MANAGEMENT OF URBAN FORM FOR TRANSPORTATION ENVIRONMENT
-GASOLINE CONSUMPTION OF HIGH DENSITY CITIES AND THEIR FACTORS-

Mamoru TANIGUCHI
Associate Professor
Department of Environmental and Civil Engineering
Faculty of Environmental Science and Technology
Okayama University
2-1-1 Tsushima-Naka Okayama, 700-0082 JAPAN
Fax. +81-86-251-8257
E-mail mamoru34@cc.okayama-u.ac.jp

ABSTRACT : Though some research has already indicated that population density is one of the most essential factors influencing the level of car usage in western cities, the same kinds of analysis for Eastern Asian cities have not been conducted in sufficient numbers. To learn the relationship between urban layout and the level of car usage is a very important first step for enforcing successful TDM (Transportation Demand Management) measures. This study aims to find the relationship between layout of cities and automobile usage patterns in higher density cities in Asia, especially focusing on gasoline consumption. The trip data was collected and processed for 67 typical cities in Japan from the National Person Trip Survey that was conducted in 1992. The relationship between population density and gasoline use is confirmed. Moreover, influences by other factors are also calibrated by the model, and its results are general enough to apply to Eastern Asian cities.

1. INTRODUCTION

There are many kinds of TDM measures in place to control urban transportation to protect and improve the environment. These measures include park-and-ride, flex time commuting, toll roads and so on. Generally speaking, these countermeasures focus only on the transportation behavior, not on the urban layout. Though these measures could be effective for specific transportation problems in each city, it is very difficult to improve the basic trend of increasing car usage. Now, because many metropolitan areas and cities in the Eastern Asian countries face problems in their transportation environment caused by cars, essential measures to control urban form to improve the situation must be undertaken.

Several studies that focused on cities in Western countries have already indicated that population density is one of the most essential factors in controlling car usage. Statistical analysis for cities in Eastern Asia is now also necessary. This analysis must be based on enough trip samples and on the same standards in order to confirm the relationships among factors accurately.

This study selected 67 typical cities in Japan to find the relationship between trip patterns and urban characteristics, especially concerning factors of urban layout. The National Person Trip Survey (NPTS) conducted in 1992 was adopted as the trip data source. The analysis was done by following two different parts.

1) The relationship between urban population density and energy consumption by automobiles is clarified. To estimate accurate gasoline consumption per capita in each city, an adjustment calculation is executed to determine the section of a trip when a car was used (hereafter referred to as the "car journey") during trips of more than one mode (hereafter referred to as "mixed-mode" or "mixed-car" trips).
2) The relationship among other factors concerning urban layout and gasoline consumption by cars is also analyzed by a multiple regression model. The parameter of each factor for gasoline consumption is estimated.

2. URBAN FORM AND CAR USAGE: PREVIOUS STUDIES

Both traffic conditions and car usage in Eastern Asian cities have changed drastically in recent years. In the case of Japan, car usage has increased in the past two decades in most cities. Figure 1 shows how typical residents in Japanese cities have changed their method of commuting during these two decades. In this figure, if public transportation modes are dominant in the city, that city is located in the upper left corner. On the other hand, if car usage is dominant in the city, that city is located in the lower left corner of this figure. During these two decades, most of cities have changed location from the upper right to the lower left corner. These movements mean that rapid increase of automobile usage has occurred in each city. This tendency is very conspicuous in local cities that are shown as black points in Figure 1. In this study, the definition of local cities is that the city does not belong to three major metropolitan areas (Tokyo, Osaka and Nagoya).

Because the basic trends of motorization have proceeded at such a high speed, most countermeasures that tried to hold back this stream ended in vain. In other words, the effects of TDM measures, such as park-and-ride and flexible time commuting, tended to be very limited. As these measures focus only on the transportation behavior, not on the urban form, it is very difficult to reverse the basic trend of increasing automobile transportation. The most important requirement for reducing car traffic is to know and control essential factors concerning the form of cities that influence the behavior of the residents.

Newton and Kenworthy (1989) calculated the relationship between urban population density and annual gasoline consumption per capita, as shown in Fig. 2. This figure shows very clearly that cities with a low density rely on car transportation. It is also very interesting that American

(Houston, Phoenix and Detroit etc.), Australian (Perth, Brisbane and Melbourne etc.), and European (Hamburg, Paris and Zurich etc.) cities form a line from the upper left corner towards the center of this figure. From the point of view of urban and transportation policy need to improve the environment and reduce energy consumption, Newton and Kenworthy (1989) suggested raising urban population density. For example, they recommended that if the urban population density could be changed from 10 persons/ha to 30 persons/ha, gasoline consumption per capita would be reduced by half.

Cities in Eastern Asia also must have the same relationship between urban population density and automobile usage. However, most of the Eastern Asian cities have already attained a higher population density than 30 persons/ha. Because of this, some new recommendations are necessary in order to improve the environment and reduce energy consumption for cities in Eastern Asia. It would also be desirable to add other sample cities to Fig.2 to investigate the relationship between urban form and car usage in Eastern Asian cities.

3. THE DATA AND CITIES

In Japan, Metropolitan Person Trip Surveys (MPTS) have been conducted in major cities and metropolitan areas for the past three decades at different times. Though they provide rich information for creating a transportation plan for each metropolitan area, they are not appropriate to utilize for this study. This study needs trip data from many cities based on the same standard and the same survey period. As a result, trip data from the NPTS (National Person Trip Survey) is preferable to the usual MPTS for this study.

The NPTS has been conducted twice so far by the Ministry of Construction of Japan. The first survey was conducted in 1987 in 131 cities, and the second survey was conducted in 1992 in 78 cities in Japan. Sample cities were selected to cover cities of a variety of types. Specifically, the following three points were considered.

a) The population size of the city,

b) the population size of the metropolitan area that the city belongs to, and

c) the location (e.g., center or periphery) of that city in the metropolitan area.

The NPTS survey was composed of two sheets for each household. One was the questionnaire for the household attributes, and the other was the questionnaire for trips undertaken by each family member. The NPTS also includes questions about the possibility of car usage for each family member.

Each sample city distributed questionnaires to at least 360 households. During the 1992 survey, the total number of distributed household questionnaires was 29,502 and personal questionnaires 80,997. Investigators visited all the selected households to distribute and collect the questionnaires.

The collected household questionnaires numbered 25,009 and personal questionnaires 67,067. As a result, the effective personal sample rate was 82.8%. It is statistically guaranteed that this 83% collection rate is large enough to reproduce basic transportation characteristics such as average trip length in each city. This means involved errors in the estimation values have already examined small enough. (Ministry of Construction 1993).

Urban areas in Japan are controlled by city planning laws, and such urban areas are designated *Urban Planning Areas*. Household samples in the NPTS were selected from the Urban Planning Area in each city. As some cities have large non built-up areas such as mountain regions that were outside of the Urban Planning Area, analysis based on the Urban Planning Area gives us more accurate results that are free from bias. Based on this point, 11 out of 78 cities were excluded from the following analysis as those 11 cities do not have designated Urban Planning Areas in the city region. Figure 3 shows the location of those 67 cities for the following study.

This NPTS covers many cities using the same survey standards and the same survey period. On the other hand, data from the NPTS also has a few weak points, as follows.

1) Though NPTS data covers what kinds of journeys (e.g. car, foot, train, etc.) compose each mixed-mode (e.g. combination) trip, it does not cover information concerning the required time and distance of each journey (e.g. leg of the trip) on each trip.
2) NPTS data does not include information about the origin and destination of each trip.

4. EXTRACTION OF CAR JOURNEYS FROM NPTS DATA

As mentioned above, though the NPTS provides very good trip data based on the same conditions, it does not cover information concerning the required time and distance of each journey that composes each mixed-mode trip. In other words, if a leg of that trip included using a car, it did not mean that was the only mode used. This means it is necessary to extract the real distance and time spent in a car on each mixed car trip.

Table 1 shows the real patterns of journey combinations that include a car journey in that mixed-mode trip. As seen in this table, the trips that are undertaken by car only were 95.3% of the total trips that included car journeys. In this type of car trip, we know accurately the trip distance and time journeyed by car directly from the survey reply. This means that the other 4.7% of trips were composed of not only car journeys, but also walking, railway and two-wheeled vehicle journeys, in other words, mixed car trips. If we include these mixed car trips in the analysis, it is necessary to estimate the distance and time journeyed by car itself. Though 4.7% looks like a small enough number to ignore safely, that rate is not the same in each city. For example, the composition rate of mixed car trips in the cities of Osaka, Yokohama, Matsudo, and Tokorozawa is higher than 10%, while that number in Sakata, Hyuuga, and Hirosaki is only around 1%. This means if we ignored all mixed car trips, the estimated gasoline consumption would be biased.

Table 1 also shows that the top four patterns cover 99.3% of total mixed car trips. This rate is the average number of all cities. It is also necessary to check whether car-related trips in each individual city are adequately covered by these four patterns. The minimum rate covered by these four patterns is 95.7% in Yokohama, and the covered ratio of all other cities is more than 96.5%. From this, it could be concluded that it is not big problem to focus on these four patterns for this analysis. The second, third, and fourth patterns are composed of car and foot journeys. Each speed and gasoline consumption by car journey is obtained from the following calculation.

The quantity of gasoline consumption of each trip is estimated using the following equation (Kaneyasu 1972).

$$q_{[cc/km]} = 0.290x_{[s/km]} + 49.3 \quad \cdots\cdots(1)$$

x : vehicle speed (in the case of surface road driving, not on the expressway)

x is calculated from the trip distance and time required that were acquired from the NPTS. In case the trip is composed of a car journey and foot journey, the distance and time required by the car journey are estimated using the following method.

First, the speed of the walking journey (ν_W) is assumed to be 4.0 km per hour. This speed is assumed to be the same in any city. Secondly, the speed of the car journey (ν_C) in each city is calculated by using car trip data that is composed only from a car journey, not from mixed trip. Moreover, data of total trip distance (S) and time (T) is acquired from the Survey replies. From this information, we get the following simultaneous equations. By solving these equations, the trip distance (S_W) and time (S_C) of each car journey that composed part of a mixed car trip are calculated.

$$\begin{cases} s_w + s_c = S \\ \dfrac{s_w}{\nu_w} + \dfrac{s_c}{\nu_c} = T \end{cases} \rightarrow \quad s_c = \frac{\nu_c(T\nu_w - S)}{\nu_w - \nu_c} \quad \cdots\cdots(2)$$

S_W: distance of walking journey (unknown)

S_C: distance of car journey (unknown)

ν_W: speed of walking journey (given)

ν_C: speed of car journey (given)

S: total trip distance

T: total trip time

The constraints are as follows:

$$1)\quad \frac{S}{T} \geq 4.0$$

$$\text{in case of} \quad \frac{S}{T} < 4.0 \quad \Rightarrow \quad s_w = S, s_c = 0$$

$$2)\quad \frac{S}{T} \leq v_c$$

$$\text{in case of} \quad \frac{S}{T} > v_c \quad \Rightarrow \quad s_w = 0, s_c = S, v_c = \frac{S}{T}$$

From these equations, gasoline consumption in each city per capita is obtained. This consumption volume is converted into energy use by using the following coefficient.

Gasoline 1,000cc : 720 g

Gasoline 1 kg : 44.1 MJ (Hayashi et al. 1995)

5. RESULTS

Figure 4 shows the relationship between population density and gasoline energy consumption in each city. As seen in this figure, population density is also a very important factor in explaining the gasoline energy consumption in Japanese cities. As this study is considering only car journeys, the gasoline consumption volume of each city tends to be lower than that in Figure 2. It can be concluded that if the figure were focused on population density, the distribution pattern of cities in this figure could resemble the distribution pattern of cities in Fig. 2.

On the other hand, Fig.4 also indicates that the population density is not the only factor needed to explain gasoline consumption in each city. If we look at cities where the population density is around 50 persons/ha, their gasoline consumption levels range from 5 to 12 thousands MJ. To uncover the influence of other factors on gasoline consumption, it is necessary to introduce multiple regression analysis for these 67 cities.

The dependent variable (Y) of the regression model is gasoline consumption per capita. Several types of regression equations have been tested, and the following log-linear type model has the best fit of all models.

$$\ln Y = a_1 X_1 + a_2 X_2 + \cdots a_n X_n + b \quad \cdots\cdots (3)$$

To build this model, about 30 explanatory variables were examined which relate to urban layout, land use intensity, historical and geographical background, and transportation condition. The explanatory variables adopted are shown in Table 2. Correlation coefficient among variables are shown in Table 3. The parameters and t-values in Table 4 show a clear image of the relationship between urban form and automobile energy consumption as follows.

1) In spite of other factors that are taken into consideration, *population density* is still the most significant factor in explaining gasoline consumption by car per capita in each city.
2) Transportation infrastructure, such as the *number of railway stations* and length of road that authorized by city planning also significantly affects the gasoline consumption rate.
3) Topographical factors are also important. *Linear port cities*, which entail topographical restrictions for urban land use, have been found to discourage car usage.
4) Cities in large *metropolitan areas*, such as Tokyo and Osaka, tend to have relatively small gasoline consumption.
5) *Castle cities and historic cities* such as Kyoto tend to show relatively small gasoline consumption. The urban layout and road network of this type of city are not suited to unrestricted car use.
6) If the residential areas are scattered, heavy car usage would be required much more in that city. Though it is not so significant, *sprawl dummy* has plus effect on car usage.
7) It is very interesting that *cities burned in WWII* now show a high rate of gasoline consumption. It could be that urban reforms carried out have made car usage much easier than in other cities.
8) There are also many other factors that encourage car usage. *Middle class prefectural capital cities* tend to have higher gasoline consumption. Cities in *the northern Kanto region* and cities that have a higher *rate of secondary industry* also show higher gasoline consumption per capita.

The adjusted R^2 of this model is greater than 0.8, and the performances of the parameters are also satisfactory.

6.CONCLUSION

Based on the processed and adjusted National Person Trip Survey (NPTS) in Japan, the relationship between gasoline consumption by automobiles and urban population density in each city is clarified. Though urban population density is a significant factor in explaining gasoline consumption in each city, it is found that many other factors also have a very important influence. Through comparing previous studies of cities in Western countries, it is seen that Eastern Asian cities have a tendency to have a higher population density. It is concluded that in such cities with a higher population density, their level of car usage is influenced by many other factors that relate to differences in urban layout. By calibrating a multiple regression model, the significance of each factor for gasoline consumption has been clarified. Not only the improvement in the level of transportation infrastructures, but also historic backgrounds and past improvement of urban form show a strong influence on gasoline consumption in each city. For further study, it is also necessary to investigate other Asian developing cities to find best solution for each city.

ACKNOWLEDGEMENTS

The author is indebted to Mr. Takeomi Murakawa for his assistance in this study.

REFERENCES

Department of the Environment and Department of Transport (1994) PPG13 (**Planning policy guidance**: transport), London: HMSO

Hayashi, Y., Katho, H., Ohomoto, J. and Sugawara, T. (1995) Estimation of reduction in CO_2 emission by modal shift policy in urban passenger transport, **Infrastructure planning review**, No.12, 277-282

Kaneyasu, K. and Kanaizumi, A. (1972) **Koutsuu kougai (Transportation pollution)**, Gijyutu-shoin

Ministry of Construction (1993) **The report of 2nd National Person Trip Survey**

Newton, P. and Kenworthy, J (1989) **Cities and automobile dependence**, a sourcebook, Hampshire, Gower Technical

Taniguchi, M. (1998) Can guidelines manage the co-ordination between land-use and transport planning? **Infrastructure planning review**, No.15, 227-234

Taniguchi, M., Ishida, H., Ogawa, H. and Kurokawa, T. (1995) Change of commuter modal choice and its relation to urban form, **Infrastructure planning review**, No.12, 443-451

The Royal Commission on Environmental Pollution's Report (1995) **Transport and environment**

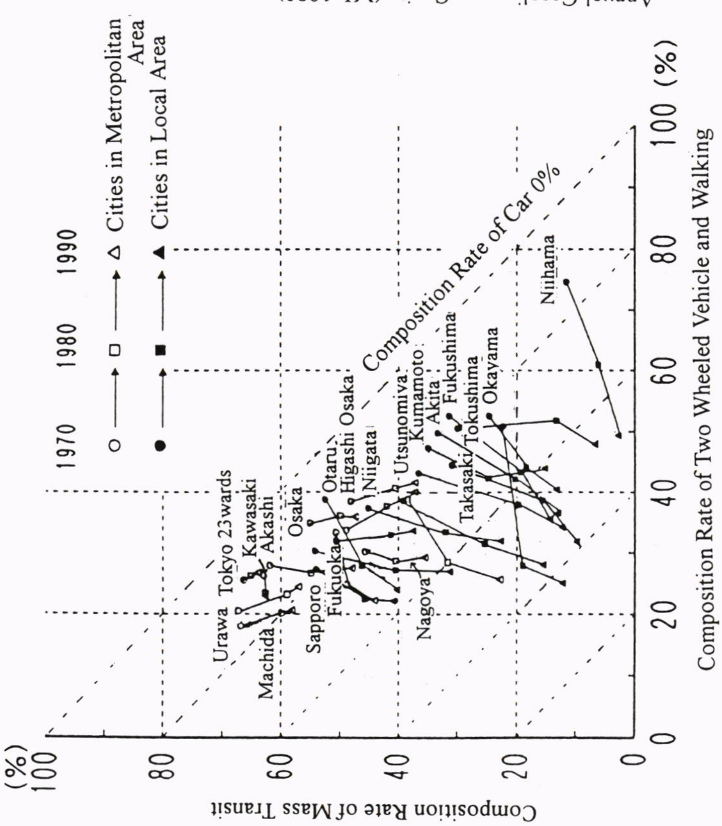

Figure. 1 Change of Modal Component in Japanese Cities (1970-90)

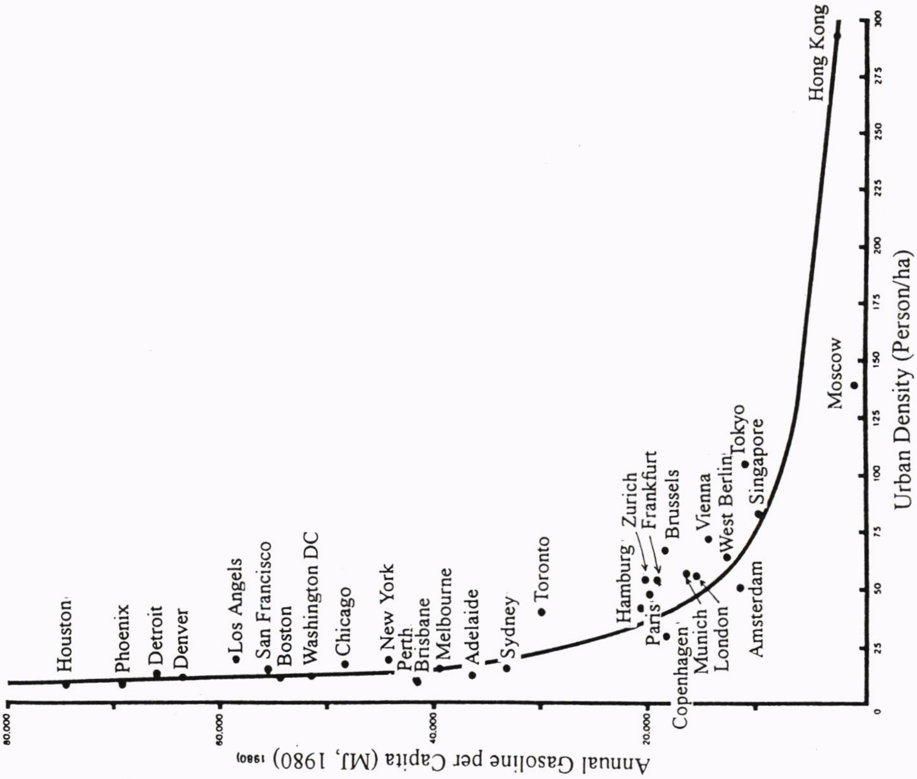

Figure.2 Urban Density versus Gasoline Use per Capita
(Newman, P. and Kenworthy, J. 1989)

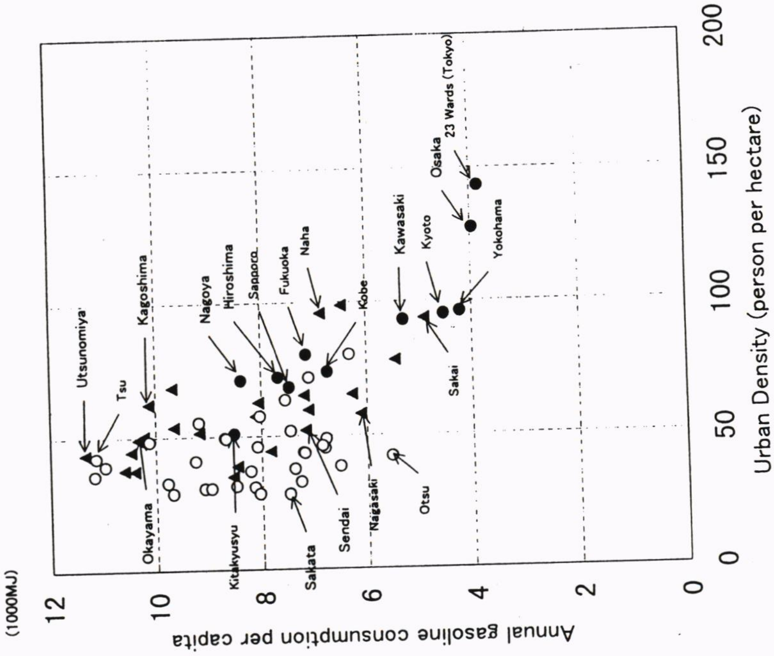

Figure.4 Urban Density versus Gasoline Use per Capita (67 Cities in Japan)

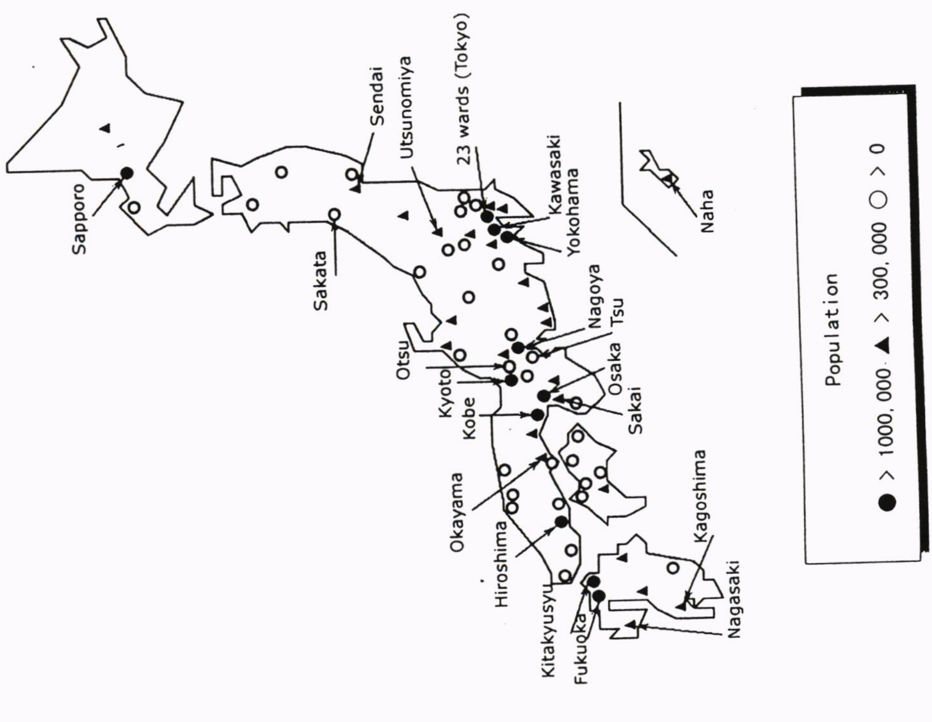

Figure.3 Location of 67 Cities for This Study in Japan

Table.1 Patterns of Modes Combination and Their Component Distribution (Concerning Trips that Include Car Journey)

Journey Combination of Each Trip	Samples	%
1) Car	57,723	95.3
2) Car + Walk	1,021	1.7
3) Walk + Car	874	1.4
4) Walk + Car + Walk	526	0.9
5) Car + Railway + Walk	117	0.2
6) Walk + Railway + Car	97	0.2
7) Car + Two wheeled vehicle	53	0.1
8) Two wheeled vehicle + Car	39	0.1

Table.2 Meaning of Adopted Explanatory Variables

Explanatory variables	Meaning
Population Density	Population density in urbanization area (Person/ha)
Number of Railway Stations	Includes LRT and AGT stations
Linear Port City Dummy	Topographical factor (Otaru, Yokohama, Kobe and Nagasaki)
Osaka Met. Area Dummy	(Ohtsu, Kyoto, Uji, Osaka, Sakai, Kobe and Nara)
Tokyo Met. Area Dummy	(Toride, Kumagaya, Tokorozawa, Chiba, Matsudo, Tokyo23 wards, Machida, Yokohama and Kawasaki)
Castle & Historical City Dummy	Excluding damaged city by WWII (Hirosaki, Morioka, Sendai, Utsunomiya, Kanazawa, Nagoya, Matsumoto, Hamamatsu, Kyoto, Osaka, Himeji, Tottori, Matsue, Tokuyama, Marugame, Imabari, Kochi, Kumamoto, Ohita)
Sprawl Dummy	(Residential area)/(DID area) × 100 ≧10.0 (Koriyama, Komatsu, Shizuoka, Yasugi, Tokuyama and Nangoku)
The Rate of Secondary Industry	
Northern Kanto Region Dummy	(Mito, Katsuta, Utsunomiya and Kiryuu)
Length of City Planning Road	
Middle Size Prefectural Capital Dummy	Population: 300 – 700 thousands (Utsunomiya, Gifu, Toyama, Kanazawa, Shizuoka, Kochi, Kumamoto, Naha, Okayama, Nara, Nagasaki, Ohita, Kagoshima)
Damaged City by WWII	Cities that more than 60% of urbanized area was stricken (Mito, Kofu, Gifu, Shizuoka, Tsu, Kobe, Okayama, Hiroshima, Tokushima, Kagoshima)

Table.3 Correlation Coeficient among Variables (1992)

	ln Y*	1) P.	2) N.	3) L.	4) O.	5) T.	6) C.	7) S.	8) T.	9) N.	10) C.	11) M.
1) Population Density	-.711											
2) Number of Railway Station	-.524	.694										
3) Linear Port City Dummy	-.319	.113	.134									
4) Osaka Met. Area Dummy	-.503	.354	.207	.120								
5) Tokyo Met. Area Dummy	-.452	.447	.269	.085	-.135							
6) Castle & Hist. City Dummy	-.011	-.013	.019	-.159	.002	-.248						
7) Sprawl Dummy	.263	-.226	-.139	-.079	-.107	-.124	-.081					
8) The Rate of Secondary Ind.	.149	-.220	-.097	-.125	.058	.010	-.139	.101				
9) North. Kanto Region Dummy	.318	-.166	-.109	-.063	-.086	-.099	-.019	-.079	.215			
10) City Planning Road Length	-.406	.618	.904	.143	.135	.207	.064	-.148	-.134	-.087		
11) Middle Size Prefect. Capital	.256	.025	-.040	.036	-.044	-.193	.110	-.022	-.321	.036	-.060	
12) Damaged City by WWII	.287	.034	.022	.071	-.006	-.165	-.264	.015	-.161	.071	-.001	.218

Y*: Annual Gasoline Consumption per Capita

Table.4 The Result of Multiple Regression Analysis

Explanatory variables	Standardized Parameter	t value
Population Density	-0.420	-4.43
Number of Railway Stations	-0.355	-2.75
Linear Port City Dummy	-0.200	-3.53
Osaka Met. Area Dummy	-0.279	-4.30
Tokyo Met. Area Dummy	-0.188	-2.55
Castle & Historical City Dummy	-0.040	-0.63
Sprawl Dummy	0.080	1.40
The Rate of Secondary Industry	0.108	1.65
Northern Kanto Region Dummy	0.142	2.46
Length of City Planning Road	0.337	2.81
Middle Size Prefectural Capital Dummy	0.208	3.43
Damaged City by WWII	0.247	3.99
Segment	2.166	24.50
Adjusted R^2	0.807	