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TRANSPORTATION BEHAVIOR ANALYSIS OF COMMUTING IN REGIONAL CITY USING FRACTAL DIMENSIONS OF STATES

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TRANSPORTATION BEHAVIOR ANALYSIS OF COMMUTING IN REGIONAL CITY USING FRACTAL DIMENSIONS OF STATES

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ABSTRACT

The fractal dimensions of states are used to quantify the state of the distribution of points within a defined region and provide a numerical expression for the distributions of the workplaces and residences among workers. This study employs the fractal dimensions of states as an index to express the influence on a worker from other workers in a workplace. This index is introduced into a disaggregated model to analyze the transportation behavior of workers commuting to work. This study was an analysis of data from a 2010 commuting survey carried out in Matsumoto, a regional city located in the central area of Japan. Among the three indices calculated to express the distributions of workplaces and residences for each office, that is, the mode share, the entropy, and the fractal dimensions of states, the model using the fractal dimensions of states is the most effective model, because the value of ρ^2 and the hitting ratio are the largest.

Keywords: the fractal dimensions of states, commuter behaviour analysis, influence on a worker from other workers

INTRODUCTION

The decline of public transportation in the majority of regional Japanese cities is becoming a problem. An increasing number of cars are used not only to go shopping in the suburbs but also for commuting to work. Consequently, various policies to encourage the use of public transportation instead of cars have been implemented in recent years. Typical transportation data for commuting on a weekday are shown in Figure 1 (Ministry of Land, Infrastructure, Transport and Tourism, 2012). Meanwhile, there are strong interpersonal ties in Japanese local areas. The behavior of a person is easily influenced by people who work at the same office and people who live in the same residential area.

Therefore, this study employs the fractal dimensions of states as an index to express the influence on a worker from other workers in a workplace. This index is introduced into a disaggregated model to analyze the transportation behavior of workers commuting to work.

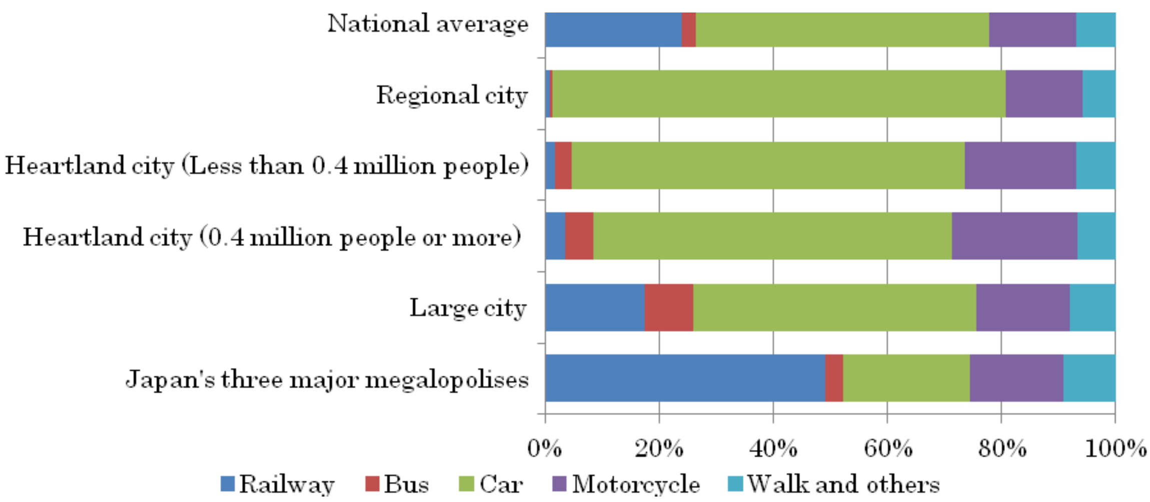

Figure 1 – Typical transportation data for commuting on weekday in 2010

Some researches using fractal dimensions have been done in the field of the city planning. Many of these researches (e.g. Batty, M. and Longley, P., 1994) were the researches of fractal dimensions with geometrical characteristics. The fractal dimensions of states extend the theory of fractal dimensions and were proposed by Ohya (Ohya, 1991; Matsuoka & Ohya, 1995). They can be used as a new measure for the complexity of states and to distinguish between two states even if their entropies have the same value. The fractal dimensions of states used in this research can be considered as a type of Ohya's method that is used to quantify the state of the distribution of points within a defined region and provide a numerical expression for the distributions of the workplaces and residences among workers.

CONCEPTUAL FRAMEWORK

To analyze the demand for commuting trips on the basis of worker behavior, many commuting behavior models that consider some individual attributes have been used, such as the cost and time. However, it is believed that people are subject to influence from their co-workers in their choice of transportation for commuting. It seems that an index to express the choice of transportation within single offices is necessary. Therefore, the fractal dimensions of the states were examined as this index. The key features of this index are that it not only indicates the magnitude such as the modal share, it is also able to describe the distributions of residences in the study region.

In this study, the box-counting dimension (Takayasu, 1986), which is one of the fractal dimensions used to quantify the distribution of points in a region of analysis, was used. To calculate the box-counting dimension, residence distribution maps for each mode of transportation for single offices were drawn up and superimposed on a grid. Moreover, the number of cells containing a point (a commuter's home) was counted.

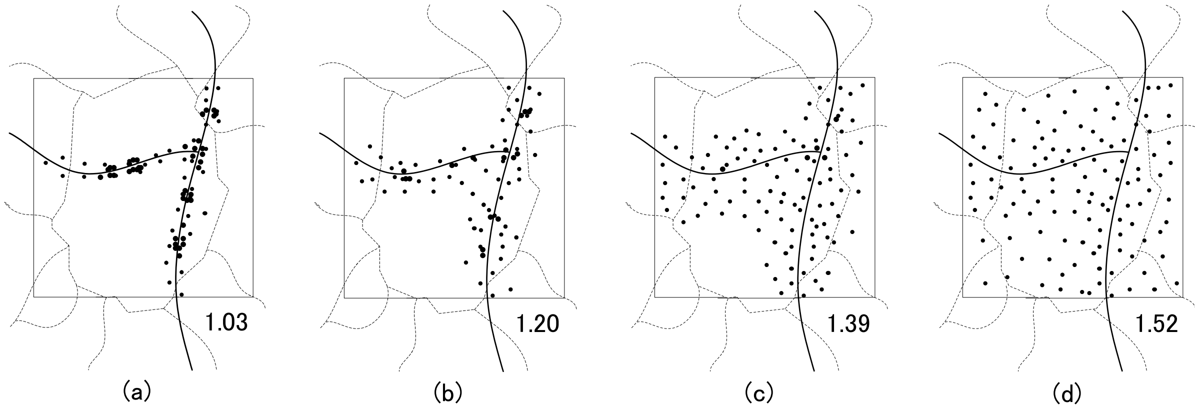

Figure 2 – Virtual maps and the fractal dimensions of states

The length of the side of a square in the grid was denoted as r, and $M(r)$ was defined as the number of cells including an object point. The absolute values of the regression coefficient a satisfy the condition defined by equation (1), which gives the box-counting dimension.

$$\log M(r) = a \log r + b + \varepsilon(r) \tag{1}$$

$\varepsilon(r)$: error term

The box-counting dimension is a noninteger from zero to two. Points are concentrated near a single point on the map when the dimension is close to zero. It has been shown that points have an approximately linear distribution when the dimension is close to one. Furthermore, points are almost uniformly distributed in a map when the dimension is close to two.
Virtual maps are shown in Figures 2(a)-(d) as examples. The area of analysis was assumed to be the square. The solid and broken lines show railway routes and administrative boundaries, respectively. Moreover, residences are marked as points, with the number of points being the same in all figures. The numerical value below each figure is the fractal dimension of states. The situation that residences are concentrated along railway lines is shown in Figure 2(a), whereas that of residences distributed over the entire area is shown in Figure 2(d). Consequently, if the residence distribution is measured by the fractal dimensions of states, the value can express the degree of spread of residences. Hence, the fractal dimensions of states were adopted as an independent variable in the model used for the mode of commuting.

MODELS

Data and models

This study was an analysis of data from a 2010 commuting survey carried out in Matsumoto, a regional city located in the central area of Japan, as shown in Figure 3. Matsumoto has implemented programs and policies regarding public transportation and actively pursues a

Figure 3 – Location of Matsumoto

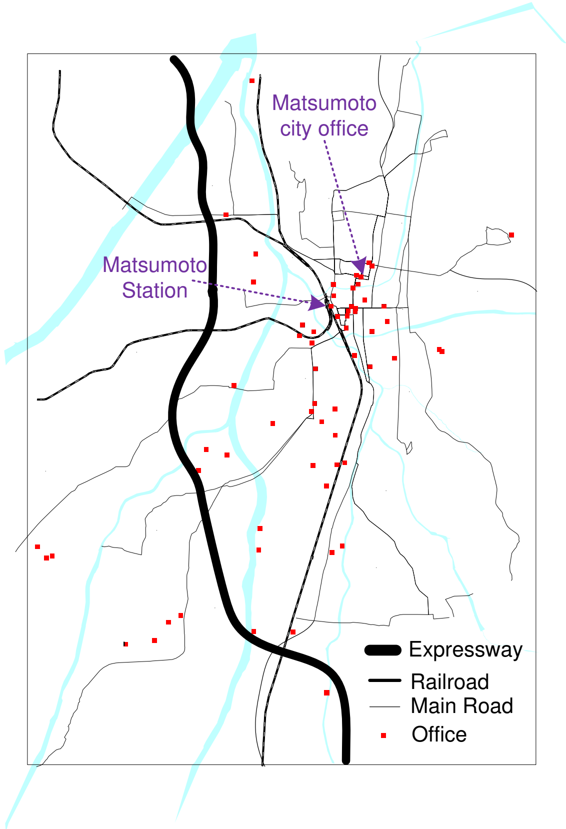

Figure 4 – Locations of offices in Matsumoto used for analysis

Table 1– Numbers of questionnaire forms

	Number distributed	Number collected	Return rate
To offices	66	54	81.8%
To workers	6216	3355	54.0%

"No Driving Day" program. It was the first regional city in Japan to enact a "car-free day". Regarding traffic network in Matsumoto, the following three points are mentioned. First of all, there are railway lines running to the north, south, and the west from Matsumoto station, which is located in the heart of the city. Second, bus routes radiate in all directions from Matsumoto station. Third, there are severe traffic jams during rush hour on major roads in the urban area.

This survey examined offices and workers in the offices. Each office was surveyed with regard to its address, the number of people employed there, and its policy on transportation to work, including its system for remunerating commuting expenses, if any. Workers were surveyed with regard to their address, the time they leave for work, how they get to work, and other factors. The numbers of questionnaire forms distributed and the return rate are shown in Table 1.

Furthermore, in this study, the users of cars and public transportation were determined for each office, whose locations are shown in Figure 4, the areas where workers lived were plotted on a map, and the fractal dimensions were calculated.

To date, the logit model has been the most widely used for the analysis of travel behavior. Accordingly, a multinomial logit model for commuter mode choice was created using the fractal dimension as one of the independent variables, and this model was analyzed. The mode choice set was composed of car, bus, and train. Walking was excluded from the mode choice set because the only choice for commuters living near the office was considered to be walking. The primary factor that influenced commuter behavior was used as an independent variable. The major independent variables were access time, access cost, and gender. Moreover, to perform a comparative study, two indices were calculated to express the states of the distributions of the offices and residences for each office: the share of each mode and the Shannon entropy (Shannon, 1948).
The Shannon entropy H is expressed as

$$H = -\sum_{j=1} p_j \log p_j \tag{2}$$

where p_j is the share of mode j. The Shannon entropy is maximum when the share of all modes is equal.
These three indices should use the value of a point in the recent past. However, it is difficult to recognize the value of a point in the recent past. It is thought that most commuters do not change their mode of transport in the short term. Therefore, in this research, we consider the values in this survey as those of a point of the recent past.

Estimation results

The estimation results from the logit model of the commuter mode choice from home to the office are shown in Table 2. The t-statistic is indicated in parentheses. In this research, four models using different independent valuables are constructed: model 1 uses fractal dimensions, model 2 uses the Shannon entropy, model 3 uses the mode share, and model 4does not use any of these variables. As shown in Table 2, the other effective independent variables for these models were decided by trial and error. Some dummy variables were used as independent variables in these models, and the gender dummy indicates whether a commuter is male or not (1, yes; 0, no).
All the estimated parameters have the correct sign and most of them are statistically significant. The feature predicted from the estimation results using these models is that almost all commuters used a car to commute. Furthermore, it is presumed that male commuters are relatively more sensitive to car use than female commuters. The values of time calculated from the estimated coefficients are as follows: 30.7 JPY/min (model 1), 33.6 JPY/min (model 2), 28.9 JPY/min (model 3), 27.5 JPY/min (model 4), and 30.2 JPY/min (average of all models). These values are comparable to the time value ordinarily used in the consideration of commuting, indicating their suitability.
Upon comparing model 1 with the other models, the value of ρ^2 and the hitting ratio as goodness-of-fit measures (Ben-Akiva & Lerman, 1985) are found to be the largest. Therefore, it is confirmed that model 1 is the most effective.

Table 2– Estimation Results of Logit Model

		Model 1	Model 2	Model 3	Model 4
	Units	Coefficient estimate	Coefficient estimate	Coefficient estimate	Coefficient estimate
Bus constant	0/1	-2.15 (-2.91)	-4.47 (-7.19)	-3.3 (-5.54)	-3.49 (-5.92)
Rail constant	0/1	-2.29 (-2.97)	-4.54 (-6.83)	-3.3 (-5.33)	-3.57 (-5.88)
Access cost	100 yen	-0.15 (-2.51)	-0.14 (-2.32)	-0.19 (-3.36)	-0.2 (-3.48)
Access time	10 min	-0.46 (-7.32)	-0.47 (-7.67)	-0.55 (-9.71)	-0.55 (-9.7)
Gender	0/1	-0.45 (-2.05)	-0.39 (-1.75)	-0.61 (-2.96)	-0.6 (-2.93)
Shannon entropy		-	3.04 (11.1)	-	-
Mode share		-	-	0.46 (2.14)	-
Fractal dimension (car)		2.46 (5.71)	-	-	-
Fractal dimension (rail and bus)		2.9 (9.9)	-	-	-
ρ^2		0.796	0.795	0.762	0.761
Hitting ratio		94.90%	94.70%	94.60%	94.40%

t-statistic is indicated in ( )

SOME EXAMPLES OF POLICES

In this section we aim to analyze some policies aiming at the reduction of car use by using the logit model (model 1) of the commuter mode choice from home to the office. The following two examples of policies are given.

Case1: the interval between trains (buses) decrease to a half.

Case 2: all commuting expenses are provided for the user of public transportation.

The predicted results for each case are shown in Figures 5 and 6. In both figures, (a) is the mode share before the policy, (b) is the mode share just after the policy is implemented, (c) is the mode share obtained from the change in the fractal dimension, and (d) is the mode share after convergence. In both cases, the policy did not have a strong influence on the mode share. However, the process of the change in the mode share could be observed.

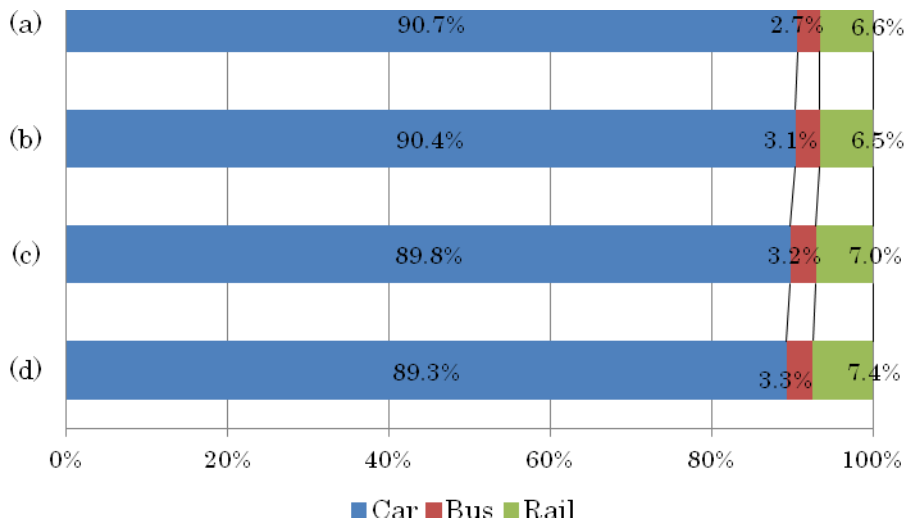

Figure 5 – Policy analysis (Case 1)

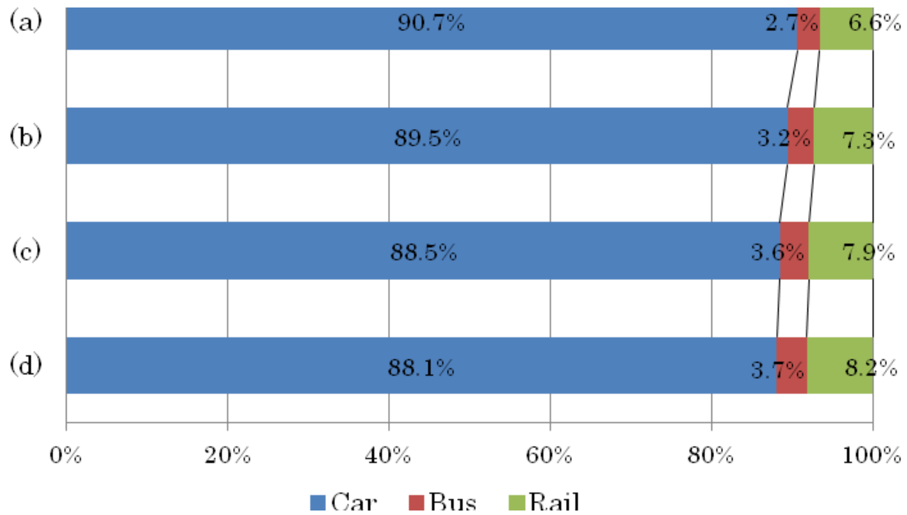

Figure 6 – Policy analysis (Case 2)

CONCLUSIONS

In this paper we presented an analysis of the transportation mode choice behavior of commuters in a regional city in Japan. A logit model of mode choice is developed using the fractal dimensions of states as one of the independent variables. The fractal dimensions of states can be used to quantify the distribution of points within a defined region, and provides a numerical value for the distributions of commuter homes and offices. In this paper, the fractal dimensions of states were used as an index to express the influence of the mode choice of colleagues in the same office. Our analysis led to a number of specific conclusions.

1. Among the three indices calculated to express the distributions of workplaces and residences for each office, that is, the mode share, the entropy, and the fractal dimensions of states, the model using the fractal dimensions of states is the most effective model, because the value of ρ^2 and the hitting ratio are the largest.
2. By using the model proposed in this study, not only the change in commuter mode immediately after a policy has been implemented but also the subsequent change can be considered.

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