INTERNATIONAL RESEARCH ON THE RELATIONSHIP BETWEEN URBAN STRUCTURE AND TRANSPORTATION ENERGY CONSUMPTION ACCORDING TO ECONOMIC LEVEL

Choi Hyunsu
Department of Urban Management, Kyoto University, Katsura Nishikyo-ku Kyoto, Japan. Email: hyunsu.choi@urban.kuciv.kyoto-u.ac.jp

Dai Nakagawa
Department of Urban Management, Kyoto University, Japan.

Ryoji Matsunaka
Department of Urban Management, Kyoto University, Japan.

Tetsuharu Oba
Department of Urban Management, Kyoto University, Japan.

ABSTRACT: As motorisation has progressed around the world, the scope of personal activity is widening due to private motorised modes. Meanwhile, motorisation leads to suburbanisation by supplying private mobility to individuals and it is also impacts on global warming. Current research exploring the relationship between urban structure and transportation energy consumption, from the perspective of economic levels in world cities, is not adequate. This research was conducted to generate a database of transportation energy consumption of private motorised modes with individual travel behaviour based on person trip data from 44 metropolitan areas in 23 countries around the world. Considering the difference in economic levels of cities around the world, we can appreciate that individual travel behaviour (average modal share, daily trip number) and transportation energy consumption are influenced by economic level.

Keywords: Economic level; transportation energy consumption; urban structure; travel behaviour; person trip data.

1. INTRODUCTION

In recent years, the range of individual travel behaviour is expanding with the progress of motorisation, and this parallels economic development in cities of the world. Urban structure is also changing to suburbanisation as the urban population is moving outside city centres. Moreover, this movement is linked to increases in transportation energy consumption, and has caused serious urban problems such as air pollution and excessive energy consumption (Nakamura *et al*., 2004).

This situation is only expected to worsen because of two trends that have been observed worldwide. First, as mentioned above, is the general increase in the standard of living with economic development (Salvatore, 2004). Second, as economies develop so too does reliance on faster transportation modes since individuals are only willing to spend a limited amount of time travelling (1.1 h/day on average); consequently, the world is shifting toward faster modes that are also more energy intensive (Schafer and Victor, 1999). In order to combat this, new city planning methods and management strategies for technical development that reduce transportation energy consumption are required. Many of the planning techniques and research since 1970 have focused on developing the urban structure based on the concept of sustainable development.

The usage of on-road gasoline and diesel in urban areas of the US is as much as 77% of total fuel consumption in the US, and fuel consumption and CO_2 emissions from gasoline and diesel in urban areas tend to be higher than that of buildings and industries (Parshall *et al*., 2010). In Europe, the concept of compact cities is used as a sustainable urban planning related to foster efficient urban space. In Japan, compact cities have been institutionally specified in a basic policy of urban planning (Taniguchi *et al*., 2008). Since suburbanisation and increases in trip length are connected to increases in transportation energy consumption, it is indispensable to control individual travel behaviour and reduce transportation energy consumption. It is important to guide travel behaviours and develop the urban areas as sustainable space in the future.

Improvements in individual mobility due to economic development, and the progression of motorisation, are accelerating suburbanisation, which in turn broadens low density zones around the urban area irrespective of country

(Eom and Schipper, 2010). Furthermore, the increase of trip lengths as a result of city suburbanisation is directly linked to increases in transportation energy consumption. This makes it difficult to say that policies for reduction of automobile use and transportation energy reduction are not successful. In this way, motorisation is increasing steadily every year as the economic level of city develops with time.

There is limited research regarding the characteristics of travel behaviours from the viewpoint of economic level for understanding the relationship between urban structure, travel behaviours and transportation energy consumption. In addition, quantitative analysis of the impact of traffic characteristics on transportation energy consumption based on economic level is insufficient. Moreover, as time progresses traffic demands from private modes of transportation are increasing parallel to economic development worldwide. Strategies need to be established to improve the energy consumption and urban-transport problems, from a traffic perspective, in order to mitigate the speed of motorisation. Therefore, it is critically important not only to estimate the transportation energy consumption of a city, but also to clarify how the relationship between transportation energy consumption and individual travel behaviours differ based on economic status.

Consequently, the authors have built a database of world cities, as the first step of study regarding the use of economic level to estimate transportation energy consumption of individual motorised modes, with related indicators of travel behaviours based from person trip data from 44 metropolitan areas in 26 countries around the world. We have used this database to clarify the causal relationship between urban structure, travel behaviours, and transportation energy consumption based on variations in economic levels of cities.

2. FEATURES OF THIS RESEARCH

Newman and Kenworthy (1989a, 1989b) and Kenworthy and Laube (1999) highlighted the strong negative correlation between population density and transportation energy consumption, which contributed to the body of research regarding sustainable urban development. However, much international comparative research on the relationship between transportation and land use has generally been limited either to comparisons of aggregate national data or to qualitative discussion (Giuliano and Dargay, 2006). These studies include Newman and Kenworthy's research that found an inverse relationship between urban density and fuel consumption per capita (Newman and Kenworthy, 1989a, 1989b). A study by van de Coevering and Schwanen (2006) criticised Newman and Kenworthy's point-of-view and suggested instead that certain unwritten rules were followed with regard to the 'organism of the city', specifically, how a city functioned with regards to transportation and land use, responding to different policy stimuli. This reflects the way an organism functions within a certain set of fixed biological rules. Jakapong and Chumnong (2010) analysed the relationship between urban structure, traffic characteristic, and the relevance of transportation energy consumption in terms of economic level by looking at motorbikes and passenger cars, and their impact on energy consumption or greenhouse gas emission in Thailand. This research was limited and highlighted the fact that research on the relationship between urban structure, travel behaviour, and transportation energy consumption from the perspective of the economic level of a city was inadequate.

The research reported here explores the difference in the economic level of 44 cities in South Korea, Japan, Europe, the United States and developing countries throughout the world, based on a previous study that identified cities in the top and the bottom 15% ranked by Gross Regional Domestic Product (GRDP) (Choi *et al*., 2011a). In addition, this research exploits person trip (PT) data that explains detailed features of travel behaviours in metropolitan areas so that the result of this research retains objectivity and reflects actual trip conditions. Moreover, the estimation model of transportation energy consumption was developed using a database containing travel behaviours that was aggregated from this PT data. Finally, we examined the causality between economic level and urban structure, travel behaviours, and transportation energy consumption for the cities of the world.

3. METHODOLOGY

(1) Definition of Trip in this Research

From the viewpoint that reduction of transportation energy consumption can be obtained by controlling the individual modes of transportation appropriately, the current research extracted the data for trips made by private motorised modes (passenger car, motorcycle, and taxi). Hence, freight traffic, which is mainly through-traffic making it difficult to determine the supplying and consumption districts for fuel, was excluded from this research. In addition, the trip mode used in the trip with the longest trip time in a complete trip was treated as the representative mode for the trip. Furthermore, the extracted trip below 4 km/h on the representative mode was excluded from target trip as walking. In this research, the trips that obey the above limitations were extracted from the total trip made within the target area and used for estimation of transportation energy consumption.

(2) Estimation Method for Transportation Energy Consumption

The most common method to estimate transportation energy consumption is to measure the total consumption of fuel in a city by applying statistical data of the total amount of fuel sold, and then converting the total sold fuel into energy per unit amount of fuel (Kenworthy and Laube, 1999; Morimoto, 2002). In addition, it is difficult to determine the supplying and consumption districts for fuel (Matsuhashi *et al.*, 2004). Alternatively, in Japan, as an estimation method of transportation energy consumption, integrating energy intensity and trip length is generally used. Although the former is suitable for grasping a discharge of the total amount or total evaluation of the measure against fuel, there are limitations regarding vehicle type and the evaluation of travel behaviour in an independent trip (Morimoto, 2002). Since the latter may differ in the estimation value of energy intensity with various statistical materials, the comparison between cities could be difficult.

This research exploits the data on traffic behaviour for every individual trip based on PT data and the formula for fuel efficiency of a gasoline vehicle considering travel speed defined from measurement of "sdsdynamo" experiment conducted by the Ministry of the Environment in Japan. From this data and estimation formula, transportation energy consumption is calculated using equation (1).

$$E_k = \left(\frac{\sum_i^{n^k} T_i \cdot I_i \times 365}{O_k} \right) / P_k \quad (1)$$

where:

E_k = Annual transportation energy consumption by private motorised modes per capita in city *k* (MJ per capita);
T_i = Transportation energy consumption by private motorized modes in single trip *i* (MJ); $i = 1,\ldots, n^k$; where n^k is the number of trip sample in city k);
P_k = Urban population in city *k*;
I_i = Expansion coefficient of each trip *i*; and
o_k = Average occupancy ratio of passenger car in city *k*.

Moreover, in formula (1), the transportation energy consumption by private motorized modes in single trip *i* can be calculated using equation (2).

$$T_i = FC_{(V_i)} \cdot HV \cdot L_i \qquad (2)$$

where:
HV = Average calorific value of gasoline (MJ/L);
$FC_{(V_i)}$= Fuel efficiency of a vehicle on trip *i* at speed *V* (cc/km; a motorcycle is assumed to have a half the efficiency of a car and vehicle is assumed to be gasoline vehicle);
L_i = Trip length of trip *i* (km); and
V_i = Trip speed of trip *i* by private motorized modes (km/h).

However, in this research, private motorised modes are limited to passenger cars, taxi and motorcycles. The fuel efficiency of private motorised modes on trip *i* at speed *V* is obtained using equation (3) (Oshiro *et al*., 2001).

$$FC_{(V_i)} = [829.3/V_i] - 0.8572V_i + 0.007659{V_i}^2 + 64.09 \qquad (3)$$

The model parameters in equation (3) are inferred from the results of research conducted in Japanese research institute. However, the model parameters can be customised to country or vehicle type. The results in equation (3) are based on the use of a passenger car. Eventually, the renewal estimation method becomes a function of vehicle speed in an individual trip. For cases where the PT data has insufficient trip information, the improved method is a form of equation (1). For European cities and several Korean cities, travel behaviours such as average vehicle speed, average trip length, and modal share of private motorised modes are representative values due to limitations in gathering world data. Therefore, we evaluated an alternative estimation method for cases lacking these data using equation (4).

$$E_k = P_k \cdot G_k \cdot \gamma_k \cdot l_k \cdot e \quad (4)$$

where:

E_k = Transport energy consumption in city k (MJ);
P_k = Population in city k (persons);
G_k = Average daily trip number in city k (trips);
γ_k = Modal share of private motorized modes in city k (%);
l_k = Average trip length in city k (km/trip); and
e = Intensity of energy consumption (MJ/person・km).

This is useful for estimating transportation energy consumption based on average trip length for private motorised modes per day, average number of daily trips in city k, modal share of the private motorized modes of transportation, and population in city k. Additionally, the average speed of the private motorized modes and intensity of heat combustion are multiplied to estimate fuel efficiency of vehicle.

If a city has its own PT data, the renewed estimation method is promising. However, when this model cannot be applied due to the lack of PT data, the alternative method can be improved by incorporating vehicle speed. This improvement is realized by changing the intensity factor e in equation (4) into e_k. The estimation method for the factor e can be revised by:

$$e_k = FC_{(V_k)} \cdot HV \quad (5)$$

where:

e_k = Intensity of energy consumption of city k (MJ/person・km);
$FC_{(V_k)}$ = Fuel efficiency of a vehicle at average speed V_k (cc/km); and
V_k = Average vehicle speed in city k (km/h).

4. DATABASE ON TRANSPORTATION ENERGY CONSUMPTION OF CITIES IN THE WORLD BASED ON ECONOMIC LEVEL

Target Metropolitan Areas

This research extracted 44 cities with the standard 15% of upper and below in Gross Regional Domestic Product (GRDP) from 119 cities selected based on previous research (*Choi et al*., 2011a). The 44 cities that were extracted from the 26 countries had a population of over 800,000, and differed in economic status (Table 1). The distribution of the target cities was as follows: 10 cities in Asia (5 cities in Korea and 5 cities in Japan), 14 cities in Europe, 14 cities in the United States, and 6 cities in developing countries.

Table 1. Target Areas in this Research.

	Extracted Cities	
	Top 15% by GRDP	**Bottom 15% by GRDP**
Asia	Osaka, Tokyo, Nagoya, Fukuoka, Hiroshima	Pusan, Kwangju, Suwon, Daegu, Sungnam
Europe	Munich, Oslo, Zurich, Hamburg, Paris, Helsinki, London	Prague, Valencia, Warsaw, Athens, Seville, Budapest, Moscow
U.S.A	Charlotte, San Francisco-Oakland, Washington, Boston, Seattle, Denver-Aurora, New York	Oklahoma, Tampa-St. Petersburg, Province, San Antonio, Buffalo-Niagara Falls, Jacksonville, Hartford
Developing Countries	Sao Paulo, Kuala Lumpur, Tripoli	Managua, Nairobi, Phnom Penh

Statistical Data Related to Travel Behaviours

In this research, statistical data for each area were based on the travel behaviours of Korea, Japan, Europe, the United States and developing countries. These data were originally collected by research institutes around the world (see the notes to Table 2).

Definitions and Calculation Methods of Travel Behaviour

Table 2 explains the data definitions used in the current research and the origins of the data. Since this research employs PT data, various data regarding different properties of travel behaviour can be extracted. The definition of calculation methods agrees with the definition of data possessing bounded means.

Table 2. Definition of Data in this Research.

Indicator	**Unit**	**Definition of Data**	**Data Sources**
Urban City	Not applicable	Boundaries of a metropolitan area are set based on different factors. Search for the most relevant area to study mobility, that is, an economic area where the bulk of daily home-work journeys occur, sometimes referred to as the "labour catchment area".	Korea: (3) Japan: (3) Europe: (2) USA: (3) Developing countries: (3)
Population	Inhabitants	Total number of residents in the urbanised area.	Korea: (2) Japan: (2) Europe: (2) USA: (2) Developing countries: (2)
Urban Density	Inhabitant /ha	Ratio between the population and urban surface area.	Korea: (2) Japan: (2) Europe: (2) USA: (2) Developing countries: (2)
GRDP per capita	$/person	Ratio between the GRDP of the urbanised area and its population.	Korea: (4) Japan: (4) Europe: (2) USA: (5) Developing countries: (2)

Table 2 (Continued). Definition of Data in this Research.

Indicator	**Unit**	**Definition of Data**	**Data Sources**
Passenger cars per thousand inhabitants	Vehicles/ 1000 inhabitants	Number of passenger cars in urbanised area includes all vehicles with three/four wheels or more used primarily for private transportation of persons, but does not include taxis or public transport vehicles. Population figures are defined above.	Korea: (4) Japan: (4) Europe: (2) USA: (4) Developing countries: (2)
Average distance of private motorised modes	Km/trip	Trips are defined by the indicator below, including automobiles, motorcycles, and taxis. The actual distance is sought, not a straight line distance. Trips extending beyond the urbanised area are considered.	Korea: (3) Japan: (3) Europe: (2) USA: (3) Developing countries: (3)
Daily trips per capita	Trip/day/ person	Characterised as: - Trips made by persons over 5 years of age who reside in the urbanised area. - Trips with at least one extreme (origin and/or destination) inside the urbanised area. - All reasons for travel and all transport modes, motorised, or otherwise. - Trips on foot are included. - Trips made using several modes are counted as one trip and assigned to a “primary mode”.	Korea: (3) Japan: (3) Europe: (2) USA: (3) Developing countries: (3)

Table 2 (Continued). Definition of Data in this Research.

Indicator	Unit	Definition of Data	Data Sources
Percentage of private motorised trips	Per cent	Percentage of the total number of daily trips made by the private motorised modes (i.e., private cars, motorcycles, taxis).	Korea: (3) Japan: (3) Europe: (2) USA: (3) Developing countries: (3)
Annual transportation energy consumption	MJ/person	Evaluating value of annual transport energy consumption by private motorised vehicles and motorcycles per capita.	Korea: (4) Japan: (4) Europe: (2) USA: (4) Developing countries: (2)

Notes:

(1) KTDB: Korean Transport Database. MLITT: Ministry of Land, Infrastructure, Transport and Tourism. JICA: Japan International Cooperation Agency. UITP: International Association of Public Transportation. FHWA: Federal Highway Administration U.S. Department of Transportation.

(2) Korea: Population and housing census (2005). Wealthy Asian: Periodic surveys (censuses, mobility studies) of International Association of (UITP) 2001. Developing countries: The study on master plan for urban transport in the metropolitan area (Cairo, Tripoli (2001); Phnom Penh, Belem, Chengdu, Jakarta, Kuala Lumpur (2000); Damascus, Managua (1998); Manila (1997); Bucharest (1999); Lima, Hanoi (2005); Ho Chi Minh (2003); Nairobi (2004)).

(3) Korea: Household Travel Survey ((2005)-Inchon. Suwon. Sungnam (2006)). Japan: The Nationwide Person Trip Survey (2005). U.S.A: NHTS (National Household Travel Survey, 2001). Developing countries: Household Interview Survey of each country (Cairo, Tripoli (2001); Phnom Penh, Belem, Chengdu, Jakarta, Kuala Lumpur (2000); Damascus, Managua (1998); Manila (1997); Bucharest (1999); Lima, Hanoi (2005); Ho Chi Minh (2003); Nairobi (2004)).

(4) Korea: The Statistics Report of each city (2005). Japan: The Statistics Report of each city (2005). U.S.A: U.S. Department of Transportation, Federal Highway Administration, Highway Statistics 2001.

(5) U.S.A: Regional Economic Accounts Bureau of Economic Analysis U.S. Department of Commerce.

To estimate transportation energy consumption, four main travel characteristics were considered: trip length, trip speed, daily trip number, and modal share of private motorised modes. These data on travel characteristics were calculated from person trip data released by public institutes around the world. However, the data fields of the person trip data differ by country. It should be noted that the calculation method of travel behaviour differs slightly by country and depends on the how the person trip data was configured. Moreover, due to the limitations in the data from European cities and some Korean cities, travel behaviours were estimated throughout the whole urban area using the cities' average of trip values on travel behaviour. A table showing the calculation methods to explain travel behaviour data is available from the authors. The database produced using these data sources and methods is provided in an appendix to Choi *et al*. (2011b).

5. THE RELATIONSHIP BETWEEN CHARACTERISTICS OF TRAVEL BEHAVIOURS AND URBAN STRUCTURE AND THE DIFFERENCE OF CHARACTERISTICS OF TRAVEL BEHAVIOURS IN AN ECONOMIC STANDARD

Using the database described in the preceding chapter, this section examines the causal relationship between urban structure and travel behaviours. Differences in travel behaviours as they relate to the economic level of city were determined. Cities selected in this research have varying levels of urban structure from low to high population density.

First, the analysis explores the relevance of the relationship between urban structure and the modal share of private motorised modes in 44 cities in the world. The results are shown in the graph of Figure 1.

It turns out that the population density of each city is lowest in the United States (average density: 11.5 inhabitants/ha), medium in Europe (average density: 57.1 inhabitants/ha) and highest in Asia (average density: 75.8 inhabitants/ha). In cities with lower population density the private modal share was increased. In particular, cities where population density is very low and the modal share of private motorised modes is very high are mainly situated in the United States. Densely-populated cities with a medium level in the modal share of private motorised modes are mainly Asian cities in Japan or South Korea.

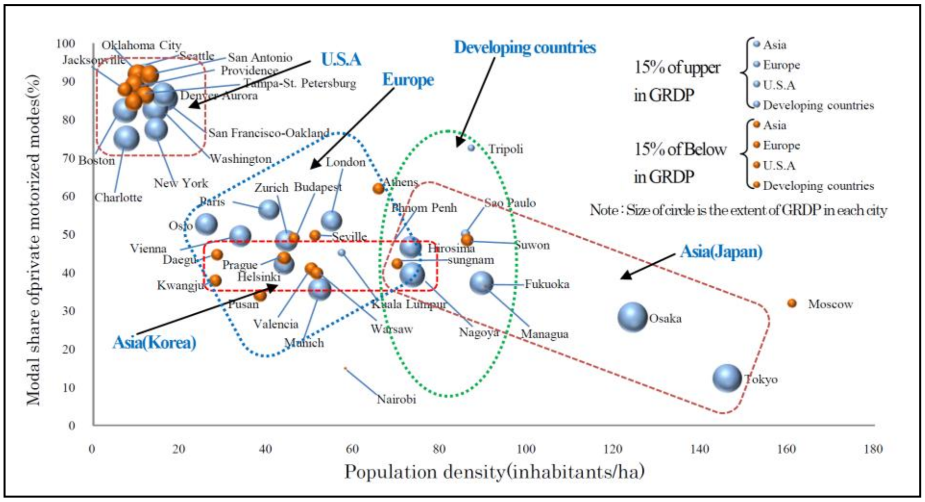

Figure 1. Relationship between Urban Structure and Modal Share of Private Motorized Modes by Economic Level.

Next, the analysis of the relationship between economic level and modal share of private motorised modes in cities with comparable population density was conducted. A higher modal share of private motorised modes was revealed in cities with a high economic level, such as London, Paris, Zurich, and Helsinki (average density of 46.0 inhabitants/ha) compared to cities with a relatively low economic level, such as Valencia, Warsaw, Budapest, and Prague (average density of 48.0 inhabitants/ha). In this context, Table 3 shows that the number of registered passenger cars is higher in cities with high economic levels. In the case of Asia, modal share of private motorized modes for Tokyo, Osaka, and Nagoya, which are high economic level (average density: 101.4 inhabitants/ha) is lower than Pusan, Kwangju, and Suwon, which are cities with a relatively low economic level (average density: 50.4 inhabitants/ha). It could be conjectured that this is the result of the development of public transport as well as the maintenance of spaces for pedestrian and non-motorised modes (NMM: walking and bicycles), since both the economic level and population density are high; therefore, traffic demands on the roads could shift the majority of public transport to non-motorised modes.

Table 3. Registered Passenger Cars in the World.

	Top 15 Per Cent		Bottom 15 Per Cent	
	Urban density (inhabitants/ha)	Passenger car (vehicles/ inhabitants)	Urban density (inhabitants/ha)	Passenger car (vehicles/ inhabitants)
Asia	101.4	0.313	50.3	0.263
Europe	46.2	0.430	67.1	0.384
USA	12.7	0.492	10.3	0.613
Developing countries	76.7	0.243	29.3	0.045
Average	*59.3*	*0.370*	*39.3*	*0.383*

Table 4. Registered Passenger Cars in the World.

	Top 15 Per Cent			Bottom 15 Per Cent		
	Private Modes	Public Modes	Non-Motorised Modes	Private Modes	Public Modes	Non-Motorised Modes
Asia	33.2	24.4	42.4	40.8	30.2	29.0
Europe	47.7	22.6	29.7	40.3	33.6	26.1
USA	82.8	5.1	12.1	89.6	2.4	8.0
Developing countries	56.2	22.3	21.5	39.8	26.9	33.3
Average	55.0	28.6	16.4	52.6	23.3	24.1

According to Table 4, the modal share of public transport and non-motorised modes is high. On the other hand, although there is a difference in the modal share of all modes between in all cities, a similar finding is seldom seen in cities of the United States. In the United States modal share of private motorised modes is lower as the economic level of a city becomes relatively high. In New York, Washington, Seattle, and Boston, which have high economic levels, the use of non-motorised modes (12.1%) and public transport (5.1%) is high. That is to say, in cities where the economic level is higher there is development of public transport and maintenance of space for a pedestrian and non-motorised modes; this holds true for cities in United States that have a low population density.

Lastly, in cities of developing countries, the modal share of private motorised modes is higher in cities with a high economic level (Tripoli and Kuala Lumpur) compared to cities with a relatively low economic level (Managua, Nairobi, and Phnom Penh). As for the high growth of economy, in developing countries, cities in high economic level were at 35% in the time period between 1991 and 95, similar to the 1960s when motorisation developed rapidly in Japan and the United States (Nakamura *et al*., 2004). Therefore, it is important to mention that the use of private motorised modes increases gradually due to the progress of motorisation in the cities in high economic levels of developing countries.

It is clear that economic level influences passenger car ownership and private modal share. Population density also plays a key role. The study by van de Coevering and Schwanen (2006) demonstrated that urban structure, determined by population density and job density, is the only variable to be statistically significantly related to commuting distance. A higher percentage of jobs in the inner city leads to a shorter average commuting distance and higher passenger car share. Moreover, population size is positively correlated with the average commuting distance. This may explain why the maximum distance between an individual's residence and workplace location can be longer in a larger city. Thus, it is important to consider the urban structure in the investigation of the difference between private modal share and economic level.

Figure 2 shows that the relationship between urban structure and daily trip number (excluding NMM) is related to differences in economic levels between cities. As population density increases, daily trip number decreases. Giuliano and Dhiraj (2003) determined that fewer trips occur within smaller density cities. We found that daily trip number in the United States (4.0 trips/day) was extremely high, and nearly two times that of European cities (2.2 trips/day) and Asian cities (2.3 trips/day). It seems that modal share of private motorised modes becomes highly inevitable since ownership of the individual transportation fleets allows people to move freely, which is needed in the cities of USA where population density is low (Table 6). Trips for the private purpose are high in the cities of the United States, and this could be due to the fact that urban structure associated with lower population density leads to higher trip frequency. Figure 2 appears to indicate that the higher economic level cities have the higher number of daily trip as well.

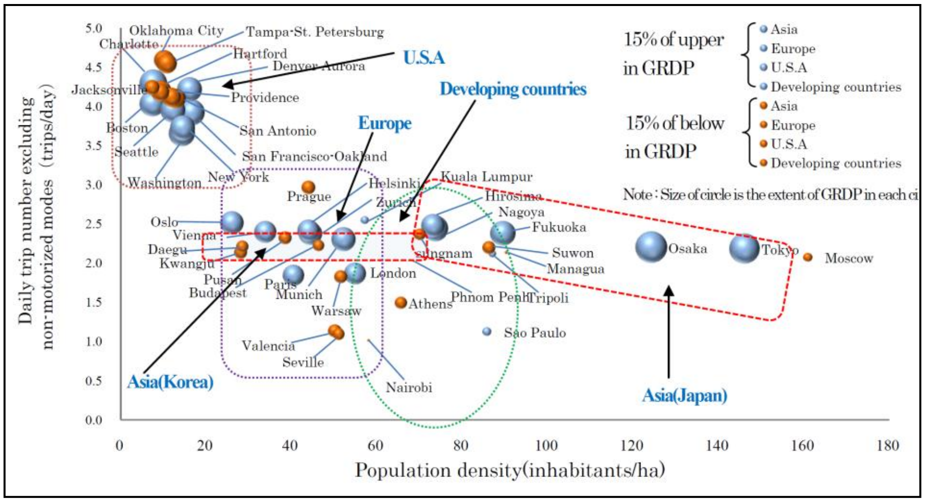

Figure 2. Relationship between Urban Density and Daily Trip Number Excluding Non-Motorised Modes.

In the case of European cities, as shown in Table 5, the number of daily trips excluding non-motorised modes in cities with a high economic level (Munich, Oslo, Zurich, Hamburg, and Helsinki) is high and relative to the economic level of cities. Even though the population density of European cities with the same level (54.7 inhabitants/ha in average), the daily trip number increases relative to economic level. We can conjecture that higher trip generation is affected by both the economic level and population density of a city, meaning that people have more opportunities taking private trips because they have a higher income, as is the case in Europe.

In the cities of Japan and Korea, a significant relationship between economic level and daily trip number is not seen. Daily trip number in Korean cities and Japanese cities is almost same. However, the important point here is the difference of modal share of NMM and population density in the two countries. Density of Japanese cities are approximately two times that of Korean, but modal share of NMM is much higher than Korean cities, likely due to population density in the city and high economic levels, which undoubtedly have contributed to improvements in infrastructure for pedestrians and bicycle riders. Moreover, shorter trips in inner area could be headed by NMM.

Table 5. Density and Daily Trip Number.

	Top 15 Per Cent		Bottom 15 Per Cent	
	Urban density (inhabitants/ha)	Daily trip no. excluding NMM (trips/day)	Urban density (inhabitants/ha)	Daily trip no. excluding NMM (trips/day)
Asia	101.4	2.33	50.3	2.33
Europe	46.2	2.18	67.1	1.83
USA	12.7	3.97	10.3	4.28
Developing countries	76.7	1.93	29.3	1.72
Average	*59.3*	*2.60*	*39.3*	*2.54*

Table 6. Trip Purpose in Cities.

	Top 15 Per Cent		Bottom 15 Per Cent	
	Commuting (%)	Private (%)	Commuting (%)	Private (%)
Asia	28.2	39.4	23.4	25.2
Europe	—	—	—	—
USA	11.6	34.7	10.7	35.9
Developing countries	24.4	18.1	17.5	13.8
Average	*21.4*	*30.7*	*17.2*	*25.0*

In the case of developing countries, differences in daily trip number are related to economic level regardless of population density (Tables 3, 4, and 5). The number of passenger cars in cities with higher economic levels is higher and trips of working and private purpose are increased. Thus, in developing countries it is likely that the dependence on private motorized modes becomes higher and more trips for private purpose are generated in cities with higher economic levels.

Figure 3 shows the relationship between urban structure and annual transportation energy consumption per capita. Similar to findings by Newman and Kenworthy (1989a, 1989b) and Kenworthy and Laube (1999a) we can ascertain that in denser cities lesser transportation energy is consumed. First, we can highlight the fact that transportation energy consumption is much larger than other target cities when we pay attention to growing cities. In terms of economic level, there is no significant difference in energy consumption in cities in the United States. However, transportation energy consumption of New York is visually lower than other cities in the United States; the average daily trip number (3.72 trips/day) and the average trip length (15.2 km/trip) is shorter in New York compared to other cities in the United States. In addition, modal share of public transport (10.5%) is the highest among the cities in the United States. New York is likely a very special case that has a high economic status, a high level of public transport, and relatively higher density compared to other cities in the United States. Overall, in cities in the United States with an extremely low population density and high ownership of passenger car, transportation energy consumption is extremely high regardless of economic level.

In the case of European cities, transportation energy consumption of Munich, Zurich, Oslo, and Vienna, which are cities in the high economic level, is somewhat higher than other cities in Europe. Although population density of European cities is similar, as shown in Figures 1 and 2, when economic level is higher so too are the modal share of private motorized modes and the number of daily trips. This is likely related to increased opportunities for going out. In addition, as mentioned above, shorter trips for commuting and high private modal share are influenced by urban structure, which can be explained by population density and job density.

Asian cities, such as Japanese cities with a high economic level, possess a more dense urban structure compared to Korean cities that have a lower population density; the amount of transportation energy consumption is smaller. Here, we identify an inverse relationship between urban density and transportation energy consumption per capita similar to the findings of Newman and Kenworthy (1989a, 1989b). In addition, the propensity of lower private modal share and higher NMM results in a relatively low dependence of private modes. Meanwhile, lower population density and higher private modal share in Korean cities appear to interact with higher transportation energy consumption than Japanese cities, although there is no significant difference in public transit modal.

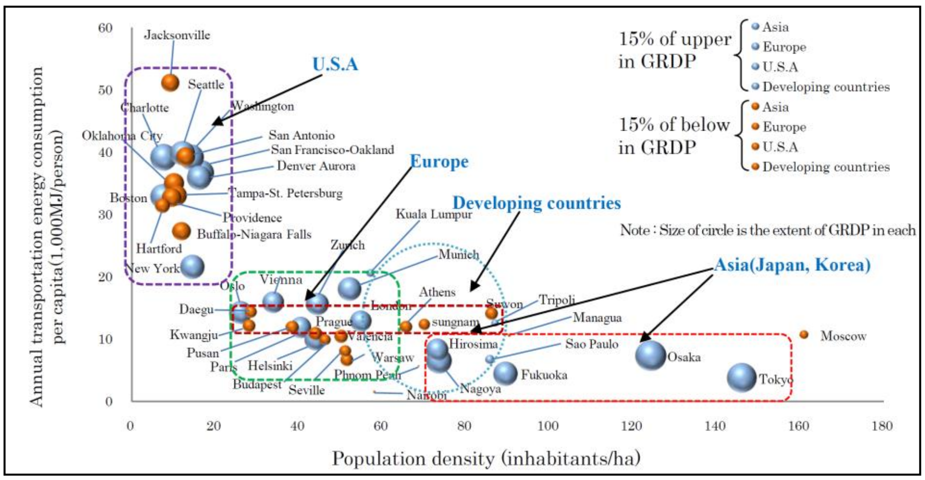

Figure 3. Relationship between Urban Structure and Transportation Energy Consumption.

Lastly, in cities of developing countries, as the economic level of city increases so too does transportation energy consumption (approximately three times). As shown in Figure 1 and Table 5, if the economic level of a city is high, private modal share is higher and trips for private purpose increases. Based on this finding, we believe that economic level of city influences to modal choice or status of infrastructure development and inevitably impacts the management of traffic demand. Figures 1, 2, and 3 demonstrate that private mode share, daily trip number, and transportation energy consumption are affected both by urban structure and by the economic level of the city. Based on this research we can make a suggestion that economic level of the city impacts on traffic demand, and that private motorised modes, public transport, and urban structure (represented by population density) can be a criteria for understanding how travel behaviours differ by population density.

6. CONCLUSION

This paper has analysed the relationship between urban structure, travel behaviours and transportation energy consumption based on the economic level of the cities in the world. Based on this analysis, we can propose that despite similarities in urban structure, the economic level of the city influences modal choice and the level of infrastructure development impacts on the control of traffic demand. Travel behaviour is the result of comprehensive urban-transport activities, making it difficult to determine the key factor impacting transportation energy consumption. However, it is certain that the traffic demand of private transportation modes parallels economic development worldwide, such that increases in economic levels leads to higher demands for private transportation modes. We, including researchers and planners, have to establish strategies that can improve the energy consumption and improve urban-transport problems (from a traffic aspect) to mitigate the speed of motorisation.

This research has showed that person trip data from around the world can be exploited to gain insight into detailed individual travel behaviours, which can in turn be used to estimate transportation energy consumption that takes into consideration type of vehicle, trip speed, and actual road traffic condition on the trip. Accordingly, we can get an objective result related to actual traffic situation. We showed that there is a relationship between the economic level of a city and urban structure, travel behaviours, and transportation energy consumption. The findings of this study suggests new questions regarding how urban-transport characteristics affect individual travel behaviours, and what is next step for energy consumption, not only estimating transportation energy consumption but also devising ways to reduce it.

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