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Modeling the Effect of Parking Fare on Personal Car Use

A. Khodaii[1], **E. Aflaki**[1,*] **and A. Moradkhani**[1]

Abstract. *In this paper, passenger behavior when travelling to business districts using their own cars, and when confronting various parking fares, is discussed. The final goal is to determine the parking fare threshold (the price at which passengers would refrain from using their own cars) in the central business district of Tehran. Also, effective variables that affect passenger reaction at different levels of parking fare are evaluated. A logit model was made to predict passenger behavior using data gathered in different parking lots, located in the surveyed area. Data have been collected by a stated and revealed preferences method. Characteristics related to passengers and their trips, as well as their reaction to a rise in parking fares, were collected by a questionnaire. Analysis of the model showed that a 400 Tomans/hr increase in the hourly parking fare would eliminate the use of personal cars by the passengers (99% decreases in personal car use). It is concluded that travel time and passenger monthly income are the most influential parameters affecting personal car usage.*

Keywords: *Tehran traditional business district; Parking fare; Binary logit model; Personal car; Travel time; Monthly income.*

INTRODUCTION

Undoubtedly, policies related to parking play a significant role in urban management of major cities all over the world. These policies not only affect the parking systems but also have an enormous effect on the transportation infrastructures and socio-economic affairs of a city. Among these policies, the ones related to parking prices always include some of the most important discussions in the travel demand management field for congested parts of cities, like CBD areas [1]. In recent years, because of the increase in traffic congestion in Tehran, application of policies related to parking cost, as one of the solutions for reducing personal car usage and propagating the culture of public transportation use, is considered by researchers, experts and urban management organizations [2]. One of the most crowded areas of Tehran that is overwhelmed with traffic and transportation problems is the traditional business district (Traditional Bazaar). Nowadays, there are many problems due to personal car use, such as increased air pollution, fuel consumption, traffic jams and road obstruction. So, discovering an effective solution for these problems in this quarter of Tehran seems to be crucial. This region is the most important business district in Tehran. In addition, it is the destination of a number of people who prefer to drive their own cars to get into this area, despite traffic limitations, parking controls and renovations in the public transportation system.

Many studies have been undertaken to peruse passenger behavior in several important and crowded cities worldwide. Using a binary logit model, a case study has been performed in the CBD of Athens by Dimitrios A. Tsamboulas [1], which analyzes drivers parking behavior when confronting various parking prices policies. Kardi Teknomo and Kazunori Hokao [2] carried out a similar research in Surabaya, Indonesia. Other studies [3] describe the travel mode choice behavior of drivers that use Eindhoven University parking, encountering various policies. But, there is no particular study about the Tehran traditional business district. In this study, an effort has been made to dispel this shortcoming.

1. *Department of Civil Engineering, Amirkabir University of Technology, Tehran, P.O. Box 15914, Iran.*
*. *Corresponding author. E-mail: eaflaki@aut.ac.ir*

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In this paper, after giving a short description of the surveyed area and data gathering, the effect of parking fares on passenger behavior is analyzed, and the effects of the most important variables in travel mode choice were discussed.

SURVEYED AREA

The surveyed area in this paper is the Tehran traditional business district (Traditional Bazaar). This region extends from the north to Imam Khomeini and Amirkabir streets, from the east to Rey Street, from the south to Shoosh Street and from the west to Vahdat Eslami Street, as shown in Figure 1. The area of this quarter is approximately 6 km^2 and its population is about 50000. About 3 km of the Tehran metro lines passes through this area and there are 4 metro stations along it. In an initial survey, it was found that there are 35 parking lots in this area, only 28 of which are in use; parking capacity differs from 50 to 180 vehicles. The parking locations considered for data collection are shown in Figure 1.

REQUIRED DATA COLLECTION

The purpose of data collection is to gather passenger characteristics, their trip properties and an evaluation of driver behavior when encountering changes in parking fares. The gathered data, directly or indirectly, were inputs of a model for analyzing the parking fare effect on travel mode choice in the traditional bazaar district. In this research, three different groups of data were collected:

Figure 1. Surveyed area (Tehran Traditional Bazaar).

- Information related to the personal, social and economical characteristics of passengers.
- Information related to the trip and travel mode used by passengers.
- Information related to passenger response to changes in parking fare [3].

The required information was collected by the stated and revealed preferences method, using a questionnaire including 22 questions about passenger criteria, their trip characteristics and their reactions to an increase in parking fare. Hypothetical prices created to evaluate passenger reactions were 500, 750, 1000, 1500 and 2000 (Tomans/hr). Direct interviews were used to complete the questionnaire for increased accuracy. To achieve the most applicable questionnaire, 30 trial questionnaires were filled out in different parking lots in the survey area and the results were used to modify the questions and compile the final questionnaire. Because no one selected 2000 Tomans/hr as the price to ignore personal car use, this level of pricing has been removed from the questions.

Data were collected by a team of 5 members over 10 days at 6 different parking lots in the surveyed area during working days from 4 pm to 7 pm. The chosen parking lots were the most important because of their significant demand and capacity. Assessment of completed questionnaires showed that 16 of them were useless due to defective information. The numbers of completed questionnaires prepared in each parking lot were proportional to its capacity.

Admitting that the effective parameters influencing mode choice are more than those expressed in this paper, the study attempted to discuss those which other researchers have reported as being the most important [4]. In this research, seventeen variables were used, eleven of which were mode abstract and others being mode specific. Five of the mode abstract variables are dummy ones (Table 1). Dummy variables are those which get a value of 1 if the event happens, and a value of zero otherwise [5]. Dummy variables that have been used in this study are described below:

1. The "gender" variable is set equal to 1 for male interviewees, and equal to 0 otherwise.
2. The "decision to cancel or continue the travel by personal car" variable is set equal to 1 when the interviewee persists on using his/her personal car if encountered with a parking fare increase, and set equal to zero if he/she changes the mode of travel.
3. The "using the personal car for all trips" variable is set equal to 1 when the interviewee uses his/her personal car in all his/her trips to the surveyed area, and set equal to 0 otherwise.
4. The "walking from parking to the final destination" variable is set equal to 1 when the interviewee walks

Table 1. Collected variables and their types.

No.	Variable	Type
1	Age	Mode abstract
2	Car ownership	Mode abstract
3	Family population	Mode abstract
4	Driver license	Mode abstract
5	Monthly income	Mode abstract
6	Number of trips per week	Mode abstract
7	Gender	Mode abstract (dummy)
8	Decision to cancel or continue traveling by personal car	Mode abstract (dummy)
9	Using a personal vehicle for all trips	Mode abstract (dummy)
10	Walking from parking to destination	Mode abstract (dummy)
11	Trip purpose	Mode abstract (dummy)
12	Travel time	Mode specific
13	Parking cost	Mode specific
14	Parking search and queue time	Mode specific
15	Travel time between parking lot and destination	Mode specific
16	Travel cost	Mode specific
17	Parking time duration	Mode specific

the distance between the parking lot to his/her destination, and set equal to 0 if he/she chooses another mode.

5. The "trip purpose" variable is set equal to 1 if the purpose of the interviewee is a work trip, and set equal to 0 otherwise.

During interviews, it was found that the majority of passengers travel to this area for shopping and work. Also, approximately, all shopping trips have a business purpose. Therefore, in this study, shopping trips were put into the group of work trips. Collected variables and their types are categorized in Table 1.

After asking interviewees the questions related to different variables, their behavior under supposed hypothetical conditions should be studied. At this stage, the passenger was asked which level of parking fare would tempt him/her to cancel personal car usage. Then, passenger hypothetical trip characteristics, if another mode of travel instead of personal car use has been chosen, were questioned.

The proposed alternative modes in this study are:

1. trip by taxi,
2. trip by bus,
3. trip by metro,
4. trip by motorcycle, itemcancelling the trip.

MODELING

In this research, two different procedures have been used to analyze passenger behavior when encountering various parking fares.

The first procedure leads to obtaining the parking fare threshold and the second determines the variables that have a significant effect on passenger behavior for each level of parking pricing. A binary logit model was used in the format below [6]:

$$P_{\text{car}} = \frac{\exp\,(U_{\text{car}})}{\exp\,(U_{\text{car}}) + \exp\,(U_{\text{noncar}})}$$

$$= \frac{1}{1+\exp\,(U_{\text{noncar}} - U_{\text{car}})} = \frac{1}{1+\exp\,(\Delta U)},$$

$$\Delta U = U_{\text{noncar}} - U_{\text{car}} = \sum\,(\alpha_i - \beta_i)X_i, \tag{1}$$

where:

P_{car}: Probability of using personal car
U_{car}: Utility value when a personal car is used
U_{noncar}: Utility value when a personal car is not used
X_i: The ith variable
α_i: The ith variable's coefficient in the U_{car} expression
β_i: The ith variable's coefficient in U_{noncar} expression

Table 2. Statistical characteristics of the models.

Model	$L(\beta)$	$L(0)$	Number of Variables	Degrees of Freedom	Critical t	ρ^2	χ^2	Critical χ^2
1	-194.61	-787.42	8	1128	1.962069	0.752847	1185.61	15.51
2	-162.39	-787.42	10	1126	1.962083	0.793762	1250.04	18.31
3	-120.97	-787.42	7	1129	1.962067	0.846369	0.89	14.07
4	-473.92	-787.42	6	1130	1.962066	0.398123	626.98	12.59

First Procedure of Modeling

In this procedure, gathered information was analyzed to identify the effect of various parameters, such as parking fare, on the choice of personal car or other modes. "Gauss" software (version 1.49) was used for optimization. The software outputs, in addition to coefficients related to variables, include the statistical t-value, the standard error of variables and the value of the maximum probability function related to the models. In the accomplished modeling process, all interviewee reactions when confronting different proposed parking fares were used in the model. Regarding the 4 different levels of parking fare for studying the behavior of 284 passengers, one comprehensive model with 284*4 (1136) observations was made. The parking fare (as one of these variables), was inserted into the model and its effect on passenger decision making, considering its sign and value, was studied [7]. By inserting different variables into "Gauss" software by a trial and error procedure to achieve a satisfactory model with suitable statistical specifications, 4 models were established whose statistical parameters are shown in Table 2. It is noticeable that the main measure for selection of the best model is the t-statistic.

Although model 2 consists of more variables, at first glance it would appear that model 3 is more suitable than others because of its better statistical specifications. But, by considering model 2, it is possible to study the effect of more variables, as mentioned before, such as age, gender, using or not using a personal car for all trips, parking time duration and trip purpose. On the other hand, in model 2, the hourly parking fare was inserted into the model independently, while in model 3, this variable was inserted into the model as the ratio of the hourly price of parking to parking time duration. Thus, model 2 was selected for studying the effect of parking fares on personal car use. Considering coefficients signs, the variables with inconsistent signs were omitted from the model and the procedure was repeated. The final structure of model 2 is expressed by Equation 2:

$$\begin{aligned}\Delta U_2 = {} & 0.026869 \text{ (parking hourly price)} \\ & - 2.098246 \left(\frac{\text{number of driving license owners in the family}}{\text{household size}} \right) \\ & - 0.024460 \text{ (monthly income)} \\ & - 1.045121 \text{ (trip purpose)} \\ & + 0.022325 \text{ (travel time)} \\ & -3.238913 \text{ (using the personal car for all trips)} \\ & - 1.897030 \text{ (ln (number of travels per week))} \\ & - 2.674244 \text{ (ln (age))} + 1.617552 \text{ (gender)} \\ & + 0.411824 \text{ (parking duration time)}. \qquad (2)\end{aligned}$$

Considering the variables coefficients in the model, their effect on the use of personal cars as a mode choice can be studied. The positive sign expresses the fact that increasing the related variable leads to a decline of personal car use, and the negative sign indicates that by increasing the related variables, the probability of using personal cars would increase. The coefficients and their statistical properties have been described in Table 3.

The results obtained from the model can be expressed as below:

- As expected, by increasing the parking fare and parking time duration, the probability of personal car use would be decreased.
- In families where driving license holders are more, there will be much more tendency to use personal cars.
- Individuals with higher monthly incomes would have more inclination to drive their own cars.
- Those people who take working trips to the surveyed

Table 3. Outputs of the Gauss software.

Variable	Coefficient	Standard Error	*t* Value	*P*-Value
Hourly parking cost	0.026869	0.003572	7.523079	0.000000
Ratio of driving license owners to family population	-2.098246	0.699487	-2.999694	0.002703
Monthly income	-0.024460	0.003849	-6.354082	0.000000
Travel purpose	-0.045121	0.460957	-2.267286	0.023373
Travel time	0.022325	0.006443	3.464742	0.000531
Using personal car for all trips	-3.238913	0.620877	-5.216679	0.000000
Logarithm of the days of the trip in a week	-1.897030	0.524132	-3.619377	0.000295
Logarithm of the age	-2.674244	0.450847	-5.931597	0.000000
Gender	1.617552	0.703660	2.298769	0.021518
Parking time duration	0.411842	0.133311	3.089331	0.002006

region (shopping and business trips) would prefer to use their personal car.

- By increasing travel time, the tendency of using personal cars will decrease.
- People who prefer to use personal cars to travel to the traditional bazaar district do not like to change their habits.
- People who take more trips to the traditional bazaar district prefer to use personal cars.
- The elderly use personal cars more than younger people.
- More women prefer to drive their own cars rather than men.

The effect of parking fares on personal car usage, which is the main subject of this study, is represented by Equation 3 and the related chart (Figure 2) for different values of parking fare. It should be noted that to derive this equation, all parameters were set equal to the average of the observed data, except the parking fare that is inserted in the model as a variable given by Equation 3 [8]:

$$P_{\text{car}} = \frac{1}{1+\exp\left(-13.9803+0.026869\ (\text{Parking cost})\right)}. \quad (3)$$

Figure 3 shows a change in probability of personal car use versus parking fare increase. It shows that a 400 Tomans/hr increase in the current parking hourly fare (300 Tomans/hr) results in an unexpected decrease in the probability of personal car use. Further increase in parking hourly fare has no considerable effect on personal car use.

Results show that 100, 200, 300 to 400 Tomans/hr increase in parking fare would lead to 3.5%, 36.5%, 89% and 99% decrease in the probability of using personal cars, respectively. It shows that 700 to 800 Tomans and

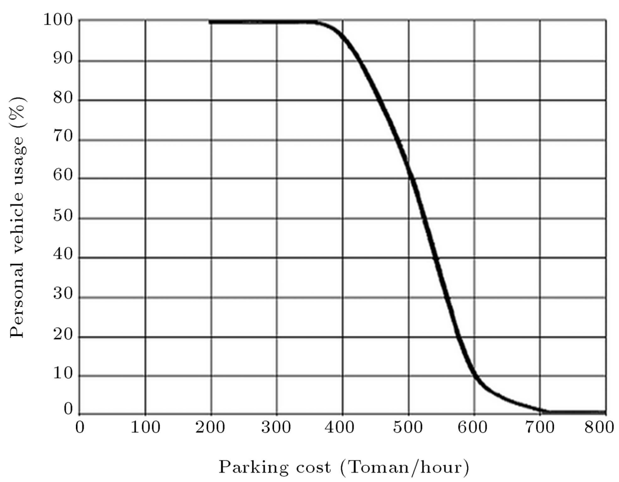

Figure 2. Parking fare effect on personal car use.

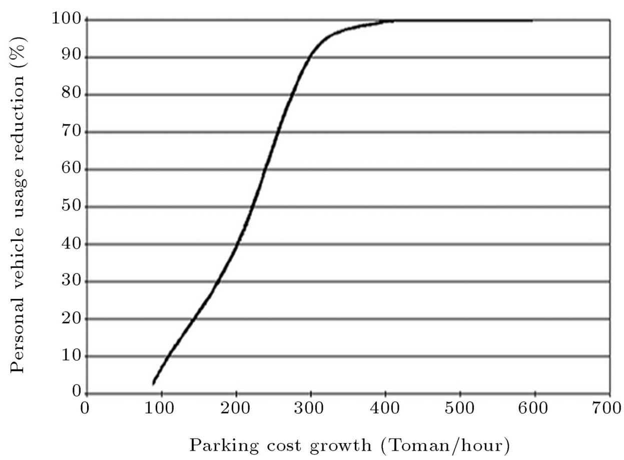

Figure 3. Personal car use reduction versus parking fare growth.

more for each hour of parking would compel drivers to choose modes other than personal car usage.

Second Procedure of Modeling

In this procedure, using Gauss software, the models of mode choice are constructed for 4 different parking fares, which could include different variables at different pricing levels. Coefficients of variables and software outputs for each model are shown in Tables 4 to 7. In this process of modeling, the parking fare was not entered in the model as a specific variable. The purpose of this procedure is the determination of variables that affect passenger decisions when confronting different levels of parking pricing. Equations 4 to 7 of the models are described below:

- For parking fee of 500 Tomans/hr:

$$\Delta U_{500} = -3.023140 - 0.020992\ (\text{income}) + 0.029799\ (\text{trip time}) + 0.043454\ (\text{age}) + 0.039061\ (\text{parking to distination}). \quad (4)$$

- For parking fee of 750 Tomans/hr:

Table 4. Software outputs for 500 Tomans per hour.

Variable	Standard Error	t Value	P-Value
Constant	0.891290	-3.391871	0.000694
Monthly income	0.005714	-3.673479	0.000239
Travel time	0.008779	3.394372	0.000688
Age	0.017879	2.430451	0.015080
Walking time to destination	0.657479	-2.267245	0.023375

Table 5. Software outputs for 750 Tomans per hour.

Variable	Standard Error	t Value	P-Value
Constant	0.566226	-4.046814	0.000052
Monthly income	0.002241	-4.052314	0.000051
Travel time	0.006860	6.907531	0.000000
Gender	0.466384	2.686298	0.007225
Travel purpose	0.409120	-2.120891	0.033931

Table 6. Software outputs for 1000 Tomans per hour.

Variable	Standard Error	t Value	P-Value
Monthly income	0.002151	-4.372064	0.021336
Trip time duration	0.006986	6.416270	0.022351
Number of trips in a week	0.073906	1.974578	0.048789

Table 7. Software outputs for 1500 Tomans per hour.

Variable	Standard Error	t Value	P-Value
Constant	0.066336	2.317749	0.020463
Monthly income	0.005932	-2.388789	0.021336
Travel time	0.012551	2.284354	0.022351

$$\Delta U_{750} = -\,2.291413 - 0.009080\text{ (income)} + 0.047387\text{ (trip time)} + 1.252847\text{ (gender)} + 0.867700\text{ (trip purpose)}. \quad (5)$$

- For parking fee of 1000 Tomans/hr:

$$\Delta U_{1000} = -\,0.009405\text{ (income)} + 0.044824\text{ (trip time)} - 0.129674\text{ (trip in week)}. \quad (6)$$

For parking fee of 1500 Tomans/hr:

$$\Delta U_{1500} = 2.471498 - 0.009898\text{ (income)} + 0.028670\text{ (trip time)}. \quad (7)$$

Statistical characteristics related to the models are shown in Table 8.

Results show that by increasing parking cost, the number of variables that affect driver behavior will decrease and only travel time and monthly income will affect travel mode choice. (For expensive parking fares, drivers are sensitive only to travel time and monthly income.)

CONCLUSION

In this paper, the effect of parking fares on personal car use in the Tehran traditional business district was studied. The study led to the determination of a parking fare threshold in this area and the variables affecting passenger decisions for different levels of parking fare. Two models were proposed in this research.

In the first model, the constructed model has a logit structure and results show that a 100, 200, 300 to 400 Tomans/hr increase in parking fare would lead to 3.5%, 36.5%, 89% and 99% decrease in the probability of using personal cars, respectively. So, the parking fare threshold is between 700 and 800 Tomans/hour.

It is noticeable that a decrease in the parking hourly fare from 300 to 200 Tomans/hr has an insignificant effect on personal car use (about 0.3%). Also, an increase in parking fare of more than 800 Tomans/hr, practically, would not affect driver behavior.

Besides the effect of parking fare on personal car use, which was presented by the model, the effects of the other variables on using personal cars were obtained. These can be summarized in two different categories:

1. People with higher incomes are more interested in using their personal cars for business trips due to the high value placed on their time. Personal car usage is still a more favorable mode of travel in contrast to public transportation services. So, it seems that by improving the public transportation system to render conditions more comfortable for the passengers, and by decreasing travel time, people could be encouraged to use public transportation systems rather than personal cars, without increasing any tariff related to trips, such as parking fares.
2. Increasing parking fares would cause a decrease in the number of variables affecting passenger decisions. Therefore, the tendency to use personal cars is mostly affected by monthly income and travel time. It shows that in order to manage driver behavior at high levels of parking fare, it is logical to work on these parameters. The effective variables on passenger decisions are shown in Table 9, as a result of the second process of modeling.

Table 8. Statistics characteristics of the models.

Model	$L(\beta)$	$L(0)$	No. of Variables	Degrees of Freedom	Critical t	ρ^2	χ^2	Critical χ^2
1	-75.89	-196.85	5	279	1.968503	0.585979	230.70	11.07
2	-152.05	-196.85	5	279	1.968503	0.206147	81.16	11.07
3	-119.09	-196.85	3	281	1.968442	0.385979	151.96	7.81
4	-46.17	-196.85	3	281	1.968442	0.765456	301.36	7.81

Table 9. Main variables according to different parking cost levels.

Parking Cost (Tomans/hour)	Main Variables			
500	Income	Travel time	Age	Walking time to destination
750	Income	Travel time	Gender	Travel purpose
1000	Income	Travel time	Number of trips in a week	
1500	Income	Travel time		

REFERENCES

1. Tsamboulas, D.A. "Parking fare thresholds: a policy tool", *Transport Policy*, **8**(2), pp. 115-124 (2001).
2. Teknomo, K., and Hokao, K. "Parking behavior in central business district- a case study of surabaya", *Indonesia, EASTS Journal*, **2**(2), pp. 551-570 (1997).
3. Farrel, S., O'Mahony, M. and Caulfield, B. "Attitudes and behavioral response to workplace parking measures", *EJTIR*, **6**(4), pp. 301-312 (2006).
4. Kuppam, A.R. and Pendyala, R.M. "Analysis of discrete stated responses to parking pricing based transportation control measures", in *Sixth TRB Conference on the Applications of Transportation Planning Methods, Transportation Research Board*, R. Donnelly and J. Dunbar, Eds., National Research Council, pp. 197-207 (1997).
5. Hess, D.B. "Effect of free parking on commuter mode choice: Evidence from travel diary data, *Transportation Research Record*, Transportation Research Board of the National Academies, **2001**, pp. 35-42 (2001).
6. Hess, S. and Polak, J.W. "Analysis of parking behavior using discrete choice models calibrated on SP datasets", Center for Transport Studies, Imperial College London, p. 29 (2004).
7. D'Acierno, L., Gallob, M. and Montella, B. "Optimization models for the urban parking pricing problem", *Transport Policy*, **13**(3), pp. 34-48 (2006).
8. Washbrook, K.F. "Estimating commuter mode choice: A discrete choice analysis of the impact of road pricing and parking charges", *Transportation*, Springer Netherlands, **33**(6), pp. 621-639 (2006).

BIOGRAPHIES

Ali Khodaii is an associate professor of civil and transportation engineering with over 25 years of industrial experience in transportation, planning, project management and consultancy. In addition to teaching many transportation subjects at undergraduate and postgraduate levels, he has published numerous papers in local and international journals and three text books. He has worked as technical advisor to the Civil Aviation Organization, a technical manager of Tehran International Airport and as project manager of an industrial port and harbour in the Bushehr province of Iran.

Esmail Aflaki is an assistant professor in engineering, geology and geotechnical engineering with 30 years of industrial experience in geotechnical engineering projects and consultancy. In addition, he has taught courses at undergraduate and postgraduate levels. He has published two text books and numerous papers in local and international journals and conference proceedings.

Ali Moradkhani received his BS degree in civil engineering from the University of Tehran and a MS degree in road & transportation engineering from Amirkabir University of Technology, Tehran, in 2008. His research experience includes transportation demand analysis, road and transportation safety & traffic engineering. He also has work experience in transportation engineering, traffic engineering, roadway geometric design, Pavement Management Systems (PMS) and structural design and construction.