model is a kind of regression model for ordinal dependent variables. In our case, the daily frequency of travels is regarded as the ordinal dependent variable (Greene and Hensher, 2010).

Let the utility function of an individual i be U_i. It is assumed that the utility function is a linear function with a random component, $U_i = \boldsymbol{\beta}\mathbf{x}_i + \varepsilon_i$, where $\mathbf{x}_i$ denotes a set of variables, including gender, income, and age; $\boldsymbol{\beta}$ denotes a set of coefficients; and ε_i denotes the random component following the logistic distribution. Then, the random ordered choice model for the travel frequency Y_i is formulated as

$$Y_i = 0 \quad \text{if} \quad -\infty < U_i \le \alpha_{0/1} \tag{1),}$$

$$Y_i = 1 \quad \text{if} \quad \alpha_{0/1} < U_i \le \alpha_{1/2} \tag{2),}$$

$$Y_i = 2 \quad \text{if} \quad \alpha_{1/2} < U_i \le \alpha_{2/3} \tag{3),}$$

where $\alpha_{j/j+1}$ denotes the threshold between travel frequency $Y_i = j$ and $Y_i = j+1$.

The probability that Y_i is equal to or lower than j, $\Pr(Y_i \le j)$, and the probability that Y_i is equal to j, $\Pr(Y_i = j)$, are expressed respectively as

$$\Pr(Y_i \le j) = \frac{\exp(\alpha_{j/j+1} + \boldsymbol{\beta}\mathbf{x}_i)}{1 + \exp(\alpha_{j/j+1} + \boldsymbol{\beta}\mathbf{x}_i)} \tag{4),}$$

$$\Pr(Y_i = j) = \Pr(Y_i \le j) - \Pr(Y_i \le j-1) = \frac{\exp(\alpha_{j/j+1} + \boldsymbol{\beta}\mathbf{x}_i)}{1 + \exp(\alpha_{j/j+1} + \boldsymbol{\beta}\mathbf{x}_i)} - \frac{\exp(\alpha_{j-1/j} + \boldsymbol{\beta}\mathbf{x}_i)}{1 + \exp(\alpha_{j-1/j} + \boldsymbol{\beta}\mathbf{x}_i)} \tag{5).}$$

The coefficients in the utility function are estimated with the likelihood maximization procedure. The likelihood function is defined as

$$L = \prod_i^I \prod_j^{K-1} \left[\Pr(Y_i = j)\right]^{\delta_{i,j}} = \prod_i^I \prod_j^{K-1} \left[\frac{\exp(\alpha_{j/j+1} + \boldsymbol{\beta}\mathbf{x}_i)}{1 + \exp(\alpha_{j/j+1} + \boldsymbol{\beta}\mathbf{x}_i)} - \frac{\exp(\alpha_{j-1/j} + \boldsymbol{\beta}\mathbf{x}_i)}{1 + \exp(\alpha_{j-1/j} + \boldsymbol{\beta}\mathbf{x}_i)} \right]^{\delta_{i,j}} \tag{6),}$$

where $\delta_{i,j}$ is equal to 1 if the travel frequency of an individual i is equal to j, and 0 otherwise, I denotes the number of individuals, and K denotes the maximum travel frequency.

3.2 Land use mix indexes

Land use mix refers to locating different types of land uses close together. The land use mix has typically been measured using entropy indexes or dissimilarity indexes (Litman and Steele, 2012). This study uses two kinds of indexes pertaining to land use mix. The first is the Gini–Simpson (GS) index, which is widely used in ecology. This is one of the entropy indexes. This index originates from the Simpson Index (Simpson, 1949), which is also known as the Herfindahl or Herfindahl–Hirschman index in economics. The Gini–Simpson index is equal to the probability that two entities taken at random from the dataset of interest represent different types. It can be expressed as

$$Gini - Simpson\ Index = 1 - \sum_k^K p_k^2 \tag{7),}$$

where p_k indicates the share of zones belonging to a land use category k among the total zones. This index increases as the numbers of land use categories become better balanced in the given area. It should be noted that a higher GS index does not necessarily guarantee the land use mix. This is because the GS index is possibly high even if the land use patterns are segregated in the given area. Thus, this index indicates the balance of land use patterns in the given area.

The second index relating to land use mix is the dispersion index. It is defined as

$$Dispersion\ Index = \frac{1}{K} \cdot \sum_{k=1}^{K} \frac{\sum_{n=1}^{N} \theta_{n,k} \cdot GD_{n,k}}{\sum_{n=1}^{N} \theta_{n,k}} \quad (8),$$

where $\theta_{n,k}$ is equal to 1 if the zone n belongs to the land use category k, and 0 otherwise, $GD_{n,k}$ denotes the distance between the zone n and the gravity point in a subgroup of zones belonging to the land use category k, and N denotes the total zones. The grid zone located in an area where land use patterns are highly dispersed has a higher dispersion index. In other words, the segregated land use patterns should give a low dispersion index. Thus, this index indicates the segregation level of land use patterns in a given area.

3.3 Land use mix indexes

First, the correlations among the potential explanatory variables are summarized in Table 6. The "GS index dummy" is equal to 1 if the Gini–Simpson Index is greater than 0.9, and 0 otherwise. The Gini–Simpson index is estimated in the area covering a five square kilometer area around an individual's home. The "dispersion index dummy" is equal to 1 if the dispersion index is greater than 7.0, and 0 otherwise. The dispersion index is estimated in the area covering a five square kilometer area around an individual's home. "Income" is equal to 1 if the monthly income of the individual's household is equal to or greater than 2,250,000 rupiahs, and 0 if not. In our dataset, 2,250,000 rupiahs is close to the average monthly household income. "Gender" is equal to 1 if the individual is male, and 0 otherwise. "Age in 30s or 40s" is equal to 1 if the individual is in his or her 30s or 40s, and 0 otherwise. "Access to bus stop" is equal to 1 if the access travel time to the nearest bus stop from the individual's home is over 20 minutes, and 0 otherwise. 20 minutes is also approximately the average access travel time to the nearest bus stop from residents' households. "Car ownership" is equal to 1 if the individual owns a car, and 0 otherwise. "Motorbike ownership" is equal to 1 if the individual owns a motorbike, and 0 otherwise. "Children" is equal to 1 if the number of children who are less than 13 years old is over three, and 0 otherwise. "Kampung area dummy," "planned area dummy," and "farm area dummy" are equal to 1 if the zone where the individual's home is located belongs to a kampung area, a planned area, or a farm area, respectively, and 0 otherwise.

Table 6 shows that most of the combinations have a low correlation coefficient. It should be noted that the correlation coefficient between the GS index dummy and the kampung area dummy is -0.40. This means that the kampung area may be less balanced with respect to land use patterns. This is quite reasonable because the kampung areas are often developed into large agglomerations where many kampung areas are located together.

Table 7 shows the estimation results of ordered logit models. Model 1 uses all the potential variables; Model 2 removes "kampung area dummy" from Model 1 by reflecting the high correlation with "GS index dummy;" Model 3 is the model with the highest final-log-likelihood after the trial-and-error process with respect to the choice of explanatory variables. First, Model 3 shows that all thresholds are significantly estimated. Second, "dispersion index dummy" is significantly positive. This means that the individuals whose home is located in the area where the land use patterns are highly dispersed travel more frequently. On the other hand, “GS index dummy” is negative in all models, although it is not significant at the 95% degree. This may mean that individuals whose home is located in the area where the land use categories are balanced tend to travel less frequently. Third, “income” is also significantly positive. This means that the individuals in higher-income households travel more frequently. Fourth, “gender” is significantly negative. This means that males travel less frequently. Fifth, “age in 30s or 40s” is positive, although it is less significant. This may mean that the individuals in their 30s or 40s tend to travel more frequently. Sixth, “car

Table 6. Correlation Matrix among Potential Explanatory Variables in Ordered Logit Model

	GS index dummy	Dispersion index dummy	Income	Gender	Age in 30s or 40s	Access bus stop
GS index dummy	1.00					
Dispersion index dummy	0.04	1.00				
Income	-0.07	0.06	1.00			
Gender	-0.08	0.07	0.00	1.00		
Age in 30s or 40s	-0.08	-0.02	-0.02	-0.08	1.00	
Access to bus stop	0.00	0.11	0.05	-0.05	0.03	1.00
Car ownership	-0.04	0.14	0.18	-0.05	-0.04	0.12
Motorbike ownership	-0.05	0.06	0.32	-0.02	-0.01	0.04
Children	-0.02	-0.05	-0.02	-0.07	0.09	-0.08
Kampung area dummy	-0.40	0.17	0.06	0.00	0.12	0.14
Planned area dummy	0.06	-0.13	0.09	0.03	-0.05	-0.13
Farm area dummy	0.21	-0.2	-0.12	-0.03	-0.05	0.05
	Car ownership	**Motorbike ownership**	**Children**	***Kampung* area dummy**	**Planned area dummy**	**Farm area dummy**
GS index dummy						
Dispersion index dummy						
Income						
Gender						
Age in 30s or 40s						
Access to bus stop						
Car ownership	1.00					
Motorbike ownership	0.09	1.00				
Children	-0.01	-0.06	1.00			
Kampung area dummy	0.06	0.11	0.02	1.00		
Planned area dummy	-0.01	-0.01	0.01	-0.57	1.00	
Farm area dummy	-0.07	-0.02	-0.01	-0.37	-0.27	1.00

Table 7. Estimation Results of Ordered Logit Models

	Model 1			Model 2			Model 3		
	Coef.	t-statistics		Coef.	t-statistics		Coef.	t-statistics	
0/2 threshold	0.31	1.11		0.13	0.68		0.26	1.78	*
2/3 threshold	2.37	8.01	**	2.19	10.04	**	2.32	13.07	**
3/4 threshold	2.83	9.25	**	2.66	11.44	**	2.78	14.31	**
4/5 threshold	3.74	10.84	**	3.56	12.69	**	3.69	14.69	**
GS index dummy	-0.12	-0.57		-0.20	-1.00		-0.23	-1.23	
Dispersion index dummy	0.44	2.02	**	0.42	1.94	*	0.45	2.18	**
Income	0.42	2.73	**	0.43	2.78	**	0.42	2.86	**
Gender	-0.50	-3.19	**	-0.50	-3.18	**	-0.49	-3.13	**
Age in 30s or 40s	0.22	1.50		0.23	1.55		0.23	1.61	
Access to bus stop	-0.22	-1.28		-0.20	-1.16				
Car ownership	0.54	1.26		0.53	1.22		0.50	1.17	
Motorbike ownership	-0.08	-0.48		-0.06	-0.37				
Children	-0.32	-1.27		-0.31	-1.25		-0.28	-1.13	

Kampung area dummy	0.24	0.89				
Planned area dummy	0.14	0.54	-0.04	-0.21		
Farm area dummy	-0.02	-0.05	-0.19	-0.83		
Initial log-likelihood	-1228		-1228		-1228	
Final log-likelihood	-792		-793		-794	
Number of observations	763		763		763	

ownership" is also positive, although it is less significant. This may mean that a car owner tends to travel more frequently. Finally, "children" is negative, although it is less significant. This may mean that individuals with many children tend to travel less frequently.

3.4 Discussion

The estimation results seem quite reasonable. Higher-income individuals travel more frequently, probably because they are more able to participate in out-of-home activities. Females travel more frequently, probably because they often go shopping to purchase the daily food. Note that Kato et al. (2010) report the results of a consumer survey in Jakarta in which housewives cook the daily meal in 79.5% of households and often visit groceries and local markets to purchase the daily food. The positive impact of the dispersion index dummy on the utility function means that less segregated land use patterns around an individual's home make the individual travel more frequently. This is probably because individuals who live in areas where the mixed land use patterns are located can access different land use zones easily. The negative impact of the GS index dummy on the utility function means that less balanced land use patterns around an individual's home make individuals travel more frequently. This may be because only specific land use categories such as commercial areas and public building areas attract individuals more than other land use categories. One of the examples of less segregated and less balanced land use pattern is a mosaic pattern composed of only two types of land use categories like a chess board. In summary, the results suggest that higher-income females living in areas with mixed land use patterns composed of a few land use categories travel more frequently from home.

Does this mean that the land use mix has less impact on the global and local environments, or more? Unfortunately, the answer is not clear from this study. It should be noted that the dispersion index and GS index are calculated for an area of five square kilometers, and that over 60% of respondents travel less than five kilometers from their home. Our dataset shows that travels of less than two kilometers are predominantly made on foot, while 2-5 kilometer travels are mainly made by motorbike. The high modal share of motorbikes is one of the noteworthy characteristics in Jabodetabek that cannot be seen in American or European cities. Thus, decreased segregation of land use patterns may lead to more motorbike traffic than walking in our case. To discuss this, however, it is necessary to analyze the travel mode choice under the given land use patterns. This is beyond this study's scope, but it is one of the most important issues for future research.

4. CONCLUSIONS

This paper analyzed the impact of land use mix on the travel frequency of individuals in a developing city. Daily activity data were collected through interview-based local surveys in the Jakarta metropolitan area, while land use data were collected via the estimation of land use patterns using an existing official database. Seven categories of land use patterns are used, including three types of residential areas: kampung areas, planned residential areas, and farm areas. Then, ordered logit models were estimated, in which the dependent variable was the daily travel frequency of individuals and the independent variables were the threshold of travel frequency, land use mix indexes, and individual and household attributes. The results show that higher-income females living in areas with less segregated land use patterns composed of less balanced land use categories travel more frequently from home.

Future research issues are summarized as follows: First, the work presented in this paper could be extended by accounting for the possible influences of self-selection on travel frequency. To do so, the attitudinal and lifestyle preference variables should be incorporated into the model. Second, the association between land use mix and the modal choice of individuals should be studied to determine the impacts of land use mix on the environment, particularly those caused by motorbikes. Third, the association of land use patterns with time use may be also investigated. In this case, the land use patterns around the destination zone should be used for the analysis. Fourth, the impact of factors other than land use mix on the travel behavior of individuals should also be analyzed. Fourth, the trip chaining behavior was not assumed in this paper although it may be one of the major characteristics of travelers in Asian urban areas. The detailed travel episode should be used for analyzing the trip chaining behavior. Finally, a comparative analysis between different developing cities may also be interesting. Although a meta-analysis on the association of the built environment and travel behavior has been presented (e.g., Ewing and Cervero, 2010), these studies have mainly used data from the developed world. Further empirical studies might contribute to land use and transportation policy in the developing regions.

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