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Site Selection of Car Parking With the GIS-Based Fuzzy Multi-Criteria Decision Making

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The management of parking spaces has become a significant challenge in middle-income developing countries due to the rapid motorization and uncertainty in urban growth patterns. This issue has severe social, economic, and environmental repercussions, including increased congestion, crash frequency, fuel and time consumption, and air pollution. Given the complexity of the public parking site selection and the diverse range of variables involved, a multi-criteria assessment is essential. To address this issue, this study employed fuzzy logic and geographical information systems (GIS) to develop a multi-criteria decision making (MCDM) model for managing parking in Shiraz's central business district (CBD). The study mined the literature for information on the variables that affect parking site placement, and a poll of experts (n = 11) was conducted to determine their relative importance. The factors considered included the distance to travel attraction centers, distance to roads, land price, population density, and available land for multi-storey parking. Furthermore, the parking space shortage for each traffic analysis zone (TAZ) was estimated by subtracting the estimated parking space supply from the estimated parking space demand. An overlay of these two layers identified locations that are in parking shortage zones and meet multiple criteria. The results of the study may aid policymakers in controlling parking demand by identifying the most promising places for investment.

Keywords: Traffic management, Estimation of parking demand, Multi-level parking, Location selection, Geographic Information System (GIS), Fuzzy Multi-Criteria Decision Making (MCDM).

Mathematics Subject Classification 2022: 22E46, 53C35, 57S20

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1. Introduction

Economic and population growth in cities has contributed to a massive demand for cars and greater mobility through metropolises.[1–3] The high number of private vehicles in cities, combined with a scarcity of parking spaces, has become a source of contention in transportation system planning and management.[4] The planners and professionals in transportation planning are primarily concerned with the mobility of cars, whereas these private vehicles spend the majority of their time parked, approximately 23 h per day for a typical vehicle,[5] in the origin or destination.[6] This means that parking is a serious social, economic, and planning issue that must be addressed.[7] The lack of sufficient public parking supply would contribute to different problems such as time waste, pollution, inefficiency in fuel consumption, and increase in congestion.

One of the critical missions of transportation planning in the Central Business Districts (CBDs) is the management of parking demand and supply.[4,8,9] Achieving a balance between the demand and supply of parking spaces is a critical issue for mitigating the environmental consequences of car mobility in urban core areas.[10–12] Saturated urban parking systems and overcrowded streets caused by cars looking for on-street parking are two of the leading causes of low efficiency in metropolitan areas' central areas. Parking, on the other hand, is a vulnerable issue. At the same time, an abundance of parking spaces would contribute to increased car usage for daily commuting and influence people's decisions about buying and using cars.[8,12,13] Subsidized parking in key parts of cities with strong demand for car usage for last-mile would diminish public transit utilization while encouraging driving.[8,14–16] In reality, in the CBD regions, a balance between supply and demand is required, and this may be viewed as an optimization subject.[17–19]

One of the issues with a lack of parking systems is that they are overcrowded during peak hours.[20] Furthermore, during peak hours, the streets suffer from an uneven distribution of parking demand.[21] Seeking on-street parking to save money when compared to off-street parking spaces is a common practice among drivers in most cities.[22] Cruising for parking results in higher fuel consumption due to the high cost of off-street parking and occupied on-street parking spaces.[23] It has been estimated that between 20% and 30% (Ref. 24) of the traffic volume in central areas of the city are related to drivers searching for an appropriate parking space,[25] which would result in making delays for other road users.[12] Furthermore, parked cars reduce road capacity and level of service (LOS), and the travel lane may be interrupted by parking and un-parking maneuver space.[24,26] Other elements influencing parking search include parking cost, time limitation, built environment and physical qualities, parking provision rules, and human traits.[27] For example, most drivers prefer to park as close to their destination as possible.

Many cities in middle-income developing countries frequently fail to strike a balance between urban parking spaces and the ever-increasing volume of cars on the road.[28] In other words, while the volume of motorized traffic is increasing due to

offering more affordable private cars, cities supply limited parking spaces for these vehicles and must optimize and prioritize their parking allocation spaces.[29] Local governments, in particular, are unable to provide enough off-street parking spaces for private cars in CBDs due to limited spaces surrounded by attractive facilities and urban spaces, which is why overcrowded streets have become the main feature of developing-country central areas.[29] The provision of parking is now a contentious issue. Some studies show that the shortage of parking supply will lead to increased transit use in CBDs and downtowns, while reducing long-term car dependency.[5,8,13,30,31] Some argue that parking pricing policies can influence commuters' willingness to use public transportation instead of private cars.[32,33] This viewpoint has piqued the interest of policymakers seeking more efficient management of travel demand,[7,15] which has resulted in a paradigm shift in parking management policies.

Parking supply is considered a priority not only by stakeholders and governments, but it is also expected that business owners provide parking space at destinations for a reasonable fee. On the other hand, rather than subsidizing parking supply, it is advised to focus on optimizing parking spaces.[28] In other words, the emphasis has shifted from supporting limitless supply to effective management of existing spaces through the use of emerging technologies such as Intelligent Transport Systems (ITS).[5] The conventional methods of parking supply planning rely on potential demand surveys, which ignore the role of potentially effective factors such as road users' socio-economic characteristics, the geographic distribution of parking sites, and, most importantly, whether the goal of parking supply is to generate financial revenues.[28] In other words, if many locational, demographic, and economic factors are considered concurrently, the efficiency of parking supply can be achieved.[5,13]

Parking modeling; regulations, technology, placement and allocation, efficiency, and its effects on other sectors have been a hot topic in recent decades in both urban and transportation planning.[1,2,9,12,15,21,26,29,34–37] Prior studies have identified parking spots using multi-criteria decision makers instead of a geographical information systems (GIS).[38] For instance, a study built a linear regression model to anticipate the number of parking spots needed to meet parking requests in suburban rail transit (LRT) stations, using data collected from a parking supply and demand model.[39] The Analytical Hierarchy Process (AHP) method was used to analyze the three regions at the University of Mesopotamia campus to determine the most probable acceptable sites for establishing car parking spaces. The parameters used in this analysis were study area, space per hour, total parking volume, total parking load, total parking time, and circulation.[40]

Another paper by the same authors used the integration of Fuzzy AHP and the technique for order performance by similarity to ideal solution (TOPSIS) to figure out where in Tuyserkan, Iran, people should park their cars. In this investigation, researchers looked at a variety of indicators, including population density, traffic congestion, air quality, proximity to public facilities, and property value. A larger

set of selection criteria may be needed to develop a solution that is sustainable in terms of economic, environmental, and social objectives. The authors argue that future research may benefit from capturing the subjective knowledge of experts in order to assess the importance of each criterion.[41] Palvisius *et al.*[42] examined the availability of parking spots in residential areas in Vilnius, Lithuania. A multi-criteria decision making (MCDM) method considered factors including population density, number of businesses per square mile, number of people in the labor force, and the availability of public transportation. To assign relative values to each criteria, the AHP was used. The parking situation in each area is then evaluated using an average method.[42]

There have been limited studies that have used the Spatial Decision Support System (SDSS) method for parking spot selection. In this regard, a research conducted in Istanbul was utilized to tackle the parking problem by employing an SDSS to select the best location for car parking. The SDSS is built on the sequential application of AHP and GIS. The data on parking lot proximity to roadways, shopping malls, health facilities, public transit stations, and parking occupancy rate all are gathered. The AHP is utilized to weight the provided criteria. The SDSS is created by including the specified criteria as map layers, with the goal of determining the best locations for parking and also places where additional parking is required.[43] Aliniai *et al.*[44] used five criteria to offer a GIS-based MCDM strategy in Metropolitan Isfahan, Iran. They identify possible regions based on limitations, then construct benchmark layers for those regions. The layers were blended with the fuzzy ordered weighted average after being weighted with AHP to generate a suitable map. Another research in Istanbul employed a GIS-based Fuzzy AHP technique to evaluate the best places for parking supply in four districts. There are three main categories where relevant criteria have been found and gathered: (a) land use, (b) finance, and (c) traffic. The research suggested that the GIS-based fuzzy AHP approach utilized in this study can be used to identify appropriate locations by doing a multi-criteria analysis of each location (i.e. grid cell) based on precise spatial data.[38]

As previously stated, several factors influence parking site/lot selection, and a rich literature has developed addressing the evaluation of suitable sites based on the direct and indirect effects of these factors on site selection. Distance to various travel attractions such as commercial, recreational, administrative, and educational areas is one of these variables,[45] availability of land for parking construction,[44] land price and construction costs,[46] investment costs, average walking distance,[47] and accessibility to main roads.[48] Other locational criteria include distance to job areas, population density in neighborhoods, distance to present parking spots, routes to important roadways, and existing parking facilities.[49]

Much of the background literature focus on possible parking spots that have already been selected. In addition, most of these studies suffered from deficiencies in spatial analysis. In addition, the accuracy, breadth, and depth of the data and

criteria used in these studies are all wanting. Differentiating this research from others is the use of fuzzy theory in conjunction with a geographic information system to provide a more effective technique for underpinning the evaluation process when uncertainties exist. Another deficiency of previous parking site selection research is that they have attempted to find the optimal site whilst neglecting the actual balance between supply and demand.

In this paper, an MCDM approach and Fuzzy AHP are used to combine quantitative and spatial methodologies for locating the most effective locations for parking sites in the Shiraz CBD example. However, the study's strength is its use of reliable GIS-based data together with subjective expert opinions. This study contributes to the literature by presenting an integrated technique that takes into account the capabilities of spatial analysis and fuzzy MCDM methods and offers decision-makers with robust data to help them make efficient judgments. Specifically, the research objectives include: a) Developing a method for calculating the public parking shortage for the case study area; b) Developing a multi-criteria method for determining the best locations for constructing multi-storey public parking in order to meet the existing parking demand within the case study area.

The remainder of this paper is organized as follows: Section 2 describes the techniques used to compute the parking balance, as well as the approach for determining the optimal locations for multi-storey parking based on a mix of GIS and fuzzy MCDM. The introduction to the case study area and the locations of current allocated parking spaces inside the traffic area zones are included in Sec. 3. The results of parking balance calculations and the MCDM approach are presented in Sec. 4. This section concludes with a map indicating the optimal places for multi-storey parking development. Section 5 discusses the results and what can be learnt for policymaking and regulating the Shiraz dilemma. Section 6 concludes and provides future study directions.

2. Methods

The target of this paper is to determine the most efficient capacity and location of parking sites in Shiraz's CBD. Various sorts of data have been gathered in order to assess both supply and demand. Shiraz municipality publishes information about off-street parking spots (Shiraz Transportation Master Plan, 2018). The on-street parking spots are computed using GIS. The demand for parking is also assessed using the regulations of the Shiraz Master Plan (Shiraz Municipality, 2016) and the Master Land Use Plan (Shiraz Municipality, 2018). The number of provided parking places, both off and on street, first is determined. The number of required parking spots is then anticipated using Shiraz's updated Master Plan as well as planning norms and standards for Shiraz's key regions. Finally, the numbers of spaces required are estimated, and the optimum locations are forecasted based on current land usage and future sites. Subtracting supply value from demand value yields the needed number of parking spots.

2.1. *Parking supply and demand*

Parking supply refers to all of the places, on and off the street, that have the ability to accommodate cars.[44] Parking spaces are provided in a variety of configurations, including on-street parking in boulevards, streets, and open areas, off-street parking in private houses, and public parking spaces. Parking capacity refers to the total number of parking spots that might possibly be utilized by cars. Furthermore, parking accumulation is the number of cars parked in the open spaces in a parking lot; this figure is derived from the number of drivers that parked their cars in a parking lot at a given period. It is often represented by a bar graph called an accumulation curve.[29]

While several approaches for calculating demand have been proposed, this study employed the fundamental method proposed by Yan Kefei (1994). This method was then promoted by Tiexin *et al.*[32] in order to take into account the turnover. Essentially, the rate of parking potential demand is determined by the type of land use activity and the quantity of prospective lands.

$$D = \sum_{i=1} r_i A_i \quad (i = 1, 2, 3, \ldots, n), \tag{1}$$

where D is parking demand, r_i is parking generation rate (based on each land use), and A_i is the land area of each lot. This model, however, requires some parking space parameters as well. One of the most important parking elements is the turnover rate, which influences the amount of parking demand in the model. In other words, this model displays the number of produced parking spots, despite the fact that each space may be used many times throughout the day. This issue might be rectified by incorporating a turnover rate into the present model.

$$t_i = \frac{S_i}{C_i}, \tag{2}$$

where t_i is the average turnover rate of parking, S_i is accumulation rate of parking spaces, and C_i is parking capacity. This characteristic demonstrates the efficiency of parking spots used during the day and night. As a result, the created model would be

$$y = \sum_{i=1}^{n} \frac{a_i}{\mu_i} R_i \ , \tag{3}$$

where a_i refers to parking generation rates, which are the quantities of parking demand in per unit area. μ_i refers to average turnover rates, which are defined as average times of parking in each turnover lot in certain hour. R_i is the individual area in square meters.[32]

2.2. *Multi-criteria decision making*

When making decisions in the real world, decision makers want to examine various elements and pursue multiple goals. Most of the time, the ideal option is decided

by making trade-offs between two or more competing goals that must be concurrently maximized.[50] MCDM is a technique that considers several factors in order to make a multi-dimensional choice.[51,52] Various players and stakeholders might be included in this technique to give potential answers to complicated challenges in human activity sectors.[53,54] The weight is the relative value of each criterion as determined by a comparison of a set of criteria. These criteria are used in the decision-making process based on the values and weights assigned to them. There are several approaches for integrating criteria based on their weight. AHP is a typical approach used in multi-criteria decision-making processes.[55] This method has been utilized in a number of studies to determine the best location for infrastructure and facilities in metropolitan settings.[29,44,45,54,56–58]

To use this technique, three main steps must be completed: first, the objective or problem should be clearly defined based on criteria and sub-criteria; second, a pairwise comparison of influencing factors will be performed to evaluate their relative importance; and finally, a decision will be made based on the aggregate weight of each factor compared to other factors.[59] The weight of each criterion is assigned a number between 1 and 9. Because the value of the criterion is reliant on the subjective assessment of experts and actors in some instances, it is preferable to use a more robust strategy to account for the uncertainty (related to personal subjective judgement). To address this issue, fuzzy-AHP has been introduced in the literature.[53,56–58,60] In other words, AHP is less useful for reflecting judgement fuzziness, and fuzzy AHP is offered to minimize manipulative disruption of judgements.[58]

In the AHP method, numbers are used to assess the value of subjective judgments. The problem is that decision makers seldom have the information necessary to provide reliable quantitative comparisons. Since some of the criteria for evaluating services are subjective, experts have a hard time expressing importance and offering reliable assessment and comparison. In this case, experts should make use of fuzzy evaluations, such as approximate numerical values and qualitative language.[61] An improved method for under-uncertainty assessment support is provided when MCDM techniques are fused with fuzzy theory.[62,63] In several cases involving consensus decision-making, the views of experts are ambiguous. For the purpose of describing this ambiguity, fuzzy information is often employed to reflect the preferences of experts, particularly when a crisp value cannot adequately represent their actual perspectives.[64] Therefore, it's best to use the Fuzzy Inference System for both analysis and location, with the criteria we establish in each serving as inputs to your final choice.[65] However, concurrent usage of applicable technologies like GIS is necessary owing to the complexity of spatial decision-making considerations. Graphical and non-graphical data with different characteristics may both be shown by MCDM-GIS systems. Human judgment error in spatial and non-spatial decision-making, such as in planning and management, may be mitigated through further investigation of this area. In addition, it frees up experts to experiment with new approaches to problem-solving by letting them modify their plans and judgments in various ways.[66] In several cases involving consensus decision-making, the views of

Table 1. Trapezoidal fuzzy numbers and subjective expression in five groups.

The quality	Trapezoidal fuzzy numbers	Inverse trapezoidal fuzzy numbers
Equal	(1, 1, 1, 1)	(1,1,1,1)
Relatively equal	(1, 2, 3, 4)	(1/4, 1/3, 1/2, 1)
Superior	(3, 4, 5, 6)	(1/6, 1/5, 1/4, 1/3)
Very superior	(5, 6, 7, 8)	(1/8, 1/7, 1/6, 1/5)
Absolute superior	(7, 8, 9, 9)	(1/9, 1/9, 1/8, 1/7)

experts are ambiguous. Furthermore, employing the hybrid methods has a positive contribution to the objectivity of the results.[67]

In this research, the geometric mean method of FAHP developed by Buckley *et al.*[60] is used (Fig. 1). The fuzzification of weights in this method is based on the original AHP procedures of assigning numbers to distinct evaluative traits, as seen in Table 1.

This approach consists of many parts; first, a matrix is created using the trapezoidal fuzzy numbers discovered in the opinions and judgments of experts and decision-makers. The geometric mean of the expert's scoring is then computed. The scoring is based on the pairwise comparison which is an essential method in MCDM for evaluating alternatives and has many uses in fields where people are involved, such as the industrial and service sectors, as well as in research and sur- veys.[68] The Mean of the rows is computed in the third step using Eq. (4). Finally,the geometric means of rows are normalized (the value of each row is the share of that row from the sum of all cells in the row) and the center of gravity of weights is computed using Eq. (5). MATLAB (multi-paradigm programming language devel- oped by MathWorks) version 12 is used for all computations. More details on the research process are shown in Fig. 1.

$$\tilde{\mathbf{Z}}_i = \left[\prod_{j=1}^{n} \tilde{t}_{ij} \right]^{\frac{1}{n}}, \tag{4}$$

$$\tilde{w}_i \sum_{i=1}^{n} \frac{\tilde{z}}{\tilde{z}_i}, \tag{5}$$

3. Case Study

Shiraz is one of eight major cities except the capital of Tehran with populations of one million or more which are referred to locally as "metropolitan". Iranian metropolises see significant levels of traffic congestion, air and noise pollution, and accidents even though the general rate of car ownership is lower than in wealthy countries.[69,70] Shiraz is the capital of Fars province and Iran's most populous and developed city in the south. The city's population increased from 0.85 million in 1986 to 1.8 million in 2016 (Statistical Center of Iran, 2016). Simultaneously, the

land area has increased from 6,000 to 15,600 hectares. Historically, the city was

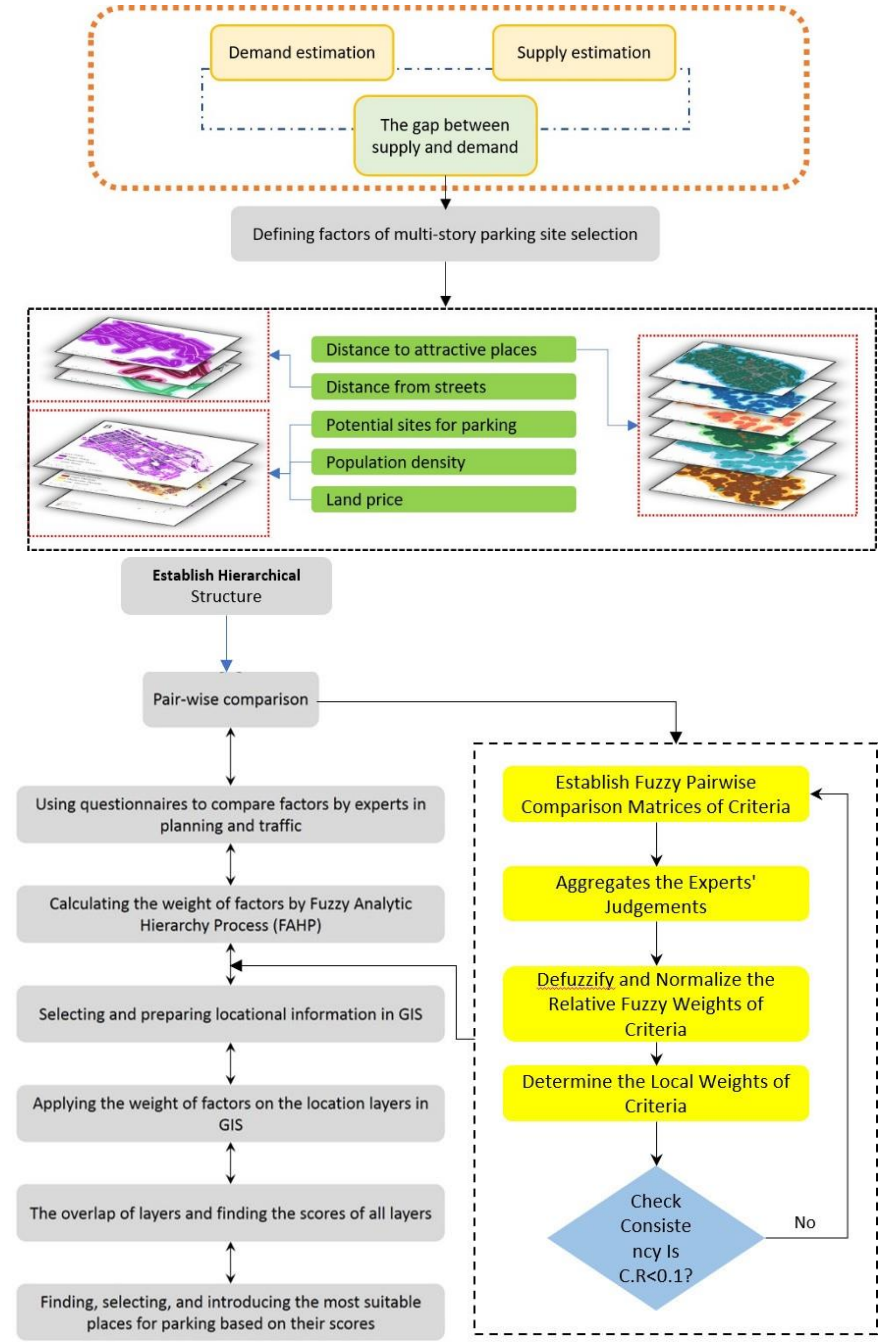


Fig. 1. The research process (*Source*: authors).

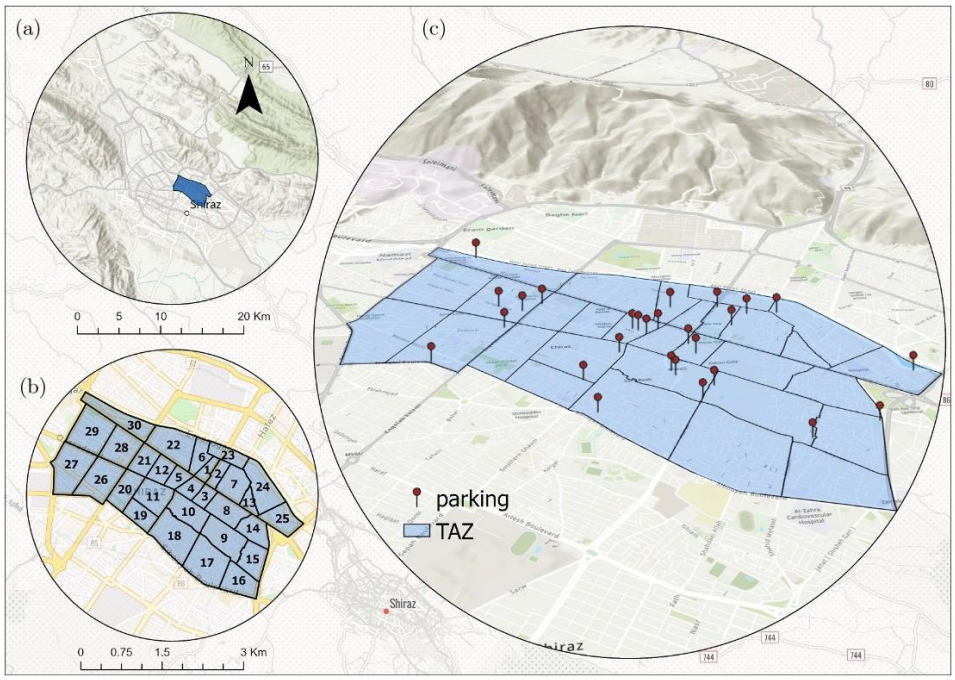


Fig. 2. The case study area: (a) Metropolitan Shiraz and its CBD area; (b) CBD area divided by TAZ; (c) Parking supply (*Source*: authors).

developed in three major stages: traditional growth around the bazaar, which dates back to the late nineteenth century, and modernization of the metropolis, which is distinguished by broad roadways that pierce the historical zones. It formed new areas via irregular crossroads and distributed growth, which occurred mostly in the previous three decades.[71,72] This paper focuses on the CBD area (Fig. 2).

Shiraz's CBD is plagued by a variety of traffic challenges. On-street parking is one of the issues that has hampered traffic movement in this area. Drivers frequently choose to park their cars on the street, due to shortage of parking supply. In addition, as previously stated, the second lane is used by on-street parked vehicles. The case study area is around 800 hectares in size, with 88 km of roads accounting for 5.5% of the overall area (approximately 43 hectares). Shiraz metropolis is split into 156 traffic zones, of which 30 TAZs in the city center, known as CBD, were chosen for this study. However, Shiraz CBD has its own quirks, such as a lower share of space for roadway and parking spaces, rigid vertical zoning constraints, and some large-scale land use activities such as professional hospitals and univer-sity campuses.[73,74] The major issue in this location is a scarcity of vacant parcels, which may be addressed with multi-storey parking spots and other development ini-tiatives such as improved public transit. Furthermore, the CBD is densely packed with various non-residential land use activities that draw a large number of people

during the day and early evening (Soltani, 2017). Due to the inefficiency of pub-lic transit, driving has become the major form of mobility, resulting in roadways congested with cars moving or hunting for parking spots.

4. Results

4.1. *Parking supply estimation*

There are various parking spaces supplied in modern cities: curbside, off-street, multi-storey, and underground.[27] Based on accessibility, there are four types: public, private, reserved, and preferred.[23] In the case of Shiraz, a number of these parking types are available. In this study, kerbside parking spaces are computed, and data on constructed parking spaces by public and private entities are acquired from Shiraz Municipality. The on-street parking spaces include all locations in the parking lane on key streets along TAZs, as well as off-street constructed surface and multi-storey buildings with parking land usage. To estimate on-street parking space, the planning codes (development plans and adopted zoning ordinances) that are included in TAZs planning documents are considered: 30 m from No-Park signs, 30 m from bus and taxi stops, 15 m from alleyways and intersections, 2 m to 6 m from crosswalks, loading and unloading of products, and emergency operations. A normal car requires 6 m of maneuvering and parking space. Based on these laws, the total number of provided parking places is projected. According to the estimate, each TAZ has a certain number of parking spaces, for a total of 22,334 parking kerbside spots.

4.2. *Parking demand estimation*

There are two main demands for parking, employees, and commuters.[35] While the latter is susceptible to the price, the former adjust parking cost with the time that the commuter has to spend on transit modes to come to work.[16] Both of these criteria are taken into account and represented in the computation in this study. All land use categories in the study region are investigated to determine the number of demanded parking spots. The number of parking spaces required for each land use varies depending on the city size, relative location to the CBD and zoning ordinances. In Iran, the Ministry of Road and Urban Development (2012) adopted a national standard for cities divided into three categories: metropolitan regions, medium-sized cities, and small towns. As a result, the parking criteria for each land use are included in the Shiraz Master Plan, which was adopted in 2014 (Table 2).

The number of parking spots supply in the case study is computed based on the land use, lot size, and the above-mentioned criteria. The number of off-street parking spots is computed using data supplied by Shiraz Municipality in 2018. The number of parking spots provided by the private sector, businesses, and households is determined based on the standards that must be satisfied in development appli-cations. Furthermore, the turnover rate of parking places varies depending on the

Table 2. Parking provision requirements of different land use in Shiraz Master Plan (2014).

One digit code	Major land use category	Two-digit code	Minor land use activity	Three-digit code	The number of parking spaces in each 100 m^2	
					Employees	Commuters
S1	Business, administration and services	S11	commercial, services	S111	According to the current state, until the next intervention plan adopted	
		S12	commercial, services and administration corridors and areas	S121	According to the current state, until the next intervention plan approved	
				S122	3	3
				S123	3	3
				S124	2	2
				S125	2	2
S2	Business, administration and services areas (with open space dominance)	S21	commercial centers and administration	S211	3	3
				S212	3	3
				S213	3	2
				S214	2	2
		S22	Centers with cultural dominance	S221	Approve based on zoning plans	
				S222		
S3	Industrial	S31	Industry	311	Based on their zoning plans	
				312	4	1
		S32	Manufacturing sites	321	2	1
				322	3	2
		S33	Industrial services	331	3	3
				332	2	2
M1	The mix of residential and other uses	M11	The mix of residential, commercial, and services	M111	3	3
				M112	2	2
				M113	2	2
				M114	2	2
		M12	Mixed industrial, residential	M121	2	2
				M122	3	3
M2	Cultural and tourism with low residential	M21	Mixed cultural, recreational	M211	2	2
				M212	2	2
		M22	Special mixed land use	M221	Based on their zoning plans	
				M222		

purpose of trip. We utilized the Shiraz Transportation Master Plan (2018) to determine how commuters and employees utilized parking spots during the day and night to generate this parameter. The time duration that parking spaces supply services is also calculated to compute the number of replacement and return of parking for different land uses in order to estimate turnover.

According to our study, administrative land use typically provides services between 8 a.m. and 2 p.m., and as a result, this land use category offers 6 h of parking. In addition, it is found that commuters use parking spots for an average of 60 min every day. Thus, the number of commuters who have utilized parking spaces is computed based on turnover, active hours of parking spaces in administrative land uses.

The number of required parking spots is computed using the following formula based on metrics of parking supply and demand (Table 4):

$$\text{Required parking space (RP)} = \text{Parking Demand (PD)} - \text{Parking Supply (PS)}. \tag{6}$$

The visual result of Eq. (6) is depicted in Fig. 3.

4.3. *The criteria affecting site selection*

Based on the literature and our local knowledge of the context, we selected the five most important factors: distance to travel attraction centers (administrative, commercial, religious, health, education, cultural, and recreational centers), distance to roads (local, collector, and arterial), land price (low, medium, and high), population density (low, medium, and high density), and available land for multi-storey

Table 3. The observations used to calculate the time occupied parking spaces for different land use activities.

The place that observation sheet was filled	1. Commuter
The parking space occupied by	2. Employee
Place and land use destination	3. Visitor
Enter time	
Exit time	
The duration parked in the parking	

Table 4. Statistical description of parking supply and demand in all traffic zones.

	Parking Supply	Parking Demand	Difference	Required
Min	190	259	−646	0
Max	2, 001	2, 431	610	610
Average	744	834	90	158
Variance	1, 488	1, 670	181	316
Total	2, 334	25, 048	2, 714	4, 740

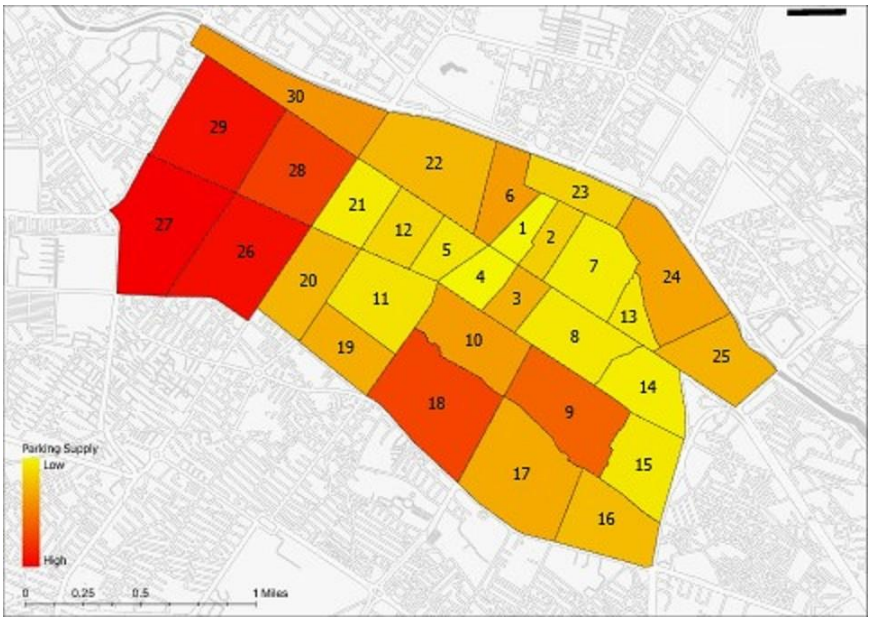


Fig. 3. Classification of TAZs based on public parking shortage (*Source*: authors).

parking were among the factors considered (vacant land, brownfields, and ruined buildings).

4.3.1. *Distance to travel attraction centers*

Because of the significant trips generated in these locations, the access and egress distance should be considered.[38,75] The density of trip generators such as shopping malls, retail and commercial, administrative and medical centers is high in the study area. This criterion is classified into six sections based on the Euclidean distances between the travel attraction centers and the proposed parking site.

4.3.2. *Distance to roads*

The placement of public parking spots close to arterial and collector roads would encourage drivers to use them as required, especially where it is paired with the regulations of on-street park regulations on neighboring streets.[75] Indeed, increasing the number of parking spaces near or next to the city's arterials would enhance service levels by lowering traffic congestion and encouraging bad-habit drivers to avoid violating parking restrictions such as parking in prohibited zones.

4.3.3. *Land price*

The value of land or property in the region is a significant consideration when selecting a location and establishing a multi-storey parking lot.[38] This criterion's

criteria are classified as low-price (from 400,000 to 650,000 Tomans), medium-price (from 650,000 to 900,000 Tomans), and high-price (900,000 Tomans and above) based on the 2020 rate. This categorization is determined by the spread and quantity of property acquisition expenses.

4.3.4. *Population density*

The population density criteria can be used as a primary factor in identifying the best site for multi-storey parking. These criteria are significant in that demographic data may be utilized in the location of multi-level parking by giving information on the density of the population living in the region and designating the areas with varying densities of the living population. In reality, taking into account this criterion, as well as the other primary factors for the site of multi-storey parking, is the people who reside in the neighborhoods. In other words, the population density criteria are used to evaluate the influence of the population living in the investigated locations, as well as the necessity to organize multi-storey parking lots for those individuals.[41] In this sense, the population density sub-criterion is separated into three main categories: low population density (0 to 125 people per hectare), medium population density (125 to 250 people per hectare), and high population density (250 people per hectare and above).

4.3.5. *Available land for multi-storey parking structures*

Multi-storey parking lots should always be constructed in the proper location so that other urban and traffic features are not impacted and are consistent with long-term urban and traffic goals and plans. As a result, three sorts of urban applications for multi-storey parking lots have been studied. which are really included as sub-criteria of acceptable locations for multi-storey parking development, such as waste land, garages, and decaying buildings.

The hierarchical network of these five criteria (five components) and their sub-criteria is depicted in Fig. 4. In addition, intervals for quantification and categorization of criteria to identify the optimal location in the FAHP model are provided for some of the sub-criteria.

Figure 5 depicts the Euclidean distance between prospective parking spaces and various trip generators. These intervals change depending on accessibility for each criterion.

An expert-opinion survey questionnaire issued to 11 professional experts working with the government or private sectors with profession/experience of urban planning, traffic engineering, civil engineering, landscape architecture, and project management was used to prioritize and weight the criteria and sub-criteria.

The weights and the FAHP process were calculated using MATLAB. The trapezoidal fuzzy numbers have been used to substitute vocal utterances. Following that, the arithmetic mean of expert opinions was computed. The weights of the

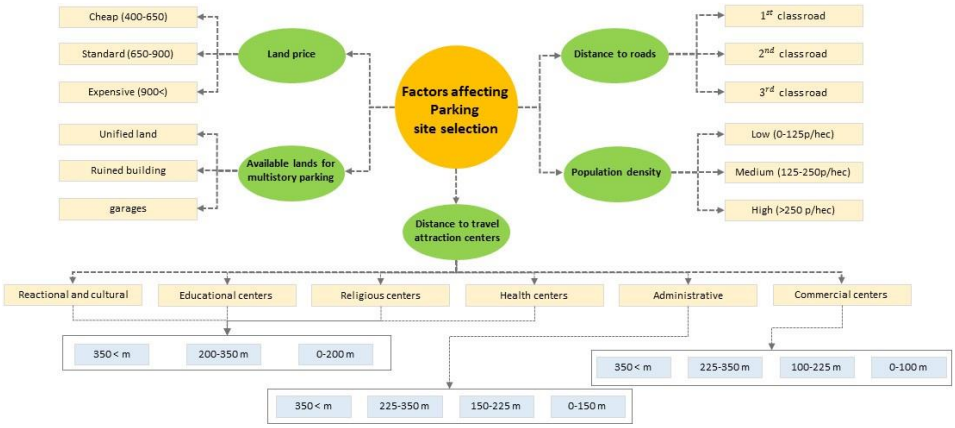


Fig. 4. Factors and indexes affect multi-storey parking site selection in the central area of Shiraz (*Source*: authors).

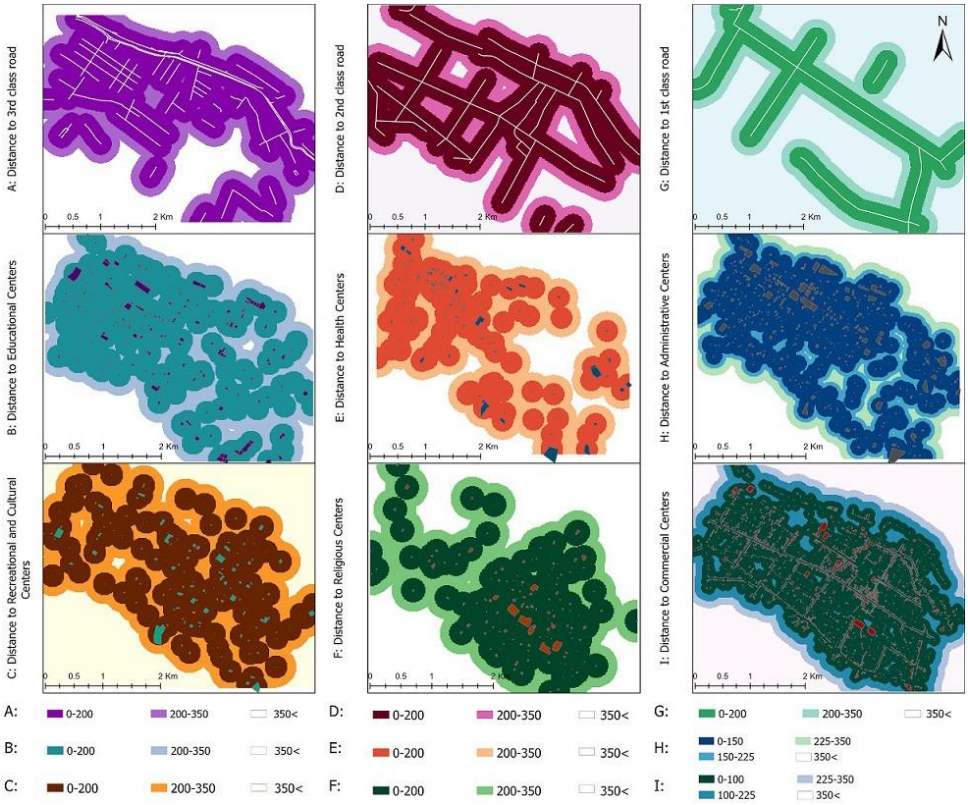


Fig. 5. Distance of potential parking locations to various land uses and facilities (*Source*: authors).

Table 5. Parking site selection criteria's weights.

Criteria	Distance to travel attraction centers	Distance to roads	Land price	Available land for multi-storey parking	Population density
Weight	0.307	0.188	0.162	0.185	0.155

RI (Random Index) = 1.36; CR (Consistency Ratio) = 0.12.

criterion were computed and normalized in the following stages, and because the weights were fuzzy, the center of gravity of the fuzzy weights was utilized to make the weights non-fuzzy, and the weights were eventually given to the layers in GIS. The fuzzy AHP (Buckley's geometric mean approach) is used to weight and rank all of these criteria and sub-criteria, and the results are displayed in Table 5.

4.4. *Finding potential efficient locations by using GIS*

ArcMap was utilized to connect the weight of the criterion to the layers, allowing AHP and GIS to find the possibly acceptable parking location. As indicated in Table 5, each criterion was processed by applying GIS to create the map and establish the weighting from the AHP approach and rating scale. An overlay analysis was performed on the map of possibly appropriate parking places, and the AHP approach was used to compute the weights and rating scale of the sub-criterion.

There are, however, certain other constraints that indicate viable alternate places for multi-storey parking spots. Other requirements must be met in order to evaluate probable locations include:

(a) Lots with the highest calculated score among all blocks in each zone, but which are not culturally or historically significant; and
(b) Having appropriate geometrics for the lot's length and breadth.

The lot should have a total size of at least 1,200 m^2. ArcMap is used to overlay the criterion layers with different weights. The combined weight has a continuous weight and score which can be classified in order to better identify the locations (based on the Natural Break method). The results can be reclassified into five scales—not suitable (<0.25), less suitable (0.25–0.35), moderately suitable (0.40–0.45), high suitable (0.45–0.50), and highest suitable (>0.5) (Fig. 6). The final parking lots has then determined through overlaying of these two layers: parking shortage layer (Fig. 3) and the Suitable locations (Fig. 6) which distinguishes locations that are in parking shortage zones and also meet multiple criteria (Fig. 7).

5. Discussion

It is argued that parking provision requirements in urban planning regulations are a limitation to effective land use and inefficiency of parking systems due to scarcity

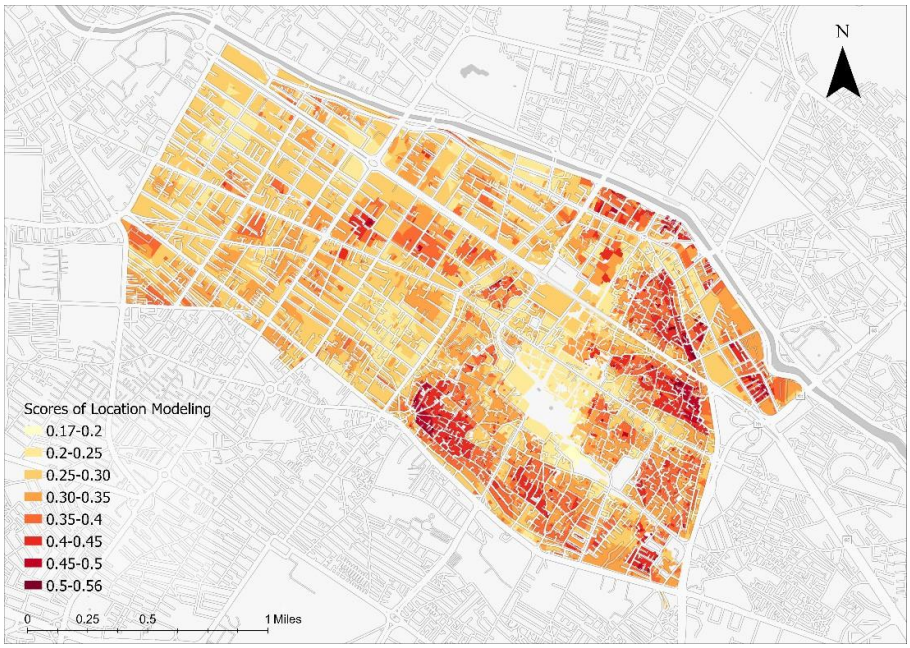


Fig. 6. Scoring of locations for accommodating multi-storey parking spaces (*Source*: authors).

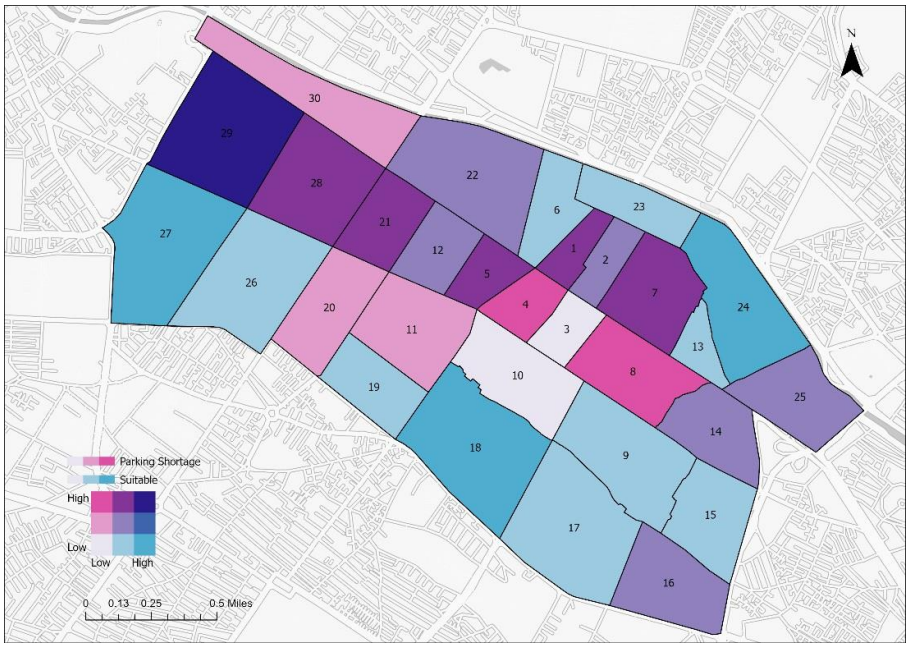


Fig. 7. Clustering of TAZs based on location suitability and parking shortage (*Source*: authors).

and high cost of land in core regions of major cities. Thus, unbundling parking is a solution to the inefficiency of parking provision that minimizes the necessity for parking provision. On the other side, on-street parking appears to be a difficulty and a risk,[29] as parking and maneuvering are one of the causes of road accidents.[26,76] It has been stated that in order to alleviate these issues, new initiatives in parking availability in core regions are required. Multi-storey parking is one of these inventions that has gained traction in the recent decade. However, finding an optimum site for establishing multi-storey parking is a multidimensional task due to complexity and multiplicity of actors and authorities, and their uncertain and conflicting behavior.

We used a combination of quantitative, and geographical models to understand the dynamics of parking demand and supply. We have focused on the issue of insufficient parking supply in the CBD of Metropolitan Shiraz. We first estimated parking supply and demand within the CBD area. While urban management authorities have worked in recent years to reduce parking provision by increasing public transportation, the demand for parking spaces in this metropolitan area is an indisputable issue that must be addressed.

As a result, we examined parking supply and demand from a broad viewpoint. Employees and commuters are the two primary users of parking.[35] While the latter is price sensitive, the latter adjusts parking costs based on the amount of time he or she has to spend on transit modes.[16] In the case of Shiraz, the parking supply study suffers from a lack of relevant data, such as turnover of parking spots and the actual number of practical on-street parking spaces. As a result, we augmented the available data by surveying the region and creating the most accurate database of available on-street and off-street parking spots in the case study. The parking space shortage is then determined in each traffic zone using a basic model of the discrepancy between supply and expected demand.

The next challenge is determining how to satisfy parking needs and where to position these suggested parking spots. The literature has a variety of site selection approaches. These models, however, are based mainly on the transportation infrastructure aspects. Parking provision management should be focused on land use considerations besides to the other factors such as the traffic volume, as done in traditional parking supply and demand studies.[15] In other words, the parking site location would be desirable if geographic, demographic, and economic considerations were all taken into account at the same time.[5,31]

The use of a GIS-based FMCDM provides a complete framework for making more logical, inclusive, efficient, and optimal judgments on the optimum locations for multi-storey parking spots. Furthermore, because kerbside parking in congested core city districts is limited owing to strong demand due to inexpensive price and convenience, economies of scale make parking development feasible in these regions.[22]

6. Conclusion

The purpose of this study was to establish a systematic framework for multi-storey parking site selection in the central area of Shiraz as a city with high motorization rate and shortage of public parking space. Making a choice in this respect should involve parameters from various perspectives, and the criteria should be based on geographical base. Therefore, determining the optimized placement for parking spaces, particularly multi-storey parking spaces that are more suited for central regions, is a multivariate problem. We used a mix of GIS and FMCDM to determine how and where to create parking spots. The most significant criteria for parking site selection are as follows: distance to travel attraction centers, distance to roads, land price, population density, and available land for multi-storey parking.

The expert panel (n = 11) is invited to score these criteria based on their personal contextual and subjective knowledge in a bottom-up approach. A hybrid process using GIS and FMDM determines the optimal location for building a parking structure. Meanwhile, the parking space shortage for each TAZ is calculated by subtracting the estimated parking space supply from the estimated parking space demand. An overlay of these two layers distinguishes locations that are in parking shortage zones and also meet multiple criteria.

Parking site selection and planning is only one area where GIS and the fuzzy MCDM may work together to provide improved results. Since GIS-based MCDM lets users create many scenarios, it offers a versatile strategy for problem solving and new points of view for city planners and administrators grappling with spatial issues. However, there were certain limitations in this study that might be addressed in future investigations. First, we included exclusively professionals from planning and transportation in the decision-making process, and future studies might include consumers and parking space users as well. Second, the needed parking requirement is based on the fact that other regulations do not contradict it. Some emerging strategies, such as carbon-zero cities, think that parking allocation should be dependent on the amount of carbon that cars produce in the city rather than supply and demand.

Future studies might include additional location-based data such as Point of Interest (POIs) to offer a more comprehensive picture of the variables influencing parking utilization in cities, or they could employ optimization methods to discover the best prospective locations for parking. Furthermore, to reduce traffic congestion in the city center, it is suggested that park-and-ride (P&R) systems be established to encourage commuters to reach the CBD area by switching from private automobiles to public transportation.[77] These schemes include providing P&R sites on the outskirts of built-up areas, close to major radial road corridors and metro stations, and on or near ring roads, which justify considering the distance to public transit stations (particularly underground metro stations in Shiraz) as a key factor in public parking site selection. Moreover, other factors from disciplines like the environment, society, and economy may be added to the mix to provide a more holistic

assessment of this issue. Parking management, in particular, requires more complete research and assessment in terms of parking demand, duration, availability, and so on, as planning rules and land use systems change in the era of low-carbon cities.[29] In fact, due to the environmental consequences of parking sites which are mostly covered by asphalt and non-permeable surfaces, the contribution of parking development on creating urban heat islands[78–81] should be considered in future research. In addition, since the parking topic needs the knowledge input of experts from other domains and those with multidisciplinary expertise, future study should see it as a large-scale GDM challenge[82] requiring the management of heterogeneous data.

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