A Spatially Transferable Pedestrian Demand and Network Modeling (STePNet) Framework

Fatemeh Nourmohammadi[a], Tanapon Lilasathapornkit [a], Taha H. Rashidi [a],Meead Saberi[a,*]

[a] Research Centre for Integrated Transport Innovation (rCITI), School of Civil and Environmental Engineering, University of New South Wales, Sydney, NSW, Australia
f.nourmohammadi@unsw.edu.au, t.lilasathapornkit@unsw.edu.au, rashidi@unsw.edu.au, meead.saberi@unsw.edu.au
[*] Corresponding author

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1 INTRODUCTION

Walking offers significant societal, public health, and sustainability benefits. Recognizing these advantages, cities worldwide are investing in initiatives to enhance the ease and appeal of walking. The shift in perspective toward prioritizing walking-friendly environments has spurred additional research into understanding and modeling walking behavior and dynamics. However, planners and policymakers often lack appropriate tools to address pedestrian planning challenges and assess investment decisions. In many early operational agent-based transportation models, the walk mode was usually omitted or combined with cycling as a single non-motorized mode (Waddell, 2002). MoPeD, an aggregated trip-based pedestrian travel demand model, was developed by Clifton *et al.* (2015, 2016b) and further improved by Zhang *et al.* (2022). It utilizes a finer-grained spatial unit called pedestrian analysis zones (PAZ) and employs binary logit models to estimate the probability of walking choice, showing sensitivity to local land use variations and demonstrating significant impacts of pedestrian accessibility on walking behavior. Additionally, MoPeD incorporates a two-stage destination choice process, where walking trips first select destination SuperPAZs and then choose constituent PAZs based on impedance measures, road density, employment distribution, and traveler characteristics. MITO, the travel demand model within the Munich Model (Moeckel *et al.*, 2020), is a microscopic model that generates individual-level trips based on socio-demographic attributes. These trips are then passed on to MATSim for route assignment along with other travel modes. In a recent study by Zhang *et al.* (2023), an integrated MITO/MoPeD was introduced to link advanced pedestrian demand modeling techniques with an agent-based modeling approach. The concept of transferability in travel demand across all modes has been well-studied for many years. Due to the high costs associated with gathering local data, many agencies borrow or transfer data Malokin *et al.* (2019) and models Sikder *et al.* (2013) from other regions, times, or spatial aggregations. Despite this, transferability in pedestrian demand modeling has received comparatively little attention. Despite the recent advances in pedestrian demand and network modeling (Lilasathapornkit *et al.*, 2022), a comprehensive understanding of the spatial transferability of pedestrian models at different aggregation levels across geographic locations and integration of pedestrian demand and network models remain less explored areas of research. This study aims to contribute to this understanding by exploring the spatial transferability of pedestrian demand models as well as integrating the pedestrian demand and network models using data from a few major Australian cities. We develop pedestrian demand models at different aggregation levels and examine their spatial transferability across Sydney, Melbourne, and Brisbane. The study also develops an initial pedestrian demand-supply modeling framework, including a network walking route choice, aiming to provide valuable insights to guide policies and urban planning for the development of more walkable communities. The proposed framework is named the Spatially Transferable Pedestrian Demand and Network (STePNet) Model.

2 METHODOLOGY

The proposed STePNet modeling framework is composed of three main components. Initially, a series of walking trip generation models are developed for various spatial resolutions and at the individual level. The extent of the spatial transferability of the estimated walking trip generation models is investigated and will be discussed. The second component includes an aggregated gravity or radiation type model based on a study by Rhoads *et al.* (2021) and disaggregated logit-based pedestrian destination choice models. The third component consists of a series of equilibrium and non-equilibrium-seeking pedestrian route choice models (Lilasathapornkit *et al.*, 2022, Lilasathapornkit & Saberi, 2022). Figure 1 shows a schematic illustration of the STePNet modeling framework.

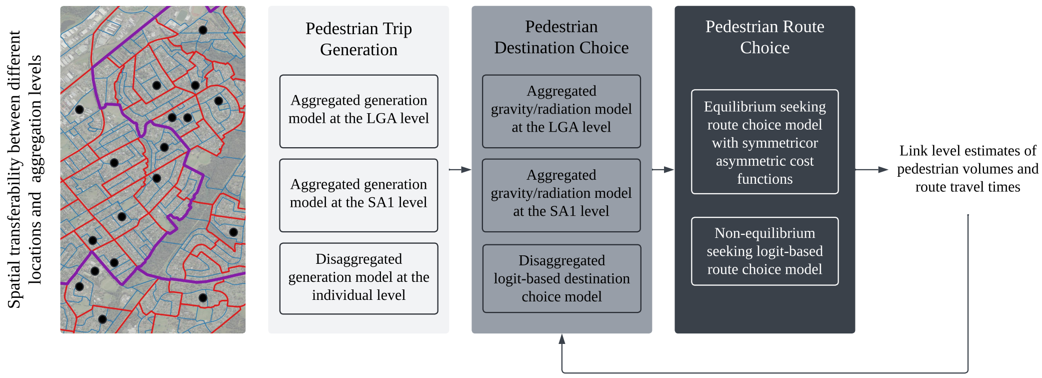

Figure 1 – *The developed STePNet modeling framework*

3 RESULTS

In this study, we first estimate aggregated pedestrian trip generation models at the Local Government Area (LGA) level using data from the Sydney and Melbourne Household Travel Surveys. The estimated models are then cross-validated for spatial transferability analysis. The estimated Sydney model is tested on Melbourne and vice versa. Further spatial transferability tests are also conducted using data from Brisbane. A set of transferability measurements including R-squared, Root Mean Squared Error (RMSE), Transfer Index (TI), and Normalized Root Mean Squared Error (NRMSE) are adopted and examined (Johnson & Badoe, 2023). See Table 1. Results suggest that the estimated pedestrian trip generation models are spatially transferable only to a limited extent. A main factor in ensuring spatial transferability is that the distribution of the input variables to the models across different geographies and spatial aggregation levels exhibit similar patterns and variability. Figure 1 illustrates a comparison of the predicted number of walking trips against the actual number of trips across different models and datasets for transferability testing.

Table 1 – *Transferability assessment results for the estimated walking trip generation models.*

Accuracy Measurements	Sydney data (Melbourne model)	Melbourne data (Sydney model)	Brisbane data (Sydney model)	Brisbane data (Melbourne model)
	Poisson Regression			
R2	0.53	0.37	0.79	0.79
TI	0.54	0.45	0.96	0.81
RMSE	106,083	164,500	122,270	123,106
NRMSE	0.14	0.14	0.14	0.14
	Random Forest Regression			
R2	0.19	0.21	0.47	0.20
TI	0.21	0.22	0.50	0.21
RMSE	139,920	183,741	192,163	239,354
NRMSE	0.18	0.15	0.22	0.28

The pedestrian destination choice component of the STePNet framework includes an aggregated gravity or radiation-type model that estimates the origin-destination as a simple function of population, Points of Interest (POIs), and distance between the origin-destination pairsRhoads *et al.* (2021). To estimate and assess the spatial transferability of disaggregated logit-based destination choice models, we use the Household Travel Survey data from Melbourne, Sydney, and Brisbane. These models predict the probability P of a pedestrian trip starting from an origin zone i and ending at a destination zone j, using the estimated utility functions that factor in both the built environment and individual pedestrian characteristics Clifton *et al.* (2016a). The proposed framework also adopts and applies two route choice models as originally developed in Lilasathapornkit *et al.* (2022), Lilasathapornkit & Saberi (2022). A non-equilibrium-seeking model was applied to an estimated walking origin-destination demand data from the Sydney CBD area (preliminary estimation only) to estimate pedestrian link flows. See Figure 2. The assessment of the spatial transferability of the estimated route choice is a subject of ongoing research.

4 DISCUSSION

This study introduced the Spatially Transferable Pedestrian Demand and Network (STePNet) modeling framework and presented preliminary results on the walking trip generation and network routing applied to the Sydney CBD sidewalk network. Results provide early indications of the limits of spatial transferability in the pedestrian demand and network modeling context. For the pedestrian trip generation models, the Poisson regression was found to exhibit greater transferability in cases where the distribution of input variables is similar across different geographies. Estimation of the aggregated and disaggregated walking destination choice models and assessment of their spatial transferability are still ongoing. While the pedestrian route choice modeling approaches are already developed, an in-depth understanding of the challenges and requirements for an integrated demand-supply pedestrian model in which the estimated walking demand feeds the network routing model is also ongoing. The proposed framework is being examined using data from Sydney, Melbourne, and Brisbane. While this provides a great cross-city comparison for transferability testing, the conclusions will still be limited to the Australian context. Using data from different cities across the world would improve the generalization of the approach.

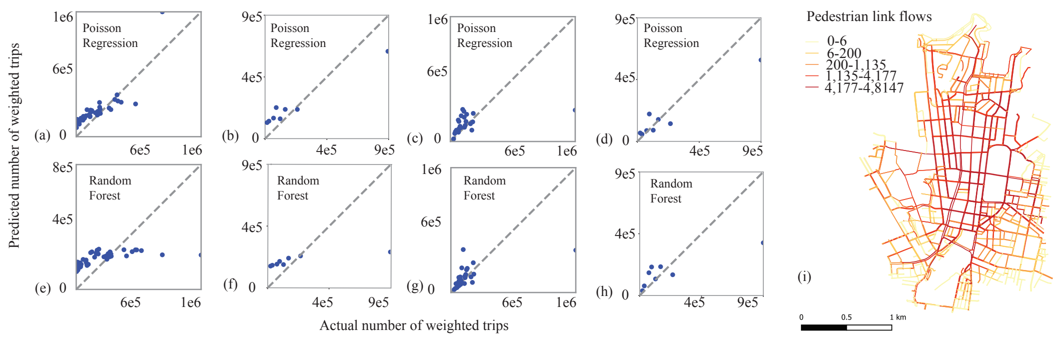

Figure 2 – *Preliminary results: (a-h) Spatial transferability assessment and (i) estimated pedestrian daily link flows for the Sydney CBD sidewalk network using a stochastic route choice model; (a-d) Poisson regression and (e-h) Random Forest regression models for pedestrian trip generation; (a) and (e) show the number of generated pedestrian trips for Sydney using the Melbourne model. (b) and (f) show the number of generated pedestrian trips for Brisbane using the Melbourne model (c) and (g) illustrate the number of generated pedestrian trips using the Sydney model for Melbourne. (d) and (h) show the number of generated pedestrian trips for Brisbane using the Sydney model.*

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