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Assessing pedestrian impacts of future land use and transportation scenarios

Qin Zhang (corresponding author)
School of Engineering and Design,
Technical University of Munich
qin.zhang@tum.de

Rolf Moeckel
School of Engineering and Design,
Technical University of Munich
rolf.moeckel@tum.de

Kelly J. Clifton
School of Community and Regional
Planning, University of British Columbia
kelly.clifton@ubc.ca

Abstract: Portland Central City has experienced growth in population and employment over the last decades, which leads to an increase in travel demand. One of the visions of the Central City 2035 plan is to encourage walking. This paper presents a model of pedestrian travel demand to help assess the impact of land use and transportation policies in the Central City area. The model is an enhanced version of the Model of Pedestrian Demand (MoPeD). Realistic scenarios and the projected population and employment are incorporated in this study. Four future scenarios for 2035 are tested and compared to 2010 base conditions. The results suggest that demographic growth and job increases can help to encourage a large share of walk trips. Pedestrian behavior is also sensitive to network connectivity, but the influence is not as impactful compared to population and job growth. Furthermore, model results show that a good street network and a dense and diverse land-use plan can maximize the effects of promoting walk trips. This paper presents the capability of the pedestrian planning tool MoPeD. It is sensitive to the small-scale variations in local land use and transport development, which can help policymakers better understand the effects of various demographic policies and infrastructure planning on the walk share.

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1 Introduction

Portland, OR, as the heart of the metropolitan area, has the densest concentration of people and jobs. With an increase in urbanization, Portland city will continue to experience population and employment growth. The city projects it is going to gain approximately 38,000 new households and about 51,000 new jobs by 2035 (City of Portland, 2018). To meet this challenge, the city issued a set of goals and policies called the Central City 2035 (City of Portland, 2018). This new plan affirms that promoting walking is one of the solutions to build an efficient urban network and that the plan should put pedestrians at the forefront of city policies. The city will encourage investments in pedestrian facilities, such as pedestrian crossings, aiming to keep people walking safely and comfortably through the city.

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Combined with increases in the density and mix of use, these infrastructure and land-use investments will support more travel by walking and other sustainable modes of transportation.

The benefits of urban pedestrian travel are well documented in the literature (Sallis et al., 2016; Saunders et al., 2013). Therefore, it is no surprise that cities like Portland incorporate these principles in their future policies. However, planners and policymakers do not often have the appropriate tools to address planning questions and assess the impact of their policies on meeting their pedestrian-related goals. Regional travel demand models have been more focused on issues of moving vehicles and planning for their infrastructure needs and less on serving pedestrian behavior. However, there have been some recent improvements to these models with respect to modeling non-motorized modes (Singleton et al., 2018). A comprehensive review of regional travel demand models in the U.S. has pointed out that only a little more than half of the urban planning tools include walking or non-motorized modal shares (Singleton et al., 2018). But to date, few practical applications focus on how these tools can be used to estimate future pedestrian demand in response to land use and transportation changes.

To illustrate the potential of these modeling tools to assess the impact of future scenarios on pedestrian demand, we use a tool called Model of Pedestrian Demand or MoPeD (Clifton et al., 2016a, 2016b; Singleton et al., 2014) for the assessment of urban and transportation scenarios for the Portland Central City area. The pedestrian modeling framework used in this study can better represent the built-environment influences on walking behavior. Accordingly, it can evaluate the impact of land-use density and diversity on walk trip generation and distribution and can also assess the effectiveness of pedestrian facilities. MoPeD is implemented at a fine-grained scale of Pedestrian Analysis Zones (PAZ), which are 80 by 80-meter grid cells. Besides walk mode choice, MoPeD employs a discrete choice model for walk trip distribution.

For the base year, we rely on population and employment conditions from the 2010 U.S. Census for these neighborhoods. For future conditions, we analyzed the impact of a planned pedestrian bridge and a newly-built car-free crossing. Aligned with these facilities, neighborhood land-use scenarios have been created based on the Portland Central City 2035 Plan (City of Portland, 2018). New households and different types of employment are allocated to PAZs based on this plan for all ten districts in the Central City area. We implement the model to the base-year scenario, two future scenarios with different land-use strategies, and two future scenarios with different growth strategies plus pedestrian facilities. Through this application, we assess the impacts of land use and transport policies on pedestrian demand and examine the performance of our pedestrian demand tool. The details of the model and the case study locations are described in more detail below.

2 State-of-the-art in pedestrian modeling

In the early stage, one common problem that the researchers faced when modeling pedestrian demand was the barrier of the data collection on pedestrian behaviors and environments. Thanks to the improvement of travel survey data and data collection technologies, a number of studies on the relationship between pedestrian behavior and built environment have recently been carried out. These studies identified the various factors which impact pedestrian behavior. It was confirmed many times that walking behavior (e.g., walking frequency and distance) is strongly related to intersection density, the number of destinations within walking distance, and population density (Ewing & Cervero, 2010; Khan et al., 2014; Kuzmyak et al., 2014).

Although the research on pedestrian travel behavior has made great progress, there are only a few studies on pedestrian modeling. Most of these studies focus on the individual microscopic pedestrian movements in a specific situation, such as crowding and queuing at a single intersection or pedestrian evacuation at train stations and shopping centers (Borrmann et al., 2012; Erdmann & Krajzewicz, 2015; Kielar & Borrmann, 2016). Only a few studies focus on pedestrian travel demand at the urban scale. A comprehensive review of urban travel demand models in the U.S. pointed out that only over half of the planning tools account for walking or non-motorized mode shares (Singleton et al., 2018). They concluded that the most promising approach for research on pedestrian modeling is agent-based models (ABMs) or more traditional pedestrian models with finer spatial resolutions. A recent study by Clifton et al. (2016b) developed a pedestrian modeling framework, which follows the traditional four-step model but it implements a finer-grained scale – called Pedestrian Analysis Zone (PAZ) – which is an 80 meter grid cell system. This is the finest scale used for modeling pedestrians in travel demand models. While this scale can better represent walking behavior, it meets the challenges in model complexity, data collection, and computational burden in running such a disaggregate scale.

3 MoPeD model description

In this study, we adopt the framework of MoPeD to quantify the impact of land use and transportation policies on walking behavior. MoPeD was described by Clifton et al., (2015, 2016a, 2016b, 2019). The framework of MoPeD is illustrated in Figure 1. This pedestrian demand prediction tool can be integrated with a four-step urban model or run as a stand-alone tool, as is the case in this paper. Firstly, MoPeD starts with trip generation at a fine spatial resolution – the pedestrian analysis zones (PAZ), which consist of 80x80 meter grid cells. Next, MoPeD adds a step to separate walk trips from other trips, using a binary mode choice model (walk/vehicular modes). Walk trips are subsequently handled by MoPeD for trip distribution at the PAZ level, while vehicular trips can be processed by a regional urban travel demand model. By modeling the choice walk/non-walk first, the conditions for the destination choice model are largely improved because the walk trips are normally much shorter than the non-walk trips, and the destination choice behavior is quite different when applying at a very fine scale. Even though MoPeD is implemented at a fine spatial resolution, making mode choice prior to destination choice can avoid dealing with massive distance matrices.

In the trip distribution stage, destination choice is first conducted at a more aggregate spatial scale – SuperPAZs, which are aggregations of PAZs into 400-meter grid cells (Zhang et al., 2019). Then, trips are allocated from the SuperPAZ of choice to the constituent PAZs. In this study, pedestrian route choices were added to this modeling suite using the shortest path algorithm.

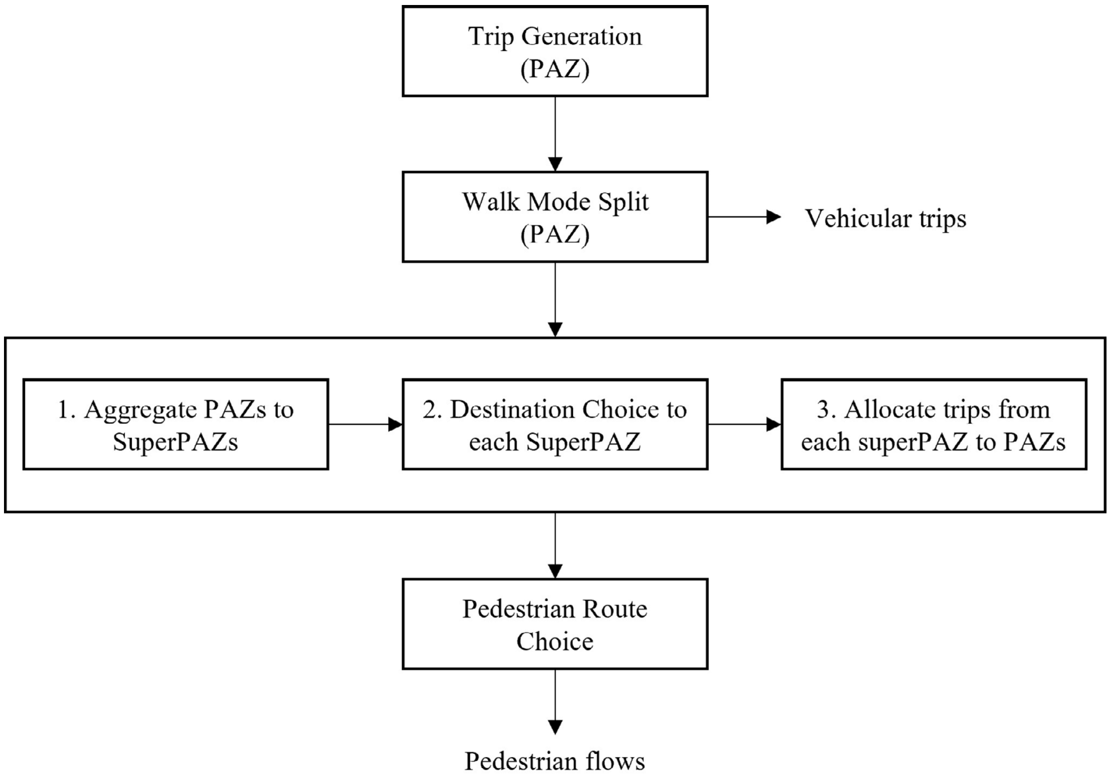

Figure 1. Modeling framework of MoPeD

MoPeD is segmented by eight trip purposes, including home-based work (HBW), home-based school (HBSch), home-based college (HBColl), home-based shopping (HBShp), home-based recreation (HBRec), home-based other (HBOth), non-home-based work (NHBW) and non-home-based other (NHBO). Home-based school and college trips were not modeled in this study because of the complexities of school assignment policies in Portland. It is recognized that this probably leads to a small underestimation of walk trips. According to the Oregon Household Activity Survey (OHAS), about 16% of walk trips were traveling from home to school or college.

We enhanced the model performance and made some modifications to the model stages from the version previously described by Clifton et al. (2015, 2016a, 2016b, 2019). These improvements were made to overcome the following limitations:

- The first implementation in R had slow run times and could only run a small subset of the Portland region at a time. It was not able to handle the entire Portland metropolitan area due to the heavy computational burden of this fine spatial resolution.
- The trip generation models for non-home-based trip purposes had a poor predictive ability.
- The Pedestrian Index of the Environment called PIE was less transferable to other applications due to the requirement of detailed land-use data at a fine spatial resolution (Clifton et al., 2019). Also, it was challenging to predict changes to the built environment due to its construct.
- The destination choice model estimation used a random sampling method to define the choice set of 10 SuperPAZs (Clifton et al., 2016a), which limited the performance of the model.

In this paper, MoPeD was improved in the following ways:

- Development of the model in Java. This change made the model efficient and operational for the entire Portland region with a runtime of a few minutes (Zhang et al., 2019).
- Updating the trip generation model for all purposes to reflect the latest improvements in the

regional travel model at Metro (Oregon Metro, 2015). This is helpful in particular for the NHB purposes, where trips are pre-estimated at home and then distributed to their origin zones based upon attractiveness.

- Constructing a new measurement of the pedestrian environment that reflects pedestrian accessibility and simplifies the built environment characteristics. It is defined as the number of jobs and population within an 800-meter network distance buffer for the pedestrian catchment area.
- Using a complete census of the SuperPAZs within a 4.8-meter radius in the destination choice model.
- In the destination choice stage, trips are further distributed from the SuperPAZ of choice to the constituent PAZs based on the attractiveness of PAZs.
- Pedestrian route choice is implemented for assigning trips to the pedestrian network.

As the focus of this paper is the scenario application, model estimates are discussed briefly here. The full estimation results can be found in the technical summary report on Github (https://github.com/Qinnnnn/MoPeD_Java).

MoPeD employs binary logit models to estimate the probability of choosing to walk. The models include three household attributes (income category, number of vehicles, and children) and pedestrian accessibility as independent variables. The pedestrian accessibility variable does represent not only the activity density but also the network connectivity between PAZs. Pedestrian accessibility was transformed to log-form, which leads to a better model fit. It shows a significant and positive impact in the model, which indicates that households living in denser neighborhoods with better street networks tend to be more likely to walk. The log-transformation suggests that differences in pedestrian accessibility matter a lot at the lower end of accessibilities. Once a certain level of pedestrian accessibility has been reached, additional growth in accessibility has less impact on the likelihood of walking.

In MoPeD, we estimated multinomial logit pedestrian destination choice models for choosing the destination superPAZ and the constituent PAZ. Destination choice models for superPAZ were specified using measures of impedance, pedestrian road density in kilometers, logged size terms, pedestrian trip supports (like the existence of parks), barriers (e.g., the proportion of industrial jobs and slope), and traveler characteristics. Distance was a significant and sensitive factor in the model. Retail and service employment was a strong attractor while the share of industrial jobs has a barrier impact on choosing a destination. If it is necessary to cross the motorway to reach the destination, then the destination zone becomes less attractive.

4 Case study areas and scenarios

The study area for this modeling exercise is the Portland Central City shown in Figure 2. The Central City area consists of ten different neighborhoods and stretches from the West Hills to East 12th Avenue, and from the Pearl and Lower Albina to the South Waterfront area and Powell Boulevard (City of Portland, 2018). Although the Central City only covers about 12 square kilometers in land area, it accounts for almost 20% of the total population in the metropolitan region. It is the densest area of people and jobs in Oregon. The Willamette River divides this area and is spanned by several bridges, including the non-automobile bridge Tilikum Crossing, completed in 2015.

Table 1 shows the population and employment for each of these neighborhoods in 2010, which is the base year for the models, and projected growth in each for 2035, which is the modeled horizon year. In the base year, Downtown is the economic center with most of the office employment, retails, and services. The Pearl District is a mixed-use district with commerce and retails and the largest number of households. The Central Eastside and Lloyd Districts are characterized as an industrial center and an office core, respectively, and are less populated. South Waterfront is not yet developed and has the lowest density of population and jobs. The base year 2010 was chosen due to the availability of detailed land use and infrastructure at the PAZ level for that year.

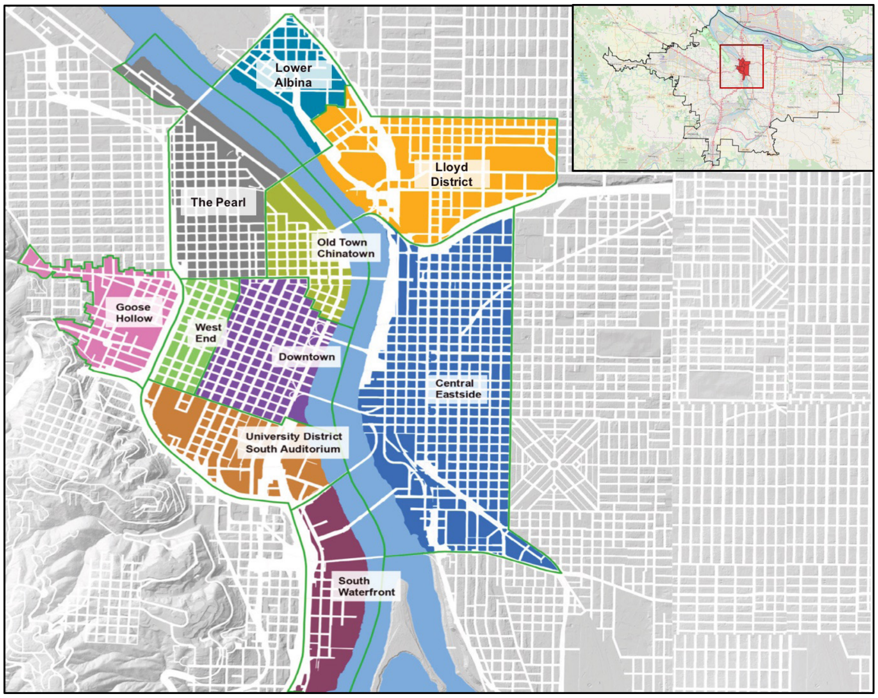

Figure 2. A map of the Portland Metropolitan area and the Portland Central City (City of Portland, 2018)

In the Portland Central City 2035 Plan (City of Portland, 2018), scenarios are outlined for each of these neighborhoods in terms of projected residential and employment growth. In addition, there is a planned pedestrian crossing (the Congressman Earl Blumenauer Bicycle and Pedestrian Bridge) that will connect the Central Eastside with the Lloyd District and the Tilikum Crossing. It was built in 2015, which is after our base year, and is a car-free facility that links the Central Eastside with the South Waterfront.

By 2035, the Central City will gain approximately 2-times more households compared to the base year and a roughly 40 percent growth in jobs. The Central Eastside, Lloyd District, and South Waterfront will be the focus of demographic growth in the future decades, with an increase of households by 800%, 778%, and 364% respectively. The emphasis of the employment development is expected to be on the South Waterfront.

Table 1. Total household and employment in 2010 and projected for 2035 by districts

District	Total households			Total employment		
	2010	2035	Change in %	2010	2035	Change in %
Central Eastside	900	7900	+778%	17000	25000	+47%
Downtown	1600	4600	+188%	48200	55200	+15%
Goose Hollow	3900	4900	+26%	5300	7300	+38%
Lloyd	1000	9000	+800%	16800	25800	+54%
Lower Albina	100	300	+200%	2100	2300	+10%
Old Town	1900	3900	+105%	5200	8200	+58%
Pearl	5600	11600	+107%	10700	14700	+37%
South Waterfront	1100	5100	+364%	1200	11200	+833%
University District	3200	6200	+94%	10400	14400	+38%
West End	3800	6800	+79%	6900	9900	+43%
Sum	*23100*	*60300*	*+161%*	*123800*	*174000*	*+41%*

To understand the impacts of planned infrastructures and growth on pedestrian travel, we have incorporated these realistic scenarios and allocated the projected population and employment growth to our PAZ structure based on the details provided in the Central City 2035 Plan. Each of the future scenarios outlined below is for the planning horizon of 2035 and compared against the base year 2010. Besides the locations described in more detail below, we also distributed housing and employment growth to other neighboring districts based on the Portland Central City 2035 Plan (City of Portland, 2018). Each district has a different distribution of population and employment growth based on the corresponding future development vision. Table 4 in the appendix summarizes the detailed housing and jobs growth plan across ten districts in Central City.

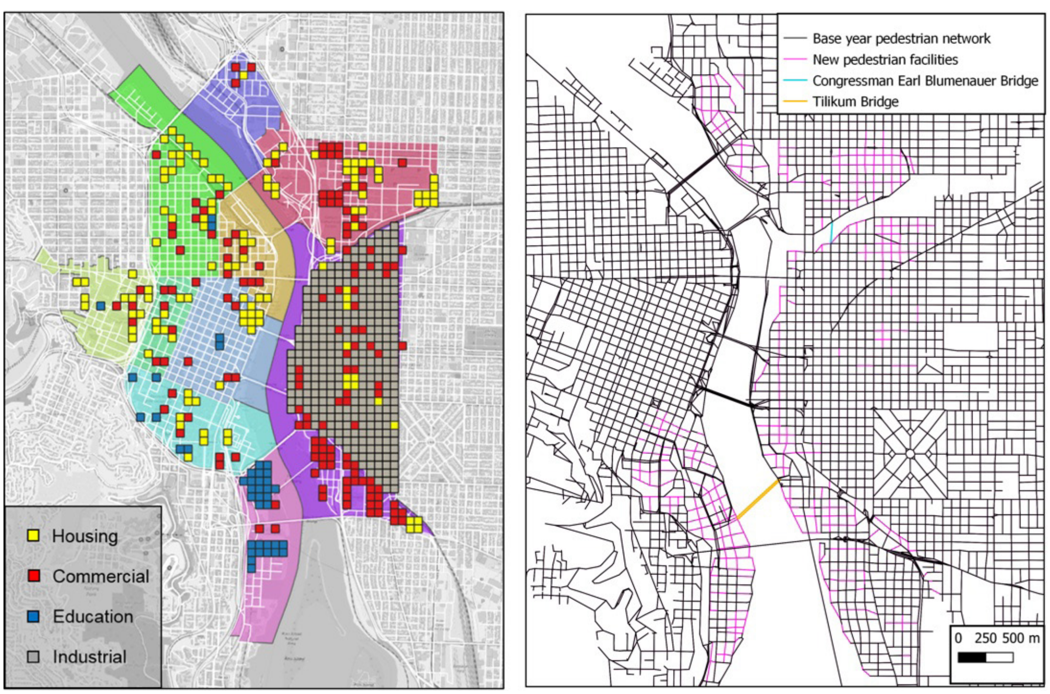

Figure 3. An overview of land-use plans (left) and pedestrian facilities (right) for 2035 in the Central City

There are two specific pedestrian bridge scenarios that we compared to the 2010 base year conditions. One is a new pedestrian bridge and the growth projected for the Lloyd Center and the Central Eastside (Case Study 1). The other is the Tilikum Bridge and the growth projected for the South Waterfront and the Central Eastside (Case Study 2). Besides two pedestrian bridges, more detailed pedestrian networks are added to several areas including the south triangle of Central Eastside, Lloyd District, and South Waterfront. In total, 41.2 kilometers of new pedestrian links were added in 2035 by extending the current grid network. These are described in more detail below and an overview is shown in Figure 3.

4.1 Case Study 1: Lloyd Center-Blumenauer Bridge-Central Eastside

A new pedestrian and bicycle facility – the Congressman Earl Blumenauer Bridge – is currently being constructed to link the Lloyd District and Central Eastside (Portland Bureau of Transportation, 2019). We aim to examine the implications of this increased connectivity and the anticipated growth described below.

The Lloyd District has been identified as an "eco-district" with a focus on equitable, sustainable, and resilient development. Between 2010 and 2035, Lloyd is expected to grow by 8,000 households and 9,000 jobs to a total of 9,000 households and 25,800 jobs. In this study, 8,000 households are distributed evenly over 33 PAZs identified as housing in Figure 4 (in yellow). Each PAZ added 242 households, and the same demographic attributes as in the 2010 distribution were assumed. For 9,000 jobs, we assume 25% distributed each to retail, finance, services, and government. In this scenario,14 PAZs around Convention and Lloyd are considered as office cores (in red). Accordingly, they will get all new finance employment (2,250), all government (2,250) jobs, 25% of service jobs (562), and 10% of retail (225). The remaining 9 PAZs will get 65% of service (1,462) and 70% of retail (1,575) employment. The remaining 10% of service (225) and 20% of retail (450) will be distributed across 33 housing PAZs.

Over the same period, the Central Eastside is expected to grow by 7,000 households and 8,000 jobs, for a total of 7,900 households and 25,000 jobs. In the growth scenario, 7,000 households are distributed evenly over the 15 PAZs identified as housing in Figure 5 (in yellow). Each PAZ added 467 households and the same demographic attributes as in the 2010 distribution were assumed. In the lower triangle, 41 PAZs will get 75% of the employment growth (shown in red). The remaining 13 PAZs targeted for commercial will get 1,500 jobs distributed by service, retail and financial. The remaining areas will realize a total growth of 500 jobs in industrial employment, distributed evenly over all the PAZs.

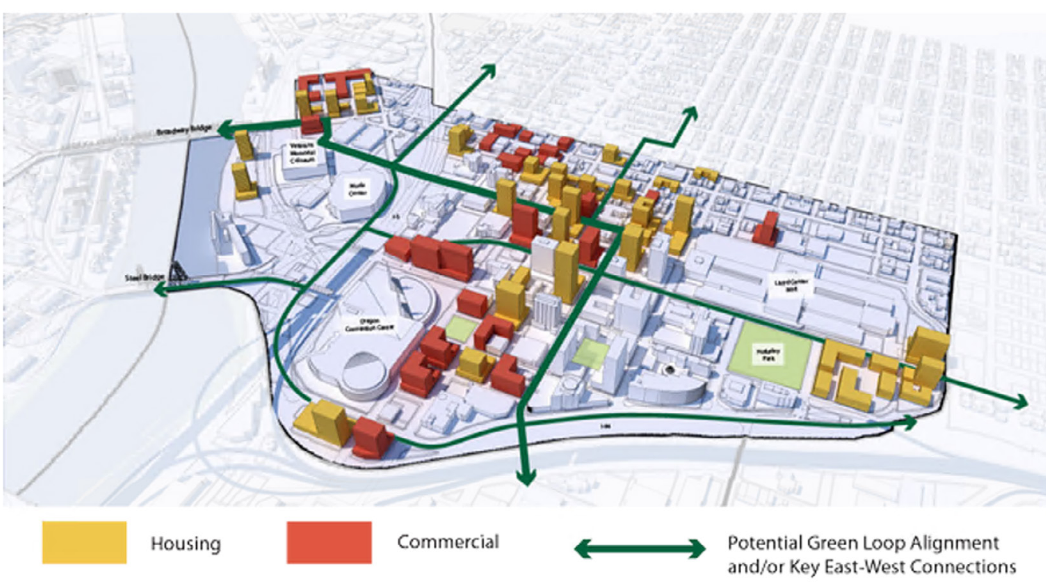

Figure 4. Land-use development plan 2035 of Lloyd District (City of Portland 2018)

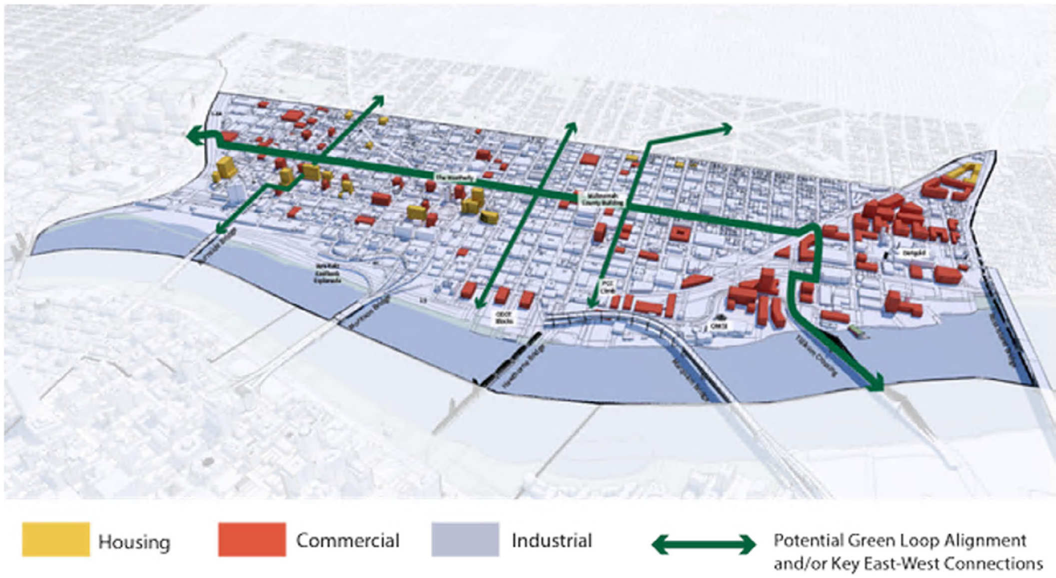

Figure 5. Land-use development plan 2035 of Central Eastside (City of Portland 2018)

4.2 Case Study 2: Central Eastside-Tilikum Crossing-South Waterfront

The Tilikum Crossing was completed in 2015 and is the longest car-free bridge in the United States. It spans the Willamette River, linking Portland's South Waterfront to the Central Eastside Industrial District, described above.

The South Waterfront is a dense, walkable, mixed-use community and is expected to grow by 4,000 households and 10,000 jobs, for a total of 5,100 households and 11,200 jobs from 2010 to 2035. The bridge directly links the South Waterfront to the development planned near the Oregon Museum of Science and Industry (OMSI) on the Central Eastside.

In the South Waterfront plan for 2035, 4,000 households are distributed evenly over the 22 PAZs identified with housing. Each of these PAZs added 182 households and assumed the same attributes as the 2010 distribution. In this scenario, 8,000 government jobs are allocated to institutional PAZs, while 1,000 service jobs are allocated to commercial PAZs. To account for the mixing of land uses, 1,000 retail jobs are evenly distributed to all PAZs.

5 Scenario discussion

We implemented the MoPeD model to test urban development scenarios. These scenarios serve to model various land use and transportation policies to assess to which degree the built environment supports an increase in the share of walk trips. For each of the locations described above, the following scenarios will be modeled:

A. 2010 Base year: A 2010 base year scenario based on the census 2010 population and employment data.
B. 2035 with average growth: A 2035 future year scenario with an average population and employment growth across all locations.
C. Scenario B + Infrastructure: Scenario B with pedestrian bridges completed and a denser street network.

D. 2035 with Central City Plan: A 2035 future year scenario with population and employment growth corresponding to the Central City Plan.
E. Scenario D + Infrastructure: Scenario D with pedestrian bridges completed and a denser street network.

Scenario A is the baseline scenario. It employs the population and employment distribution in 2010. Scenario B is a business-as-usual scenario with an average of 1.5% increase in population and employment across all locations. In scenario D, future population and job growth for 2035 are applied corresponding to the Central City Plan, which is described in the previous section. Pedestrian accessibility measures are recalculated with the new population and new jobs. In scenarios C and E, pedestrian facilities are tested with different population and job growth strategies. As a result of the new bridges and new pedestrian links, the pedestrian catchment area is enlarged, and the accessibility measures also increase.

5.1 Impacts on network connectivity

Network connectivity for pedestrians can be measured by pedestrian catchment ratio (PCR). Here the PCR is the ratio of the pedestrian catchment area to the theoretical circle area with a radius of 800 meters around the centroid of the same PAZ. The higher the PCR, the better the network connectivity. Figure 6 shows that the distribution of PCR under the bridge scenario is generally shifted to the right, which indicates that new bridges and pedestrian streets can help improve pedestrian network connectivity.

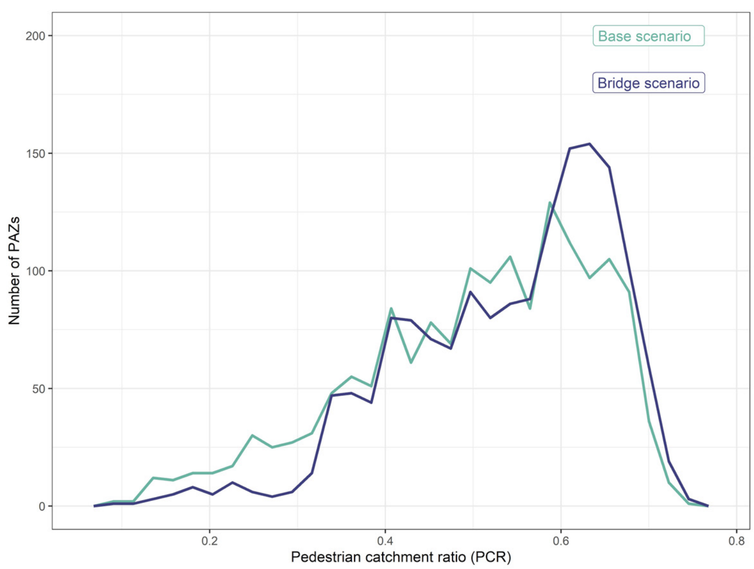

Figure 6. Frequency distribution of pedestrian catchment ratios under different scenarios

Figure 7 shows the spatial distribution of the increase in pedestrian catchment ratio (PCR) comparing between with and without the new bridges and new pedestrian streets. Most PAZs close to the new bridges experience an improvement in network connectivity. The newly built pedestrian streets also play important roles in improving network connectivity, which leads to dramatic increases of PCR on the left side of the Tilikum bridge.

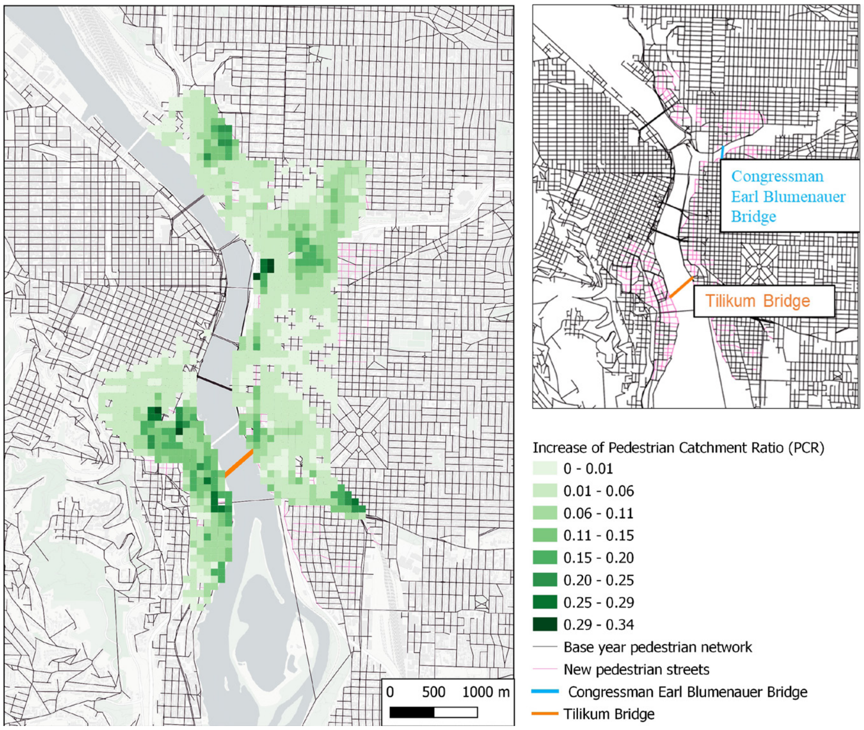

Figure 7. Increases of pedestrian catchment ratio of each PAZ when comparing between with and without new bridges and new pedestrian streets

5.2 Impacts on walk share

The policy scenarios evaluated in this study have varying degrees of impact on the share of walk trips. Two scenarios with average growth (Scenario B and C) have little impact on increasing the walk share, while two Central City Plan scenarios (Scenario D and E) significantly influence the walk share. Figure 8 compares the distributions of PAZ walk shares based on different scenarios. Table 2 provides an overview of the number of walk trips and walk shares under five scenarios as well as their relative changes compared to the baseline.

Table 2. Total trips, walk trips and walk share across the whole Portland Central City area of five scenarios

Scenario	A: 2010 Base year	B: 2035 with average growth	C: Scenario B + infrastructure	D: 2035 with Central City Plan	E: Scenario D + infrastructure
Households	23,100	23,446	23,446	60,300	60,300
…% change compared to base		*+1.5%*	*+1.5%*	*+161.0%*	*+161.0%*
Number of trips (all modes)	282,948	287,170	287,170	533,367	533,367
…% change compared to base		*+1.5%*	*+1.5%*	*+88.5%*	*+88.5%*
Number of walk trips	84,452	86,255	87,624	184,370	189,174
…% change compared to base		*+2.1%*	*+3.8%*	*+118.3%*	*+124.0%*
Share of walk trips	29.8%	30.0%	30.5%	34.6%	35.5%
…% change compared to base		*+0.6%*	*+2.2%*	*+15.8%*	*+18.8%*
Total trips/household	12.25	12.25	12.25	8.85	8.85
…% change compared to base		*0.0%*	*0.0%*	*-27.8%*	*-27.8%*
Walk trips/household	3.66	3.68	3.74	3.06	3.14
…% change compared to base		+0.6%	+2.2%	-16.4%	-14.2%

In the two scenarios with average growth (Scenario B and C), the population evenly grows by 1.5% across all PAZs with the assumption that household compositions remain unchanged. The distributions of walk shares by PAZ are very similar to the baseline. As shown in Table 2, the overall walk shares of the two average growth scenarios are fairly close to the baseline walk share.

In the Central City Plan scenario, the distribution of PAZ walk shares shifts towards the right, which indicates moderate-high walk shares. Most PAZs experience an increase in the share of walk trips. The same shift is observed in the Central City Plan scenario with the pedestrian facility development. The shift is even slightly larger than in the Central City Plan scenario without infrastructure (Scenario D). The pedestrian facility development appears to only show an impact for zones in the catchment area of the bridges. Overall, under two Central City Plan scenarios, the whole Central City area will produce roughly 100,000 more walk trips in 2035 (an increase of about 120%).

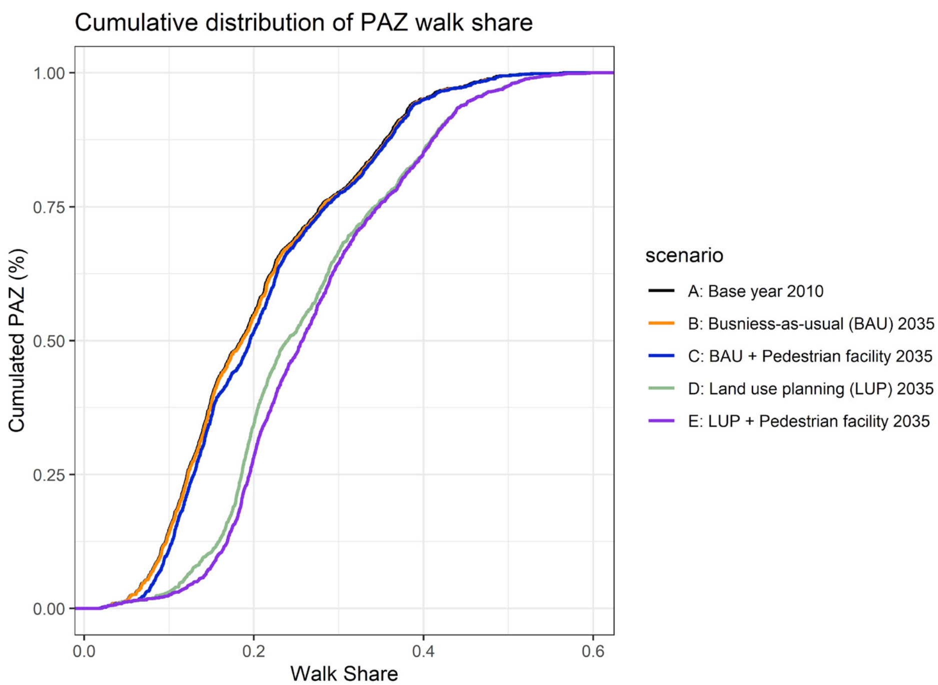

Figure 8. Cumulative distribution walk shares by PAZ

Although the Central City Plan scenarios have notable effects on encouraging higher walk shares, it is observed that the value of average walk trips per household decreases by 16.4% and 14.2% separately in two Central City Plan scenarios (shown in Table 2). One reason for this notable decrease is the assumption that the household composition of PAZs with no household in the base year follows the average distribution of households in the Central City Plan scenarios, where 49% are assumed to be single-person households. Those households tend to generate fewer trips than larger households (Zhang et al., 2019), reducing the number of walk trips per household. The decrease may also imply the limitation of the trip generation model used in MoPeD. In this study, trip generation models can only reflect the demographic changes but are insensitive to the changes in land-use development. The effects of pedestrian accessibility are currently not considered.

The following sections will illustrate the impacts of policy scenarios on individual districts. Table 3 provides an overview of the resulting walk shares of each district under different scenarios and the comparison to the reference scenario.

In the base year 2010, the West End district has the highest walk share, followed by its two neighboring districts, Downtown and Old Town. A higher density of households and jobs, as well as good street connectivity, create an attractive built environment to support walking in those districts. South Waterfront is the least walkable district because in the base year it was not yet developed with vacant brownfield sites and buildings were underutilized. Central Eastside and Lower Albina also have relatively low walk shares in the base scenario. This might be because they were characterized by an industrial core with a high share of manufacturing buildings and a low share of residential and commercial land use. Under the average growth scenario, the characteristics of each district are retained, and the growth is evenly distributed. Thus, walk shares are slightly increased.

As expected, the Central City Plan scenario without infrastructure leads to an increase in the walk share in all districts. Their increases in walk shares range from 12% to 119%. In particular, the walk share in South Waterfront is more than doubled. The change is caused by a large amount of development in housing and employment with a total of 4,000 new households and 10,000 jobs. Similar to South Waterfront, Lloyd District and Central Eastside also gain substantial increases in walk shares due to the rapid and large-scale development in residential and commercial uses. It reveals that the increased rates of walk shares largely depend on the number of new households and new jobs in the district and in the neighboring districts. However, the walk share does not necessarily grow proportionately with population and jobs. The walk mode choice model is designed with a logarithmic relationship between walk shares and pedestrian accessibility. Thus the marginal impact of additional population and jobs is a decreasing function. Figure 9 shows the nature of the logarithmic relation. It indicates that the magnitude of rates of change in walk shares highly depends on the baseline pedestrian accessibility. For example, although a large number of new households and jobs are placed in the Downtown and West End districts (purple and light green dots in Figure 9), the walk shares of these two districts grow only moderately compared to other districts. It suggests that Portland downtown is already very dense and has already reached a certain level of pedestrian accessibility. More activity density does not encourage many more walk trips.

In the scenarios with pedestrian facility development (Scenario C and E), the increase in walk shares is much more pronounced. When comparing the infrastructure scenarios with their corresponding growth-only scenarios (Scenario B and D), the changes in walk shares of the infrastructure scenarios only occur in the districts associated with the new pedestrian facilities. Those are Central Eastside, Llyod District, Lower Albina, South Waterfront, and University District. Almost no changes are noticeable in the remaining districts.

Table 3. Share of walk trips across different districts in five scenarios

Scenario/District	**A: 2010 Base year**	**B: 2035 with average growth** % change compared to A	**C: Scenario B + infra-structure** % change compared to B	**D: 2035 with Central City Plan** % change compared to A	**E: Scenario D + infra-structure** % change compared to D
CENTRAL EASTSIDE	14.1%	+0.8%	+4.9%	+55.4%	+4.1%
DOWNTOWN	38.5%	+0.6%	+0.1%	+19.0%	+0.1%
GOOSE HOLLOW	27.9%	+0.7%	+0.0%	+17.3%	+0.0%
LLOYD	20.6%	+0.8%	+3.6%	+43.8%	+2.7%
LOWER ALBINA	9.7%	+0.9%	+6.1%	+62.8%	+1.3%
OLD TOWN	32.3%	+0.6%	+0.0%	+16.6%	+0.0%
PEARL	28.8%	+0.7%	+0.0%	+12.0%	+0.0%
SOUTH WATERFRONT	8.3%	+1.0%	+13.5%	+118.9%	+24.1%
UNIVERSITY DISTRICT	28.7%	+0.7%	+9.5%	+12.3%	+9.0%
WEST END	41.8%	+0.5%	+0.1%	+13.0%	+0.0%

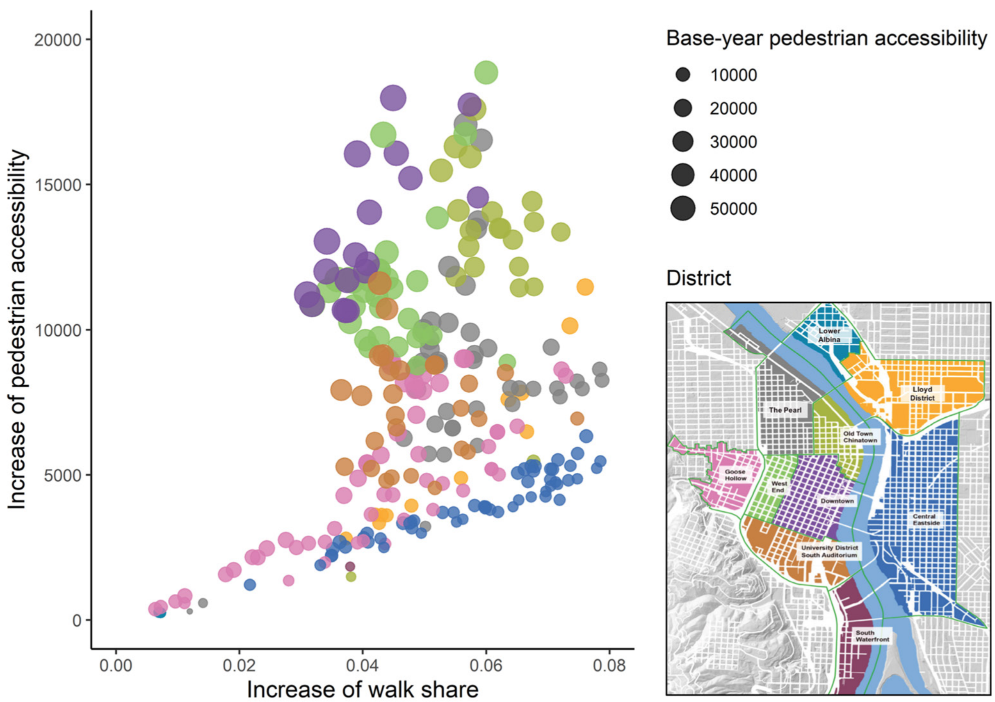

Figure 9. The changes in walk shares and pedestrian accessibility (defined as population + employment within 800 meters) in the baseline scenario and the Central City Plan scenario without infrastructure

To have a closer look into the pedestrian facility scenario, we compared the walk share of each PAZs between scenario D and scenario E (shown in Figure 10). New bridges and links enlarge the pedestrian catchment area because of good and direct connectivity. Most PAZs close to the new facilities experience an increase in walk share. PAZs located on the north side of Congressman Earl Blumenauer Bridge have smaller increases in walk shares than those located on the south side. According to the land-use development plan shown in Figure 3, the south side of the bridge generally has less diverse growth than the north side of the bridge. While people living in the north of the Lloyd District could easily visit locations on the other side of the bridge, a lack of diversity on the south side of the bridge limits the growth in walk trips. The same situation of unbalanced growth is also found near the Tilikum Bridge. The bridge offers good connectivity to the west side of the river. Nevertheless, the land-use growth on the west side lacks diversity and focuses on education. Thus, the Tilikum Bridge is not as attractive for people working and living on the east side of the bridge.

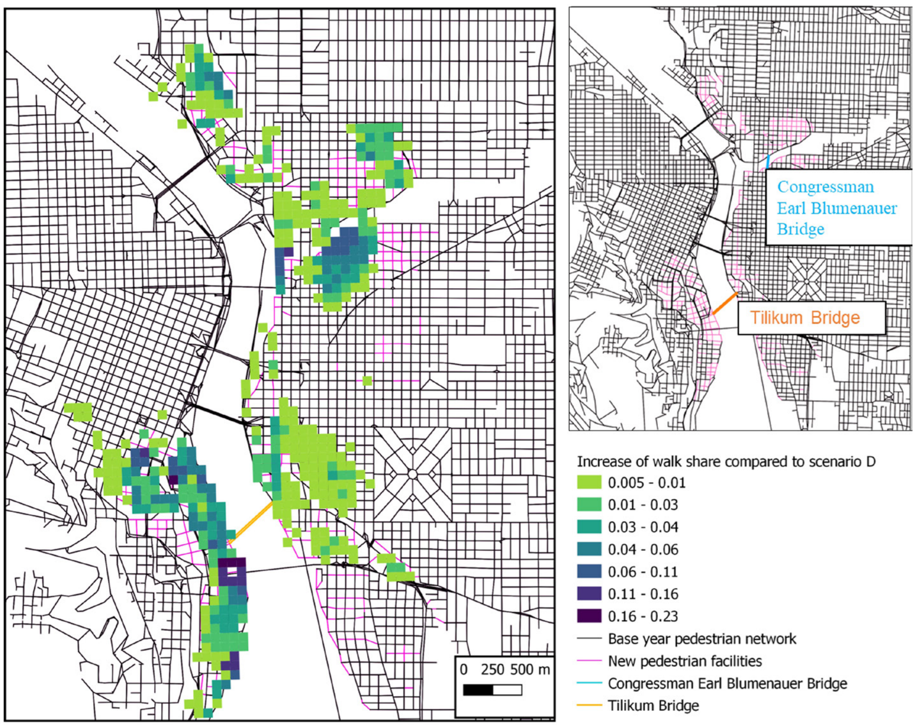

Figure 10. Comparison of walk shares under Central City Plan scenarios with/without pedestrian facilities (scenarios D and E)

5.3 Impacts on average trip length

The average trip distance is largely dependent on the attractiveness of the surrounding district and the district itself. When the district itself has a good street network to access many opportunities, people tend to travel within the district. Otherwise, people will be attracted more strongly to neighboring districts. Figure 11 shows the cumulative distribution of the average trip length by PAZ under the five scenarios. In general, the impact of land use and infrastructure on average trip length is not particularly large. Three typical districts that represent three different distribution patterns are selected for discussion.

Scenario B with average growth has almost no effect on average trip length, and the curves of baseline and scenario B mostly overlap. Under the average growth scenario with pedestrian facility development in the Llyod district (blue lines in Figure 11), the distribution noteworthily shifts to the left, indicating an increase in walk shares. However, the distribution in the South Waterfront shows rather moderate changes. This is because the South Waterfront is still undeveloped in the average growth scenarios. Although the denser pedestrian network improves connectivity in the district, densities are relatively low. This suggests that the development of a denser pedestrian network without corresponding population and employment densities has a limited impact on walk shares.

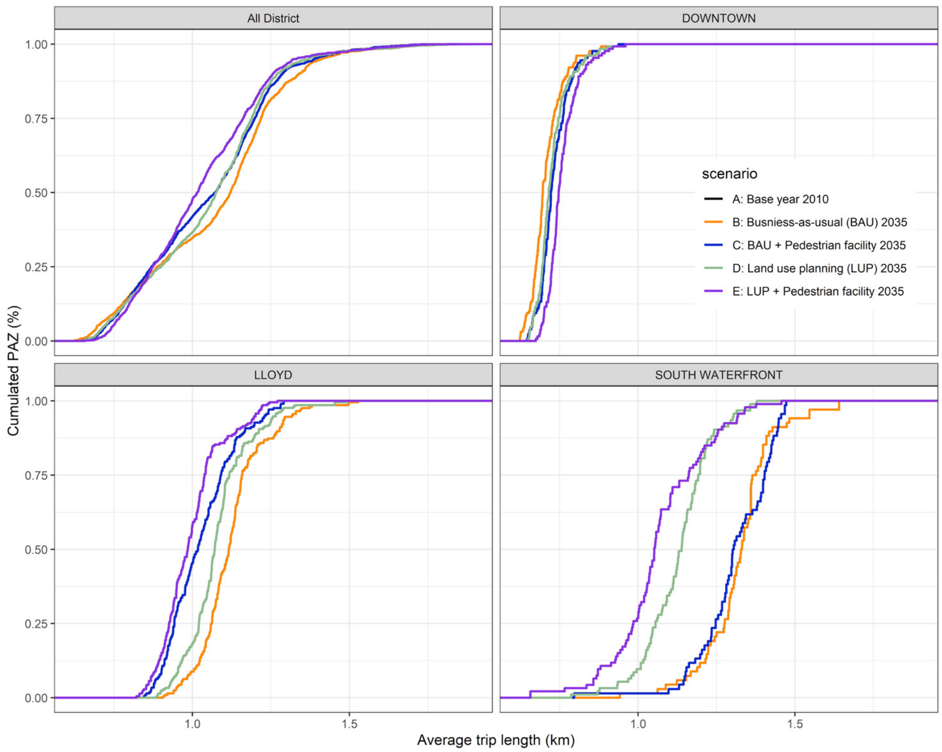

Figure 11. Cumulative distribution of average trip length by PAZ in selected districts

5.4 Impacts on pedestrian flows

Pedestrian route choices were implemented to assign walk trips to the pedestrian network. Figure 12 demonstrates how the pedestrian flows are distributed in the pedestrian network in different scenarios.

In the base year scenario, most of the pedestrian flows are populated in the downtown areas, with the highest segment usage of 2596 pedestrian trips. Many streets on the east side of the river had daily pedestrian trips under 150. Due to the moderate growth strategy, the pattern of pedestrian flow distribution in scenario B is unchanged. In scenario C, the Congressman Earl Blumenauer bridge is used by 320 pedestrians and it also slightly impacts the volumes of the surrounding links. However, the usage of the Tilikum bridge is relatively low with an average pedestrian volume of 111 in both directions. Scenario D with Central City Plan significantly influences the pedestrian volumes in the entire study area. On the one hand, the pedestrian flows in the downtown area boosted to a higher level. The busiest street is crossed by 7321 pedestrians. On the other hand, there are more pedestrian flows occurring on the east side of the river, especially in the Lloyd District. It also increases the usage of the existing bridges connecting the two sides of the river. In scenario E, the pedestrian flows are sprawled across the east side of the study area. The usage of the minor roads is increased. The usage of the Tilikum bridge is increased to an average pedestrian volume of 797 in both directions. The variation plots in Figure 12 give us a better understanding of how the new pedestrian infrastructure impacts daily pedestrian flow. The Tilikum Bridge facilitates the number of pedestrians along the west side of the river, while the Congressman Earl Blumenauer bridge in the Lloyd District enhances the pedestrian volume along the freeway. Also, the new pedestrian roads in the Lloyd District attract a large number of walkers as well as relieve the burden of pedestrian traffic on the surrounding main roads.

Figure 12. Daily pedestrian volumes on the pedestrian network in different scenarios

6 Conclusion

This paper applied a pedestrian planning tool MoPeD into practice, which is often neglected in the transportation planning process. It is also one of the first to apply the fine-grained pedestrian model in an urban study area for the assessment of various land use and transport policies.

Based on the model results, we discuss the effectiveness of policies for promoting a higher share of walk trips. Firstly, the land-use scenario proves the importance of activity density for encouraging walk trips. In general, more populated areas and areas with higher employment density tend to generate more walk trips. The applications found that the effects of activity growth on walk shares are more remarkable in undeveloped districts than in downtown Portland. It implies that land-use development in the less-densely populated areas matters more for the walk probability than in the central areas. However, population and employment growth in downtown Portland is still associated with an increase in walk trips that should not be ignored. Furthermore, the scenario with pedestrian infrastructures suggests that pedestrian behavior is sensitive to network connectivity as well. Compared to population and job growth, the influence of network connectivity is smaller. Especially in the areas which already have mature pedestrian networks, the influence of the new bridge is not as impactful. Most importantly, the application of Congressman Earl Blumenauer bridge shows that although the bridge offers good connectivity to two districts, it won't be attractive if the activity density and diversity in the catchment area are low. It suggests that a good street network cooperating with a dense and diverse land-use plan can maximize the effects of promoting walk trips. In addition, the Tilikum bridge application implies that a good local street network at the end of the bridge is essential to make the new pedestrian infrastructure easily accessible and attractive.

This research still faces some limitations that should be addressed in future work. The pedestrian model appears to be only sensitive to the level of street connectivity rather than the quality of street connectivity. The new bridge with the wide and dedicated pedestrian lane is treated as the same as the old bridge with an unpaved pedestrian lane. This could be one of the reasons that there are no big changes in walk share in the bridge applications. The mode choice model lacks the attributes that can reflect the quality of connectivity. Therefore, in future research, characteristics of the pedestrian facility need to be added to the choice model. Furthermore, when we allocated households and jobs into the PAZ structure, we assumed the average demographic attributes based on the 2010 distribution. In further research, demographic changes such as aging or car ownership should be considered in the projection.

Overall, the pedestrian planning tool MoPeD is sensitive to the small-scale variations in local land use and transport development. It can help the policymakers to have a better understanding of the effects of various demographic policies and infrastructure planning on the walk probability. Most importantly, it can address the planning issues. It can assess how the Central City 2035 policies support increased pedestrian activities. Moreover, it can support planning effective pedestrian networks based on maximizing accessibility and connectivity.

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