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Evaluation of Micro EV's Spreading to Local Community by Multinomial Logit Model

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ABSTRACT

Micro Electric Vehicles are considered as a solution for reducing CO_2 emissions, however, it is difficult to evaluate its impact in a local community when it has been introduced. In this study, we evaluated how to spread the Micro EV within the community, using the utility derived from a multinomial logit model, and analyze the effect on CO_2 emissions. The householder's utility model is based on an investigation about Kiryu citizen's activities of shopping, transportation methods, etc. Using the geographic information system, we get the distances of each householder and the stores, and estimate a multinomial logit model about the combination choices of shopping stores and transportation method.

Keywords: Multinomial Logit Model, Direct Product Alternatives, Utility, CO_2 Emission, Geographic Information System, Data Mining

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1. INTRODUCTION

Japanese society has two issues for sustainability. One is the rapid aging of population, especially, in local cities where this issue is severe as shown in Figure 1, because young persons tend to leave for larger cities. It has resulted in the decay of urban area of the local small cities, along with the exodus of young residents from the inner cities to the suburbs of the cities during the period of rapid economic growth in the postwar era of Japan. The spread population gives rise to operational difficulties of public transportations in local cities. Under these circumstances, most of the residents in local city use his/her private automobiles for daily short trips. The other issue is the energy-saving for anti-global-warming. To resolve this issue, it is needed to reduce CO_2 emissions, that is, to save fossil fuel. However, automobiles consume much more fossil fuel than public transportation methods.

One of the solutions is a multimodal urban region (Bertolini and Clercq, 2003). Combined use of public transformation methods for longer trips and personal transportation methods for shorter trips produces a low-carbon society. Micro electric vehicles (micro EV's) are considered as one method for personal transformation in this scenario. Micro EV is an EV for one personal use. It has small and light body, low speed, and has characteristics of an automobile and a bicycle. It is easy even for elderly persons to drive, and its energy can be supplied from solar energy (Toshio, 2011). From December 2011, use of micro EV was demonstrated in Kiryu, a local city in Japan, founded by the Minister of Land, Infrastructure, Transportation and Tourism (MLIT, 2010; Hada, 2009).

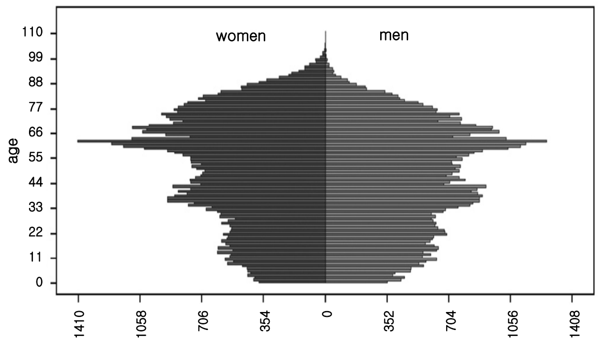

Figure 1. Population pyramid of Kiryu city.

However, it is difficult to evaluate its impact in a local community when it has actually been introduced. In this study, we evaluated how to spread the micro EV within the community, using the utility derived from the multinomial logit model and analyzed the effect on CO_2 emissions.

First, we propose a generalization of multinomial logit model (Ben-Akiva and Lerman, 1995; Train, 2009) for direct product alternatives of shopping stores and transportation methods to the stores. Using a result of questionnaire survey, we estimate this model, and clarify the utility structure for the combination of shopping store and transportation method. This model explains discrete choices of combinations according with other variables such as distance to the store, his/her age, etc.

Next, we assume some conditions of utility of micro EV's, and estimate the probability of citizens' choices of the combinations. This new method was added as a new choice of transportation. From this probability, we estimate CO_2 emissions for shopping trips in Kiryu city.

Our approach in this paper may be used for evaluating how widely a new technology can be spread to a society, and be able to forecast the demand level in the saturated case.

2. MULTINOMIAL LOGIT MODEL FOR DIRECT PRODUCT ALTERNATIVES

2.1 Multinomial Logit Model

The multinomial logit model is one of discrete choice models which explain the probabilities to select alternatives in a finite choose set C. These models assume that alternatives in the choice set are mutually exclusive, exhaustive. Based on the utility-maximizing theory that states that decision maker chooses the alternative which maximizes his/her utility, the probability that decision maker i choose an alternative c is

$$\begin{aligned} P_{ic} &= \mathrm{Prob}(U_{ic} > U_{ic'}, \forall c' \neq c) \\ &= \mathrm{Prob}(V_{ic} + \varepsilon_{ic} > V_{ic'} + \varepsilon_{ic'}, \forall c' \neq c) \end{aligned} \quad (1)$$

where U_{ic} is the utility of the alternative c for the decision maker i. V_{ic} is a representative part of U_{ic}, which is the function of attributes of the alternative c and the decision maker i. ε_{ic} is a random part of U_{ic}, which summarizes the contribution of unobserved variables and distributes independently and identically extreme value distribution. We can find the closed form of the probability as the Eq. (2).

$$P_{ic} = \frac{\exp(V_{ic})}{\sum_{c' \in C} \exp(V_{ic'})} \quad (2)$$

If we observe $K+K'$ attributes from the alternatives and the decision makers, and among them, K attributes are categorical factor attributes and K' attributes are continuous variables $x_{k'ic}$. We usually formulate the function V_{ic} of attributes as Eq. (3), for example, in the regression model.

$$V_{ic} = \beta_0 + \sum_{k=1}^{K} \beta_{kl_{kic}} + \sum_{k'=1}^{K'} \beta_{k'} x_{k'ic} \quad (3)$$

where β_0 is the intercept constant, β_{kl}'s and $\beta_{k'l}$'s are the coefficients for the attributes of the categorical factor and the continuous variables, respectively. l_{kic} is the level of the k^{th} factor attribute of choice ic and $x_{k'ic}$ is the value of k'^{th} continuous attribute of choice ic. However, in the multinomial logit model, β_0 and one of the β_{kl}'s for each k must be set 0, to avoid the indetermination of coefficients because of equivalent ratio of Eq. (3) between the choices. In this paper, we set $\beta_{kl} = 0$, i.e., the coefficients of the first categories are set zero.

2.2 The Model for Direct Product Alternatives

The choice set of the multinomial logit model is a direct product of two sets, for example, set of shopping stores and the set of transportation methods. Let the two sets be S and T. The choice set is C = $\{(s, t) | s \in \mathrm{S}, t \in \mathrm{T}\}$. In this example, a decision maker chooses a combination of shore s and transportation method t to the selected store. Utilities are defined for the combinations.

Estimation method of the model is the same for the most part to ordinary logit model. However, we need some attention to parameterization of coefficients. Because utility is a latent index, and its values are relative in each decision maker, we must set coefficients of base categories to zero, as mentioned above. So attributes of the two sets are parameterized, as setting their coefficients of first categories to zero, respectively. Furthermore, if we need to estimate any interaction term that includes two attributes, the coefficient of the interaction whose level is the first category, at least in one attribute, must be set zero. An example of this formulation is given in section 4.

3. SURVEY IN KIRYU CITY

The information needed for estimation of the model is based on a survey conducted in Kiryu in October 2009. Kiryu is a local city in Gunma prefecture, and is located about 100 km north of Tokyo.

This study is part of the main project “Construction of the town of Kiryu for the future with anti-global-warming through the regional power” supported by Japan Science and Technology Agency, and the main goal is to reduce 80% of CO_2 emitted in the city. We research to understand the effect of modal shift of shopping from the information given on the questionnaires.

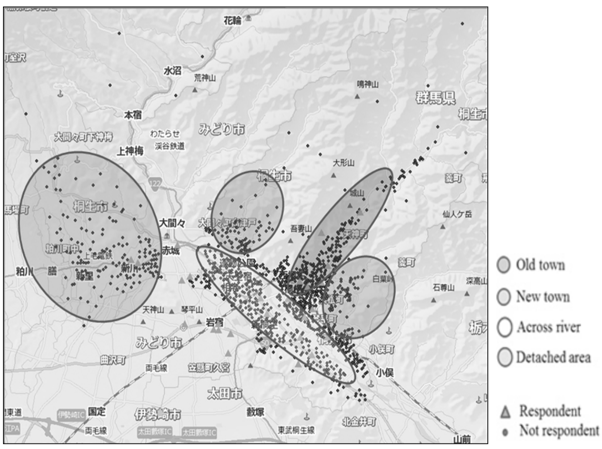

Figure 2. Areas of Kiryu city and sampled householders.

This questionnaire was sent to random sampled 10,000 householders from a total of 50,163 householders of Kiryu and returned 2,269 questionnaires; it means the 4.52% of the total or the 22.69% of the sample. We divided Kiryu city into 4 areas in order to analyze the relationships between them. These areas are represented as: old town, new town, across river, and detached area in Figure 2.

In this survey, we asked about shopping to the main person who usually goes to shopping in his/her home. The main part of the question is about the frequency per month. We must specify the visited store to obtain the distance from his/her home. However, it is too difficult to ask all of the stores located in Kiryu city. For that reason, we limited alternatives in the questionnaire to the representative shopping places in Kiryu. We have selected 41 representative stores and shopping areas in/near the city, and we have selected some shopping activities done in the store, such as: foods, clothes, daily goods, window-shopping, etc. The frequencies are asked for every store and for every kind of shopping activity. In addition with these frequencies, we asked about the means of transportation used to go to every store. The categories of transportation are bicycle, car, bus, train, and non use (walk).

In addition, we surveyed the demographic information of the respondents; sex, age, location, whether he/she had a car license.

We used a geographic information system (ArcGIS ver. 9.5; Esri, Redlands, CA, USA) to get the location of each householder and the stores from their addresses, and also to get the Euclidean distance between them.

4. ESTIMATION OF SHOPPING TRIP UTILITY

In this paper, we restrict the kind of shopping activity to food shopping, which is the most frequent activity, and estimate a multinomial logit model for alternatives which are direct product of set of shopping stores and the set of transportation methods. The set of stores are 12 shopping places as listed in Table 1. These places are

Table 1. Shopping places investigated

Name	Location	Abbreviation	No. of places
1 Old shopping street	Old town	Old-st	2 areas
2 Large-scall retail store	Old town	LS	1 shop
3 Supermarket C	Old town/across river	SM-C	3 shops
4 Supermarket R	Old town/across river	SM-R	3 shops
5 Supermarket F	Across river	SM-F	1 shop
6 Supermarket V	all area except across river	SM-V	3 shops
7 Supermarket P	Across river	SM-P	1 shop
8 Supermarket B	New town	SM-B	2 shops
9 Shopping mail S	Detached area	M-S	1 mall
10 Shopping mail Y	Across river	M-Y	1 mall
11 Large-scall shopping mail S	Outskirt of the city	LM-S	1 mall
12 Large-scall shopping mail A	Outskirt of the city	LM-A	1 mall

selected from 41 stores as the stores selling foods, and all branches having the same name are summarized to one store.

Also, in the original data we have distinguished transportation methods: car, bus, train, and bicycle. Nevertheless, in order to reduce the number of categories that are few checked, we have created a new transportation category called public transportation, it takes into account the information about bus and train. We consider that the respondent who checked no transformation method walks to the store, and we merge this case to the bicycle. Finally, we distinguish three transportation methods; walk/bicycle, public transportation, and car.

Our dataset consists of 4,871 selected alternatives that are selected by 1,618 householders. It means that each householder selects 3.01 pairs of stores and methods from 12 × 3 = 36 pairs on average. For each selected alternative, numbers of trips in the month are observed; the total of these numbers is 26,092 times.

Using the above data set, we developed different kind of models, which explain the representative utility by 5 attributes and the interactions between them and choices. The used attributes are distance to the store and age, sex, place area, car license status of respondents. Estimated models are evaluated by Akaike information criteria (AIC). From these results, we select the next model.

$$V_{ist} = \beta_{1t} + \beta_{2s} + \beta_3 \log(d_{is}) + \beta_{4t} \log(d_{is}) + \beta_{5tl_i} + \beta_{6t} A_i + \beta_{7tr_i} + \beta_{8t} O_s + \beta_{9s} A_i \quad (4)$$

where

i : Householder.

s : Store choice. $s \in$ {old town shopping area, supermarket 1, ⋯, 9, huge shopping mall 1, 2}

t : Transportation method choice.

V_{ist} : Utility of visit to store s by the method t for the individual i.

d_{is} : Distance from the home i to the store s.

A_i : Age of householder i.

r_i : Place area where home of i is located. $r_i \in$ {old town, new town, across river, detached area}.

O_s: Is store s in old town. $O_i \in \{0, 1\}$

l_i: Car license status of householder i. $l_i \in$ {hold, not hold}

$\beta_{k\cdot}$: Coefficient of k^{th} attribute ⋅ .

The estimated coefficients for the model are shown in the Table 2.

First, effects related with the kind of transportation method are shown in the Figure 3. This figure indicates the effect to utility of distance from home i to store s and possession of driving license: $\beta_{1t} + (\beta_3 + \beta_{4t})\log(d_{is}) + \beta_{5tl}$ for each t and l. For the trip less than 1.37km, for the average person who does not have a car driving license, walk/bicycle, car and public transformation have much utility in this order, and the opposite for the longer trip. However, checking the interaction between transportation method and car license, if he/she has a car license, car's utility become higher (+1.4), and public transportation's drop -1.85. Accordingly, car drivers always have maximum utility for car in practical distance, and they don't tend to use public transportations. As for the effect of age to utility: β_{6t}, elderly persons tend to avoid car driving.

Table 2. Estimated model coefficients

	Factor	levels	Estimate	Std. error	t-value	Pr(>|t|)
Main effect	Trans. method β_{1t}	Bicy/walk (base)	0.0000	-	-	-
		Public	-5.9986	0.9149	-6.5565	0.0000 ***
		Car	1.7175	0.1801	9.5337	< 2.2e-16 ***
	Stores β_{2s}	Old-st (base)	0.0000	-	-	-
		LS	1.7942	0.6097	2.9431	0.0032 **
		SM-C	2.3256	0.6132	3.7926	0.0001 ***
		SM-R	3.3258	0.5916	5.6215	0.0000 ***
		SM-F	2.7506	0.6580	4.1801	0.0000 ***
		SM-V	2.1884	0.6035	3.6264	0.0003 ***
		SM-P	1.5712	0.6863	2.2892	0.0221 *
		SM-B	3.4550	0.6004	5.7545	0.0000 ***
		M-S	2.2997	0.6319	3.6395	0.0003 ***
		M-Y	2.9006	0.6028	4.8117	0.0000 ***
		LM-S	2.1557	1.0318	2.0893	0.0367 *
		LM-A	3.1488	0.7950	3.9609	0.0001 ***
	log (distance) β_3		-1.4336	0.0366	-39.1948	< 2.2e-16 ***
Interaction effect	log (dist.) and trans. β_{4t}	Bicy/walk (base)	0.0000	-	-	-
		Public	1.6582	0.2640	6.2804	0.0000 ***
		Car	0.4996	0.0368	13.5643	< 2.2e-16 ***
	Trans. and license β_{5tl} (base = Not possession and bicy/walk)	Bicy/walk	0.0000	-	-	-
		Public	1.4233	0.3743	3.8024	0.0001 ***
		Car	-1.8526	0.1274	-14.5456	< 2.2e-16 ***
	Age and trans. β_{6t}	Bicy/walk (base)	0.0000	-	-	-
		Public	-0.0123	0.0138	-0.8919	0.3724
		Car	-0.0094	0.0029	-3.2018	0.0014 **
	Area and trans. β_{7tr} (base = old town & bicy/walk)	New town Public	0.3153	0.5052	0.6240	0.5326
		New town Car	0.3050	0.0990	3.0817	0.0021 **
		Across river Public	1.0971	0.4381	2.5042	0.0123 *
		Across river Car	0.4381	0.0905	4.8426	0.0000 ***
		Detached area Public	-0.9555	0.8110	-1.1782	0.2387
		Detached area Car	0.4592	0.1611	2.8515	0.0044 **
	Old town shop? and trans. β_{8t}	Bicy/walk (base)	0.0000	-	-	-
		Public	2.6763	0.4130	6.4806	0.0000 ***
		Car	-0.7768	0.1140	-6.8120	0.0000 ***
	Age and stores β_{9s}	Old-st (base)	0.0000	-	-	-
		LS	0.0035	0.0100	0.3532	0.7239
		SM-C	-0.0142	0.0101	-1.4049	0.1600
		SM-R	-0.0200	0.0097	-2.0609	0.0393 *
		SM-F	-0.0357	0.0110	-3.2327	0.0012 **
		SM-V	-0.0124	0.0099	-1.2474	0.2123
		SM-P	-0.0104	0.0113	-0.9149	0.3603
		SM-B	-0.0235	0.0098	-2.3948	0.0166 *
		M-S	-0.0068	0.0104	-0.6553	0.5123
		M-Y	-0.0112	0.0098	-1.1396	0.2545
		LM-S	-0.0376	0.0186	-2.0183	0.0436 *
		LM-A	-0.0343	0.0137	-2.4971	0.0125 *

Signif. Codes: 0 '***' 0.001 '**' 0.1 '*' 0.05 '.' 0.1 ' ' 1.

Next, we consider the effect of areas. Householders residing in the new town or across river area tend to use some transportation method; public one or car, compared with old town and detached area. The reason is considered that four railways have come to Kiryu city, and they cover across river area and some part of the new city area. Furthermore, bus network covers these areas, though it is not so frequent. Householders in these areas, who need to trip longer distance than old town area, use the some transportation method. On the other hand, in the detached area, access to these transportation methods is inconvenient and the services are less frequent, so they depend on car self-sufficiently. We represent this effect by term β_{7tr}.

With respect to the location of stores, we distinguish whether the store is in the old town. The result of estimated β_{8t} indicated that public transportation, not car, tends to be selected for the trips to the store in old town.

Finally, we confirm the effect of store: β_{2s} and β_{9s}. Every store have higher utility than the old shopping street, and have higher utility to younger person, except for old-st and LS, that are located in the old town area.

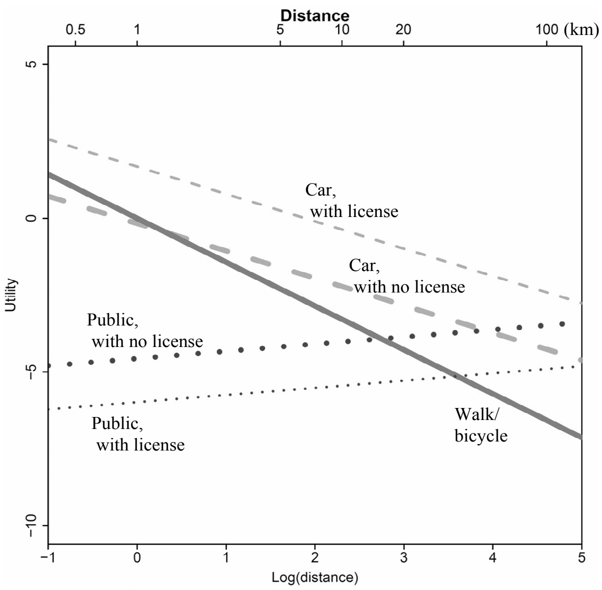

Figure 3. Utility function of moving distance of each transformation method.

5. ESTIMATION OF CO_2 EMISSION

5.1 How to Estimate the Spread of New Techno logy

Once we have estimated utilities of alternatives for each householder, using the multinomial logit model, we can estimate any probability that a householder choices a alternative; a combination of a store and a transportation method. Adding some assumption about the utility of new technology, we can estimate the probability that the new technology is selected by each person.

In our case, we estimate the probabilities of micro EV in food-buying trip. To calculate the probability, we assume below assumptions:

- The utility of the micro EV is the mean of car and bicycle in every situation of householder i and store s, as below equation. The utilities of the other methods are invariant under the introduction of the micro EV.

$$V_{isEV} = (V_{isBicy} + V_{isCar})/2 \tag{5}$$

- The citizens can buy this transportation method, if he/she likes it.
- The citizens don't change the frequency of food-buying trip.
- The population volume and its demographic situation of the citizen will remain constant.

Once we could calculate the utility value of micro EV, we can estimate the probability of each combination of store and method using Eq. (2). This calculation can be sound, if we could assume an appropriate condition to the utility of the new technology to the original state.

We have already one month frequency of food-buying for each householder, so we can estimate expected frequency of the alternatives by multiplying the selection probability by the frequency. Each alternative; a trip to a store, has distance of trip. Therefore, we can estimate the one month accumulated trip distance of each householder for each transportation method. The results are listed in Table 3.

5.2 Effect the Spread of Micro EV

First, we see the trip distance per person in Table 3. In surveyed data, car distance is longest among all methods, and at old town it is shortest among the other areas. This feature is the same in the estimated result added micro EV.

After the introduction of micro EV, micro EV became the second method, and it is used in 24.8% of all trip in distance on the average weighted by number of persons. Car remains the first method, however, its use is reduced 20.9%. Micro EV is used in old town most frequently, because of short mean distance of trips.

5.3 Assessment of the Emission of CO_2

We assess the rough amount of CO_2 emissions in Kiryu for food-buying in a year using Eq. (6).

$$A_s = \frac{12}{0.04523} \sum_{ijm} d_{ij} n_{ij} r_{ijm} \rho_m \tag{6}$$

where,

i :	Householder.
j :	Store.
m :	Transportation method.
d_{ij} :	Distance between i and j.
n_{ij} :	Frequency of visits in a month.
r_{ijm} :	Ratio of visiting method m.
ρ_m :	Methods m's average CO_2 emission (g/km).
0.04523:	Rate of respondents among all citizens.
12:	Number of months in a year.

Table 3. Impact of introduction micro electric vehicles (EV) to trip distance

			Raw data					Percentage				
			Old town	New town	Across river	Detached area	All area	Old town	New town	Across river	Detached area	All area
Number of persons			527	374	541	176	1618	32.57	23.11	33.44	10.88	100
Number of trip			8450	5828	8790	2255	25324	33.37	23.01	34.71	8.91	100
Present status from surveyed data	Total trip distance (km/mo)		18105.39	15020.9	20035.45	8394.17	61555.90	29.41	24.40	32.55	13.64	100
	Mean distance (km/trip)		2.14	2.58	2.28	3.72	2.43	88.14	106.03	93.77	153.12	100
	Trip distance per person (km/mo)	Walk/bicy	6.47	5.95	4.93	5.87	5.77	18.8	14.8	13.3	12.3	15.2
		Public	0.42	0.36	0.52	0.55	0.45	1.2	0.9	1.4	1.2	1.2
		Car	27.47	33.85	31.58	41.28	31.82	80.0	84.3	85.3	86.6	83.7
		Total	34.36	40.16	37.03	47.69	38.04	100	100	100	100	100
Status after Intro-duction of EV estimated by logit model	Total trip distance (km/mo)		18009.57	15749.5	18311.15	9524.86	61595.07	29.24	25.57	29.73	15.46	100
	Mean distance (km/trip)		2.13	2.70	2.08	4.22	2.43	87.62	111.10	85.65	173.64	100
	Estimated trip distance per person (km/mo)	Walk/bicy	4.89	4.32	3.53	5.49	4.37	14.3	10.3	10.4	10.2	11.5
		Public	0.24	0.30	0.47	0.54	0.36	0.7	0.7	1.4	1.0	1.0
		Car	20.08	27.27	21.68	35.01	23.90	58.8	64.8	64.0	64.7	62.8
		EV	8.97	10.21	8.17	13.08	9.44	26.2	24.3	24.1	24.2	24.8
		Total	24.17	42.11	33.85	54.12	38.07	100	100	100	100	100

It is difficult to assess precisely Eq. (6), because we do not have precise information about the type of transportation method, for example, fuel consumption of householders' cars. So, we use the representative value shown in Table 4. In this table the emissions related with bicycle for CO_2 are 0, because it does not use any fuel. For the public transportation, we use the value of bus as a leading method. As to this value, we assume an average number of passengers equal to 10, and divide the value 403.1 in Table 4 by 10. As to the micro EV, it is also difficult to assess its CO_2 emission (De Boncourt, 2011), we assume that its emission rate is estimated at 1/20 of car's one.

Table 4. CO_2 emissions rate

Transportation method	CO_2 emissions (gCO_2/km)
Car	137.3[a)]
Bus	403.1[b)]
Bicycle	0.
Micro electric vehicles	4.84

[a)] 2.32 $tCO_2/kL/16.9$ $km/L \times 1000$ (Ministry of the Environment, 2011; Japan Automobile Manufacturers Association Inc., 2011).

[b)] 2.58 $tCO_2/kL/6.4$ $km/L \times 1000$ (ME, 2011). The fuel consumption is a value of bus (Hino type HA6JLAE) that are used in Kiryu city.

Using above assumptions, we assess the amount of CO_2 emission in Kiryu city at 188.3 (t/year) after micro EV was introduced, against 142.3 (t/year) in the present situation. This is 46.0 (t/year) (24.4%) reductions as indicated in Table 5. Emission per person is smallest in old town, and is largest in detached area. Furthermore, in detached area, where population is sparse and residents need long trips for living, the emission does not reduce so much after the introduction of EV. Therefore, it is important for anti-global-warming to construct compact city, where almost residents live in a compact area in the city, and move by bicycle or energy-saving EV.

Table 5. Amount of CO_2 emission and reduction

			Old town	New town	Across river	Detached area	Total
Total (t/yr)	Emission	present	53.0	46.3	62.5	26.6	188.3
		after EV	38.9	37.5	43.2	22.7	142.3
	Reduction		14.0	8.8	19.3	3.9	46.0
Per person (kg/yr)	Emission	present	100.5	123.7	115.6	150.9	116.4
		after EV	73.9	100.2	79.9	128.8	87.9
	Reduction		26.6	23.5	35.7	22.1	28.4

EV: electric vehicles.

6. CONCLUSION

The multinomial logit model is useful, because it helps us to understand the process of choice. This model allows us to calculate the utility using different variables of alternatives' and decision makers' attributes. We generalized this model for the combinations of direct product alternatives such as stores and transportation methods.

Using the proposed model, we clarified the structure of CO_2 emission from food-buying shopping in a local city, and assessed the impact of introduction of micro EV. We estimated these CO_2 emissions from personal behavior. This approach gives us only a gross estimate of CO_2 emission, compared with detailed estimate from consumption levels of different fuels in the city. However, when we think how we can reduce the emission, this approach may be rewarding, because it is informative about why the emission occurs.

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