An Analysis of Personal Mobility Promoting Factors Considering the Social Network in Old Newtown

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Abstract: This study focuses on identifying promoting factors for Personal Mobility (PM) technologies as immediate means of responding to the mobility needs of elderly populations. It is known that in the case of new products largely unfamiliar to customers, the behaviors and judgments of friends and acquaintances have a powerful effect on people's desire to gather information and, ultimately, to purchase. In order to analyze quantitatively the effect of friends and acquaintances on individuals' decision-making behavior, we developed a discrete choice model considering the impact of PM product penetration. We likewise modeled friend and acquaintance relationships by applying the complex network analysis method. The empirical analysis of questionnaires collected in Koyo Newtown in Hiroshima city reveals the existence of a social conformity effect with respect to PM-use preferences. The influence of friends and acquaintances in that setting has an impact equivalent to a net 5% decrease in PM rental prices.

Keywords: Personal Mobility (PM), social network, social conformity, friendships, discrete choice model, complex network analysis

1. INTRODUCTION

Newtowns were developed in response to Japan's drastic urban housing shortage, which started with the mass migrations of the early 1960s, and were sited along the railway network and the highway network to facilitate easy commuting. However, the percentage of young, working residents in Newtowns has decreased in recent years, and a large number of the town's original residents of the baby-boom generation have reached retirement age. Therefore, Japan's Newtowns have become a sort of "Old" Newtowns: facing aging residents and facilities alike.

In much of Newtowns, shops and recreational facilities are arranged systematically based on urban regional planning theory, which conceives of each elementary school district as a community unit. Meanwhile, the towns have successfully employed traffic abatement measures—such as curving roadways and roads with intentionally poor visibility in order to prevent automobile thru traffic from entering residential areas. Accordingly, a suitable environment has been created for pedestrians and bicycles. However, now that many of the residents are elderly, this type of roadway design has caused transportation challenges for residents who do not own automobiles or who have difficulty driving.

We expect that aging residents of Newtowns will have fewer opportunities to go outside in the future as their ability to exercise and move about will continue to decline with age. Hampered by limited mobility, people tend to create isolated households marked by less time spent in the out-of-doors and less involvement with others. Accordingly, we are concerned about residents' shrinking networks of personal contacts and the resulting collapse of community throughout the Newtown region. It is essential to ensure opportunities for outdoor recreation and transport for the elderly in order to revitalize Newtowns and to create comfortable, attractive, and bustling residential neighborhoods where people help each other.

To date, many researchers have examined the social mobility support system and have suggested a number of measures to facilitate elderly mobility, such as expanding public transportation (e.g., bus) routes in the district, relocating critical service facilities (e.g., commercial and medical facilities), and promoting downtown living, among others. However, these support measures could be difficult to realize because they come at enormous cost and also require long periods of time to complete. This study thus focuses on the promise of Personal Mobility technologies (hereafter PM), which refer to single-seat vehicles with electric motors. PM affords an economical and immediate solution for the growing senior mobility problem in "Old" Newtowns. How, then can PM adoption be promoted?

Among other factors, an individual's behavior is usually influenced by the opinions and behavior of others (Thorndike, 1938; Davis, 1976; Ajzen, 1991, Corfman and Gupta, 1993; Rose and Hensher, 2004). Behavior resulting from the influence of others is called "social conformity." The phenomenon of molding one's actions under social pressure has profound implications for individuals' social and economic choices. Many researchers in the fields of social psychology and marketing have explored the extent and characteristics of conformity to social pressure in various contexts; most studies have demonstrated that individual psychological processes are subject to social influence. Rogers (2003) stated that social conformity has a particularly strong influence on consumer behavior with respect to new products. This is because consumers do not have full information about a product's quality until it is purchased and consumed. Thus, whatever initial information exists about new products is dependent on other individuals and their experiences. As a result, it is reasonable to believe that social conformity may be especially important in shaping consumer preferences for PM since consumers are unlikely to have previous personal experience with this type of technology.

The primary objective of this study is to identify promoting factors for PM as immediate means of responding to the mobility needs of elderly populations. For that purpose, this study focuses on the elder's intention to possess of PM. Further, we analyze the strength of the social conformity effect with respect to PM adoption, using stated preference (hereafter SP) survey data, and develop a discrete choice model considering the influence of social conformity. In addition, we develop a social network model according to the attributes of the study area by using the above survey and other available statistical data and by applying complex network analysis. Moreover, using the estimation results provided by the discrete choice model and the generated social network model of the target area, we analyze how individual behavior changes have an impact on the entire society. The proposed model will be examined using data collected in Koyo Newtown in Japan. "Koyo" is the name of a district in Hiroshima city, and Koyo Newtown has typical attributes of Japanese Newtowns. We can thereby suggest efficient measures for promoting PM use.

2. LITERATURE REVIEW

Many previous studies have discussed ways of adapting to the fact that the elderly will account for the majority of the population in the future. Previous studies have suggested measures to prevent accidents for senior citizens, who lose their judgment and physical performance along with increased age (Daigneault e*t al*., 2002; Welsh *et al.*, 2006), measures to improve convenient access to service facilities (Su and Bell, 2009; Mollaoglu e*t al*., 2010) and support measures to encourage seniors to go outside without assistance (Mollenkopf e*t al*., 1997; Kim, 2011). These latter have pointed out the need to relocate road traffic facilities and daily living facilities, to potentially reroute public transportation, and to implement continuous review of the level of such services. However, these approaches require enormous cost and implementation time in a rural city facing a declining birth rate and a growing proportion of elderly people. Therefore, we focus on PM promotion as new social mobility support system for seniors in this study (Figure 1). Because of the slow maximum speed of PM vehicles (capped at around 6 kilometers per hour), PM use could decrease the risk of serious accidents for the aged compared to automobile use. Further, if people can more easily transfer to and from accessible facilities, it becomes possible to utilize existing facilities without the need for remodeling or relocating them. Furthermore, we expect that PM promotion will enable seniors to move about in the out-of-doors freely, without the help of family, because PM use does not require a driver’s license and vehicles can be easily operated by anyone.

Figure 1. Examples of PM technologies (Electric wheelchair)

On the other hand, an individual is subject to the ties of human relationships—such as those with close family, extended relatives, friends, and acquaintances—and makes decisions under the influence of these relationships. In the field of transportation planning, the social interactions that affect individuals’ decision-making processes are classified into global interactions and local interactions, and analytical methods have been proposed for each. The former looks at the average effects from the entire reference group; the latter refers to interaction effects between particular individuals. The pioneering work about representing global interaction in decision-making analysis was conducted by Manski (1993). Models with global interaction have been developed and applied to a wide range of contexts within the fields of both economics and social science. As an example of a previous study on global interactions, Fukuda and Morichi (2007) conducted a case study surveying the problem of illegally parked bicycles within the framework of discrete choice models. The authors showed that it is possible to measure global interactions and analyze their effect on a collective phenomenon by the use of appropriate models and sufficient data collection. As an example of a study focused on local interactions, Wen and Koppelman (1999) incorporated the intra-household interaction based on a nested logit (NL) model. The resulting model structure meets the requirements of random-utility maximization. Based on empirical results, it is shown that the upper level is choice of the number of household maintenance stops and the lower level is allocation of these stops to household members. Note that such a nested structure could vary contextually. Zhang *et al.* (2012) developed a household discrete choice model by integrating different types of household choice models based on latent class modeling approach under the principle of random utility maximization, where a household utility function for each model is defined to theoretically reflect preferences of its members and intra-household interactions.

Thus, several studies have focused on social interactions relevant to the field of transportation planning. However, it is the field of marketing that tells us that word-of-mouth endorsements from friends and acquaintances are more important than the information provided by newspaper articles, television advertisements, and household members when it comes to consumption preferences like purchasing behavior. This effect is also significant for new products not familiar to customers (Rogers, 2003). PM technologies for the elderly typify these kinds of new, unfamiliar products. As mentioned above, a body of studies has accumulated on global and local interactions in the field of transportation planning; however, an analysis explicitly considering the influences of friends and acquaintances has never been conducted. In order to understand the influence of friends and acquaintances on individual consumers' decision making, it is necessary to understand the human ties in the target community, or the structure of the local social network. Here, a social network may be represented graphically by regarding individuals as nodes and friend relationships between nodes as links.

In order to consider the influence of social conformity on PM use, this study focuses on mathematical properties of the social network and investigates the real-world social network in the residential area of "Old" Newtown. We model a social network that conforms to the results of the investigation by applying the methods of complex network theory. Then, we identify PM promoting factors using the discrete choice model and considering the effects of social conformity with friends generated by using the developed social network model.

3. SUMMARY OF STATED PREFERENCE (SP) SURVEY

3.1 Survey Area

The survey area of this study is Koyo Newtown, which was built in the suburbs of Hiroshima in 1972. Koyo Newtown is made up of seven districts. It has a population of 31,877 and contains 12,097 individual households. The share of residents over 65 years old is 20.97%, the share of those over 60 years in age is 30.38%, and there are 1,102 one-person households comprised of seniors 65 years in age or older. Because Koyo Newtown is spread out over 268 hectares, with many hills and height differentials, the elderly generally have trouble getting around without automobiles.

3.2 Design of SP Survey

We consider that factors affecting PM use preferences include household attributes (e.g., family structure, type of housing, etc.) and individual attributes (e.g., usual activities and physical ability). Thus, we included questions about household and individual attributes within the survey. Specifically, the questions about household attributes ask the following: respondents' address, parking capacity at their house, and number of household vehicles. Questions about individual attributes ask about gender; age; whether or not respondents have a valid driver's license; respondents' physical condition, such as their ability to walk and frequency of hospital visits; their social participation, such as their ability to travel and go shopping; and their social connections, such as whether or not they have a caretaker, the frequency with which they go to service facilities necessary for daily life, and their main travel mode(s). In addition, we include a question about the number of friends respondents have in Koyo Newtown in order to understand their social network.

We analyze PM-use preferences using SP data. Table 1 shows the attributes and the level of SP cards for this study. The attributes of "Penetration among friends" and "Penetration in the entire region" are introduced in the SP in order to investigate the effects of social conformity. The attribute of "penetration among friends" indicates PM ownership rate by each of the respondent's friends. The attribute captures the "word-of-mouth communication" effect. On the other hand, the attribute of "Penetration in the entire region" represents the ownership rate across the entire population of Koyo Newtown. This attribute captures the influence on PM use preference according to how likely each respondent is to encounter PM in daily life. When PM is sufficiently widespread, there exists a definite correlation between these two attributes. However, considering the fact that "word-of-mouth communication" is one of the important factors underlying penetration, PM will initially be owned by certain types of people. Therefore these two attributes are not always correlated in the beginning stage of penetration.

There exist 3^7=2187 different profiles because each attribute has three levels. We made a selection of 18 different profiles by using the orthogonal method of experimental design. Each respondent was then given 6 profiles and asked to choose his or her preferred alternative from among the profile options.

Table 1. Attributes and levels for alternatives

Attributes	Level 1	Level 2	Level 3
Percentage of priority roads among main roads in the entire region	10%	30%	50%
Location of PM-accessible	Bank, Post office, Shopping facility	Bank, Post office, Hospital	Shopping facility, Hospital
Location of new PM parking lot	Near bus stop	Near shopping center	None
Penetration among friends	10%	30%	50%
Penetration in the entire region	20%	40%	60%
Rental price of PM	1000yen/month	2000yen/month	4000yen/month

3.3 Implementation of SP Survey

The survey was conducted from October to November 2011 in the districts of Magame and Kamezaki of Koyo Newtown. We distributed the questionnaire to seniors and obtained 335 samples from among those living in the survey area. Out of these samples, 235 were valid.

Figure 2 shows the household and individual attributes of respondents. By age distribution, 65-74-year-olds come in first at 50%, followed by under-64-year-olds at 31%. In terms of driving ability and access, 74% of respondents answered that they hold a driver's license and 87% of respondents said that their households own an automobile. In addition, a significant 50% of respondents said they use a car for their primary transportation; by contrast, only 13% cited the bus as their primary mode of transportation. Nevertheless, in response to our question about whether respondents are able to walk more than 200 meters without a break, 95% answered "Yes." In addition, 64% responded that they had been to the hospital within the last year, but only 4% stated that they go to the hospital more than six times per month. The above results suggest that the people living in the study area are able to go outside by themselves, that they are largely healthy, and that their primary mode of transportation is generally the automobile. In terms of the household composition, 44% of answered that they are part of two-person households; 27% of respondents are single-person households. These responses suggest that the majority of the elderly surveyed live alone or with a spouse.

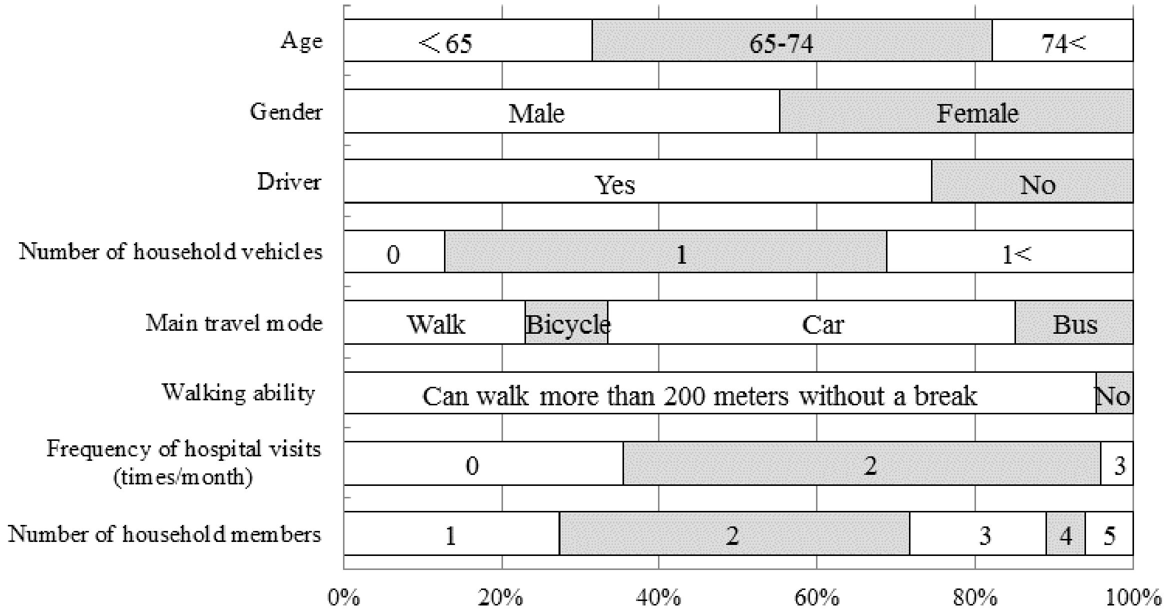

Figure 2. Household and individual attributes of the survey respondents

Figure 3 shows the distribution of respondents' number of friends in Koyo Newtown. The average number of friends is 6.73. In terms of the distribution of responses, 18% of the survey sample answered that they have 10 friends in Koyo Newtown. Furthermore, the number of respondents answering 20 or 30 friends is too large to ignore. The respondents likely rounded their answers for reporting convenience. Therefore, the responses are subject to a suspected rounding-off error.

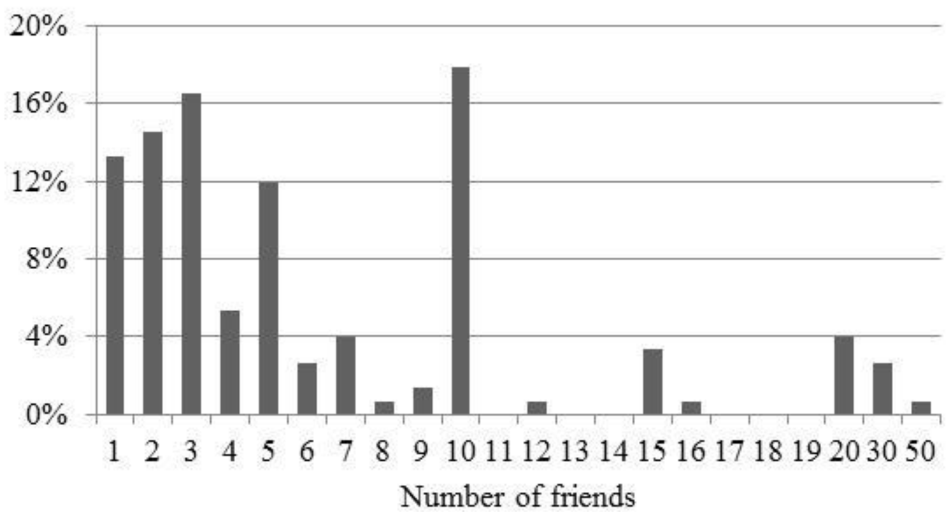

Figure 3. Distribution of number of friends

4. ANALYSIS OF PM-USE PREFERENCES

4.1 Model Development

We conduct the analysis of PM-use preferences by setting two terms, “use” and “no use” by using a logit model in this study. The choice probability of individual *i* (*i*= *1, 2, ..., N*) for alternative *j* (*j =1*:use PM, *j=2*:not use PM) is illustrated as follows:

$$P_{ij} = \frac{\exp(V_{ij})}{\exp(V_{ij}) + \exp(V_{ij})} \tag{1}$$

where V_{ij} is the utility function.

We consider the influence of social conformity in this study: namely, that individuals’ decision-making processes depend on others’ behavior. This study thus introduces the PM penetration rate z_i among the friends of individual i and the PM penetration rate in the entire region s into the utility function as explanatory variables expressing the degree of social conformity. These variables related to product penetration, and having to do with others’ behavior, proxy expectations about the usability and reliability of PM technologies. The utility function related to PM-use considering the penetration rate among friends z_i and the penetration rate in the entire region s is expressed by equation (2).

$$\begin{aligned} V_{i1} &= \sum_k \alpha_k x_{ik} + \sum_k \beta_k y_k + \gamma z_i + \eta s \\ V_{i2} &= 0 \end{aligned} \tag{2}$$

Here, x_{ik} is the explanatory variable related to the *k*th household and individual attributes of sample *i*; y_k is the explanatory variable related to the *k*th quality and environment for PM-use; z_i is the PM penetration rate among friends of individual *i*; and s is the PM penetration rate in the entire region. α_k, β_k, γ, η are unknown parameters.

4.2 Estimation Results of the PM-use Choice Model

The estimation results of the suggested model, including social conformity effects for greater accuracy, are reported in Table 2. Table 2 indicates that PM-use preferences increase if the parameter sign is significantly positive, and PM-use preferences decrease if it is significantly negative. The likelihood ratio is relatively low at 0.124. This means that the factors affecting PM-use choice are not sufficiently captured by the explanatory variables. Improving the goodness of the fit is an important issue, and it is one which can be achieved by introducing more variables related to household and individual attributes and daily traffic patterns. It is also considered that applying the models dealt with heterogeneity problems such as “mixed logit” and “latent class logit” as one means of improving the likelihood ratio.

In terms of the parameters of the explanatory variables related to individual attributes in Table 2, the parameter for the composite dummy variable of driver’s license and vehicle ownership (i.e., respondents who have a driver’s license and own a vehicle) shows a significantly positive value. This indicates that the people who can drive currently have high PM-use preferences. In addition, parameters of the walking ability dummy (i.e., cannot walk more than 200 meters without a break) and the explanatory variables related to the number of hospital visits are also significantly positive. That is to say, people who have difficulty walking over long distances or who go to hospital frequently due to health problems are shown to have high PM-use preferences in order to get about outside the home without the help of others. Considering the parameters of the explanatory variables related to age (i.e., the over-75-year-old dummy and the 85-year-old dummy), only the latter was significantly negative, which means that PM-use preferences appear to decrease after 85 years of age.

The parameters related to policy variables—namely, the percentage of priority roads variable and the dummy related to placing a PM parking lot near the bus stop—are both positive and significant. The parameter of rental price was significant and negatively signed. These estimated results were sign conditions as expected. That is to say, these results show that PM-use preferences increase along with environmental changes favoring PM use (such as priority roads or PM parking lots) and when the price of PM vehicles declines. On the other hand, the driving into hospital dummy parameter became significantly negative. We can presume that this is because respondents considered that there is little need drive PM into hospitals; in fact, PM vehicles might cause unnecessary congestion given that wheelchairs and patient attendants, doctors, and nurses provide assistance currently.

Focusing on the parameters of the explanatory variables related to the social conformity effect, the parameters of penetration among friends and penetration in the entire region are significantly positive. This shows that PM-use preferences increase along with increased PM use, and that social conformity affects individual PM-use preferences—confirming the research hypothesis of this study. In addition, comparing the parameters, the one pertaining to penetration in the entire region takes on a larger value than the one corresponding to penetration among friends. This shows that the influence of those who use PM throughout the region is relatively stronger than the influence from particular friends on peoples' PM-use preferences.

Table 2. Estimated results of PM-use preference model

Explanatory variables	Parameter	t-value	
Household and individual attributes			
Driver's license dummy× Vehicle ownership dummy	0.318	2.576	*
Number of household members	-0.027	-0.606	
Walking ability dummy	0.064	7.799	**
Frequency of hospital visits (times/month)	0.123	4.299	**
Over 75 years old dummy	-0.165	-1.043	
Over 85 years old dummy	-0.393	-61.063	**
Policy variables			
Priority roads	8.212E-03	28.816	**
Driving into shopping facility dummy	-0.169	-1.586	
Driving into hospital dummy	-0.336	-3.183	**
Placing PM parking lot near the bus stop dummy	0.340	2.746	**
Rental price (JPY/month)	-0.001	-13.637	**
Effect of social conformity			
Penetration among friends (%)	8.767E-05	2.021	*
Penetration in the entire region (%)	2.300E-03	10.380	**
Constant term	0.500	9.959	**
Number of samples	1533		
Number of parameters	14		
Initial log-likelihood	-1062.595		
Converged log-likelihood	-931.171		
Likelihood ratio	0.124		

**: Significant at 1%, *: Significant at 5%

5. ANALYSIS OF PM PROMOTING FACTORS USING COMPLEX NETWORK ANALYSIS

5.1 Mathematical Properties and Classification of Social Networks

A social network that exists in the real world is diverse and complex in structure. However, it is considered that social networks may have some basic mathematical properties. In general, these include: 1) a "scale-free property," expressed as power low degree distributions; 2) a "small-world property," expressed as small average internodal distance; and 3) a "cluster property," expressed by a large clustering coefficient (Jackson, 2008). In previous studies of complex networks, such as social networks, various modes of analysis and parameters have been applied to reflect the three mathematical properties above; however, to our knowledge, no study has revealed empirically which model to apply and which parameters to set according to the type of situation.

Therefore, in order to represent the relationships in the survey region of Koyo Newtown using the complex networks approach, it is necessary to know which of the three mathematical properties are relevant for the social network in the study region. However, complex questions and a sufficient number of samples are necessary to identify and verify the small-world and cluster properties. Because this study is limited in scope (targeting only the elderly) and involves a relatively brief questionnaire, we decided that the small-world and cluster properties do not apply for the purposes of our analysis. Some surveying techniques have been proposed to identify and verify the small-world and cluster properties, but the development of efficient research methods that incorporate them is an important future challenge.

As we have mentioned, the scale-free property describes a network in which some vertices are adjacent to many other vertices, but the majority of vertices are adjacent to only a small number of vertices. A scale-free network is a network whose degree distribution follows a power law, at least asymptotically. That is, the fraction $p(k)$ of nodes in the network having k links to other nodes goes for large values of k as per:

$$p(k) = ak^{-r} \tag{3}$$

Here, the term a is the normalization constant, and r is a parameter. Many networks are conjectured to be scale-free, including Internet links, biological networks, and social networks.

In order to investigate whether the social network in Koyo Newtown is scale-free, we estimate the parameters in Equation (3) using the collected survey data. Table 3 shows the result of the parameter estimation of Equation (3). The coefficient of determination adjusted for the degrees of freedom was 0.377, which means that the model accuracy was very low. Moreover, using the Kolmogorov-Smirnov test (KS-test), we tested whether there is a significant difference between the distribution of the number of friends obtained by model estimation and observation. The result of the KS-test shows that there is a significant difference between the two. In other words, the scale-free property does not appear to apply to the social network in Koyo Newtown.

Based on the above result, we select the generation model of a social network for our complex network analysis. As representative analytical models that do not take into account the scale-free property, random graph and Watts-Strogatz (WS) models are often used. Since the average internodal distance is a small value, the random graph model reflects the small-world property. However, cluster and the scale-free properties cannot be expressed because the degree distribution becomes binomial in nature, and the clustering coefficient approaches 0. Although the WS model incorporates a small average internodal distance and does not meet the power law degree distribution like the random graph, it is possible to express the degree of cluster by setting the parameter values exogenously. However, in order to avoid arbitrarily setting the parameter values to express cluster (which could not, in fact, be gleaned from the survey data), we used the random graph method, which does not express the scale-free and the cluster properties, in this study.

Table 3. Estimated results of the scale-free model

Variables	Parameter	t-value	
Normalization constant	0.179	2.980	**
Power index	-0.796	-3.177	**
Number of Sample	151		
Coefficient of determination	0.419		
Coefficient of determination adjusted for the degree	0.377		

**: Significant at 1%, *: Significant at 5%

5.2 Representing the Social Network in Koyo Newtown using a Complex Network Model

The random graph model is one of the most extensively studied models for social networks. In random graph, for instance, out of all possible networks on *n* nodes, one could simply pick one completely at random, with each network having an equal probability of being chosen. Alternatively, one could specify that the network should have *M* links and then pick one of the networks at random with equal probability. Some of these models of random networks have remarkably similar properties. If in a nework each link is formed with indpendent probability *q*, we expect to have $qn(n\text{-}1)/2$ links formed, where $n(n\text{-}1)/2$ is the potential number of links. While we might end up with more or fewer links, for a larger number of nodes, an application of the law of large numbers ensures that the final number of links will not deviate too much from this expected number in percentage terms. This result guarantees that a model in which links are formed independently has many properties in common with a model network that is prescribed to have an expected number of links (Jackson, 2008).

While random graphs have been used in the analysis of networks, the model also has obvious shortcomings; in particular, the degree distribution is essentially a convex combination of a degenerate distribution (with all weight on a single degree) and a Poisson distribution. Such a degree distribution is fairly specific to this model and is not often observed of real social networks. In other words, it is hard to track the general degree distribution and adjust it to match that of actual, observed networks.

To address this problem (i.e., to generate random networks with a given degree distribution), various methods have been proposed. One of the most widely used is the configuration model developed by Bender and Canfild (1978). The model has been further elaborated by Wormald (1987) and Molloy and Reed (1995), among others. A configuration network is constructed in the follwing manner. Each node has a desired degree k_i, so we imagine that each node has k_i link "stubs" attached to it. Links are then assigned by randomly choosing two stubs and drawing a link between them. This results in a relatively simple random graph model that can reproduce any desired degree sequence. Yet, this configuration model presents several computational difficulties. For instance, the individual links are not independent events, so it is difficulat to obtain the probability that two particular nodes are connected. This is important because one might be intereseted in quantities like the average number of links lying within a certain set of nodes, which rely on such probabilities. The solution to these difficulties is to use a slightly different random graph model which merely fixes the expected degree sequence rather than the actual degree sequence. This model was originally introduced by Chung and Lu (2002).

Now suppose that we wish to generate the degree sequence (d_1, d_2, …, d_n) in a network of n nodes. Form a link between nodes i and j with probability $Q_{ij} = d_i d_j / \sum_k d_k$, where the degree sequence is such that $(\max_i d_i)^2 < \sum_k d_k$, so that each of these probabilities is less than 1. Then, the expected degree of a node is given by:

$$\langle k_i \rangle = \sum_j P_{ij} = d_i \sum_j d_j / \sum_k d_k = d_i \tag{4}$$

as desired.

However, this standard presentation of the Chung-Lu model ignores self-links. In our discussion, self-links should be ignored since this study focuses on the influence of social conformity with other people. Therefore, one can immediately see that self-links are unnecessary, for without the possibility of self-links, the expected degree of a node becomes:

$$\langle k_i \rangle = \sum_{j \neq i} Q_{ij} = d_i \sum_{j \neq i} d_j / \sum_k d_k = d_i \left(1 - \frac{d_i}{\sum_k d_k} \right) \tag{5}$$

The Chung-Lu model without self-links leads to a degree distribution more closely tied to the random graph. This study thus applies the Chung-Lu model without self-links. We represent the social network in Koyo Newtown according to the distribution of number of friends—gleaned from the survey and presented in Figure 3—which is used as a degree distribution.

5.3 Simulation Analysis of PM Promotion

In this section, we conduct a simulation analysis of PM promotion. Firstly, using the distribution of number of friends data obtained in the survey (see Figure 3), we generate the social network by applying the Chung-Lu model without self-links for the survey area. Then, based on the number of friends, household and individual attributes are added onto each node. The conceptual framework of these methodologies is illustrated in Figure 4. Finally, we conducted a simulation analysis of PM promotion by using the result of the parameter estimation of the PM-use preference model in Table 2, and the generated social network under the various different scenarios.

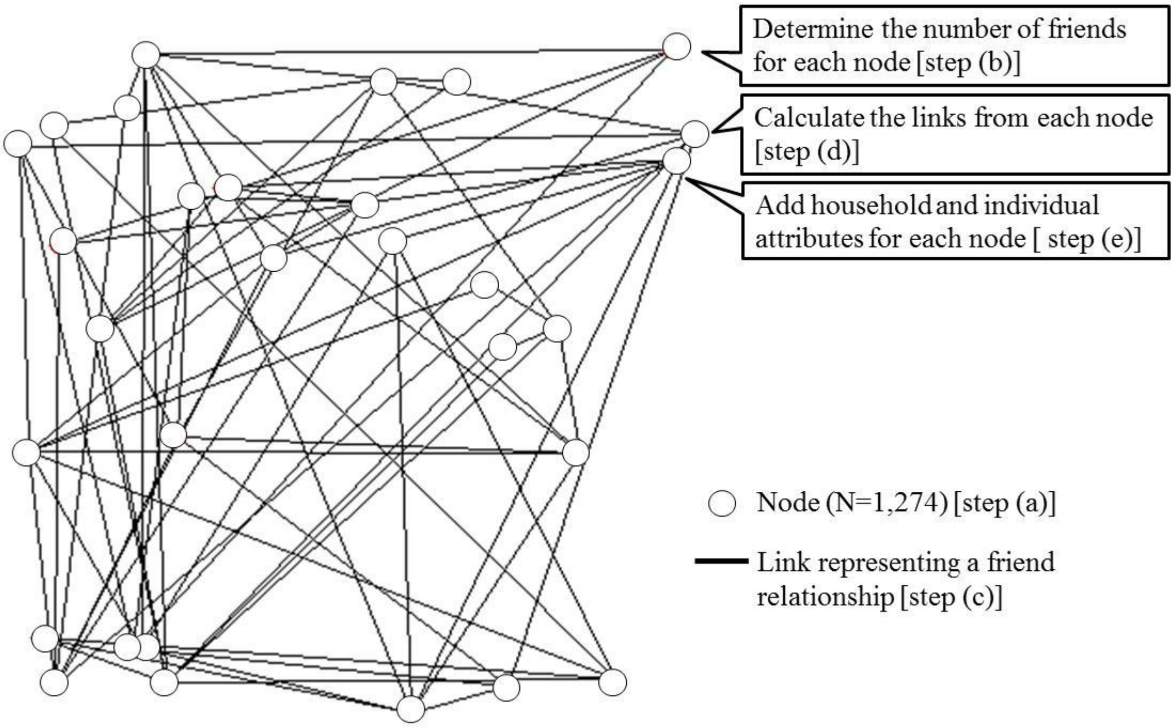

Figure 4. Framework of social network generation

Specific steps are as follows:

(a) Put the number of nodes on virtual space, that is, the number of decision makers corresponding to the number of seniors in the study area. In this case study, we set the n = 1,274 nodes based on the statistical data for Koyo Newtown.

(b) Determine the number of friends d_i for each node i (i.e., degree of node) based on generated uniform random numbers and the distribution information obtained in the survey (Figure 3).

(c) Generate the social network by using the Chung-Lu model without self-links based on the degree distribution created in step (b).

(d) Calculate the number of friends for each node d'_i (i.e., degree of node) from the generated social graph in step (c).

(e) Calculate the distribution of household and individual attributes for each degree $Q_d(x_m)$ by using the number of friends from the results of the survey. Here, $Q_d(x_m)$ is the percentage of category m related to household and individual attributes x of the people who have d friends ($\sum_m Q_d(x_m) = 1$). Using generated uniform random numbers, determine the household and individual attributes x_i of each node i from the distribution of household and individual attributes.

(f) Set the explanatory variables related to policy variables y_k, including the percentage of priority roads set, the driving into shopping facility dummy, driving into hospital dummy, and placing a PM parking lot near the bus stop dummy, for the scenarios. By using those policy variables y_k and the household and individual attributes x_i generated in step (e), calculate the choice probability of PM-use of each node using the estimation results in Table 2. Next, calculate the ownership rate OR by making up the individual choice probability ($OR = \sum_n P_{n,j=1} / n$). Here, assign 0 to penetration among friends z_i and penetration in the entire region s as an initial value. The ownership rate with penetration among friends z_i and penetration rate in the entire region s at 0 may be called the "initial ownership rate."

(g) Update the value of penetration among friends of each node z_i and penetration rate in the entire region of each node *s* by using the initial ownership rate calculated in step (f). Calculate again the choice probability and the PM ownership rate according to each node. Repeatedly calculate it until the ownership rate no longer changes. The ownership rate when it no longer changes, that is to say, when it converges, is called the "final ownership rate."

(h) In order to ensure the robustness of the solution, repeat the procedure 100 times from (b) to (g), and calculate the average values and standard deviations.

Figures 5 to 7 show the comparisons of distributions between observed values and values in the generated social network. Figure 5 is an illustrated comparison in terms of number of friends; Figure 6 represents comparisons of household size distributions, and Figure 7 shows comparisons of age distribution. Error bars in the figures represent the standard deviation of 100 repeated computations. We can see that the standard deviations shown in the figures are exceedingly small. Moreover, we conducted a Chi-square test for each variable to see whether there is a significant difference between the observed distribution and generated distribution. As a result of the Chi-square test, no significant difference was observed. For reasons of space, we show only the distributions relating to number of friends, household size, and age, although the other variables also show the same trends. That is to say, these results indicate that the generated social network is able to represent the observed sample attributes.

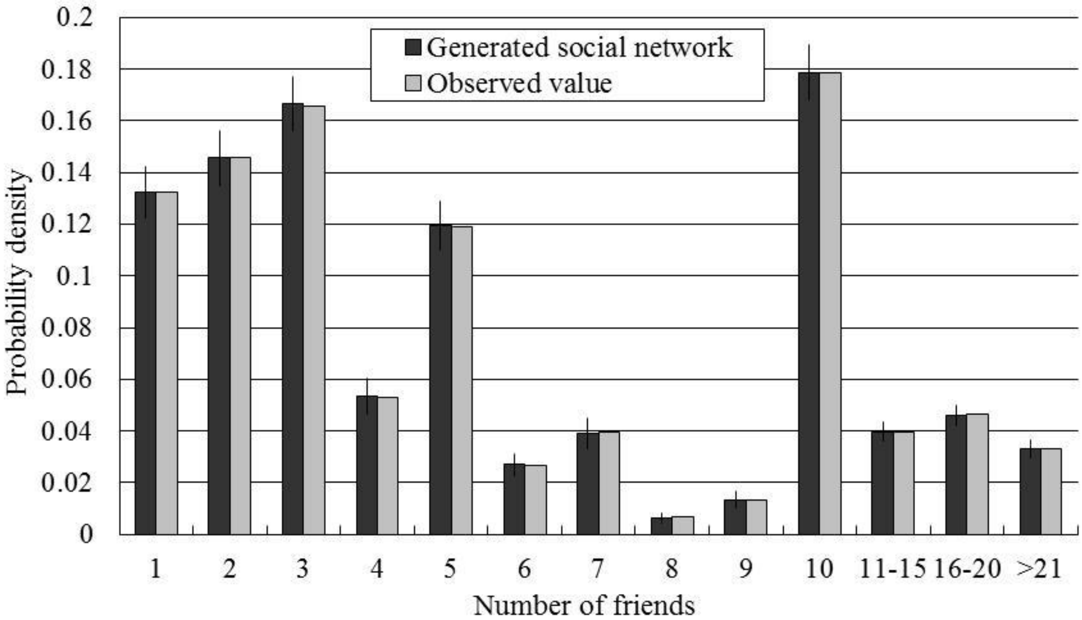

Figure 5. Comparison of number of friends distribution

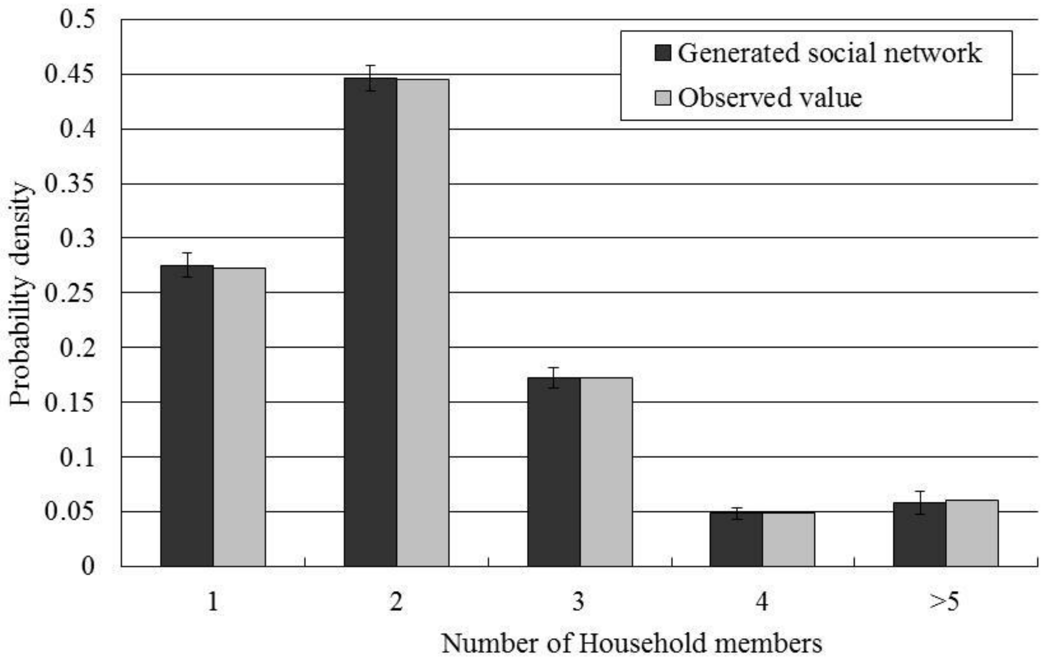

Figure 6. Comparison of household size distribution

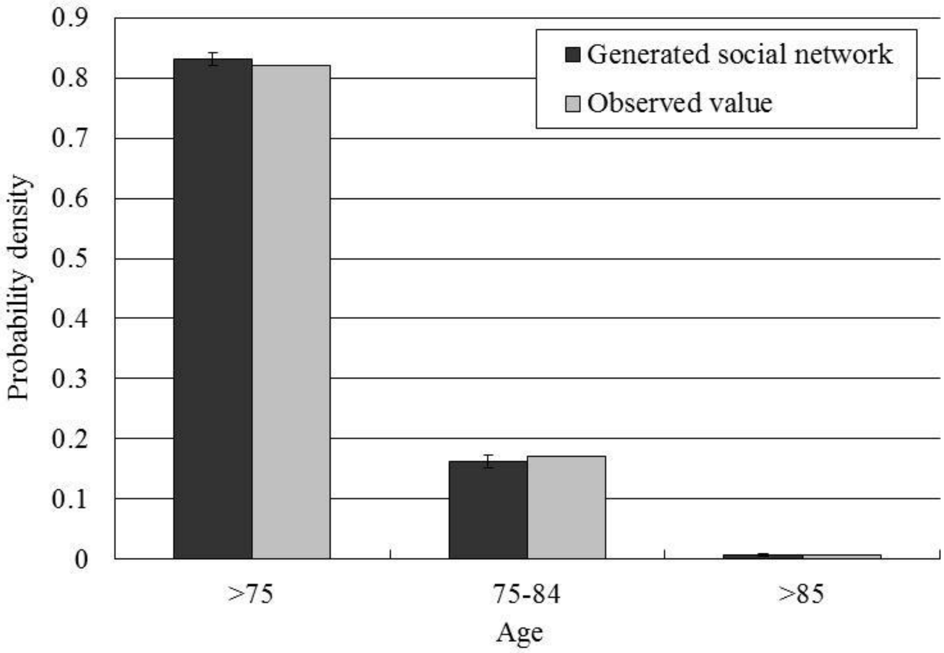

Figure 7. Comparison of age distribution

In the scenario analysis, we set up three patterns relating to different levels of PM friendliness in the environment: 1) Business As Usual (BAU); 2) 50% of roadways are PM priority roads (priority road); and 3) PM parking lot placed near the bus stop (PM parking). Figure 8 shows the results of the scenario analysis. Because the maximum value of the standard deviation in each of the three scenarios was very small, at 0.0089, this simulation result could be considerably robust. Therefore, hereafter we only focus on the average values in each scenario.

The results of the scenario analysis shown in Figure 8 suggest that the ownership rate in the entire region becomes 27.5% in Scenario 2, and 26.1% in Scenario 3 when the rental price is 2,000 yen per month. This means that the ownership rate increases around 7 points compared with the BAU Scenario. However, we can see the effect of the environment becomes very small when the rental price is more than 2,000 yen per month. These results show that although the maintenance of priority roads and the installation of a PM parking lot are effective means of PM promotion, instead of implementing them as individualized measures, it is necessary to consider them as composite measures in addition to rental price. Furthermore, comparisons of the initial ownership rate and final ownership rate reveal that the influence of social conformity contributes to a 2-point increase in ownership rate when the rental price is 2,000 yen per month. This shows that the social conformity effects on PM-use preferences have an impact equivalent to a 5% price reduction.

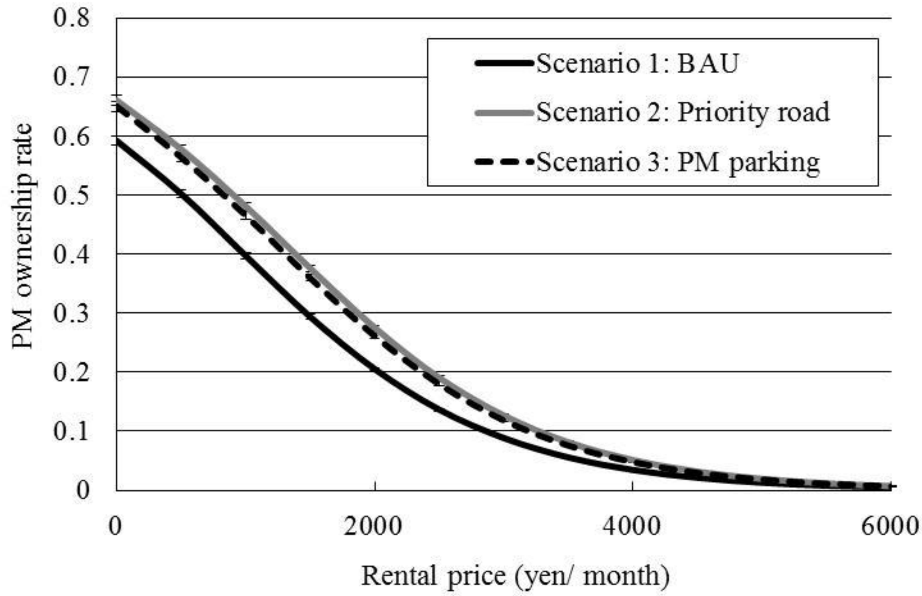

Figure 8. Estimation results of simulation analysis

5. CONCLUSIONS

Previous research has shown that social conformity often plays a very important role in new product purchasing decisions, as the consumer is not familiar with the product's quality or attributes. This study has proposed a new approach for providing quantitative analysis of the social conformity effect on individual decision making using the discrete choice model and social network analysis. In order to improve mobility for the elderly demographic in "Old" Newtown—where the share of aged residents is increasing, and it is expected that many will not be able to use their automobiles in the near future—this study focused on PM options. We applied the approach suggested above to assess citizens' PM-use preferences and analyzed PM promoting factors.

In order to clarify which factors effectively promote PM use, this study conducted an SP survey to analyze PM ownership intentions of residents in Koyo Newtown in 2011. Based on the collected SP data, we developed a new PM-use choice model along the lines of a discrete-choice model which takes into account social conformity with friends and the entire region. Drawing from the PM-use choice model, the installation of a priority road and a parking lot near the bus contributed to the promotion of PM-use by creating an environment suitable for PM equipment. Moreover, we recognized that the penetration of PM vehicles among respondents' friends and in the region generally has an influence on the promotion of PM; in other words, for PM promotion and adoption, there appears to be a social conformity effect.

In addition, in order to analyze the social network in the study area, we suggested applying a complex network modeling as a new and novel approach. In this case study, we applied the Chung-Lu model, without self-links, so as to generate the social network according to any desired degree sequence. Through our empirical study, we demonstrated that the model can reproduce the social network in the study area by using the observed distribution of the number of friends. Moreover, we added the household and individual attributes on each node in the generated social network, and the simulation results provided empirical evidence for the effectiveness of the suggested approach in terms of both its performance and applicability. Following the results obtained from the PM-use choice model and the social network model, we conducted a scenario analysis of PM-use under different environmental conditions. The results of this latter analysis revealed that the social conformity effect has an impact equivalent to a 5% reduction in rental price. This is new insight shows the effectiveness of the unique analytical system suggested by this study.

Through the empirical study, we present that the uniqueness and contribution of this study lies in the development of an analytical approach to capture a social network—in such a way as mirrors household and individual attributes and relationships with friends in a target area. As we mentioned in Section 2, a number of group-based choice models have been developed in existing studies that attempt to capture the influence of others' opinions, preferences, or behaviors on an individual's decision marking. However, the application of existing studies has been restricted to specific small groups, such as the members of a household, school course, or travel party, since observing human ties in large group settings is quite difficult. We expect that applying the suggested analytical framework in this study, which is able to capture a social network, will help extend the range of application of these group-based choice models for larger groups or communities and more clearly reveal decision-making mechanisms.

As to challenges for the future, in order to analyze the influence of the promotion of PM technology for the sake of elderly mobility, it will be necessary to conduct a comprehensive analysis that captures behavior changes from the intention to possess to actual possession, as well as post-purchase evaluations. This study focused only on the intention to possess as a first step; accordingly, we could not analyze the direct contribution of our interventions to the improvement of elderly mobility. The measurement of PM efficacy considering behavior changes and the evaluation of PM users will be an increasingly important priority. Moreover, we simulated the promotion of PM assuming that improvement of the usage environment and penetration are independent. However, it is generally considered that generalized user cost declines with growing penetration. Therefore, it is considered that environmental improvements, such as priority roads and infrastructure—and rental price, perhaps most importantly—will become better as the penetration rate improves. It is necessary to incorporate these relations explicitly into the analysis system in order to refine predictions concerning PM promotion.

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