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Walkability index across trip purposes

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ABSTRACT

Development of non-motorized modes of transportation has recently become a common trait among urban planners toward sustainable transportation, and walkability has been introduced as one of the most interesting concepts in the past two decades. A number of researchers put efforts to develop walkability indices (WIs) to show the status of walkability for specific zones. However, further investigation has not been conducted to account for the effect of trip purposes on WI. The literature presented transportation network design (design), land use diversity (diversity) and population density (density) as main built environment criteria and previous studies have used these criteria to develop different indices to capture walkability. In this paper, the concept of WI is developed based on the zonal walk share. Therefore, a WI has been developed and then calibrated across three specific trip purposes (i.e., job, educational and shopping) in addition to all of the trips on 112 Traffic Analysis Zones (TAZs) of the city of Rasht, Iran. According to the result of this study, diversity was found to be the most prominent criterion with the WIs. Furthermore, WI was discovered more beneficial for describing the term of walk share in shopping trips than other trip purposes.

1. Introduction

Promoting non-motorized transportation can significantly affect the transportation status of a city toward sustainability (Sun & Zacharias, 2017). Therefore, switching to non-motorized modes of transportation such as walking would dramatically benefit a society. In addition, encouraging people to walk as a transportation demand management strategy helps save nonrenewable energies and reduce pollution in cities (Maleki & Zain, 2011; Moghadam, Toniolo, Mutani, & Lombardi, 2018). In this regard, researchers have focused on the factors which encourage people to walk more in their daily life (Talen & Koschinsky, 2013).

For a long time, Built Environment (BE) has been known as an influencing factor on an individual's tendency to walk and, therefore, researchers try to account for the effective environmental factors on walking. The BE is defined as a human-made space in which people live, work and recreate on a daily basis (Roof & Oleru, 2008). To capture the BE, transportation network design (design), land use diversity (diversity) and population density (density), known as 3Ds, are the most common criteria addressed in previous studies (Cervero & Kockelman, 1997; Ewing & Cervero, 2010; Frank, Schmid, Sallis, Chapman, & Saelens, 2005). Nevertheless, destination accessibility and distance to transit have been recently suggested to add to the criteria above (Ewing & Cervero, 2010).

In the last two decades, a wide range of studies has been conducted to investigate the relationship between walkability and the BE characteristics (Cerin, Saelens, Sallis, & Frank, 2006; Ewing & Cervero, 2001, 2010; Frank, Greenwald, Winkelman, Chapman, & Kavage, 2010; Frank et al., 2005; Gori, Nigro, & Petrelli, 2014; Handy, Paterson, & Butler, 2003; Maghelal & Capp, 2011; Talen & Koschinsky, 2013). Walkability is a measure of how friendly an area is to walking (Litman et al., 2009). Some of the previous studies developed a Walkability Index (WI) based on a weighted combination of BE criteria (Berrigan, Pickle, & Dill, 2010; Frank, Greenwald et al., 2010, Frank et al., 2005; Gori et al., 2014). However, they have not taken into account the effect of the purpose of the trips on walkability and a general WI has been devoted to all kinds of trip purposes. Considering the effect of trip purposes on choosing walking as a mode of travel and the walkability definition, a question may arise whether trip purposes are also affecting the walkability. In other words, does walkability perceived differently across different trip purposes.

In the planning phase, using a general WI would result in a similar pattern to encourage walking for all trip purposes across all Traffic Analysis Zones (TAZs). However, in some cases, transportation planners may intend to enhance the walking situation of trips with special purposes. In other words, providing walking facilities in favor of some trip purposes may be more beneficial. For instance, as most schoolchildren are not able to drive, and schools are located in their walkable distance,

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Table 1
BE indices used in the literature.

	Variable	Description	Impact[a]	References
Part 1 -Design indices				
1	Intersection density	Number of intersections per unit area	+	Frank et al. (2005), Frank, Sallis et al. (2010), McCormack, Cerin, Leslie, Du Toit, and Owen (2008), McGinn, Evenson, Herring, Huston, and Rodriguez (2007), Wells and Yang (2008), Nagel, Carlson, Bosworth, and Michael (2008), Van Dyck et al. (2009), Holt, Spence, Sehn, and Cutumisu, (2008), Badland et al. (2009), Koohsari et al. (2016)
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 and Brown (2004)
4	Pedestrian catchment area	Pedestrian accessible area (PA)/ Ideal pedestrian accessible area (IA)	+	Gori et al. (2014), Schlossberg, 2006 Schlossberg, (2006), Schlossberg and Brown (2004), Porta and Renne (2005), Chin, Van Niel, Giles-Corti, and Knuiman (2008)
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 (1982)
7	Ratio of minor streets[b] to major streets[c]	–	+	Dill (2004)
8	Block density	Number of blocks per unit area	+	Dill (2004), Song and Knaap (2004), Hooper, Knuiman, Foster, and Giles-Corti (2015)
9	Block length	Average length of blocks in an area	–	Handy et al. (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 and Kukadia (1902)
13	Grid pattern	Similarity of a street network to grid network	+	Southworth and 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	*	Gori et al. (2014), Berrigan et al. (2010), Dill (2004), Schlossberg, 2006 Schlossberg, (2006), Schlossberg and Brown (2004)
16	Alpha index	Ratio of number of actual loops to the number of all possible loops	*	Gori et al. (2014), Berrigan et al. (2010), Dill (2004), Schlossberg, 2006 Schlossberg (2006), Schlossberg and Brown (2004)
17	Node Connectivity	0.817 (Percentage of four way intersection) + 0.817 (The ratio of intersection to nodes)	+	Hatamzadeh et al. (2017a)
18	Link Connectivity	0.862 (The ratio of minor roads to major roads) + 0.762 (street density)	+	Hatamzadeh et al. (2017a)
Part 2 - Diversity indices				
1	Entropy	$-\frac{\sum_{i=1}^{n} p_i \log p_i}{\log n}$ P_i: Percentage of land use i (area-based) n: Total number of land uses	*	Cervero and Kockelman (1997), Frank et al. (2005), Frank, Sallis, et al. (2010), Taleai and Amiri (2017)
2	Herfindal-Hershman index (HHI)	$p_1^2 + p_2^2 + \ldots + p_n^2$ P_i: Percentage of land use type i n: Total number of land uses	−	Eriksson, Arvidsson, Gebel, Ohlsson, and Sundquist (2012)
3	Mixed-use Index (MXI)	$\lvert P-50 \rvert$ P: Percentage of residential land use of a specific area	−	Van den Hoek (2008)
4	Job-population balance	$1-\left\lvert\frac{Job-0.2\times Pop}{Job+0.2\times Pop}\right\rvert$ job: Number of jobs within a specific area pop: Number of residents within a particular area	+	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 and Kockelman (1997)

[a] +, − and * show the positive, negative and contradictory impact of the indices in the previous studies on walking.
[b] Minor street is considered as two-way two-lane urban street that often services to low traffic and low speed.
[c] Major street is considered as two-way four-lane or more urban street (multilane streets) that can serve more vehicles with high average speed.

they potentially can take a walk to go to school. Therefore, investment in development of BE factors which are most effective on educational trips would be useful to increase the share of walking in school buffers. Such investment would result in elimination of escort trips, which is highly appreciated in transportation demand management.

In order to develop WI, it would be desirable to consider a vast area, such as a city that includes a variety of zones with distinct characteristics. Such area would result in outcomes that are more robust for transportation planners who intend to set policies in favor of walking situation, and could be applicable to the entire city.

While walkability has become a critical research topic in developed countries (Frank et al., 2005; Gori et al., 2014), it has not received enough attention in developing countries. Therefore, a study in a developing country can provide a base to compare the effects attributed to BE criteria in different part of the world and the result can improve the insight to pedestrian-oriented planning around the world. This study tries to overcome the gap in the current literature by studying the walkability across trip purposes within a typical city in Iran, Rasht.

According to the above limitations, this study possesses a couple of benefits. First, distinct WI is developed for each of the studied trip purposes. Second, as there is a dearth of walkability research in developing countries, this study can shed a light on this part of the world.

In this study, the most referred indices which were used in previous studies for BE criteria, were employed to assess the walkability in Rasht.

WIs have been developed based on the share of walking produced from/attracted to 112 TAZs of Rasht. Assessing the resulting WIs, one can see the effect of each BE criterion on WI for a specific trip purpose.

The remainder of this paper is organized as follows. In the next section, the review of literature will be explained, and the case study and data collection will be reviewed in the following. After that, the fourth part offers a brief explanation of the method used. Results are presented in the fifth section and conclusion is the final section of the paper.

2. Literature review

2.1. Built environment

Most of the studies investigated the impact of BE addressed by design, diversity, and density on daily walking trips. In addition, distance to transit and destination accessibility has been introduced in a few studies that are more recent. These criteria are more discussed in the following parts.

2.1.1. Design

Design represents street network features within an area (Ewing & Cervero, 2010). A well-connected road network, which is suitable for walking is a network that has many short links, numerous intersections, and minimal dead-ends (cul-de-sacs) (Adeniyi, 2014). A number of indices (e.g., density of intersections, block length, Cul-de-sac density), has been suggested to capture the impact of transportation network design on walking (Berrigan et al., 2010; Dill, 2004; Gori et al., 2014; Schlossberg, 2006). The literature used a wide range of design indices across previous studies according to their available data and the research team preference (Frank, Sallis et al., 2010, 2005; Glazier et al., 2012; Krizek, 2003). In fact, regarding multi-collinearity between indices, it is not possible to use all of them in an analysis at the same time. Therefore, to explore the role of design, one index has been used in each of the previous studies. It is worth noting that a few studies have calculated a large number of design indices and conducted Principal Component Analysis (PCA) to avoid multi-collinearity (Berrigan et al., 2010; Frank & Pivo, 1994). By using this method, Hatamzadeh et al. extracted two combined indices from all design indices, which can explain 71.02% of variations of all their studied indices (Hatamzadeh, Habibian, & Khodaii, 2017a). Their first combined index, node connectivity index, consists of percentages of four-way intersections and connected node ratio (ratio of nodes with more than one connection to the dead-end nodes). The second combined index, link connectivity index, includes the ratio of minor streets to major streets and street density (for more details see Hatamzadeh et al., 2017a).

According to the literature, the first part of Table 1 displays 17 design indices. Table 1 also shows the positive, negative or contradictory impact of each index on walking in previous studies.

2.1.2. Diversity

Diversity is given by the extent of different land use types in a neighborhood (Ewing & Cervero, 2010). Frank and Pivo argued that living in an area with a greater diversity of land uses increases the likelihood of people walking to different destinations or the transit stops (Frank & Pivo, 1994). They showed that it can also result in increasing public transit usage and decreasing automobile dependence (Frank & Pivo, 1994). Maghelal and Capp explained that diversity is the most influential BE criteria in the studies of the last two decades (Maghelal & Capp, 2011). They showed that 16 out of 25 studies used different types of land use diversity indices.

Different 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 (e.g., Entropy, HHI, MXI and job-population balance) (Cervero & Duncan, 2006). Although the large extent of literature has used the Entropy index, Christian et al. examined different entropies based on the various combinations of land use mixes and concluded that varying the combinations of the land uses can significantly affect the result (Christian et al., 2011). Ewing et al. showed that higher values of "job-population balance" as a proxy of proper land use diversity results in a 15% reduction in VMT[1] in a zone (Ewing, DeAnna, Heflin, & Porter, 1996). Assessing previously mentioned diversity indices, Cervero and Duncan reconsidered the "job-population balance" concept and concluded that it is a superior index in comparison with other indices such as entropy (Cervero & Duncan, 2006).

2.1.3. Density

Density as a BE criterion is considered as a ratio of the population of a specific zone in the area of that zone (Frank, Greenwald et al., 2010; Koh, Leow, & Wong, 2015). This rate is usually higher in the Central Business District (CBD) of cities in which it is more suitable to walk (Dobesova & Krivka, 2012).

2.1.4. Destination accessibility

Destination accessibility is defined as the ease of reaching different destination locations. It can be measured by distance to various destinations or number of destinations around a place (Ewing & Cervero, 2010). Zhang et al. suggested using the distance to the Central Business District (CBD) of a city as a proxy for this criterion (Zhang, Hong, Nasri, & Shen, 2012).

2.1.5. Distance to transit

Distance to transit represented by the shortest street distance from residences to the closest transit stop. This criterion is also measured by the number of bus stops located in a respondent residential area (Ewing & Cervero, 2010). While it is more common to consider a 400-meter buffer for this area (Schlossberg & Brown, 2004), some studies also assumed higher values (Duncan, Aldstadt, Whalen, Melly, & Gortmaker, 2011; Ewing et al., 2014; Sehatzadeh, Noland, & Weiner, 2011).

2.2. Walking and trip purposes

The role of trip purposes of walking has been investigated in the literature (Frank & Pivo, 1994; Handy, 1992; Hatamzadeh, Habibian, & Khodaii, 2014; Yang & Diez-Roux, 2012). Yang and Diez-Roux found that walking distance and duration are highly associated with the trip purpose. For example, they showed that distance and duration of walking for recreation were significantly longer than those for other trip purposes (Yang & Diez-Roux, 2012). Frank and Pivo considered job and shopping as two trip purposes and showed that the influencing factors differ in the resulting models (Frank & Pivo, 1994). Handy found that walking for errands is more likely in high walkable areas versus low walkable areas. She concluded that while utilitarian trips (e.g., shopping) are the source of difference in share of walking between regions with low and high walkability, the differences are not discernable for other purposes such as exercise (Handy, 1992). It is worth mentioning that while the literature shows a number of walking-related studies that have considered trip purposes, no study conducted to calibrating WIs across them.

2.3. Walkability index

Different approaches have been used to quantify the situation of walkability in different areas. In 2005, Frank et al. introduced an index based on a Z-Score method and utilized design (intersection density), diversity (entropy index) and density (net residential density) as constituents of WI. The weight of design, diversity and density in that study is set to 1, 6 and 1, respectively (Frank et al., 2005). In 2010, Frank et al. added retail floor area index as a destination accessibility criterion

[1] Vehicle Miles Traveled.

and considered the weight of design twice the others (Freeman et al., 2013).

Other methods have also been used to introduce WI. One of them is re-scaling the walkability criteria and combining them into an index by summation of transformed values into deciles, which results in walkability scores between 4 and 40 (Coffee, Howard, Paquet, Hugo, & Daniel, 2013). Walkability indices were also developed using other criteria and through different combinations. Glazier et al. (2012) created a WI for Toronto, Canada, which comprised population density, dwelling density, street connectivity (in the form of number of intersections), and retail stores and services available (counted) within a 10-minute walk from census tract centroids (Glazier et al. (2012)).

However, some studies only focus on one criterion to develop a WI. For example, a study calculated nine indices to determine the design criteria through principal component analysis and addressed it as a WI. It is worth noting that this study is one of the few studies that used several design indices (Berrigan et al., 2010).

Besides the indices mentioned above, there is also a widely used index known as Walkscore (publicly available at www.walkscore.com). Walkscore is a WI which estimates the walkability score for a user input address based on its surrounding land uses, such as grocery stores, restaurants, schools and parks weighted by the walking distances traveled to get there, and based on population density, intersection density and block length criteria. The index uses free data sources such as Google, Open Street Map, US Census and it can be calculated for larger areas like neighborhoods or cities. The index values can range between 0 and 100 (Brewster, Hurtado, Olson, & Yen, 2009). However, according to the lack of accurate data, in some of the developing countries (e.g., Iran) the results are not reliable.

Among the studies mentioned above, the method and coefficients suggested by Frank et al. are used in several studies as part of the IPEN (International Physical Activity and the Environment Network) project all around the world. This project assumed that the WI developed by Frank, Sallis et al. (2010) is transferable to other places. Several countries (e.g., the U.S. (Frank, Sallis et al., 2010), Canada (Glazier et al., 2012), UK (Millington et al., 2009), Belgium (Van Dyck, Deforche, Cardon, & De Bourdeaudhuij, 2009), Sweden (Sundquist et al., 2011), Czech Republic (Dobesova & Krivka, 2012) and Hong Kong (Cerin et al., 2011)) have joined the project and used the same methodology based on an objectively measured WI. It is worthy of note that the above method is considered mainly because of its simplicity (Frank, Sallis et al., 2010). Table 2 shows the method, criteria and formulation of the previously developed WIs.

In summary, almost all the case studies (e.g., Atlanta (Frank et al., 2005), Washington (Frank, Sallis et al., 2010), Los Angeles and San Diego (Berrigan et al., 2010) in the U.S., Montreal (Lefebvre-Ropars, Morency, Singleton, & Clifton, 2017) and Toronto (Glazier et al., 2012) in Canada, Perth (Porta & Renne, 2005) and Adelaide (Coffee et al., 2013) in Australia, and also in UK (Millington et al., 2009), Italy (Gori et al., 2014), Belgium (Van Dyck et al., 2009), Sweden (Sundquist et al., 2011), Czech Republic (Dobesova & Krivka, 2012) in Europe and Hong Kong (Cerin, Chan, Macfarlane, Lee, & Lai, 2011) in Asia) were conducted in a developed country. However, one may be curious about the change in results if a city of a developing country is investigated. Also, calibrating the WI for each of the trip purposes provides a helpful tool for transportation planners. In this regard, the focus of this study is to calibrate WIs for each trip purpose in a scale of a city of a developing country.

3. Case study

3.1. Area of study

The city of Rasht (with a population of about 640 thousand in 2007) is located in the North of Iran. The urban area in Rasht includes 112 TAZs which are shown in Fig. 1. As each TAZ (which had been defined by the Rasht Household Travel Survey (RHTS) in 2007) had different geometrical shape, the TAZ area is nominated as a reasonable geographical parameter. However, to make more sense, the radius of a circle that has equal area with that TAZ (i.e., equivalent circle) is determined as equivalent radius of a TAZ. Determining equivalent radius for each TAZ, the average value is derived around 400 m and it ranges from 200 to 1000 m.

Unplanned settlements with disordered pathways, dense residential areas and weak infrastructure form a significant part of the spatial structure in the city (Hatamzadeh, Habibian, & Khodaii, 2017b). Radiating streets of the city center in conjunction with ring roads shapes the primary structure of street layout which gives a significant role in the city center (Andishkar consulting engineers, 2011). The traditional bazaar (TAZ 1) as the leading retail center is located in the core of the city which imposes a substantial congestion in the central part of the 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 from the city center and the traditional bazaar. Since most of the streets in Rasht are minor streets (86.6% of road network length), it

Table 2
Previously developed WI's in the literature.

WI Study	Case study	Method	Criteria	Formulation
Frank et al. (2005)	Atlanta, US	Z-score	- Intersection density - Residential density - Land use mix	WI = z-score (intersection density) + z-score (residential density) + 6 z-score (land use mix)
Frank, Sallis, et al. (2010)	Washington, US	Z-score	- Intersection density - Residential density - Land use mix - Retail floor area	WI = 2z-score (intersection density) + z-score (residential density) + z-score (land use mix) + z-score (Retail floor area ratio)
Coffee et al. (2013)	Adelaide, Australia	Sum of deciles	- Intersection density - Residential density - Land use mix - Net retail area	WI = Summation of transformed criteria into deciles
Glazier et al. (2012)	Toronto, Canada	Principal component analysis	- Population density - Residential density - Retail stores and services - Street connectivity	WI = 90 (Population density) + 94 (Residential density) + 77 (Retail) + 70 (Connectivity)
www.walkScore.com	N/A	Distance decay function	- Destinations - Population density - Intersection density - Block length	WI = Equal weighted summation of the criteria

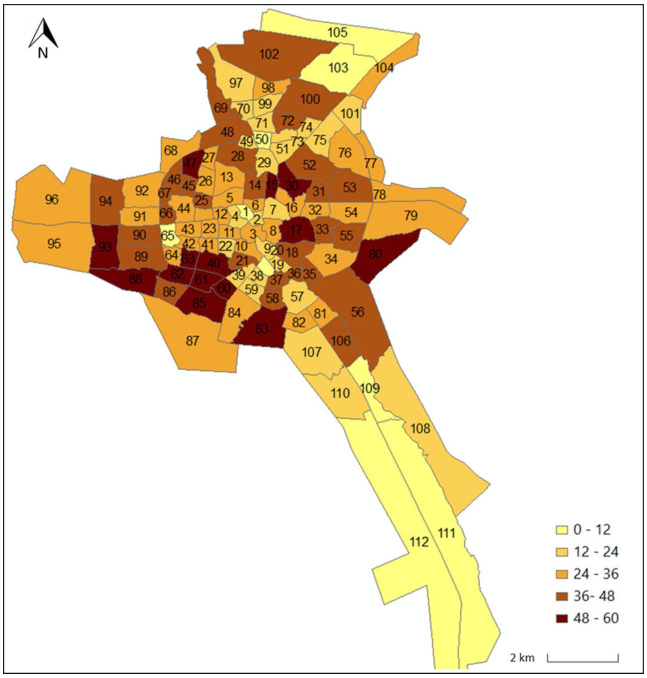

Fig. 1. Walk share in TAZs of Rasht.

made the public transit not properly developed (only about 2% of trips are made by public transit) and, therefore, not a favored mode. Moreover, urban planning studies have shown that the city of Rasht is treated as a compact city, therefore, the major part of the trips is at a walkable distance. Considering low car ownership per capita (mean: 0.162) and special situation of taxis[2], walking has become a favored mode of transportation (Azimi, 2005; Bahrainy, 1998; Berjisian & Habibian, 2017; Hatamzadeh et al., 2017a). Share of walking in this city is about one-third of all trips (Bahrainy, 1998).

3.2. Data description

In this study, the information about RHTS in 2007[3] was used. As a part of the RHTS study, a questionnaire was designed and randomly distributed among more than 5,000 households (more than 17,000 individuals and 30,000 trips) who reside in 112 TAZs (2.6% of the city population). The survey aimed to collect detailed information about every journey taken by all members of each participating household. Each person was asked to fill out a trip diary for a specific day, including the modes of travel, starting and ending time of each trip and its purpose. Besides, household information comprising 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 also collected (Andishkar consulting engineers, 2011). The first section of Table 3 reports the descriptive statistics of the socio-economic variables of data as well as geometric characteristics of TAZs. One can see the low values of bike, motorcycle and car ownership per capita of Rasht.

It is worth mentioning that average zonal attributes of paths such as slope, adjacent traffic volume and width of sidewalks, due to lack of data, have not entered into the analysis. Besides, as the exact location of the respondent was not reported in the database, the origin and destination TAZs were adopted.

[2] Taxis in Rasht are shared cars that should pass in assigned direction, not common taxis around the world.

[3] It is worth mentioning that as RHTS has not been updated since 2007, no more recent data has been available.

In this study, walk share in job, educational, and shopping trips for both produced and attracted trips of each TAZ, were considered as dependent variables. Comparing the mentioned trip purposes, the walk share related to job, educational, and shopping trips are 16.2%, 36.9% and 47.3%, respectively (Andishkar consulting engineers, 2011). Number of trips of each purpose are presented in Table 4.

3.3. Built environment criteria

Among the five aforementioned BE criteria, design, diversity, density and destination accessibility have been calculated based on Rasht data. It is worth noting that due to available data, distance to transit was not included in the analysis since there is no well-developed infrastructure of public transit in the city.

3.3.1. Design

Design indices were calculated based on the GIS database of the transportation network of Rasht, which has been gathered as a part of RHTS. Arc GIS software was used to calculate indices (mentioned in Table 1) in each of 112 TAZs of Rasht (Andishkar consulting engineers, 2011). Design indices mentioned in this study are reported in some of the previous studies and presented in the second part of Table 3. Intersection density is the most frequent design index reported in previous studies. It has been calculated by Ewing et al. as 172.47 (S.d.: 117.25) which is the average value of 15 diverse regions in the U.S.) (Ewing et al., 2014). Frank et al. 2005 reported this value in Atlanta, Georgia as 37.27 (S.d.: 16.62) (Frank et al., 2005) while it is reported as 47.05 (S.d.: 21.72) and 39.25 (S.d.: 18.28) in Los Angeles and San Diego, respectively (Berrigan et al., 2010). The results reveal the higher density of intersections in Rasht (average: 244.5, S.d.: 134.32) versus other case studies. Despite the intersection density, other design indices are not widely reported in the literature and may be limited only to specific cases. The percentage of 3-way intersections is reported as 27.13 (S.d.: 26.4) by (Ewing et al., 2014) while it is completely different from Rasht (average: 85.9, S.d.: 10.32) which highlights the different road network design between these two case studies. Connected Node Ratio (CNR) is reported as 0.863 (S.d.: 0.123) and 0.751 (S.d.: 0.133) in Los Angeles and San Diego, respectively (Berrigan et al., 2010) while the average and standard deviation in Rasht is 0.62 and 0.1, respectively. It shows that nodes in Rasht are less connected to their adjacent nodes comparing to the nodes in Los Angeles and San Diego networks. Besides, Rasht has a less ratio of actual links to possible links (gamma index) and ratio of actual loops to possible loops (alpha index) comparing Los Angeles and San Diego. In fact, Rasht gamma index is 0.390 (S.d.: 0.050), while this index is 0.449 (S.d.: 0.056) and 0.416 (S.d.: 0.060) in Los Angeles and San Diego, respectively. Also, the alpha index in Rasht is 0.090, (S.d.: 0.059), while it is 0.163 (S.d.: 0.084) and 0.113 (S.d.: 0.090) in Los Angeles and San Diego, respectively.

3.3.2. Diversity

Land use diversity indices are calculated based on the Rasht land use database, which had been gathered in RHTS (Andishkar consulting engineers, 2011). The third part of Table 3 shows the descriptive statistics of calculated diversity indices. The average entropy index in Rasht TAZs is 0.33 while in 13 regions of Atlanta in Frank et al. (2005) is reported as 0.38 (Frank et al., 2005) and in Ewing et al. (2014) research, which has used the household travel survey of the 15 diverse regions of the U.S., is reported as 0.22 (Ewing et al., 2014). This shows that Rasht possesses a higher level of mixture of land uses versus Ewing et al. (2014) case study (Ewing et al., 2014) and lower values comparing Frank et al. (2005) case study (Frank et al., 2005). The job-population balance found as 0.56 in Rasht, while it is found as 0.59 in Ewing et al. (2014) study. Therefore, the balance of jobs and residential area in both case studies are close.

Table 3
Zone-based descriptive statistics.

		Average	Standard deviation	Min	Max	Unit
Part 1- Socio-economic variables						
1	Age	30.01	2.83	22.33	40.25	year
2	Household size	3.51	0.19	3	4.33	person
3	Average bike ownership	0.188	0.034	0.106	0.287	per capita
4	Average motor ownership	0.034	0.02	0	0.122	per capita
5	Average car ownership	0.162	0.068	0.074	0.27	per capita
6	Zone area	0.612	0.624	0.119	2.930	km^2
7	Zone perimeter	3.309	1.657	1.547	9.565	km
8	Equivalent radius	0.441	0.45	0.2	1.0	km
Part 2 - Design indices						
1	Cul-de-sac density	146.11	91.01	0	407.8	number/km^2
2	3-way intersection density	210.88	116.92	1.24	535	number/km^2
3	4-way intersection density	33.62	23.98	0	121.2	number/km^2
4	Intersection density	244.5	134.32	1.24	656.29	number/km^2
5	Percentage of 3-way intersections	85.9	10.32	61.09	100	%
6	Percentage of 4-way intersections	14.1	6.44	0	38.9	%
7	Density of major[a] 3-way intersections	19.2	16.27	0	73.84	number/km^2
8	Density of major 4-way intersections	4.1	6.10	0	45.34	number/km^2
9	Percentage of cul-de-sac to nodes	37.01	9.22	0	60	%
10	Ratio of minor streets to major streets	11.57	25.63	0	187.56	%
11	Street density	17.9955	8.487	0.405	35.276	m/10^3*km^2
12	Major street density	3.6534	2.9675	0	16.1494	m/10^3*km^2
13	Minor street density	15.342	8.836	0.610	35.041	m/10^3*km^2
14	Connected node ratio	0.62	0.1	0.4	1	–
15	Ratio of links to nodes	1.86	0.2	1.55	2.25	–
16	Average link length	54.37	24.95	27.2	227.46	m
17	Average major link length	85.5	211.13	0	2039.3	m
18	Gamma index	0.39	0.05	0.33	0.63	–
19	Alpha index	0.09	0.059	0.01	0.36	–
20	Node connectivity index	0.60	0.13	0.32	1.34	–
21	Link connectivity index	18.3	26.20	0.03	166.5	–
Part 3 -Diversity indices						
1	Entropy index	0.33	0.19	0	0.83	–
2	HHI	0.72	0.18	0.29	1	–
3	MXI	35.8	11.3	1.64	50	–
4	Job-pop balance	0.56	0.29	0	1	–
Part 4 -Density indices						
1	Population density	10100	6600	0	28700	People/km^2
Part 5 – Destination accessibility indices						
1	Distance to CBD (Aerial)	2.588	0.751	0	5.466	km
2	Distance to CBD (Network)	2.977	0.948	0	7.645	km

[a] At least one of the legs is major street.

Table 4
Walking trips for each trip purpose.

	Job	Educational	Shopping
Number of all trips	5501	4896	2737
Number of walking trips	892	1805	1295
Percentage of walking (produced or attracted)	16.2	36.9	47.3

3.3.3. *Density*

The population density that has been calculated for each zone of Rasht is presented in the fourth part of Table 3. Rasht is one of the densest cities by population in Iran (population density 10100/km^2). The density of Frank's study area (13 regions in Atlanta) is about 4900 people per km^2 (Frank et al., 2005) which is lower than the case of Rasht. Population density in other walkability studies is also reported as 3860 people/km^2 in Portland (Azimi, 2005) and 8305 people/km^2 in GMA (the Greater Montreal Area) (Azimi, 2005). Since higher population density is favorable for WI, Rasht may provide a better situation for walking versus other case studies.

3.3.4. *Destination accessibility*

Destination accessibility is determined through distance to the CBD in terms of aerial and network distance, which are shown in the fifth part of Table 3. As it can be seen, the average aerial and network distances of TAZs to the CBD are about 2.6 km and 3 km, respectively.

4. Methodology

In this study, the normalized distribution (Z-score) of each criterion (i.e., design, diversity, density and destination accessibility) was used to determine WI. The Z-score is the number of standard deviations by which the value of an observation is above the mean value of what is being observed or measured. Observed values above the mean have positive standard scores, while values below the mean have negative standard scores (Montgomery, Runger, & Hubele, 2009). Therefore, the Z-score of each BE criterion was taken through Eq. (1) which shows the value of Z-score, Z_{ij}, for criterion i in zone j.

$$Z_{ij.\,i=1,2,3,4} = \frac{x_{ij} - \overline{x}_i}{s.d._i} \tag{1}$$

"x_{ij}" is the value of BE criterion i for zone j, "$\overline{x_i}$ "is the mean of BE criterion i over all zones and " $s.d._i$ " is the standard deviation of BE criterion i. Eq. (2) shows the relationship between Z_i and WI where β_i shows the coefficient of each BE criterion in WI.

$$WI = \beta_1 Z_{1j} + \beta_2 Z_{2j} + \beta_3 Z_{3j} + \beta_4 Z_{4j} \tag{2}$$

Employing linear regression analysis results in β s with the least

Table 5
Correlation between design indices and walk share (Job, Educational, Shopping and All trips).

		Walk share (Job)	Walk share (Educational)	Walk share (Shopping)	Walk share (All)
Design Indices					
1	Cul-de-sac density	0.383**	0.402**	0.531**	0.514**
2	3-way intersection density	0.328**	0.305**	0.464**	0.407**
3	4-way intersection density	0.200*	0.208*	0.247**	0.274**
4	Intersection density	0.322**	0.303**	0.448**	0.403**
5	Percentage of 3-way intersections	0.153	0.151	0.163	0.180
6	Percentage of 4-way intersections	0.035	0.055	0.040	0.076
7	Density of major1 3-way intersections	−0.063	−0.075	−0.128*	−0.092
8	Density of major 4-way intersections	−0.089	−0.136*	−0.045	−0.112
9	Ratio of cul-de-sac to nodes	0.127	0.225*	0.164	0.290**
10	Ratio of minor streets to major streets	0.166	0.210*	0.180	0.155
11	Street density	0.381**	0.431**	0.503**	0.518**
12	Major street density	−0.113	−0.201*	0.029	−0.150
13	Minor street density	0.326**	0.345**	0.490**	0.445**
14	Connected node ratio	0.061	−0.015	0.042	−0.031
15	Ratio of links to nodes	0.148	0.219*	0.197*	0.291**
16	Average link length	−.282**	−0.341**	−0.417**	−0.351**
17	Average major link length	−0.242*	−.193*	−0.324**	−0.353**
18	Gamma index	−0.074	−0.068*	−0.129	−0.133
19	Alpha index	−0.172	−0.196*	−0.240*	−0.302**
20	Node connectivity	0.089	0.059	0.101	0.089
21	**Link connectivity**	0.417**	0.480**	0.495**	0.492**
Diversity Indices					
1	Entropy	−0.093	−0.126	−0.271**	−0.128
3	HHI	0.105	0.59	0.324**	0.151
2	MXI	−0.151	0.68	0.105	−0.141
4	**Job-Pop balance**	0.485**	0.228*	0.463**	0.685**
Density Index					
1	**Population density**	0.250**	0.356**	0.534**	0.331**
Destination accessibility Indices					
1	Distance to CBD (Aerial)	0.135	0.097	0.080	0.118
2	Distance to CBD (Network)	0.103	0.067	0.83	0.091

** and * represent 1% and 5% level of significance, respectively.

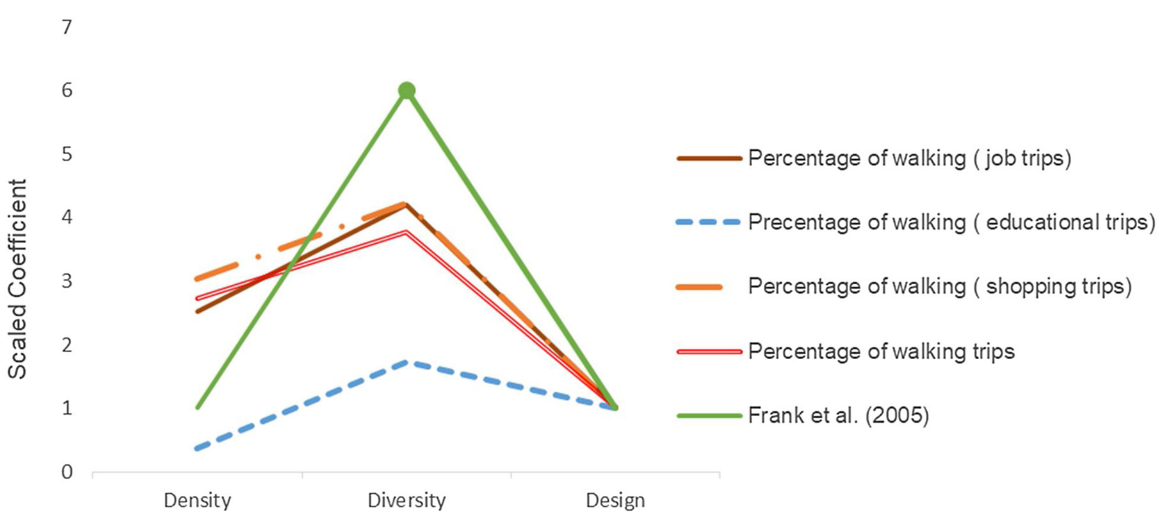

Fig. 2. The resulting WI for each trip purpose.

squares of error term and the highest goodness of fit. In this study, walk share originated from or attracted to a TAZ considered as a proxy for walking and, therefore, treated as a dependent variable. Furthermore, the values of Z-score for each criterion are regarded as independent variables. Eventually, the coefficient of design criterion that was usually the lowest β (with one exception for educational trips) has been fixed to 1.0 and the others have been scaled based on it. The process has been done for all trips as well as each trip purpose.

To calibrate the WI, the strategy suggested by Frank et al. (2005) has been followed in this study. However, based on the correlation analysis between the variables (Table 5), the most representative indices of each criterion are selected. As for design criterion a number of indices were significantly correlated with the walk share, the PCA approach has been adopted. Therefore, as suggested by Hatamzadeh et al., all link-related indices were converted to link connectivity index and all node-related indices were summarized in the node connectivity index through the PCA (Hatamzadeh et al., 2017a). It is worth noting that, as shown in Table 5, only the former was significantly correlated with the studied walk shares. Table 5 also shows that the job-population index is significantly correlated with the walk share for each trip purpose in addition to all trips. For the density criterion only the population density of a zone was examined which was significantly correlated

Table 6
The resulting coefficients and goodness of fits.

Walk share (Dependent Variable)	Density	Diversity	Design	Goodness of fit
Job trips	2.52**	4.21*	1**	0.470
Educational trips	0.36*	1.73**	1*	0.566
Shopping trips	3.04**	4.23*	1*	0.614
All trips	2.72**	3.77**	1*	0.626

** and * means 5% and 10% level of significance, respectively.

with walk share of each trip purpose as well as all trips. For the destination accessibility, however, either form of distance to the CBD (i.e., aerial and network) were not correlated with walk share for the studied trip purposes. Therefore, no more analysis is performed on this criterion. Finally, the link connectivity (resulting from the PCA), job-population balance and population density indices (which are bolded in Table 5) were used to represent the design, diversity and density, respectively.

5. Results and discussion

Fig. 2 shows that the resulting weights of BE criteria for all trips, in addition to each of the studied trip purposes. To determine the weights of each BE criteria, all studied indices, which were correlated to each trip purpose walk share, have been examined considering the highest possible goodness of fit value. Table 6 shows the resulting coefficients and goodness of fits. As mentioned, these weights are determined based on fixing the design coefficient of each trip purpose to 1.0. Therefore, the resulted values should be treated as ratios to the design criterion of each trip purpose and comparing weights across the trip purposes is meaningless.

Considering the resulting WIs for all trips presented in Table 6, the diversity criterion is derived as the highest. This result is the same as Frank et al. (2005) who assigned higher coefficients to the diversity criterion. Density has been found as the second important criteria in the city of Rasht for all trips (2.72). It can be seen that density in this study is derived far more influential regarding the value assigned by Frank et al. (2005) study.

Similar to all trips, the weight of diversity is derived as the highest BE criterion for each of the studied trip purposes. Table 6 shows that the weight of diversity (i.e., ratio of diversity to design) is 4.21, 1.73 and 4.23 for the job, educational and shopping trips, respectively. The lower ratio of diversity to design for educational trips may reflect the higher effect of design criterion for this type of trips. As mentioned above, design criterion reflects the street density and ratio of minor streets to major streets of a zone. The former reveals the possibility of walking and the latter shows the quality of safe walking. A number of studies discussed about the safety of children in school trips as a big concern of their parents (Carver, Timperio, & Crawford, 2008; Kerr et al., 2006; McDonald & Aalborg, 2009). Therefore, one may expect higher effect of design criterion for walking for educational trips. Another study also confirmed that the importance of safety for students has been underscored in the literature (Giles-Corti et al., 2011).

The density criteria were found to be the second important criteria for the studied trip purposes except for educational trips. In fact, the derived weights (i.e., ratio of density to design) for the job, educational and shopping trips were 2.52, 0.36 and 3.04, respectively. Such result indicates the different role of density across trip purposes. Again, the lower ratio of density to design for educational trips may reflect the higher effect of design criterion for this type of trips, which is addressed earlier.

In this study, the method is the same as Frank et al. (2005), while different indices based on their correlations and higher goodness of fit values have been used. For example, the job-population balance index has been used for the diversity criterion, instead of the entropy index. In fact, the correlation of different calculated indices of diversity criterion showed that the job-population balance index is more meaningful in describing walkability. Such result is in accordance with Cervero and Duncan findings, which concluded that the job-population balance better illustrates the ability to walk in a place (Cervero & Duncan, 2006). Furthermore, in studies by Frank et al., the intersection density has been used as a design measure, while in the current study, an index resulting from PCA analysis has been used due to its higher goodness of fit values with WIs. Employing the resulting index enabled WIs to cover more connectivity indices, which may provide more profound knowledge. It is worth mentioning that considering correlation-based indices for measuring the walkability is recommended by other studies (Manaugh & El-Geneidy, 2011).

As shown in Fig. 2, trends of the resulting coefficients are close to the trend of coefficients of Frank et al. (2005), although there is an exception for educational trips. According to the correlation values presented in Table 6, WI has been more successful in describing shopping trips (R^2 = 0.614) in comparison with the job (R^2 = 0.470) and educational trips (R^2 = 0.566). Therefore, BE criteria are more responsible to show variation in walk share of shopping trips.

6. Summary and conclusion

Promoting walking as a sustainable mode of transportation is an issue considered by transportation planners of cities. In this regard, a few studies have been conducted to assess various WIs, which can show how the BE encourages individuals to walk more. In this paper, developing an objectively measured index and calibrating it for each trip purpose is considered. This study used a large-scale data bank for a city of a developing country. It is necessary to specify that, the term walkability in this study may be also considered as walking propensity, since it shows the walking due to coercive features (Cervero & Kockelman, 1997). However, in this paper, to be in line with most of the related literature, the term walkability has been used.

The results highlight the effect of considering trip purposes in calibrating WI. Results certify that, calibrating WI based on trip purposes would shed light on how planners could encourage individuals to do more walking by focusing on special groups or specific trips. For instance, according to the results, while density is a more effective criterion than design to encourage people to walk for non-educational trips, this is not the case for educational trips. It means that, in a case the issue is enhancing share of walking trips among students, investing in design index instead of density index within their school area would be a wiser instrument.

According to the findings, the diversity has the highest coefficient in all studied trip purposes, but there is a slight variation in the resulting coefficients determined for BE criteria for the job, shopping, educational and all trips. Although density is the least important factor in educational trips, it is considered as the second highest coefficient among other BE factors for job, shopping and all trips. It can be concluded that the general pattern of the resulted WIs is almost close to the pattern developed by Frank et al. (2005) except the unequal values specified for density and design criteria. Differences may be attributed to the specific characteristics of the city of Rasht including higher population density, lower car ownership, and different form of network which is discussed earlier. However, this subject is open to future studies across other cities. Furthermore, one may conclude that in cities with more educational trips the results may be closer to the mentioned study which is the matter of trip purposes.

According to the results, the goodness of fit of job trips is the lowest among other trip purposes. It seems that when individuals are more coercive to be at a specific place at an exact time (e.g., work and educational), they would less consider the BE criteria and, therefore, these criteria would not be as representative as what they are for other trip purposes (e.g., shopping trips). The results will help policymakers to realize that by investing in which segments and improving which parts of the city would result in more walkable city and in reaching their desirable goals toward sustainability.

The results of this paper would be helpful in term of finding the optimal location for building new facilities to maximize the share of walking in each trip purpose. For example, awareness of high walkable zones with educational trips would help to find the best location to construct a new school.

According to the result, in line with some other studies mentioned in the literature (Brown et al., 2009; Christian et al., 2011), this study shows the inappropriateness of entropy index for describing the walkability. Entropy index, which is commonly used in the literature, according to Table 6 is not considered as a successful index in describing dependent variable and not entered into the analysis. Although, in various studies, it was used as a proxy of diversity in WIs, this study even shows the negative correlation of it.

It should be borne in mind that data on travel behavior in a city of a developing country such as Iran is minimal. Therefore, some limitations are significant to point out. A major barrier of this research was the lack of information about the actual distance traveled, which should be considered in future research. The available data for origin and destination travel zone were not completely accurate in this study. It also should be considered that while the shape of zones is not like circular form, the equivalent radius of zones is considered. Furthermore, there are limited environmental variable that is possible to control in this study. For instance, various path attributes such as slope, adjacent traffic volume, and the presence (and width) of sidewalks and some indices such as pedestrian route directness and the pedestrian catchment area could be helpful in reflecting some key factors influencing WI in various trip purposes. Besides, using a more up-to-date data would result in more realistic outcomes. Despite some recent research, a criterion was not considered in this study. Since there is no sufficient public transit in the city of Rasht, distance to transit criterion has not been assumed to play a key role in Rasht's WIs. Therefore, considering this criterion is suggested as a subject for future studies. This study tried to show the importance of trip purpose in walkability. To develop this study, more studies can be conducted to include more trip purposes, or calculation of more indices. Furthermore, focusing on different age groups for educational trips may be of interest to assess the effect of BE criteria for students as one may expect a higher impact of safety (design criterion) on younger students. Finally, similar findings in other cities would be required to compare WIs across different trip purposes.

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