Sustainable Urban Transportation Policy for Compact City

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ABSTRACT

We will show a micro-economic based quantitative analysis scheme to evaluate the degree of compactness of cities that takes into accounts 1)the utility theory based on transportation and composite goods consumption behavior, and 2) a consistency between the level of utility and energy consumption. Such scheme is sometimes used in microeconomic modeling for policy analysis. However, we evaluate such the spatial structure of urban form as a transportation network configuration and land use condition that can reduce the energy consumption and get cities much compact.

Keywords: sustainable urban transportation, compact city, energy consumption, micro-economic policy analysis

1. INTRODUCTION

A concept of sustainability has become a paradigm in urban development and there is also a belief that the sustainability could be achieved by compact city. The principle of sustainability is known as 'the development that meets the needs of the present without compromising the ability of the future generation to meet their own needs'. The idea of a compact city is one of the popular alternatives of urban form facing the sustainability paradigm. To evaluate the compactness of cities, energy consumption by urban activities has often become a major concern. The reasoning is that compact cities, developed at higher densities and with a mixture of land uses, affect the total amount of energy consumption. Also the intensity of activities, such as traffic and industry, are seen as major factors influencing energy consumption. Consequently, the total amount of energy consumption seems to be very important and effective index to evaluate the compactness of cities. If we reduce the amount of energy consumption in our daily life, it is only natural that the quality level of our life declines. However, from the viewpoint of urban and transportation planners, even if citizens reduce the amount of energy consumption, we should propose some urban and transportation developments and policies which do not decline the present level in their quality of life.

There are many studies of compactness such as high density, transit oriented development, and however, most of them are only descriptive and empirical studies which analyze on a relation between population density and gasoline consumption per capita or urban form and energy consumption par trip using statistical data. The famous figure by Kenworth and Newman which shows a relation between population density and gasoline consumption in worldwide major mega-cities is one example of these discussions. Even if we use a volume of energy consumption as an indictor which shows the compactness of cities, energy consumption are strongly related to actual land use and transportation as well as descriptive index like a population density. Also, we should consider various kinds of consumption behavior which affect the achievement of quality level of life. The other study framework on compactness is scenario based policy measure using land-use/transportation integrated model. This type of study is capable of dealing with space and time with adequate details. In addition, it can output some kind of compact city measure indicators such as travel costs and administrative cost for some kinds of policy alternatives respectively. However, the accuracy of every indicator depends on the reliability of the model.

2. METHODOLOGY

The concept of our model we developed is shown as follows;

1. Variables which represent urban activities are the amount of composite goods x_{1i} and the number of trips by car x_{2Ci} and Mass-Transit x_{2Mi}.
2. We want to know the level of urban activities which minimize the total energy consumption $E_i(x_{1i}, x_{2Ci}, x_{2Mi})$.
3. We want to find the optimal solutions of these variables on the condition that we keep the present utility level $u_i^*(x_{1i}^*, x_{2i}^*)$. This utility level is achieved by both the level of composite goods consumption and mobility.

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4. There is a substitutive relation between the number of car trips and MT trips, and mobility level is defined as a function of them.
5. At the same time, there is a substitution between the amount of composite goods consumption and mobility level.

$$\min_{x_{1i}, x_{21ij}, x_{22ij}} : E_i(x_{1i,}x_{2Ci}, x_{2Mi}) = e_1 x_{1i} + e_{2C} t_{2Ci} x_{2Ci} + e_{2M} t_{2Mi} x_{2Mi}$$

$$s.t. \quad u_i^*(x_{1i}, x_{2i}) = \left\{ \alpha_1 x_{1i}^{(\sigma_1 - 1)/\sigma_1} + \alpha_2 x_{2i}^{(\sigma_1 - 1)/\sigma_1} \right\}^{\sigma_1/(\sigma_1 - 1)}$$

$$where\ x_{2i}(x_{2Ci}, x_{2Mi}) = \left\{ \alpha_{2C} x_{2Ci}^{(\sigma_2 - 1)/\sigma_2} + \alpha_{2M} x_{2Mi}^{(\sigma_2 - 1)/\sigma_2} \right\}^{\sigma_2/(\sigma_2 - 1)}$$

We assume that representative consumer in zone *i* consumes 3 types of good; those are car trips and Mass-transit trips and composite goods. Utility, that is the quality level of life, is defined as a function both of the consumption amount of composite goods and the mobility level. This mobility level is a function of the number of trips by car and Mass-transit. We use the Nested type CES function as the utility function. The transportation behavior by a representative consumer living in zone *i* in the 1st stage is formulated by a revealed mobility level maximization problem that is subject to budget constraint in transportation. Revealed mobility level is defined as the function both of the number of trips by private car and mass-transit. The functional form is CES as well. The representative consumer's consumption behavior in zone *i* in the 2nd stage is formulated as a utility maximization problem that is subject to budget constraint.

It is highly likely that we consume the amount of composite goods and car trips and mass-transit trips which optimize the before-mentioned mathematical optimization problems. The main purpose is to find different amount of composite goods and the number of trips by private car and mass-transit, by which we minimize his total amount of energy consumption. This problem is shown as following energy consumption minimization problem that is subject to the utility level constraint. This constraint shows that the utility level should kept in the present level even if we introduce a policy which minimizes the energy consumption.

3. APPLICATION AND RESULTS

We apply this evaluation model to Kumamoto urban area. This area is composed of 2 cities, 4 towns and 1 village. The center city is Kumamoto city and is about 20th biggest city in population in Japan. Its population is 0.66 million. Total population of this urban area is about 1.0 million. Fig. 1 shows that the DID in this urban area is enlarging and the DID in 1995 becomes over two times larger than one in 1965. Fig.2 shows both the area of DID and population density inside DID from 1960 to 2000. The area of DID is increasing, on the other hand, population density is decreasing.

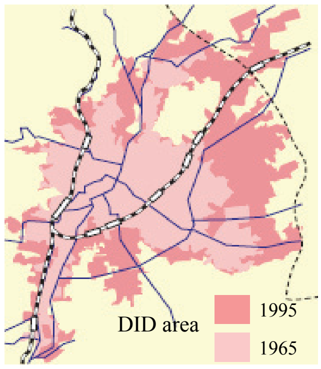

Fig.1. DID in Kumamoto urban area

For recent two decades, Person Trip surveys from which we can get many kinds of dataset in applying our method were conducted two times in 1984 and in 1997. We can suppose that the level of compactness of this area in 1984 is higher than that in 1997, because the population density in 1984 is higher than one in 1997. We can compare some indices obtained from our model which represent the levels of compactness in 1984 and in 1997.

Fig.3 shows the comparison between actual and optimum amount of total energy consumption in 1984 and in 1997, and also shows the proportion of composite goods and car trip and MT trip to all amounts. From this figure, we can find following results;

1. The actual amount of total energy consumption in 1997 has increased 1.53 times (=1.40*1010/9.13*109) compared with that in 1984.
2. The ratio of car trip to MT trip in 1997 is bigger than that in 1984.
3. The reduction of energy consumption keeping the level of present utility is practicable by reduction of car use and its

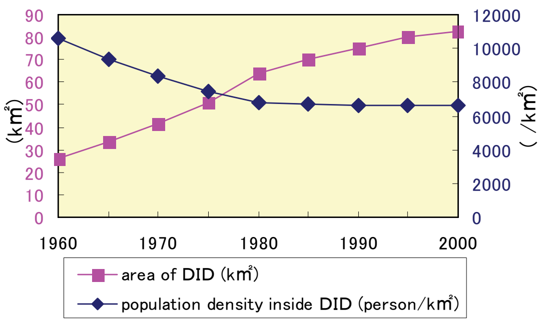

Fig.2. Area of DID and population density inside DID

substitutive rise of composite goods consumption.

4. Increasing the relative share of mass-transit makes it possible to minimize the total energy consumption keeping the present level of quality of life.

To analyze the spatial distribution of energy consumption, we define an energy efficiency index, which shows the utility level against the level of energy consumption by zone *i*.

1. Fig.4 shows the spatial distribution of energy efficiency index in 1984 and one of 1997. In both figures, the value of this index in the central area is higher than that in suburban area.
2. The value of energy efficiency index in the areas along main Mass-transit line is higher than in the rest of areas.
3. We assumed that the energy efficiency level in 1984 is higher than that in 1997, because the population density in 1984 is higher than that in 1997. However, we cannot distinguish such a marked tendency from these both results. On the contrary, the energy efficiency level in 1997 is rather higher than that in 1984. At the present moment, we cannot state the reason why such results happen.

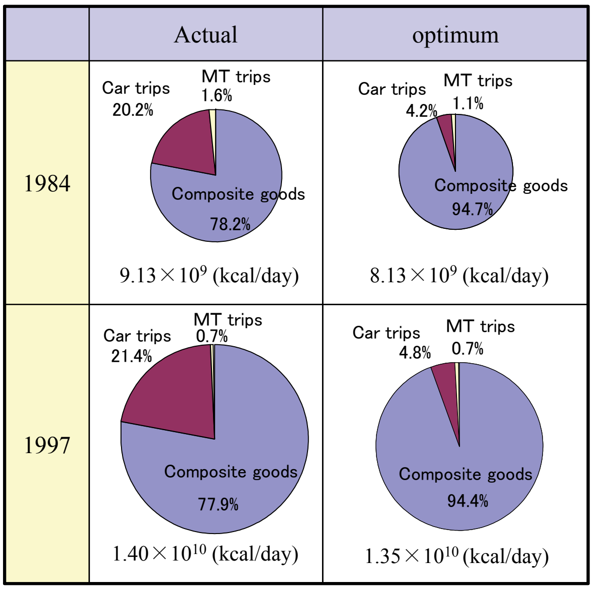

Fig.3. Comparison between actual and optimum amount of total energy consumption in 1984 and in 1997

We want to represent the level of energy consumption efficiency by using the indexes which show the urban structure and characteristics such as population density and number of stations. Table 1 shows results of the regression analysis. From this table, we can get the following findings;

1. The higher population density is, the higher the utility level for energy consumption is.
2. Also, the higher the level of public transport service is, the higher the energy efficiency level is.

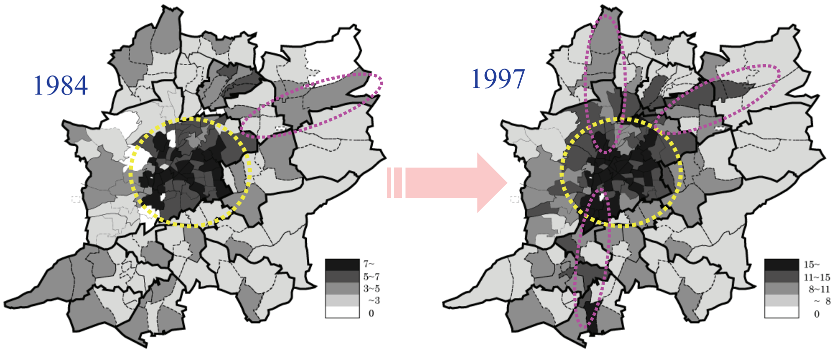

Fig.4. Spatial distribution of energy consumption

4. CONCLUSIONS

We conclude our study as follows;

1. This study is going and has developed a proto-type model with a micro-economic method for policy analysis. Our model enables us to investigate factors which affect the degree of compactness of cities in terms of energy consumption.
2. The higher the population density and the level of public transport service of area is, the higher the utility level for energy consumption is.
3. It is possible that the policy measures, which include the adequate combination of fuel tax rate and MT fare reduction, reduce total energy consumption and result in compactness of cities.

Table 1. Regression results

variables	coefficient	t-value
Population density (/km^2)	0.000649	3.73
Secondary employees	0.00200	3.13
No. of stations	0.688	2.10
No. of bus stops	0.113	1.19
Distance from station (km)	-0.555	-3.07
Constant	11.764	6.00
F-value	17.87	
proportion	0.51	