IJTE, Vol. 11, No. 1, Summer 2023, pp. 1267-1283

Research Paper

Analysis of Pedestrian Access on Transit-Oriented Development (Case Study: District 6 of Tehran)

Shokoufeh Rasoulzdeh Sheikh[1], Farshidreza Haghighi [2,*], Mohammad Azmoodeh[3]

Received: 2019/05/06 *Accepted: 2023/06/11*

Abstract

Transit-Oriented Development (TOD) is considered one of the most comprehensive urban theories concerning land use and transportation. Improving pedestrian access and urban public transport is a key objective of TOD, leading to an enhanced level of TOD within a given zone.

This study aims to examine the impact of pedestrian access on public transportation, particularly through access to transit stations. A range of indicators related to pedestrian access to public transportation, such as the service area of public transportation, number of transport stations, speed, parking availability, commercial density, residential density, public spaces, walking distance, connectivity, transport modes, slope, and population density, were collected for this purpose. The quantitative values for these indicators were subsequently computed for District 6 of Tehran (selected as a case study) utilizing ArcGIS. The aim was to determine the correlation between these indicators and the percentage of trips made using public transportation within the zone, serving as a functional criterion for assessing the level of TOD in the area. Subsequently, a model for pedestrian access modes to public transit in different zones was developed using the multi-layered perceptron neural network (MLP) technique.

Based on the results, the network output with R=0.9517 and MSE=4.8881 indicated the satisfactory performance of the model. Furthermore, the sensitivity analysis results revealed the highest impact to be associated with parking, while the lowest impact was attributed to public spaces.

Keywords: Pedestrian access, urban planning and transportation, neural network, geographic information system, TOD

---

[*] Corresponding author. E-mail: Haghighi@nit.ac.ir

[1] Department of Road and Transportation Engineering, Faculty of Civil Engineering, Babol Noshirvani University of Technology, Babol, Iran

[2] Department of Road and Transportation Engineering, Faculty of Civil Engineering, Babol Noshirvani University of Technology, Babol, Iran

[3] Department of Road and Transportation Engineering, Faculty of Civil Engineering, Babol Noshirvani University of Technology, Babol, Iran

1. Introduction

Urban transit planning aims to reduce car usage and promote the development of public transit infrastructure. For this reason, governments and organizations have directed their policies towards redesigning urban development in more compact models that incorporate mixed-use elements and prioritize the increase of public transport, pedestrian-friendly spaces, and cycling infrastructure alongside road traffic. [Cervero and Day, 2008; Mu and de Jong, 2012, Mirzahossein et al.2020]. As part of these policies, Transit-Oriented Development (TOD) is a concept that emphasizes the integrated development of transit systems and land use, with a particular focus on the development of land in proximity to public transit stations. [Loo et al.2010]. This type of development will be implemented through the creation of an integrated model that combines land use patterns and transport planning, with the aim of increasing the utilization of public transit.

Combined with high-density, mixed-use developments that incorporate both residential and non-residential areas in proximity to public transportation or surrounding areas, TOD is an urban development approach that aims to decrease car usage while promoting increased utilization of public transportation, walking, and cycling. [Padeiro et al.2019; Stojanovski, 2020]. This approach results in reducing the impacts of car travel, such as air pollution, noise, and resource depletion. [Hasibuana et al.2014, Ming Wey.2015; Yildirim et al.2020]. Calthorpe, one of the early proponents of this development approach, defined Transit-Oriented Development (TOD) as a community with a mix of land uses, located within an average walking distance of 2000 feet from a transit stop and the central commercial area. TODs integrate residential, retail, office, open space, and public amenities in a pedestrian-friendly environment, providing convenience for residents and employees to travel by transit, bicycle, walking, or car. [Calthorpe, 1993]. This theory has evolved since its initial definition by Calthorpe up to the present. However, it still remains rooted in its fundamental principles, which involve dense and mixed development around public transportation stations or commercial cores, aiming to achieve objectives such as promoting walking and cycling and encouraging the use of public transportation.

[Calthorpe, 1993; ITDP, 2017].

Studies have been conducted to measure TOD levels around public transportation stations. [Singh et al., 2014, Singh et al., 2017, Teklemariam and Shen, 2020]. These studies utilized suitable parameters to measure TOD but employed multi-criteria decision-making methods, which rely on people's decisions rather than directly measuring the performance of TOD.

Walking is one of the objectives of TOD. pedestrian access conditions affect people's use of public transit. So, TOD success is dependent on the capacity of pedestrians to move and access to land use near the transit stations. Hence, the higher level of pedestrian access in the area can be expected and the TOD level of the region will be more favorable. Several studies have been done to evaluate the conditions of pedestrian access [Mavoa et al. 2012, Daniels and Mulley, 2013, Garcia-Palomurse et al.2013, Peiravian et al. 2014, Talavera-Garcia and Soria-Lara, 2015]. In these studies, practical values were not used for modeling purposes.

In this study, a method is presented that utilizes the use of public transit to assess pedestrian access conditions and determine the level of Transit-Oriented Development (TOD) in the areas. Increasing the share of public transport is recognized as one of the objectives of Transit-Oriented Development (TOD). In our model, we utilize this share as a measure of pedestrian access. Importantly, our model is not solely based on people's decisions. The key novelty of this study lies in the use of functional criteria to assess pedestrian access, which represents a significant advancement in TOD research. For this purpose, a set of effective indicators has been collected in the TOD theory, categorized into four criteria: transit, diversity, design, and density.

A pedestrian access model is developed in this study using a GIS-based method and the artificial MLP (Multi-Layer Perceptron) technique. The study aims to examine the relationship between access conditions and the share of public transport trips in a metropolitan area, with District 6 of Tehran serving as a case study. Furthermore, the impact of the access factor on improving the level of public transportation, specifically through the pedestrian mode, will also be investigated.

Section 2 provides a review of previous studies focusing on pedestrian access and TOD assessment around transit stations. The methodology employed in this study, along with the definition of the parameters used, is presented in Section 3. Section 4 introduces the study area and outlines its scope. In Section 5, the model's effectiveness is evaluated through a case study conducted in District 6 of Tehran. This section also highlights the key findings of the study. Finally, Section 6 concludes the paper.

2. Literature Review

Various studies have been conducted on pedestrian access and the assessment of TOD levels, which are discussed as follows.

Mavoa et al. (2012) investigated the correlation between public transit access and pedestrian access, and evaluated their integration by proposing two models for measuring public transit access. The first model, known as the Public Transit and Walking Accessibility Index (PTWAI), quantifies the potential for accessing destinations through public transit and walking by considering travel time and standard waiting time at each transit stop. The second model, referred to as transit frequency, measures the average number of unique public transit trips passing through each transit stop [Mavoa et al., 2012]. In another study focusing on walking distance, Daniels and Mulley (2013) examined the potential factors influencing the distance people walk from their homes to public transportation. According to their findings, individuals in Sydney tend to walk greater distances to train stations compared to bus stops. Demographic characteristics such as age, gender, income, labor status, as well as trip characteristics including trip purpose, time of day and week, fare and ticket, and trip duration were found to be insignificant in explaining the variations in walking distance to different public transport modes. The authors emphasized that the chosen public transport mode was the most influential factor in determining walking distance, highlighting the variations in supply and spacing among the different modes [Daniels and Mulley, 2013]. In another study, Garcia-Palomurse et al. (2013) conducted an assessment of the pedestrian access quality to the transit station in Madrid. Through the utilization of microdata and GIS analysis, the walking distance was computed for various demographic groups to the metro station, resulting in an average walking distance from home to the station of 420.5 meters. Additionally, an index was introduced to evaluate the pedestrian access quality to a transit station, considering the ratio of public transit passengers to the local residents in the Madrid region [Garcia-Palomurse et al., 2013].

Peiravian (2014) introduced a model for assessing pedestrian access quality in Chicago. The model, known as the Pedestrian Environment Index (PEI), utilized four indicators: land use diversity, population density, commercial density, and intersection density. The study area was evaluated for each of these indicators, and the overall pedestrian access quality was examined based on the PEI [Peiravian et al., 2014].

Talavera-Garcia and Soria-Lara (2015) proposed a model for the Quality of Pedestrian Level of Service in Spain. They reviewed 61 articles and extracted factors related to pedestrian environmental characteristics and access to public transit stations. These factors included pavement width, distance to destination, pavement type, slope, connectivity, lighting, traffic speed, traffic volume, trees, cleanliness, public space, furniture, shops, public transport stops, parking lots, and more. The factors were categorized into four groups: accessibility, safety, comfort, and attractiveness, based on walking requirements. A survey was conducted in Granada to assess the importance of each parameter based on pedestrian feedback [Talavera-Garcia and Soria-Lara, 2015].

Singh et al. (2014) investigated the levels of Transit-Oriented Development (TOD) in the Netherlands, specifically in the urban areas of Arnhem and Nijmegen. Four criteria were used for evaluation: density, land use diversity, mixed use, and economic development. The study identified areas with high TOD levels but poor transit connectivity, suggesting the need for improved transit connectivity [Singh et al., 2014]. In a subsequent study in 2017, Singh et al. developed a model based on the TOD Index within a walkable distance of a transit node. They described eight TOD principles related to urban development and transit, and identified eight criteria for evaluation: density, land use diversity, walkability and cyclability, economic development, capacity utilization of transit, user-friendliness of the transit system, access and accessibility, and parking at the station. The study evaluated 21 train stations in Arnhem and Nijmegen within an 800-meter radius (10-minute walking distance) using. Multiple Criteria Analysis (MCA)[1]. The indicators were standardized, and their weights were calculated using the MCA method. The results showed that economic development, capacity utilization of transit, density, access and accessibility, user-friendliness of the transit system, parking at the station, walkability and cyclability, and land use diversity had the greatest influence on the TOD level of the area [Singh et al., 2017].

The study conducted by Teklemariam and Shen in Addis Ababa, Ethiopia, focused on measuring the current level of Transit-Oriented Development (TOD) in the area. The researchers defined several indicators within the walkable distance of Light Rail Transit (LRT) stations to quantitatively measure TOD. These indicators included Density, Diversity, Distance Accessibility, Distance to Transit, and Design. The study evaluated these indices for 22 stations along the Addis Ababa East-West LRT line. Based on the TOD indicator values, the development potential of the stations was assessed, highlighting the areas that require attention [Teklemariam and Shen, 2020].

In this section, the study examines both the level of Transit-Oriented Development (TOD) in the area and the models of pedestrian access to public transit. However, most of the evaluation methods used in previous studies rely on individual opinions. For instance, Peiravian et al. did not provide a method to determine the importance of indicators and considered the importance of each of the four indexes equally. On the other hand, some other studies, such as Singh et al., used Multiple-criteria decision analysis methods to determine the importance of parameters. Nevertheless, previous studies lack a model based on functional value. For this reason, in this study, we have tried to provide a model based on functional criteria for evaluating pedestrian accessibility in TOD.

3. Methodology

In the initial phase of this study, relevant research was conducted to identify and measure the factors that influence pedestrian access to public transit. Following that, GIS maps were prepared for the study area to facilitate the required analyses and quantify these factors.

---

[1] MCA is a unique method that allows for a comprehensive assessment of multiple criteria or indicators with different units of measurement.

Assuming that individuals who utilize public transit in the area typically walk to the transit stations, the percentage of public transit usage during peak hours is used as a measure of pedestrian access in the modeling process. By incorporating the obtained data from the parameters and the share of public transportation usage in the area, a pedestrian access model for public transit was developed using a multilayer perceptron neural network.

3.1. First Step: Identification of Criteria and Indicators

Transit-Oriented Development (TOD) is based on four criteria: transit, density, diversity, and design [Cervero, 1997; Bertolini and Spit, 2005; Dittmar and Ohland, 2012]. In accordance with the literature, relevant indicators were identified to align with the walking requirements within these four criteria. Table 1 provides a summary of these indicators.

Table 1. Description of Variables

Criteria	indicators	Literature source
Transit	Transit service coverage	Motieyan & Saadi Mesgari (2018)
	number of stations	ITDP (2017), Motieyan & Saadi Mesgari (2018)
	speed	Talavera-Garcia & Soria-Lara (2015)
	parking	Lyu et al. (2016), ITDP (2017), Azmoodeh & Haghighi (2017)
Density	commercial density	Sung &Oh (2011), Peiravian et al. (2014), Lyu et al. (2016), Motieyan & Saadi Mesgari (2018)
	population density	Peiravian et al. (2014), Motieyan & Saadi Mesgari (2018), Azmoodeh & Haghighi (2017)
Diversity	residential density	Sung &Oh (2011), Nasri & Zhang (2014), Motieyan & Saadi Mesgari (2018)
	public space	Talavera-Garcia & Soria-Lara (2015)
Design	walking distance	Talavera-Garcia & Soria-Lara (2015)
	connectivity	Talavera-Garcia & Soria-Lara (2015), ITDP (2017)
	Transit options	Lyu et al. (2016), ITDP (2017), Motieyan & Saadi Mesgari (2018)
	Slope	Behbahani & Haghighi (2009), Talavera-Garcia & Soria-Lara (2015), Azmoodeh & Haghighi (2017)

According to the Institute for Transportation and Development Policy (ITDP), a 500m walking distance is defined as the maximum distance for accessing certain urban services. To measure the parking indicator, blocks whose geometric center is located within a 500m walking distance from each public parking area were identified. The parking indicator value for these blocks was calculated as the ratio of the parking area to the total area. This method was also employed to measure residential and commercial densities. In addition, the 500m walking distance was used to determine the connectivity indicator, which considers the number of intersections from the center of each block. A coefficient of 0.75 was assigned for a three-way intersection, a coefficient of 1 for a four-way intersection, and a coefficient of 1.25 for a five-way intersection [ITDP, 2017].

ITDP has defined a maximum walking distance of 1,000m or less for rapid transit systems (such as subway, BRT, LRT), and 500m or less for direct service (such as local bus) to transit stations [ITDP, 2017]. The number of stations located within these walking distances from the center of each block was used to determine the number of public transit stations. Furthermore, these walking distances were utilized in the transit service coverage indicator to identify the blocks served by public transit stations and calculate the ratio of transit service coverage area to the block area.

The desirable number of transportation modes for each region was determined based on regional conditions, including pedestrians, buses, and rapid transit systems (such as subway, BRT, and LRT). The count of accessible modes within a 500m walking distance was used to assess transit options.

To measure the public space indicator, the ratio of public space area adjacent to sidewalks to the total sidewalk environment in each block was calculated. Average speed limits adjacent to each block were also considered as speed values. Additionally, the average slope percentage and the number of residents per hectare were utilized to assess slope and population density, respectively. The walking distance from each block to the nearest transit station was also taken into account when calculating these indicators for each block.

3.2. Second Step: Geographic Information System

GIS (Geographic Information System) is a system that enables the generation, processing, analysis, and management of geographic information. In simple terms, GIS is a tool for managing and analyzing geographic data, capable of collecting, storing, analyzing, and visualizing geographic information. It is designed to work with both spatially and descriptively related data, providing a means to store, organize, manage, and analyze geographic information.

The processes involved in GIS can be divided into four main sections [Huisman & Rolf, 2009]:

- Input data: This involves the collection and classification of data.
- Data management: This includes the storage and organization of data, as well as data recycling or updating.
- Data analysis: This involves performing various analyses and integrating different datasets.
- Data output: This includes presenting the results of analyses in the form of tables, graphs, and maps.

In GIS, information is categorized into two main types: descriptive and spatial information.

- Spatial information: Spatial information encompasses the shape, location, and relationships between geographic features depicted on a map. It provides a representation of real-world features using geometric elements.

Spatial information can be stored in two categories:

- vector data

Vector data represents features in the real world using geometric elements such as points, lines, and polygons. Each shape is precisely located by a pair of geographic coordinates (X, Y) in a coordinate system. Vector data is suitable for representing discrete features such as roads, buildings, and boundaries.

- Raster data

Raster data consists of pixelated information, where each pixel is associated with a specific geographical location. Raster data can include satellite imagery, aerial photographs, elevation data, and various cartographic maps. It is commonly used for continuous phenomena, such as terrain elevation, land cover, and vegetation.

Both vector and raster data formats are utilized in GIS to represent and analyze spatial information, providing a comprehensive understanding of geographic features and their relationships.

- Descriptive information

This type of information provides details about the characteristics of spatial features. For instance, descriptive information about cities within a country may include attributes such as area, altitude, population, and more. In this study, both spatial and descriptive information were utilized. Vector data, such as public transport stations, routes, and blocks, were used to represent spatial features. Additionally, descriptive data such as population counts for each block and path speed were incorporated.

Quantitative values for the identified

parameters were obtained for each block using ArcGIS. The necessary data and maps included the network analysis map, public transport stations (bus, subway, BRT, and LRT), pedestrian pathways, slope percentage, land use diversity, public spaces, public parking, pedestrian intersections, and population density in the study area.

3.3. Third Step: Multi-Layered Perceptron Neural Network (MLP)

Artificial neural networks simulate the learning process of the human brain. Neurons play a crucial role in the functioning of a neural network by receiving inputs and generating outputs through nonlinear operations [Godarzi et al., 2014]. Each neuron in the network has its own input and output [Kia, 2011]. Figure 1 illustrates the structure of a single-input neuron, where the variables p and a represent the input and output of the neuron, respectively.

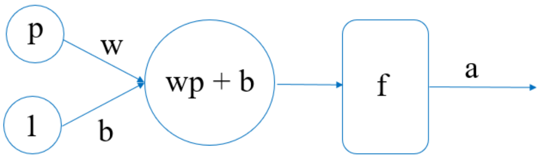

Figure 1. The structure of artificial neurons

The value of wp + b is provided as input to the transfer function f, which determines the value of a as the output according to equation 1.

$$a = f(wp + b) \quad (1)$$

Parameters w and b are adjusted through training algorithms in order to align the output of the neuron with a specific target [Shakiba et al., 2015]. Neural network training can be categorized into two types [Rafiq et al., 2001]:

- supervised learning

In this type of training, the training algorithm has access to both the actual output and the desired output of the network at each training step. Inputs are fed into the network, and the output is compared with the target output. The training process is repeated to minimize the error, and the network parameters (weights) are adjusted to establish a stronger correlation between the network output and the target output.

- unsupervised learning

In this type of training, there is no specific target for the input data. The network parameters (weights) are adjusted to group similar inputs together. Examples of networks that use unsupervised learning algorithms include the Hub, Cohennon, and Hopfield networks.

One of the commonly used neural network architectures is the Multilayer Perceptron (MLP), which is widely utilized in various fields due to its simplicity and effectiveness. The MLP consists of neurons arranged in input, hidden, and output layers (Fig. 2). The number of neurons in the input layer is equal to the number of input data provided to the network. The number of neurons in the output layer is determined by the number of predicted outputs. The number of neurons in the hidden layer, which acts as the data processing unit, is usually determined through trial and error to optimize the network's performance.

The data in a neural network is typically divided into three categories. A portion of the data is used for training the network, during which the network's parameters are adjusted based on the encountered errors. Another portion is reserved as validation data to evaluate the network's generalization capability and determine the appropriate stopping point for training if further improvement is not observed. The test data, however, is not used during the training process and is instead employed as an independent measure of the network's performance both during and after training.

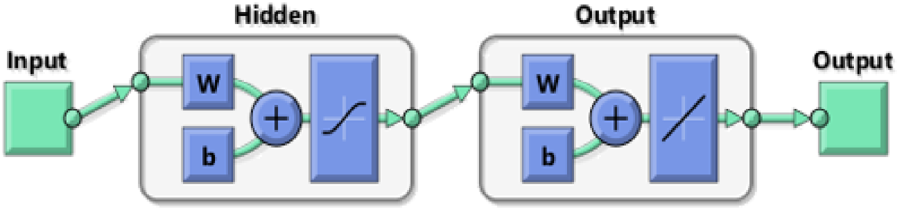

Figure 2. Multi-layer perceptron neural network structure

The MLP artificial neural network model was developed using MATLAB R2017a. The network inputs consist of a matrix with a number of columns equal to the number of indicators and a number of rows equal to the number of blocks. The target matrix includes the share of public transport travel and also has a number of rows equal to the number of blocks. Consequently, the number of input neurons in the network corresponds to the number of indicators, while the output layer has neurons representing the share of travel with each public transit mode. The determination of the number of neurons and hidden layers is based on trial and error, taking into account the network's performance. The commonly used transfer functions for the hidden layer include the sigmoid function, while the linear transfer function is often applied to the output layer, depending on the data types.

Various learning algorithms, such as the Levenberg-Marquardt algorithm, can be utilized during the learning process to enhance the network's performance. After constructing the network, its performance can be evaluated using two methods: the linear correlation coefficient (R) and the mean square error (MSE). These values are calculated according to equations (2) and (3). Ideally, the correlation coefficient (R) should be 1 and the mean square error (MSE) should be 0, indicating a strong correlation between the predicted and actual values of the network [Ashrafian et al., 2018].

$$R = \sqrt{\frac{\sum_{1}^{n}(O - T_{avg})^{2}}{\sum_{1}^{n}(T - T_{avg})^{2}}} \tag{2}$$

$$MSE = \frac{\sum_{1}^{n}(T - O)^{2}}{n} \tag{3}$$

T= Target data

T_{avg} =Average target data

O=network output corresponds to the target data

n= Number of data

4. Case Study

In this study, the data and maps of District 6 in the center of Tehran were utilized. District 6 covers an area of 2137.9 hectares, which accounts for 3% of the total area of Tehran. As of 2016, the district had a population of 251,384 individuals, representing 2.9% of the total population of Tehran [Municipality of District 6 Tehran, 2015]. This district holds significant importance due to the high percentage of administrative, commercial, educational, and cultural activities.

The study area consists of 21 subway stations, 20 BRT (Bus Rapid Transit) stations, and 145 bus stations, providing essential public transportation services to the residents and visitors of District 6.

To assess pedestrian access in the area, the share of travel by public transit during the peak hour in 2017 was used as an indicator. It represents the ratio of trips made using public transit to the total number of trips in District 6. It was assumed that all individuals utilizing public transit would reach the stations on foot.

To facilitate the analysis, District 6 of Tehran was divided into 1231 blocks based on the number of streets in the area.

The share of travel by public transit in the district is received based on larger zones that encompass multiple blocks. Although these zones are not extensive in size, it is assumed that blocks within the same zone have a similar percentage of public transit usage with an acceptable level of error.

Quantitative parameters for the district were calculated using the methodology described, utilizing GIS data and various layers such as public transit stations (bus, subway, BRT), walking paths, public parking, pedestrian intersections, public spaces, and land use. The network analysis method in Arc Map was employed to derive the parameters based on walking distance. Figure 3 illustrates the GIS layers that were used in the data analysis for the zone. On the other hand, Figure 4 presents the calculated values of each parameter for the 1231 blocks within District 6.

The impact of these indicators on public transit usage, serving as a measure of pedestrian access, was then analyzed. The values of the indicators, obtained from ArcGIS, were used as input, while the share of public transit travel was set as the target variable for the MLP neural network. During the modeling process, 70% of the data was randomly selected for training, 15% for testing, and another 15% for validation. The Levenberg-Marquardt algorithm was utilized for the training phase. Additionally, the number of neurons in the hidden layer was adjusted through trial and error to enhance the network's performance for that particular layer.

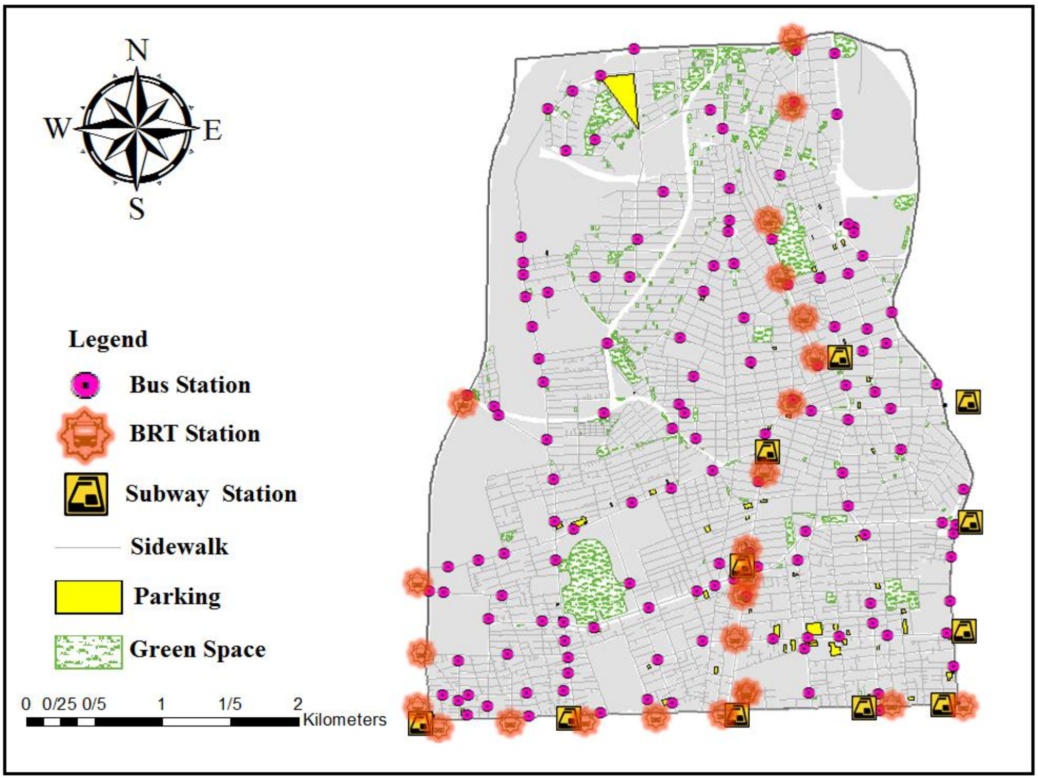

Figure 3. GIS layers of District 6 of Tehran

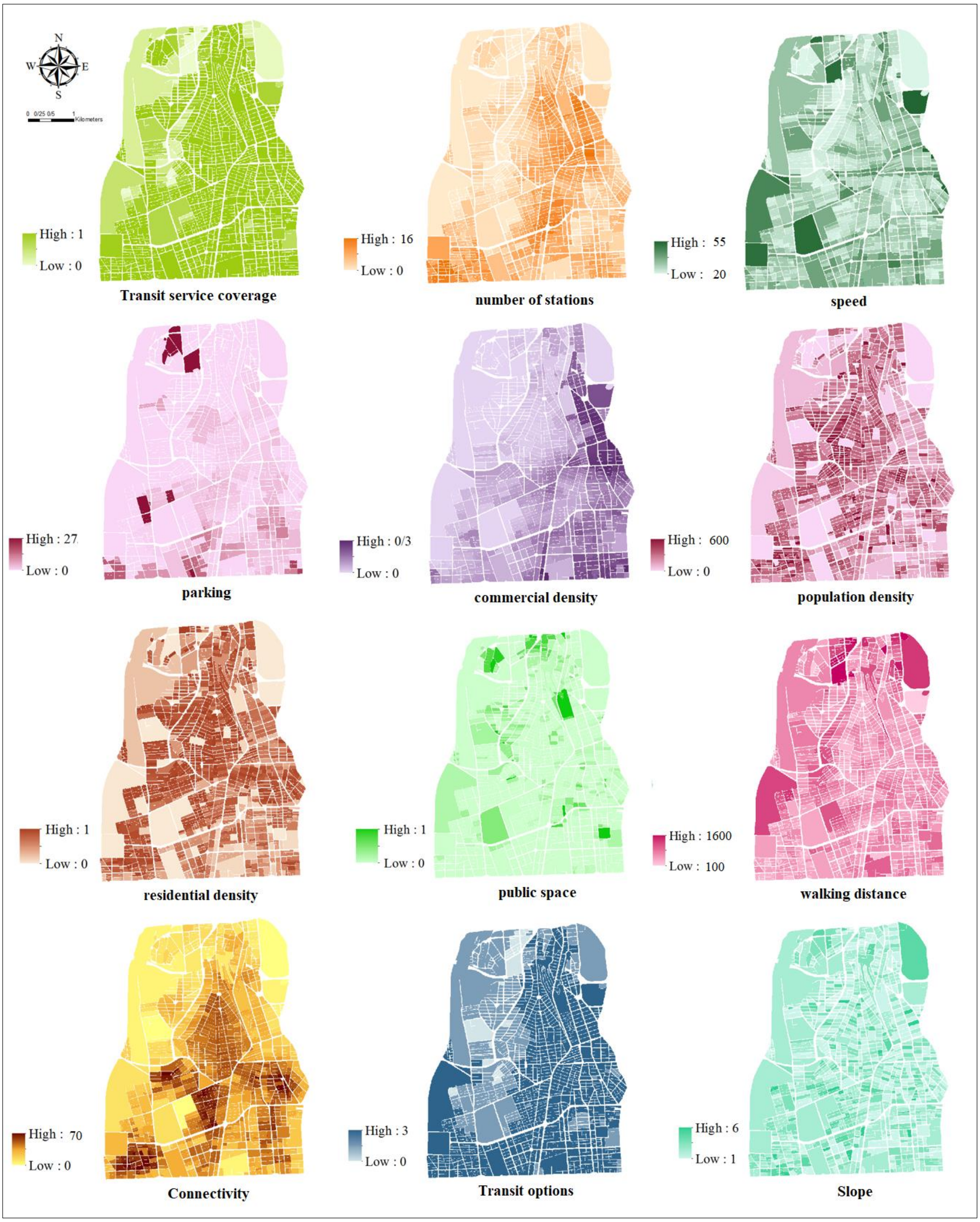

Figure 4. Quantitative values calculated for each parameter

5. Results and Discussion

A range of thirty to six hundred neurons was considered to determine the optimal number of neurons in the hidden layer during network design. Figure 5 illustrates the Mean Square Error (MSE) and R-value for various numbers of neurons evaluated. It can be observed that with 50 neurons, the network achieved the lowest MSE of 4.8881 and the highest R-value of 0.9517. Hence, the optimal number of neurons was determined to be 50.

The performance of the MLP neural network model with 12 inputs, 3 outputs, and 50 neurons in the hidden layer was evaluated using the Leungberg-Marquardt learning algorithm. Figure 6 shows the decreasing trend of mean square error (MSE) for the learning, validation, and test data during each epoch of the training process. The lowest MSE of 6.0691 was observed for the validation data at epoch 30. Additionally, the lowest MSE values of 4.5288 and 6.0957 were obtained for the training and test data, respectively. The overall MSE for the entire dataset was 4.8881. While the MSE for the training data continued to decrease after epoch 30, it remained relatively constant for the testing and validation data.

Figure 7 displays an error histogram for the training, validation, and test data. The horizontal axis represents the difference between the target and the output of the network. A smaller error value closer to zero indicates better performance of the network. As shown in Figure 7, the errors are distributed around zero for all types of data.

Figure 8 illustrates the regression between the network output and its corresponding target. An R-value of 0.93 or higher is considered indicative of a well-performing network in the training, validation, and testing phases. In this case, the R-values in all three phases exceeded 0.93, and the overall R-value was equal to 0.95611, indicating the satisfactory performance of the network.

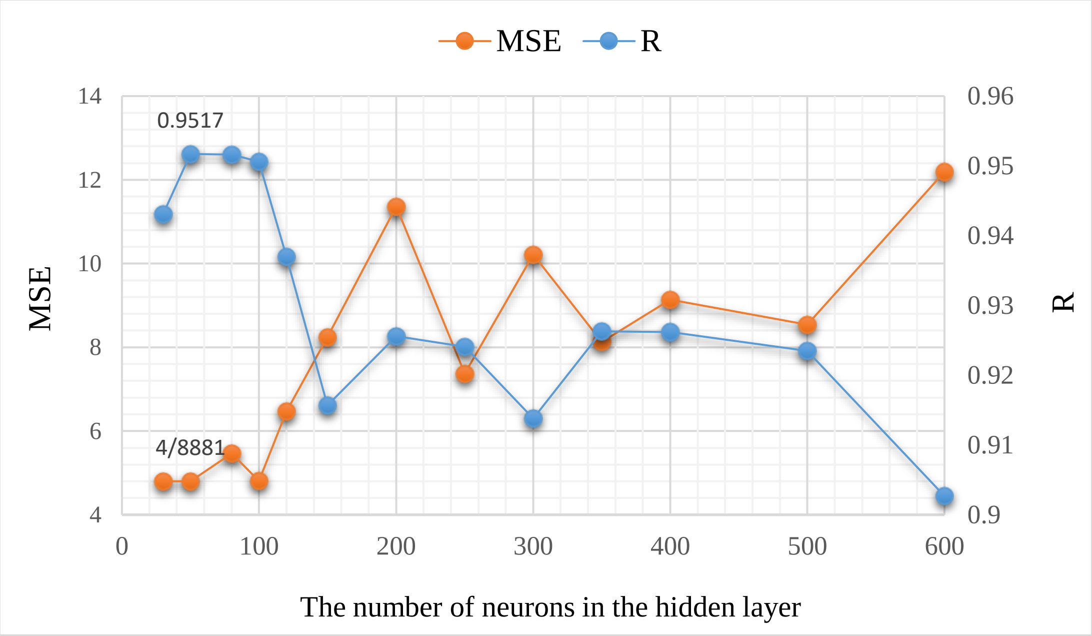

Figure 5. Diagram of determining the number of optimal neurons in the hidden layer

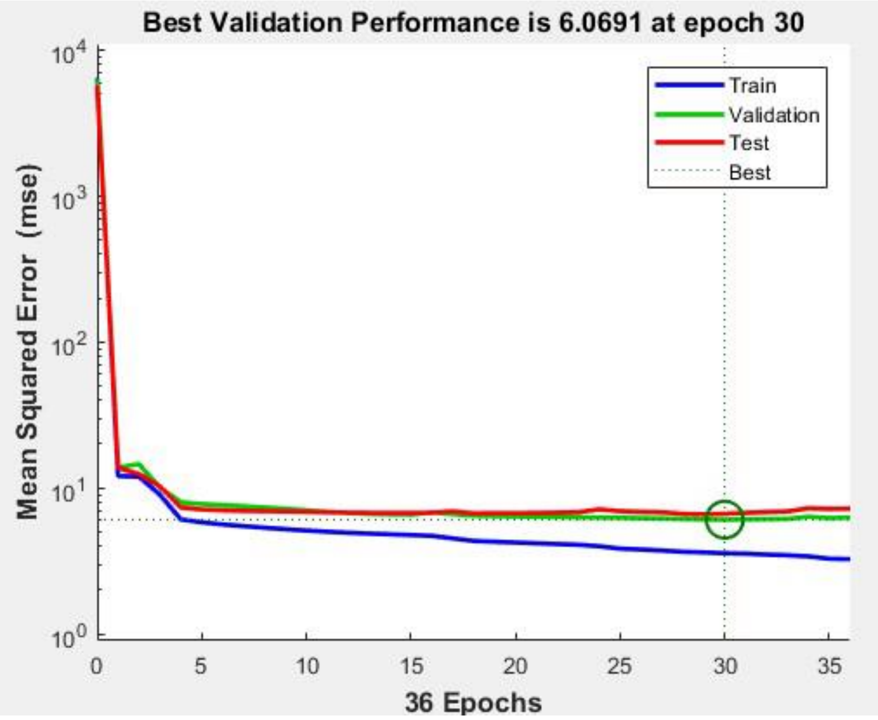

Figure 6. The mean square error for training, validation, and test data in the epoch

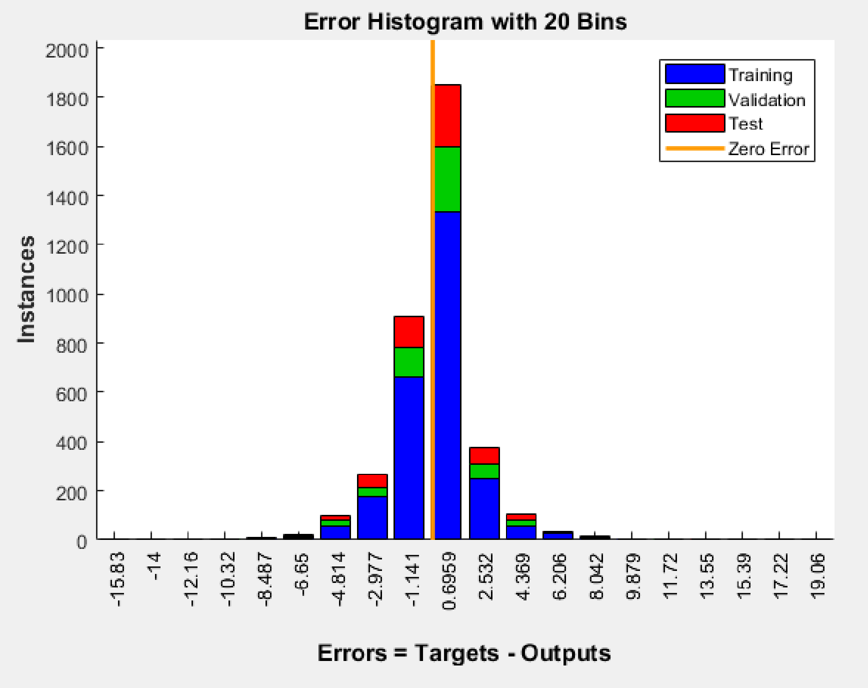

Figure 7. Error histogram for training, validation and the test data

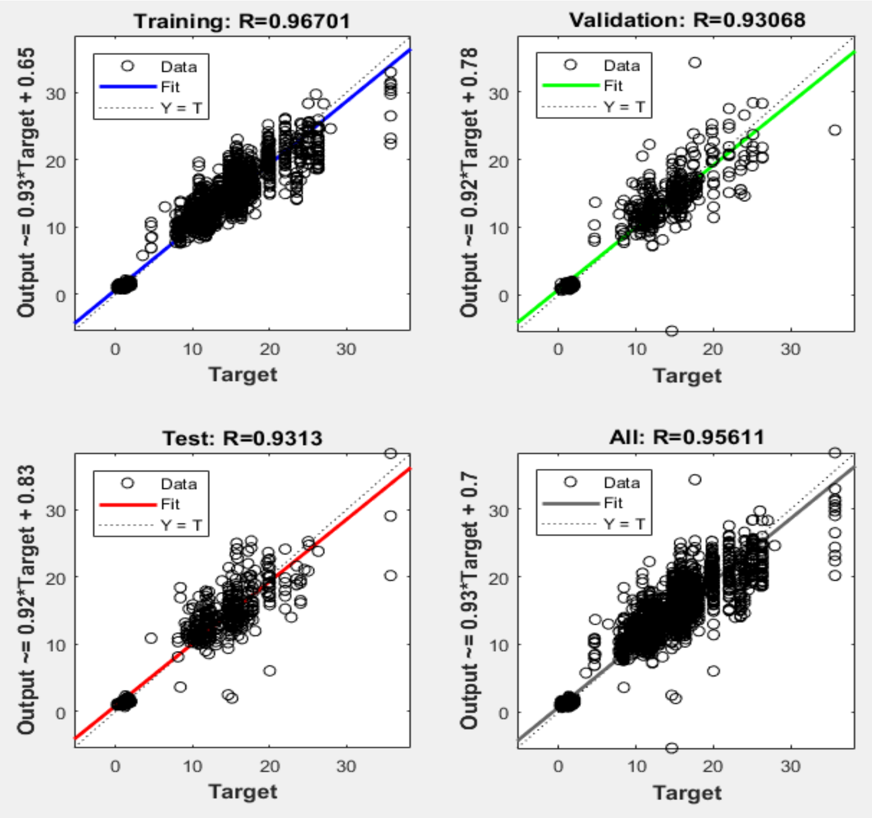

Figure 8. The regression between the output of the network and target

The relationship between inputs and outputs in the MLP neural network model is complex and not easily interpretable, as the model does not explicitly express the underlying relationships. To better understand the effect of indicators on the share of travel by public transport, sensitivity analysis methods can be employed.

Table 2 presents the results of sensitivity analysis, indicating the relationships between different indicators and the share of travel by public transport. The analysis reveals that transit service coverage, number of stations, and connectivity have a direct positive relationship with the share of travel by public transport. As these indicators increase, the share of travel by public transport also increases. On the other hand, speed and walking distance exhibit an inverse relationship with the share of travel by public transport. Therefore, an increase in the values of these indicators leads to a decrease in the share of travel by public transport.

There is no significant change in the optimal parking in the area in the case of parking indicator. However, if the area exceeds the optimal parking capacity, the share of public transport travel decreases significantly. This is because an excessive amount of parking can encourage unnecessary driving behavior. Similarly, commercial density and residential density also exhibit a similar relationship with parking availability. The need for diversity in the area and the inconsistency of land use with Transit-Oriented Development (TOD) principles contribute to this relationship.

Initially, it was expected that public spaces would positively contribute to the appeal of walking paths, leading to an increase in the utilization of public transport. However, the results revealed an unexpected outcome, showing a negative correlation between this indicator and the share of public transport usage. This finding diverged from the initial expectations.

When considering the availability of transit options, it was observed that the share of travel by public transport experienced a significant increase when the number of available modes increased from 1 to 2, compared to the increase from 2 to 3 modes. The slope in the presented model did not show significant changes in the range of 1 to 3 percent, indicating that it had little impact on the share of travel by public transport. However, in the range of 3 to 6 percent, it had a negative effect. Furthermore, as the population density increased from 0 to 200 people per hectare, there was an increasing trend in the share of travel by public transport. However, at higher population densities, the trend remained relatively stable.

The changes in the share of public transport usage were calculated for a 1% increase in each indicator to determine the most influential factors. The results are presented in Table 2. Parking was identified as the most impactful parameter, as for every 1% increase in parking (beyond the optimal area), the share of public transport was reduced by 239%. On the other hand, for every 1% increase in slope (greater than 3%), the share of public transport was reduced by 0.046, indicating it as the least effective indicator.

Table 2. Changes in the share of travel by public transport for each indicator

indicators	Indicative changes range	Changes in the share of travel by public transport	changes in the share of travel by public transport of 1% increase in each indicator
Transit service coverage (d*)	0-1	5.02	0.0502
number of stations(n*)	0-16	19.15	0.1844
Speed (km/h)	20-55	-3.72	-0.0372
Parking (%)	0-10	1.22	0.033
	10-27	-15.1	-0.239
commercial density(d)	0-0.1	1.93	0.058
	0.1-0.3	-13.32	-0.199
population density(n)	0-200	2.56	0.0803
	200-600	-1.47	-0.022
residential density(d)	0-0.7	8.48	0.121
	0.7-1	-1.7	-0.056
public space(d)	0-0.6	-5.14	-0.085
	0.6-1	0.93	0.023
walking distance(m)	100-1600	-7.81	-0.078
Connectivity(n)	0-70	6.71	0.0671
Transit options(n)	1-2	2.7	0.054
	2-3	0.022	0.011
Slope (%)	1-3	1.58	0.039
	3-6	-2.78	-0.046

* Dimensionless

* Number

6. Conclusion

Based on Transit-Oriented Development (TOD), as one of the most comprehensive urban theories that focuses on the relationship between urban and public transportation, this study examined indicators affecting pedestrian access. To this end, efforts were made in this study to overcome the limitations and shortcomings of the previous studies to provide a comprehensive model for pedestrian access.

A comprehensive dataset was collected regarding the relevant indicators for pedestrian access in TOD urban areas. These indicators were chosen based on their significance in various studies and are not specific to the study area. Furthermore, these indicators were defined in a way that allows for the evaluation of the entire area, rather than just focusing on the vicinity of transportation stations.

The parameter intervals were determined based on walking distance. It should be noted that Euclidean distances are approximate measures of walking distances and may significantly differ from the actual values in certain situations.

The quantitative values of these indicators were calculated for each of the 1231 blocks in District 6 of Tehran using ArcGIS. The results were analyzed to determine the indicators that have an impact on pedestrian access in the area. In this study, an MLP neural network model was developed to analyze the share of public transport usage in the region, considering pedestrian access. The model evaluated the actual pedestrian conditions using various parameters. The results obtained from the MLP neural network highlighted that parking had the highest impact, while slope had the lowest impact among the other indicators.

The improvement of public transportation and pedestrian access in urban areas is widely acknowledged as a key objective in the theory of Transit-Oriented Development (TOD). In Iran, there has been a body of literature on TOD for the past twenty years. However, the practical implementation of effective measures to establish TOD zones has been limited. Redesigning already developed cities, like Tehran, presents significant challenges. Therefore, the initial step in promoting TOD is to identify potential locations for establishing TOD zones. Assessing the level of TOD can be instrumental in identifying areas with a high potential for successful TOD implementation.

Although the model presented in this study was developed using data from District 6 of Tehran, it is not limited to measuring TOD in Tehran alone. This model can be applied to estimate the level of TOD in any urban area.

Moreover, the model is capable of assessing the level of pedestrian access improvement by enhancing each parameter. This feature enables the identification of necessary measures to achieve higher levels of TOD and pedestrian access. Consequently, the presented model can play a significant role in decision-making processes and urban planning.

7. References

- Ashrafian, A., Taheri Amiri, M. J., Rezaie-Balf, M, Ozbakkaloglu, T., & Lotfi-Omran O. (2018) Prediction of compressive strength and ultrasonic pulse velocity of fiber reinforced concrete incorporating nano silica using heuristic regression methods. Construction and Building Materials, 190, 479–494.

- Azmoodeh, M., & Haghighi, F. (2017) Land Use Evaluation Based on Transportation Accessibility (Case Study: Zone 6 of Tehran). Journal of Research and Urban Planning, 8, 135–148.

- Behbahani, H., & Haghighi, F. (2009) Presentation of Land-use and Traffic Efficiency Assessment. Journal of Environmental Engineering and Landscape Management, 17(2), Ia–Ii.

- Bertolini, L., & Spit, T. (2005) Cities on rails: The redevelopment of railway stations and their surroundings. Routledge.

- Calthorpe, p. (1993) The Next American Metropolis (ecology, community and American dream). Princeton, Princeton Architectural Press.

- Cervero, R., & Kockelman, K. (1997) Travel demand and the 3Ds: Density, Diversity, and Design. Transportation Research Part D: Transport and Environment 2, 199–219.

- Cervero, R., & Day, J. (2008) Suburbanization and transit-oriented development in China. Transport Policy 15 (5), 315–323.

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

- Dittmar, H., & Ohland, G. (2012). The new transit town: best practices in transitoriented development. Island Press.

- García-Palomares, J., Gutiérrez, J., & Cardozo, O. (2013) Walking accessibility to public transport: an analysis based on microdata and GIS. Environment and Planning B: Planning and Design, vol 40, 1087-1102.

- Godarzi, A A., Madadi Amiri, R., Talaei, A. & Jamasb, T. (2014) Predicting oil price movements: A dynamic Artificial Neural Network approach. Energy Policy, 68, 371-382.

- Hasibuana, H., Soemardia, T., Koestoerb, R. & Moersidikc, S. (2014) The Role of Transit Oriented Development in constructing urban environment sustainability, the case of Jabodetabek, Indonesia. Procedia Environmental Sciences, 20, 622-631.

- Huisman, O., & Rolf, A. Principles of Geographic Information Systems, An introductory textbook, Fourth edition, ITC, Enschede, 2009.

- Institute for Transportation and Development Policy, TOD Standard, 3rd ed. New York: ITDP, www.itdp.org (2017).

- Kia, M. (2011) Neural Networks in MATLAB. Green Computer Publishing Services.

- Loo, B., Chen, C., & Chan, E. (2010) Rail-based transit-oriented development: Lessons from New York City andHong Kong. Landscape and Urban Planning, 97, 202–212.

- Lyu, G., Bertolini, L., & Pfeffer, K. (2016) Developing a TOD typology for Beijing metro station areas. Journal of Transport Geography, 55, 40–50.

- Mavoa, S., Witten, K., McCreanor, T. & O'Sullivan, D. (2012) GIS based destination accessibility via public transit and walking in Auckland, New Zealand. Journal of Transport Geography, 20, 15-22.

- Motieyan, H., & Saadi Mesgari, M. (2018) An Agent-Based Modeling approach for sustainable urban planning from land use and public transit perspectives, Cities, 81, 91–100.

- Mu, R., & de Jong, M. (2010) Establishing the conditions for effective transit-oriented development in China: the case of Dalian, Landscape and Urban Planning, 97, 202–212.

- Mirzahossein, H., Rasafi, A., Sadeghi, K. & Safari, F. (2020) Overview of the Literature on the Transit-Oriented Development Policy to Investigate a Practical Solution for Traffic Congestion in Iran Cities. International Journal of Transportation Engineering, vol 7 (N28), 355-372.

- Ming Wey, W. (2015) Smart growth and transit-oriented development planning in site selection for a new metro transit station in Taipei, Taiwan. Habitat International, 47, 158-168.

- Municipality of District 6 Tehran, http://region6.tehran.ir, 2017.

- Nasri, A. & Zhang, L. (2014) The analysis of transit-oriented development (TOD) in Washington, D.C. and Baltimore metropolitan areas, Transport Policy, 32, 172–179.

- O'Sullivan, D. (2012) GIS based destination accessibility via public transit and walking in

Auckland, New Zealand, Journal of Transport Geography, 20, 15-22.

- Padeiro, M., Louro, A. & Marques da Costa, N. (2019) Transit-oriented development and gentrification: a systematic review, Transport Reviews, 39:6, 733-754.

- Peiravian, F., Derrible, S., & Ijaz, F. (2014) Development and application of the Pedestrian Environment Index (PEI). Journal of Transport Geography, 39, 73-84.

- Rafiq, M.Y., Bugmann, G., & Easterbrook, D.J. (2001) Neural network design for engineering application, Computers & Structures, vol 79(17), 1541-1552.

- Shakiba, H., Khosravi, M., Tusi, T & Ajdari Moghaddam, M. (2015) Predicting the minimum temperature of Karaj station using data from remote link indices and artificial neural network, Natural Geography, 11 (40), 85-103.

- Singh, Y., Fard, P., Zuidgeest, M., Brussel, M., & Maarseveen, M. (2014) Measuring Transit oriented development: a spatial multi criteria assessment approach for the City Region Arnhem and Nijmegen, Journal of Transport Geography, 35, 130-143.

- Singh, Y., Lukman, A., Flacke, J., Zuidgeest, M. & Maarseveen, M.F.A.M. Van. (2017) Measuring TOD around transit nodes - Towards TOD policy. Transport Policy, 56, 96-111.

- Stojanovski, T. (2020) Urban design and public transportation – public spaces, visual proximity and Transit-Oriented Development (TOD). Journal of Urban Design, 25:1, 134-154.

- Sung, H., & Oh, J. (2011) Transit-oriented development in a high-density city: Identifying its association with transit ridership in Seoul, Korea. Cities, 28, 70–82.

- Teklemariam, E., & Shen, Z. (2020) Determining transit nodes for potential transit-oriented development: Along the LRT corridor in Addis Ababa, Ethiopia, Frontiers of Architectural Research, 9, 606-622.

- Talavera-Garcia, R., & Soria-Lara, J. (2015) Q-PLOS, developing an alternative walking index. A method based on urban design quality, Cities, 45, 7-17.

- Yildirim, Y., & Jones Allen. D., & Arefi, M (2020) How does transit-oriented developments (TODs) deviate noise pollution of buildings? A comparative study of TODs and non-TODs. Environmental Science and Pollution Research, 27, 25390-25403.