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Making strides: State-of-the-practice of pedestrian forecasting in regional travel models

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Abstract

Much has changed in the 30 years since non-motorized modes were first included in regional travel demand models. As interest in understanding behavioral influences on walking and policies requiring estimates of walking activity increase, it is important to consider how pedestrian travel is modeled at a regional level. This paper evaluates the state-of-the-practice of modeling walk trips among the largest 48 metropolitan planning organizations (MPOs) and assesses changes made over the last five years. By reviewing model documentation and responses to a survey of MPO modelers, this paper summarizes current practices, describes six pedestrian modeling frameworks, and identifies trends.

Three-quarters (75%) of large MPOs now model non-motorized travel, and over two-thirds (69%) of those MPOs distinguish walking from bicycling; these percentages are up from nearly two-thirds (63%) and one-half (47%), respectively, in 2012. This change corresponds with an increase in the deployment of activity-based models, which offer the opportunity to enhance pedestrian modeling techniques. The biggest barrier to more sophisticated models remains a lack of travel survey data on walking behavior, yet some MPOs are starting to overcome this challenge by oversampling potential active travelers. Decision-makers are becoming more interested in analyzing walking and using estimates of walking activity that are output from models for various planning applications. As the practice continues to mature, the near future will likely see smaller-scale measures of the pedestrian environment, more detailed zonal and network structures, and possibly even an operational model of pedestrian route choice.

Introduction

A growing number of U.S. metropolitan planning organizations (MPOs) have incorporated walking and other non-motorized modes into their regional travel demand forecasting models (*1*). These models are used for long-range planning, allowing regions to analyze land use and transportation scenarios and projects for their impacts on walking and bicycling. Models that can forecast walking also have many other applications. In the short-term, they are useful for prioritizing non-motorized infrastructure investments. In the long run, models that are sensitive to how the pedestrian environment influences travel behavior could better predict mode shifts and the resulting impacts on motor vehicle emissions of greenhouse gases and other air pollutants. Regional pedestrian models can also inform traffic safety analyses and health impact assessments, providing needed estimates of the location and number of walk trips.

Partly in response to these new policy demands and partly due to advances in computational power, travel demand models are becoming more sensitive to finer-grained representations of travelers themselves and the environments through which people travel. The growing number of implemented activity-based models is one example of this evolution. Two other major trends support these modeling enhancements. First, archived spatial data on the built environment are becoming ubiquitous, allowing small-scale, pedestrian-relevant environmental measures to be included in models (*2*). Second, research on pedestrian travel behavior and its environmental determinants has advanced to the point of offering at least initial guidance about which relationships may be important to represent (*3*, *4*).

In the face of these trends and opportunities, MPOs have taken various approaches to characterizing walk trips in their travel demand models. The purpose of this study is to assess the state of the practice with respect to how pedestrian travel is incorporated into these regional models; specifically, this paper reviews if and how the largest 48 MPOs model walk trips. The authors assess frameworks, spatial scales, behavioral and environmental data, applications, challenges, and innovations. This paper offers agency and consultant staff a better understanding of how regional pedestrian modeling is currently done and how it might evolve in the future, so that they can adapt techniques and improve their own models. It also serves as an update to several other recent (and not-so-recent) reviews on this topic (*1*, *5–8*).

A few notes about the scope of this study are warranted. First, although the focus of this paper is on walking or pedestrian travel, some of its results may also be relevant for bicycle modeling. Walking and bicycling modes have been frequently lumped into a single "non-motorized" mode for modeling purposes. This practice is starting to change, and bicycle modeling has in some ways eclipsed pedestrian modeling, especially in the area of route choice and trip assignment procedures. We encourage interested parties to examine the state of the practice of regional bicycle modeling in more detail (*9–11*), as this is beyond the scope of this study. Second, we focus on "pure" walk trips, not instances of walking linked to accessing other modes. Modeling practices for walk-access-to-transit trips are relatively well-established, although they may still benefit from some of the discussions herein. Third, this paper is narrowly focused on large MPO regional forecasting models. We acknowledge that many modeling innovations are taking place at sub-regional scales and through smaller and non-MPO agencies, including the use of sketch-planning and accessibility-based tools (*12–15*). Some of these standalone pedestrian planning tools may be easier to develop, more agile to apply, and/or better suited to addressing certain policy questions than are regional travel demand models (*14*), yet we leave this subject for others to address. Fourth, our objective is to provide a broad overview of the state of the practice; therefore, we do not have the space to describe specific case studies in depth. A number of other pedestrian modeling resources (*8*, *14*, *15*) include such case studies, and we encourage interested readers to contact the MPOs we describe throughout this paper for more information on their respective practices.

The remainder of this paper begins with a Background giving a brief history of non-motorized and pedestrian modeling practices and trends. Next, a short Method section describes the state-of-the-practice survey and analysis procedures. The Results section then presents and discusses findings regarding pedestrian modeling frameworks, spatial scales and networks, and built environment measures. It also discusses barriers and challenges as well as model applications. The paper concludes by summarizing the major contributions of this work, describing innovative pedestrian modeling practices, and noting opportunities and directions for the field.

Background

Until the early 1990s, regional travel demand models did not consider walking, for several reasons. First, the conventional four-step travel forecasting process evolved out of multiple efforts in the 1950s and 1960s during a time in which regional and national transportation policies were focused on planning for and accommodating rapid growth in automobile travel and constructing the Interstate Highway System (*16*). Traffic analysis zones were too large and street networks too coarse to adequately represent walking trips. By the 1970s, “multimodal” models could also analyze travel by public transit; they were developed in part to support applications for new federal transit grant programs (*16*). Second, the travel surveys and other data collection processes necessary to construct these models either underreported or did not consider non-motorized travel (*17*, *18*). In fact, many surveys in the 1980s asked for non-motorized trips to be reported only if they were home-based work (i.e., commute) trips (*19*).

As far as we have been able to document, the first regional travel demand model to include non-motorized travel was developed in 1988 at the Metropolitan Service District (now Metro) in Portland, Oregon (*20*). In preparation for a light-rail expansion project, a 1985 travel survey was used to estimate a motorized/non-motorized mode split model for home-based trips, based on trip distance and the relative number of cars and workers per household; other trip purposes used a static non-motorized mode share (*7*, *17*, *21*). In 1993, Sacramento’s MPO was perhaps the first to separate walk and bicycle modes within a mode choice model (*20*). Despite these initial efforts, models were slow to change: none of the ten major MPOs (not including Portland) examined in a 1992 study modeled non-motorized modes (*22*, cited in *20*). Nevertheless, by the late 1990s, regions as diverse as Baltimore, Boston, Chicago, Hampton Roads, Los Angeles, Philadelphia, Portland, Sacramento, and the San Francisco Bay Area either had or were in the late stages of incorporating non-motorized modes into their models (*7*, *20*).

Contemporaneous to non-motorized modes being added to regional travel models was an increased awareness of, interest in, and research on built environment and land use effects on travel demand (e.g., *23*). Several pedestrian-specific measures of the built environment were developed for use in travel forecasting. One of the first measures, the pedestrian and bicycle friendliness index—a combination of land-use mix, building setback, bus shelters, bicycle infrastructure, and extent of sidewalks—was developed in 1988 at the Maryland-National Capital Park and Planning Commission (*5*, *17*). A second influential project during the early-to-mid 1990s—Making the Land Use, Transportation, Air Quality Connection (LUTRAQ)—developed the pedestrian environment factor (PEF) for Portland’s MPO, Metro (*5*, *7*, *17*). The PEF, an index representing the ease of street crossings, sidewalk continuity, grid street pattern, and terrain, was used in Metro’s pre-mode choice non-motorized split model (*21*, *24*). The PEF or similar indexes have since been applied in many models, including in the Chicago, Hampton Roads, Miami, Philadelphia, Portland, Sacramento, and Salt Lake City regions (*7*, *20*, *25–27*). In time, agencies (including Portland's Metro) have transitioned from subjectively defined indices to more objectively calculated and empirically defined pedestrian environment measures (*1*).

Advances in pedestrian modeling have continued into the 21st century as more MPOs have added non-motorized modes to their travel demand forecasting models. A 2005 TRB study found that more than half of large MPOs (54%, $N = 35$) reported modeling non-motorized travel (*28*, *29*). A few years later, somewhere between almost half (41–45%, $N = 29$) and around two-thirds (68%, $N = 28$) of large MPOs included non-motorized travel in their trip-based models, with about half (53%) of those doing so in the mode choice stage (*8*). In 2012, two of the authors of the present article surveyed the 48 largest MPOs and found that nearly two-thirds (63%) modeled non-motorized travel, with about half (47%) of those distinguishing between walking and bicycling (*1*). This paper updates that study by summarizing the state of the practice of pedestrian modeling as of 2017: three-quarters (75%) of large MPOs model non-motorized travel, and more than two-thirds (69%) of those distinguish between walking and bicycling.

Method

To assess the current state of pedestrian demand modeling practice, we conducted a survey of the 48 largest MPOs, those serving populations greater than 1,000,000 people as of the 2010 US Census (*30*). TABLE 1 lists these MPOs and their respective major cities. We decided to focus on only the largest MPOs for several reasons. First, they collectively serve over 156 million people, slightly more than half of the US population; decisions made at large MPOs can impact projects and plans that affect the lives of many people. Second, large MPOs tend to have larger staffs and greater resources for investing in research and development; they can be industry leaders in travel demand modeling.

Information on how walking is addressed within regional travel forecasting models was obtained in a variety of ways. We first developed an online questionnaire for MPO modeling staff members, including questions about model structures, incorporation of walking (and bicycling) modes, spatial and network systems, built environment measures, barriers and challenges, and planning applications of walking forecasts. In May–June 2017, this survey was sent via email to staff at all 48 MPOs; 29 responses were received, a 60% response rate. Next, we obtained and analyzed model documentation for as many MPOs as possible through agency websites, survey responses, and direct correspondence. A similar process (survey and documentation review) was conducted in 2012 (*1*); 29 responses (60%) to that survey were received. While focusing on the 2017 survey, this paper also incorporates results from the 2012 survey and compares maturity of the practice over the five-year span.

Results

Results from the MPO survey and model documentation review are presented in the sections below. First, we classify and describe six pedestrian modeling frameworks, reflecting different ways by which walking (and bicycling) can be represented in regional travel forecasting models. Next, we discuss key findings with respect to geographic and environmental attributes of the models, including spatial/zonal scales, street networks, and built environment measures. We then discuss challenges and barriers hampering further modeling of walk trips, before noting ways in which these models have been applied in practice. This section concludes with a summary of key findings.

Pedestrian modeling frameworks

After reviewing MPO model documentation and informed by previous work (*1*, *5*, *8*), we have identified six frameworks for how walking (and bicycling, or non-motorized) travel can be incorporated into model structures. There are specific variations within these typologies, but the six pedestrian modeling frameworks provide a useful approximation of the spectrum of options that have been used by MPOs. These frameworks are generically applicable to both trip-based and activity-based model structures, as both typically still follow a four-step travel forecasting process: trips (or tours), destinations, modes, and routes. The frameworks are distinguished by the point in the process where walk trips are identified. They also suggest how much information the model provides about walk trips: trips generated, trip matrices, routes, etc. FIGURE 1 represents and compares these pedestrian modeling frameworks graphically. TABLE 1 indicates the frameworks used in 2017 and in 2012 for each large MPO. The sections that follow describe each pedestrian modeling framework and summarize both current practice and recent trends.

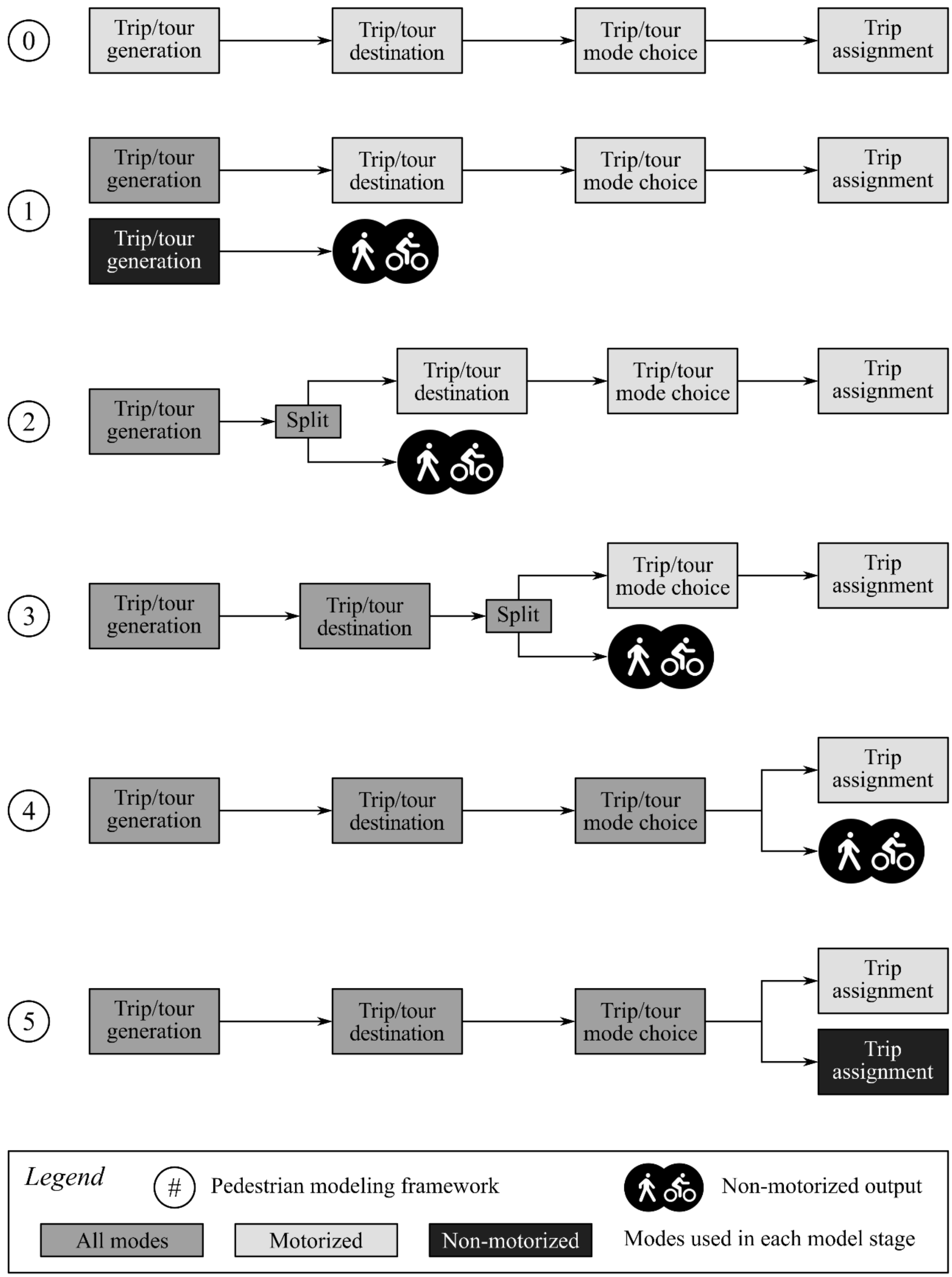

FIGURE 1 Pedestrian modeling frameworks.

TABLE 1 Large MPOs and their Pedestrian Modeling Frameworks

City, State	*Metropolitan planning organization*	*Model framework 2012*	*Model framework 2017*
Atlanta, GA	Atlanta Regional Commission (ARC)	2	4[a]
Austin, TX	Capital Area MPO (CAMPO)	4	4
Baltimore, MD	Baltimore Regional Transportation Board (BRTB)	2	2
Boston, MA	Boston Region MPO	4	4
Buffalo, NY	Greater Buffalo-Niagara Regional Transportation Council (GBNRTC)	4	4[b]
Charlotte, NC	Charlotte Regional Transportation Planning Organization (CRTPO)	4	4[b]
Chicago, IL	Chicago Metropolitan Agency for Planning (CMAP)	2	4[a]
Cincinnati, OH	Ohio-Kentucky-Indiana Regional COG (OKI)	0	0
Cleveland, OH	Northeast Ohio Areawide Coordinating Agency (NOACA)	4	4
Columbus, OH	Mid-Ohio RPC (MORPC)	4[a]	4[a,b]
Dallas, TX	North Central Texas COG (NCTCOG)	0	0
Denver, CO	Denver Regional COG (DRCOG)	4[a]	4[a]
Detroit, MI	Southeast Michigan COG (SEMCOG)	0	2
Fort Lauderdale, FL	Broward MPO	3	4[a]
Houston, TX	Houston-Galveston Area Council (HGAC)	0	0
Indianapolis, IN	Indianapolis MPO	0	4
Jacksonville, FL	North Florida Transportation Planning Organization (TPO)	0	4[a]
Kansas City, MO	Mid-America Regional Council (MARC)	0	0
Las Vegas, NV	Regional Transportation Commission of Southern Nevada (RTC)	0	2
Los Angeles, CA	Southern California AOG (SCAG)	4	4[a]
Louisville, KY	Kentuckiana Regional Planning and Development Agency (KIPDA)	0	0
Memphis, TN	Memphis Urban Area MPO (MPO)	4	4
Miami, FL	Miami-Dade Transportation Planning Organization (TPO)	3	4[a]
Milwaukee, WI	Southeastern Wisconsin RPC (SEWRPC)	1	4
Minneapolis, MN	Metropolitan Council	4	4[a]
Nashville, TN	Nashville Area MPO	0	4[a]
New Orleans, LA	New Orleans Regional Planning Commission (RPC)	0	0[b]
New York, NY	New York Metropolitan Transportation Council (NYMTC)	3[a]	3[a]
Newark, NJ	North Jersey Transportation Planning Authority (NJTPA)	2	2
Oklahoma City, OK	Association of Central Oklahoma Governments (ACOG)	0	0[b]
Orlando, FL	MetroPlan Orlando	0	0
Philadelphia, PA	Delaware Valley RPC (DVRPC)	1	2
Phoenix, AZ	Maricopa AOG (MAG)	0	4[a]
Pittsburgh, PA	Southwestern Pennsylvania Commission (SPC)	0	0[b]
Portland, OR	Metro	4	4
Providence, RI	Rhode Island State Planning Council	0	0
Raleigh, NC	North Carolina Capital Area MPO (CAMPO)	3	3

		Model framework	
City, State	*Metropolitan planning organization*	*2012*	*2017*
Sacramento, CA	Sacramento Area COG (SACOG)	4[a]	4[a]
Salt Lake City, UT	Wasatch Front Regional Council (WFRC)	4	4
San Antonio, TX	Alamo Area MPO (AAMPO)	4	4
San Diego, CA	San Diego AOG (SANDAG)	4	4[a]
San Francisco Bay Area, CA	Metropolitan Transportation Commission (MTC)	4[a]	4[a]
Seattle, WA	Puget Sound Regional Council (PSRC)	4	4[a]
St. Louis, MO	East-West Gateway COG (EWG)	4	4
Tampa, FL	Hillsborough County MPO	0	0
Virginia Beach, VA	Hampton Roads Transportation Planning Organization (HRTPO)	0	0
Washington, DC	National Capital Region Transportation Planning Board (TPB)	2	2
West Palm Beach, FL	Palm Beach Transportation Planning Agency (TPA)	3	4[a]
Total, Option Zero	Models that do not include non-motorized travel.	18	12
Total, Option One	Models with separate non-motorized trip generation.	2	0
Total, Option Two	Models that split non-motorized trips before trip distribution.	5	6
Total, Option Three	Models that split non-motorized trips after trip distribution.	5	2
Total, Option Four	Models with non-motorized modes in mode choice.	18	28
Total, Option Five	Models that assign walk & bicycle trips to the network.	0	0
	Total activity-based models	5	17
	Total models reviewed	48	42

Notes:
[a] An activity-based model.
[b] For these MPOs, survey responses were not received and recent model documentation was not found, so it was assumed that pedestrian modeling frameworks have not changed.
Acronyms:
AOG = Association of Governments; COG = Council of Governments;
MPO = Metropolitan Planning Organization; RPC = Regional Planning Commission

Option Zero

This framework represents models that exclude walk (and bicycle) trips and explicitly only consider motorized transportation. As a result, it is impossible to use these models alone to evaluate improvements to pedestrian infrastructure and corresponding effects on non-/motorized trip-making.

This framework is becoming less common as more MPOs have some representation of non-motorized modes in their models. While 18 MPOs (38%) used this framework in 2012, 12 MPOs (25%) use this framework in 2017.

Option One

MPOs with option one model frameworks forecast walking or non-motorized travel using a trip/tour generation process that is separate from that used for motorized modes, applying unique trip production/attraction rates or models. Thus, they can evaluate how at least the number of walk trips might change given future scenarios. More advanced versions of this framework could include a completely separate multi-step modeling process for walk (and/or bicycle) trips. A significant downside to this framework is the lack of interaction between the motorized and non-motorized model processes, which does not allow for representing mode shifts in response to external, transportation, or environmental changes. Nevertheless, it is a simple way for MPOs to begin modeling walk trips without having to fully update the rest of their travel demand models.

Continuing with trends identified in 2012, MPOs are moving away from using this framework, which was once relatively common (*1*). Of the two MPOs (4%) that used this structure in 2012, Philadelphia moved to an option two framework, and Milwaukee moved to an option four framework. Based upon the model documentation reviewed, no large MPO currently uses this pedestrian modeling structure.

Option Two

In option two models, trips/tours by all modes are generated, but walk or non-motorized trips are removed using a special mode split model (usually binary logit) prior to trip/tour distribution or destination choice. The modal substitution patterns allowed by models of this type depend upon the variables, sensitivities, and feedback mechanisms incorporated into generation models. Therefore, this framework can yield walk trip productions/attractions but does not link trip ends together or assign destinations to walk trips. As a result, such models may not be able to determine the locations of specific barriers to walking or potential impacts of pedestrian infrastructure improvements, instead only highlighting areas that originate (and in the case of trip attractions, attract) more or fewer walk trips.

For some MPOs, the option two framework represents one step on a natural evolution to more robust pedestrian modeling capabilities. Although a similarly small number of MPOs use this framework today as did five years ago—five (10%) in 2012 and six (13%) in 2017—several agencies have shifted: Detroit's and Las Vegas's MPOs jumped from an option zero model, Philadelphia's MPO evolved from using an option one model, while Chicago's and Atlanta's MPOs began using option four frameworks.

Option Three

Like in option two, this framework describes models that also incorporate a special (often binary logit) mode split model, except that for option three, walk or non-motorized trips are separated after trip/tour distribution or destination choice but before mode choice. This pre-mode-choice/split model has advantages: by analyzing both trip ends, it accommodates the use of level-of-service variables (e.g., travel time or distance), and it allows for the creation of an origin-destination matrix of walk trips. It may be easier for MPOs with insufficient records of walk or non-motorized trips to estimate a binary mode split model than a full mode choice model; the downside is the ability to represent only limited modal substitution patterns.

As with the option two framework, option three seems to be used as a stepping-stone to more sophisticated pedestrian modeling frameworks. In 2012, five MPOs (10%) used this model structure. In 2017, only New York and Raleigh (two, 4%) continue to do so; the other three MPOs moved to the option four framework, described below.

Option Four

Models with an option four framework use tour/trip mode choice models to distinguish walk or non-motorized trips from trips by other modes. There is considerable variety within this framework: some models are trip-based while others are tour- or activity-based; some group walking and bicycling together into a single non-motorized mode while others keep them separate; and both multinomial and nested logit models are utilized. This framework accommodates more flexible mode shifts and produces origin-destination matrices of walk trips, but it also requires more walk (and bicycle) trip survey records for estimating the mode choice model.

As the most common pedestrian modeling framework, this is now standard practice. In 2012, 18 MPOs (38%) used this framework; over half of large MPOs (28, 58%) do so in 2017. This increase has largely corresponded with the rise of activity-based modeling; eight of the ten MPOs that developed new option four models did so in the process of developing activity-based models. Furthermore, most (25, 89%) option four mode choice models include walking and bicycling as separate modes.

Option Five

The final pedestrian modeling framework takes walk or non-motorized trips that are estimated from a pre-/mode choice step and assigns them to a route on a non-motorized network. This may be done crudely by models utilizing the earlier frameworks when calculating walk-specific level-of-service variables (i.e., skims), but only models that go beyond simple shortest-path routing algorithms qualify. With predicted pedestrian paths, many new and more detailed model applications arise: specific non-motorized infrastructure projects, safety analysis, health impact assessments, and more (see the Application section for more details). Many of the same link-based analyses that are currently done for automobile travel could also be performed for walk trips.

For bicycle modeling, this framework represents emerging practice. Incorporating route choice models estimated with field data, forecasting models in places like Minneapolis, Portland, San Diego, San Francisco, and Seattle now route bicycle trips on a network, according to survey responses and published literature (*9*, *10*). Pedestrian route choice modeling has lagged behind other aspects of pedestrian modeling and remains in the research realm. To our knowledge, no large MPOs' models currently assign pedestrian trips, although Boston and Phoenix reported planning to start doing so during model updates. Part of this gap is due to a relative lack of research on factors influencing pedestrian route choice (*31*). Another contributing factor may be the fact that link-based pedestrian capacity issues are rare. However, safety issues are a ubiquitous concern that may benefit from pedestrian trip assignment being incorporated into regional models.

Activity-based models

Activity-based models (ABMs), while similar to trip-based models, accommodate more complex and realistic linkages between activities and travel both for individuals and for households (*32*). Nevertheless, they still involve a similar process: activity generation, destination choice, mode choice, and network assignment; therefore, we include then in TABLE 1. Continuing recent trends (*28*, *33*), ABMs have become more widespread among large MPOs in the last five years, increasing from five (10%) in 2012 to 17 (35%) in 2017. As previously mentioned, this growth in ABMs has brought with it a growth in utilization of the option four framework; only Indianapolis and Milwaukee moved to this framework without also implementing an ABM. It is reasonable to assume that the complex transition to an ABM provided many MPOs the opportunity to add more sophisticated walk or non-motorized modeling capabilities. Furthermore, most ABMs are based on a few common frameworks (*32*, *34*, *35*) that typically include walking as an option in mode choice models. In the 2017 survey, seven MPOs (23%)—Baltimore, Boston, Cincinnati, Cleveland, Houston, Philadelphia, and Portland—reported preparing to transition to ABMs in the near future; only three of these MPOs already utilize an option four framework. Of course, an ABM does not automatically count as an option four pedestrian modeling framework; see New York for an example.

Geographies and environments

Spatial/zonal scales and networks

The 2017 questionnaire asked respondents to report the spatial/zonal system used to represent travel; there were 23 responses, with 14 responses representing trip-based models and nine from MPOs with ABMs. Many trip-based models had transportation analysis zones (TAZs) that roughly followed Census geographies: tracts, block groups, or a combination of the two (with the smaller block groups more commonly used in denser parts of the region). Numbers of zones were in the 1,000–5,000 range. Several ABMs used a greater number of parcels instead. Only one MPO (San Diego) reported using specific smaller zones for non-motorized analysis: approximately five subzones for every TAZ.

The 2017 survey also asked about the networks and speeds used to represent non-motorized travel and to calculate walk/bicycle travel times for mode choice; 12 responses were received. Many networks for non-motorized travel started with the roadway network (including minor arterials or collectors, but often excluding local streets), removed limited-access highways, and added some (usually but not all) off-road paths and trails. ABMs were more likely to utilize an all-streets network. Reported walking speeds ranged from 2.5–3.0 mph and bicycling speeds were in the range of 8–12 mph; these values closely match the same speed ranges documented in the 2012 review (*1*). Denver and Boston reported that their models vary bicycling speeds to account for terrain and specific infrastructure locations.

Built environment measures

Both the 2017 questionnaire (N = 27) and the 2012 study (N = 26) identified specific measures of the built environment that are used to represent walking or non-motorized travel conditions. Density-type variables remain most common: 22 MPOs (85%) in 2012 and 24 MPOs (89%) in 2017 reported using population, employment, and/or activity density. Only five MPOs (19%) used a diversity variable like land-use mix in 2012 to model pedestrian travel; in 2017, this number has grown to 16 reported MPOs (59%). Among those reporting using street network design variables like block, intersection, or street network density, 10 MPOs (38%) modeled walk trips using these variables in 2012; about the same number of MPOs (13, 48%) included these design variables in their models in 2017. Currently, some MPOs are even representing small-scale measures of the pedestrian environment, including traffic control devices (five, 19%), sidewalks and other pedestrian facilities (four, 15%), and traffic calming devices (three, 11%).

Barriers and challenges

Surveys in both 2012 (N = 19) and 2017 (N = 25) asked MPO modelers about challenges faced when modeling walking or non-motorized travel and barriers to doing so or doing so more robustly. These barriers and challenges can be grouped into the general categories of data and forecasting as well as decision-maker interest, described in the subsections below.

Data and forecasting

Behavioral data remains among the most substantial challenges for modeling walking; one MPO modeler stated that a "Lack of data is by far our biggest issue." In 2012, 16 MPOs (84%) described limited records of walking (and bicycling) in household travel surveys as being a barrier. In 2017, all 25 MPOs (100%) reported not having enough non-motorized behavioral data for model development and/or validation, and 21 (84%) listed few resources for data collection as being a challenge. Written responses also noted that travel surveys did not always adequately represent non-motorized travel. Some MPOs reported over-sampling walking and bicycling modes in order to help alleviate this problem.

Another data limitation, perhaps more relevant for forecasting, is about measures of the built environment. In the 2017 survey, 12 MPOs (48%) listed forecasting future scenarios as a challenge. This could be tied to challenges measuring or predicting pedestrian-relevant environmental and land use attributes. Ten MPOs (40%) had insufficient information on the built environment in 2017; in 2012, 11 MPOs (58%) noted limited resources for collecting such data. A related issue (not addressed in the surveys) could be that MPOs often rely on cities and counties to report projects and land use changes in future scenarios, and there may be variations in how their constituent municipalities collect and archive this information. Additionally, some respondents (in both surveys) noted a more fundamental issue: that a large regional model may not be the best tool for analyzing shorter-distance walk trips.

Decision-maker interest

Although data issues remain challenging, one barrier that may be lessening is interest in walking and non-motorized travel from decision-makers. In 2012, nine MPOs (47%) noted a lack of decision-maker interest in their rationale for not further modeling non-motorized travel. In 2017, only four (16%) MPOs reported non-motorized travel not being a priority among decision-makers, and only one (4%) said it was not a priority among the public. From this small-sample survey, it appears that there is increasing interest among decision-makers and the public in being able to understand and model walking and bicycling at a regional level.

Applications

The outputs of travel demand models—walk trips, to varying degrees of specificity—have many potential uses to MPO respondents. To examine planning applications that may be motivating improvements to pedestrian modeling practice, the 2017 survey asked respondents (N = 23) to report both current and desired future applications for estimates of walking travel. (The 2012 survey did not examine this issue.) The most common use of these types of non-motorized model outputs was for traditional activities like project prioritization (14, 61%) and scenario planning (10, 43%). Other more specialized applications included corridor planning (10, 43%), traffic safety analysis (eight, 35%), health impact assessment (eight, 35%), and infrastructure gap analysis (seven, or 30%). For instance, MPOs in the Portland and San Francisco Bay areas use their travel demand models to inform public health performance measures related to physical activity (*36*). Interestingly, five MPOs (22%) reported not using estimates or forecasts of walk trips for any particular planning purpose.

Respondents were interested in using estimates of walk (and bicycle) trips for all of these applications, including project prioritization (18, 78%), scenario planning (15, 65%), corridor planning (14, 61%), and traffic safety analysis, health impact assessment, and infrastructure gap analysis (all 13, 57%). These results suggest an interest in and willingness to use the outputs of more robust pedestrian models for a variety of planning applications.

Discussion

This study analyzed the current state of the practice with respect to incorporating pedestrian travel in regional travel demand forecasting models at the 48 largest MPOs. It specifically updated and compared results with a 2012 study on the same subject (*1*), allowing for an analysis of trends in pedestrian modeling. In the paragraphs below, we summarize key findings, discuss innovative practices, and consider future directions in the areas of pedestrian modeling frameworks, behavioral and environmental data (and representations thereof), and interest in and applications for estimates of walking activity.

The last five years have seen a marked increase in the number of agencies whose models represent walk or non-motorized trips to some degree. Furthermore, pedestrian modeling capabilities have become more robust and sophisticated, moving later in the travel demand modeling process and yielding more detailed outputs of walking activity. The option four framework—modeling walking alongside other modes in the mode choice module—has become common practice. From the perspective of model frameworks, innovations will likely soon happen in the area of pedestrian route choice: assigning walk trips to the network. This task has been hampered by a relative lack of research on pedestrian route choice and other characteristics of walking behavior, but a handful of MPOs plan to develop ways to assign pedestrian trips to the network in the near future.

The growing adoption of activity-based models has helped to propel pedestrian modeling practice forward. ABMs can capture the constraints and linkages among individual/household travel and often characterize walk trips within mode choice stages by default. They are also more likely to utilize more detailed spatial/zonal structures and more complete networks of streets and pedestrian paths. (Of course, many of these innovations are not limited to ABMs; even a basic four-step model could employ fine-grained built environment measures and more accurately represent walk trip distances by using disaggregate zonal and network structures.) Further diffusion of ABMs may be one of the most effective ways of increasing both the number and sophistication of pedestrian-sensitive regional travel forecasting models. However, this opportunity requires ABM developers to carefully consider the best ways to model walk trips. Representations should take into account current knowledge about pedestrian behavioral influences from research and allow for the emergence of more detailed and widely available pedestrian environment measures.

Regarding representation of the built environment, traditional measures of density, diversity, and design still predominate, although land-use mix (diversity) variables saw a significant increase in use from 2012 to 2017. Some MPOs have begun to collect and represent micro-scale attributes like sidewalks, traffic calming devices, crosswalks, and stop signs (*37*), allowing for the development of more complex and behaviorally-sensitive models. A related issue is the representation of zones and networks in travel demand models. Zonal and network structures have not changed significantly: models still tend to use a few thousand zones and rough approximations of street networks. However, as computational limitations become less problematic, models may be able to utilize smaller spatial units such as "pedestrian analysis zones"

(*38*), and more detailed networks, similar to ABMs detailed above. These trends may soon allow for walk trips to be modeled while being nearly unaffected by zonal and network aggregation issues.

Although obtaining (and forecasting) measures of the pedestrian environment is challenging, the more critical barrier is a lack of data on walking from both pedestrian counting programs and travel surveys. Better pedestrian models are impossible without better data, and according to our survey results, this is the biggest impediment currently faced by MPOs. Nevertheless, some MPOs are making strides to overcome the significant data barrier. For instance, during their regional household travel surveys, Portland and San Diego specifically oversampled households with higher likelihoods of walk and bicycle trip-making, ensuring that there would be a sufficient sample of trips for estimating mode choice models with these modes. As new travel surveying efforts get underway, it is important to consider how to target a representative and sufficiently large sample of these active travelers for future model estimation.

Although data challenges remain, a lack of decision-maker interest is no longer the barrier it was just five years ago. MPOs and their leaders are becoming increasingly aware of the value of being able to analyze, model, and predict walking (and bicycling) travel demand. There is growing interest in using model outputs, including walk trip estimates, for a variety of traditional and emerging planning applications. For instance, MPOs are beginning to consider the health and safety impacts of transportation systems in their regional planning initiatives (*36*). Numbers of walk trips along or across a corridor can be used as a measure of exposure when calculating crash rates and assessing traffic safety. Additionally, walk trips with detailed origins and destinations could be used to calculate units of physical activity (metabolic equivalents, METs), values that are critical inputs to health impact assessment models. Routing walk trips on a pedestrian-relevant network would only improve the precision of these estimates. The increased interest in non-motorized travel modeling and its applications among decision-makers and the public removes a key challenge, leaving, for many MPOs, only resources and data as remaining barriers to a more complete representation of pedestrians in travel demand models.

Conclusion

Through a thorough review of the state of the practice of modeling walk trips among large MPOs, this study contributes to travel demand modeling practice. It fills a gap in the literature in this regard. It provides an updated snapshot of how models currently account for walk and non-motorized trips and sketches broad trends about the evolution of practice. The review also identifies best-practice regional pedestrian modeling techniques and suggests opportunities for the field's next steps.

Staff members at consultancies, MPOs, and other government agencies can use this review to compare their own models to others currently in the field, identifying potential techniques to borrow. Teams looking to improve their pedestrian modeling capabilities can use the summaries contained in this paper to select the framework best suited to their organizations' planning needs and modeling capabilities. Other parties interested in obtaining estimates of walking activity can reference this study when borrowing or developing forecasting procedures of their own. Finally, researchers today and in the future can use this paper as a benchmark against which to evaluate the progress of how urban travel demand models forecast walking. Overall, pedestrian modeling practices still lag those for other modes, but they are making strides and moving forward.

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Author contribution statement

The authors confirm contribution to the paper as follows: study conception and design: PAS, KJC; data collection: JCT; analysis and interpretation of results: PAS, JCT, JPO, RJS, KJC; draft manuscript preparation: PAS, JCT, JPO, RJS, KJC. All authors reviewed the results and approved the final version of the manuscript.

References

1. Singleton, P. A., and K. J. Clifton. Pedestrians in Regional Travel Demand Forecasting Models: State-of-the-Practice. Presented at the 92nd Annual Meeting of the Transportation Research Board, Washington, DC, 2013.
2. Brownson, R. C., C. M. Hoehner, K. Day, A. Forsyth, and J. F. Sallis. Measuring the Built Environment for Physical Activity: State of the Science. *American Journal of Preventive Medicine*, Vol. 36, No. 4, 2009, pp. S99–S123. https://doi.org/10.1016/j.amepre.2009.01.005.
3. Saelens, B. E., and S. L. Handy. Built Environment Correlates of Walking: A Review. *Medicine and Science in Sports and Exercise*, Vol. 40, No. 7 Suppl, 2008, pp. S550–556. https://doi.org/10.1249%2FMSS.0b013e31817c67a4.
4. Ewing, R., and R. Cervero. Travel and the Built Environment: A Meta-analysis. *Journal of the American Planning Association*, Vol. 76, No. 3, 2010, pp. 265–294. http://doi.org/10.1080/01944361003766766.
5. Replogle, M. Integrating Pedestrian and Bicycle Factors into Regional Transportation Planning Models: Summary of the State-of-the-art and Suggested Steps Forward. *Urban Design, Telecommuting and Travel Forecasting Conference*, 1997, pp. 75–94.
6. Porter, C., J. Suhrbier, and W. L. Schwartz. Forecasting Bicycle and Pedestrian Travel: State of the Practice and Research Needs. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1674, 1999, pp. 94–101. https://doi.org/10.3141/1674-13.
7. Rossi, T. F. Modeling Non-Motorized Travel. Presented at the 79th Annual Meeting of the Transportation Research Board, Washington, DC, 2000.
8. Liu, F., J. Evans, and T. Rossi. Recent Practices in Regional Modeling of Nonmotorized Travel. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2303, 2012, pp. 1–8. https://doi.org/10.3141/2303-01.
9. Broach, J., J. Dill, and J. Gliebe. Where do Cyclists Ride? A Route Choice Model Developed with Revealed Preference GPS Data. *Transportation Research Part A: Policy and Practice*, Vol. 4, No. 10, 2012, pp. 1730–1740. https://doi.org/10.1016/j.tra.2012.07.005.
10. Hood, J., E. Sall, and B. Charlton. A GPS-Based Bicycle Route Choice Model for San Francisco, California. *Transportation Letters*, Vol. 3, No. 1, 2011, pp. 63–75. http://doi.org/10.3328/TL.2011.03.01.63-75.

11. Zimmermann, M., T. Mai, and E. Frejinger. Bike Route Choice Modeling using GPS Data Without Choice Sets of Paths. *Transportation Research Part C: Emerging Technologies*, Vol. 75, pp. 183–196. https://doi.org/10.1016/j.trc.2016.12.009.
12. Bomberg, M., L. Zorn, and E. Sall. Incorporating User Based Perspective of Livability Projects in SF-CHAMP Mode Choice Models. *Transportation Letters*, Vol. 5, No. 2, 2013, pp. 83–95. http://doi.org/10.1179/1942786713Z.00000000010.
13. Hood, J., G. Erhardt, C. Frazier, and A. Schenk. Estimating Emissions Benefits of Bicycle Facilities with Stand-Alone Software Tools: Incremental Nested Logit Analysis of Bicycle Trips in California's Monterey Bay Area. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2430, 2014, pp. 124–132. https://doi.org/10.3141/2430-13.
14. Kuzmyak, J. R., J. Walters, M. Bradley, and K. M. Kockelman. *Estimating Bicycling and Walking for Planning and Project Development: A Guidebook*. NCHRP Report 770. Transportation Research Board, 2014. https://doi.org/10.17226/22330.
15. Aoun, A., J. Bjornstad, B. DuBose, M. Mitman, and M. Pelon. Bicycle and Pedestrian Forecasting Tools: State of the Practice. Pedestrian and Bicycle Information Center, 2015.
16. Weiner, E. *Urban Transportation Planning in the United States: History, Policy, and Practice*. Springer, New York, NY, 2013. https://doi.org/10.1007/978-1-4614-5407-6.
17. Cambridge Systematics, Inc., and Barton Aschman Associates. *Short-Term Travel Model Improvements: Final Report*. Publication DOT-T-95-05. Travel Model Improvement Program, Federal Highway Administration, U.S. Department of Transportation, 1994. https://ntl.bts.gov/DOCS/445.html.
18. Cambridge Systematics, Inc., and Parsons, Brinckerhoff, Quade & Douglas. *Analysis of Alternatives: Volume 5*. Making the Land Use Transportation Air Quality Connection, 1000 Friends of Oregon, 1996. http://www.friends.org/resources/reports#LUTRAQ.
19. Clifton, K., and C. Muhs. Capturing and Representing Multimodal Trips in Travel Surveys: Review of the Practice. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2285, 2012, pp. 74–83. https://doi.org/10.3141/2285-09.
20. Purvis, C. Review of the Literature: Home-Based Work Mode Choice Models: Technical Memorandum HBWMC #1. Memo. Metropolitan Transportation Commission, 1997.
21. Cambridge Systematics, Inc., Parsons, Brinckerhoff, Quade & Douglas, and S.H.Putman Associates, Inc. *Model Modifications: Volume 4* (revised). Making the Land Use Transportation Air Quality Connection, 1000 Friends of Oregon, 1996. http://www.friends.org/resources/reports#LUTRAQ.
22. Institute of Transportation Engineers. *Travel Demand Forecasting Processes Used by Ten Large Metropolitan Planning Organizations*. Institute of Transportation Engineers, 1994.
23. Cervero, R., and K. Kockelman. Travel Demand and the 3Ds: Density, Diversity, and Design. *Transportation Research Part D: Transport and Environment*, Vol. 2, No. 3, 1997, pp. 199–219. https://doi.org/10.1016/S1361-9209(97)00009-6.
24. Parsons Brinckerhoff Quade & Douglas, Inc., Cambridge Systematics, Inc., and Calthorpe Associates. *The Pedestrian Environment: Volume 4A*. Making the Land Use Transportation Air Quality Connection, 1000 Friends of Oregon, 1993. http://www.friends.org/resources/reports#LUTRAQ.
25. Nourzad, F. Modeling of the Non-Motorized Travel Interregional Travel Model Development (Phase I-Task 3). Memo. Wasatch Front Regional Council, 2000.

26. Eash, R. Incorporating Urban Design Variables in Metropolitan Planning Organizations' Travel Demand Models. *Urban Design, Telecommuting and Travel Forecasting Conference*, 1997, pp. 167–186.
27. Eash, R. Destination and Mode Choice Models for Nonmotorized Travel. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1674, 1999, pp. 1–7. https://doi.org/10.3141/1674-01.
28. Transportation Research Board. *Metropolitan Travel Forecasting: Current Practice and Future Direction*. Special Report 288. Transportation Research Board, 2007. http://onlinepubs.trb.org/onlinepubs/sr/sr288.pdf.
29. Vanasse Hangen Brustlin, Inc. *Determination of the State of the Practice in Metropolitan Area Travel Forecasting: Findings of the Surveys of Metropolitan Planning Organizations*. Transportation Research Board, 2007. http://onlinepubs.trb.org/onlinepubs/reports/VHB-2007-Final.pdf.
30. Transportation Planning Capacity Building Program. *Metropolitan Planning Organization (MPO) Database*. Federal Highway Administration, U.S. Department of Transportation, 2014. https://www.planning.dot.gov/mpo.asp.
31. Broach, J., and J. Dill. Using Predicted Bicyclist and Pedestrian Route Choice to Enhance Mode Choice Models. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2564, 2016, pp. 52–59. https://doi.org/10.3141/2564-06.
32. Castiglione, J., M. Bradley, and J. Gliebe. *Activity-Based Travel Demand Models: A Primer*. SHRP 2 Report S2-C46-RR-1. Transportation Research Board, 2015. https://doi.org/10.17226/22357.
33. Donnelly, R., G. D. Erhardt, R. Moeckel, and W. A. Davidson. *Advanced Practices in Travel Forecasting: A Synthesis of Highway Practice*. NCHRP Synthesis 406. Transportation Research Board, 2010. https://doi.org/10.17226/22950.
34. Bowman, J. L., and M. E. Ben-Akiva. Activity-based Disaggregate Travel Demand Model System with Activity Schedules. *Transportation Research Part A: Policy and Practice*, Vol. 35, No. 1, 2001, pp. 1–28. https://doi.org/10.1016/S0965-8564(99)00043-9.
35. Vovsha, P., J. Freedman, V. Livshits, and W. Sun. Design Features of Activity-based Models in Practice: Coordinated Travel-Regional Activity Modeling Platform. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2254, 2011, pp. 19–27. https://doi.org/10.3141/2254-03.
36. Singleton, P. A., and K. J. Clifton, K. J. Considering Health in US Metropolitan Long-range Transportation Plans: A Review of Guidance Statements and Performance Measures. *Transport Policy*, Vol. 57, 2017, pp. 79–89. https://doi.org/10.1016/j.tranpol.2017.02.003.
37. Singleton, P. A., R. J. Schneider, C. D. Muhs, and K. J. Clifton. The Pedestrian Index of the Environment (PIE): Representing the Walking Environment in Planning Applications. Presented at the 93rd Annual Meeting of the Transportation Research Board, Washington, DC, 2014.
38. Clifton, K. J., P. A. Singleton, C. D. Muhs, and R. J. Schneider. Representing Pedestrian Activity in Travel Demand Models: Framework and Application. *Journal of Transport Geography*, Vol. 52, 2016, pp. 111–122. https://doi.org/10.1016/j.jtrangeo.2016.03.009.