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WALKING TRIP GENERATION AND BUILT ENVIRONMENT: A COMPARATIVE STUDY ON TRIP PURPOSES

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Abstract: In recent decades, enhancing the share of walking in individuals' daily trips has become a priority for transportation policymakers, urban planners and public health researchers as an interdisciplinary area. In this regard, determining influential factors on walking has become a matter of contention to move toward a sustainable mode of transportation. This study investigates the impact of the influencing factors on the share of walking in trip generation from/to Traffic Analysis Zones (TAZ) of a city across four trip purposes. In this study, individuals' trip information for four trip purposes has been tested in order to detect influencing factors on walking trip generation based on 112 TAZs for the city of Rasht, Iran. According to the results, density and design are found to be more influential for produced walking trips and diversity is shown to be more effective for attracted walking trips.

Keywords: walking, built environment, trip generation, transportation network design, population density, land use diversity.

1. Introduction

Switching to walking as a non-motorized mode of transportation could significantly affect the transportation statuses of cities (Ewing and Cervero, 2010; Southworth, 2005; Hatamzadeh and Hosseinzadeh, 2019; Hosseinzadeh, 2019; Shamshiripour *et al.,* 2020). Alongside transportation, numerous benefits of promoting walking as an interdisciplinary research area, including environment (Sharifi *et al.,* 2020), economy (Talen and Koschinsky, 2013; Habibian *et al.,* 2015) and public health (Braun *et al.,* 2016), have been focused on in the recent years.

In the past two decades, built environment (BE) has been recognized as a factor that acts as a hidden motivation for individuals to walk more. Therefore, researchers try to identify the influencing environmental factors on walking. According to the definition given by Roof and Oleru (2008), the BE is "a human-made space in which people live, work and recreate on a day-to-day basis" (Roof and Oleru, 2008). To capture the BE, various studies suggest using the three Ds: transportation network *design*, land use *diversity* and population *density* (Cervero and Kockelman, 1997; Ewing and Cervero, 2010; Frank *et al.,* 2005). However, *destination* accessibility and *distance* to transit were added to the aforementioned criteria (Ewing and Cervero, 2010).

Although a wide range of studies investigate the relationship between BE and walking, only a few papers elaborate about how this

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relationship would be changed if various trip purposes were considered separately. Besides, previous studies only consider a single index as representative of each criterion, even though there is a wide range of proposed indices in the literature. Furthermore, most of the studies just consider individuals' residential zones, so the impact of trip attraction zones is unclear. Eventually, most of the objective studies were conducted in small zones in cities of developed countries.

The study possesses five major benefits. First, this research identifies the indices that are effective on various trip purposes. Second, the current study provides an extensive number of indices for each criterion. Therefore, based on the study trip purposes, this study shows which of the investigated indices are more successful in describing walking trip generation. Third, both sides of trip generation have been considered to show which side is more successful in describing walking. Fourth, current research addresses a city of a developing country. Finally, this study has been conducted in the whole city of Rasht, Iran.

In this study, effective factors on the share of walking trips in four trip purposes based on 112 Rasht TAZs have been modeled using various indices, which have been introduced in the literature review. Due to the possibility of different influences of produced and attracted trips, results are reported separately.

The remainder of this paper is organized as follows. The next section provides an overview of the indices of each BE criterion previously proposed. The third section offers a brief explanation of the method that has been used and provides overviews of the case study and descriptive statistics. The results and conclusion are the fourth and final section of the paper.

2. Literature Review

2.1. BE Criteria

Design

Design represents street network characteristics within an area. Quite a few indices have been recommended to encapsulate the effect of transportation network design on walking (Berrigan *et al.,* 2010; Dill, 2004; Gori *et al.,* 2014; Schlossberg, 2006, Behbahani *et al.,* 2019a). Data availability and researchers' preferences are the main determinants of which indices have been used in previous studies (Frank *et al.,* 2010; Frank *et al.,* 2005; Glazier *et al.,* 2012; Krizek, 2003; Behbahani *et al.,* 2019b). What impeded researchers in previous studies to employ all indices is multicollinearity among them. Therefore, studies used one index or employed Principal Component Analysis (PCA) in order to combine several indices and extract one index as their combination (Berrigan *et al.,* 2010). Based on this method, Hatamzadeh *et al.* (2017) suggested two combined indices that have resulted from PCA. According to their result, two components were extracted that were capable of delineating 71.02% of variations of all design indices. The first component consists of percentages of four-way intersections and connected node ratio (node connectivity). The second component includes the ratio of minor streets to major streets and street density (link connectivity) (Hatamzadeh *et al.,* 2017). For more detailed literature review of indices see Habibian and Hosseinzadeh (2018).

Diversity

Extent and mixture of different land uses in a neighborhood defines diversity (Ewing and Cervero, 2010; Nickkar *et al.,* 2019). Diversity is introduced as the most influential BE criteria in the studies of the last two decades (Maghelal and Capp, 2011). In a longitudinal study, Bentley *et al.* (2018) certified a positive association between walking and diversity by considering the changes over the years and variation in individuals' walking (Bentley *et al.,* 2018).

Various indices are proposed to measure the diversity of land uses. Table 1 shows the definition and determination method of two common diversity indices in the literature (Habibian and Hosseinzadeh, 2018). Although a large number of studies have implemented the entropy index, Christian *et al.* (2011) explored the variation of entropy by considering different types and categories and conclude that entropy index could greatly change due to slight modification in land use categorization (Christian *et al.,* 2011). Sugiyama *et al.* (2019) employed isometric substitution analysis and called the performance of entropy index under question (Sugiyama *et al.,* 2019). Ewing *et al.* (2015) conclude that high job-population balance in a zone resulted in a 15 percent decrease in Vehicle Mile Traveled (VMT) in that zone (Ewing *et al.,* 2015). Cervero and Duncan (2006), after reconsidering the job population balance, result that the mentioned index is superior comparing other indices such as entropy (Cervero and Duncan, 2006).

Table 1

Formulation of Two Diversity Indices in the Literature

Index	Formulation	Source
Entropy	$-\frac{\sum_{i=1}^{n} p_i \log p_i}{\log n}$ Pi: Percentage of land use i; n: Number of land uses;	(Frank et al., 2005)
Job-population balance	$1-\left\|\frac{Job - 0.2 \times Pop}{Job + 0.2 \times Pop}\right\|$ job: Number of jobs in a specific area; pop: Number of residents in a specific area;	(Ewing et al., 2015)

Density

Proportion of the population of a zone to the area of that zone is defined as population density (Frank *et al.,* 2010). This ratio is generally higher at the Central Business District (CBD) of cities in which it is more appropriate to walk (Dobesova and Krivka, 2012).

Destination Accessibility

Destination accessibility defines as ease of reaching different destinations. It can be measured by distance to various destinations or number of destinations around a location (Ewing and Cervero, 2010). Boakye- Dankwa *et al.* (2019) show improving access to destinations within a 10-min walk from home may increase walking in both Australia and Hong Kong case studies (Boakye-Dankwa *et al.,* 2019).

Distance to Transit

Previous studies use various indices to capture distance to transit criteria. Ewing and Cervero use the shortest distance of an individual's home/workplace to the adjacent public transit stop as representative of this criterion (Ewing and Cervero, 2010; Rahimi *et al.,* 2020). The other indices in the literature are total length of the public transit network per area in a zone, average distance between stations in a specific zone and number of stations in a zone (Ewing *et al.,* 2015).

2.2. Walking and Trip Purposes

The impact of trip purposes on walking has been investigated in the literature. Yang and Diez-Roux found that walking distance and duration are largely associated with the trip purpose. In this study, seven trip purposes have been discussed (Yang and Diez-Roux, 2012). Frank and Pivo (1994) considered two trip purposes, work and shopping, and show the influencing factors that differ in the resulting models (Frank and Pivo, 1994). Gehrke and Clifton (2017) considered two types of trip purposes in their analysis: walking for transportation and discretionary trips. The results of this study reveal the strong effects of BE in promoting walking in both mentioned trip purposes (Gehrke and Clifton, 2017). Handy (1992) found that walking for errands is more likely in high-walkable versus low-walkable areas. She also concludes that utilitarian trips (e.g., shopping) are the sources of difference in the share of walking between areas with low- and high-walkability (Handy, 1992). For purposes such as exercise, the differences are not discernable (Handy, 1992). In a recent study in Luxembourg among older adults, Perchoux *et al.* (2019) conclude that walking distance could be greatly different based on trip purposes (Perchoux *et al.,* 2019). In summary, although there is a wide range of studies that consider trip purposes for walking, none of them consider a TAZ-based analysis to investigate influencing factors.

Although an extensive range of indices is introduced in the literature, there is no mutual consent among the researchers about which of them are most influential. This is because none of the previous studies calculate all the indices in an area to compare the results on encouraging walking. Besides, there is not much knowledge about which of the indices has a greater impact on each trip purpose in TAZ-level analyses. Aggregate studies in the scope of a city could provide an apt ground for decision-makers to take proper action in long-term planning and policymaking.

3. Data

3.1. Area of Study

The city of Rasht (population approximately 640,000 in 2007) is located in the North of Iran. The urban area in Rasht contains 112 traffic analysis zones (TAZs), which are presented in Figure 1. Unplanned settlements with disordered pathways, low quality and/or condensed houses and weak infrastructure constitute a major part of the spatial structure in the city. With the development of the city and limited space of the bazaar, some commercial activities have moved out from the city center and the traditional bazaar. A poor transit system has made private cars and taxis the most favorable modes of transportation in daily trips (Azimi, 2005; Hatamzadeh *et al.,* 2017).

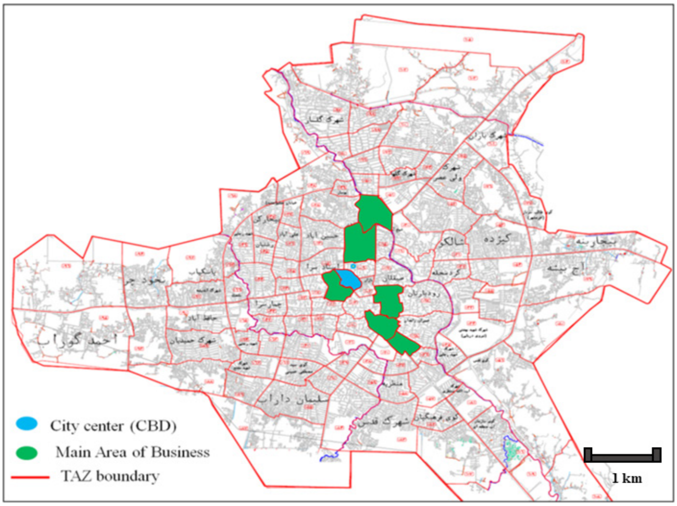

Fig. 1.
Traffic Analysis Zones in Rasht

3.2. Data Description

In this study, information from the 2007 Rasht Household Travel Survey (RHTS) is used. As a part of the study, a questionnaire was designed and distributed among more than 5,000 households across 112 TAZs. The aim of the survey was to collect detailed information about every trip taken by all members of each participating household. Each person was asked to fill out a travel diary for a specific day that included the modes of travel, starting and ending time of the trip and the trip purpose. In addition, household information including the number of vehicles owned by type (e.g., car, motorcycle, and bicycle) and household size, as well as individual socio-demographic information such as age, gender and job status were collected (Rasht, 2011).

The data consists of more than 5,000 households, 17,000 individuals and 30,000 trips (5,501 work trips, 4,896 educational trips, 2,737 shopping trips and 15,355 return-to-home trips). According to RHTS, 97.25% of work trips, 99.42% of educational trips and 95.35% of shopping trips are home-based, and 62.62% of Rasht residents have service jobs (Rasht, 2011). Comparing the considered trip purposes, the walk-share related to shopping is higher than others; 47% of shopping trips are walking although the walk-share in all trips is 31%.

3.3. Method

In this study, linear regression analysis is used to model the influencing factors on the share of walking trips. The share of walking trips in a zone is considered a dependent variable, and socio-demographic characteristics and built environment criteria are used as independent variables. Thus, the model can be represented in equation 1:

$$Y_i = \beta_1 + \beta_2 x_{2i} + \beta_3 x_{3i} + \ldots + u_i \qquad (1)$$

Given a data set of n TAZs, a linear regression model assumes that the relationship between the share of walking Y_i and each of the independent variables is linear (equation 1).

This relationship is modeled through an error term u_i, an unobserved random variable that adds noise to equation 1.

In developing equation 1, it has assumed the error term has population mean of zero (equation 2), no serial correlation (equation 3), homoscedasticity of the error term (equation 4), zero covariance between u_i and each x_i variables (equation 5), no specification bias and no exact collinearity between the x variables. The validity of assumptions has been checked to ensure no assumptions violations exist.

$$E\ (u_i \mid X_{2i}, X_{3i}) = 0 \text{ for each } i \quad (2)$$

$$Cov\ (u_i, u_j) = 0 \quad (3)$$

$$Var\ (u_i) = \sigma^2 \quad (4)$$

$$Cov\ (u_i, X_{2i}) = Cov\ (u_i, X_{3i}) = 0 \quad (5)$$

The goodness of fit and adjusted goodness of fit for the model resulted from equation 6 and equation 7.

$$R^2 = \frac{ESS}{TSS} = \frac{\widehat{\beta_2}\sum y_i x_{2i} + \widehat{\beta_3}\sum y_i x_{3i} +}{\sum y_i^2} \quad (6)$$

$$\overline{R^2} = 1 - \frac{\sum \hat{u}_i^2 / (n-k)}{\sum y_i^2 / (n-1)} \quad (7)$$

3.4. Analysis

To capture the variation resulted in trip generation, the walk-shares of produced and attracted trips are considered. In addition, walking trips are considered for four purposes of trips (i.e., work, education, shopping and return-to-home). Since the length of the trip is not reported in the data, the distance between centroids of the produced and attracted TAZs is used as trip length. The variables of this study consist of walk-share as a dependent variable, while socio-economic variables and indices related to each of the BE criteria are treated as independent variables. Descriptive statistics, number and percentage in each purpose of the trip are presented in Table 2.

Table 2

Number and Percentage of All Trips and Walking Trips in Each Trip Purpose

		Work	Education	Shopping	Return-to-home
Number of all trips		5501	4896	2737	15355
Number of walking trips		892	1805	1295	4901
Walking share (produced and attracted) (Percent)		16.2	36.9	47.3	31.9
Produced	**Average**	16.1	33	41.1	34.1
	Standard deviation	10.4	16.8	21.6	16.3
Attracted	**Average**	18	37.5	62.7	28.7
	Standard deviation	13.3	24.4	31.4	11

Socio-demographic variables within each TAZ, including the average age, household size, bike ownership, motorcycle ownership and car ownership, are calculated. Descriptive statistics of the socio- demographic variables are presented in the first part of Table 3. Design indices are calculated based on the GIS database of the transportation network of Rasht, which has been collected as a part of RHTS. GIS software has been used to

calculate indices in 112 TAZs of Rasht. The first part of Table 3 shows descriptive statistics of the design indices.
Land use diversity variables are calculated based on the Rasht land use database, which was gathered in RHTS. The second part of Table 3 shows the descriptive statistics of calculated diversity variables.

The population density that has been calculated in each TAZ of Rasht is represented in the third part of Table 3.

Table 3
Zone-based Independent Variables Descriptive Statistics

		Average	S.D.	Min	Max	
Part 1- Socio-economic Variables						
1-1	Age average	30.01	2.83	22.33	40.25	-
1-2	Household size	3.51	0.19	3	4.33	-
1-3	Average bike ownership	0.66	0.12	0.375	1.008	-
1-4	Average motor ownership	0.12	0.07	0	0.43	-
1-5	Average car ownership	0.57	0.24	0.26	0.95	-
Part 2- Connectivity Indices						
2-1	Intersection density	244.5	134.32	1.24	656.29	$1/km^2$
2-2	Percentage of 4-way intersections	14.1	6.44	0	38.9	-
2-3	Cal-de-sac density	146.11	91.01	0	407.8	$1/km^2$
2-4	Number of cal-de-sac	75	62.6	0	363	-
2-5	Number of 3-way	104	80.6	3	449	-
2-6	Number of 4-way	15	11.96	0	69	-
2-7	Ratio of minor streets to major streets	11.57	25.63	0	187.56	-
2-8	Street density	0.017	0.0084	0.004	0.035	m/km^2
2-9	3-way intersection density	210.88	116.92	1.24	535	$1/km^2$
2-10	4-way intersection density	33.62	23.98	0	121.2	$1/km^2$
2-11	Connected node ratio	0.62	0.1	0.4	1	-
2-12	Ratio of links to nodes	1.86	0.2	1.55	2.25	1/m
2-13	Gamma index	0.39	0.05	0.33	0.63	-
2-14	Alpha index	0.09	0.059	0.01	0.36	-
2-15	Percentage of 3-way intersections	85.9	10.32	61.09	100	-
2-16	Number of major 3-way intersections	7.61	7.48	0	49	-
2-17	Number of major 4-way intersections	1.34	1.67	0	11	-
2-18	Ratio of cal-de-sac to nodes	37.01	9.22	0	60	-
2-19	Major street density	3653.4	2967.5	0	16149.4	m/km^2
2-20	Minor street density	21648	8836.3	610	36898	m/km^2
2-21	Average link length	54.37	24.95	27.2	227.46	m
2-22	Node connectivity	0.6	0.13	0.32	1.34	-
2-23	Link connectivity	18.3	26.20	0.03	166.5	-
Part3-Diversity Indices						
3-1	Entropy index	0.33	0.19	0	0.83	-
3-2	HHI	0.72	0.18	0.29	1	-
3-3	MXI	35.8	11.3	1.64	50	-
3-4	Job-population balance	0.56	0.29	0	1	-
Part4-Density Index						
4-1	Population density	10100	6600	0	28700	$1/km^2$
Part5-Destination Accessibility Indices						
5-1	Areal distance to CBD	2629	1712	0	10626	m
5-2	Network distance to CBD	3334	2318	0	14782	m

4. Results and Discussion

Walking Trip Production

The first part of Table 4 shows percentages of walking in produced trips for considered trip purposes in Rasht, which reports effective variables and significance levels. In Table 4, population density positively affects the walk-share among all trip purposes. A wide range of studies found the positive impact of higher population density on walking (Frank *et al.,* 2010; Frank *et al.,* 2005; Hong *et al.,* 2014). Population density is also important in the produced return- to-home trips.

Table 4

Produced and Attracted Trip Models for Each Trip Purpose

		Work	Educational	Shopping	Return-to-Home
Produced	Constant	0.12***	0.259**	0.215***	0.101***
	Population density	0.000293**	0.000622**	0.0001093***	0.000288*
	Link connectivity	-	0.42**	0.66***	-
	Job-population balance	-	-	0.129**	0.362***
	Ratio of minor to major streets	0.00066***	-	-	-
	R^2	0.066	0.173	0.396	0.479
	Adj-R^2	0.049	0.158	0.380	0.470
Attracted	Constant	0.054***	0.232***	0.228***	0.255***
	Population density	0.000293**	-	0.000744***	0.000699*
	Job-population balance	0.218***	0.387***	0.548**	
	Average length of links	-	-0.00147*	-	-0.00085**
	R^2	0.234	0.287	0.338	0.262
	Adj-R2	0.227	0.273	0.326	0.249

*Note: ***, ** and * denote a 99%, 95% or 90% level of significance, respectively.*

Results also show the importance of design indices. Link connectivity, as a design index, is positively effective in shopping and educational trip models. Higher link connectivity means a denser street network, as well as a higher ratio of minor to major streets. Since shopping opportunities are more frequent in minor streets, higher values of this index improve the shopping chance from passing individuals while walking. Thus, a denser street network in minor streets, which is a significant part of link connectivity, results in denser shopping opportunities. The compound design index, link connectivity, also increases educational walking trips (Educational trips consist of students between 7 to 18 years old who go to school and more than 18 years old who attend the university). In major streets, cars with high speeds and wide streets make crossing difficult for students (Hong *et al.,* 2014). In this case, students are more vulnerable and less experienced compared to adults. Therefore, the "ratio of minor streets to major streets" can represent the situation properly. Previous studies in the literature highlight safety concerns of parents in their children's educational trips (Boarnet *et al.,* 2005; Buliung *et al.,* 2017; Kerr *et al.,* 2006; Karimpour *et al.,* 2019).

In work trips, a denser street network secures more diverse routes, which provides the possibility of choosing a more direct or more attractive route. Increasing the ratio of minor streets to major streets enhances safety and, thus, encourages individuals to do more walking in their work trips. Since cars usually are driven at lower speed on minor streets, citizens are more likely to walk along them (Jacobsen, 2015). As illustrated in Table 4, the larger ratio of minor streets to major streets results in a higher percentage of walking in work trips. In the produced trips model, BE factors have been more successful in describing walking in return-to-home and shopping trips.

4.1. Walking Trip Attraction

The second part of Table 4 shows the influencing factors on walking trip attraction models. In this study, all the diversity indices have been entered in the model to determine which ones are more successful in describing walking. Results show the positive impact of diversity indices in work, educational, and shopping trips in the destination zone. The job-population balance, as a diversity index, means more balance between residents and available jobs in a zone. For instance, in work trips, residential land uses adjacent to zones with existing job opportunities increases the possibility of working near the residential location. As a result, more walking to work takes place due to the short distance between workplace and home (Ewing *et al.,* 2015). Although each of the diversity indices mentioned in Part 3 of Table 3 were tested in the model, the job-population balance was the only one found to be significant. This result is different from most previous studies, in which the entropy index is considered as a proxy of diversity (Badland *et al.,* 2009; Frank *et al.,* 2010; Frank *et al.,* 2005; Talen and Koschinsky, 2013). However, another study casts doubt about the sufficiency of the entropy index because it assumes equal weight for all land uses (Christian *et al.,* 2011). The average length of streets in the street network shows the distance between nodes in the network, which has been found to be influential in educational and return-to-home trips. Negative values of the coefficients mean individuals do not have a tendency to reach destinations by taking long roads. In fact, shorter roads indicate the possibility to choose a more efficient route to reach a destination and prevent people from walking along lengthy and boring streets. Additionally, drivers must reduce their speed before reaching intersections on short roads. It seems that the index is more influential in educational attracted trips because students are less experienced in interacting with cars, so streets with lower traveling speed are more suitable for students to walk (Kerr *et al.,* 2006).

The impact of population density on job trips is the lowest among all trip purposes, which is aligned with findings of Ramezani *et al.* (2018) (Ramezani *et al.,* 2018). Moreover, in the modeling of work trips, attraction model is more successful than produced model. This finding is in accordance with the recent study that highlights the importance of workplace surroundings (Adams *et al.,* 2016).

5. Conclusion

In this study, effective indices on walking trip generation are investigated. Five different factors from all those calculated were found to be significant in all eight models.

Density and design demonstrated a positive effect on walking to work, educational- and shopping-produced and return-to-home attracted trips. These findings reveal that density and design were more important around peoples' residences. Comparing all the significant variables in the walk-share of trip generations, the population density index was found to be influential in seven out of eight models. Design indices (i.e., average length of links, ratio of minor roads to major roads and link connectivity) have been significant in five out of the eight models, four of which are in individuals' residential TAZs. This finding is aligned with the previous studies that consider these criteria in a buffer around the homes of the participants in the surveys (Cao, 2014; Frank *et al.,* 2005; Lamíquiz and López-Domínguez, 2015; Talen and Koschinsky, 2013)

Job-population balance, a diversity index, has been found significant in five out of the eight total models. Diversity was found to be important in the destination, not including the individuals' places of residence. This is in contrast with studies in the literature that assumed that diversity was important around peoples' homes (Frank *et al.,* 2005; Talen and Koschinsky, 2013). In addition, among all diversity indices, the job-population balance was found to be significant in the city of Rasht, while most parts of the literature suggest using the entropy index as a proxy of diversity (Talen and Koschinsky, 2013).

According to the reported goodness of fit in the walk-share trip generation, shopping and return-to-home trips had the highest goodness of fit. In work and educational trips, people need to be at their destinations at a certain time. Faster modes of transportation are preferred and BE characteristics may not affect them. However, in shopping and return-to-home trips, people have more time, so it is more probable that environmental characteristics have an impact on walking.

Some limitations are important to point out. First, the major way of commuting is reported by individuals, rather than the details of their trip chains. Furthermore, there is information about individuals' production and attraction TAZs, not the exact routes of their trips. If the exact route was given, all the TAZs involved in the trip could be included in the analysis. Although a wide range of indices are calculated, there are some others that could help to reach more profound results: density of bus stops, pedestrian catchment area, block density and pedestrian route directness. In addition, various path attributes such as slope, adjacent traffic volumes and presence/width of sidewalks have not been calculated in this study, which could be helpful in reflecting on some key factors influencing walking for various trip purposes.

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