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Urban Accessibility and Affordability: A Case Study for Istanbul

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Abstract: Application of sustainable transportation policies for resolving the transportation problem of Istanbul that has a population of 14.7 million in 2015 is of vital importance. This study focuses on economical and social goals of sustainable transportation by researching the relationship between urban accessibility, affordability and the transportation system. The purpose of this study is to investigate the combined role of affordability and accessibility and to introduce an accessibility measure to compare different transportation infrastructure schemes in Istanbul. For this purpose, the accessibility has been measured by means of a joint logit model. The main outcomes have been shown on an accessibility map and an elasticity analysis has been presented for different user groups. It has been concluded that accessibility is much higher in the central areas and decreases in the outskirts of the city. Results of the joint logit function have indicated that the effects of gender, income and car availabilities on mode choice are significant. The elasticity analysis has shown that mode choice decisions of car users are not sensitive to the transportation cost.

Kentsel Erişilebilirlik Ve Ödenebilirlik: İstanbul İçin Bir Durum İncelemesi

Anahtar Kelimeler
Kentsel Erişilebilirlik,
Ödemebilirlik,
Birleşik Logit Model

Özet: 2015 yılı itibarıyla 14,7 milyon nüfuslu İstanbul'un ulaşım problemlerinin çözümü için sürdürülebilir ulaşım politikaları hayati önem taşımaktadır. Bu çalışma, kentsel erişilebilirlik, ödenebilirlik ve ulaştırma sistemi arasındaki ilişkiyi araştırarak sürdürülebilir ulaştırmanın ekonomik ve sosyal hedeflerine odaklanmıştır. Bu çalışmanın amacı, ödenebilirlik ve erişilebilirliğin birleşik etkisinin incelenmesi ve İstanbul için farklı ulaştırma yatırımı şemalarının karşılaştırılabileceği bir erişilebilirlik ölçütünün sunulmasıdır. Bu doğrultuda birleşik logit model ile erişilebilirlik hesapları yapılmıştır. Çıktılar görselleştirilerek erişilebilirlik haritası oluşturulmuş ve farklı kullanıcı grupları için esneklik analizi yapılmıştır. Çalışmada, erişilebilirliğin kent merkezindeki bir çekirdek alanlarda yüksek olduğu, dış kısımlarda azaldığını sonucuna varılmaktadır. Birleşik logit model sonuçları cinsiyet, gelir, otomobil sahipliliği değişkenlerinin tür seçimi üzerinde önemli bir etkisinin olduğunu vurgulamaktadır. Esneklik analizi, otomobil kullanıcılarının tür tercihi kararlarının ulaşım maliyetine duyarlı olmadığını göstermiştir.

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1. Introduction

Transport and infrastructure development enables economic and social development but is often detrimental to sustainable development due to congestion, accidents, air pollution as well as greenhouse gas emissions [1]. Thus, decisions and policies about transport and transport related infrastructure investments should be made with great precision, especially in developing countries with tighter budgets. There are several studies focusing on how transportation policies can be decided ethically and equally [2]. However, there are no specific or solid indicator to measure how these investments can contribute to promoting better access to opportunities particularly for the most vulnerable segments of the population [3].

Evaluations of transport policy plans are generally based on cost-benefit analyses. Accessibility changes are included in such analyses indirectly. But accessibility is broader than is assumed by this perspective and also incorporates equity and related distribution effects as well as social exclusion [4]. This paper aims at presenting a new approach (perspective) to accessibility in evaluation of urban transport investments, focusing on sustainability related social elements such as equity and urban transportation affordability. Accessibility refers to the ease of reaching goods, services, activities and destinations, which together are called opportunities. There are different types of accessibility measures. In this study, a utility based accessibility measure is prefered because of its higher capability of reflecting social and economical effects. Even utility based accessibility measures usually uses transportation cost only as variable instead of transportation affordability [5-6]. This study is targeting to use affordability as a variable in accessibility calculations.

Within this scope, Istanbul is chosen as the case city because of that it is a megacity trying to cope with income inequalities, irrepressible transport related problems and extensive transport infrastructure investments. On the contrary to global research arena, accessibility studies are limited in Turkey [7-11].

The next section of the paper gives a brief information about the study area. Section 3, describes accessibility and transportation affordability, and explains data and method used in the analysis. Concluding section discusses the results and further studies that have to be done.

2. About Istanbul

Istanbul is a unique megacity with over 14 million inhabitants spread both Asian and European sides of the Bosphorus. North of the city is mostly rural and forest areas. According to Istanbul Transportation Master Plan Household Study [12] data, population densities are higher on the southern of the city (Figure 1). On the other hand, distribution of working people seems more widespread (Figure 2).

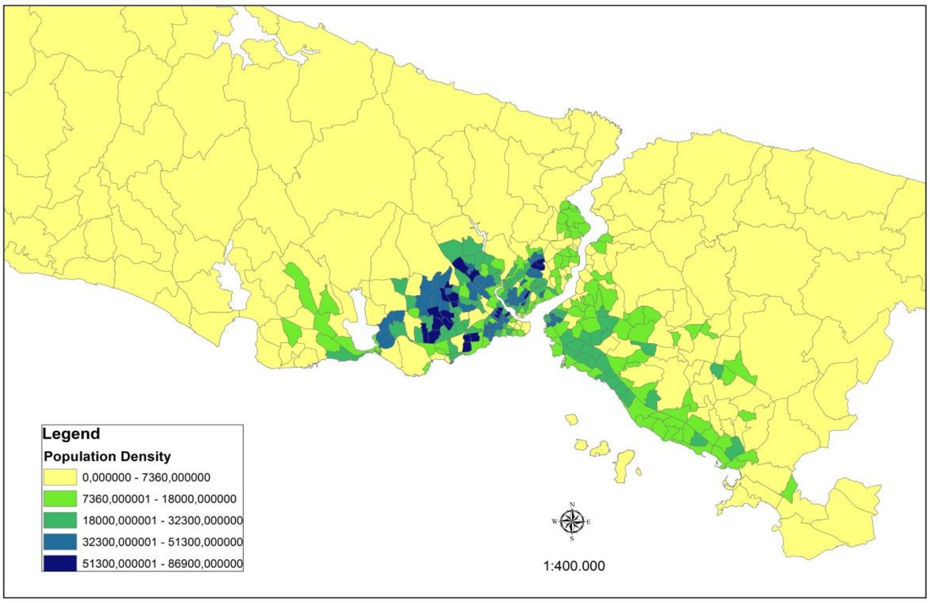

Figure 1. Population density in Istanbul (2007)

Districts with highest number of working people are close to the districts with highest number of employment, which are generally industrial areas (Figure 3).

Distribution of household income does not present a distinctive geographical pattern (Figure 4). It is often possible to spot a high income zone surrounded by low income zones and vice versa.

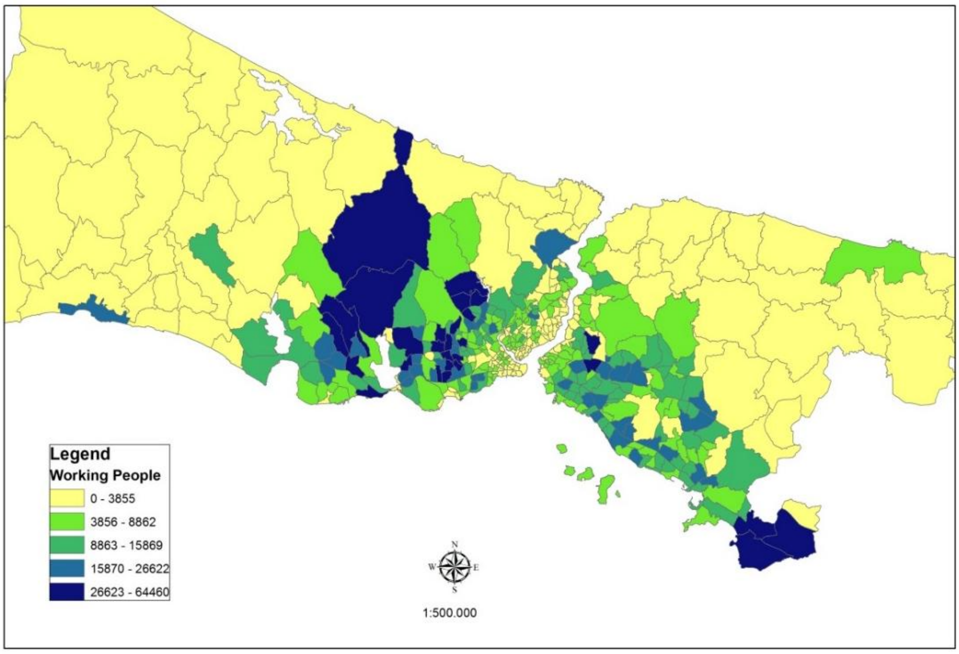

Figure 2. Number of working people in Istanbul (2007)

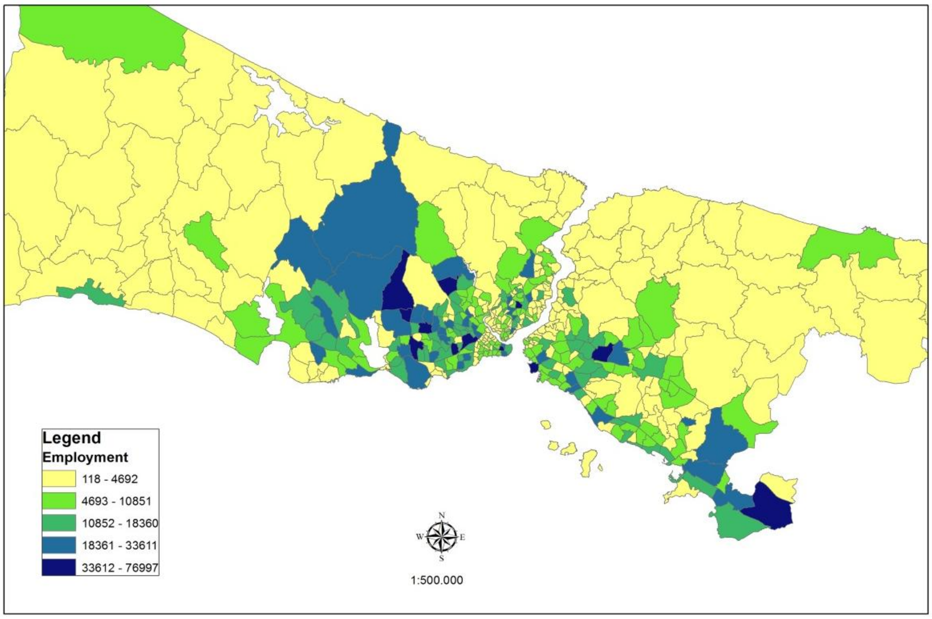

Figure 3. Number of employment in Istanbul (2007)

Car ownership distribution (Figure 5) of the city has shown similar characteristics with income distribution, i.e., zones with highest car ownership values are the zones of higher income groups.

Despite its relatively large area and massive population, the public transport system is mostly road-based and not sufficient to meet the travel demand. As shown in Figure 6 and Figure 7, transportation network of the city is road dominated.

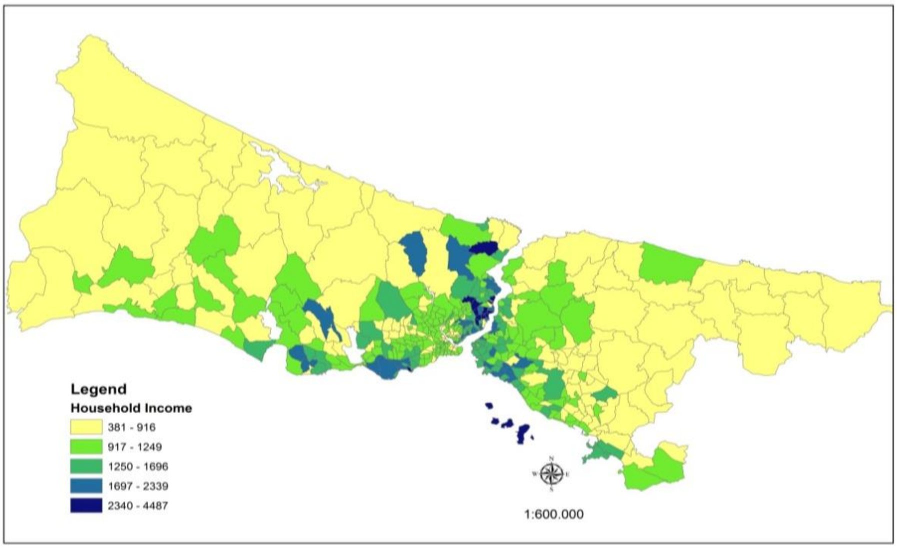

Figure 4. Household income distribution (2007)

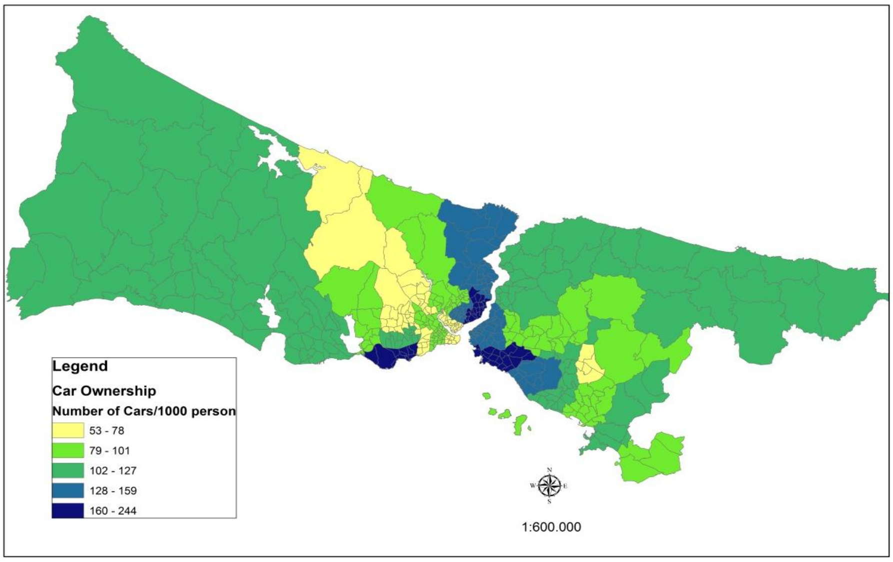

Figure 5. Car ownership distribution (2007)

Railway system is inadequate and although city is divided by the Bosphorus, the share of sea transport is dramatically low. Three highway bridges crossing the Bosphorus Strait carry road traffic between Asian and European sides of the city. Relatively higher number of job places are located in the European side (73 % of jobs and 65 % of inhabitants) and this creates a high travel demand in the east-west direction in the morning and opposite direction in the evening peak hours. The bottlenecks created by the two bridges and unbalanced travel demand causes long queues and traffic congestion not only in morning and evening peaks but almost all day long.

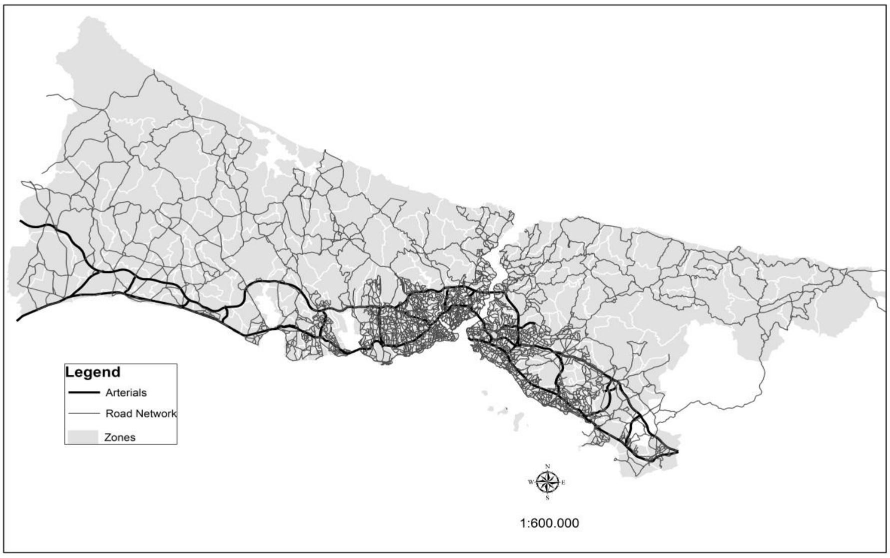

Figure 6. Road network of Istanbul (2007)

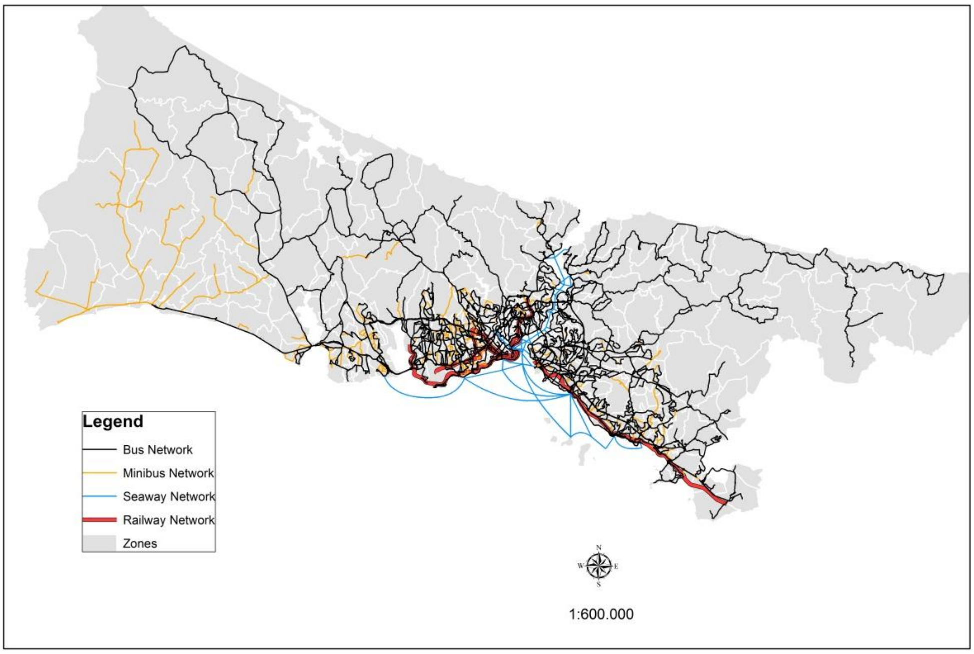

Figure 7. Public transportation network of Istanbul (2007)

3. Methodology

Transportation affordability means that user financial costs of transport are not excessive, particularly for basic access. According to Litman [13], it means that people can purchase access to basic goods and activities (medical care, basic shopping, education, work and socializing), which typically means that low- and medium-income households spend less than 20% of their budgets on transport and less than 45% on transport and housing combined. The terms, sustainability and affordability require improving transportation modes like public transport, cycling and walking. Affordability is also important for transport related social exclusion and transport equity, especially for low income groups. There are significant number of studies about relations between accessibility, affordability and equity [14-18].

On the other hand, accessibility is a term often used by transportation experts from both academic and practical backgrounds. It has many definitions in literature such as: the potential of opportunity for interaction [19], overall benefits provided by a given transport system [20] and, the ease of reaching goods, services, activities and destinations, which together are called opportunities [21]. For an overview of the literature on accessibility see, for example, Handy and Niemeier [22] or Páez et al. [23]. According to Geurs and Van Wee [24] accessibility measures can be categorized according to their components which are land-use, transport and individual elements. Besides its several advantages, an utility based approach is used in this study especially for its capability of representing all these three components [25].

Choise models are frequently used in accessibility studies [26]. There are several utility based accessibility measures available in the literature like multinomial logit, joint logit [27-29] and nested logit models [30]. In order to estimate both destination and mode choices of travellers, joint logit models and nested logit models are applicable. Nested logit has a sequential tree structure but joint logit model estimates destination and mode choices together. A joint logit model has been preferred in this study due to its relatively simpler structure.

3.1. Data

Home-based work trips data from the household travel surveys that were carried out in 2006 for Istanbul Transportation Master Plan Study [12] have been provided by the Transportation Planning Department of Istanbul Metropolitan Municipality. The data contains information of approximately 20,000 home-based work trips from 451 traffic analysis zones of Istanbul. In this study, private car and public transport trips of about 8,000 individuals have been used.

3.2. Joint Logit Model

Suppose that a multidimensional choice set Cn for individual n, whose elements are defined as mode and destinations. Let us define Udm as the total utility of the element of Cn consisting of mode m and destination d. It is assumed that some elements Cn share common observed elements as a consequence of their sharing the same mode or destination. By extension of the partition of the total utility into systematic and random components, it can be written as,

$$U_{dm} = V_d + V_m + V_{dm} + \varepsilon_{dm} \quad \forall (d,m) \in C_n \tag{1}$$

where,

V_d is the systematic component of utility common to all elements of C_n using destination d, V_m is the systematic component of utility common to all elements of C_n using mode m, V_{dm} is the remaining systematic component of utility specific to the combination (d,m) and ε_{dm} is the random utility component.

Our model has the following variables for alternative $i \in C_n$:

x_{i1} is the travel time for mode/destination combination i, x_{i2} is the out-of-pocket cost for mode mode/destination combination i divided by monthly household income (affordability term of the model), x_{i3} is the employment ratio at the destination included in alternative i, x_{i4} is a a gender-specific constant defined as 1 if the gender is male and 0 for otherwise, x_{i5} is car availability defined as 1 if the household owns one auto and 0 for otherwise, x_{i6} is car availability defined as 1 if the household owns more than one auto and 0 for otherwise, x_{i7} is the mode specific constant.

Here, the first two variables x_{i1} and x_{i2} would be part of V_{dm} because they vary across both the mode and destination. Variable x_{i3} would be part of V_d because its value do not vary across elements of C_n using d; any mode and destination combinations having the same destination have the same values of x_{i3}. Finally x_{i4}, x_{i5} and x_{i6} vary only across modes. Two dummy variables (x_{i5} and x_{i6}) are used to represent households having zero, one and more than one cars.

Thus,

$$V_{dm} = \beta_1 x_{i1} + \beta_2 x_{i2} \tag{2}$$

$$V_d = \beta_3 \, x_{i3} \qquad (3)$$

$$V_m = \beta_4 \, x_{i4} + \beta 5 \, x_{i5} + \beta_6 \, x_{i6} + \beta_7 \qquad (4)$$

The distribution of the ε_{dm}'s across the alternatives and across the population defines the choice probabilities. Multinomial logit model has been used for the joint choice of destination and modes, assuming these disturbances are independent and identically gumbel distributed (with the scale parameter μ normalized to 1) as follows:

$$P_n(d,m) = \frac{e^{V_m+V_d+V_{dm}}}{\sum_{(m,d)\in C_n} e^{V_m+V_d+V_{dm}}} \qquad (5)$$

Equation above is called the joint logit model. Let $_i$ denote (*d,m*) destination/mode choice combination, natural logarithm of equation (5)'s denominator is used as accessibility measure for individual *n*.

$$A_n = ln \sum_{i \in C_n} e^{V_m+V_d+V_{dm}} \qquad (6)$$

3.2.Aggregate Accessibility Measure

For spatial accessibility analysis, it is necessary to produce some accessibility-affordability measures aggregated on zonal basis. The aggregate accessibility measure of a zone *z* can be calculated by applying the joint disaggregate measure of individuals to each group (category) in that zone and expanding these accessibilities to the entire population of zone *z*.

In order to do this, population in each zone *z* is divided into *K* nearly homogenous subgroups with *sizes N1, N2,…,Nk*. The number of groups may be calculated by equation (7).

$$K = N_g . N_c . N_i$$
$$K = 2x3x3 = 18 \; (k = 1, N_k) \qquad (7)$$

where,

K is the number of groups, N_g is the number of gender groups (*male, female*) which is equal to 2 (g=1, N_g), N_c is the number of car-ownership groups (*no car available*, *1 car available*, *more than 1 can available* per household) which is equal to 3 (c=1, N_c), and N_i is the number of household income groups (0-1000 TL/month, *low*, 1000-3000 TL/month, *middle*, > 3000 TL/month, *high*) which is equal to 3 (i=1, N_i).

Equations (2), (3) and (4) can be written as equations (8), (9) and (10) by using variables $\overline{x}_{zi1}$ (average travel time from zone z for mode/destination choice i) and $\overline{x}_{zij}$ (average out-of-pocket travel cost / household income group j).

$$\overline{V}_{zij} = \beta_1 . \overline{x}_{zi1} + \beta_2 . \overline{x}_{zij} \qquad (8)$$

$$V_d = \beta_3 . x_{i3} \qquad (9)$$

$$V_{mgc} = \beta_4 x_{i4} + \beta_5 x_{i5} + \beta_6 x_{i6} + \beta_7 = V_{mk} \qquad (10)$$

Therefore, utility of zone *z* for category *k* becomes,

$$U_{zki} = V_d + \overline{V}_{zkj} + V_{mk} \qquad (11)$$

Accessibility measure of zone z for category k is defined by,

$$A_{zk} = ln \sum_i e^{U_{zki}} \qquad (12)$$

Then, the aggregated accessibility measure for zone *z* is defined by the formula given below, where W_{zk} is the number of working people in zone z belong to category *k*.

$$A_z = \sum_k W_{zk} . A_{zk} \qquad (13)$$

$$A_z = \sum_k W_{zk} . ln \sum_i e^{U_{zki}} \qquad (14)$$

4. Results

4.1. Results of the Joint Logit Model

The estimated coefficients and t-statistics of the joint logit model for mode and destination choices are given in Table 1.

Table 1. Estimation results of Joint Logit Model

Variable	Coefficient	t-stats
β_1	-0.04504802	-37.402*
β_2	-5.26844073	-20.415*
β_3	4.53209045	16.245*
β_4	0.95696531	13.712*
β_5	2.40162860	42.050*
β_6	2.80048098	29.593*
β_7	-3.32058474	-40.286*
*Significant at 95% confidence level		

According to t-statistics, the variables are significant and the pseudo-R^2 (ρ^2) value, which is 0.21, for the model also suggests a moderate model on the basis of overall goodness-of-fit.

4.2. Results of the Spatial Analysis

After the calculation of aggregated accessibilities, the results have been visualized by the ArcMap and shown in Figure 8. From the figure, it is possible to distinguish three rings with different degrees of accessibility in the central area of Istanbul.

The core area (measured via ArcGIS® according to accessibility colour contours) consists of an ellipse with R_1= 5.8 km and R_2= 7.9 km radius covering the Historical Peninsula, Fatih, Beyoğlu and parts of the Bakırköy, Beşiktaş, Üsküdar and Kadıköy districts. This core area is surrounded with a relatively narrow second ring with an average width of 3 km covering parts of Bakırköy, Bahçelievler, Beşiktaş, Güngören, Bağcılar, Esenler, Gaziosmanpaşa, Eyüp, Bayrampaşa, Kağıthane, Kadıköy, Üsküdar, Şişli and Zeytinburnu. The third ring has a width of approximately 4.8 km and covers the districts of Ümraniye, Kartal, Sultanbeyli, Maltepe, Küçükçekmece and some parts of Sarıyer and Beykoz. The triangle outside these three rings covers the zones with relatively less populated areas with less job densities. The outer zones in the rest of the map are generally rural areas whit low degree of accessibility.

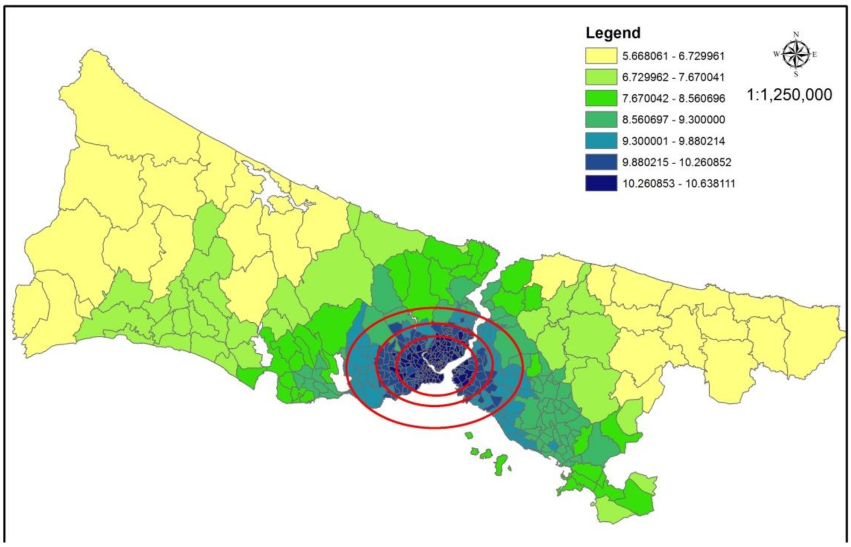

Figure 8. Accessibility map of Istanbul

4.3. Elasticities

A disaggregate elasticity represents the responsiveness of an individual's choice probability to a change in the value of the selected attribute [31].

Let $E_{xi}^{P_{n(i)}}$ be the elasticity of the probability of an individual choosing alternative *i* with respect to a change in some attribute x_i which is an independent variable in the model.

$$E_{xi}^{P_{n(i)}} = \frac{\partial P_n(i)}{\partial x_i} \cdot \frac{x_i}{P_n(i)} = \frac{\partial \ln P_n(i)}{\partial \ln x_i} = [1 - P_n(i)] x_i \beta_k \quad (15)$$

Likewise, the disaggregate cross elasticity of the probability of an individual choosing alternative *i* that is selected with respect to a change in alternative *j* is,

$$E_{xj}^{P_{n(i)}} = \frac{\partial \ln P_n(i)}{\partial \ln x_j} = -P_n(j) x_j \beta_k \quad (16)$$

In order to calculate elasticities, individuals have been categorized into 18 groups according to their gender (male, female), household income level (low, middle, and high), and car availability of the household (no car available, one car available, and more than one car available). An origin-destination zone pair is selected and changes in utilities have been calculated for each of 18 categories and for 2 cases: In Case 1, private car users costs have been increased by 10 % and 15 %. In Case 2, public transportation travel times have been reduced by 10 %. Elasticities for Case 1 and 2 are shown in Table 2.

Table 2. Elasticities for Case 1 and for Case 2

Category	Gender	Income	Car Ownership	Base Case		Case 1			Case 2		
				P_A	P_{PT}	P_A	P_{PT}	**E**	P_A	P_{PT}	**E**
1	Male	Low	0	0.01	0.99	0.01	0.99	**-2.87**	0.01	0.99	**2.23**
2	Male	Low	1	0.13	0.87	0.08	0.92	**-2.67**	0.10	0.90	**1.97**
3	Male	Low	1+	0.18	0.82	0.11	0.89	**-2.57**	0.15	0.85	**1.85**
4	Male	Middle	0	0.09	0.91	0.08	0.92	**-0.81**	0.08	0.92	**2.05**
5	Male	Middle	1	0.53	0.47	0.49	0.51	**-0.45**	0.47	0.53	**1.06**
6	Male	Middle	1+	0.63	0.37	0.59	0.41	**-0.36**	0.57	0.43	**0.84**
7	Male	High	0	0.13	0.87	0.12	0.88	**-0.40**	0.10	0.90	**1.97**
8	Male	High	1	0.61	0.39	0.60	0.40	**-0.18**	0.56	0.44	**0.87**
9	Male	High	1+	0.70	0.30	0.69	0.31	**-0.14**	0.65	0.35	**0.67**
10	Female	Low	0	0.01	0.99	0.00	1.00	**-2.88**	0.00	1.00	**2.24**
11	Female	Low	1	0.05	0.95	0.03	0.97	**-2.80**	0.04	0.96	**2.14**
12	Female	Low	1+	0.08	0.92	0.05	0.95	**-2.76**	0.06	0.94	**2.08**
13	Female	Middle	0	0.04	0.96	0.03	0.97	**-0.85**	0.03	0.97	**2.17**
14	Female	Middle	1	0.30	0.70	0.27	0.73	**-0.64**	0.26	0.74	**1.57**
15	Female	Middle	1+	0.39	0.61	0.36	0.64	**-0.57**	0.34	0.66	**1.37**
16	Female	High	0	0.05	0.95	0.05	0.95	**-0.43**	0.04	0.96	**2.14**
17	Female	High	1	0.38	0.62	0.36	0.64	**-0.29**	0.33	0.67	**1.40**
18	Female	High	1+	0.48	0.52	0.46	0.54	**-0.25**	0.42	0.58	**1.18**

In Base Case (no change in auto travel cost and in public transport travel time), categories 5, 6, 8 and 9 choose private car. People in these categories are male, in middle or high income groups, and own one or more than one car. In Case 1, private car users costs have been increased by 10 %. In this case, none of the categories has changed their mode choices. In Case 2, private car users costs have been increased by 15 %. In this case, only the car users in Category 5 have shifted from private car to public transportation. As it can be seen from the elasticities of Category 5, 6, 8 and 9, private car users are inelastic to travel cost increase (Case 1). Effect of travel time changes on mode choice is higher (even elastic for Category 5) than the effect of the travel cost.

5. Conclusions

The role of sustainable transport policies for a better quality of life in cities is undeniable. Policies such as improving public transportation, promoting walking and cycling, managing travel demand not only reduce the share of private cars, traffic congestion and air pollution, but also increase accessibility and create more liveable cities.

The main outcomes of this study can be summarised as follows:

•Effects of gender, income and car availabilities on mode choice are significant.
•A small portion of people, which are male, belong to middle or high income groups and own one or more private cars choose to travel by car on their home-based-work trips. It is difficult to change their mode choices by only reducing public transportation travel time or increasing costs of private car. Improving public transportation network, creating more convenient and comfortable mobility alternatives may be a better option.
•Despite the fact that most people prefer public transport system for home-based work trips, public transport network, particularly rail transit system, is still far from being sufficient to meet the increasing demand in Istanbul.
•Accessibility is much higher in the central areas and decreases in the outskirts of the city.

In order to assess the effects of different major transportation projects on accessibility, further studies are planned by using the model proposed in this paper.

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