Abstract

This paper describes an innovative, spatially-disaggregate framework to integrate pedestrian demand estimation with trip-based travel models: MoPeD, a model of pedestrian demand. Designed for the Portland, Oregon, region, the proposed method applies trip generation to new 264ft by 264ft (80m by 80m) gridded pedestrian analysis zones (PAZs). Next, a binary logit walk mode split model - using a new pedestrian index of the environment (PIE) measure - estimates the number of walk trips generated. Non-walk trips are aggregated up to larger transportation analysis zones for destination choice, mode choice, and traffic assignment. Finally, opportunities exist for destination choice and potential routing of PAZ pedestrian trips. This innovative framework improves travel models' policy sensitivity to walking influences, and it could operate as a standalone pedestrian planning tool for rapid scenario analysis.

Statement of Financial Interest

The authors have no financial interest in and will receive no financial gain from promulgating or distributing the concepts and innovations contained in this submission.

Statement of Innovation

This research brief describes an innovative, spatially-disaggregate framework to integrate pedestrian demand estimation with trip-based travel demand models. It proposes a new zonal structure, environment measure, and method to analyze pedestrian travel. Notably: 1) Trips are analyzed at a sensible spatial scale for each mode; 2) Pedestrian travel can be predicted with more behaviorally-relevant built environment measures; 3) Existing travel model structures require minimal modification to implement this method; and 4) This framework sets the stage for developing a useful pedestrian planning tool. This research brief directly addresses three topic areas of innovation. A) #3. Innovations in Modeling Under-Studied Travel Markets, 2: Emerging modes such as bike, walk. B) #2. Innovations in Improving the Sensitivity of Models, 2: Capturing the impact of the pedestrian environment on travel and its incorporation in travel models. C) New topic #4. Advances in bike and pedestrian modeling.
Introducing MoPeD 2.0: A Model of Pedestrian Demand, Integrated with Trip-Based Travel Demand Forecasting Models

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ABSTRACT
This paper describes an innovative, spatially-disaggregate framework to integrate pedestrian demand estimation with trip-based travel models: MoPeD, a model of pedestrian demand. Designed for the Portland, Oregon, region, the proposed method applies trip generation to new 264ft by 264ft (80m by 80m) gridded pedestrian analysis zones (PAZs). Next, a binary logit walk mode split model—using a new pedestrian index of the environment (PIE) measure—estimates the number of walk trips generated. Non-walk trips are aggregated up to larger transportation analysis zones for destination choice, mode choice, and traffic assignment. Finally, opportunities exist for destination choice and potential routing of PAZ pedestrian trips. This innovative framework improves travel models’ policy sensitivity to walking influences, and it could operate as a standalone pedestrian planning tool for rapid scenario analysis.
INTRODUCTION
Planning for pedestrians is important for public health, urban planning, and transportation engineering. Efforts to improve the quality of the walking environment, including investments to promote pedestrian travel, have increased throughout the United States. At the same time, metropolitan planning organizations (MPOs) are expanding regional travel demand forecasting models to include pedestrian and bicycle modes. These efforts intend to widen the capacity of models to evaluate policy issues such as infrastructure planning, air quality, public health, and climate change. Better representation of walking in travel demand models can:

- improve model sensitivity to variables relevant for pedestrian travel;
- provide better prediction of modal shifts;
- create results that are more responsive to policy interventions (e.g. smart-growth strategies, energy and parking pricing, pedestrian facility investments); and
- make model outputs useful for pedestrian planning and performance measurement.

The motivation for improving how travel models represent walking has never been stronger. Cities are interested in making more strategic investments to support active transportation. Laws related to greenhouse gas emissions and climate change mandate accounting for mode shifts away from automobile travel. These new policy demands require upgrades to transportation planning and modeling tools to better reflect travel behavior, especially walking and bicycling, at finer spatial and temporal scales. At the same time, recent research has improved pedestrian data collection and analysis methods (1) along with an understanding of relationships between walking and environmental conditions (2).

Nevertheless, most MPOs lack experience forecasting pedestrian travel. While nearly two-thirds (63%) of the largest 48 MPOs model non-motorized travel, less than half (47%) distinguish walking from cycling (3). A wide variety of methods are used: walk trips may be generated on their own, split off before or after distribution, distinguished during mode choice, or grouped with bicycle trips into a “non-motorized” mode. Other pedestrian modeling challenges include the use of environmental measures and large spatial analysis units.

Research over the past two decades has demonstrated that the built environment (BE) is associated with pedestrian behavior (2, 4). Walking is more common in areas with higher residential/employment density, greater land use mix, more pedestrian network connectivity, and greater transit accessibility. Several issues complicate the study of environmental influences on travel behavior, including that many BE characteristics associated with walking tend to be spatially correlated. Therefore, it is difficult for statistical methods to identify which BE features actually influence behavior, challenging forecasts of pedestrian responses to policy interventions.

Another challenge is that the transportation analysis zone (TAZ) geographies used in travel demand models are inadequate for representing pedestrian travel. Even medium-sized TAZs often obscure variations in the BE, from land use intensity to sidewalk coverage. Since many walk trips are short, they frequently occur completely within or between adjacent zones; traditional modeling techniques for representing intrazonal travel and calculating zone-to-zone skims make assumptions that affect pedestrian demand estimates. Some MPOs have begun using smaller zonal structures and more complex calculations for walking analysis (5). Clearly, smaller pedestrian analysis zones (PAZs) are necessary.

This paper introduces a conceptual framework describing one way to improve how MPO travel models estimate pedestrian demand. Termed MoPeD 2.0 (2nd Model of Pedestrian
Demand), it builds off the authors’ experiences developing an earlier MoPeD model in Baltimore (6). The innovative methodology addresses some of the theoretical and practical challenges involved with forecasting pedestrian demand. Notably, it uses small, uniform PAZs and a new pedestrian environment measure to develop a standalone pedestrian planning tool that is also integrated with the travel model. Although the procedure was designed for the Portland, Oregon, region, it is transferrable. The following sections introduce the proposed MoPeD framework, present results of a partial application, and discuss implications and contributions to the practice of travel modeling.

PROPOSED MOPED 2.0 METHODOLOGY
Several overarching considerations drove the development of MoPeD 2.0:

1. Use a spatial analysis unit more compatible with pedestrian behavior.
2. Develop better representations of the pedestrian environment.
3. Allow the construction of a standalone pedestrian planning tool.
4. Maintain integrity with existing trip-based travel model stages without excessively burdening data collection and other processes.

By utilizing existing model structures, smaller zones, and a more appropriate pedestrian environment measure, the proposed method should result in a more realistic representation of walking and ultimately better model performance. FIGURE 1 illustrates the conceptual framework of the MoPeD 2.0 methodology. The process includes four innovative steps.

1. Trip Generation using PAZs
As described above, TAZs are inadequate geographies for representing walking. Instead, smaller PAZs are used. Several options are available: 1) constructing a uniform set of raster grid cells; 2) developing nested sub-TAZs; and 3) using parcels. Option 3 is the most spatially-accurate method, since Options 1 and 2 both aggregate to a hypothetical centroid point, but it requires regional parcel-level data. Option 2 has fewer input data needs but still requires the construction of new zones and calculations to account for different-sized zones. Option 1 may be a useful intermediary between TAZs and parcels; if small enough, grid cells can eliminate intrazonal travel, and their uniformity makes for simple calculations and zonal comparisons.

To maintain consistency with trip-based modeling processes, the first step performs trip generation using PAZs. A prerequisite is that necessary PAZ-level data must be available or calculated. Trip generation models typically rely upon socio-demographic household information and basic BE measures (3). Environmental data are becoming increasingly available at micro-scale geographies, so these inputs can be easily calculated. Depending on the availability of joint distributions of household characteristics, some disaggregation may be needed. This PAZ allocation process may involve assuming equivalent higher-level values or distributions, developing pre-generation models to predict these factors, or constructing a population synthesizer. Conceptually, most trip generation structures—cross-classification and regression models—are scalable from TAZs to PAZs without adjustment.
2. Walk Mode Split Model
The next step separates pedestrian and vehicular (auto, transit, and bicycle) trips using a walk mode split model. An appropriate choice is a binary logit regression model structure; binary logit is used by many agencies for non-motorized mode split models (3) and by researchers looking at non-motorized mode choice (7). More complex logit structures (e.g., multinomial, nested) are not possible; travel times/costs cannot be calculated because trip ends have not been linked. Instead, the walk mode split model can be estimated using household travel survey data, regressing the choice of walking on socio-demographic characteristics and origin/destination-based measures of the BE and accessibility. In fact, a key component of this model should be a measure of the pedestrian environment.

3. Aggregation of Vehicular Trips to TAZs
Next, trips by vehicular modes are aggregated from PAZs back up to TAZs to proceed through remaining stages. This approach allows for detailed consideration of walk trips without adding significant additional complexity or data requirements. While downstream travel model stages (destination/mode choice) may require re-estimation, this task is much less burdensome than using PAZs for all stages.

4. Walk Trip Destination Choice Model
Once daily pedestrian trips are determined for PAZs, there are many opportunities for utilizing these estimates. The most promising extension is to develop a pedestrian planning tool that distributes walk trips to PAZs and/or predicts potential pedestrian paths through a network of

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**FIGURE 1** Conceptual diagram of MoPeD 2.0 methodology.
PAZs; similar non-motorized tools exist (8). A walk trip destination choice model connects PAZ trip origins and destinations based on distance, destination attractiveness (number of relevant establishments), and path-based BE measures. If pedestrian routing data are available, a route choice model could be developed and integrated with the destination choice model (9). These estimates could then be compared to intersection/segment pedestrian counts, providing a robust model validation method.

MoPeD 2.0 and its extensions are integrated with the full travel demand model (through trip generation and walk mode split), but they can also operate as a standalone pedestrian planning tool, allowing rapid analyses of multiple scenarios. This procedure would facilitate estimates of corridor walk trips and pedestrian-miles-traveled, useful information for transportation performance measures. Such a tool could assist many other analyses, including pedestrian activity modeling, active transportation plan evaluation, and health impact assessments.

RESULTS
An application of MoPeD 2.0 is underway in Portland, Oregon, for Metro, the local MPO. This section describes preliminary application results.

1. Trip Generation using PAZs
The project team and Metro selected Option 1 (constructing a uniform set of raster grid cells) for PAZs: 264ft by 264ft (80m by 80m) grid cells; Metro had already developed these geographies for previous projects (10). There are 2,147 TAZs and 1,465,252 PAZs within the four-county region. Option 3 (parcels) was not selected because regional parcel-level data were incomplete. Other applications could select alternative PAZs based on regional data availability and modeling needs.

Base year trip generation was performed using existing TAZ trip generation models applied to PAZ-level data. Employment inputs were taken from the point locations of establishments in the 2009 Quarterly Census of Employment and Wages database. BE data were calculated from Metro’s Regional Land Inventory System GIS database. Household totals were from parcel-based estimates of US Census data, weighted to match block group totals. Joint distributions of PAZ household characteristics were assumed to match TAZ distributions. Future work could investigate the advantages of household population synthesis. Also, creating forecast year inputs may be more challenging. Although not presented here, trip generation results are available from the authors upon request.

2. Walk Mode Split Model
Estimation of the walk mode split model used trip data from the 2011 Oregon Household Activity Survey (OHAS) (11). Trip origins and destinations were located using addresses and assigned to PAZs. Only 90% (N = 50,271 trips) of the Portland-region OHAS dataset was used; a 10% random sample—stratified by pedestrian/vehicular mode and trip purpose—was withheld for model validation. Only single-mode walk trips were considered. Household characteristics—age of household head, income, size, workers, vehicle availability, and children—were chosen to match those in the existing model (12). Models were specified for production trip ends only (a destination choice model matches trip ends). Separate models were estimated for each of three purposes—home-based work (HBW), home-based other (HBO), and non-home-based (NHB)—again for consistency with other stages (12).
The BE was represented by an innovative new construct: the pedestrian index of the environment (PIE). The PIE is a factor of six different BE measures—people per acre, transit access, pedestrian-friendly businesses, block size, sidewalk density, and comfortable facilities—originally chosen and calculated by Metro (10). The research team calibrated these measures—using observed walking data—to construct the PIE, a 20–100 scale that best represented the pedestrian environment. The PIE helps to address the multicollinearity issue in the BE. It improves upon other pedestrian indices (such as the pedestrian environment factor) by having stronger theoretical and mathematical relationships with walking and being based on more objective and reproducible BE measures. Further information on PIE can be found in other documents (13).

The PIE was a significant and positive factor in all walk mode split model estimation results (13), indicating that the composite BE measure was a good walking indicator when controlling for socio-demographics. Effects were similar across all purposes: one-point increases in PIE were associated with 3.6%, 4.4%, and 5.3% increases in the odds of a pedestrian production trip end for HBW, HBO, and NHB purposes, respectively. Model validation reproduced the walk mode shares of the validation sample (13).

The walk trip destination choice model has yet to be applied in Portland. More work is needed to complete the implementation of the full pedestrian modeling methodology.

**DISCUSSION: IMPLICATIONS AND INNOVATIONS**

The sections above described the MoPeD 2.0 pedestrian demand modeling framework and a (partial) field application. This innovative approach to representing walking in trip-based travel models strikes a balance between geographic sensitivity, downstream model realism, and applicability. The framework allows for spatially-disaggregate walking sensitivity without excessively burdening model systems. MoPeD 2.0’s contributions towards improving pedestrian modeling practice include the following:

1. Trips are analyzed at a sensible spatial scale for each mode. Shorter walk trips can operate at a small scale (PAZs). Auto trip ends may not need such spatial resolution.
2. Pedestrian travel can be predicted with more behaviorally-relevant BE measures at appropriate scales: the PIE. Larger TAZs obscure variation in walking-sensitive BE factors that are more accurately measured for PAZs.
3. Splitting off walk trips after generation but before distribution means fewer calculations are necessary; later model stages like vehicular destination/mode choice can use TAZs instead of PAZs.
4. Existing travel model structures require minimal modification. Models that do not currently represent walking must only re-estimate trip generation; trip generation models that do include pedestrian travel can be retained. An ideal time to apply this method is following a new regional travel survey, when model re-estimation must already occur.
5. This framework sets the stage for developing a pedestrian planning tool that operates outside of the travel modeling paradigm. Such a tool could use the same basic inputs yet be run much more quickly for testing pedestrian-related scenarios. Because of its integration, this tool also affords other modes some sensitivity to pedestrian investments.

Despite these contributions, there are opportunities for improving MoPeD 2.0, especially as applied in the Portland region. Future work may examine developing population synthesis
methods for obtaining PAZ-level joint distributions of household characteristics, constructing the PIE from widely-available data sources, completing the destination choice model, developing a full pedestrian planning/demand estimation tool, and validating the entire methodology in another region. As MPOs continue experimenting with improved non-motorized representation in travel models, the experience gained—particularly regarding spatial scales and environmental influences—will be useful for pedestrian and bicycle planning.

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