completed and at least two other regions (Philadelphia and San Diego) that are currently engaged in the development of network assignment processes for bicycle and/or walk trips. Non-motorized assignment can improve estimates of actual walk and bicycle travel times to feed back into earlier modeling stages. Past barriers, including insufficiently-detailed sidewalk and bikeway networks and the lack of walk and bicycle route data, are falling. In recent years, GPS-based travel surveys and GPS trace analyses have made possible the creation of bicycle route choice and network assignment models (25, 26). It is only a matter of years or even months before the first walk trip network assignment process becomes operational in a regional travel demand forecasting model.

In the meantime, aspects of preferred walk and bicycle routes can be incorporated into models through network skim modifications. Sacramento's bicycle skims use a network with link distances that have been adjusted based on preferences for or aversions to various cycling conditions; this generates a preferred route for which an actual distance is calculated. A similar method could be developed for walk trips, considering speed and volume of traffic, sidewalk buffer or exposure, and grade, among other variables.

CONCLUSION

The stage is set for significant improvements in the regional modeling of pedestrian travel that will make travel forecasting tools more sensitive to policy concerns, such as evaluating the congestion and emissions effects of mode shifts resulting from smart-growth land use scenarios. At the same time, these models should become more useful for pedestrian planning purposes. The application of travel demand forecasting techniques to synthetic populations at disaggregate spatial scales, alongside non-motorized network assignment, would provide a wealth of detailed walking demand data that, even if crudely estimated, rivals the product of other pedestrian aggregate demand and sketch planning tools. Even if walking trips are not carried through the entire demand modeling structure, they can be spun off to create a stand-alone pedestrian demand tool.

This paper fills a gap in the literature by documenting the development and current state-of-the-practice of representing pedestrian travel in MPO regional travel demand forecasting models. It comprehensively describes and discusses the modeling frameworks, model structures, and variables used, providing a snapshot of how large MPOs currently account for walk and non-motorized trips. This review also identifies best-practice regional pedestrian modeling techniques and suggests opportunities for improvement.

MPO staff members can use this review to identify how their models compare to other modeling techniques, select those methods that are most applicable to their organization's planning needs and modeling capabilities, and/or identify the practices that will provide the greatest return on investment. Other parties interested in predicting pedestrian demand can

1 reference this paper when borrowing or developing forecasting procedures of their own. Future
2 researchers can also use this paper as a benchmark upon which to evaluate the progress of
3 representing pedestrian travel in regional demand forecasting models.
4

5 **ACKNOWLEDGEMENTS**

6 This work was made possible by a project grant from the Oregon Research and Education
7 Consortium and a Graduate Fellowship from the Dwight David Eisenhower Transportation
8 Fellowship Program. Contributions from MPO staff members who responded to the survey are
9 greatly appreciated. The authors also thank colleagues from Metro, Portland State University,
10 Toole Design Group, and the Universities of California, Berkeley and Davis for their insights
11 and interest in this topic.

1 REFERENCES

- 2 1. Cambridge Systematics, and Barton Aschman Associates. *Short-Term Travel Model*
3 *Improvements: Final Report*. Publication DOT-T-95-05. Travel Model Improvement
4 Program, Federal Highway Administration, U.S. Department of Transportation, 1994.
- 5 2. Purvis, C. Review of the Literature: Home-Based Work Mode Choice Models: Technical
6 Memorandum HBWMC #1. Memo. Metropolitan Transportation Commission, 1997.
- 7 3. Replogle, M. Integrating Pedestrian and Bicycle Factors into Regional Transportation
8 Planning Models: Summary of the State-of-the-art and Suggested Steps Forward. *Urban*
9 *Design, Telecommuting and Travel Forecasting Conference*, 1997, pp. 75-94.
- 10 4. Eash, R. Incorporating Urban Design Variables in Metropolitan Planning Organizations'
11 Travel Demand Models. *Urban Design, Telecommuting and Travel Forecasting Conference*,
12 1997, pp. 167-186.
- 13 5. Eash, R. Destination and Mode Choice Models for Nonmotorized Travel. *Transportation*
14 *Research Record: Journal of the Transportation Research Board*, No. 1674, Transportation
15 Research Board, National Academies of Science, Washington, D.C., 1999, pp. 1-7.
- 16 6. Porter, C., J. Suhrbier, and W. L. Schwartz. Forecasting Bicycle and Pedestrian Travel: State
17 of the Practice and Research Needs. *Transportation Research Record: Journal of the*
18 *Transportation Research Board*, No. 1674, Transportation Research Board, National
19 Academies of Science, Washington, D.C., 1999, pp. 94-101.
- 20 7. Nourzad, F. Modeling of the Non-Motorized Travel Interregional Travel Model
21 Development (Phase I-Task 3). Memo. Wasatch Front Regional Council, 2000.
- 22 8. Rossi, T. F. Modeling Non-Motorized Travel. Presented at the 79th Annual Meeting of the
23 Transportation Research Board, Washington, D.C., 2000.
- 24 9. *Metropolitan Travel Forecasting: Current Practice and Future Direction*. Special Report
25 288. Committee for Determination of the State of the Practice In Metropolitan Area Travel
26 Forecasting, Transportation Research Board, National Academies of Science, 2007.
- 27 10. Vanasse Hangen Brustlin, Inc. *Determination of the State of the Practice in Metropolitan*
28 *Area Travel Forecasting: Findings of the Surveys of Metropolitan Planning Organizations*.
29 Committee for Determination of the State of the Practice In Metropolitan Area Travel
30 Forecasting, Transportation Research Board, National Academies of Science, 2007.
- 31 11. Liu, F., J. E. Evans, and T. Rossi. Recent Practices in Regional Modeling of Non-Motorized
32 Travel. Presented at the 91st Annual Meeting of the Transportation Research Board,
33 Washington, D.C., 2012.
- 34 12. Cambridge Systematics, Inc., Vanasse Hangen Brustlin, Inc., Gallop Corporation, C. R. Bhat,
35 Shapiro Transportation Consulting, LLC, and Martin/Alexiou/Bryson, PLLC. *Travel*
36 *Demand Forecasting: Parameters and Techniques*. NCHRP Report 716. National
37 Cooperative Highway Research Program, Transportation Research Board, National
38 Academies of Science, 2012.
- 39 13. Cambridge Systematics, Inc., and Parsons, Brinckerhoff, Quade & Douglas. *Analysis of*
40 *Alternatives: Volume 5*. Making the Land Use Transportation Air Quality Connection, 1000
41 Friends of Oregon, 1996.
- 42 14. Clifton, K. J., and C. D. Muhs. Capturing and Representing Multimodal Trips in Travel
43 Surveys: A Review of the Practice. Presented at the 91st Annual Meeting of the
44 Transportation Research Board, Washington, D.C., 2012.

- 1 15. Cambridge Systematics, Inc., Parsons, Brinckerhoff, Quade & Douglas, and S.H.Putman
2 Associates, Inc. *Model Modifications: Volume 4* (revised). Making the Land Use
3 Transportation Air Quality Connection, 1000 Friends of Oregon, 1996.
- 4 16. Parsons Brinckerhoff Quade & Douglas, Inc., Cambridge Systematics, Inc., and Calthorpe
5 Associates. *The Pedestrian Environment: Volume 4A*. Making the Land Use Transportation
6 Air Quality Connection, 1000 Friends of Oregon, 1993.
- 7 17. Transportation Planning Capacity Building Program. *Metropolitan Planning Organization*
8 *(MPO) Database*. Office of Planning, Environment & Realty, Federal Highway
9 Administration, U.S. Department of Transportation.
- 10 18. Cervero, R., and K. Kockelman. Travel Demand and the 3Ds: Density, Diversity, and
11 Design. *Transportation Research Part D: Transport and Environment*, Vol. 2, No. 3, 1997,
12 pp. 199-219.
- 13 19. Stein, B. Regional Bicycle Demand Model: In Use Today in Portland. Presented at the 13th
14 National Transportation Planning Applications Conference, Reno, Nevada, 2011.
- 15 20. Zorn, L., E. A. Sall, and M. Bomberg. Completing the Cycle: Incorporating CycleTracks into
16 SF-CHAMP. Presented at the 4th Annual Conference on Innovations in Travel Modeling,
17 Tampa, Florida, 2012.
- 18 21. Ewing, R., and R. Cervero. Travel and the Built Environment: A Meta-Analysis. *Journal of*
19 *the American Planning Association*, Vol. 76, No. 3, 2010, pp. 265-294.
- 20 22. Mohammadian, A., and Y. Zhang. Investigating Transferability of National Household
21 Travel Survey Data. *Transportation Research Record: Journal of the Transportation*
22 *Research Board*, No. 1993, Transportation Research Board, National Academies of Science,
23 Washington, D.C., 2007, pp. 67-79.
- 24 23. Johnson Gardner. *An Assessment of the Marginal Impact of Urban Amenities on Residential*
25 *Pricing*. Metro, 2007.
- 26 24. Donnelly, R., G. D. Erhardt, R. Moeckel, and W. A. Davidson. *Advanced Practices in Travel*
27 *Forecasting: A Synthesis of Highway Practice*. NCHRP Synthesis 406. National Cooperative
28 Highway Research Program, Transportation Research Board, National Academies of
29 Science, 2010.
- 30 25. Broach, J., J. Gliebe, and J. Dill. Bicycle Route Choice Model Developed Using Revealed
31 Preference GPS Data. Presented at the 90th Annual Meeting of the Transportation Research
32 Board, Washington, D.C., 2011.
- 33 26. Hood, J., E. Sall, and B. Charlton. A GPS-Based Bicycle Route Choice Model for San
34 Francisco, California. *Transportation Letters*, Vol. 3, No. 1, 2011, pp. 63-75.