EFFECTS OF URBAN FORM, DENSITY AND LAND VALUE ON URBAN MOBILITY IN LARGE METROPOLITAN AREA: ISTANBUL, TURKEY

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ABSTRACT

Relationship between the urban transportation system and city form is always of an interest by many researchers. It is very well known that this relationship is a two-way interaction. Spatial interaction on the urban land among different levels of subcenters and the city centre is made possible through the transportation system. If accessibility is improved for a particular land through the expansion of the current transportation system, the interaction between that part and the rest of the city increases based on the characteristics of the transport system provided. To understand this relationship between the urban form and the transportation system, in this paper, it is attempted to investigate the effects of urban structure (form, density and land value) on urban mobility in the city of Istanbul, Turkey. It is concluded that people living in city centers or urbanized areas present different transport behaviors than those living in suburbs or rural areas due to the differences in the level of service provided by the transportation system.

Keywords: travel survey, mobility, trip rate, urban form, density, land value, Istanbul

INTRODUCTION

Transportation has a significant effect on cities' macro form. It lets the human settlements be spread or compact in form. Highway and auto dependent transport networks create relatively low density settlements compared to cities with good-quality transit services. Thus, land use, density and level of transportation service affect transport behavior. Over the last several decades, many studies have explored the role of the built environment in influencing travel behavior (Pan et al., 2009).

A widely accepted view is that people travel to attend to a timely compulsory or social activity, or free-time travels for pleasure, thus the travel is not an end itself. In this case, travel can be effectively modified or altered through land use planning (Lansing et al., 1970; Cervero, 1989; Newman and Kenworthy, 1999) or can be replaced by some technological ways such as video-conferencing to in order be involved in some activities or to communicate with others via e-mails or instant messages. However, recent publications in this field, which include a disproportionately large number by American researchers, have shown that the connection between the built environment and people's travel behavior is surprisingly elusive (see, for example, Giuliano, 1991; Boarnet and Sarmiento, 1998; Crane, 2000; Boarnet and Crane, 2001; Krizek, 2003). While there is strong empirical evidence showing that the overall spatial structure of a metropolitan area has a significant effect on the residents' commuting (Shen, 2000; Yang, 2005), it is far less clear how urban design and land use characteristics of smaller areas, such as neighborhoods, influence people's travel (Boarnet and Sarmiento, 1998; Crane, 2000).

In this study, it is attempted to investigate the effects of urban structure (form, density and land value) on urban mobility (trip propensities, trip length, travel time, and mode choice) in the city of Istanbul, Turkey. The structure of this paper is as flows: The next section gives some brief information on the characteristics of the study area. The following section analyzes the effects of urban structure on trip productions, travel length and time, and mode split. The last section of the paper presents the conclusions of the current research and some recommendations for future research.

CHARACTERISTICS OF THE STUDY AREA

City of Istanbul

City of Istanbul is situated at the north-west of Turkey, a bridge between Asia and Europe. Its population is almost 13 million according to 2009 census. Istanbul is in the first 10 urban agglomerations out of 100 with its 5389 km^2 territory. The rate of population growth has been slowly declining in Istanbul, but it is yet high at over 3% per annum. The recent annual increase ranged from 0.4 to 0.5 million. With an annual growth of 3%, the population of Istanbul will have exceeded 20 million in 2023. At a lower growth derived from the past trend, the population will have reached 18 million. The 2023 comprehensive urban plan of the Istanbul Metropolitan Municipality suggests some measures to control the growth of population over 16 million. It is requisite to implement decisive policy instruments to curb the population density (IMM, Almec and Nippon Koei, Co, 2009).

2006 household travel survey revealed that the registered automobiles in the metropolitan region totaled to 1.33 million. With the expected economic growth, the number of motorized vehicles will increase rapidly by more than 3.14 times to 4.19 million in 2023. Registered automobiles per thousand of population were 111 vehicles in 2005 and will increase to 245 by 2023. In 2006, 31% of the metropolitan households owned one passenger car and 4%

two or more. The passenger car owner households are estimated to increase to 67% of the households in 2023 (IMM, Almec and Nippon Koei, Co, 2009).

Figure 1 shows the master plan projects by their completion period. The total investment required for the master plan projects amounts to US$24.2 billion. US$ 11 billion is required for 52 road projects and US$13.2 billion for 16 railway projects. The total cost of 10 projects scheduled for completion after 2023 is US$5.5 billion. Figure 2 shows the base network of railway projects. Gray lines represent the lines in operation. Red lines are the ones completed by 2013 and the green ones are to be completed between 2014 and 2018 (IMM, Almec and Nippon Koei, Co, 2009).

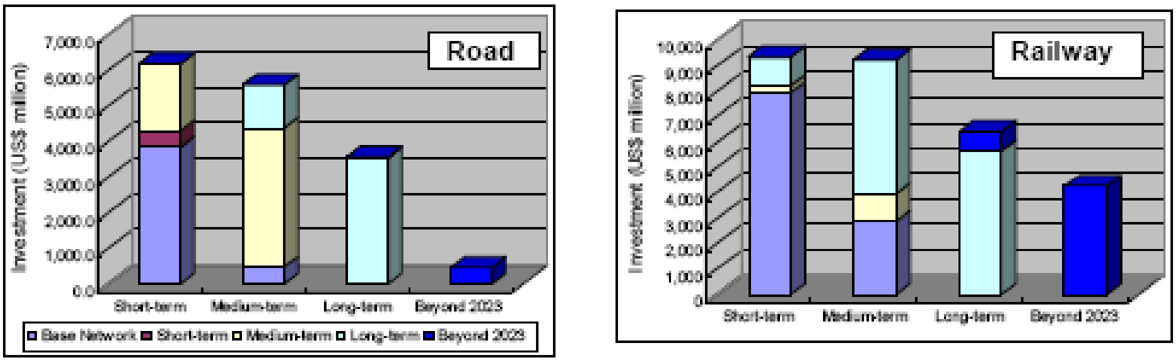

Figure 1 – Master Plan Projects by completion period

Figure 2 – Base network of railway projects

Figure 3 shows the Bosporus crossing demand by daily 1000 passengers. The master plan proposes the completion of the 3rd bridge by 2023 as both railway and highway links across the Strait. The new bridge is needed simply to meet the expected growth of demand. However, there are many arguments against the new bridge. Main points of contention are the problem of land acquisition and the adverse impact on natural environment and landscape. It is necessary to undertake careful studies over these issues and explain the circumstances of project formulation until a general consensus begins to emerge (IMM, Almec and Nippon Koei, Co, 2009).

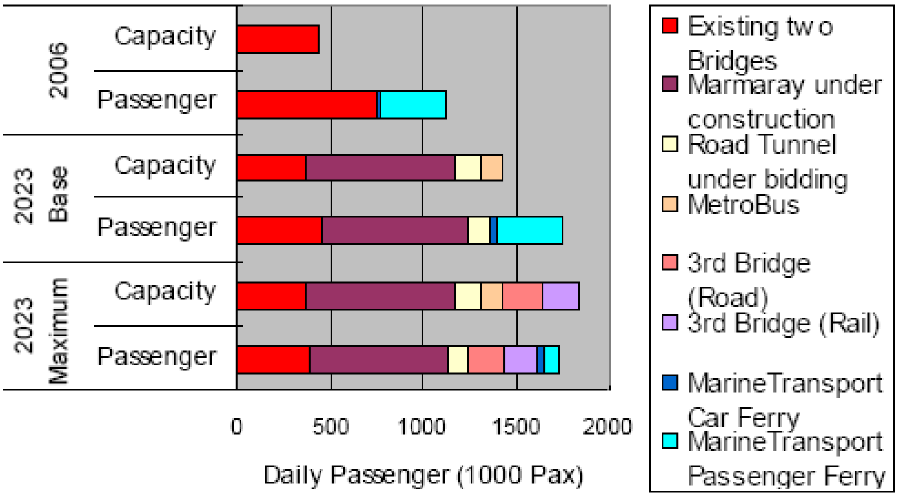

Figure 3 – Bosporus crossing demand by daily passenger (1000 pax)

Description of the Urban Structure

Residents living at different locations of the city may present different transport behaviors. For example, people living closer to the city center might use public transit modes and travel shorter distances, but those who live at suburbs or rural areas have limited choices regarding transport modes and most probably use automobiles and travel to longer distances. In order to determine how the urban structure affects urban transport behavior or mobility characteristics of the residents living in different locations of the city, e.g., at locations with different densities or land values, urban area is classified by urban form, population density and land value as seen in Table 1.

Urban Area Classification

In order to disclose spatial differences over the metropolitan area, urban land is classified into zones using population potential contour lines. Night population is used to calculate population potentials[1] by which potential izohips (contour lines) are drawn. Later, those izohips are grouped together into five zones in order to determine the boundaries of 1) CBD, 2) Urban, 3) Suburban, 4) Rural and 5) Outer rural areas (See Figure 4).

Table I – Definition of the Urban Structure

1. Urban Zone Classification[1]	1. CBD, 2. Urban, 3. Suburban, 4. Rural, 5. Outer rural.
2. Population Density Classification[2]	1. Low (<100 person/ha) 2. Medium (101-300 person/ha) 3. High (>300 person/ha)
3. Land Value Classification [2,3]	1. Low (<50 YTL/m^2) 2. Medium (51-150 YTL/m^2) 3. High (>150 YTL/m^2)

[1] Population potential= Population / Distance (distance is measured between the gravity centers of the zones around the subject area)

References: 1) Istanbul's Landuse Trip Generation Handbook Study, IMM, Directorate of Transportation Planning, 2007. 2) IMP, Housing and Quality of Life Group, 2006. 3) T.R. Ministry of Finance, Istanbul Revenue Department, 2002 General Decleration Term List of Land and Property Unit Values per square-meter.

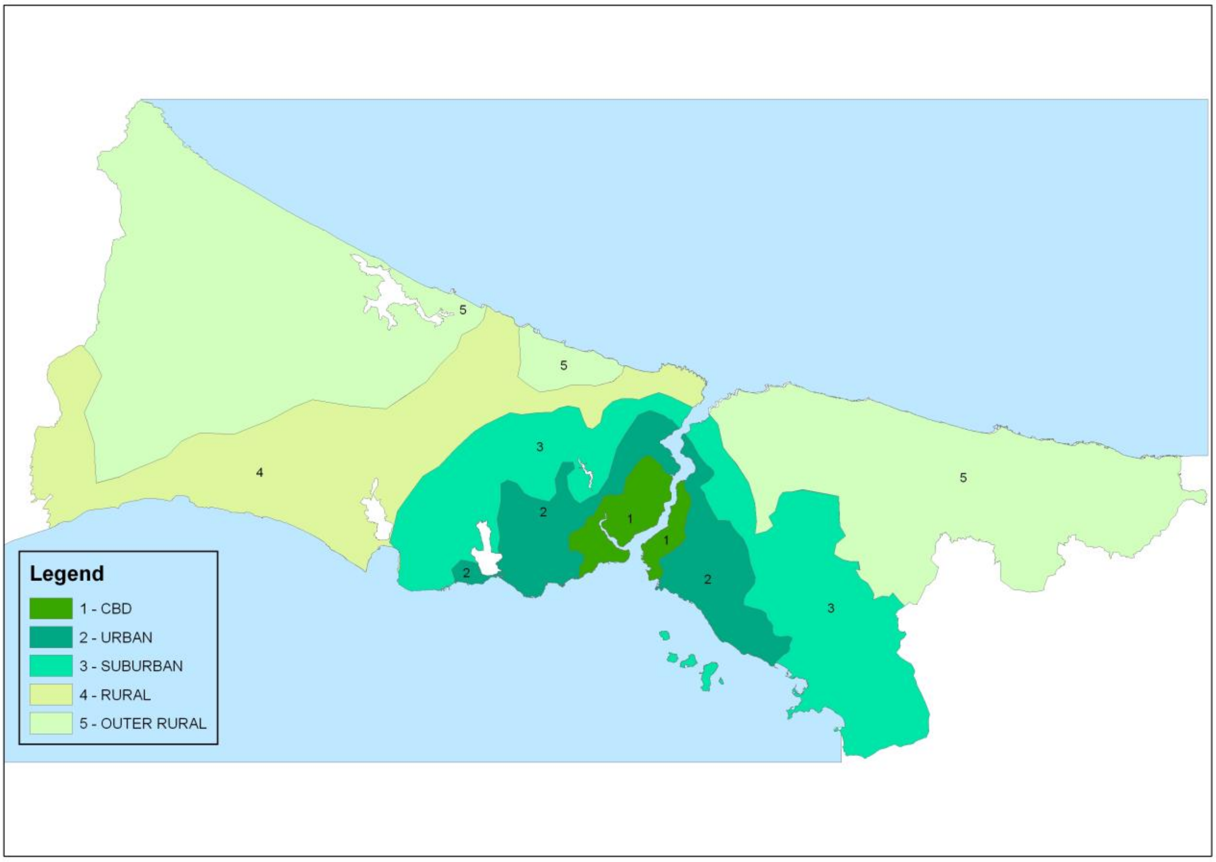

Figure 4. Urban Area Classification of Istanbul Province

Reference: Istanbul's Landuse Trip Generation Handbook Study, IMM, Directorate of Transportation Planning, 2007.

Table 2 describes the characteristics of urban zone classes in terms of size, population estimation, density and land value per square-meter.

Table 2 – Characteristics of Urban Classes

Urban Zone Classification	Area Size (ha)	Pop. Estimation (2005)	Pop. Density (pers./ha)	Average Land Values in 2002 ([2]TL/m²)
1. CBD	12,764	2,261,797	153.60	7,563,509,868
2. Urban	47,504	6,593,057	147.62	8,486,861,186
3. Suburban	107,407	2,275,904	21.48	2,867,080,652
4. Rural	98,004	353,995	3.42	1,297,456,061
5. Outer Rural	273,301	121,588	0.42	74,786,268
[3] Inside of 3030 boundary	183,788	10,763,600	58.57	7,151,844,316
Outside of 3030 boundary	355,192	813,300	2.29	2,431,036,570
Total[4]	**538,980**	**11,576,900**	**21.48**	**5,324,630,789**

Reference: Istanbul's Landuse Trip Generation Handbook Study. IMM, Directorate of Transportation Planning, 2007.

[2] Monetary unit before 2005.
[3] Boundary of Istanbul Metropolitan Municipality (IMM) before 2004.
[4] Boundary of Istanbul Metropolitan Municipality (IMM) after 2004.

Classification of Population Density

Population density is classified into three groups as follows (see Figure 5):

1. Low (<100 pers./ha)
2. Mid (101-300 pers./ha)
3. High (>300 pers./ha).

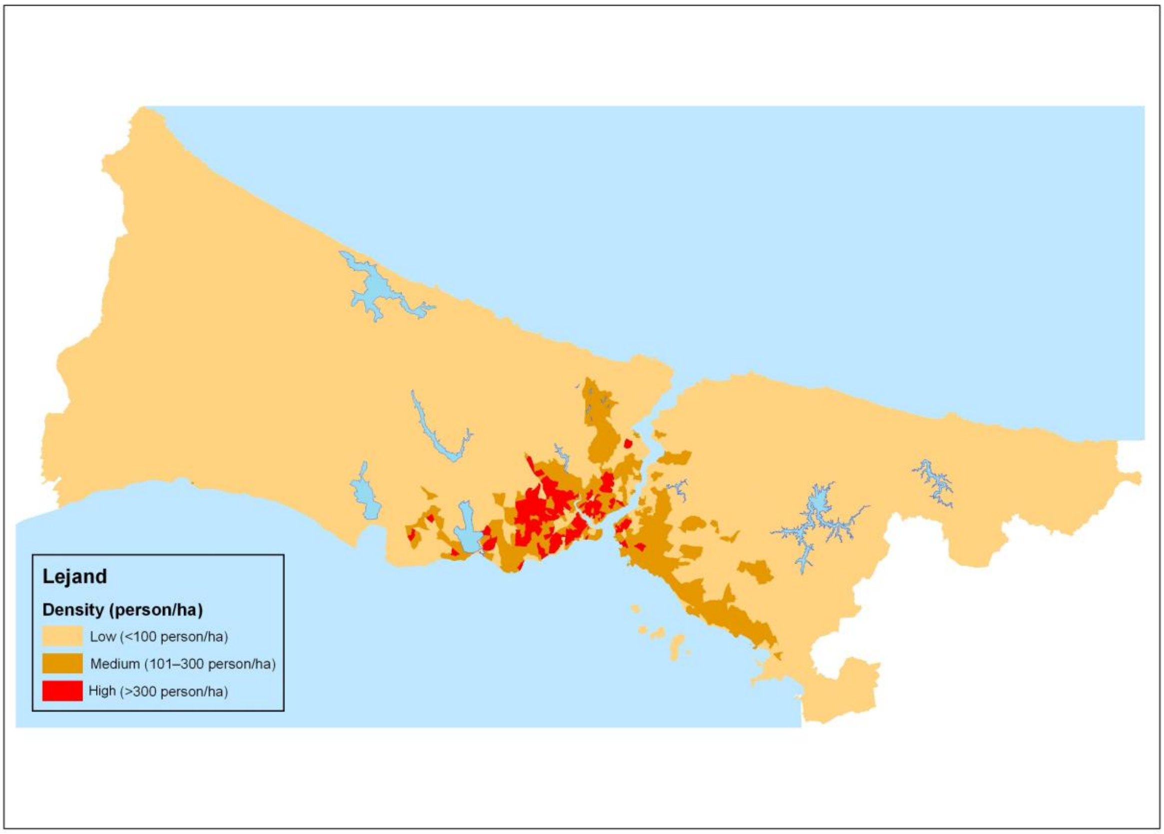

Figure 5. Classification of Population Density

Reference: IMP, Housing and Quality of Life Group, 2006.

Table 3 describes the characteristics of the urban area classified by population density in terms of size, population estimation, density and land value.

Table 3 – Characteristics of Population Density Classes

Classification based on Pop. Density	Pop. Density (pers./ha)	Area Size (ha)	Pop. Estimation (2005)	Average Land Values in 2002 ([5]TL/m²)
1. Low (<100 pers./ha)	5.40	494,650	2,671,917	2,915,106,848
2. Mid (101–300 pers./ha)	137.59	35,063	4,824,295	8,085,730,833
3. High (>300 pers./ha)	443.57	9,266	4,110,129	6,583,418,468
Total	**21.53**	**538,980**	**11,606,341**	**5,324,630,789**

[5] Monetary unit before 2005.

Land Value Classification

Land values are classified into three groups as follows (see Figure 6):

1. Low (<50 YTL/m^2)
2. Medium (51-150 YTL/m^2)
3. High (>150 YTL/m^2)

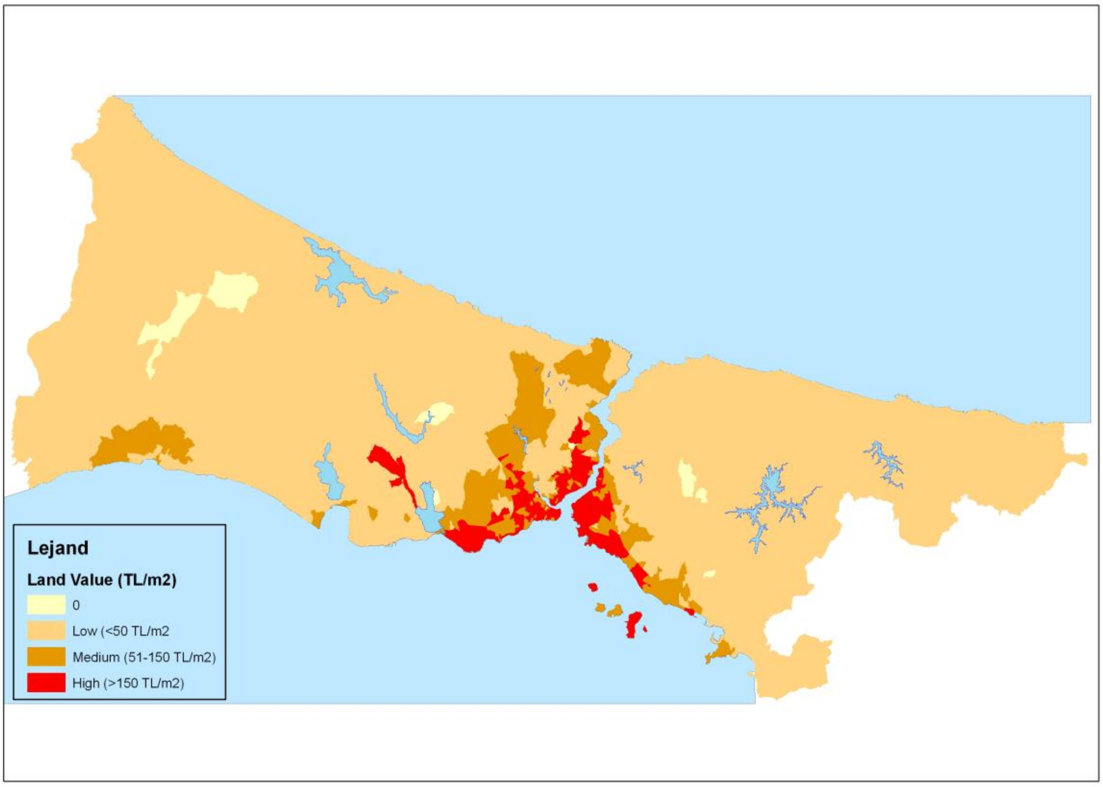

Figure 6. Classification of Land Value

Reference: IMP, Housing and Quality of Life Group, 2006.

Table 4 describes the characteristics of the urban area based on the classification of land value in terms of size, population estimation and density.

Table 4 – Characteristics of Land Value Classes

Classification based on Land Value (LV)	**Area Size (ha)**	**Pop. Estimation (2005)**	**Pop. Density (pers./ha)**
1. Low (<50 YTL/m^2)	472,336	4,788,762	10.13
2. Mid (51–150 YTL/m^2)	39,311	4,737,736	120.51
3. High (>150 YTL/m^2)	16,982	2,078,982	122.42
0 (Military land. and so on)	10,350	861	0.08
Total (Avg. LV = 5,324.63 YTL)	**538,980**	**11,606,341**	**21.53**

[1] YTL: Monetary unit between 2005 and 2008.

ANALYSIS OF URBAN STRUCTURE AND TRANSPORT BEHAVIOR

Analysis of Urban Form and Trip Production, Trip Length and Travel Time

The effects of urban form and characteristics on transport behavior must be analyzed in order to determine urban transport policies who favor sustainable urban plans. For example, dense urban form might support the provision of good quality of public transport modes and less auto use. On the other hand, low density urban form promotes the use of automobile and highway system. Table 5 presents trip behavior and land characteristics of the metropolitan area of Istanbul by the urban zone classification as areas of CBD, urban, suburban, rural and outer rural. Population density is the highest at CBD by 177.3 pers./ha and followed by the urban zone with a density of 138.8 pers./ha. It is 21.2 pers./ha at the suburban zones. Average land value is the highest in the urban zone followed by CBD, and then decreases dramatically. Same trend is observed for trip productions, attractions, trip lengths and travel times. But the reverse is valid for travel speed. Travel speed is the highest in the outer rural area (34.4 km/h) and decreases to 11.1 km/h towards CBD. Total trip productions and attractions are about 20.224 thousands. Total trip length is about 103 million km and the travel time is about 492.2 million minutes or 8.2 million hours. In other words, daily travel is about 2567 times the length of the equator. In every minute, travelers of Istanbul travel 1.8 times of the equator's length. Total daily travel time is about 936.5 years.

Table 5 – Characteristics of the metropolitan area of Istanbul by the urban area classification

Urban Zone Classification	Population (2005)	Area (Km^2)	Avg. Land Value in 2002 (TL/m2)	Auto per 1000 capita	Total Trip Production P_{uf}	Total Trip Attraction A_{uf}	Total Trip Length (km)	Total Travel Time (min.)	Travel Speed (km/h)
CBD	2,261,797	127.6	7,563,509,868	125.30	4,722,019	5,998,232	25,980,260	141,055,900	11.1
Urban	6,593,076	475.0	8,486,861,186	127.93	11,200,703	10,159,269	49,525,091	253,557,381	11.7
Suburban	2,275,885	1,074.1	2,867,080,652	112.06	3,359,635	3,190,202	20,617,869	82,547,558	15.0
Rural	353,995	980.0	1,297,456,061	104.54	652,304	624,133	4,667,153	11,402,292	24.6
Outer Rural	121,588	2,733.0	74,786,268	112.29	289,839	251,181	2,090,793	3,650,228	34.4
Total	**11,606,341**	**5,389.8**	**5,324,630,789**	**121.71**	**20,224,500**	**20,223,018**	**102,881,166**	**492,213,359**	**12.5**

Figure 7 shows the variations in population density, auto ownership per 1000 capita and land value per m^2 over the metropolitan area. By decrease in density, land value and auto ownership decrease as well from CBD towards the periphery of the city. In Figure 8, trend in total trip productions and attractions quite follows the trend in land value (TL/m^2). Figure 9 shows that trip productions and attractions per capita follows a similar trend in auto ownership per 1000 capita. In Figure 10 as auto ownership per km^2 decreases, trip productions and attractions per km^2 decrease as well from CBD towards periphery of the city. Figure 11 shows the magnitude of the traffic congestion over the metropolitan area. Starting from CBD and up to suburban areas, traffic congestion is effective since travel speed is lower than 20 km/ha (11.1 and 11.7 km/ha, respectively) which corresponds to the level of service D (TRB, 2000). In rural parts of the city no major congestion is observed, where travel speed is higher than 25 km/h which also corresponds to the level of traffic service D.

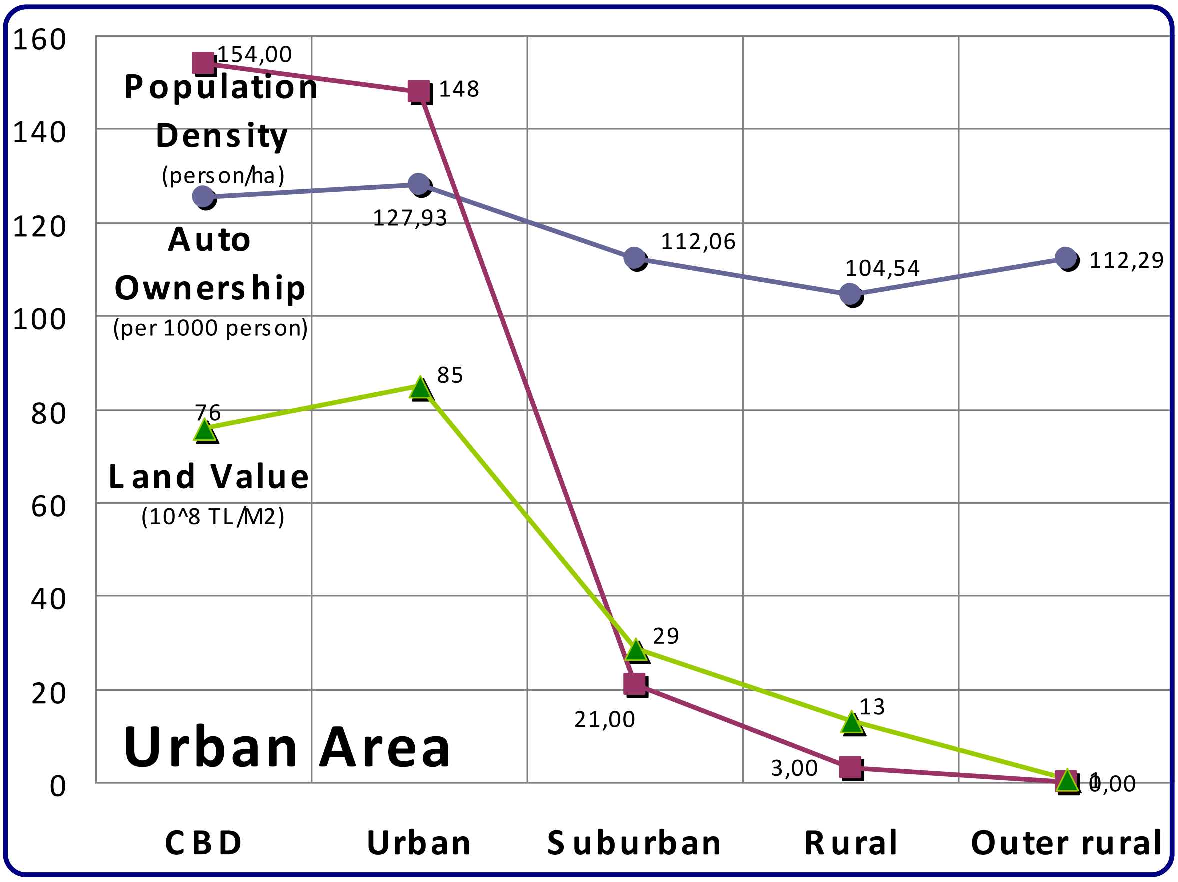

Figure 7 – Characteristics of urban zones by population density, auto ownership and land value

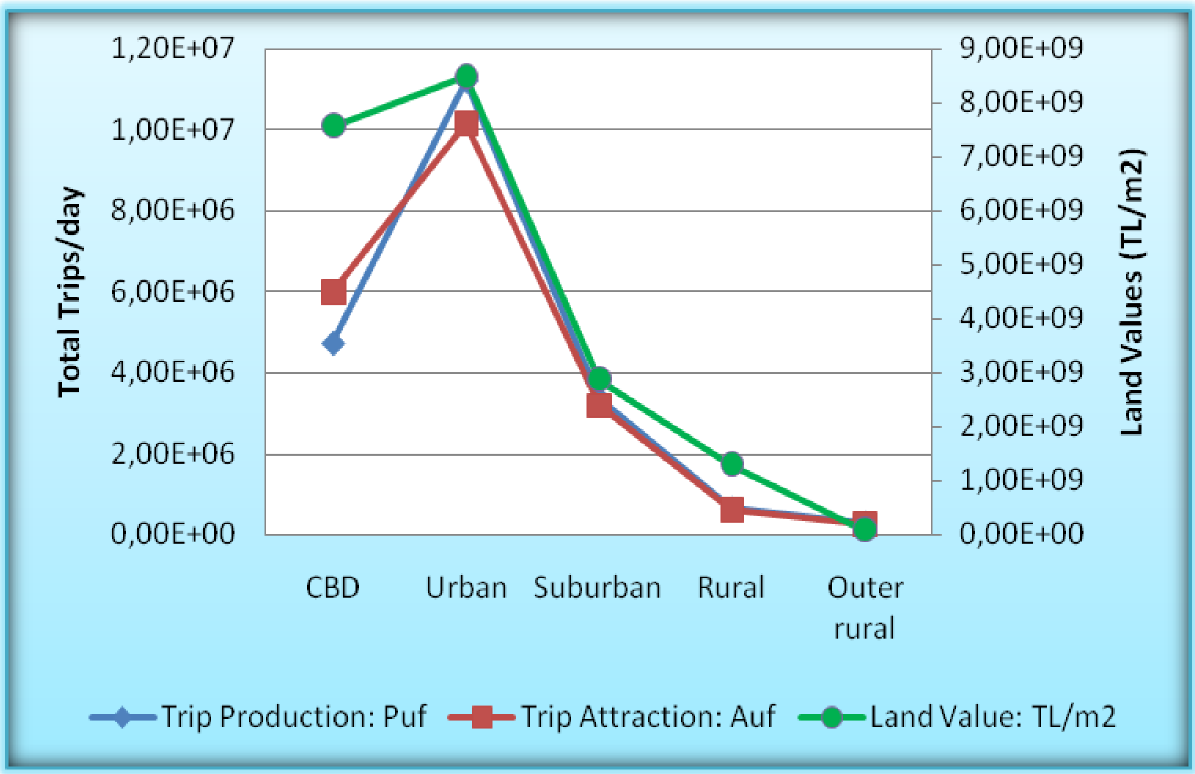

Figure 8 – Trip production characteristics of urban areas and land value (TL/m^2) by urban zoning: total daily trips produced (P_{uf}) and attracted (A_{uf})

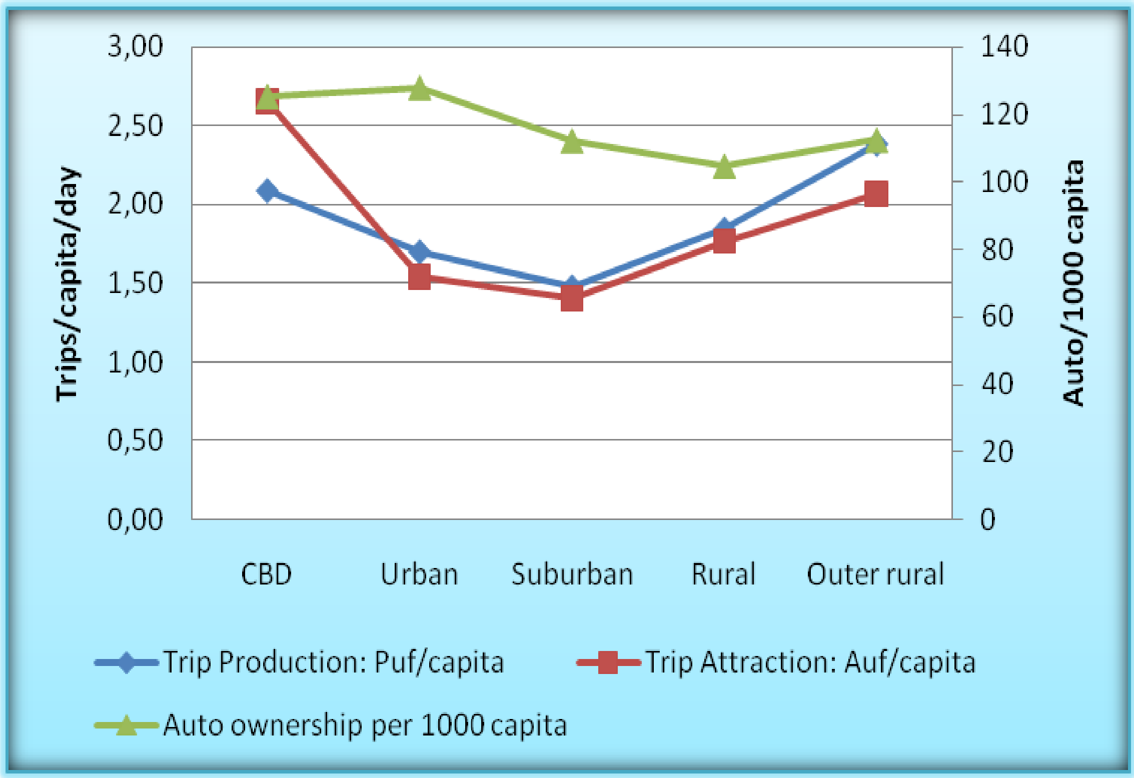

Figure 9 – Trip production characteristics of urban areas by automobile ownership per 1000 capita: trip productions (P_{uf}) and attractions (A_{uf}) per capita

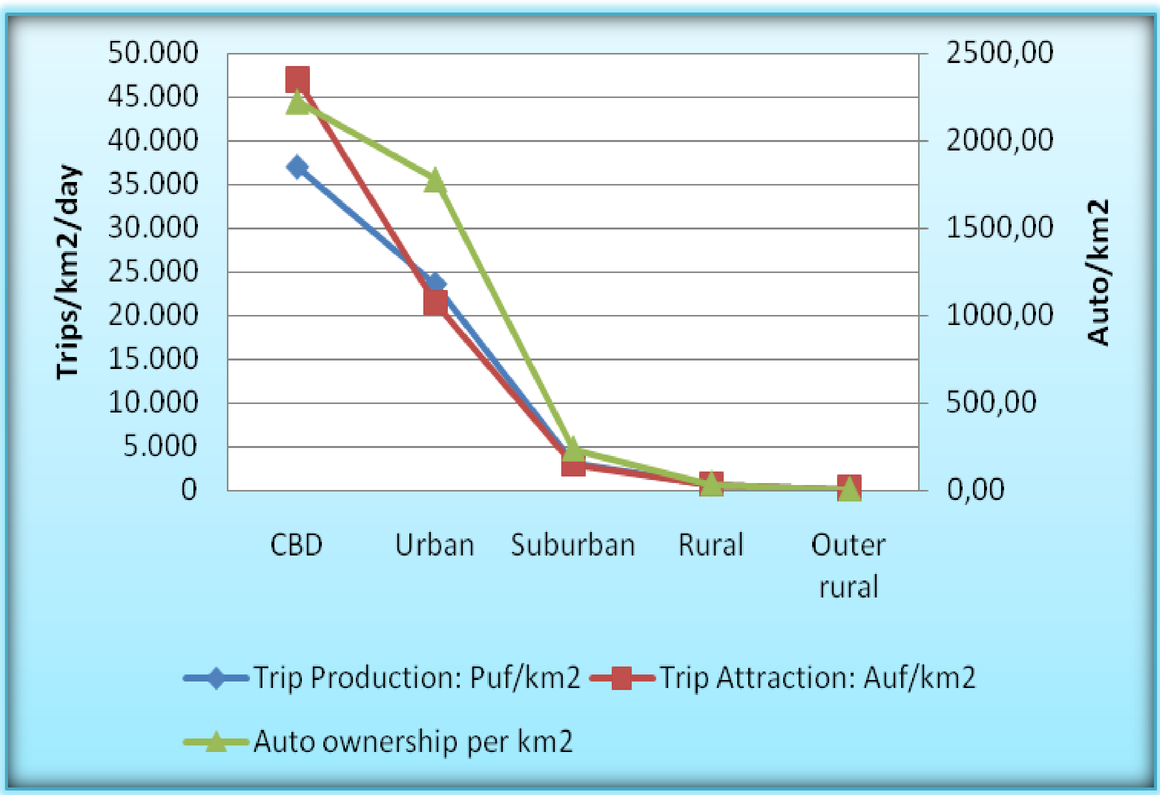

Figure 10 – Trip production characteristics of urban areas by automobile ownership per km^2: trip productions (P_{uf}) and attractions (A_{uf}) per km^2

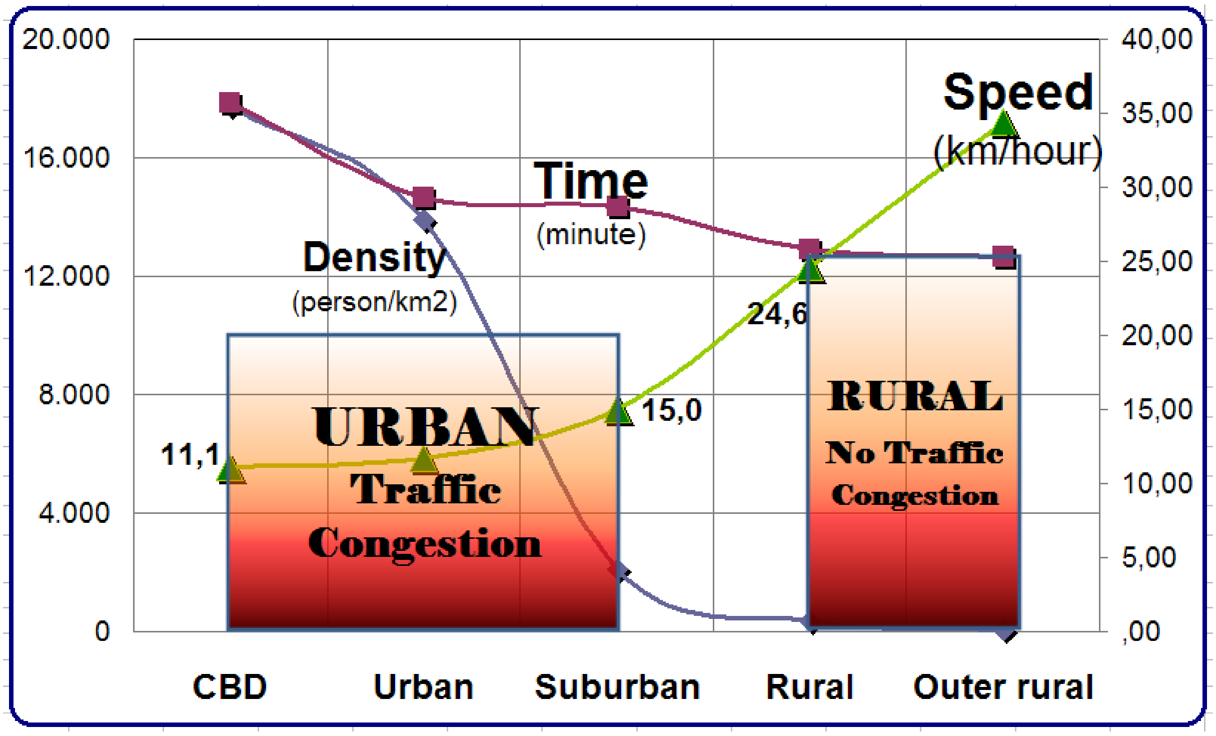

Figure 11 – Characteristics of traffic congestion by urban form and density: travel time (min.) and speed (km/hr)

Analysis of Population Density and Trip Production

Population increased total trip productions and attractions as well as trip length and travel time. But density has some prevailing effects on trip productions. Although the population is about the same, higher density may produce lower productions, length and travel time due to traffic congestion. Table 6 presents the characteristics of the land of Istanbul by the population density classification as low (<100 pers./ha), medium (101-300 pers./ha) and high densities (>300 pers./ha). Average land value is the highest in the medium density area followed by the high density, and then decreases dramatically. Total trip production and attraction values are very similar at high and medium density areas where the population is the highest, but at low density areas both are reduced by about 50% or so. On the other hand, total trip length at the low density areas is 48% higher than that in the high density areas. Total travel times at both areas are very close to each other. Total trip length and travel time are the highest at the medium density areas. As expected, travel speed is the highest at the low density areas and is the lowest at the high density zones. Overall speed is about 12,5 km/h in the metropolitan area of Istanbul.

Figure 12 shows the variations in the auto ownership per 1000 capita and the land values (TL per m^2) over the metropolitan area. Land value is the lowest at the low density areas and the highest at the medium density areas. On the other hand, auto ownership is the lowest at the high density areas. By this result, sustainable urban policies (e.g., increasing urban density results in lower auto ownership) make quite sense. Average auto ownership per 1000 capita at the high density areas is 34.9 and 46.5% lower than those in the low and medium density areas, respectively.

Table 6 – Characteristics of the metropolitan area of Istanbul by the population density

Pop, Density Classification	Population (2005)	Area (Km²)	Avg, Land Value in 2002 (TL/m2)	Auto per 1000 capita	Total Trip Production P_{pd}	Total Trip Attraction A_{pd}	Total Trip Length (km)	Total Travel Time (min.)	Travel Speed (km/h)
Low (<100 pers./ha)	2,671,917	4,946.50	2,915,106,848	127.11	3,634,888	4,489,910	34,463,525	132,375,866	15.6
Medium (101-300 pers./ha)	4,824,295	350.6	8,085,730,833	138.07	8,421,661	8,448,979	45,137,951	223,393,059	12.1
High (>300 pers./ha)	4,110,129	92.7	6,583,418,468	94.22	8,167,950	7,284,129	23,279,690	136,444,434	10.2
Total	**11,606,341**	**5,389.80**	**5,324,630,789**	**121.71**	**20,224,500**	**20,223,018**	**102,881,166**	**492,213,359**	**12.5**

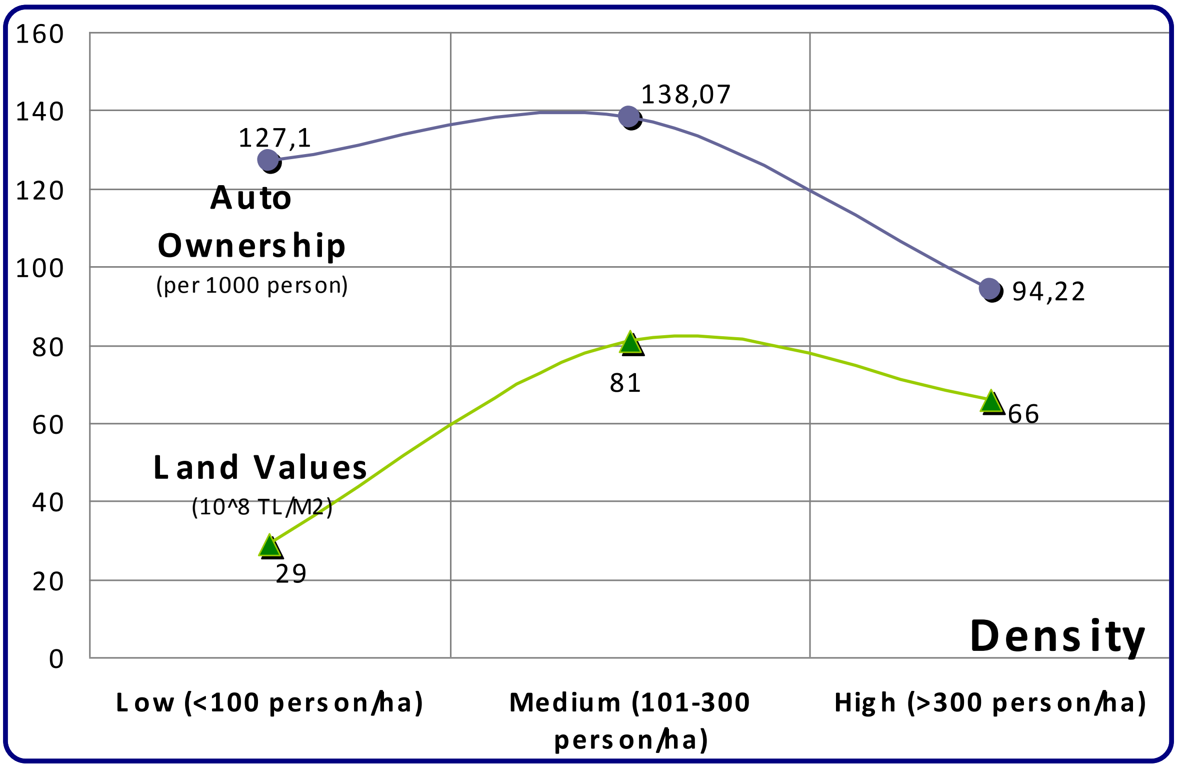

Figure 12 – Characteristics of population density by auto ownership per 1000 capita and land values (TL/m²)

Figure 13 shows the variations in total trip productions and attractions by auto ownership per 1000 capita over the metropolitan area. While the auto ownership decreases, trip productions and attractions decrease as well. Figure 14 shows the variations in trip productions and attractions per capita by the auto ownership. While the trip attractions per capita does not show any significant variation by population density over the study area, trip production per capita increases from the low towards the high density areas. Figure 15 shows the variations trip productions and attractions, and auto ownership per km² by population density. All variables increase while the density increases. This prevails the phenomenon of traffic congestion in urbanized areas. Figure 16 shows the variations in travel time and speed by density. As density increases, travel speed as well as travel time decreases. Decrease in travel speed is obvious dues to traffic congestion. Low travel time in high density areas shows the advantage of accessibility in such an urban form. In contrary to low density areas, high density urban form results in shorter trips.

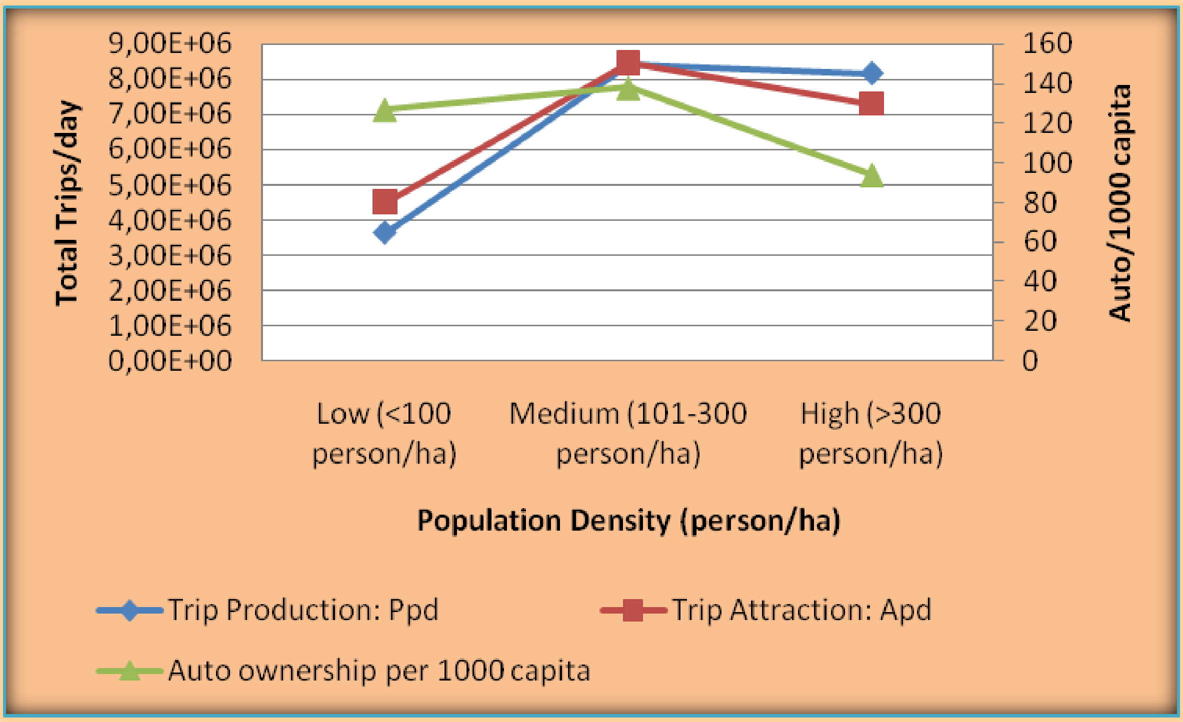

Figure 13 – Trip production characteristics of urban areas and auto ownership per 1000 capita by population density (pd): total daily trips produced (P_{pd}) and attracted (A_{pd})

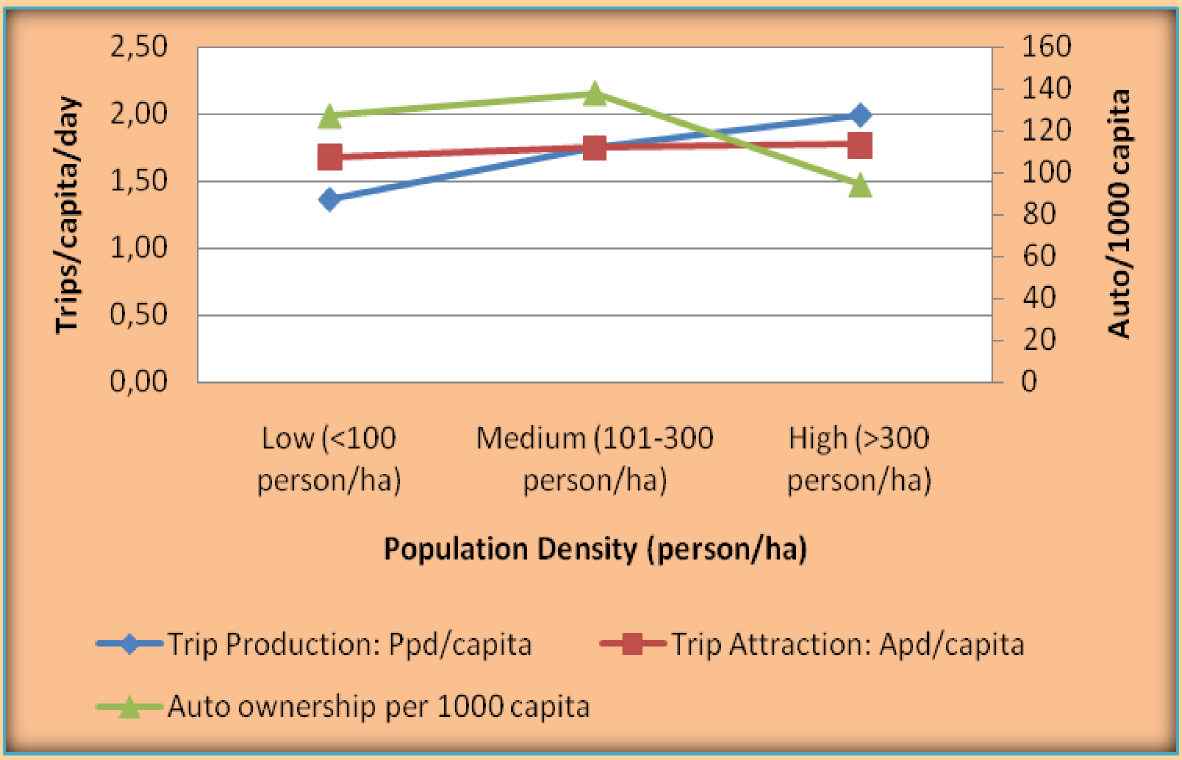

Figure 14 – Trip production characteristics of urban areas per capita and automobile ownership per 1000 capita by population density (pd): trip productions (P_{pd}) and attractions (A_{pd}) per capita

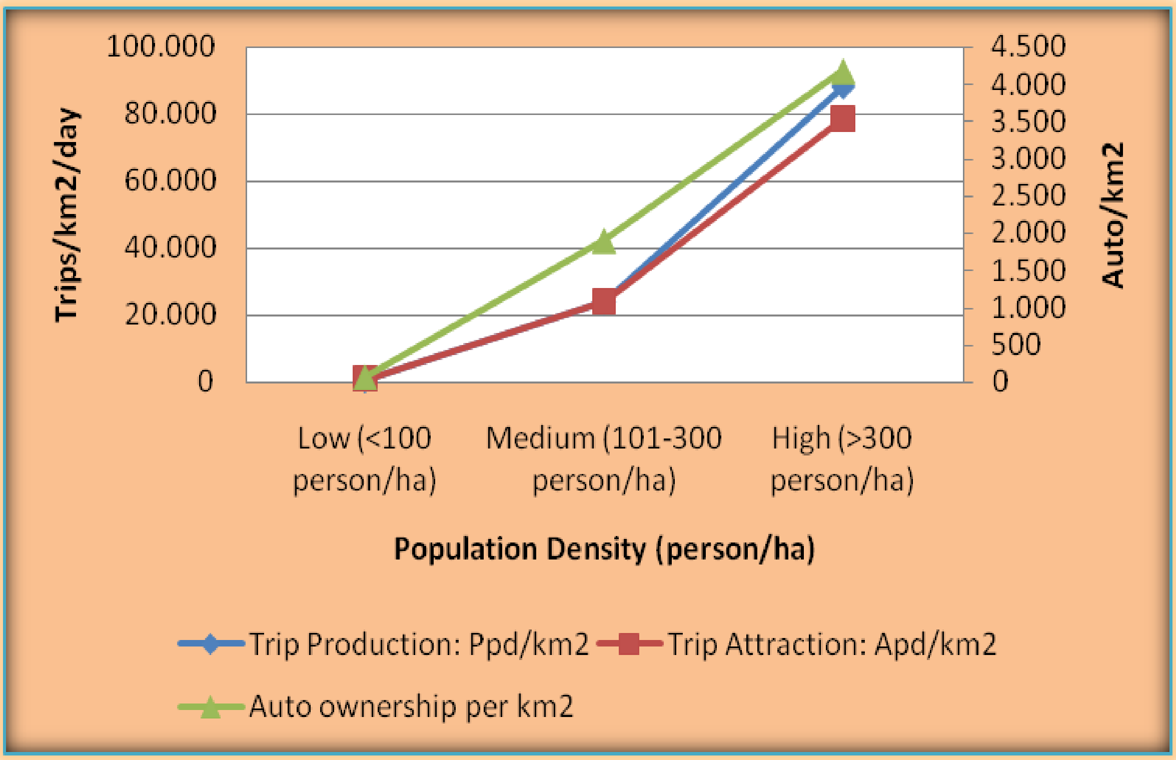

Figure 15 – Trip production characteristics of urban areas per km^2 and automobile ownership per km^2 by population density (pd): trip productions (P_{pd}) and attractions (A_{pd}) per km^2

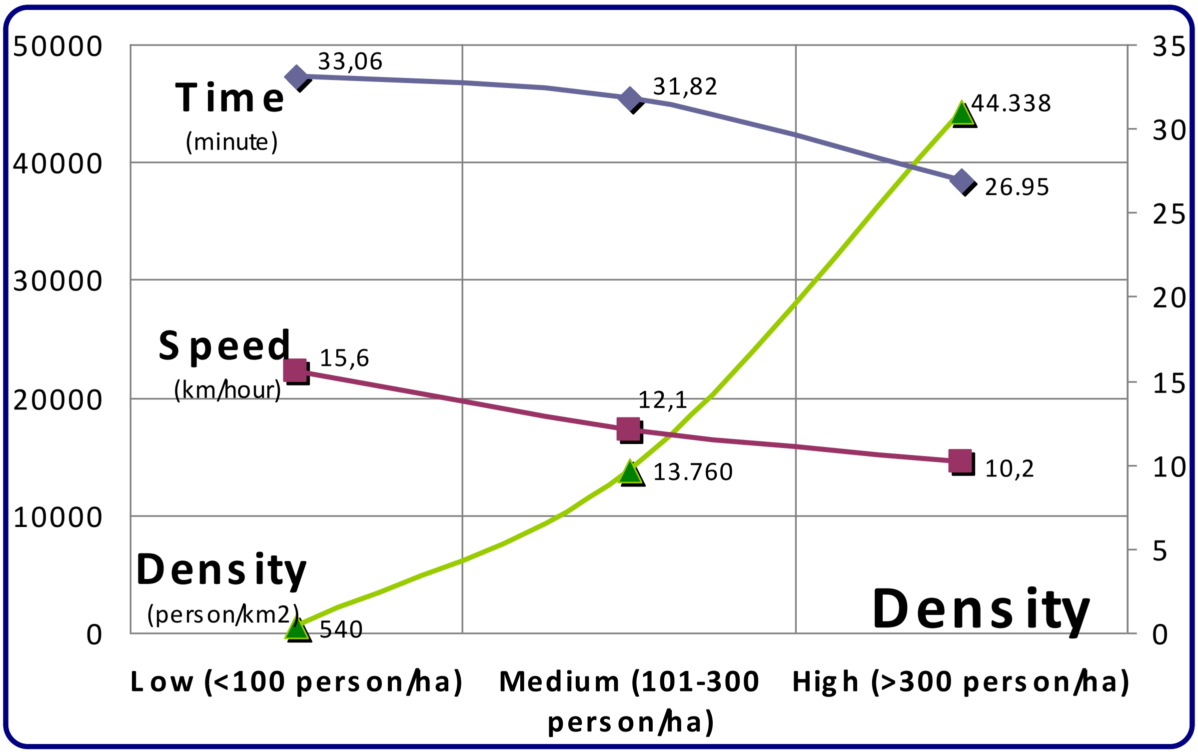

Figure 16 – Characteristics of traffic congestion by density: travel time (min.) and speed (km/hr)

Analysis of Land Value and Trip Production, Trip Length and Travel Time

Value of land obviously increases from the periphery towards the city center. In parallel to the increase in land value, population density as well as traffic congestion increases. Thus, CBD being the most valuable land is the most congested part of a city. Also, most of the commercial activities occur at CBD and urban areas. The value of exchanges increases both the value of land as well as the human activity. Table 7 presents the characteristics of the metropolitan area of Istanbul by the land value classification as low (<50 TL/m^2), medium (51-150 TL/m^2) and high values (>150 TL/m^2). Total trip production is the highest at the medium value areas and trip attraction is the highest at the high value lands. Total trip length as well as travel time, on the other hand, is the highest at the low value areas due to longer distances between activity locations. Travel speed is the highest at the low value areas (14,3 km/h) due to no or little congestion.

Table 7 – Characteristics of the Metropolitan Area of Istanbul by the Land Values

Land Value Classification	Population (2005)	Area (Km^2)	Auto per 1000 capita	Total Trip Production P_{lv}	Total Trip Attraction A_{lv}	Total Trip Length (km)	Total Travel Time (min.)	Travel Speed (km/h)
Low (<50 TL/m^2)	4.788.762	4.723,40	102,77	6.671.304	6.061.281	41.339.663	173.098.853	14,3
Medium (51-150 TL/m^2)	4.737.736	393,1	115,88	7.567.603	6.416.023	30.890.768	164.556.657	11,3
High (>150 TL/m^2)	2.078.982	169,8	158,24	5.985.593	7.745.714	30.650.736	154.557.850	11,9
Total	**11.606.341**	**5.389,80**	**121,71**	**20.224.500**	**20.223.018**	**102.881.166**	**492.213.359**	**12,5**

Figure 17 show the variations in auto ownership per 1000 capita and population density (person per ha) by land value over the study area. By the increase in land value over the metropolitan area, auto ownership is increased. But the population density is quite the same in the medium and high land value areas. Figure 18 shows that total trip attraction is higher than total trip production in the high land value areas, but it is the reverse for the low and medium density areas. In Figure 19 while auto per 1000 capita increases, trip productions and attraction per capita are increased as well. In the high land value areas, which typically correspond to CBD and urban areas, trip attraction per capita is higher than trip production per capita. Figure 20 shows the variations trip productions and attractions, and auto ownership per km^2 by land value. All variables increase while the land value increases. Figure 21 shows the variations in travel time and speed by density. As density increases from the low to the medium, travel speed as well as travel time decreases, but increases again from the mid towards the high density areas. Decrease in travel speed is obvious due to traffic congestion. Low travel time in high density areas shows the advantage of accessibility in such an urban form. In contrary to low density areas, high density urban form results in shorter trips.

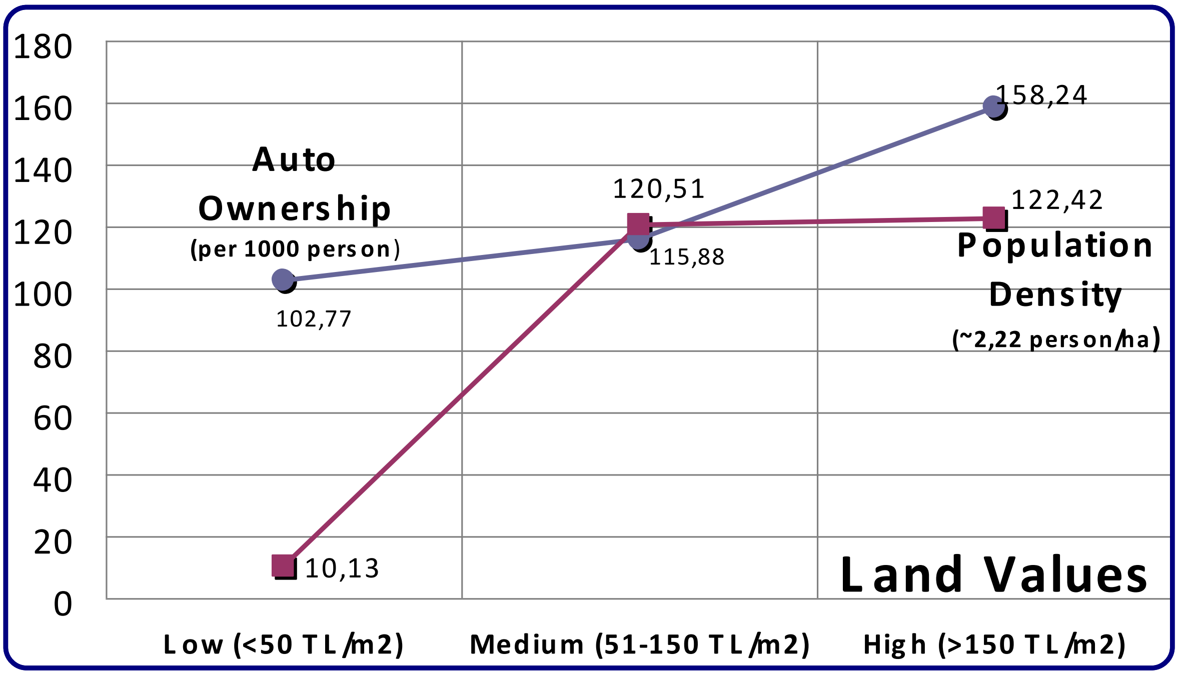

Figure 17 – Characteristics of the urban zones by land value, auto ownership and land values

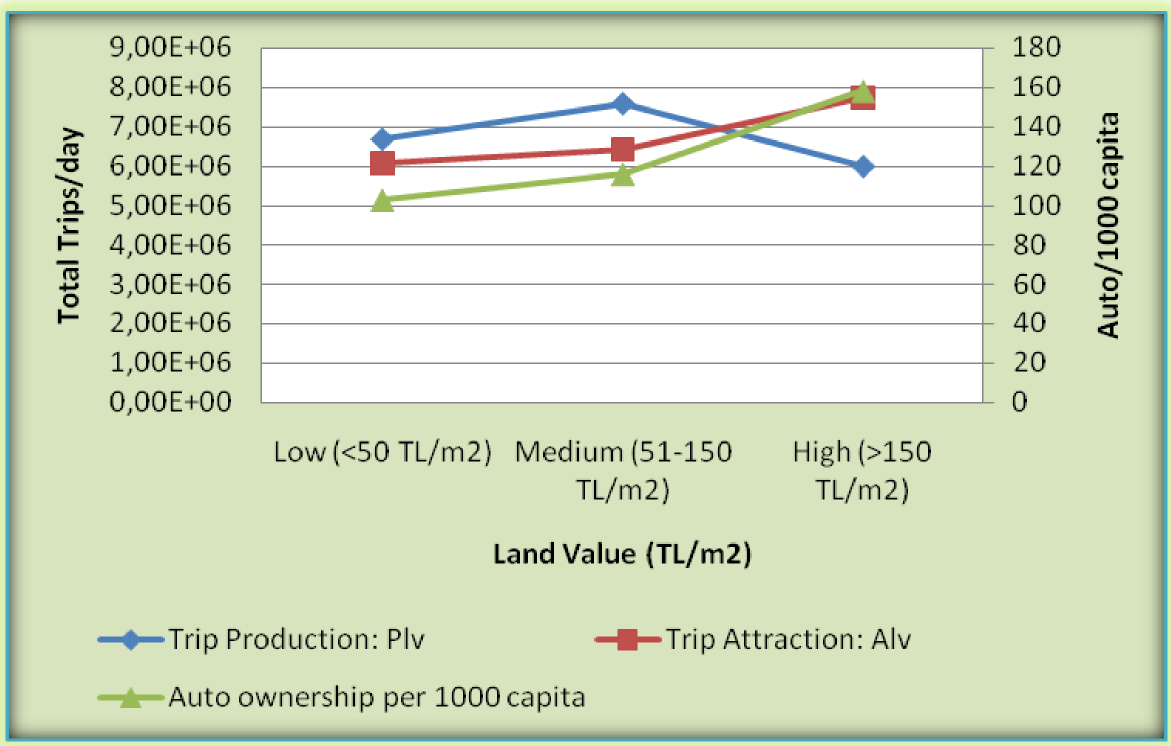

Figure 18 – Trip production characteristics of urban areas and auto ownership per 1000 capita by land value (lv): total daily trips produced (P_{lv}) and attracted (A_{lv})

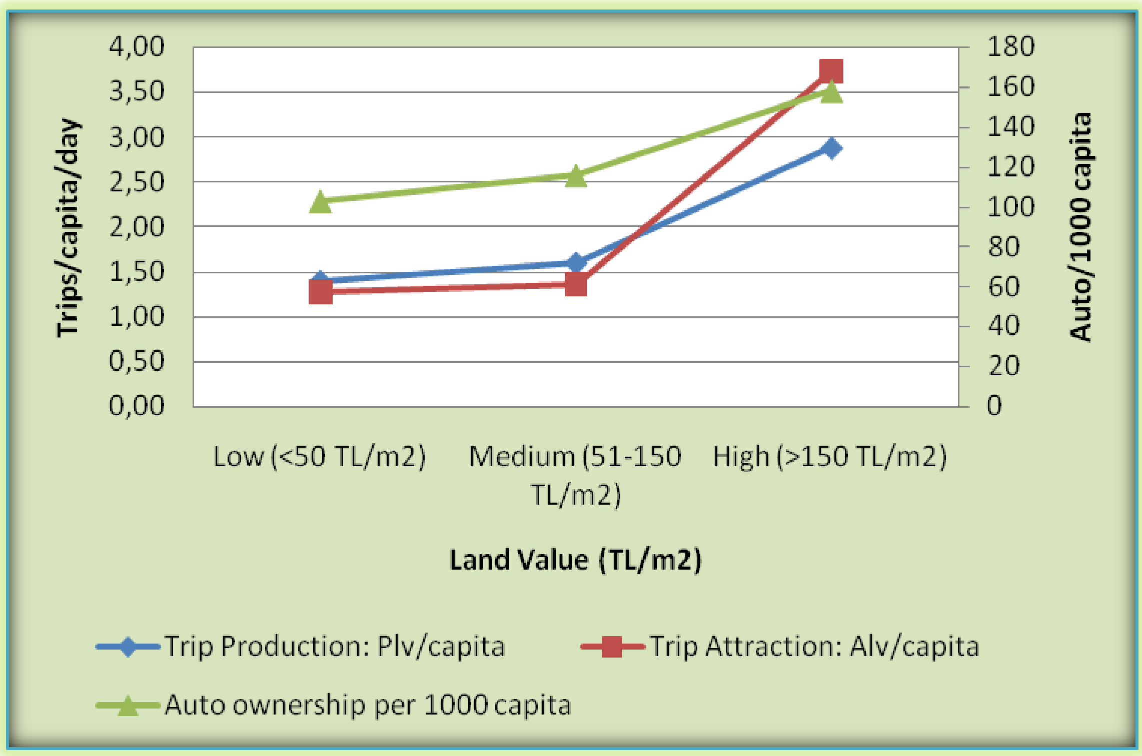

Figure 19 – Trip production characteristics of urban areas per capita and automobile ownership per 1000 capita by land value (lv): trip productions (P_{lv}) and attractions (A_{lv}) per capita

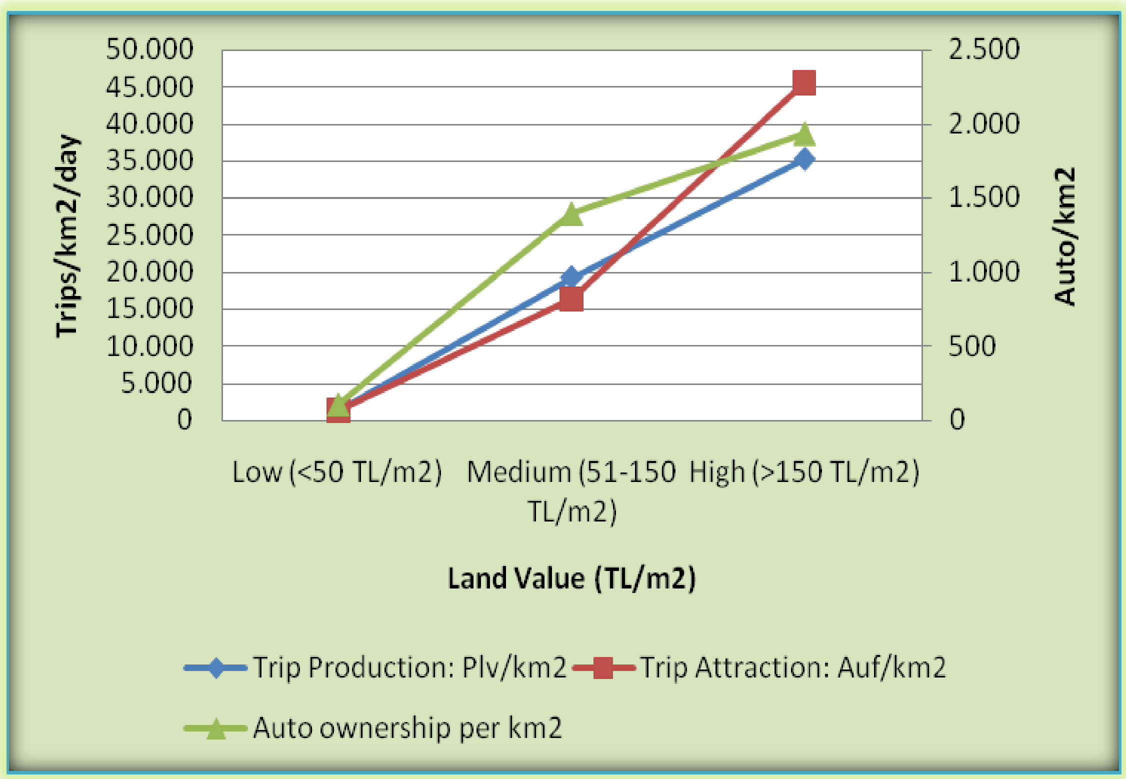

Figure 20 – Trip production characteristics of urban areas per km^2 and automobile ownership per km^2 by land value (lv): trip productions (P_{lv}) and attractions (A_{lv}) per km^2

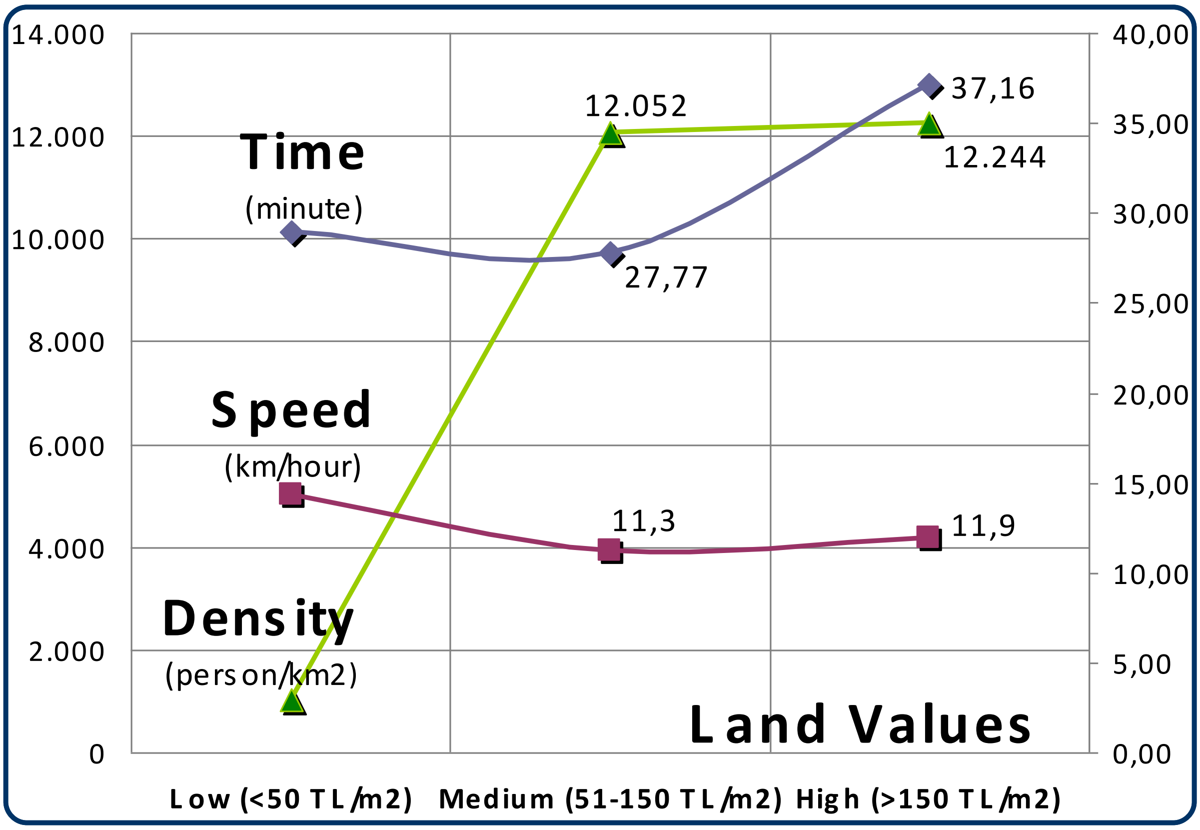

Figure 21 – Characteristics of traffic congestion by land value: travel time (min.) and speed (km/hr)

Analysis of Urban Form and Modal Split

Mode split over a transportation network gives clues about the strength and weakness or the quality of the level of services provided by available and competing transportation modes. Availability as well as the quality of the level of service of transport modes across the region strongly affects their preferability. Figure 22 presents the modal split over the metropolitan area of Istanbul. In CBD, the highest share belongs to public transit modes, namely, bus, minibus, tram, ferry and commuter train lines. In the urban area, walking and riding by car or taxi are the most preferred modes. However, in the suburban area, van- or bus-pooling has got the highest share. In the urban area, shares of the modes are ordered, from the highest to the lowest, as walk, car-taxi, van-bus pool, public transit and other modes. Figure 23 shows the mode use across the metropolitan area. Walking has got the highest share of all modes at all locations and it is the highest at the outer rural zone and decreases towards CBD. On the other hand, public transit modes have the highest share at CBD and their ridership decreases towards the periphery in parallel to the decrease in the level of service.

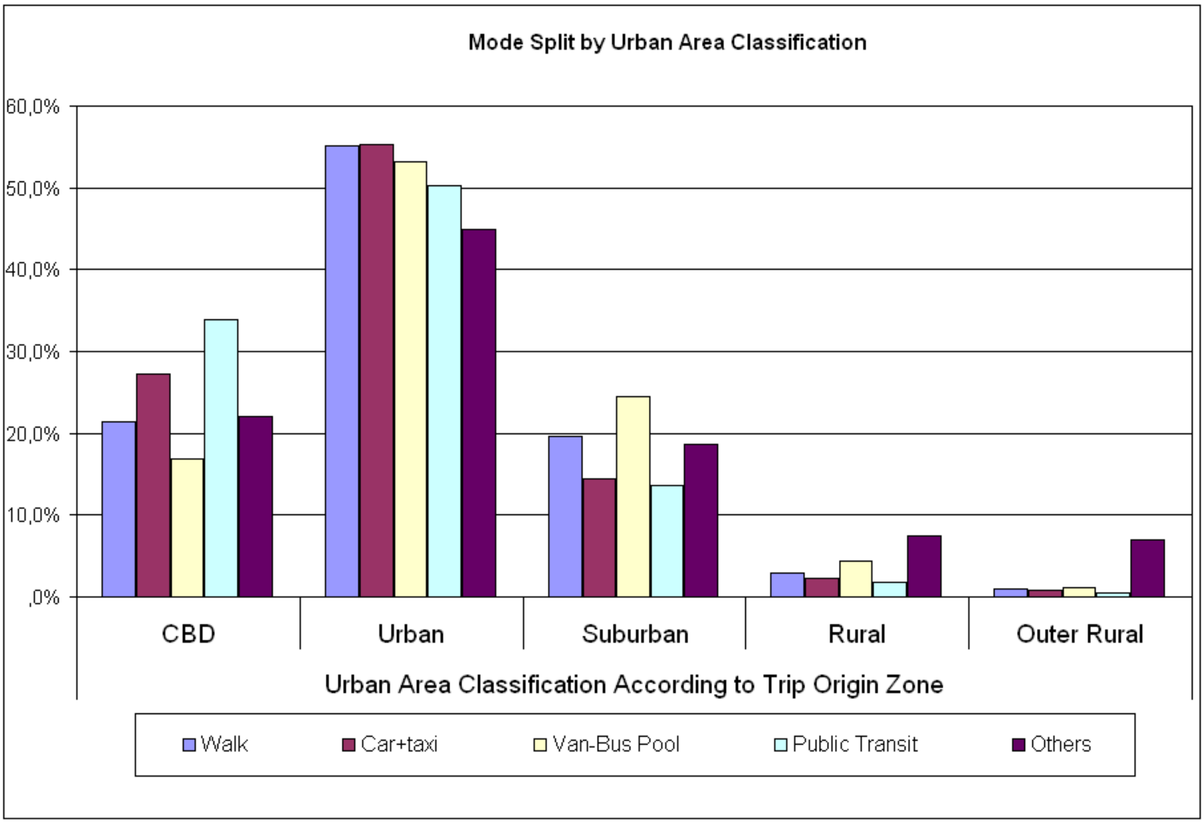

Figure 22 – Mode split by urban area classification

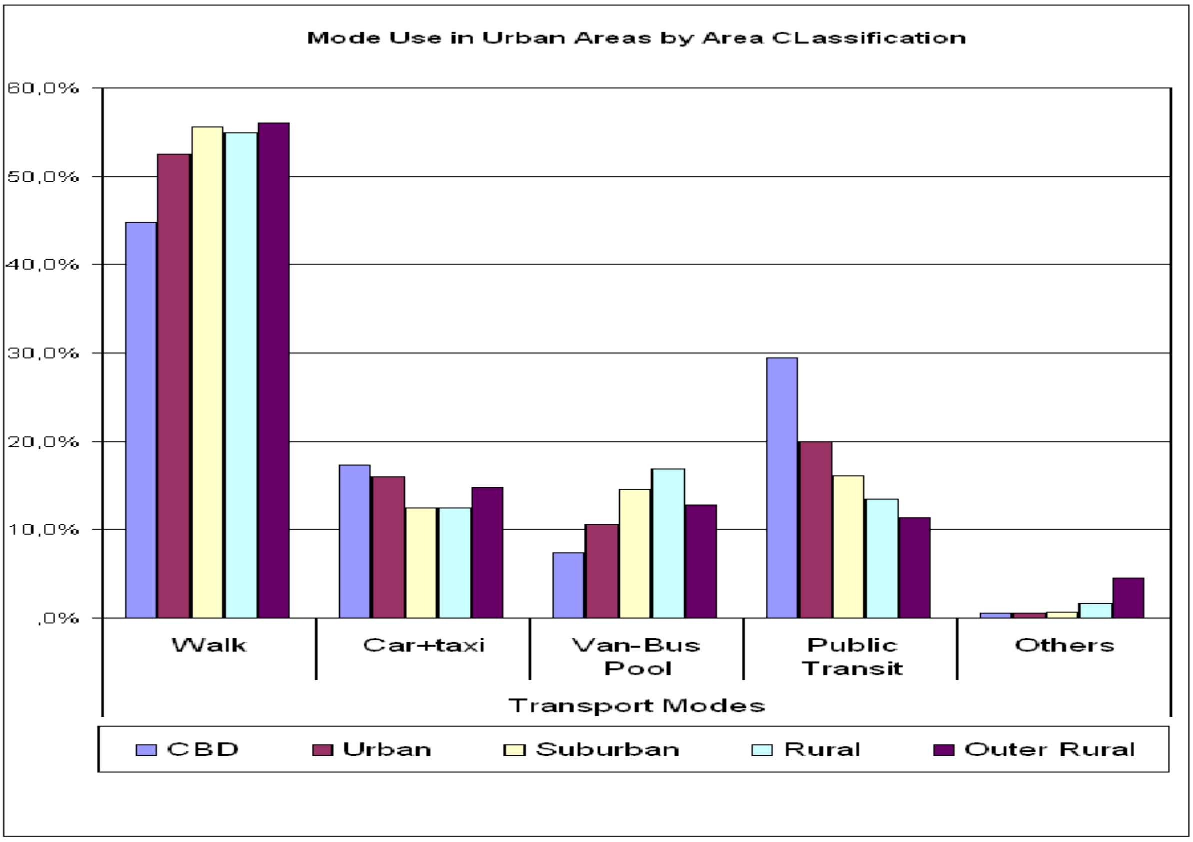

Figure 23 – Mode use in urban areas by area classification

Analysis of Population Density and Modal Split

Population density is another parameter affecting the viability of the level of service provided by basic transport modes. For example, at zones with low density public transit modes are not financially feasible to operate. As seen in Figure 24 public transit modes have the highest share at the medium density zones. The share of public transit at the high density areas is lower than that in the medium density zones. This is probably due to the fact that high density areas experience higher congestion since the share of all motorized modes, except public transit, is the lowest at the high density zones.

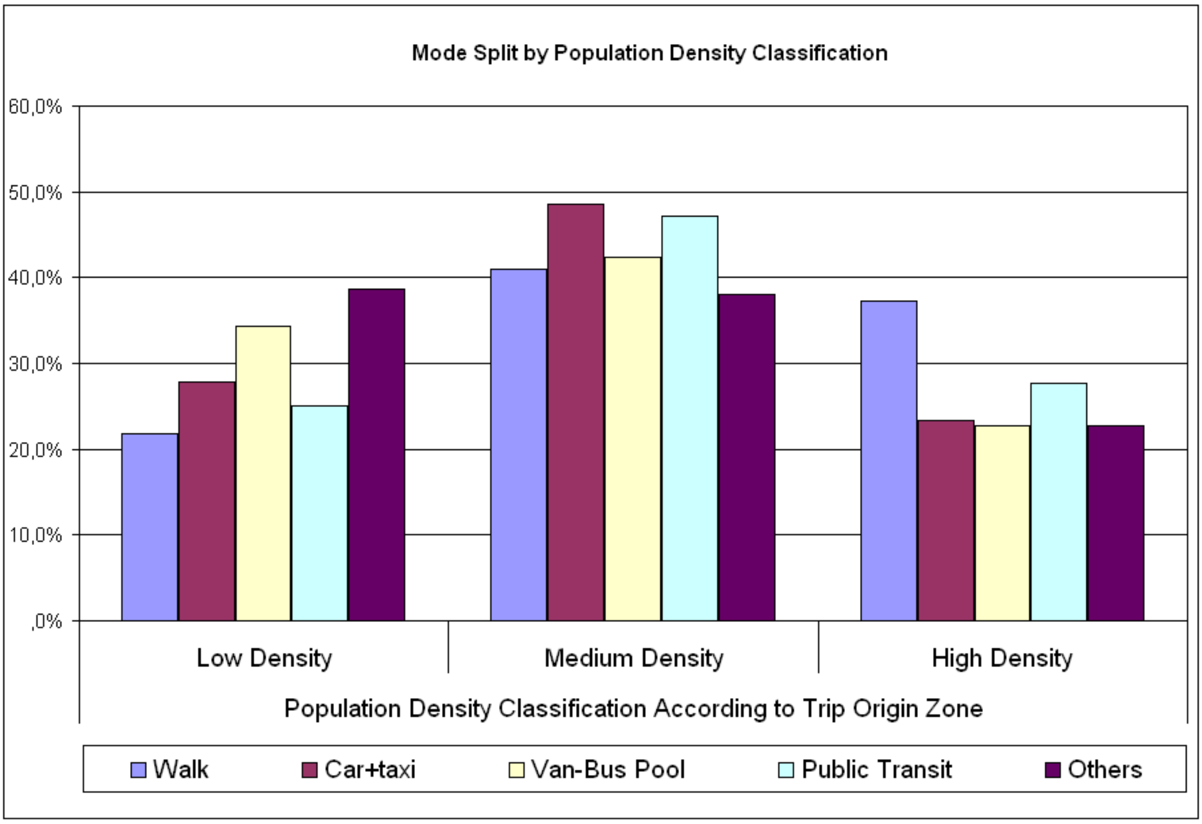

Figure 24 – Mode split by population density classification

As seen in Figure 25, walking has the highest share in the high density areas and decreases towards the low density zones. The use of car+taxi modes is almost the same in the low and medium density areas. The share of public transit modes does not vary very much regarding the population density classification. The use of van-bus pool modes is the highest at the low density zones and decreases towards the high density zones due to the availability of public transit modes there instead.

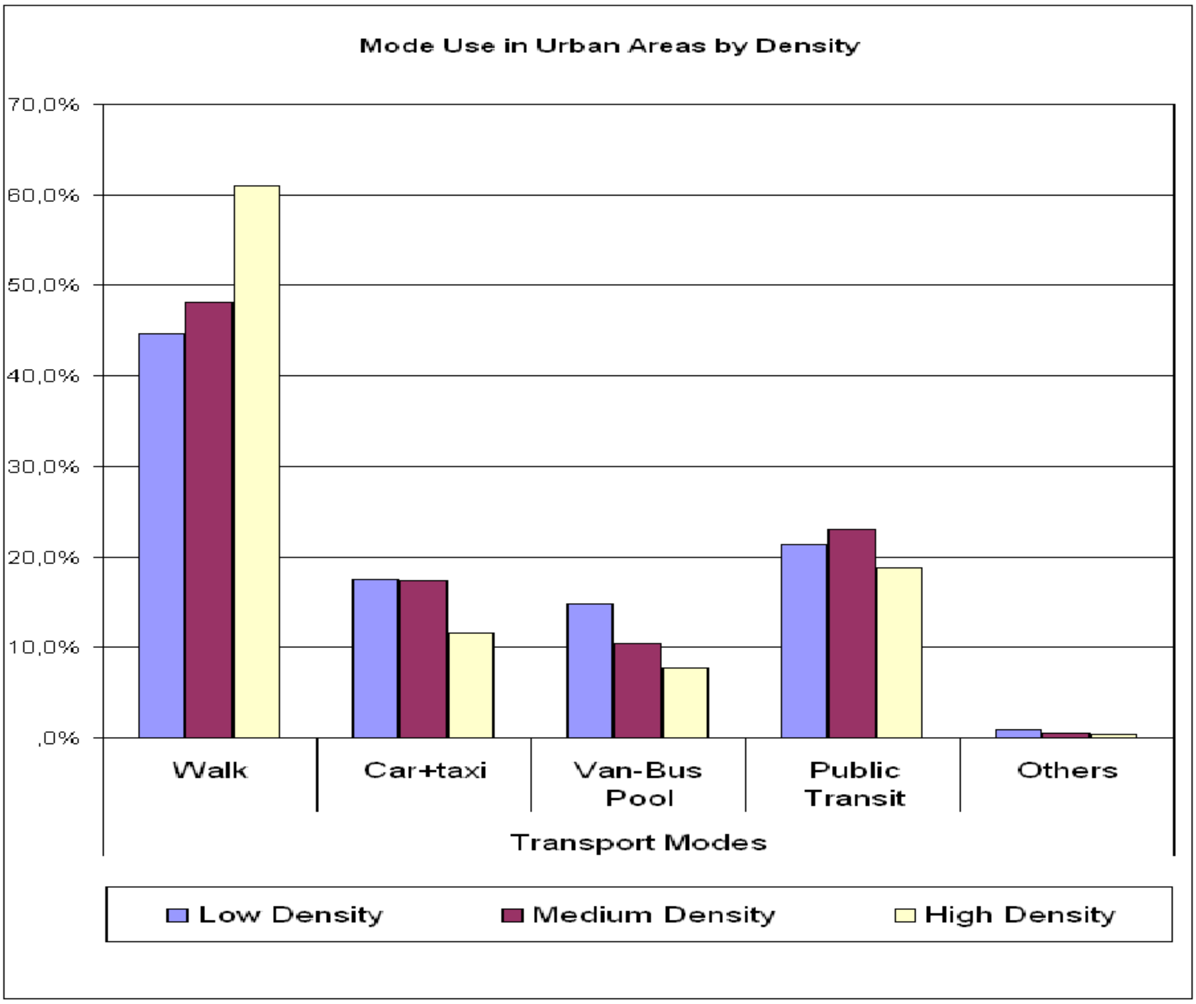

Figure 25 – Mode use in urban areas by density classification

CONCLUSIONS OF THE CURRENT RESEARCH AND RECOMMENDATIONS FOR FUTURE RESEARCH

The relationship between urban transportation system and city form is always of an interest by many researchers. Transportation has a significant effect on cities' macro form. It lets the human settlements be spread or compact in form. It is very well known that this relationship is a two-way interaction. Spatial interaction over the urban land among different levels of subcenters and the city centre is made possible through the transportation system. To understand this relationship between the urban form and the transportation system, in this paper, it is attempted to investigate the effects of urban form, density and land value on urban mobility in the city of Istanbul, Turkey. Results of the analyses with respect to effects of urban structure (urban form, population density and land value) on transport behavior (trip productions and attractions, trip length, travel time and mode choice) in the metropolitan city of Istanbul, Turkey are as follows:

1. Effects of urban form on urban mobility:

a. By decrease in population density, land value and auto ownership decrease as well from CBD towards the periphery of the city.

b. Total trip production and attraction are the highest in the urban area followed by CBD, and then decreases dramatically. Same trend is observed for trip lengths and travel times. But the reverse is valid for travel speed.

c. Daily travel in the city of Istanbul is about 2567 times the length of the equator. In every minute, travelers of Istanbul travel 1.8 times of the equator's length. Total daily travel time is about 936.5 years.

d. From CBD towards the suburban zones, traffic congestion is effective. Beyond there, no major congestion is measured based on the travel speed data.

e. In CBD, the highest share belongs to public transit modes, namely, bus, minibus, tram, ferry and commuter train lines. In the urban area, walking and riding by car or taxi are the most preferred modes. However, in the suburban area, van- or bus-pooling has got the highest share. In the urban zone, shares of the modes are ordered, from the highest to the lowest, as walk, car-taxi, van-bus pool, public transit and other modes.

f. Walking has got the highest share of all modes at all locations and it is the most preferable mode at the outer rural area and decreases towards CBD. On the other hand, public transit modes have the highest share at CBD and decrease towards the periphery in parallel to the decrease in the level of service.

g. Overall travel speed is about 12.5 km/h in the metropolitan area of Istanbul.

2. Effects of population density on urban mobility:

   a. Total trip production and attraction values are very similar at the high and medium density zones where the population is the highest, but at the low density zones both are reduced by about 50% or so.

   b. Total trip length at the low density areas is 48% higher than that in the high density areas. Total travel times at both areas are very close to each other. Total trip length and travel time are the highest at the medium density areas. As expected, travel speed is the highest at the low density areas and the lowest at the high density zones.

   c. Auto ownership is the lowest at the high density areas. Average auto ownership per 1000 capita at the high density areas is 34.9 and 46.5% lower than those in the low and medium density areas, respectively. This leads to the conclusion that increasing urban density results in lower auto ownership makes quite sense as a sustainable urban policy because while the auto ownership decreases, trip productions and attractions decrease as well.

   d. As density increases, travel speed as well as travel time decreases. Decrease in travel speed is obvious dues to traffic congestion. Low travel time in high density areas shows the advantage of accessibility in such an urban form. In contrary to low density areas, high density urban form results in shorter trips. This also contributes to sustainable urban policies and green environment with less greenhouse gas effects.

e. Share of public transit at the high density areas is lower than that in the medium density zones. This is probably due to the fact that the high density areas experience higher congestion since the share of all motorized modes, except public transit, is the lowest at the high density zones.

f. Walking has the highest share in the high density areas and decreases towards the low density. The use of car+taxi modes is almost the same in the low and medium density areas. The share of public transit modes does not vary very much regarding the population density classification. The use of van-bus pool modes is the highest at the low density zones and decreases towards the high density zones due to the availability of public transit modes there.

3. Effects of land value on urban mobility:

   a. Total trip production is the highest at the medium value areas and trip attraction is the highest at the high value lands. Total trip length as well as travel time, on the other hand, is the highest at the low value areas. Travel speed is the highest at the low value areas (14.3 km/h).

   b. By an increase in the land value, auto ownership is increased as well. Total trip attraction is higher than total trip production in the high land value areas, but it is the reverse for the low and medium density areas. In the high land value areas, typically corresponding to CBD and urban areas, trip attraction per capita is higher than trip production per capita.

The followings are the recommendation for future research regarding the subject of the effects of the urban structure on urban mobility:

a. Modeling of auto ownership, trip rates, travel times and lengths with multiple linear regressions sure adds more values to such an analysis of the plan scenarios of smart growth and suburbanization.

b. The use of the multiple-criteria method lets combine different travel parameters such as trip production, travel time and trip length to evaluate sustainable development scenarios.

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