Built Environment and Walking: 
Short vs. Long Walking Trips

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Abstract

In recent decades, many studies investigated the influencing factors on walking. Although there are lots of finding about these factors, only a few of them conducted to differentiate between short and long walking trips and their associated influencing factors. Current research investigates the impact of the influencing factors on the share of walking trips in short and long walking trips. To do so, in the first step a proxy between short and long trip should be recognized. Furthermore, investigation in two mentioned cases has been conducted in trip generation zones, across four trip purposes. While a significant portion of the walking literature is made up of studies that are focused on a single trip purpose, this research investigated influencing factors on the share of walking in a diverse range of trip purposes. In this study, individuals’ trip information for four trip purposes (i.e., work, education, shopping and return to home) have been tested in order to detect influencing factors on short and long walking trips in 112 traffic analysis zones (TAZs) for the city of Rasht, Iran. In this regard, indices mentioned in the literature review are derived from a transportation network database and land use data. According to the results, density in both trip generation sides in short trips is significant. Furthermore, built environment factors are more successful in describing short walking trips comparing long ones. Models are able to describe share of walking up to 0.277 in short return to home and 0.11 in long educational walking attraction trips.

Keywords: Walking, Built Environment, Transportation Network Design, Connectivity, Population Density, Land Use Diversity
Introduction

Walking plays a significant role in urban transportation (Reid Ewing & Cervero, 2010; Piatkowski, Krizek, & Handy, 2015; Shaaban, Muley, & Elnashar, 2018; Staats, Diakité, Voûte, & Zlatanova, 2019). Alongside providing access to other motorized modes, walking can be considered as independent travel mode stand alone, especially in shorter trips. Besides transportation, numerous benefits of promoting walking include the environment, economy (Talen & Koschinsky, 2013) and public health (Braun et al., 2016) have been mentioned in the literature.

In recent years many studies showed the positive impact of Built Environment (BE) on walking. To capture the BE impact, studies considered 5Ds, including: transportation network design (design), land use diversity (diversity) and population density (density), destination accessibility and distance to transit (Cervero & Kockelman, 1997; Reid Ewing & Cervero, 2010; L. D. Frank, Schmid, Sallis, Chapman, & Saelens, 2005).

Although a wide range of studies investigate the relationship between BE and walking, just a few studies explored how this relationship would be changed if short and long walking trips are considered separately. It would help to identify which criteria is more influential on short trips and which criteria is better in long ones. Besides, the effect of trip purposes on walking has been involved in a few scholarly papers. Furthermore, most of the studies only consider the residential place and the impact of trip destination zones is unclear. Eventually, most of the objective studies conducted in a small zone in the city of a developed country, while the focus of this study is the extent of the city in a developing country.

Current study addresses influencing factors on walking in trip generation zones in short and long trips by considering the boundary of short and long walking trips as well as different trip purposes. In this study, the effective factors on the share of walking trips are based on 112 Rasht TAZs have been modeled, considering using various indices which have been introduced in the literature review. Due to the possibility of different influences of trip produced and attracted trips, results are reported separately.

This study would help policy makers to identify which segments they can encourage people to walk more in their short trips, also to identify the factors that may be more effective on longer walking trips. By saying longer trips, it means trips that can potentially be a walking trip. The main question is, is there a significant difference between the influencing factors in short and long trips? Aggregate studies in the scope of a city provide a proper foundation for decision makers to take a convenient attitude about long-term planning and policymaking. In this study zonal based approach have been considered to evaluate walking situation in Rasht TAZs.

The remainder of this paper is organized as follows. The next section provides an overview of indices related to each BE criterion previously proposed and studies which considered the length of walking trips. The third section offers a brief explanation of the method that has been used, an overview of the case study and the descriptive statistics. The results and conclusion are the fourth and final section of the paper.
Literature review

The first section is a discussion about BE criteria that have been mentioned in the literature. The next part is about studies that considered short and long walking trips and different trip purposes.

**Built Environment 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, Pickle, & Dill, 2010; Dill, 2004; Gori, Nigro, & Petrelli, 2014; Schlossberg, 2006). Data availability and researchers’ preference are the main determinants of which indices have been used in previous studies (L. D. Frank et al., 2010; L. D. Frank et al., 2005; Glazier et al., 2012; Krizek, 2003). The reason that impeded researchers in previous studies to employ all indices is the multicollinearity among them. Therefore, studies used one index or combined several indices and extract one index as their combination by applying Principal Component Analysis (PCA) (Berrigan et al., 2010). Based on this method, Hatamzadeh et al. suggested two combinatorial indices that have resulted from principal component analysis (Hatamzadeh, Habibian, & Khodaii, 2016). According to their result, two components were extracted, which are capable of delineating 71.02% of variations of all design indices (Hatamzadeh et al., 2016). 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) (for more details see (Hatamzadeh et al., 2016). The first part of Table 1 represents the previously employed indices in the literature (Habibian & Hosseinzadeh, 2018).

**Diversity**

Extent and mixture of different land uses in a neighborhood defines diversity (Reid Ewing & Cervero, 2010). Diversity introduced as the most influential BE criteria in the studies of the last two decades (Maghelal & Capp, 2011). In a longitudinal study, Bentley et al. (2018) certified 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 use. Table 1 shows the definition and determination method of each diversity index in the literature (Habibian & Hosseinzadeh, 2018). Although a large number of studies has implemented the Entropy index, Christian et al. explored the variation of entropy based on considering different types and categorization. They conclude that entropy index could hugely 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). On the other hand, Ewing et al. (1996) conclude that another diversity index, high Job-population balance in a zone resulted in 15 percent decrease in VMT\(^2\) in that zone (Reid Ewing, DeAnna, Heflin, & Porter, 1996). Cervero and Duncan, after reconsidering the job-population balance,

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\(^2\)Vehicle Mile Traveled
result that the mentioned index is superior comparing other indices such as entropy (Cervero & Duncan, 2006).

**Density**

Density as a BE criterion is considered as a ratio of the population of a specific zone to the area of that zone (L. D. Frank et al., 2010). A higher ratio can be found at the Central Business District (CBD) of cities in which it is more encouraging to walk (Dobesova & Krivka, 2012).

Table 1 BE indices in the literature review ((Habibian & Hosseinzadeh, 2018))

| Variable                      | Description                                                                 | Impact<sup>3</sup> | References                                                                                       |
|-------------------------------|-----------------------------------------------------------------------------|---------------------|--------------------------------------------------------------------------------------------------|
| **Design indices**            |                                                                             |                     |                                                                                                  |
| 1 Intersection density        | Number of intersections per unit area                                       | +                   | (Badland et al., 2009; L. D. Frank et al., 2010; L. D. Frank et al., 2005; Holt, Spence, Sehn, & Cutumisu, 2008; Koohsari et al., 2016; McCormack, Cerin, Leslie, Du Toit, & Owen, 2007; McGinn, Evenson, Herring, Huston, & Rodriguez, 2007; Nagel, Carlson, Bosworth, & Michael, 2008; Van Dyck, Deforce, Cardon, & De Bourdeaudhuij, 2009; Wells & Yang, 2008) |
| 2 Percentage of 4-way intersections | Ratio of 4-way intersections to all intersections × 100                    | +                   | (Dill, 2004)                                                                                     |
| 3 Cul-de-sac density          | Number of cul-de-sacs per unit area                                         | -                   | (Schlossberg & Brown, 2004)                                                                        |
| 4 Pedestrian catchment area   | Pedestrian accessible area (PA)/Ideal pedestrian accessible area (IA)       | +                   | (Chin, Van Niel, Giles-Corti, & Knuiman, 2008; Gori et al., 2014; Porta & Renne, 2005; Schlossberg, 2006; Schlossberg & Brown, 2004) |
| 5 Modified pedestrian catchment area | Modified pedestrian accessible area (MPA)/Ideal pedestrian accessible area (IA) | +                   | (Gori et al., 2014)                                                                              |
| 6 Impeded pedestrian catchment area | Pedestrian accessible area considering impedances / Ideal pedestrian accessible area (IA) | +                   | (Schlossberg, 2006)                                                                               |

<sup>3</sup> +, - and * show the positive, negative and contradictory impact of the indices in the previous studies.
|   |                                |                          |   |                     |
|---|--------------------------------|-------------------------|---|---------------------|
| 7 | Ratio of minor streets\(^4\) to major streets\(^5\) | -                       | + | (Dill, 2004)        |
| 8 | Block density                  | Number of blocks per unit area | + | (Dill, 2004; Hooper, Knuiman, Foster, & Giles-Corti, 2015; Song & Knaap, 2004) |
| 9 | Block length                   | Average length of blocks in an area | - | (S. Handy, Paterson, & Butler, 2003) |
| 10| Street density                 | Total length of streets per unit area | + | (Dill, 2004)        |
| 11| Connected node ratio (CNR)     | Number of intersections divided by the number of intersections plus cul-de-sacs | + | (Berrigan et al., 2010; Dill, 2004; Hooper et al., 2015) |
| 12| Ratio of link-nodes            | Ratio of links to nodes per unit area | + | (Berrigan et al., 2010; Dill, 2004; Zhang & Kukadia, 2005) |
| 13| Grid pattern                   | Similarity of a street network to grid network | + | (Southworth & Owens, 1993) |
| 14| Pedestrian route directness (PRD) | Ratio of route distance to straight-line distance for two selected points | - | (Dill, 2004)        |
| 15| Gamma index                    | Ratio of number of actual links to the number of all possible links | * | (Berrigan et al., 2010; Dill, 2004; Gori et al., 2014; Schlossberg, 2006; Schlossberg & Brown, 2004) |
| 16| Alpha index                    | Ratio of number of actual loops to the number of all possible loops | * | (Berrigan et al., 2010; Dill, 2004; Gori et al., 2014; Schlossberg, 2006; Schlossberg & Brown, 2004) |
| 17| Node connectivity              | 0.817 (Percentage of four-way intersection) + 0.817 (The ratio of intersection to nodes) | * | (Hatamzadeh et al. 2017) |
| 18| Link connectivity              | 0.862 (The ratio of minor roads to major roads) + 0.762 (street density) | + | (Hatamzadeh et al. 2017) |

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\(^4\) Minor street is considered as two-way two-lane urban street that often services to low traffic and low speed.

\(^5\) Major street is considered as two-way four-lane or more urban street (multilane streets) that can serve more vehicles with high average speed.
|   | Entropy | \(- \sum_{i=1}^{n} p_i \log p_i \) | \( \log n \) | \( P_i \): Percentage of land use i (area-based) | \( n \): Total number of land uses | * | (Cervero & Kockelman, 1997; L. D. Frank et al., 2010; L. D. Frank et al., 2005; Taleai & Amiri, 2017) |
|---|---|---|---|---|---|---|---|
| 2 | Herfindal-Hershman index (HHI) | \( p_1^2 + p_2^2 + \cdots + p_n^2 \) | \( P_i \): Percentage of land use type i | \( n \): Total number of land uses | - | (Eriksson, Arvidsson, Gebel, Ohlsson, & Sundquist, 2012) |
| 3 | MXI | \( |P - 50| \) | \( P \): Percentage of residential land use of a specific area | - | (Van den Hoek, 2008) |
| 4 | Job-population balance | \( \frac{1}{2} \left( \frac{|\text{Job} - 0.2 \times \text{Pop}|}{|\text{Job} + 0.2 \times \text{Pop}|} \right) \) | \( \text{Job} \): Number of jobs within a specific area | \( \text{Pop} \): Number of residents within a specific area | + | (R. Ewing et al., 2014) |
| 5 | Dissimilarity index | \( \frac{X_i}{8} \) | \( X_i \): Number of dissimilar land uses adjacent to a considered land use | + | (Cervero & Kockelman, 1997) |

**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 adjacent public transit stop as representative of this criterion (Reid Ewing & Cervero, 2010). The other indices in the literature are the total length of the public transit network per area in a zone, the average distance between stations in a specific zone and a number of stations in a zone (R. Ewing et al., 2014).

**Destination Accessibility**
Destination accessibility defines as ease of accessing different destination locations. It can measure by distance to various destinations or number of destinations around a location (Reid Ewing & Cervero, 2010).

**Short and Long Walking Trips**

Few studies have divided short and long trips based on their length. Ferrer et al. considered duration less than 30 - 45 minutes of walking as short walking trips (Ferrer, Ruiz, & Mars, 2015). In another study, 1600 meters considered as a proxy for short walking trips (Napier, Brown, Werner, & Gallimore, 2011). Mackett has investigated the potential of mode transfer in short trips. In this study, the factors which can induce mode change on short trips have been identified (Mackett, 2003).

How long usually people walk? It is an important question in walking literature. In a study, Iacono et al. (2008) assessed distance decay functions for different modes and various trip purposes. In this regard, it shows how the tendency of walking decrease as the distance increase and also, how the travel behavior change based on the purpose of the trip (Iacono, Krizek, & El-Geneidy, 2008). Based on their resulted function, in shopping trips, people are less desirable to walk while in entertainment trips; they are more likely to walk (Iacono et al., 2008).

Short walking trips normally mentioned in previous studies when their distance to public transit was the matter. Ewing and Cervero report a meta-analysis showing a public transport demand elasticity of -0.29, suggesting a 10 percent increase in distance to a public transit stop would decrease public transport use by approximately 3 percent (Reid Ewing & Cervero, 2010). A study of elderlies in Florida, bus usage of people who have lived in 200 meters of the bus route, three times greater than usage at the distance of 400 meters (Neilson & Fowler, 1972). As a rule of thumb, 400 meters (quarter-mile) or multiples such as 800 meters (half a mile) considered as key distances in network and service planning (Daniels & Mulley, 2013).

**Walking and Trip purposes**

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

**Case study**

**Area of Study**

The city of Rasht (population about 640 thousand in 2007) is the largest city on Iran’s Caspian Sea coast (the north of Iran). The urban area in Rasht includes 112 traffic analysis zones (TAZs), which are shown in figure 1. Unplanned settlements with disordered pathways, dense residential and weak infrastructure form a significant part of the spatial structure in the city (Hatamzadeh, Habibian, & Khodaii, 2017). Radiating streets from the city center in conjunction with ring roads shape the primary structure of street layout which gives a significant role to the city center Rasht comprehensive transportation planning study, 2011). The traditional bazaar (TAZ 1), as the leading retail center is located in the core of the city, which imposes substantial congestion to the central part of city. Over the past decades, there has been a change in the spatial pattern of activities in Rasht. During the development of the city and limited space of the bazaar, some commercial businesses have moved out of the city center and the traditional bazaar. Since most of the streets in are minor (86.6% of the road network are minor), made the public transit not properly developed (only about 2% of trips are done by public transit) and therefore not a favorable mode. Considering low car ownership (mean: 0.576) and special situation of taxis7, walking has become a favorable mode of transportation (Azimi, 2005; Bahrainy, 1998; Berjisian & Habibian, 2017; Hatamzadeh et al., 2016; Hatamzadeh, Habibian, & Khodaii, 2019). Furthermore, urban planning studies shows that the city of Rasht is treated as compact city, therefore, the major part of trips is in a walkable distance (Bahrainy, 1998). Share of walking in this city is 31.2 percent of all trips.

**Data Description**

In this study, the information of Rasht Household Travel Survey (RHTS) in 2007 is used8. As a part of the study, a questionnaire was designed and distributed among more than 5000 households who reside in 112 TAZs. It worth noting that the average equivalent radius of TAZs are about 400 meters and there are in the range of 0.2 –1.3 kilometers. 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 including the modes of travel, starting and ending time of the trip and the trip purpose. In addition, household information including a 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 also collected (Rasht comprehensive transportation planning study, 2011).

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6 Vehicles per household

7 Taxi in Rasht are shared cars which should pass in assigned direction, not common taxis around the world

8 It is worth mentioning that as RHTS has not been updated since 2007, no more recent data has been available
The data consists of more than 5000 household and 17000 individuals and 30000 trips (5501 work trips, 4896 educational trips, 2737 shopping trips and 15355 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. 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% (Rasht comprehensive transportation planning study, 2011).

Socio-demographic

Socio-economic variables in zones including an average of age, an average of household size, an average of bike ownership, an average of motorcycle ownership and an average of car ownership are calculated. Descriptive statistics of each of the socio-economic variables are presented in the first part of Table 2.

Design

All the design variables in this study are about transportation network connectivity. Connectivity indices are calculated based on the GIS database of the transportation network of Rasht, which has been gathered as a part of Rasht Household Travel Survey (RHTS). GIS software has been used.
to calculate indices (mentioned in Table 1) in 112 TAZs of Rasht city. The first part of Error! Reference source not found. shows descriptive statistics of the design indices.

**Diversity**

Land use diversity variables are calculated based on the Rasht land use database, which was gathered in RHTS. The second part of Error! Reference source not found. shows the descriptive statistics of calculated diversity variables.

**Density**

The population density that has been calculated in each zone of Rasht as represented in the third part of Table 2.

Table 2. Zone-based descriptive statistics

| Part 1- Socio-economic variables | Average | Standard deviation | Min     | Max     |
|----------------------------------|---------|--------------------|---------|---------|
| 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  |
| 2-2 Percentage of 4-way intersections | 14.1    | 6.44               | 0       | 38.9    |
| 2-3 Cul-de-sac density           | 146.11  | 91.01              | 0       | 407.8   |
| 2-4 Number of cul-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   |
| 2-9 3-way intersection density   | 210.88  | 116.92             | 1.24    | 535     |
| 2-10 4-way intersection density  | 33.62   | 23.98              | 0       | 121.2   |
| 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    |
| 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       | 7.61    | 7.48               | 0       | 49      |
|   | Number of major 4-way intersections | Ratio of cul-de-sac to nodes | Major street density | Minor street density | Average link length | Entropy index | HHI | MXI | Job-pop balance | Areal distance to CBD | Network distance to CBD |
|---|-----------------------------------|-----------------------------|----------------------|----------------------|---------------------|---------------|-----|-----|-----------------|-----------------------|------------------------|
| 2-17 | 1.34 | 1.67 | 0 | 11 | 37.01 | 9.22 | 0 | 60 | | 2629 | 1712 | 0 | 10626 | 3334 | 2318 | 0 | 14782 |
| 2-18 | | | | | | | | | | | | | | | | | | |
| 2-19 | | | 3653.4 | 2967.5 | 0 | 16149.4 | m/km² | | | | | | | | | | |
| 2-20 | | | 21648 | 8836.3 | 610 | 36898 | m/km² | | | | | | | | | | |
| 2-21 | | | 54.37 | 24.95 | 27.2 | 227.46 | m | | | | | | | | | | |
| 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-pop balance | 0.56 | 0.29 | 0 | 1 | | | | | | | | | | | | |
| Part4-Density index | | | | | | | | | | | | | | | | | | |
| 4-1 | Population density | 10100 | 6600 | 0 | 28700 | Person/km² | | | | | | | | | | | |
| Part5-Destination accessibility indices | | | | | | | | | | | | | | | | | | |
| 5-1 | Areal distance to CBD | | | | | m | | | | | | | | | | | |
| 5-2 | Network distance to CBD | | | | | m | | | | | | | | | | | |

**Methodology**

In this study, linear regression analysis is used to modeling the influencing factors on the share of short and long walking trips. Share of short and long walking trips in a zone is considered as 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:

\[
Y_i = \beta_1 + \beta_2 X_{2i} + \beta_3 X_{3i} + \ldots + u_i \tag{1}
\]

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 modeled through an error term \(u_i\), an unobserved random variable that adds noise to equation 1.

In developing equation 1, it has assumed 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.

\[
E(u_i | X_{2i}, X_{3i}) = 0 \text{ for each } i \tag{2}
\]

\[
\text{Cov}(u_i, u_j) = 0 \tag{3}
\]

\[
\text{Var}(u_i) = \sigma^2 \tag{4}
\]

\[
\text{Cov}(u_i, X_{2i}) = \text{Cov}(u_i, X_{3i}) = 0 \tag{5}
\]

The goodness of fit and adjusted goodness of fit for the model resulted from equation 6 and equation 7.
\[ R^2 = \frac{ESS}{TSS} = \frac{\beta_2 \sum y_i x_{2i} + \beta_3 \sum y_i x_{3i}}{\sum y_i^2} \quad (6) \]

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

**Analyzing process**

In this study, a linear regression model is developed based on the percentage of walking trips that are produced or attracted to 112 TAZs of Rasht. A zone-based approach has been used for analysis based on all TAZs in Rasht. To capture the variation resulted in generated trips, the walk shares of produced and attracted trips are considered as a dependent variable. In addition, four trip purposes considered in walking trips (i.e., work, education, shopping and return to home). 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 presented in Table 3.

| Table 3. Number and percentage of all trips and walking trip in each trip purpose |
|---------------------------------|----------------|----------------|----------------|----------------|
|                                 | Work           | Educational    | Shopping       | Return to home |
|                                 | Number         | Percent        | Number         | Percent        | Number         | Percent        |
| All Trips                        | 5501           | 17.5           | 4896           | 15.6           | 2737           | 8.6            | 15355          | 48.9           |
| Walking Trips                    | 892            | 16.2           | 1805           | 36.9           | 1295           | 47.3           | 4901           | 31.9           |
| Short Walking Trips              | 359            | 40.3           | 603            | 33.5           | 589            | 45.5           | 1835           | 37.5           |
| Long Walking Trips               | 533            | 59.7           | 1202           | 66.5           | 706            | 54.5           | 3066           | 62.5           |

**Short and Long Walking Trip Threshold**

In this section, we have tried to investigate which distance could be considered as a boundary for long and short trips. According to cumulative frequency chart presented in Figure 2, there is a tangible difference in trends of the chart in 600 meters walking trips. In this regard, 600 meters choose as the threshold for short and long trips. As it mentioned before, since there is not any actual length of each trip in the database, the distance between centroids of origin and destination zones are considered as the length of the trips. As far as Rasht TAZ's have the same approximate area of the zones (TAZs in CBD not the suburb), the error is not considerable. In enter-zonal trips the distance between centers of equivalent radius of zones considered as the length of walk trips. In intra zone walks, the equivalent radius of each zone considered as the walk length. It is worth mentioning that the real data of the exact travel distance and time in walking is always an issue in
household travel surveys. Agrawal and Schimek in their study, which have been used NHTS\textsuperscript{9} data in 2001 in United States, acknowledge that since many people have only an imprecise sense of distances, considering trip length is likely to estimate inaccurately (Agrawal & Schimek, 2007). The fact should be considered is that the mode which is the main mode considered as the mode of trip. For instance, if a person walks to public transit and use it to reach the destination, public transit has been reported as mode of his/her trip in the data.

![Figure 2. Short and long trip threshold](image)

**Result and Discussion**

*Walking Trip Production*

In this part, walking trip production models are represented and discussed.

|                  | Short trips | Long trips | All trips |
|------------------|-------------|------------|-----------|
| **Work trips**   |             |            |           |
| Constant         | 0.023***    | -          | 0.12***   |

\textsuperscript{9} National Household Travel Survey

\textsuperscript{10} ***, ** and * means 99%, 95% and 90% level of significance, respectively.
| Variable                  | Educational trips | Shopping trips | Return to home trips |
|--------------------------|-------------------|----------------|---------------------|
| Constant                 | 0.196**           | 0.102***       | -0.017***           |
| Population Density       | 0.00048**         | 0.0009***      | -0.001***           |
| Car ownership            | -0.126**          | -0.121         | 0.129**             |
| Link Connectivity        | 0.019*            | 0.068***       | 0.068***            |
| Average link length      | 0.094             | 0.288          | 0.274               |
| Goodness of Fit          | 0.111             | 0.222***       | 0.288               |
| Adjusted Goodness of Fit | 0.094             | 0.066          | 0.059               |
|                          |                   |                |                     |
| Link Connectivity        | 0.00066***        | 0.066          | 0.049               |
| Goodness of Fit          | 0.123             | 0.123          | 0.115               |
| Adjusted Goodness of Fit |                   |                | 0.049               |
According to Table 4, population density in all short walking trips production is significant. In educational and shopping trips (which usually their production zone is in individuals' home), car ownership found significant. It means individuals prefer to use their car in longer trips which is intuitive. This would be more influential in shopping trips since the long length of trip and carry stuff would be hard for a walker.

Connectivity measures in short and long educational and shopping trips found significant. Link connectivity and the average length of links are influential in four models out of seven. Link connectivity ensures a denser minor road network. Being significant in educational trips may be due to lower car speeds in minor links which provide safety for children in educational trips. Previous studies also verified the importance of safety in educational walking trips (Buliung, Larsen, Faulkner, & Ross, 2017; Giles-Corti et al., 2011; Rothman, Buliung, Howard, Macarthur, & Macpherson, 2017). The negative sign in the average length of links means shorter length provide higher walk share. It would be due to the lower speed of cars in these links since drivers do not have enough time to increase their speeds between two intersections. It is necessary to mention, the road network in Rasht is rudimentary since there are not separate streets and sidewalks.

As it shows in the models, BE criteria are more successful in describing walking trip production in shopping and return to home short walking trips comparing long ones. The reason could be individuals more free time on these trips versus work and educational trips which shorter distances motivate them to walk.

Walking Trip Attraction

In this part, walking trip attraction models represented and discussed.

| Table 5. Walking trip attraction models across various trip purposes |
|---------------------------------------------------------------|
| **Short trips** | **Long trips** | **All trips** |
| Work trips |
| Constant         | 0.16***       | 0.041*       | 0.054**       |
| Population density | 0.0004***     | -            | -             |
|                          | Educational trips          | Shopping trips          | Return to home trips                  |
|--------------------------|----------------------------|-------------------------|---------------------------------------|
| **Job-pop balance**      | 0.086**                    | 0.045                   | 0.113***                              |
| **Goodness of Fit**      | 0.175                      | 0.002***                | 0.131***                              |
| **Adjusted Goodness of Fit** | 0.16            | 0.209*                  | 0.001***                              |
| **Educational trips**    |                            |                         |                                       |
| **Constant**             | 0.006***                   | 0.045                   | 0.113***                              |
| **Population density**   | 0.001***                   | 0.002***                | 0.131***                              |
| **Job-pop balance**      | 0.123**                    | 0.209*                  | 0.001***                              |
| **Average link length**  | -                          | -                       | -0.001*                               |
| **Goodness of Fit**      | 0.112                      | 0.164                   | 0.209*                                |
| **Adjusted Goodness of Fit** | 0.096          | 0.164                   | 0.001***                              |
| **Shopping trips**       |                            |                         |                                       |
| **Constant**             | 0.045                      | 0.209*                  | 0.113***                              |
| **Population density**   | 0.002***                   | 0.048                   | 0.001***                              |
| **Job-pop balance**      | 0.209*                     | 0.244**                 | 0.085***                              |
| **Goodness of Fit**      | 0.164                      | 0.048                   | 0.338                                 |
| **Adjusted Goodness of Fit** | 0.147          | 0.038                   | 0.085***                              |
| **Return to home trips** |                            |                         |                                       |
| **Constant**             | 0.113***                   | 0.131***                | 0.113***                              |
| **population density**   | 0.001***                   | -                       | 0.001***                              |
| **Job-pop balance**      | -                          | 0.058*                  | -                                     |
| **Average link length**  | -0.001**                   | -                       | -0.001***                             |
Job-population balance, as a proxy of diversity, shows if there is a balance between job opportunities and residents in a zone. The positive sign of the index in the models means this balance has a positive impact on increasing walking share in a zone. According to the results, in the work, educational and shopping which the attraction zone of trips is the other side of their residing zone, job – population balance finds influential. In fact, it seems that job-population balance ensures that the attraction zone is interesting enough to encourage people to walk.

Overall, decomposing trips to short and long trips, doesn't mean a better description of trips comparing all trips. In three models out of four in production walking trips models, and in three models out of four in attraction walking trips, general models are more successful.

**Conclusion**

In this study, 16 models have been developed in order to identify influencing factors on walking. In this regard, based on the diagram of the cumulative trips and length of trips, 600 meters choose as a proxy between short and long trips.

According to the results, population density is significant in all eight produced and attracted models of short walking trips while it isn't in any of the long walking trip models. This finding perfectly highlights the importance of density in short walking trips. Beside the previous studies, mostly consider the population density just in residual place of the respondents (L. D. Frank et al., 2010; L. D. Frank et al., 2005; Talen & Koschinsky, 2013).

In short and long walking trip attraction, in seven models out of eight job-population balance is significant. This finding highlighted the importance of job-population balance as an index of diversity criteria. Although in most of the previous studies, all the BE criteria assessed around individuals residual place, this study shows some criteria that would be better to assess in another side of the trip.

Generally, shopping and return to home short walking trips resulted in the higher goodness of fit comparing work and educational trips. The reason could be the individuals free time in shopping and return to home trips. Work and educational trips may limit individuals to be a specific place in a fixed time. However, the models couldn’t find any specific relationship in the goodness of fit in long walking trips.

Comparing short and long walking trips, shows that the goodness of fit in short trips are higher than long trips. It seems that shorter distances are more compatible with walking. In other words, as the short distance increase the impact of BE decrease.
Some limitations are important to point out. First, the exact length of trips is not reported in the database and in order to evaluate the trip length, distance between centroids of trip origin and attraction have been used. In a macro-scale analysis 600 meters is considered as a threshold between short and long walking trips, based on the considerable difference in slope of the cumulative diagram. However, this value may be affected by the scale of the study zones. Second, the major way of commuting is reported by individuals, not the details of their trip chain in a day. Furthermore, there is information about individuals’ production and attraction zone, not the exact route of their trip. If the exact route was given, all the zones involved could be considered in the analysis. Although wide ranges of indices are calculated, there are some others, which could help to reach more profound results; indices in the literature such as 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 (and width) of sidewalks have not calculated in this study, could be helpful in reflecting some key factors influencing walking for various trip purposes.

References

Agrawal, A. W., & Schimek, P. (2007). Extent and correlates of walking in the USA. Transportation Research Part D: Transport and Environment, 12(8), 548-563.
Azimi, N. (2005). Restructuring Urban Morphology, a Case Study of Rasht in Iran. Geographical Research, 53(1), 13-25.
Badland, H. M., Schofield, G. M., Witten, K., Schluter, P. J., Mavoa, S., Kearns, R. A., . . . Jensen, V. G. (2009). Understanding the Relationship between Activity and Neighbourhoods (URBAN) Study: research design and methodology. BMC Public Health, 9(1), 224.
Bahrainy, H. (1998). Urban planning and design in a seismic-prone region (the case of Rasht in Northern Iran). Journal of urban planning and development, 124(4), 148-181.
Bentley, R., Blakely, T., Kavanagh, A., Aitken, Z., King, T., McElwee, P., . . . Turrell, G. (2018). A longitudinal study examining changes in street connectivity, land use, and density of dwellings and walking for transport in Brisbane, Australia. Environmental health perspectives, 126(5), 057003.
Berjisian, E., & Habibian, M. (2017). Walking Accessibility, Gravity-Based Versus Utility-Based Measurement (No. 17-02983).
Berrigan, D., Pickle, L. W., & Dill, J. (2010). Associations between street connectivity and active transportation. Int J Health Geogr, 9(1), 20.
Braun, L. M., Rodriguez, D. A., Song, Y., Meyer, K. A., Lewis, C. E., Reis, J. P., & Gordon-Larsen, P. (2016). Changes in walking, body mass index, and cardiometabolic risk factors following residential relocation: Longitudinal results from the CARDIA study. Journal of Transport & Health.
Buliung, R. N., Larsen, K., Faulkner, G., & Ross, T. (2017). Children’s independent mobility in the City of Toronto, Canada. Travel behaviour and society, 9, 58-69.
Cervero, R., & Duncan, M. (2006). ‘Which Reduces Vehicle Travel More: Jobs-Housing Balance or Retail-Housing Mixing? Journal of the American planning association, 72(4), 475-490.
Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: density, diversity, and design. Transportation Research Part D: Transport and Environment, 2(3), 199-219.
Chin, G. K., Van Niel, K. P., Giles-Corti, B., & Knuiman, M. (2008). Accessibility and connectivity in physical activity studies: the impact of missing pedestrian data. Prev Med, 46(1), 41-45. doi:10.1016/j.ypmed.2007.08.004
Christian, H. E., Bull, F. C., Middleton, N. J., Knuiman, M. W., Divitini, M. L., Hooper, P., . . . Giles-Corti, B. (2011). How important is the land use mix measure in understanding walking behaviour? Results
from the RESIDE study. *International Journal of Behavioral Nutrition and Physical Activity, 8*(1), 55.

Daniels, R., & Mulley, C. (2013). Explaining walking distance to public transport: The dominance of public transport supply. *Journal of transport and land use, 6*(2), 5-20.

Dill, J. (2004). *Measuring network connectivity for bicycling and walking.* Paper presented at the 83rd Annual Meeting of the Transportation Research Board, Washington, DC.

Dobesova, Z., & Krivka, T. (2012). *Walkability index in the urban planning: a case study in olomouc city:* INTECH Open Access Publisher.

Eriksson, U., Arvidsson, D., Gebel, K., Ohlsson, H., & Sundquist, K. (2012). Walkability parameters, active transportation and objective physical activity: moderating and mediating effects of motor vehicle ownership in a cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity, 9*(1), 123.

Ewing, R., & Cervero, R. (2010). Travel and the built environment: a meta-analysis. *Journal of the American Planning Association, 76*(3), 265-294.

Ewing, R., DeAnna, M., Heflin, C., & Porter, D. (1996). Best development practices.

Ewing, R., Tian, G., Goates, J., Zhang, M., Greenwald, M. J., Joyce, A., . . . Greene, W. (2014). Varying influences of the built environment on household travel in 15 diverse regions of the United States. *Urban Studies, 52*(13), 2330-2348. doi:10.1177/0042098014560991

Ferrer, S., Ruiz, T., & Mars, L. (2015). A qualitative study on the role of the built environment for short walking trips. *Transportation research part F: traffic psychology and behaviour, 33*, 141-160.

Frank, L. D., & Pivo, G. (1994). Impacts of mixed use and density on utilization of three modes of travel: single-occupant vehicle, transit, and walking. *Transportation research record, 44*-44.

Frank, L. D., Sallis, J. F., Saelens, B. E., Leary, L., Cain, K., Conway, T. L., & Hess, P. M. (2010). The development of a walkability index: application to the neighborhood quality of life study. *Br J Sports Med, 44*(13), 924-933. doi:10.1136/bjsm.2009.058701

Frank, L. D., Schmid, T. L., Sallis, J. F., Chapman, J., & Saelens, B. E. (2005). Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. *Am J Prev Med, 28*(2 Suppl 2), 117-125. doi:10.1016/j.amepre.2004.11.001

Gehrke, S. R., & Clifton, K. J. (2017). A pathway linking smart growth neighborhoods to home-based pedestrian travel. *Travel behaviour and society, 7*, 52-62.

Giles-Corti, B., Wood, G., Pikora, T., Learmonth, V., Bulsara, M., Van Niel, K., . . . Villanueva, K. (2011). School site and the potential to walk to school: The impact of street connectivity and traffic exposure in school neighborhoods. *Health & place, 17*(2), 545-550.

Glazier, R., Weyman, J., Creatore, M., Gozdyra, P., Moineddin, R., Matheson, F., . . . Booth, G. (2012). Development and validation of an urban walkability index for Toronto, Canada. In: Toronto Community Health Profiles.

Gori, S., Nigro, M., & Petrelli, M. (2014). Walkability indicators for pedestrian-friendly design. *Transportation Research Record: Journal of the transportation research board*(2464), 38-45.

Habibian, M., & Hosseinzadeh, A. (2018). Walkability index across trip purposes. *Sustainable Cities and Society, 42*, 216-225.

Handy, S., Paterson, R. G., & Butler, K. (2003). *Planning for street connectivity: getting from here to there.*

Handy, S. L. (1992). Regional versus local accessibility: neo-traditional development and its implications for non-work travel. *Built Environment (1978-)*, 253-267.

Hatamzadeh, Y., Habibian, M., & Khodaii, A. (2016). Walking behavior across genders in school trips, a case study of Rasht, Iran. *Journal of Transport & Health.

Hatamzadeh, Y., Habibian, M., & Khodaii, A. (2017). Walking and jobs: A comparative analysis to explore factors influencing flexible and fixed schedule workers, a case study of Rasht, Iran. *Sustainable Cities and Society, 31*, 74-82.
Hatamzadeh, Y., Habibian, M., & Khodaii, A. (2019). Measuring walking behaviour in commuting to work: investigating the role of subjective, environmental and socioeconomic factors in a structural model. *International Journal of Urban Sciences*, 1-16.

Holt, N. L., Spence, J. C., Sehn, Z. L., & Cutumisu, N. (2008). Neighborhood and developmental differences in children's perceptions of opportunities for play and physical activity. *Health & Place, 14*(1), 2-14.

Hooper, P., Knuiman, M., Foster, S., & Giles-Corti, B. (2015). The building blocks of a ‘Liveable Neighbourhood’: Identifying the key performance indicators for walking of an operational planning policy in Perth, Western Australia. *Health & Place, 36*, 173-183.

Iacono, M., Krizek, K., & El-Geneidy, A. M. (2008). Access to destinations: how close is close enough? Estimating accurate distance decay functions for multiple modes and different purposes.

Koohsari, M. J., Sugiyama, T., Mavoa, S., Villanueva, K., Badland, H., Giles-Corti, B., & Owen, N. (2016). Street network measures and adults' walking for transport: Application of space syntax. *Health & Place, 38*, 89-95.

Krizek, K. J. (2003). Operationalizing neighborhood accessibility for land use-travel behavior research and regional modeling. *Journal of Planning Education and Research, 22*(3), 270-287.

Mackett, R. L. (2003). Why do people use their cars for short trips? *Transportation, 30*(3), 329-349.

Maghelal, P. K., & Capp, C. J. (2011). Walkability: a review of existing pedestrian indices. *URISA Journal, 23*(2), 5.

McCormack, G. R., Cerin, E., Leslie, E., Du Toit, L., & Owen, N. (2007). Objective versus perceived walking distances to destinations: correspondence and predictive validity. *Environment and Behavior.*

McGinn, A. P., Evenson, K. R., Herring, A. H., Huston, S. L., & Rodriguez, D. A. (2007). Exploring associations between physical activity and perceived and objective measures of the built environment. *Journal of urban health, 84*(2), 162-184.

Nagel, C. L., Carlson, N. E., Bosworth, M., & Michael, Y. L. (2008). The relation between neighborhood built environment and walking activity among older adults. *Am J Epidemiol, 168*(4), 461-468. doi:10.1093/aje/kwn158

Napier, M. A., Brown, B. B., Werner, C. M., & Gallimore, J. (2011). Walking to school: Community design and child and parent barriers. *Journal of Environmental Psychology, 31*(1), 45-51.

Neilson, G. K., & Fowler, W. K. (1972). Relation between transit ridership and walking distances in a low-density Florida retirement area. *Highway Research Record (403).*

Perchoux, C., Brondeel, R., Wasfi, R., Klein, O., Caruso, G., Vallée, J., . . . Chaix, B. (2019). Walking, trip purpose, and exposure to multiple environments: a case study of older adults in Luxembourg. *Journal of Transport & Health, 13*, 170-184.

Piatkowski, D. P., Krizek, K. J., & Handy, S. L. (2015). Accounting for the short term substitution effects of walking and cycling in sustainable transportation. *Travel behaviour and society, 2*(1), 32-41.

Porta, S., & Renne, J. L. (2005). Linking urban design to sustainability: formal indicators of social urban sustainability field research in Perth, Western Australia. *Urban Design International, 10*(1), 51-64.

Rasht comprehensive transportation planning study; Final report (final edition); Municipality of Rasht (Andishkar consulting engineers): Rasht, 2011.

Rothman, L., Buliuang, R., Howard, A., Macarthur, C., & Macpherson, A. (2017). The school environment and student car drop-off at elementary schools. *Travel behaviour and society.*

Schlossberg, M. (2006). From TIGER to audit instruments: Measuring neighborhood walkability with street data based on geographic information systems. *Transportation Research Record: Journal of the transportation research board*(1982), 48-56.

Schlossberg, M., & Brown, N. (2004). Comparing transit-oriented development sites by walkability indicators. *Transportation Research Record: Journal of the transportation research board*(1887), 34-42.
Shaaban, K., Muley, D., & Elnashar, D. (2018). Evaluating the effect of seasonal variations on walking behaviour in a hot weather country using logistic regression. *International Journal of Urban Sciences, 22*(3), 382-391.

Song, Y., & Knaap, G.-J. (2004). Measuring urban form: Is Portland winning the war on sprawl? *Journal of the American Planning Association, 70*(2), 210-225.

Southworth, M., & Owens, P. M. (1993). The Evolving Metropolis: Studies of Community, Neighborhood, and Street Form at the Urban Edge. *Journal of the American Planning Association, 59*(3), 271-287. doi:10.1080/01944369308975880

Staats, B., Diakité, A., Voûte, R., & Zlatanova, S. (2019). Detection of doors in a voxel model, derived from a point cloud and its scanner trajectory, to improve the segmentation of the walkable space. *International Journal of Urban Sciences, 23*(3), 369-390.

Sugiyama, T., Rachele, J. N., Gunn, L. D., Burton, N. W., Brown, W. J., & Turrell, G. (2019). Land use proportion and walking: Application of isometric substitution analysis. *Health & place, 57*, 352-357.

Taleai, M., & Amiri, E. T. (2017). Spatial multi-criteria and multi-scale evaluation of walkability potential at street segment level: A case study of Tehran. *Sustainable Cities and Society, 31*, 37-50.

Talen, E., & Koschinsky, J. (2013). The walkable neighborhood: a literature review. *International Journal of Sustainable Land Use and Urban Planning (IJSLUP), 1*(1).

Van den Hoek, J. (2008). *The MXI (Mixed-use Index) an instrument for anti sprawl policy?* Paper presented at the A Way Towards Sustainable Urbanization Urban Growth without Sprawl 44th ISOCARP Congress, Dalian, China.

Van Dyck, D., Deforche, B., Cardon, G., & De Bourdeaudhuij, I. (2009). Neighbourhood walkability and its particular importance for adults with a preference for passive transport. *Health & Place, 15*(2), 496-504.

Wells, N. M., & Yang, Y. (2008). Neighborhood design and walking: a quasi-experimental longitudinal study. *American journal of preventive medicine, 34*(4), 313-319.

Yang, Y., & Diez-Roux, A. V. (2012). Walking distance by trip purpose and population subgroups. *American journal of preventive medicine, 43*(1), 11-19.

Zhang, M., & Kukadia, N. (2005). Metrics of urban form and the modifiable areal unit problem. *Transportation Research Record: Journal of the transportation research board*(1902), 71-79.