

Enhancing Pedestrian Trips in Urban Areas: A Macro-Level Approach (Case Study: Shiraz City)

Salman AghidiKheyrabadi¹, Amir Reza Mamdoohi^{1,2,*}

Received: 2023/07/31

Accepted: 2024/01/09

Abstract

The focus on sustainable transportation and pedestrian-friendly urban environments has gained importance, emphasizing the need to prioritize pedestrians over cars in transportation planning. Pedestrian trip modeling poses several challenges, including predicting the number of pedestrian trips generated in specific areas, identifying the variables influencing walk-trip generation, and measuring their impact. Most researchers have developed trip generation models based on trip purposes rather than travel modes. Furthermore, some studies have used variables similar to those used for other travel modes to model walking trips. This study aimed to identify influential variables and measure their impact. Developing trip production models exclusively for walk trips, along with the corresponding variables, and addressing the challenge of zero-walk trips in many zones are regarded as innovations. Shiraz City was utilized as a case study, encompassing 325 pedestrian analysis zones, to model walk-trip production using linear regression. Walk trips, categorized into home-based and non-home-based trips, were estimated for the base year. The Herfindahl-Hirschman Index, access to land use, and car ownership at the neighborhood level significantly influence walk-trip production. An increase in car ownership reduces home-based walking trips and increases non-home-based ones. Additionally, a 1% rise in access to green spaces resulted in a 4% increase in home-based walking trips. These models can predict future walking trips and assess the impact of urban design plans on pedestrian activity. Prioritizing pedestrian-friendly transportation planning leads to more sustainable and people-centric urban areas.

Keywords: Pedestrian trips, Walking, Trip production, Transportation planning, Four-step demand model

* Corresponding author. E-mail: armamdoohi@modares.ac.ir

¹ Faculty of Civil and Environmental Engineering, Tarbiat Modares University, Tehran, 1411713116, Iran

² Civil, Geological and Mining Engineering Department, Polytechnique Montréal, H3T 1J4, Canada

1. Introduction

In recent years, the concept of sustainable transportation (the shift from car-oriented to human-oriented cities) has led to a special place for walking in many studies. Attempts are being made to design cities as environments for human life rather than for passing cars. This has led many transportation modelers to change their approach, including walking as an important mode of transportation in the transportation planning process [Aghidi Kheyraadi and Mamdoohi; 2024]. One of the challenges ahead of these models is the prediction of future walking trips. Addressing this challenge requires the development of a trip-generation model [Saffarzadeh et al. 2022]. Commonly used trip demand modeling methods predict the total number of trips (or, in earlier models, only motorized trips) and choose the travel mode based on variables such as household demographic characteristics, travel time, travel cost compared to other modes, and built environment features [Tian and Ewing, 2017].

Therefore, in developing a walk trip generation model, it is necessary to consider the effects of built environment and policy-related variables. This study aims to identify the factors that affect walking trips for policy-making purposes. The main questions that this research seeks to answer are whether the land use mix index and accessibility variables for land use and car ownership influence walking trip production, and if so, to what extent.

Because different land use types are associated with various kinds of activities, it is expected that significant variations in trip rates will be observed across different land use types. Among the economic and social variables, built environment variables, and land use variables, land use variables are better suited to predict trip generation rates than other variables [Mukherjee and Kadali, 2022].

The combination of land use types and their accessibility plays a significant role in

connecting the supply network to pedestrian demand. An innovation of the model developed in this study is that it considers important variables that affect pedestrian travel demand, such as the land use mix index and accessibility to different land use types in the area, and determines the impact of each variable if it is effective. Typically, to create walk travel demand models, variables similar to those in other studies are considered without the presence of pedestrians, and important variables such as accessibility to land use types are not taken into account. As previously mentioned, travel demand models have been developed for trip purposes without distinguishing between the different modes of travel. A novelty of this paper is the development of a unique trip model for walking trips as a specific and separate mode from other modes of travel.

After data collection and database construction, variables that have a significant impact on model prediction are identified, and separate models are developed for home-based and non-home-based trips using linear regression. Furthermore, non-home-based walk trips are considered in the walk trip generation models, and the challenge of zero non-home-based trips is addressed. The results of the models are presented and significant variables are identified.

The application of the walk-trip production models in this research can first be understood using walk-trip demand models. However, owing to the weaknesses and issues in considering the walking mode in these models, it can be modeled separately. In this paper, the variables considered were specific to the walk mode. Therefore, significant indices in walk-trip production models can be identified, and the effectiveness of each index can be calculated to predict future walking trips. Second, models can be used to meet pedestrian requirements. Additionally, these models can be used to evaluate the impact of urban design plans on pedestrian activities.

In this research, first, the problem, necessity, objectives, research gaps, and innovations of the present research are stated in the introduction section, followed by a review of previous studies on modeling walk trips and an analysis of the models and variables used in each will be presented. In the Data section, the database used in the research and the method of collecting it are introduced. After identifying the effective variables, in the modeling section, for generating walk trips, walk-trip production models are developed for both home-based and non-home-based trips. Then, the results of each of these models are analyzed, and in the last section, the findings of the current research and some suggestions for future research are presented.

2. Literature Review

Statistical models such as regression are commonly used to estimate the trip generation stage. Any errors in this stage can be transferred to other stages, which may be compensated for or exacerbated by errors in other stages [Mashaghzadefard, 2000].

The trip generation model data are at both the aggregate and disaggregate levels. The primary purpose of aggregating the level trip generation models is to categorize individuals or households into distinct groups. A common level of aggregation assumes that individuals or households located in a Traffic Analysis Zone (TAZ) are homogeneous. At this level, the total or average generated trips in the TAZ are described as a function of the total or average characteristics of the TAZ and independent variables such as the average household income and car ownership in the TAZ [Mashaghzadefard, 2000].

Disaggregate models are based on individual or household decision making and are known as behavioral models [Jahaniaghdam et al.; 2023]. Some researchers have emphasized the individual, whereas others have focused on households as the production unit of the trip. The data necessary for developing and

calibrating disaggregate trip demand models include household members' trip behavior, socioeconomic characteristics, and residential location [KhorramDehnavi et al.; 2024].

Built environment variables generally include land use patterns, transportation systems, road infrastructure, sidewalks, services provided by them, urban design, and the arrangement and appearance of physical elements [Saelens and Handy, 2008].

In the four-step urban planning process, the first step is trip generation, which includes two models: trip production and attraction. The main goal of production and attraction models is to identify and determine the effective factors as independent variables on trip production and attraction in the current situation and ultimately predict the number of trips produced and attracted to each TAZ in the future. In this regard, resources and tools are required to provide information on these variables to achieve a suitable structure for modeling [Everett, 2009].

The NCHRP 770 report recommends that both trip generation and tour-based models consider the usual socio-economic characteristics of travelers. Additionally, it suggests using land use variables, including parking availability and cost, intersection density, residential density, mixed land use types, and accessibility to both motorized and non-motorized modes [Kuzmyak et al. 2014].

A noteworthy point to underscore is that none of the examined trip generation models directly includes access mode and destination choice models. However, in travel demand models, network conditions such as accessibility are explicitly considered [Kuzmyak et al. 2014]. On the other hand, Khan and his colleagues considered access measure components in their non-motorized travel model (trip generation) using Logsums and found that the number of non-motorized trips is directly related to access to non-motorized trips and negatively related to access by single-occupancy vehicles [Khan et al.2014].

The range of variables affecting trip generation is very wide. Population characteristics and socio-economic conditions are particularly important factors in trip generation. Household income, number of employed individuals, and vehicle ownership are some of the independent variables in trip production models. Although residential density and distance from commercial areas may be used as independent variables, their usage is not common [Askari et al. 2020]. Meanwhile, the built environment and policies can influence physical activity and active transportation [Blanchette et al. 2019].

In general, regional models contain a component for predicting the total number of trips (or tours) that individuals in a particular area generate based on their socioeconomic characteristics and create travel. It is often important for such models to incorporate non-motorized trips for various reasons mentioned earlier [RSG and The RAND Corporation, 2019].

Travel demand models usually include variables related to land use variables (such as access and mixed land use types), infrastructure, network, and facilities variables (such as travel time and societal cost [Hosseinlou, Kheyraadi, and Zolfaghari; 2015], distance, slope, roughness, and the availability and connectivity of bicycle and pedestrian facilities), and economic and social variables and traveler characteristics (such as age, gender, income, vehicle ownership, occupation, and education) are among the factors affecting the decision to walk or bike in travel demand models [RSG and The RAND Corporation, 2019].

In recent years, various researchers have proposed different approaches for modeling walk trips, which differ in terms of the type of models used, complexity, framework, accuracy, and data requirements [Saffarzadeh et al. 2022]. One of these approaches is the development of a four-step transportation demand modeling to predict walk trips. In the context of transportation modeling, a home in a home-

based trip or the origin of a non-home-based trip is defined as trip production.

Increasing walk trips can be impacted by safety concerns, particularly when road designs and land use planning neglect to provide essential pedestrian facilities [World Health Organization (WHO), 2023]. Ghana observed that 98% of pedestrian collisions occurred in areas distant from designated pedestrian crossings or in their absence [Obeng-Atuah et al. 2017]. How pedestrians perceive their surrounding environment was analyzed in India. Results showed that female pedestrians walk less frequently than males and perceive a higher probability of collision or near-collision incidents against male pedestrians [Saxena and Yadav, 2022]. In another research by developing SEM and PLS, the relationship between different variables (such as pedestrian crossing) and the driver hazard avoidance index were investigated [Asadamraji et al. 2022].

Since different land use types are related to various activities, it is expected that significant changes in trip rates will be observed in different land use types. This is while among economic and social variables, artificial environmental variables, and land use variables, land use variables can better predict the rate of travel than other variables [Mukherjee and Kadali, 2022].

3. Data

This research was conducted using Shiraz City as a case study. Shiraz City is the capital of Fars province, with an area of 122,608 square kilometers and a population of 1,683,052 people according to the estimated population in 2016. It is the fourth most populous city in Iran [Statistical Center of Iran, 2021]

To create a database for this research, first, the database and outputs of the models were collected from the comprehensive urban transportation study. Then, necessary data, such as walk trip origin-destination information, was collected through online surveys. The origin-destination survey was conducted through

home interviews by students. The sample size was approximately 3.21% based on the estimated population, and ultimately, 16,618 questionnaires were entered into the database. The number of non-walk daily trips for residents of Shiraz City was estimated to be approximately 2,983,159 (approximately 1.81 trips per day). Traffic analysis zones (TAZs) were also considered with 325 internal TAZs for transportation planning purposes [Aghidi et al. 2019]

Due to the lack of information on walk travel alongside other modes of travel in the collected dataset, various questionnaires have been designed. The questionnaires have been designed in a way that not only considers the COVID-19 conditions during the survey but also meets the needs of the current research. Therefore, an online survey was chosen. After designing the questionnaire based on previous studies and expert opinions, and conducting three stages of design and pilot testing, the final questionnaire was designed based on yesterday's walk travel questionnaire and distributed among pupils from 87 schools in different areas of Shiraz City. Data collection was carried out from August to December 2021, and during the survey period, 4729 responses were received, of which 1547 people reported walking travel on the previous day. Finally, household information and the total number of their walk trips were obtained, and categorized by home-based and non-home-based trips.

In this paper, in order to model walk trip production in the city of Shiraz, the walk trip rate model was applied to the collected data for the base year. The number of produced walk trips, categorized into home-based and non-home-based trips, was predicted for the base year (Figure 1).

4. Variables

Various variables have been considered to examine their impact on the walk travel model, among which the variables that had a significant effect on the walk travel model have been presented in Table 1. These variables include economic and social variables such as the population of the origin PAZ and car ownership per capita, as well as land use variables such as the ratio of green space area to total land use area, access to green space, and recreational, religious, cultural, tourism, and sports land use. The accessibility index to each land use, assuming each land use is denoted by k and the desired PAZ is denoted by i , is calculated using equation (1).

$$\text{Accessibility}_i^k = \sum_{j=1}^n \frac{LUA_j^k}{PTT_{ij}} \quad (1)$$

In this equation:

Accessibility_i^k : access to land use k in area i ,

LUA_j^k : the land use area of k in PAZ j ,

PTT_{ij} : the walking travel time from PAZ i to j ,

n : number of PAZs.

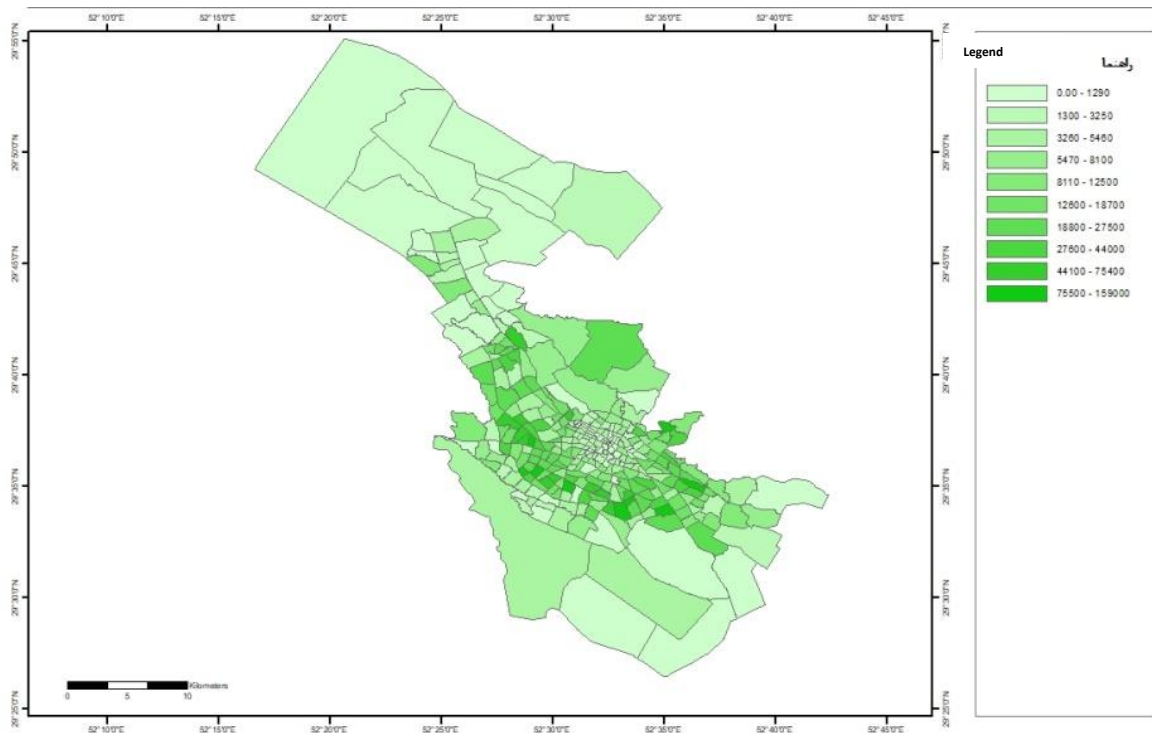


Figure 1. The ratio of the total number of walk trips produced to the area of the PAZ in Shiraz City

The walking travel time between PAZs is calculated using equation (2).

$$PTT_{ij} = \frac{PD_{ij}}{0.072} \quad (2)$$

In this equation, PD_{ij} is the distance between the centers of the two PAZs. If $i=j$, the distance is set equal to the square root of the area of that PAZ.

Herfindahl-Hirschman Index is a variable that represents the level of diversity in land use in a PAZ [Eriksson et al. 2012] and has also been

shown to be significant in the walk travel demand model for the city of Shiraz (equation 3).

$$HHI = P_1^2 + P_2^2 + \dots + P_n^2 \quad (3)$$

In this equation:

P: the share of land use i (based on area),

n: the total number of land use types.

According to this equation, the higher the HHI value, the lower the diversity of land use in that area, and vice versa.

Table 1. Definition of variables used in walk trip production modeling

Row	Variable	Explanation	Minimum	Maximum	Mean	Standard deviation
1	Pi	The residential population in PAZ i.	0.000	35263.068	5078.453	4329.538
2	Cari	The per capita car ownership of residents in PAZ i.	0.128	0.526	0.326	0.093
3	pj8	The ratio of green space area to the total area of land use types in PAZ i.	0.00	0.810	0.073	0.131
4	CLNCj	The number of clinics in PAZ j.	0.000	3	0.42	0.645
5	HHI	Herfindahl-Hirschman Index (HHI) – The mixture of different land use types in an area.	8.740	128.669	33.854	16.384
6	STUi	The number of students in PAZ i.	0.170	0.948	0.412	0.151
7	USTi	The number of students in their place of study in PAZ i.	0.000	7210.157	1055.756	945.172
8	ei	Residential employment	0.000	2258.215	350.752	327.008

Enhancing Pedestrian Trips in Urban Areas: A Macro-Level Approach (Case Study: Shiraz City)

Row	Variable	Explanation	Minimum	Maximum	Mean	Standard deviation
9	Accessibility 1	Commercial accessibility	0.689	15.166	3.964	2.172
10	Accessibility 8	Green space accessibility	20.690	13053.825	1720.776	1332.885
11	LandUse3 Recreational	Area of recreational, religious, cultural, tourism, and sports land use (hectares)	0.000	58.846	1.228	4.161
12	Dummy_hospital	The dummy variable of the hospital's presence in the area	0.000	1	0.104	0.306
13	Dummy_Namazi	Dummy variable of Namazi hospital in Shiraz	0.000	1	0.003	0.055
14	Dummy_industrial	Dummy variable of the industrial town	0.000	1	0	0.055

5. Model Results

In this section, the results of the linear regression model for walking trips in Shiraz Table 2.

According to Model 1, the production of walking trips increases with an increase in the resident population in the area. Additionally, an increase in the ratio of green space to the total land-use area also leads to an increase in the production of walking trips. Access to green spaces also has a direct impact on the production of home-based walking trips in Shiraz City. Furthermore, the number of students in the area has a positive effect on the production of walking trips, while the number of university students in the area has a negative effect. The ownership of cars by residents has an inverse effect on the production of walking trips, as indicated by the significant negative coefficient.

In the non-home-based walk trip production model (Model 2), the dependent variable has been transformed to $\ln y$ to address the challenge of zero non-home-based walk trips.

Based on the model results presented in Table 2, in the non-home-based model of walk trips (Model 2), the variables of employment (residential employment), commercial accessibility, and green spaces have been significantly positively correlated with non-home-based walk trip production. This means that these variables have a direct effect on non-home-based walk trip production. On the other

City are presented, and categorized based on home-based and non-home-based trips. The findings are shown in

hand, the HHI variable, which indicates the level of land use mix, has been significantly negatively correlated, indicating that the more land use mix in an area, the more non-home-based walk trips are produced. The variable of car ownership rate, number of clinics, and dummy variable of the number of hospitals have been significantly positively correlated, indicating that an increase in these variables increases the production of non-home-based walk trips. It should be noted that a high car ownership rate can indicate the luxury of the area under consideration, which has a higher potential to attract non-home-based walk trips. The land use variable for recreational areas has also been significantly negatively correlated, indicating the inverse effect on non-home-based walk trip production. Two dummy variables, industrial town, and Namazi Shiraz Hospital, have also been significantly negatively correlated, indicating their inverse effect on non-home-based walk trip production. The coefficient of determination for the models is 0.998 for home-based walk trips and 0.570 for non-home-based walk trips. A scatter plot of predicted versus observed values was also generated to provide a more in-depth examination of the models. These scatter plots are presented in Figure 2 and Figure 3. As evident in these figures, the predicted and

observed values have a very high conformity with each other. Part of this conformity is due to the large and logical variables used in the model, and partly due to the extension of origin and destination data using population. Therefore, the use of population variables in Model 1 has led to a high correlation with the dependent variable and consequently an increase in the accuracy of prediction.

5.1. Sensitivity Analysis and Marginal Effect Analysis

In order to calculate the approximate elasticity in linear regression models when the dependent and independent variables are in their original form, equation 4 is used.

$$\Delta y = \beta_1 \Delta x \tag{4}$$

And when the variable y is logarithmic, equation 5 is used

$$\% \Delta y = (100\beta_1) \Delta x \tag{5}$$

In these equations, x refers to the independent variables and y refers to the dependent variable. Therefore, equation 4 can be used to analyze the sensitivity of the linear regression model for the production of walk trips in Shiraz City based on home-based activities. Also, since the dependent variable in the model for the production of walk trips in Shiraz based on non-home activities is in the form of lny, equation 5 is used to analyze the sensitivity of this model. The sensitivity analysis results for each variable of the two models are presented in Table 3.

Table 2. The linear regression model results for producing home-based and non-home-based walking trips

Variables	Model 1		Model 2	
	Coefficient	Significance level	Coefficient	Significance level
Constant coefficient			5.362 (0.244)	0.000
Resident population in the area	0.630 (0.014)	0.000		
Employment			0.00042 (0.000)	0.000
The number of students in the area	0.337 (0.050)	0.000		
The number of university students in the area	-0.295 (0.068)	0.000		
The per capita ownership of cars by residents in the area	-633.866 (94.426)	0.000	1.587 (0.513)	0.002
The ratio of green space land-use area to the total land-use area	1215.260 (114.992)	0.000		
Green space access	4.456 (1.042)	0.000	0.007 (0.003)	0.013
Commercial access			1.07 (0.021)	0.000
Land use for recreational, religious, cultural, tourism, and sports purposes			-0.046 (0.009)	0.000
Herfindahl-Hirschman Index (The proportion of different land use types in an area)			-1.626 (0.299)	0.000
Dummy variable of the industrial town			-1.897 (0.797)	0.018
The number of clinics			0.170 (0.065)	0.010

Enhancing Pedestrian Trips in Urban Areas: A Macro-Level Approach (Case Study: Shiraz City)

Variables	Model 1		Model 2	
	Coefficient	Significance level	Coefficient	Significance level
Dummy variable for the presence of a hospital in the neighborhood			0.300 (0.134)	0.026
Dummy variable Namazi Shiraz Hospital			-1.471 (0.722)	0.043
Samples	324		324	
R ²	0.998		0.57	

The numbers inside the parentheses () represent the standard error values.

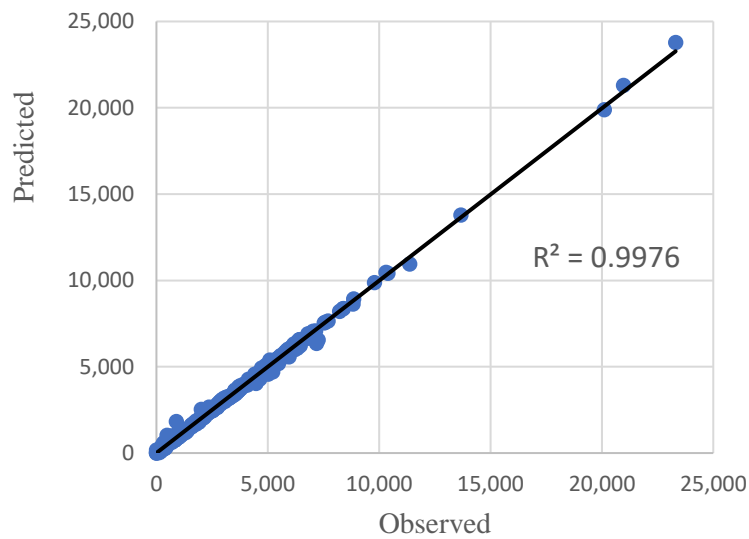


Figure 2. The comparison between predicted and observed values for the production of home-based walking trips in each PAZ

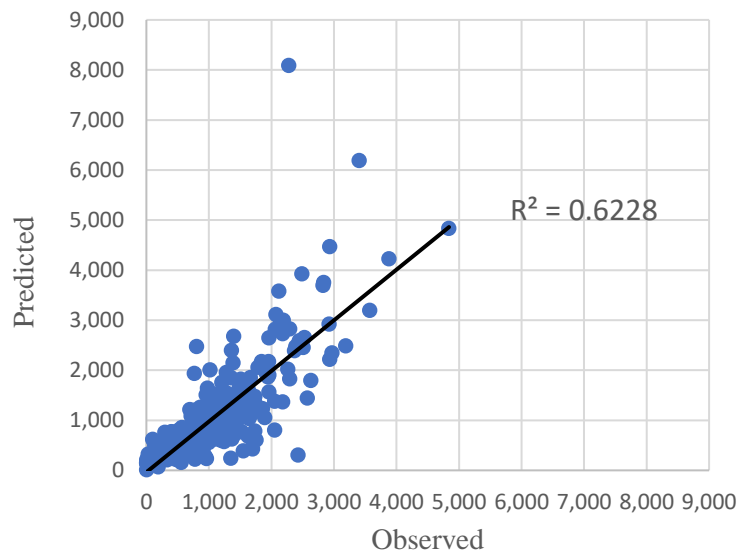


Figure 3. The comparison between predicted and observed values for the production of non-home-based walking trips in each PAZ

6. Discussion

The current research models indicate that the population variable in the home-based walk trip production model for Shiraz City has a significant positive coefficient. The sensitivity analysis results indicate that for every 10-person increase in the residential population of PAZ, the number of walking trips originating from that PAZ will increase by approximately 6 trips.

The number of students in a PAZ in the home-based walk trip production model also has a significant positive coefficient. However, the variable for the number of university students in the PAZ has a significant negative coefficient. For every additional 10 students in a PAZ, the production of home-based walk trips in that PAZ increases by approximately 3 trips. Conversely, for every additional 10 university students in a PAZ, the number of home-based walk trips in that PAZ decreases by 3 trips. This

implies that the enrollment of students in universities leads to a reduction in their walk trips. It should be noted that parents often choose the travel mode for their children (especially primary school students), and based on studies in this context, psychological and attitudinal variables of parents, risk assessment and safety, accident experiences, socio-economic factors, and built environment characteristics and distance to school can influence the choice of walk mode for these trips [Mamdoohi et al. 2018; Fallah Zavareh et al. 2023; Mehdizadeh et al. 2017]. Therefore, the travel behavior of students changes with age. Studies in the field of student travel have shown that students exhibit differences in social composition and travel behavior compared to the general population [Khattak et al. 2011]. Hence, the reason for the reduction in the number of walk trips with the entry of students into university can be attributed to the change in their travel behavior.

Table 3. Results of sensitivity analysis of the models

Model	Independent variable	Dependent variable	Elasticity
level-level Model 1	Production of home-based walk trips	Resident population in the area	0.63
		The ratio of green space land-use area to the total land-use area	1215.26
		The number of students in the area	0.337
		The per capita ownership of cars by residents in the area	-633.866
		The number of university students in the area	-0.295
		Green spaces access	4.456
		Employment	0.042
		HHI (The proportion of different land use types in an area)	-162.6
		Commercial access	107
		Green spaces access	0.7
log-level Model 2	Production of non-home-based walk trips	The per capita car ownership of residents in the neighborhood	158.7
		Land use for recreational, religious, cultural, tourism, and sports purposes	-4.6
		Dummy variable of the industrial town	-189.7
		The number of clinics	17
		Dummy variable for the presence of a hospital in the neighborhood	30
		Dummy variable Namazi Shiraz Hospital	-147.1

Car ownership is one of the economic variables that is negatively associated with walk trips in the home-based model and positively

associated with the non-home-based model. The results regarding the negative effect of car ownership on the number of home-based walk

trips are consistent with numerous previous studies [Tian and Ewing, 2017] and [Ahmadipour et al. 2021], [Mitra, 2013; Guan,2020; Kaplan et al, 2016]. The results of one research indicate that households without car ownership have a higher likelihood of walking or cycling [RSG and The RAND Corporation 2019]. In another research that focused on Tehran city as a case study, the modeling results showed that the likelihood of walking decreases when both the residence in a house with an area larger than 100 square meters and car ownership are present simultaneously. This is because these two variables are used as indicators of the individual's economic status [Ahmadipour et al. 2021]. The findings of another research also indicate that the number of walking trips for households without car ownership is approximately 3.5 times higher than for households with at least one car [Tian and Ewing, 2017]. It is worth noting that in these studies, the production of walking trips was not differentiated between home-based and non-home-based trips. However, in the present research, the results indicate that a 1% decrease in car ownership per capita among residents of PAZ leads to a 7-fold increase in the production of walk trips originating from home. Similarly, a 0.1 increase in car ownership per capita in the PAZ results in a 15.8% increase in the production of non-home-based walk trips. It can be concluded that an increase in car ownership per capita will reduce walk trips from home and increase non-home-based walk trips. In other words, car owners choose other locations and places for walking besides their home surroundings.

Furthermore, another notable result from the model in this research is the positive effect of residents' employment on the production of non-home-based walking trips. Specifically, an increase of one unit in residents' employment leads to approximately a 0.4% increase in the production of non-home-based walking trips. Similar findings regarding the positive impact

of employment on walking trips have also been reported in [Huang et al. 2019]. However, in [Macioszek et al. 2022], the effect of employment on the likelihood of choosing walking mode for mandatory trips was observed to be negative. In this research, the inflexibility of work trip start times and individuals' reluctance to choose walking as their mode of transportation were identified as contributing factors to this finding.

Among the variables related to land use, a 1% increase in the ratio of green space to total land use area causes a 13-fold increase and a 1% increase in access to green space results in a 4.4% increase in walk home-based travel. The high value of the coefficient for the share of green space in the total land use of a PAZ can indicate a deficiency in the provision of green spaces in many PAZs of Shiraz. Further investigations in the database reveal that in numerous PAZs of the city, a significant portion of the land use is allocated to residential or less attractive land use types, resulting in a negligible share of green spaces, often reaching zero percent in these areas. This factor plays a considerable role in reducing the production of walk trips. On the other hand, it should be noted that allocating an excessive share of a PAZ's land use to green spaces also leads to a reduction in walk trips. In such areas, land use types that produce walk trips constitute only a small portion of the total land area, consequently resulting in a substantial decline in walk trip production in those PAZs, and for every unit increase in access to green space, non-home-based walk travel will increase by 0.70%. In fact, it can be concluded that green space significantly contributes to the pedestrian-oriented. Indeed, in some previous studies, a positive correlation has been found between walk trips and green spaces [Oliver et al. 2011],[S. Zhang et al. 2023] and [García De Jalón et al. 2021]. In some other studies, a positive relationship between walk trips and access to green spaces has been observed [Sugiyama et al. 2010]. It is important to note

that in these studies, the proximity or accessibility to green spaces is commonly measured using Euclidean distance or network distance [X. Zhang et al. 2020]. However, in the current research, accessibility is defined based on travel time and the area of green space land use.

Another noteworthy point is that for every unit increase in commercial access in an area, non-home-based walk travel will double. Similar results regarding the positive effect of commercial land use on walk trips have also been found in previous studies [Seong et al. 2021].

However, if recreational, religious, cultural, or sports land use increases by one hectare, non-home-based walk travel will decrease by about 5%. The reason for this reduction could be that these types of land use types attract non-home-based trips rather than generating them. Based on the obtained results, it is suggested to focus on modeling destination choice for discretionary trips in future research and investigate the reasons for this behavioral change.

The HHI index is another variable related to land use that is significant in the model of non-home-based walk travel. If the HHI index increases by 0.01 unit or in other words, land use diversity decreases by 0.01 unit, non-home-based walk travel will decrease by approximately 1.6%. Land use mix is one of the influential variables and is considered a significant factor in walk travel behavior. Previous studies have also shown a positive effect of different land use mixes on generating walk trips [Hatamzadeh et al. 2020] and [Wang and Wen, 2017]. A suitable mix of land use types plays a significant role in increasing recreational walk trips as well as daily walk trips [Sallis et al. 2012].

Another notable point is the effect of hospitals and medical centers on walk trips. The number of clinics in a neighborhood and the dummy variable of the presence of a hospital have a positive effect on generating non-home-based

walk trips. Specifically, for each additional clinic in the neighborhood, the production of non-home-based walk trips increases by approximately 17 percent. It should be noted that most visitors to hospitals are individuals accompanying patients, and this cultural characteristic may be less prevalent in other communities. It appears that the visiting hours for patients in hospitals could be a significant factor in the model of generating non-home-based walk trips. Typically, the visiting hours in most hospitals are between 2 PM and 4 PM in Shiraz, during which people usually travel from non-home origins (such as workplaces or educational institutions) to the hospitals.

On the other hand, the presence of Namazi Hospital has a negative effect on producing non-home-based walk trips. This could be attributed to the significant allocation of space in the neighborhood to the Namazi hospital and the availability of all related services within that area. Similarly, the dummy variable of the existence of an industrial town also has a negative effect on producing non-home-based walk trips. The industrial town occupies a considerable area, and other trip-attracting and trip-producing land use types in this area have a negligible share. Consequently, this situation leads to a reduction in the creation of walk trips in this PAZ.

7. Conclusions and Suggestions

In recent years, the concept of sustainable transportation has been pursued, and walk travel modeling has always faced challenges such as predicting the number of walk trips, identifying influential variables, and measuring their impact. In most studies, travel production models have been developed separately for different trip purposes and not for different travel modes.

On the other hand, in some studies, walk travel modeling has used similar variables to those used in modeling other travel modes. However, in this research, with an approach to improving the transportation planning process, the walk

travel production model has been developed separately from other travel modes, utilizing variables that affect walk demand such as land use. The approach used and the variables considered in the modeling, as well as addressing the challenge of zero walk trips in many areas, are considered innovations of this research. These models have the capability to forecast forthcoming walking trips and can be applied to assessing how urban design proposals influence pedestrian behavior.

In this paper, considering Shiraz City as a case study and developing a linear regression model, walk trips have been modeled separately for home-based and non-home-based trips.

The modeling results indicate that land use variables, accessibility to land use types, and socio-economic variables have an impact on both home-based and non-home-based walk trips. Among these variables, the land use diversity index, access to green spaces, and car ownership are notable. The car ownership per capita variable has a negative and significant effect on home-based walk trips, while it has a positive and significant effect on non-home-based walk trips. This indicates that with an increase in car ownership per capita, the number of home-based walk trips decreases while the number of non-home-based walk trips increases. The significance of the green space land use variable in the home-based walk trip model shows that in many PAZs of Shiraz, there is a high density of residential land use and a scarcity of green spaces. This negatively affects walk trip production to a considerable extent.

The combination of land use types, the number of clinics in the area, and the dummy variable of the presence of a hospital have a positive effect on non-home-based walk travel. On the other hand, the presence of a Namazi hospital and an industrial town, due to their large area allocation, have a negative impact on these trips.

The ratio of walk trips produced in the PAZs shows that the density of walk trips produced in the central business center is higher than in

suburban areas, and in the southern parts of the city. In addition, the density of home-based walk trips produced is higher than the density of non-home-based walk trips produced.

It is recommended for future research to model walk trip production by travel purpose in order to identify the influencing factors more accurately. In this paper, the HHI index, which indicates the diversity of land use types in the area, is found to be significant. It should be noted that the combination of certain land use types (such as storage, industrial, and abandoned areas) might have a negative impact on non-home-based walk trip production, while the combination of others (such as green spaces, commercial, and residential areas) may have a positive impact. Therefore, it is suggested that other forms of land use combination indicators be evaluated in future research to identify the effects of land use combinations on walk trip production.

8. References

- Aghidi Kheyraadi, Salman., Ghaemi, Seyed Ali., and Askari, Sajad. (2019). "Updating Study of the Comprehensive Transportation Planning for Shiraz City, Summary of the Management Report on Comprehensive Transportation and Traffic Studies."
- Aghidi Kheyraadi, Salman., and Mamdoohi, Amir Reza. (2024). "The Influence of Origin Attributes on the Destination Choice of Discretionary Home-Based Walk Trips." *ISPRS International Journal of Geo-Information* 13 (7): 218. <https://doi.org/10.3390/ijgi13070218>.
- Ahmadipour, Fatemeh., Mamdoohi, Amir Reza., and Wulf-Holger, Arndt. (2021). "Impact of Built Environment on Walking in the Case of Tehran, Iran." *Journal of Transport & Health* 22 (September): 101083. <https://doi.org/10.1016/j.jth.2021.101083>.

- Asadamraji, Morteza., Ross, Veerle., and Yarahmadi, Ali. (2022). “A Novel Hazard Avoidance Model Based on Young Drivers’ Characteristics: A Driving Simulator Study.” *Applied Neuropsychology: Adult*, August, 1–11.
<https://doi.org/10.1080/23279095.2022.2112959>.
- Askari, Sajad., Banani Ardakani, F., & Yousefi, M. (2020). “Travel Generation and Attraction Models Report - Upgrading Comprehensive Studies of Urban Transportation and Traffic in Shiraz.” Transportation and Traffic Research Center, Shiraz University.
- Blanchette, Sébastien., Lemoyne, Jean., Rivard, Marie-Claude., and Trudeau, François. (2019). “Municipal Officials’ Propensity toward Active Transportation: A Rural-Urban Comparison.” *Journal of Transport & Health* 12 (March): 349–58.
<https://doi.org/10.1016/j.jth.2018.12.005>.
- Eriksson, Ulf., Arvidsson, Daniel., Gebel, Klaus., Ohlsson, Henrik., and Sundquist, Kristina. (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.
<https://doi.org/10.1186/1479-5868-9-123>.
- Fallah Zavareh, Mohsen., Barati, Mehdi., Mamdoohi, AmirReza., and Abraham, Michael. (2023). “The Role of Walkability, Socio-Economic and Parental Cognitive Characteristics in Long Walking Journeys to School.” *Transportation Research Record: Journal of the Transportation Research Board* 2677 (1): 1473–89.
<https://doi.org/10.1177/03611981221104805>.
- García De Jalón, Silvestre., Chiabai, Aline., Quiroga, Sonia., Suárez, Cristina., Ščasný, Milan., Máca, Vojtěch., Zvěřinová, Iva., Marques, Sibila., Craveiro, Daniela., and Taylor, Timothy. (2021). “The Influence of Urban Greenspaces on People’s Physical Activity: A Population-Based Study in Spain.” *Landscape and Urban Planning* 215 (November): 104229.
<https://doi.org/10.1016/j.landurbplan.2021.104229>.
- Guan, Xiaodong. (2020). “The Links among the Built Environment, Travel Attitudes, and Travel Behavior: A Household-Based Perspective.”
- Hatamzadeh, Yaser., Habibian, Meeghat., and Khodaii, Ali. (2020). “Walking Mode Choice across Genders for Purposes of Work and Shopping: A Case Study of an Iranian City.” *International Journal of Sustainable Transportation* 14 (5): 389–402.
<https://doi.org/10.1080/15568318.2019.1570404>.
- Hosseinlou, Mansour Hadji., Kheyraadi, Salman Aghidi., and Zolfaghari, Abbas. (2015). “Determining Optimal Speed Limits in Traffic Networks.” *IATSS Research* 39 (1): 36–41.
<https://doi.org/10.1016/j.iatssr.2014.08.003>.
- Huang, Ruizhu., Moudon, Anne V., Zhou, Chuan., and Saelens, Brian E. (2019). “Higher Residential and Employment Densities Are Associated with More Objectively Measured Walking in the Home Neighborhood.” *Journal of Transport & Health* 12 (March): 142–51.
<https://doi.org/10.1016/j.jth.2018.12.002>.
- Jahaniaghdam, Tannaz., Mamdoohi, Amir Reza., Kheyraadi, Salman Aghidi., Mehryar, Mehdi., and Ciari, Francesco. (2023). “Preferences for Alternative Fuel Trucks among International Transport Companies.”

Enhancing Pedestrian Trips in Urban Areas: A Macro-Level Approach (Case Study: Shiraz City)

World 4 (4): 795–815.
<https://doi.org/10.3390/world4040050>.

– Jaideep Mukherjee and B. Raghuram Kadali. (2022). “A Comprehensive Review of Trip Generation Models Based on Land Use Characteristics.” *Transportation Research Part D: Transport and Environment* 109 (August): 103340.
<https://doi.org/10.1016/j.trd.2022.103340>.

– Jerry Don Everett. (2009). “An Investigation of the Transferability of Trip Generation Models and the Utilization of a Spatial Context Variable.” University of Tennessee - Knoxville.

– Kaplan, Sigal., Nielsen, Thomas Alexander Sick., and Prato, Carlo Giacomo. (2016). “Walking, Cycling and the Urban Form: A Heckman Selection Model of Active Travel Mode and Distance by Young Adolescents.” *Transportation Research Part D: Transport and Environment* 44 (May): 55–65.
<https://doi.org/10.1016/j.trd.2016.02.011>.

– Khan, Mobashwir., M. Kockelman, Kara., and Xiong, Xiaoxia. (2014). “Models for Anticipating Non-Motorized Travel Choices, and the Role of the Built Environment.” *Transport Policy* 35 (September): 117–26.
<https://doi.org/10.1016/j.tranpol.2014.05.008>.

– Khattak, Asad., Wang, Xin., Son, Sanghoon., and Agnello, Paul. (2011). “Travel by University Students in Virginia: Is This Travel Different from Travel by the General Population?” *Transportation Research Record: Journal of the Transportation Research Board* 2255 (1): 137–45.
<https://doi.org/10.3141/2255-15>.

– KhorramDehnavi, Sedigheh., MorovatiSharifabadi, Ali., AghidiKheyrabadi, Salman., and HosseiniBamakan, Seyed Mojtaba. (2024). “Evaluating Private Car

Users’ Preference to Congestion Pricing: A Study on Trip Cancellation Behavior.” *Case Studies on Transport Policy* 18 (December): 101300.
<https://doi.org/10.1016/j.cstp.2024.101300>.

– Kuzmyak. (2014). “National Cooperative Highway Research Program.” *Transportation Research Board, National Academies of Sciences, Engineering, and Medicine*.

– Kuzmyak, J. Richard., Walters, Jerry., Bradley, Mark., Kockelman, Kara M., National Cooperative Highway Research Program., Transportation Research Board., and National Academies of Sciences, Engineering, and Medicine. (2014). *Estimating Bicycling and Walking for Planning and Project Development: A Guidebook*. NCHRP Report 770. Washington, D.C.: Transportation Research Board.
<https://www.nap.edu/catalog/22330>.

– Macioszek, Elżbieta., Karami, Ali., Farzin, Iman., Abbasi, Mohammadhossein., Mamdoohi, Amir Reza., and Piccioni, Cristiana. (2022). “The Effect of Distance Intervals on Walking Likelihood in Different Trip Purposes.” *Sustainability* 14 (6): 3406.
<https://doi.org/10.3390/su14063406>.

– Mamdoohi, Amir Reza., Saffarzadeh, Mahmoud., Aghidi Kheyrabadi, Salman., Ahmadipour, Fatemeh., Sefidgari, Maedeh., Shami, Sepideh., Pirouzniam, Ali., et al. (2022). “Modeling Pedestrian Trips in Comprehensive Studies of Transportation and Traffic in Shiraz Metropolis, Report of Results Analysis and Modeling.” Tarbiat Modares University.

– Mashaghzadefard, S. (2000). “Transferability of Travel Demand Models.” Sharif University of Technology.

- Mehdizadeh, Milad., Nordfjaern, Trond., Mamdoohi, Amir Reza., and Shariat Mohaymany, Afshin. (2017). “The Role of Parental Risk Judgements, Transport Safety Attitudes, Transport Priorities and Accident Experiences on Pupils’ Walking to School.” *Accident Analysis & Prevention* 102 (May): 60–71.
<https://doi.org/10.1016/j.aap.2017.02.020>.
- Mehdizadeh, Milad., Nordfjaern, Trond., and Mamdoohi, AmirReza. (2018). “The Role of Socio-Economic, Built Environment and Psychological Factors in Parental Mode Choice for Their Children in an Iranian Setting.” *Transportation* 45 (2): 523–43.
<https://doi.org/10.1007/s11116-016-9737-z>.
- Mitra, Raktim. (2013). “Independent Mobility and Mode Choice for School Transportation: A Review and Framework for Future Research.” *Transport Reviews* 33 (1): 21–43.
<https://doi.org/10.1080/01441647.2012.743490>.
- Obeng-Atuah, Daniel., Poku-Boansi, Michael., and Cobbinah, Patrick Brandful. (2017). “Pedestrian Crossing in Urban Ghana: Safety Implications.” *Walking and Walkability: A Review of the Evidence on Health* 5 (June): 55–69.
<https://doi.org/10.1016/j.jth.2016.06.007>.
- Oliver, Lisa., Schuurman, Nadine., Hall, Alexander., and Hayes, Michael. (2011). “Assessing the Influence of the Built Environment on Physical Activity for Utility and Recreation in Suburban Metro Vancouver.” *BMC Public Health* 11 (1): 959.
<https://doi.org/10.1186/1471-2458-11-959>.
- RSG and The RAND Corporation. (2019). “Evaluation of Walk and Bicycle Demand Modeling Practice.” NCHRP 08-36, Task 141.
- The National Academies of Sciences, Engineering, and Medicine.
- Saelens, Brian E., and Handy, Susan L. (2008). “Built Environment Correlates of Walking: A Review.” *Medicine & Science in Sports & Exercise* 40 (7): S550–66.
<https://doi.org/10.1249/MSS.0b013e31817c67a4>.
- Sallis, James F., Floyd, Myron F., Rodríguez, Daniel A., and Saelens, Brian E. (2012). “Role of Built Environments in Physical Activity, Obesity, and Cardiovascular Disease.” *Circulation* 125 (5): 729–37.
<https://doi.org/10.1161/CIRCULATIONAHA.110.969022>.
- Saxena, Aditya., and Yadav, Ankit. (2022). “Clustering Pedestrians’ Perceptions towards Road Infrastructure and Traffic Characteristics.” *International Journal of Injury Control and Safety Promotion* 30 (August): 1–11.
<https://doi.org/10.1080/17457300.2022.2112234>.
- Seong, Eun Yeong., Lee, Nam Hwi., and Choi, Chang Gyu. (2021). “Relationship between Land Use Mix and Walking Choice in High-Density Cities: A Review of Walking in Seoul, South Korea.” *Sustainability* 13 (2): 810.
<https://doi.org/10.3390/su13020810>.
- Sugiyama, Takemi., Francis, Jacinta., Middleton, Nicholas J., Owen, Neville., and Giles-Corti, Billie. (2010). “Associations Between Recreational Walking and Attractiveness, Size, and Proximity of Neighborhood Open Spaces.” *American Journal of Public Health* 100 (9): 1752–57.
<https://doi.org/10.2105/AJPH.2009.182006>.
- Tian, Guang., and Ewing, Reid. (2017). “A Walk Trip Generation Model for Portland, OR.”

Enhancing Pedestrian Trips in Urban Areas: A Macro-Level Approach (Case Study: Shiraz City)

Transportation Research Part D: Transport and Environment 52: 340–53.

– Wang, Luqi., and Wen, Chen. (2017). “The Relationship between the Neighborhood Built Environment and Active Transportation among Adults: A Systematic Literature Review.” *Urban Science* 1 (3): 29. <https://doi.org/10.3390/urbansci1030029>.

– World Health Organization (WHO). (2023). “Pedestrian Safety: A Road Safety Manual for Decision-Makers and Practitioners Second Edition.”

– Zhang, Surong., Li, Jingwen., Wang, Lan., Kwan, Mei-Po., Chai, Yanwei., Du, Yirui., Zhou, Kaichen., Gu, Hao., and Sun, Wenyao. (2023). “Examining the Association between the Built Environment and Active Travel Using GPS Data: A Study of a Large Residential Area (Daju) in Shanghai.” *Health & Place* 79 (January): 102971. <https://doi.org/10.1016/j.healthplace.2023.102971>.

– Zhang, Xiaohu., Melbourne, Scott., Sarkar, Chinmoy., Chiaradia, Alain., and Webster, Chris. (2020). “Effects of Green Space on Walking: Does Size, Shape and Density Matter?” *Urban Studies* 57 (16): 3402–20. <https://doi.org/10.1177/0042098020902739>.