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Multi-agent Simulation for Promoting Clean Energy Vehicles from the Perspective of Concern for the Environment and Local Interactions

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Abstract: Clean energy vehicles (CEVs) such as EV or PHV should be promoted for the reduction of greenhouse gas emissions in the transportation sector. However, it is important to note that social interactions affect the promotion of CEVs. Therefore, a multiagent simulation system for promoting CEVs has been developed in the present study from the perspective of not only concern for the environment but also for local interaction processes in terms of social conformity. Intention of holding CEV is described with the database of the questionnaire survey about purchasing vehicles. The social network of the artificial society is described as a small-world network model. The time series changes of the numbers of clean energy vehicles and the volume of greenhouse gas emissions are estimated by the proposed multiagent simulation. Finally, it can be concluded that the proposed multiagent simulation with local interaction is useful for promoting the planning of CEVs.

Keywords: Local interaction, Social conformity, Small-world network, Vehicle choice

1. INTRODUCTION

The global warming problem caused by greenhouse gas emissions has become more serious. In the transportation sector, clean energy vehicles (CEVs) such as electric vehicles or plug-in hybrid electric vehicles should be promoted, along with a modal shift in means of transport, since CEVs can be used with fewer consequences for the global environment.

Researchers have often used the Bass model (Bass, 1969) to analyze demand and diffusion in the fields of marketing research. The Bass model combined with a discrete choice model has been developed to accommodate the effects of substitution and competition among technologies in demand forecasting (Lee *et al*., 2006). In terms of diffusion of low-emission vehicles, willingness-to-pay extra for low-emission vehicles is computed based on the estimated parameters using a nested logit model (Potoglou & Kanaroglou, 2007).

However, it should be noted that social conformity has a particularly strong influence on consumer behavior when consumers buy a new product (Rogers, 2003). Thus, some studies have focused on the social conformity aspect in the choice behavior associated with types of low-emission vehicles. Axsen *et al*. (2009) estimate preference dynamics associated with the adoption of hybrid electric vehicles to improve the behavioral realism of the energy-economy model considering the neighbor effect with joint SP–RP estimation techniques. Kuwano *et al*. (2013) take into account social conformity as well as choice set formation and heterogeneity over the sample set for the decision-making process for choice of vehicle type.

On the other hand, multiagent simulation is often applied in marketing research as an approach to develop or explore models of complex systems. The final condition of the artificial

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society is derived as a result of interactive behavior between the agents and the global environment (Epstein & Axtell, 1996). Positive feedback by social interaction can be described with multiagent simulation through the mechanism of information exchange and copying behavior between agents. At the same time, the heterogeneity of individuals can be given by the attributes of the agent. Therefore, multiagent simulation is suitable for describing social interactions and the heterogeneity of the drivers.

The multiagent simulation system for promotion planning of CEVs is developed in the present study while considering not only concern for the environment but also local interaction processes as social conformity. Intention of holding CEV is described with the database of the stated preference questionnaire survey about purchasing vehicles, whereas the social network of the artificial society is described using a small-world network model. The promotion process of CEVs in the artificial society is estimated with the proposed MAS system.

2. DESIGN OF THE MULTIAGENT SIMULATION

2.1 Structure of the Proposed Multiagent Simulation System

The outline of the proposed multiagent simulation system is illustrated in Figure 1. The simulator consists of five interactive calculation processes: the social interaction process, the environmental concern process, the vehicle choice process, the carbon dioxide emission process, and the possession process.

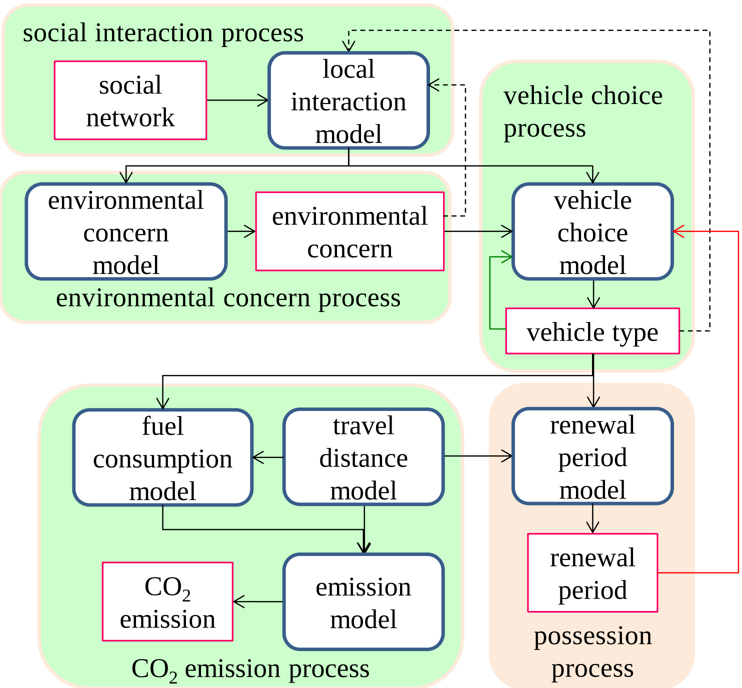

Figure 1. Simulation processes of the proposed multiagent system

The decision process relating to vehicle choice is influenced by the social interaction process and the environmental concern process. Thus, the vehicle choice model uses inputs of the influence of the local interaction and the concern for the environment.

On the other hand, the carbon dioxide emission process consists of three submodels: the travel distance model, the fuel consumption model and the emission model. The fuel consumption of each vehicle is determined based on the vehicle type as well as the travel distance of the agent. The carbon dioxide emission of the agent is measured by the fuel consumption. The influence of traffic congestion is ignored in the study.

The possession process consists of only the renewal period model. Period of vehicle choice is determined by the vehicle type as well as by the travel distance of the agent. Over all, the day-to-day condition of the artificial society is simulated by calculating these processes one by one.

2.2 Constitution of the Artificial Society

The artificial society is constructed based on Tokushima City in Japan, where the stated preference questionnaire survey about purchasing vehicles was carried out. Daily activity of an agent is defined as driving only.

The internal condition of an agent is determined using those constant elements and changeable elements related to the external circumstances and interactions of agents. The attributes of 10,000 agents was set up in reference to a result of the questionnaire survey. It is equivalent to around a one-tenth of commuters in Tokushima City in Japan.

A 10-year simulation using units of one week was carried out with the proposed system. In other words, 520 cycles of estimation were calculated for one trial. Five times of trials are carried out with the proposed multiagent simulation system, and the mean for each week was calculated.

2.3 Questionnaire Survey for the Modeling

According to the structure of the multiagent simulation system, the questionnaire survey is designed to obtain data for the model development. The environmental concern model, the vehicle choice model, the travel distance model, the fuel consumption model and the renewal period model should be described with the data from the questionnaire survey as the decision process of the agent.

It can be assumed that the common explanatory factors for these processes include individual attributes, household attributes, main vehicle attributes and an individual’s concern for environment. The explained variables consist of the expected renewal period of the main vehicle, the preferable vehicle type and the fuel efficiency. The expected renewal period and the preferable vehicle type are classified into the item group for preferences of vehicle purchase. The intention of the individual in purchasing a clean energy vehicle or low-emission vehicle is queried as the preferred vehicle type. The fuel efficiency can be measured as one of the main vehicle attributes.

Items of the questionnaire survey are constructed in consideration of the abovementioned points. The survey items and alternative responses on the questionnaire are summarized in Table 1.

The questionnaire survey about social influences and the travel behavior of the commuters was conducted in October 2011 using web-survey monitors. Commuters in Tokushima City in Japan were targeted for the questionnaire survey. Responses to the questionnaire were collected through the survey website and provided 464 valid samples for analysis.

2.4 Summary of Questionnaire Survey

The response rates for alternative replies for all survey items are given in Table 1.

Table 1. Survey items and alternative responses on the questionnaire

Item groups	No.	Survey item	Alternatives	Percentage
household attributes	Q1	family structure	[1] single	13
			[2] couple	20
			[3] plural member	61
			[4] other	6
	Q2	member in a household [multiple answer]	[1] little child or baby	13
			[2] primary school child	16
			[3] elderly person	29
	Q3	household income per year	[1] < 5million yen ; low income	50
			[2] 5-15 million yen	47
			[3] >= 15million yen ; high income	3
main vehicle attributes	Q4	vehicle type	[1] electric vehicle(EV)	0
			[2] plug-in hybrid vehicle(PHV)	0
			[3] hybrid vehicle(HV)	2
			[4] low emission gasoline vehicle(LGV)	7
			[5] normal gasoline vehicle(GV)	89
			[6] other type	2
	Q5	body type	[1] light vehicle	36
			[2] small vehicle	32
			[3] normal vehicle	29
			[4] light van	3
	Q6	main driver	[1] young man	4
			[2] young woman	5
			[3] middle-aged man	48
			[4] middle-aged woman	36
			[5] elderly man	5
			[6] elderly woman	2
	Q7	travel distance [km]	[numerical value]	see Table 2.
	Q8	fuel efficiency [km/liter]	[numerical value]	
purchace of vehicle	Q9	expected renewal period [year]	[numerical value]	
	Q10	the first preferred vehicle type	[1] EV, [2] PHV, [3] HV, [4] LGV [5] GV, [6]other	see Figure 2.
		the second preferred vehicle type		
		the third preferred vehicle type		
	Q11	preference of EV or PHV in case that a close friend owns EV or PHV [local interaction]	[1] strongly preferred	7
			[2] preferred	29
			[3] neutral	37
			[4] not preferred	18
			[5] not at all	9
environmental concern	Q12	interest for global warming problem	[5]strongly concerned, [4]concerned, [3]neutral, [2]not concerned, [1]not at all	see Figure 3.
	Q13	sympathy for the reduction of GHG with effort		
	Q14	sympathy for the reduction of GHG with time use		
	Q15	sympathy for the reduction of GHG with time use		
	Q16	interest for global warming problem of familiar person		
	Q17	reusable shopping bag	[1]act or [0]not	28
	Q18	purchase recycled goods		45
	Q19	separate trash		99
	Q20	keep proper temperature of air conditioner		77

Some descriptive statistics for the numerical variables such as travel distance, fuel efficiency and expected renewal period are shown in Table 2. These variables are applied as the explained variables to the travel distance model, the fuel efficiency model and the renewal period model, respectively.

Table 2. Descriptive statistics of numerical variables in the questionnaire

Survey item	Unit	Valid responses	Mean	Median	Standard deviation
travel distance	km	381	18.8	12	21.2
fuel efficiency	km / liter	323	13.3	12	4.7
renewal period	year	240	4.6	4	3.5

The response rates for preferred vehicle type for next purchase are illustrated in Figure 2. As both EV and PHV are included in preferable vehicle type for 5% of respondents, the rate of the respondents who include CEVs in preferable vehicle type is 23%. The variable for preferred vehicle type is applied as the explained variable to the vehicle choice model.

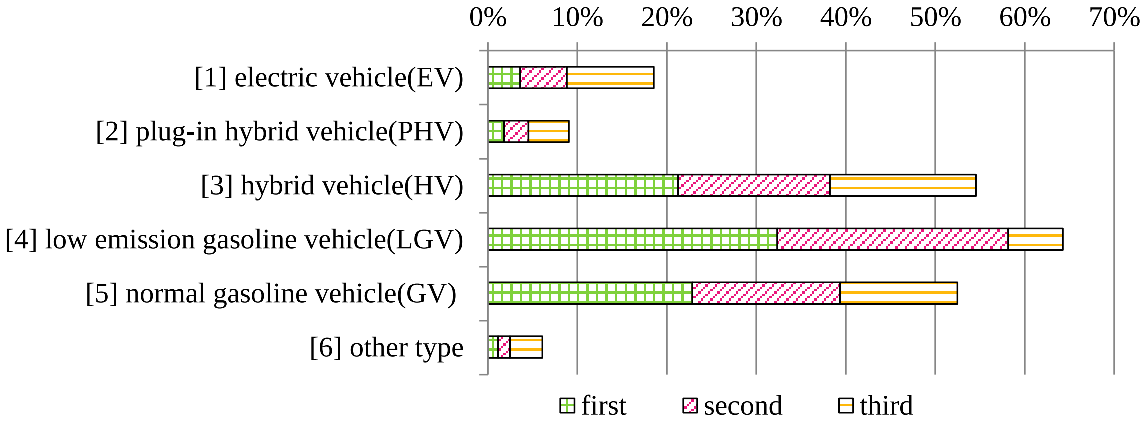

Figure 2. Response rates for preferred vehicle type for next purchase

The response rates for alternatives for the survey items relating to environmental concern are illustrated in Figure 3.

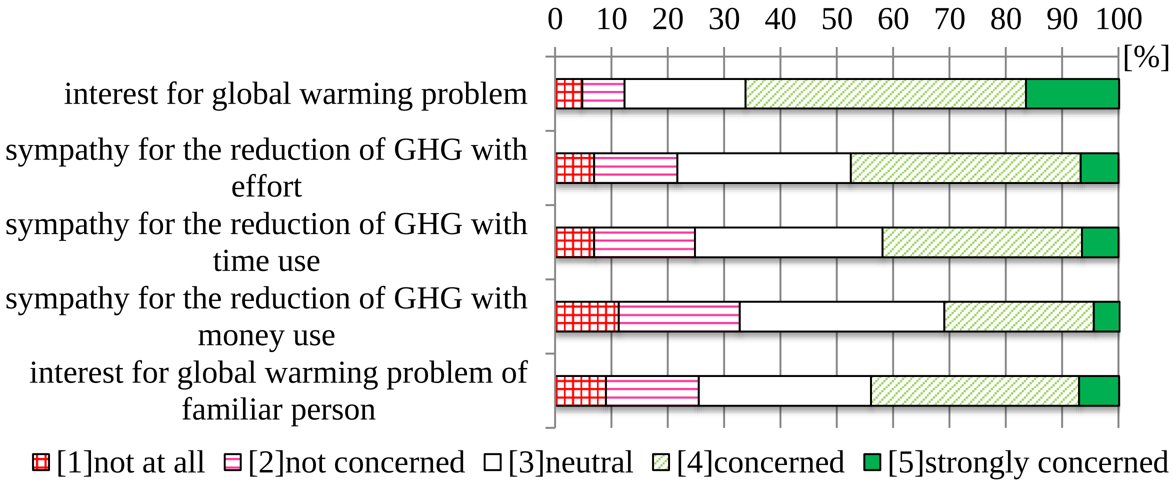

Figure 3. Response rates for environmental concern

A positive response to question no. 12 such as “[4]concerned” or “[5]strongly concerned” is regarded as the explanatory dummy variable of “interest in the global warming problem” for the vehicle choice model. A negative response to question no. 12 of “[1]not at all” or “[2]not concerned” is defined as the explanatory dummy variable of “indifference to the global warming problem”.

Similarly, a positive response to question no. 13 of “[4]concerned” or “[5]strongly concerned” is regarded as the explanatory dummy variable of “sympathy for the reduction of GHG” for the vehicle choice model. A negative response to question no. 13 of “[1]not at all” or “[2]not concerned” is defined as the explanatory dummy variable of “indifference to the reduction of GHG”.

3. MODELING OF THE MULTIAGENT SIMULATION

3.1 Social Interaction Process

Some existing research studies on social networks describe the interaction between agents. The social network of the real world has an essentially nonlocal structural peculiarity. The graph of the character like a social network of the real world is generated with an extremely simple algorithm (Watts & Strogatz, 1998). Therefore, the relation between commuter agents like a social network of the real world is generated with a simple algorithm by the small-world network model.

According to the small-world network model, all agents are connected by a link with a neighboring agent. All those links are connected at random again according to a certain probability. In the present study, this conversion probability is assumed to be 5%.

The extent of the impact of interacting agents is defined by a limiting distance. Therefore, there is no linkage between agents when the distance between agents is larger than the limiting distance. As the result, the average number of links for an agent is set as 6.575. The relationship between agents is defined in formula (1).

$$\gamma_{[i,k]} = 1 - \frac{l_{[i,k]}}{L_{max}} \tag{1}$$

where

$\gamma_{[i,k]}$: extent of the impact of interacting agents

$l_{[i,k]}$: distance between agents

L_{max} : limiting distance.

The local share of CEV owners as an index of the social conformity for agent i is calculated by formula (2) using the information from the directly linked agent k.

$$sc_{[i]} = \frac{\sum_k \gamma_{[i,k]} \cdot \delta_{[k]}^{CEV}}{\sum_k \gamma_{[i,k]}} \tag{2}$$

where

$sc_{[i]}$: social conformity for agent i

$\delta_{[k]}^{CEV}$: dummy variable for whether agent *k* holds a CEV or not.

3.2 Environmental Concern Process

The structure of the concern for the environment process with the local interaction is analyzed using structural equation modeling.

Some latent variables are defined, such as “individual concern for environment”, “cooperative intention for prevention of global warming”, “behavior for protecting environment” and “perceived concern for environment of familiar person”. The structural relation of these latent variables and some observed variables is described with the multiple indicator multiple cause model. It is assumed that “individual concern for environment” is influenced by “perceived concern for environment of familiar person”. It is assumed that both “cooperative intention for prevention of global warming” and “behavior for protecting environment” are caused by “individual concern for environment”.

The relational parameters between variables in the structural equation model can be estimated with the maximum likelihood method (Bollen, 1989). When relations are not statistically significant at the 5% level of significance, they are removed one by one from the structure of interaction on the concern for the environment. Finally, all relations between variables in the structural equation are statistically significant. The estimation results of standardized parameters are summarized in Table 3.

Table 3. Estimation result of parameters in the structural equation model

relation				standardized estimeted value	t-statistic
individual concern for environment	-->	interest for global warming problem	[Q12]	0.883	-
	-->	behavior for protecting environment		0.764	8.848 ***
	-->	cooperative intention for prevention of global warming		0.898	20.004 ***
cooperative intention for prevention of global warming	-->	sympathy for the reduction of GHG with effort	[Q13]	0.930	-
	-->	sympathy for the reduction of GHG with time use	[Q14]	0.942	36.569 ***
	-->	sympathy for the reduction of GHG with money use	[Q15]	0.794	24.307 ***
behavior for protecting environment	-->	reusable shopping bag	[Q17]	0.490	-
	-->	purchase recycled goods	[Q18]	0.639	8.375 ***
	-->	separate trash	[Q19]	0.533	7.667 ***
	-->	keep proper temperature of air conditioner	[Q20]	0.595	8.114 ***
perceived concern for environment of familiar person	-->	interest for global warming problem of familiar person		0.713	-
	-->	individual concern for environment	[Q16]	0.868	6.875 ***

***: 1% statistical significance

As the result of estimation, most of the latent variables are approved as the construct, because the relations between each latent variable and the observed variable are statistically significant. The relation between “individual concern for environment” and “perceived concern for environment of familiar person” is statistically significant. The structure of interaction on concern for environment can be summarized by the path diagram as shown in Figure 4.

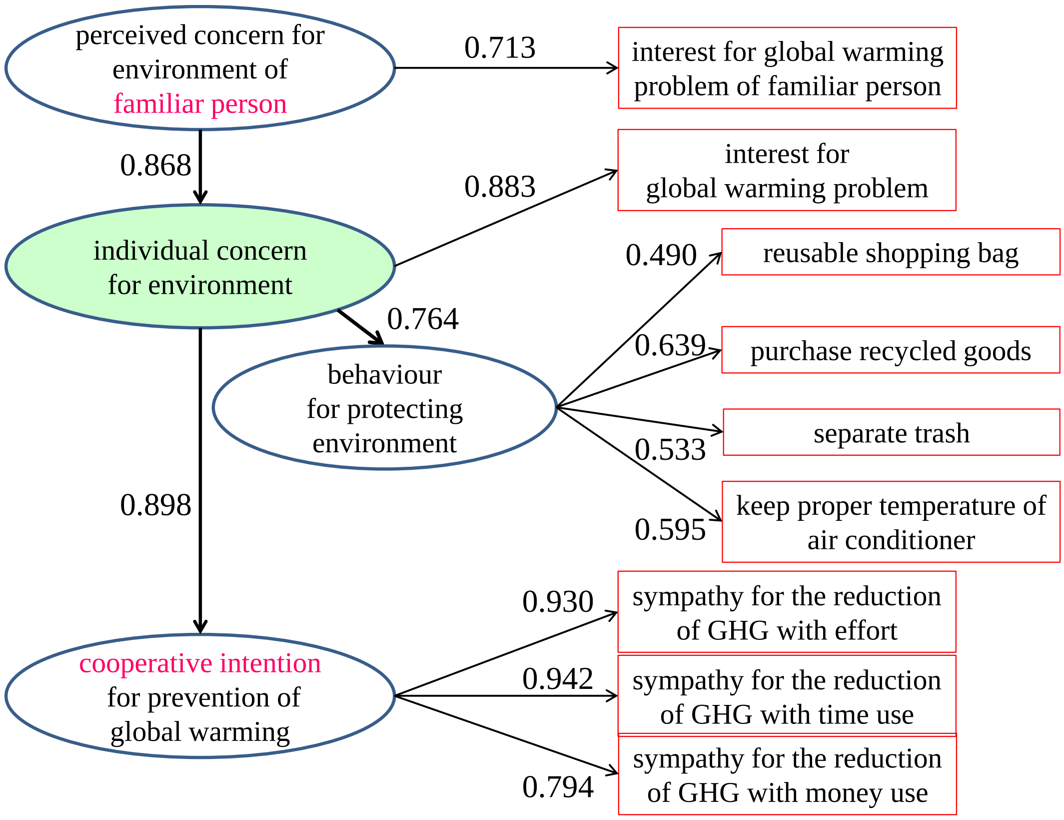

Figure 4. Structure of interaction on concern for environment

As a result of the covariance structure analysis, it can be confirmed using the structural equation model that the individual concern for the environment is influenced by the local interaction of the individual connections.

The local interaction of the individual concern for the environment is described by the estimation result of the structural equation model.

The external improvement of the individual concern for the environment for agent *i* is formulated with the index of cooperation to related agents in formula (3) using information from the directly linked agent *k*.

$$eic_{[i]} = \frac{\sum_k \gamma_{[i,k]} \cdot (eco_{[k]}(t) - eco_{[i]}(t))}{\sum_k \gamma_{[i,k]}} \qquad (3)$$

where

$eic_{[i]}$: external improvement of the concern for the environment for agent *i*

$eco_{[k]}(t)$: individual concern for the environment for agent *k* at time *t*.

The individual concern for the environment is changed with the external improvement by related agents in formula (4).

$$eco_{[i]}(t+1) = eco_{[i]}(t) + \omega \cdot eic_{[i]} \qquad (4)$$

The coefficient ω is set as 0.868 with reference to the estimation result of the structural equation model.

3.3 Vehicle Choice Process

Components of vehicles, such as purchase price, kilometer range between refueling or recharging, charging time of the EV and fuel operation cost, should be regarded as important factors for vehicle choice. These components may be improved by technological innovation.

However, vehicle types vary in the real market. Because it is not easy to describe the vehicle choice behavior in detail, technological innovation for vehicles is ignored and policies for the promotion of CEVs or low-emission vehicles (LVs) are not considered in the study. It is assumed that performances of vehicle components are not changed and can be ignored for the vehicle choice item. The aim is only to note approximate shares of CEVs and LVs at the ten year later in the vehicle choice model.

It is assumed that vehicle choice is affected by local interactions with specific familiar persons as well as by the concern for environmental problems in the model. The local interaction with specific familiar persons is regarded as social conformity in the community.

The questionnaire survey asks, if CEV is selected as the stated preference, if a friend owned a CEV when the respondent bought a new car. If a friend owned a CEV, the rate of positive responses increases 24%. Therefore, it can be confirmed that local interactions influence the replacement to a CEV and should not be ignored.

The structure of the vehicle choice model has two steps. The first step, using a binary logit model, describes whether the household includes CEV in a choice set or not. The probability of the choice set including CEV is defined as formula (5) using the logistic function.

$$P_{[i]}^{CS} = \frac{1}{1+\exp\left[-\theta_{CS,sc}\cdot sc_{[i]} - \sum_{k}\theta_{CS,m}\cdot\delta_{CS,m,[i]}\right]} \tag{5}$$

where

$P_{[i]}^{CS}$: the probability of the choice set including CEV for agent *i*

$\theta_{CS,m}$: coefficient parameters for the dummy variables of factor *m*

$\delta_{CS,m,[i]}$: dummy variables of factor *m* for agent *i*.

The parameters of the choice set model are estimated using the database of the stated preference survey by the maximum likelihood method. The factor variables are limited using trial and error. The estimation results of parameters in the choice set model are summarized in Table 4.

Table 4. Estimated parameters for the choice set model

factor variables		coeff.	t-statistics
$\delta_{CS,0}$; const.		-1.529	-7.895
$\delta_{CS,1}$; plural member in a household dummy	Q1-[3]	0.527	2.910
$\delta_{CS,2}$; interest for global warming problem dummy	Q12-[4]or[5]	0.665	3.754
$\delta_{CS,3}$; indifference for global warming problem dummy	Q12-[1]or[2]	-1.316	-5.385
sc ; local ineteraction	Q11-[1]or[2]	0.623	3.976

From the estimated result, the coefficient parameter of “local interaction” is statically significant in the decision process of the choice set. As the holding CEV by familiar person influences significantly the intention of obtaining a CEV, it can be confirmed that the local interaction should not be ignored for analysis of CEV promotion.

The second step has two parts. If a CEV is included in a choice set, the choice set consists of three vehicle types: CEV, LV and other (GV). LV consists of a hybrid electric vehicle (HV) and a low-emission gasoline vehicle. The multinomial logit model is applied for the vehicle choice including the CEV. The liner utility functions for each type of vehicle are defined as formula (6) and the probability of choosing CEV is defined as formula (7).

$$V_{TYPE,[i]} = \sum_{m} \theta_{TYPE,m} \cdot \delta_{TYPE,m,[i]} \tag{6}$$

where

$V_{TYPE,[i]}$: deterministic components of utility for the vehicle [TYPE] of agent i

$\theta_{TYPE,m}$: coefficient parameters for the dummy variables of factor m

$\delta_{TYPE,m,[i]}$: dummy variables of factor m for agent i.

$$P_{\mathrm{CEV,[i]}} = P_{\mathrm{[i]}}^{CS} \cdot \frac{\exp\left(V_{CEV,[i]}\right)}{\exp\left(V_{CEV,[i]} + V_{LV,[i]} + V_{GV,[i]}\right)} \tag{7}$$

If a CEV is not included in the choice set, a binary logit model is used in the second step where the household chooses from only two vehicle types (i.e., LV and other). Therefore, the probability of choosing LV is defined as formula (8).

$$P_{\mathrm{LV,[i]}} = \frac{P_{\mathrm{[i]}}^{CS} \cdot \exp\left(V_{LV,[i]}\right)}{\exp\left(V_{CEV,[i]} + V_{LV,[i]} + V_{GV,[i]}\right)} + \frac{(1 - P_{\mathrm{[i]}}^{CS})}{1 + \exp\left(-V'_{LV,[i]}\right)} \tag{8}$$

The parameters of vehicle choice models are estimated using the database of the stated preference survey by the maximum likelihood method respectively. The factor variables of the model are limited after trial and error. The estimation results of parameters are summarized in Table 5 which provides data for the multinomial vehicle choice model and in Table 6 for the binary vehicle choice model.

Table 5. Estimated parameters for the CEV choice model

choice set	factor dummy variables			coeff.	t-statistics
LV; low emission vehicle	$\delta_{LV,0}$;	const.		1.383	3.478
	$\delta_{LV,1}$;	indifference for the reduction of GHG	Q13-[1]or[2]	-1.335	-2.006
	$\delta_{LV,2}$;	middle-aged man	Q6-[3]	1.693	2.463
	$\delta_{LV,3}$;	travel distance from 10 to 35 km	Q7	1.050	1.996
CEV	$\delta_{CEV,1}$;	light van owner	Q5-[4]	2.840	2.027
	$\delta_{CEV,2}$;	elderly man or elderly woman driver	Q6-[5]or[6]	2.240	2.631
	$\delta_{CEV,3}$;	sympathy for the reduction of GHG	Q13-[4]or[5]	1.389	2.496
GV; other	$\delta_{GV,1}$;	expected renewal period under 2 years	Q9	2.976	3.111
	$\delta_{GV,2}$;	interest for global warming problem	Q12-[4]or[5]	-2.705	-2.023

Table 6. Estimated parameters for the LV choice model

factor dummy variables		coeff.	t-statistics
$\delta_{LV',1}$; small vehicle owner	Q5-[2]	0.837	3.712
$\delta_{LV',2}$; indifference for the reduction of GHG	Q13-[1]or[2]	-1.067	-4.592

Table 7. Estimated parameters for the renewal period model

factor variables		coeff.	t-statistics
$\delta_{rp,0}$; const.		1.503	29.69
$\delta_{rp,1}$; little child or baby dummy	Q2-[1]	0.293	2.43
$\delta_{rp,2}$; high income dummy	Q3-[3]	-1.046	-4.50
p_{rp} ; shape parameter		1.426	-7.04

From the estimated result, the coefficient parameter of "sympathy for the reduction of GHG" is statically significant in the decision process of CEV choice. Therefore, concern for the environment can be found as the factor of choice for CEV.

3.4 Possession Process

It can be anticipated that vehicle holding duration differs substantially among households. The actual duration that a vehicle is held by a household has been examined using hazard-based duration models in the existing research (Yamamoto & Kitamura, 2000).

The Weibull distribution was applied to represent the distribution of intended durations in this study. Therefore, the cumulative distribution function of the intended duration is defined as formula (9).

$$F_{rp}(x_{rp}) = 1 - \exp\left[-x_{rp}{}^{p_{rp}} \cdot \exp\left(-p_{rp} \cdot \sum_{m} \beta_{rp,m}\delta_{rp,m}\right)\right] \tag{9}$$

where

x_{rp} : intended duration of the renewal period

p_{rp} : shape parameter of the distribution for the duration of the renewal period

$\delta_{rp,m}$: dummy variables of factor *m* for the renewal period

$\beta_{rp,m}$: coefficient parameters for the dummy variables of factor *m*.

The parameters of the renewal period model are estimated by the maximum likelihood estimation method. The factor variables of the model are limited after trial and error. The estimation result of parameters for the intended vehicle holding duration are summarized in Table 7.

It was found that the intended vehicle holding duration is long for households that include an infant or a baby, and short for high-income households. The period of vehicle choice in the multiagent simulation is determined by the renewal period model with the estimated parameters.

3.5 Carbon Dioxide Emission Process

The carbon dioxide emission process consists of three submodels: the travel distance model, the fuel consumption model and the emission model.

3.5.1 Travel distance model

The Weibull distribution is examined as the distribution of the travel distance in the study. Therefore, the cumulative distribution function for the travel distance is defined as formula (10).

$$F_{td}(x_{td}) = 1 - \exp\left(-\alpha_{td} x_{td}^{\ p_{td}}\right) \tag{10}$$

where

x_{td} : travel distance
p_{td} : shape parameter of the distribution of the travel distance
α_{td} : scale parameters for the distribution of the travel distance.

The parameters of the travel distance model are estimated by the maximum likelihood estimation method. The factor variables of the model are limited after try and error. The estimated parameters for the distribution of travel distance are summarized in Table 8.

From the estimated result, the both of the scale parameter and the shape parameter are statically significant. However, no factor related to travel distance can be found.

3.5.2 Fuel consumption model

The Weibull distribution was used to examine the distribution of the efficiency of the fuel consumption in the study. The framework of the Weibull regression analysis is the same as the hazard-based duration model with the Weibull distribution. The cumulative distribution function for the efficiency of the fuel consumption is defined as formula (11).

$$F_{fl}(x_{fl}) = 1 - \exp\left[-x_{fl}^{\ p_{fl}} \cdot \exp\left(-p_{fl}\left(\beta_{fl,td} x_{td} + \sum_m \beta_{fl,m} \delta_{fl,m}\right)\right)\right] \tag{11}$$

where

x_{rl} : efficiency of the fuel consumption
p_{fl} : shape parameter of the distribution for the fuel consumption
$\delta_{fl,m}$: dummy variables of factor *m* for the fuel consumption
$\beta_{rfl,m}$: coefficient parameters for the dummy variables of factor *m*.

Table 8. Estimated parameters for the travel distance model

variables	estimated value	t-statistics
α_{td} ; scale parameter	3.061	57.21
p_{td} ; shape parameter	1.099	-2.44

Table 9. Estimated parameters for the fuel consumption model

factor variables			coeff.	t-statistics
$\delta_{fl,0}$;	const.		2.308	66.23
$\delta_{fl,1}$;	light vehicle owner dummy	Q5-[1]	0.431	10.36
$\delta_{fl,2}$;	small vehicle owner dummy	Q5-[2]	0.305	7.82
$\delta_{fl,3}$;	HV owner dummy	Q4-[3]	0.750	6.81
$\delta_{fl,4}$;	young woman dummy	Q6-[2]	0.304	3.43
$\delta_{fl,5}$;	middle-aged woman dummy	Q6-[4]	0.273	4.77
x_{td} ;	travel distance [km]	Q7	0.002	2.04
p_{fl} ;	shape parameter		3.840	-29.98

The parameters of the fuel consumption model are estimated by the maximum likelihood estimation method. The factor variables of the model are limited after trial and error. The estimation result of parameters for fuel consumption is summarized in Table 9.

Fuel consumption efficiency is high for light vehicles, small vehicles and hybrid electric vehicles. Furthermore, as the coefficient parameter of "travel distance" is statically significant, the fuel consumption efficiency might be improved according to travel distance.

The fuel consumption efficiency for the case without CEVs in the multiagent simulation is determined by the fuel consumption model with the estimated parameters.

3.5.3 Carbon dioxide emission model

The carbon dioxide emission $ce_{[i]}$ by each vehicle of agent i is equal to the product of the discharge rate of carbon dioxide e_0 and the fuel consumption. However, the influence of traffic congestion is not considered when estimating the carbon dioxide emission for simplicity. Therefore, the discharge rate of carbon dioxide e_0 from vehicles of agent i is fixed as 2.3 kg-CO_2 per one liter.

Fuel consumption is calculated as a result that the travel distance x_{td} is divided in the he efficiency of the fuel consumption x_{fl}. The carbon dioxide emission is defined in formula (12).

$$ce_{[i]} = e_0 \frac{x_{td,[i]}}{x_{fl,[i]}} \tag{12}$$

The carbon dioxide emission in the whole of the artificial society is calculated by summing the emission $ce_{[i]}$ of each vehicle i.

4. SIMULATION OF PROMOTING CLEAN ENERGY VEHICLES

The diffusion process of CEV and LV into the artificial society can be observed with the proposed multiagent simulation system.

4.1 Verification of Simulation

The performance of the proposed multiagent simulation system is verified in this section. This is done by ignoring the external improvement in concern for the environment and by considering only the local share of CEV owners as an index of social conformity.

First, the estimated share of CEVs is illustrated in Figure 5. The estimation results from five repeated trials are almost the same. The share of CEVs increases from the initial point.

However, this share is estimated at less than 5% at the end of simulation. The share of CEVs almost accords with a result of the questionnaire survey. As the share of CEVs is still low after 10 years, the remarkable influence of the holding of a CEV by a familiar person cannot be found.

Second, the estimated share of low-emission vehicles but excluding CEVs is illustrated in Figure 6. The estimation results from five repeated trials are almost the same. The share of low-emission vehicles increases from the initial point and is estimated to be around 50% after 10 years. The share of low-emission vehicles almost accords with a result of the questionnaire survey. However, the diffusion rate decreases after almost 10 years and finally confirms a tendency toward a stagnation in the spread.

The time series change of carbon dioxide emissions by vehicles in the whole of society is illustrated in Figure 7. With the diffusion of CEVs and low-emission vehicles into the market, the quantity of carbon dioxide emission is gradually reduced. It is estimated that 30% of carbon dioxide emission is finally reduced. However, this depends mainly on the diffusion of low-emission vehicles. However, the reduction rate decreases after almost 10 years and can finally confirm a tendency toward a stagnation in the reduction.

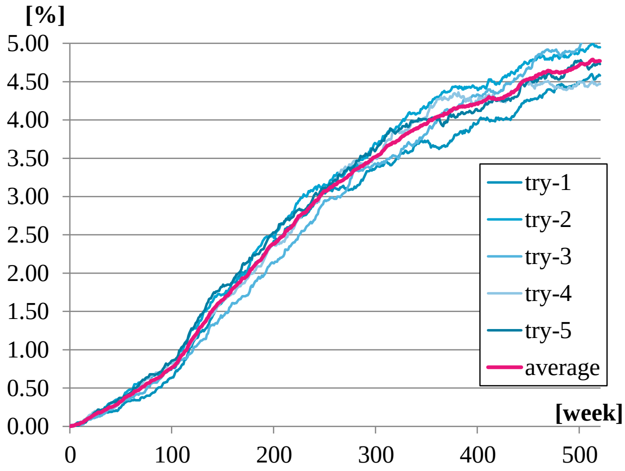

Figure 5. Share of clean energy vehicles for verification

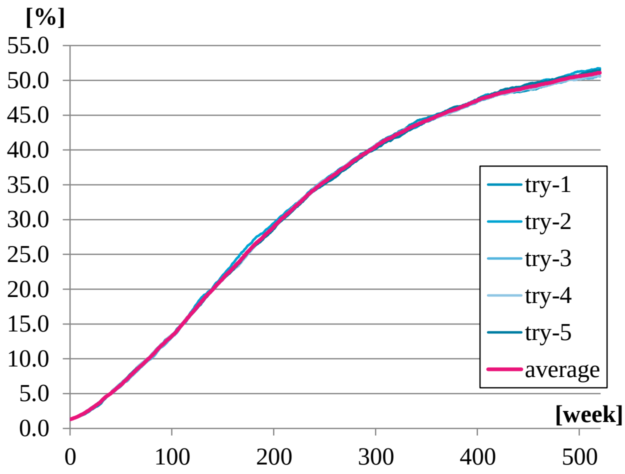

Figure 6. Share of low-emission vehicles for verification

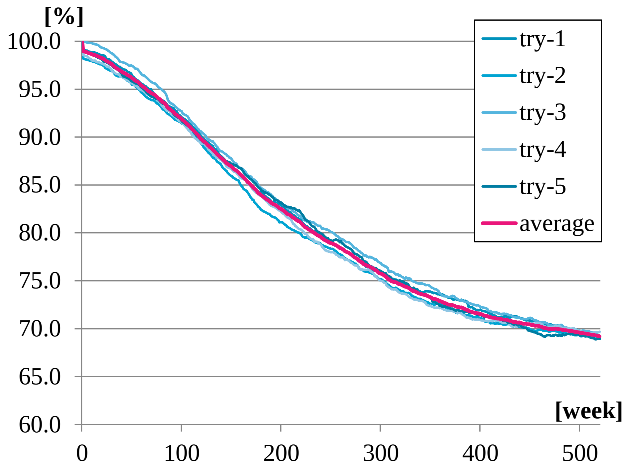

Figure 7. Emission rate of carbon dioxide for verification

4.2 Estimation of Vehicle Share and Carbon Dioxide Emission

The impact on the estimation result caused by the external improvement to the concern for the environment should be measured. Similarly, the impact of the local share of CEV owners as an index of social conformity should be measured. Estimation cases are summarized in Table 10.

Table 10. Estimation cases

	case-0	case-1	case-2	case-3	case-4	case-5
the external improvement of the concern for environment	ignored	ignored	ignored	considered	considered	considered
the local share of CEV owner as index of the social conformity	ignored	considered	strongly considered	ignored	considered	strongly considered

In case-2 or case-5 in Table 10, formula (2) is changed as follows:

$$\begin{cases} sc_{[i]} = 1.0 \quad if \quad \sum_k \delta_{[k]}^{CEV} > 0 \\ sc_{[i]} = 0.0 \quad if \quad \sum_k \delta_{[k]}^{CEV} = 0 \end{cases} \tag{12}$$

First, the estimated share of CEVs is illustrated in Figure 8. While the share of CEVs is lower in those cases where the external improvement of the concern for the environment is considered, the share of CEVs is higher in case-2 and case-5. However, the share of CEVs is almost the same in case-0 and case-1. Therefore, it can be confirmed that CEV ownership only increased when the influence of the local interaction was strong.

Second, the estimated share of low-emission vehicles but excluding CEVs is illustrated in Figure 9. The share of LVs is higher in those cases where the external improvement of the concern for the environment is considered. In those circumstances, the share of CEVs is decreased and the share of LVs is increased. On the other hand, there is no evidence of any influence of the share of LVs on the local share of CEV owners as an index of social conformity.

Finally, a time series change of carbon dioxide emission by vehicles in the whole of society is illustrated in Figure 10. The reduction rate in case-4 is larger than in the other cases. However, the difference of the reduction rate is not remarkable.

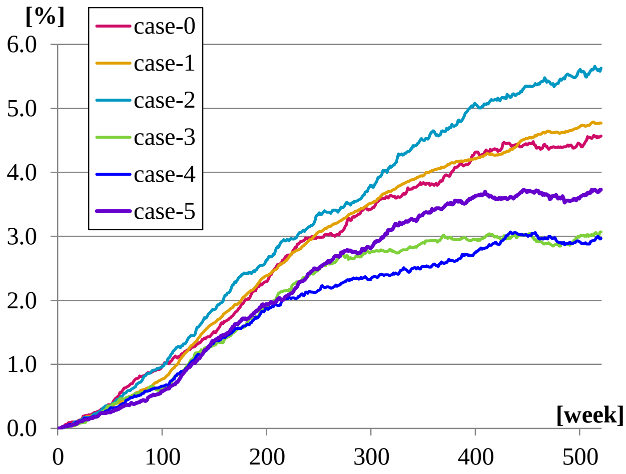

Figure 8. Share of clean energy vehicles

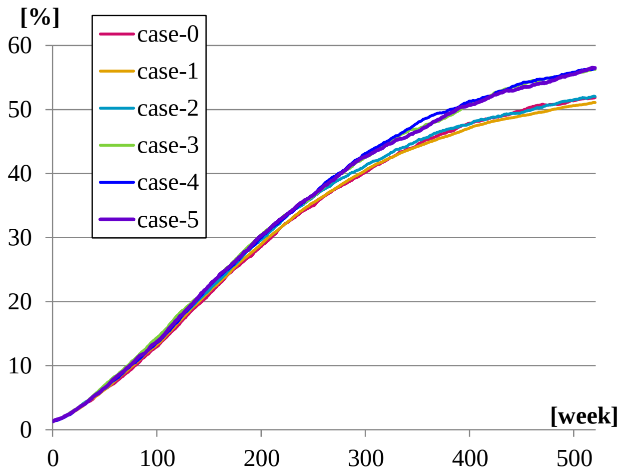

Figure 9. Share of low-emission vehicles

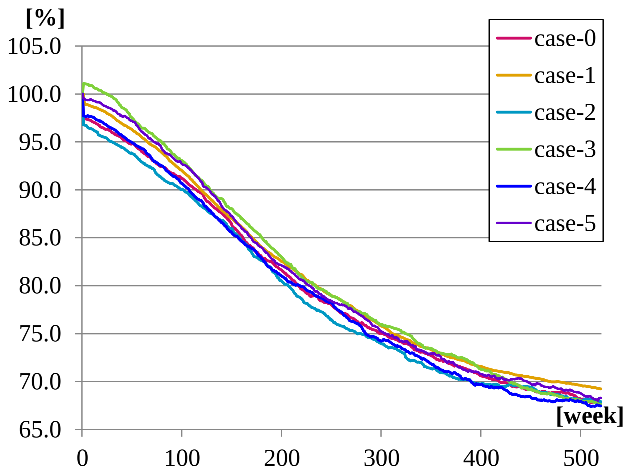

Figure 10. Emission rate of carbon dioxide

5. CONCLUDING REMARKS

The multiagent simulation system for promotion planning for CEVs is developed considering local interaction processes of social conformity and environmental concern. A summary of the findings of the study follows.

[1] The proposed MAS system consists of three interactive calculation processes: the vehicle choice process, the emission process and the possession process. The decision process of vehicle choice is described with local interactions at the social network level. Therefore, the promotion process of CEVs in the artificial society can be estimated with the proposed MAS system.

[2] The concern for the environment problem and the vehicle choice of the commuter in a local city were investigated by the questionnaire survey. The covariance structure about the concern for the environment was analyzed using the database of the questionnaire survey by structural equation modeling. As a result, it can be confirmed that the individual's concern for the environment is influenced by the local interactions of the individual's social connections.

[3] Intention of holding a CEV is described in two steps: the choice set step and the vehicle choice step. These models assume that the vehicle choice is affected by local interactions as well as by concern for the environment. The parameters of these models are estimated using the database of stated preferences in answer to the questionnaire survey about purchasing vehicles.

[4] Carbon dioxide emission in the whole of society can be estimated based on the efficiency of fuel consumption and the travel distance of agents. The hazard-based duration model with Weibull distribution was applied as the distribution of the efficiency of fuel consumption.

For future research, quantitative validity or soundness of the model should be examined and compared with other models.

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