Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 4, No. 6, June, 2018

An Innovative Method for Estimating the Spatial Distribution of Parking Demand in Different Areas

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Received 08 May 2018; Accepted 28 June 2018

Abstract

Parking facilities in the urban road network are of the most essential parts of the transportation and traffic system. Considering that many users are not interested in parking in or near the destination zone, or in some cases it is not basically possible to park in this area, the parking demand in each area is not merely associated with the actual land use of that area and is sometimes affected by the land use of the surrounding area. Therefore, estimating the spatial distribution of parking demand is essential to accurately determine the real parking demand, especially in non-marginal urban areas. In conventional methods of estimating the parking demand in each area, it is assumed that the parking areas are located in the same area or distributed uniformly in the surrounding areas, without considering the desirability of the surrounding areas, which has sometimes led to unrealistic estimations. Accordingly, new methods, capable of estimating the real parking demand in each area, are needed. In present study, an innovative method is proposed to predict the spatial distribution of parking demand and then it is applied to the central area of Tehran.

Keywords: Parking Demand; Parking Area; Spatial Distribution.

1. Introduction

In general, the time interval in which a car is stopped in the city is far longer than the time it is moving. So it needs a place to stop. Therefore, it should be possible to stop the vehicle, either for a long or short period of time. Meanwhile, the necessary facilities for accessing these places and the possibility of using them for everyone should be also provided. Therefore, parking facilities in urban road networks are of the essential parts of the transportation and traffic system.

The lack of sufficient parking area for cars and the lack of parking space in the downtown area have led the drivers to spend a lot of time to find parking lot and to cover extra mileage on their vehicle. This leads to increasing the traffic volume as well as increasing the air pollution, excessive fuel consumption, vehicle depreciation, and undesirable psychological effects. On the other hand, the lack of proper parking management policies leads to an uncontrolled increase in marginal parking, which results in reducing the capacity, reducing the speed, and increasing the accidents, especially in downtown areas.

Therefore, parking studies, as part of urban transportation planning studies, play a significant role in quantitative and qualitative improvement of transportation.

Basically, any planning and decision-making about parking in an area requires an estimation of the actual parking demand in that area. In conventional methods for estimating the parking demand in each area, it is assumed that the

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http://dx.doi.org/10.28991/cej-0309179

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parking areas are located in the same area or distributed uniformly in the surrounding areas, without considering the desirability of the surrounding areas, which has sometimes led to unrealistic estimations.

This is particularly noteworthy because many users do not tend to park in or near the destination zone, or in some cases there is basically no possibility of parking in this area. Therefore, the parking demand in a particular area is not merely associated with the land use of that area, and is sometimes affected by the land use of the surrounding areas. In conventional methods for estimating the parking demand in each area, it is assumed that the park spaces are located in the same area or distributed uniformly in the surrounding areas, without considering the desirability of the surrounding areas, which has sometimes led to unrealistic estimations. The importance of this issue becomes clearer when facing the lack of parking demand in some densely populated areas, or excessive parking demand in some areas despite the lack of travel-attracting land use. Therefore, it is necessary to accurately estimate the spatial distribution of parking demand in order to determine the real need for parking areas in different zones, especially in the field of parking area locating in non-marginal zones.

2. Research Background

Basically, several methods are being employed to estimate parking demand, some of which are highly complex due to factors such as population size, city size, number of personal vehicles, and portion of the trips made with the public transportation system, and the distribution of the land uses. On the other hand, other simplified methods are not capable of making very accurate estimations.

One of the most important methods for estimating parking demand is the use of parking rates. In this method, the parking demand for each type of land use is approximately determined using some tables prepared based on statistical methods .This method was firstly suggested by the ITE Institute in 1985. The ITE Institute published a book entitled "Parking Generation" which is continually being updated at certain time intervals. In this book, the rate of parking generation for different land uses is presented. In the third edition of this book, information about the parking demand for 91 land uses based on peak hours, different days of the week (working and non-working), months of the year, and type of zone, is presented in terms of parking demand rates [1]. The lack of sufficient accuracy in estimating the parking demand, ignoring the variation of the parking demand due to changes in traffic condition and surrounding land uses, the application of different parking policies, as well as restrictions on the geographical distribution of parking demand are of the limitations of this method. Because of the aforementioned limitations, this method is not capable of identifying the parking problems and possible solutions in a region. However, despite these problems, this method is widely used due to its simplicity [2].

In Iran, although the "parking rates" method has been employed in some cases, very few studies have been conducted to localize the parking coefficients, determine the coefficients in accordance with the country's condition, and present solutions to reduce or eliminate the probable disadvantages.

Ahmadi and Saeedian [3] estimated the parking demand in terms of type of land use in Mashhad. In this study, parking charts are obtained for 13 different land uses and the results are compared with the parking coefficients provided by the ITE Institute.

Darzi et al. [4] studied the parking demand for the administrative and commercial land uses in Tehran. The purpose of this study is to provide a model for estimating the parking demand of administrative and commercial land uses in Tehran in terms of some parameters such as area, number of employees, space per capita and so on.

Another research conducted by Asadi et al. [5] investigates the parking demand in work centers considering two categories of revealed demand and hidden demand. According to the results, the proportion of hidden demand to apparent demand for the study area is 0.43.

In 2007, Seyed Mousavi examined the lack of parking area in Isfahan and determined the required number of public parking areas with respect to population size, travel demand and the number of vehicles [6].

Xue et al. [7] investigated the parking demand prediction with scenario analysis. Compared with the traditional prediction methods, the scenarios of these prediction methods are single. With future scenarios have great changes, traditional prediction methods will no longer apply. In order to overcome these shortcomings, a parking demand forecasting method based on scenario analysis was proposed. By analyzing the situation of parking demand that may arise in the future, three scenarios were set up to analyze the influence factors of the parking demand. The data were processed and analyzed by SPSS software, the prediction model of parking demand and the parameters in the model were determined. Finally, the developed models were used to predict the parking demand of Beijing City in 2020 [7].

Zheng et al. [8] Focused on the CBD of urban area, taking its land and traffic characteristics into consideration, based on the intensity of trip attraction and traffic mode split, a model of parking demand forecasting for shared parking facilities in CBD.

Wu and Fan [9] presented a paper entitled "Model of the Parking Demand Prediction for Urban Complex". In this paper, the traveler behavior characteristics in Urban Complex are analyzed first and the correlation coefficients matrix among different functional subsystems is built. Then a modified parking generation rate model of the Urban Complex is developed. This model can eliminate the parking repetition in traditional parking generation rate model. The validation result shows that the model has higher accuracy in parking demand prediction [9].

Yao and Zhang [10] considered the parking demand in urban centers located in the Frigid Zone. As the parking demand in the urban centers located in the Frigid Zone is significantly affected by the climate, a parking demand prediction model based on random utility theory and consideration of different influencing factors is put forward in this paper in order to analyze the parking behavior. First, the model of the relationship between the static traffic demand and travel generating purposes is established. The model takes the ice and snow into account as factors affecting travel behavior. Then, the traffic volume prediction function, based on the traveling utilities of residents, is presented. Ultimately, the static traffic demand prediction model resulting from analysis of the residents' behavior in the considered area is accomplished [10].

Another research introduces the concept of regional development factors and the parking demand forecast takes full account of the economy, society, transportation and other levels of development affecting parking demand in different regions. We use development factors to modify the trip attraction model and then apply it to two Chinese districts [11].

Wong et al. presented a paper entitled "Development of Parking Demand Models in Hong Kong". This paper describes the parking demand models for private cars and goods vehicles developed as part of a parking demand study that was completed in Hong Kong in 1995. In the model, it is assumed that there is a linear and additive demand function relating land-use variables in a zone (such as jobs, schools, or households) with parking demand. Further, the parking activity associated with each land-use variable is assumed to have a unique parking accumulation profile. Surveys were conducted to determine these profiles. A unit graph, which is defined as the parking accumulation profile per parking activity, was constructed for each land-use variable. Given the land-use variables, the parking demand function and the unit graphs, the total parking accumulation profile in each zone is determined [12].

The other paper presents an idea to forecast the parking demand to each parking lot by traffic assignment model. It is assumed that each traveler chooses parking lot to minimize his or her generalized cost, including running time by car, waiting time in parking lot and walk time. The model can be used to estimate the parking demand to each parking lot and hence to evaluate the effect of parking policy and new parking lot [13].

Tiexin et al. [14] are the other researchers that have studied the parking demand estimation. On the basis of the Parking Generation Rate Model, the improved model was set up, considering more factors, such as the average turnover rate, parking place occupancy, service level, parking fees and growth rate of automobiles. Meanwhile, the capacity of road network is applied to rectify the short-term parking demand forecast. Finally, the model was applied to Binjiang Road CCD, Tianjin, China.

Ibeas et al. [15] improved a model to estimate parking demand. In their study, Multiple linear regression (MLR) and geographically weighted regression (GWR) models are used for estimating parking demand in areas with paid short stay parking systems. These models have been applied to the city of Santander (Cantabria, Spain) to check their goodness of fit and their predictive ability.

By reviewing 40,000 residents in Beijing, Yao et al. [16] analyzed the relationship between parking supply and private usage. They found that the vehicle ownership is influenced by income, family size, location, and parking fee.

Tembhurkar and Khobragade developed a parking demand model for Visvesvaraya National Institute of Technology in Nagpur, India. Several independent variables considered include trip attraction, trip characteristics, facilities, turn over and utilization rate [17].

Das et al. [18] studied on street parking demand using sensitivity analysis in Kolkata. The predicted demand was found to be three times higher than the supply. They suggested several actions to reduce on street parking such as to provide sufficient off-street parking spaces, increase on street parking fees, and improve public transport system. Therefore, it is required that every activity has to provide adequate parking spaces and proper parking management in order to reduce on-street parking.

3. The Proposed Method

In order to estimate the parking demand of a particular area in a given time period (for example, one hour) the total number of vehicles approaching that area, from the previous hours until the end of that period, must be examined. For this purpose, the vehicles that still occupy the parking area, with respect to their parking duration, must be considered. Accordingly, the trips are divided into several groups based on the characteristics affecting the parking duration, and each group is assigned a parking time. The easiest way to perform this method is to group them in accordance with the purpose of the trip. In this case, riding trips with the purpose of traveling "p" are attributed a parking time "τp". The interpretation of these numbers is that if a vehicle with trip purpose of p travels to a region at time ti, he will continuously occupy a parking area in that region until ti+ τp. Consequently, the parking demand per hour for a given area is equal to the parking demand of the vehicles arriving that area at that time, together with that of the vehicles parked in the previous hours and will remain at that time depending on their parking time. Therefore, it is necessary to determine the number of vehicles getting into that area at different times, separately for different trip purposes. Travel demand estimation models are employed to perform this task. Figure 1 shows the process of estimating parking demand.

But the travel demand estimation models determine the amount of vehicles merely for the traffic areas. People usually tend to park as close as possible and have the most convenient access to the intended land use. Therefore, they would accept to walk from the vehicle to the destination only for a distance not longer than a certain value (according to the results of numerous studies up to 400 meters). Hence, the study of parking demand at traffic area level, especially for traffic areas with relatively large dimensions, is not appropriate. Because it is possible that the final destination is area i, but due to the lack of parking lot or due to the particular condition of the road network in which sometimes the driver needs to go through a longer distance in order to get closer to the destination, one parks the vehicle in area j, which is in less distance than 400 meters from his destination. Therefore, it is necessary to create some areas called parking areas so that a large percentage of the parking demand related to existing land uses in that area, could be inclined toward parking in the same parking area and the determination procedure depends on the characteristics of the road network of the area and its land uses.

These parking areas consist of the total area of minor and major arterial streets, collector and distributor streets, and the traffic areas boundary (henceforth referred to as the "constituent units of the parking area"). It should be noted that this is due to the fact that, considering the existence of main roads around the parking areas, the majority of drivers park their vehicles in the parking area where their final destination is located and do not tend to park in the adjacent areas. On the other hand, since the traffic areas are selected in a way that the economic-social characteristics and land uses in the whole area are approximately uniform, the parking demand of each area is accurately proportional to the ratio of the unit area to the area of the traffic zone in which it is located. If the unit is located in several traffic areas, the demand for segments located in different traffic areas are separately estimated and summed up. Taking into consideration that the parking areas are comprised of different constituent units, the next step for estimating the parking demand is to combine the units and also to realize which units should be combined. This combination of units in the formation of parking areas is considered in such a way as to ensure that the parking location is desirably close to the destination. Toward this goal, a locating problem is defined and appropriate solution is presented. In this problem, a number of units that have the highest concentration of land uses and thus the highest rate of travel attraction are considered as virtual destinations for the trips to that parking area, and the rest of the units are considered as the possible parking areas for visitors to these virtual destinations, in such a way that the amount of walking in the entire area is minimum, and the mean value of walking distance in each parking area is less than or equal to the desirable walking distance which is taken herein as 400 meters.

$$Min\, z = \sum_{i \in I} \sum_{j \in J_i} d_j x_{ij} l_{ij} \tag{1}$$

$$\sum_{i \in I} x_{ij} = 1 \qquad \forall j \tag{2}$$

$$\sum_{j \in J_i} x_{ij} \le B y_i \qquad \forall i \in I \tag{3}$$

$$\frac{\sum_{i} \sum_{j \in J_i} d_j x_{ij} l_{ij}}{\sum_{j \in J_i} d_j x_{ij}} \le 400 \qquad \forall i \in I \tag{4}$$

$$\sum_{i} l_{ij} x_{ij} \le \frac{\sum_{i} y_i\, l_{ij}}{\sum_{i} l_{ij}} \tag{5}$$

$$x_{ij} = 0\, or 1 \tag{6}$$

$$y_{ij} = 0\, or 1 \tag{7}$$

Where;

J: The set of parking units.

I: The set of candidate areas for virtual destinations.

d_j: Parking demand of visitors of destination j.

l_{ij}: The distance between the centers of the parking units.

J_i: The set of parking area units that can be attributed to the virtual destination i.

B: A large number.

y_i: If i is considered as the selected unit for the virtual destination 1, otherwise, 0.

x_{ij}: If the parking unit j is attributed to the park unit i as a virtual destination 1, otherwise, 0.

Equation 1 indicates that the parking areas are determined in such a way as to minimize the amount of walking distance between parking units and the selected virtual destinations.

Equation 2 shows that each parking unit is attributed only to a single virtual destination, while 3 indicates that only if unit i is selected as the virtual destination (y_i=1), a parking unit can be attributed to it.

Equation 4 describes the limits of walking distance in each parking area.

Equation 5 indicates that each parking unit is attributed to a virtual destination which is located at a distance less than the distance from other virtual destinations. This is due to the fact that people tend to park in closest possible location to their final destination.

The aforementioned locating model is a large-scale integer planning problem with a very complicated and time-consuming solution especially for large cities. A strategy to solve this problem for a real problem is to reduce its dimensions. For this purpose, the set Ji is considered for the candidate unit i. It should be noted that parking at distances far away from destination, apart from the walking distance issue, results in undesirable psychological effects. Therefore, it is noteworthy about the set Ji that attributing a parking unit to a very distant candidate unit sounds so unrealistic. So the set can be defined as:

$$J_i = \{ j \mid l_{ij} \leq 1km \} \tag{8}$$

Thus, the number of variables x_{ij} is greatly reduced. Another way to achieve this is to reduce the number of candidate units for virtual destinations. In a way that only the units with a greater chance of final selection are included in the set I. This reduces the number of both variables y_i and x_{ij} variables.

After solving the above problem, the parking units whose virtual destinations are the same are considered as a parking area, where the demand for each of these areas is equal to the total demand of the constituent parking units.

4. Spatial Distribution of Parking Demand for the Central District of Tehran

Based on the proposed method of present research, for estimating the spatial distribution of parking demand it is required to estimate the number of vehicles with the destination of each area, which will not necessarily stop in that area. Therefore, the estimation of parking demand for each area is firstly initiated with the assumption that all the vehicles getting into a destination area are parked in the same area and sufficient parking space is also provided there. In this study, the number of vehicles getting into a traffic area at different hours and depending on the trip purpose is obtained from the results of the modeling of Tehran transport system utilizing emme2 software.

Emme2 is a complete travel demand modelling system for urban, regional and national transportation forecasting. Emme2 is used in over half the world's most populous cities and runs some of the world's most complex transportation forecasting models. The most advanced modellers in the industry have relied on Emme2's flexible, open modelling approach to easily leverage established techniques or to adapt and innovate to new model applications with unrivaled flexibility. Emme2 offers a transport modeling application framework for leading computational performance and unmatched technical rigor, and makes assembling model workflows efficient. Figure 1 shows an example of software outputs in Tehran.

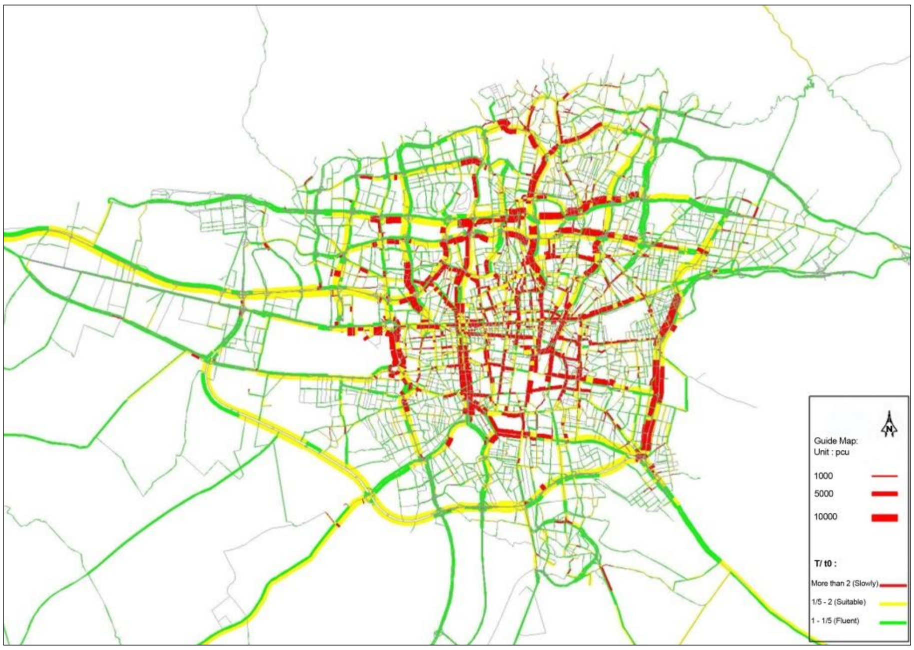

Figure 1. Example of Emme2's outputs in Tehran

Afterwards, according to the average parking time of each trip purpose which is obtained from the results of the databases of the origin-destination trips in Tehran (Table 1), the parking demand of each area is determined based on the aforementioned assumption.

Table 1. Average parking time for different trip purposes (hr)

Trip purpose	Work	Education	Shopping	Free-time	Non home-base
Parking time	7	6	2	3	2

The formation of parking units is the next step for estimating the parking demand. According to the proposed method of present research, these units are considered to be the areas confined between the degree 1 and 2 arterial streets, collectors and distributors, and the boundaries of traffic areas. Accordingly, the central area of Tehran metropolis which includes 142 traffic areas is divided into 1113 parking units. As noted above, the parking demand for each of these parking units is proportional to the ratio of the unit area to the area of the traffic area. It should be noted that if all these areas are considered as candidate areas for virtual destinations (I=J) and each unit can be attributed to the candidate areas, then we will face a problem with about 10^6 integer variables. However, if only some of the units can be attributed to each of the candidate areas (according to the definition of set Ji) and if the average number of members in each of these sets is assumed to be 20, then the number of variables will be reduced to about 25,000 variables. Although the number of variables is decreased, solving the problem is still very time-consuming. Therefore, it is necessary to reduce the variables as much as possible. Toward this goal, the number of candidate areas for virtual destinations is reduced. In accordance with the objective function of the locating problem, an important and key factor in the selection of candidate units for virtual destinations is the parking demand of existing land uses in those areas. Certainly, the larger value of this quantity for one unit, the unit will have a greater chance of being selected. Thus, the units with a parking demand of more than 1000 vehicles in the peak time interval are considered as candidate areas for virtual destinations. Accordingly, the number of candidate units is reduced to about 500 units.

After solving the above problem, considering the aforementioned items, the parking areas are obtained as shown in Figure 2.

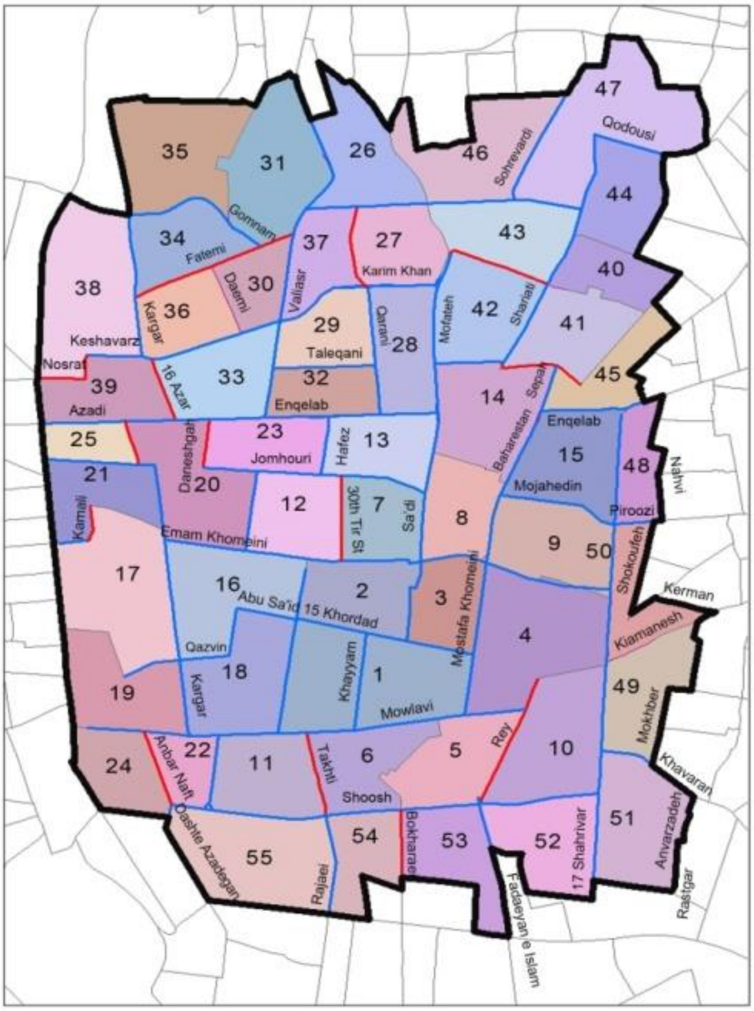

Figure 2. Parking areas formed based on the proposed method

As is clear from Figure 1, some of the parking areas have a larger area compared with the others, and consequently, the walking distance in these areas may exceed the maximum limit. These parking areas are made up of only one constituent unit and have a large area due to the large area of their constituent unit. But this shows no discrepancy with the behavior of drivers who are willing to walk up to a maximum distance of 400 meters from the parking area. Because according to the pattern of parking units' formation, the wideness of a parking area implies the long distances between the main roads, and this indicates the concentration of land uses in a specific area. In other words, the development of land uses leads to the development of transportation and the development of transportation leads to the development of land uses.

Taking into account that the parking demand of each parking area is equal to the total parking demand of its constituent units, the parking demand of each area is obtained and presented in Table 2.

Table 2. The final parking demand for different parking areas

Parking area	Parking demand	Parking area	Parking demand
1	30019	29	7125
2	8330	30	4625
3	4707	31	6415
4	2853	32	5785
5	1638	33	10386
6	1385	34	6052
7	6821	35	3327
8	6608	36	2914
9	1512	37	4960

10	1828	38	4252
11	2736	39	6381
12	4872	40	1257
13	6254	41	1473
14	4933	42	4185
15	2285	43	42158
16	2005	44	1986
17	3285	45	2583
18	2367	46	6986
19	2355	47	6649
20	5450	48	2499
21	2175	49	1532
22	2285	50	1568
23	4673	51	1945
24	1563	52	2143
25	1971	53	1980
26	11852	54	398
27	4445	55	901
28	6397	Total	280069

5. Conclusion

Basically any planning and decision-making about the parking area in a region requires an estimation of the actual parking demand in that region. The actual demand is the demand based on the practical tendency to park in that area and does not necessarily commensurate with the prevailing land uses. This is due to the fact that several factors can affect the parking behavior, the most important of which are accessibility, traffic condition of the area, uncertainty in finding appropriate parking area and so on. Accordingly, a fraction of the parking demand of each area is willing to park in the surrounding areas. However, in conventional methods for estimating the parking demand in each area, it is assumed that the parking areas are located in the same area or distributed uniformly in the surrounding areas, regardless of the desirability of these regions, which has sometimes led to unrealistic estimations. The critical condition of parking on the passageways around subway stations can be deemed as an example of this issue. Therefore, the correction of the estimated parking demand for each area based on its land uses is a necessary step in estimating the real parking demand for each region.

In present study, a method was proposed in which the study area is divided into some areas known as parking area. The formation of these areas was made in such a way that the parking location in each area is in the first priority for the vehicles with the final destination of that area, and parking in the surrounding areas, except in certain cases, is not desirable. Therefore, the proposed method can be promisingly utilized in the field of parking planning. Other advantages of the proposed method include the possibility of considering the effects of transportation policies such as developing the public transportation system, imposing restrictions on personal vehicles such as the extending the traffic limitation zones, the movement of land uses, etc. Therefore, the parking areas benefit from a dynamic nature and it is possible to form different parking areas based on the transportation policies.

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