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A STUDY FOR AGENT-BASED MODELING OF MIGRATION BEHAVIOR OF SHOPPERS

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Abstract: The aim of this study is to develop a framework of multi-agent-based models for investigating pedestrian movements with fine-scale considerations. In this paper, we analyze migration behavior of shoppers in a shopping center to suggest a generic model of such behavior. The routes that 18 shopper took for two-hour shopping in the building of shopping mall was identified by video images. Questionnaires about profiles of shoppers with respect to their preference of shops and purpose of trip making are used for classifying their shopping styles. This demographic data is used for a correlation analysis between shopper's attributes and behavioral tendencies that were observed in the routing. Based on this analysis, we suggested two factors that may have influence on shopper’s behavior. Then one of the models that combine these two factors was examined by comparison between actual footpath data and the results of simulations.

Keywords: pedestrian behavior, multi-agent-based model, shopper.

1. INTRODUCTION

1.1 Background

As the trend to move towards "compact city", social-economic importance of town centers is increasing more than ever. There have been growing needs for certain pedestrian behavior models in order to predict how people move around in urban central areas. Since it is important to understand the way of spatial movement of pedestrian for any design processes of facilities in various fields, not only urban planners or government officials but also retailers and advertising agents have been interested in pedestrian behavior modeling.

Although there have already been several spatial behavior models, such as *Huff model*, *Logit model* and *Marcov-chain model*, which is effective enough to estimate a potential attraction of a new shop, or to predict the approximate number of visitors or probability that a certain place will be chosen as someone's destination, they can not deal with each pedestrian movement in more fine-scale environment such as commercial districts and shopping malls. Pedestrian behavior models that can be applied to erratic movements of users in such places are strongly needed.

1.2 Aims and Structure of the study

As pedestrian behavior seems to be susceptible to a number of factors in urban environment, we should carefully examine each factor to identify most influential factors and to see their synergistic effects. One of the techniques used to search for behavioral patterns or possible influential factors is Spatial Data Mining, proposed by *Hato, E. et al*. (2002). This technique fits to find hidden structure of the data. In addition, the concept of agent-based modeling and the simulation technique enables us to take account of many variables, their correlation as well. This is suitable not only for verification of models but also for parameter tuning. The prime aim of this study is hence to develop a framework of multi-agent-based models for investigating pedestrian movements with more fine-scale considerations. In this paper, we focus on migration behavior of shoppers in a shopping center and obtained data of spatial movement by measurement systems for mining process. Based on the basic analyses on behavioral patterns found in the real routes that each shopper took during shopping and the results from marketing surveys, generic models are suggested and examined for further development.

As a part of modeling, empirical knowledge from observation or existing behavior models also deserves to be studied closely. Because it suggests behavioral tendencies or common ideas to understand the mechanism of human behavior, which might be a great help to identify the factors that cause erratic movements. Section 2 describes and discusses the findings from literature review in order to understand the requirements for new models. The behavioral patterns found in the real routes that each shopper took during a survey in a shopping center are described in section 3. The survey included inquiries and interviews about the attributes or preferences of shoppers. The result of basic analysis on the correlation between behavioral patterns and demographic or other personal factors is also analyzed in this section. This aims to reconsider and improve the framework of the models for their further development. In section 4, the results from simulation are compared with the real routes obtained by measurement systems. Section 5 presents conclusions and future works.

2. FINDINGS FROM LITERATURE REVIEW

The findings of a trans-disciplinary review of literature on existing human behavior models are presented in the following section. This aims to identify the requirements for new models.

2.1 Overview

Most of the existing human behavior models are based on the same assumption that every spatial behavior follows the principle *utility optimization* to decide on the option that is supposed to be of highest benefit to decision-makers in achieving their goals.

Fine-scale pedestrian movements, however, always accompany seemingly erratic behavior, which might be overlooked in this process. As argued by *Ishibashi, K et al* (1998a), what brings this unpredictability to pedestrian behavior is perhaps that each pedestrian is apt to change his/her original destination or that information he/she newly get whilst they are walking around leads to create another option. New models are expected to represent this changeability of pedestrian movement and to explain its mechanism.

2.2 Logit model

Among various current models suggested in traffic management and urban planning, the *Disaggregate Logit model* and its variation has been most widely used to predict human spatial behavior. Possibility of a certain place being chosen as the next destination explains a trip, a movements from point A to point B in the space. A sequence of these possibilities amounts to whole route that each pedestrian goes through during his/her journey.

Ishikawa (2002) developed and showed the validity of a scheduling behavior model based on the idea of *Mixed Logit model*. This model introduces a probability distribution that reflects the difference amongst travelers in perception of expected delay of each transportation measure into the function. By doing so, the model can take account the uncertainties of the time required for each trip and the different attitudes of travelers towards them. Although its basic concept is *utility optimization*, the results of parameters estimation showed that the model can handle changeability of people's behavior.

2.3 Markov-chain model

Markov-chain is a collection of random variables $\{X_t\}$ (where the index t runs through 0,1,…) having the property that, given the present, the future is conditionally independent of the past. *Ishibashi. K et al* (1998b) applied a disaggregate model that makes use of Markov-chain to predict the number of visitors of each shop in the central commercial area. Although this model can represent spatial movement as a series of possibility of a certain place being chosen as the next destination and can show when people change their behavior, it does not explain the reason of the changeability.

2.4 Other models

It has been demonstrated in a number of studies in the field of architecture or cognitive science that personal experiences and knowledge about the place have strong influence on the spatial perception, in other word *Cognitive map*, which determines traveler's destinations and routes (*Abu-Obeid, N.*, 1998). Since it is understandable that an action taken by each pedestrian usually accompanies reaction from others or environment as a feedback, his/her cognition or knowledge of external world may well updated by the next time to make a choice. Thus the criteria and estimated utility of each option may be changed. This dynamism is called *learning and adaptation*. This learning process was introduced to autonomous robot architecture, which makes use of the stimulation-response mechanism in conjunction with a knowledge-based behavioral schema was proposed (Arkin, R.C, 1990). The *Genetic Algorithm* is important measure to integrate learning and adaptation process into the behavior schema. It autonomously develops criteria for finding desirable options by taking all the controlling variables and all the possible extraneous influences into account. When attempting modeling of pedestrian movements we need to utilize this feedback structure in order to represent interactions between pedestrians and environment.

2.5 A Framework of New Pedestrian Models

A tentative generic model was suggested by *Kitazawa, K. et al.* (2002) on the basis of requirements described above; it includes transition of tasks and aims of journey and information processing and feedback-loop of cognitive process as represented in Figure. 1.

There are 4 levels of tasks in proportion to the degree of consciousness; not existing, potential tasks (needs), overt tasks and concrete tasks. Stimuli from environment, perceived by physical sensors can be a trigger for some of these tasks to be realized. As there are some constraints on behavior such as cost and time required for achievement of the task, the resource allocation process is hired to make a tentative schedule, which loosely defines behavior in future. Using the idea of *Mixed Logit model*, the susceptibility of the schedule to the changes in tasks is explained. Stimuli from environment are stored in a database of experience as cognitive schema of the space. They control resource allocation process by providing necessary information for making decision. Learning and adaptation mechanism is used here to represent dynamic relationship between behavior, experience and environment. To the step of choice making, the *utility optimization* principle can be applied. Distribution of the utility value is defined by cost and attractiveness of each space (shops), approximated by assortment of materials, impression, and uncertainty. The map itself is to be revised at the timing that pedestrian make another step of behavior.

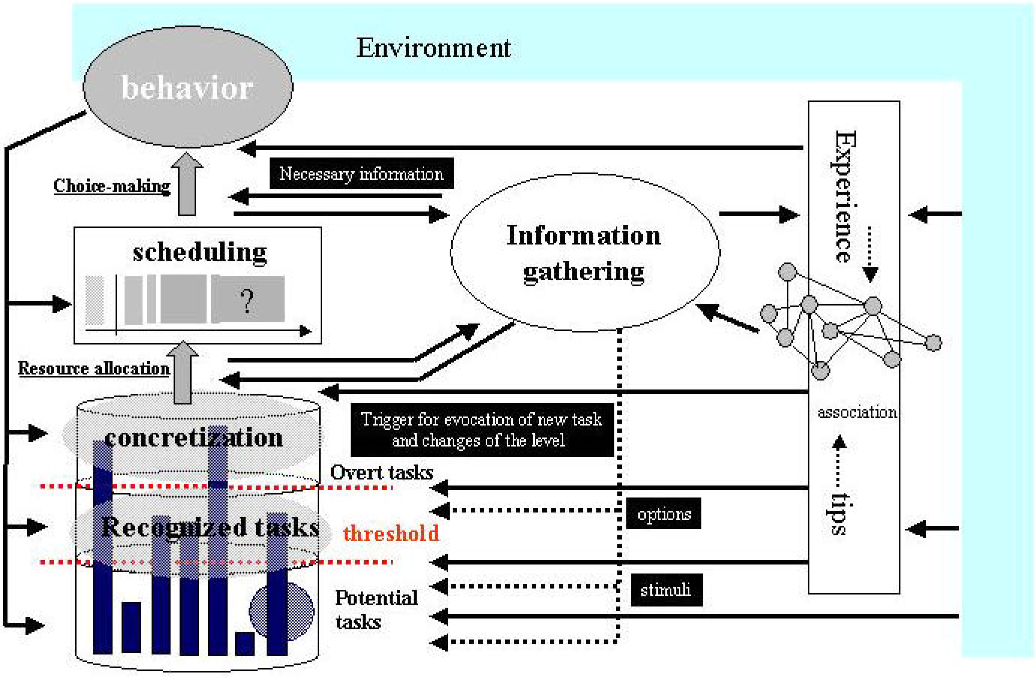


Figure 1 A Generic Model of Pedestrian Behavior

3. A SURVEY ON MIGRATION BEHAVIOR OF SHOPPERS

3.1 A Working Hypothetical Model

Within the framework developed in section2, a working hypothetical model was set up. In the model, spatial movements of shoppers are described as interactions among 3 agents; shoppers, shops and a network of passages. Their attributes are shown in table 1.

Table 1 Atrributes of Agents

	Attributes used in this study	Attributes not used in this study
Shopper	• Objectives and tasks of the trip • Spatial knowledge about the place (the number of times of visiting)	• Physical strength • Degree of content or tiresomeness • Budgets and time limitation
Shop	• Suitability to each shopper's taste (preference) • Good/Bad valuation evaluated by each shopper based on her previous experience or impression	• Area of the shop • Targeting segments (e.g. age) • Cycle of changes in selection
Network	• Length of each link • Topological info (e.g. a lift to the 2nd floor)	• The number of shops around and other passage flow into it

The model used in this study assumes that shoppers have an image or knowledge of each shop in the shopping center, based on their taste of fashion or on the impressions of the last visit. On this assumption, attractiveness of shop *i* for a shopper *n* is expressed as A_{in} by the function explained below:

$$A_{in} = V_{in} + \bar{\varepsilon}_{in} = V_{in} + \eta_{in} + \varepsilon_{in} \quad (1)$$

$$V_{in} = \sum_{k} \beta_{is} x_{is} \quad (2)$$

$$\eta_{in} = \sum_{j \in J} \mu_{ij} Z_{ij} \quad (i \neq j) \quad (3)$$

Equation 1 consists of V_{in} as a systematic component and $\bar{\varepsilon}_{in}$ as a spurious error term. Mixed Logit model introduces parameter η_{in} to represent error correlation into the equation. Equetion 2 calculates V_{in} by summation of explanatory variables x_{is} each of which is weighted by value β_{is}. The value of β_{is} is mean and variance of parameter *s* that has normal distribution. In equation 3, μ_{ij} as a vector of random variable, which has normal distribution with 0 as its mean. It also includes dummy variable Z_{ij} in order to take into account of similarities among choices. Uncertainty that accompanies the process of choice of destinations or routes such as spatial knowledge about the place, cost-effectiveness of options can be considered by using this function.

The value of the attractiveness varies by the tasks of the trip. If the shoppers do not have definite objectives or tasks, the value of weighting parameters on shop preference increases and becomes more influential. The value also reflects uncertainties such as vague spatial knowledge and contingencies of impassable links of the network or anxiety that the goods planned to buy might be not available or sold out.

A distribution map of attractiveness of shops can be drawn for each shopper. The behavior rules set in the model is that the shoppers enter the shop, whenever they approach the shop with high attractiveness or come within the area in which the shop is visible Then the map may be revised depending on whether the task is achieved or not (Figure 2).

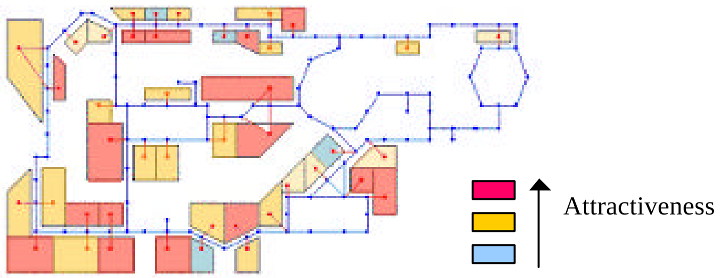


Figure 2 Networks and Distribution Maps of the Attractiveness of Shops

3.2 Methodology

In order to verify the model suggested in section 3.1, a series of surveys on behavior of shoppers was undertaken at a huge shopping center in Tokyo, Japan. The center is composed of more than 140 shops for young women. This is to eliminate influence of age and gender on behavioral patterns in order to simplify the analyses. Then 18 shoppers, female graduate students who are in their twenties, were asked to shop around for 2 hours and the routes they took were tracked and recorded. For the purpose of obtaining as much detail of the movement of each shopper as possible, digital video cameras were used as main sensors of the measurement systems in this study. Every 30 seconds, the node that is closest to the shopper's location was identified from video images in order to represent the route on the network.

The panel technique was used in this study in order to see the influence of both accumulation of spatial knowledge about the shopping center itself and impression of each shop from previous experience on the routing process. The same experiments were carried on once every two weeks from 18/11/2002 to 10/01/2003 for a total of three times.

Every tracking survey was followed by an interview with respect to the tasks and impressions both of each shop and of the whole shopping. Additionally, profiles of shoppers such as preference of shops and attitudes toward shopping were obtained in Questionnaires survey and analyzed to classify their shopping style.

Figure 3 presents the three sorts of data obtained in the survey, which is colored in gray, and their position in the working hypothetical model. Behavioral tendencies that were observed in the routes of migrations are used in identifying influential factors in the model as well as mining other factors. The demographic data are used for a correlation analysis between shopper's attributes and shop preference. In this survey, distribution maps of shop preference were developed in advance. Shops are evaluated categorized into 3 groups:

- Preference 1. Shops that suit to the one's taste; Shops that are frequently visited
- Preference 2. Shops that are visited not so often; but shoppers are interested in those within this category;
- Preference 3. Shops that do not attract shoppers

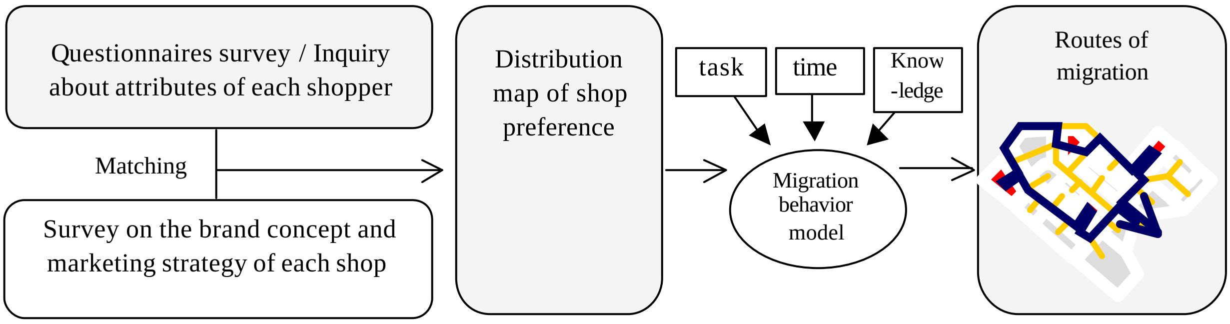


Figure 3 A Summary of the Working Hypothetical Model and Data Acquired in the Survey

3.3 Results

The number of shops that shoppers visited during two-hour shopping seems to be 23 on average (Table 2). The data of those who could not participate in all surveys are excluded.

Table 2 Average number of shops visited in each survey

	Valid value	Mean	Std. Error	Mode	Std. Dev.	Min	Max
Survey 1	14	23.50	2.198	20	8.225	12	49
Survey 2	14	21.71	2.121	21	7.937	10	34
Survey 3	14	22.54	2.007	23	7.510	14	44

As it was difficult of statistical analyses, due to the small amount of data, behavioral patterns were spotted by visualization of the data. Figure 4 shows the changes in the number of shops visited by shoppers among 3 surveys. Half of the shoppers dropped by more shops during Survey 3 than other two. Some shoppers visited twice as many shops as her previous visit.

Based on the information obtained from interview, these tendencies can be explained by some events such as sales or existence of important tasks that should be completed during the trip.

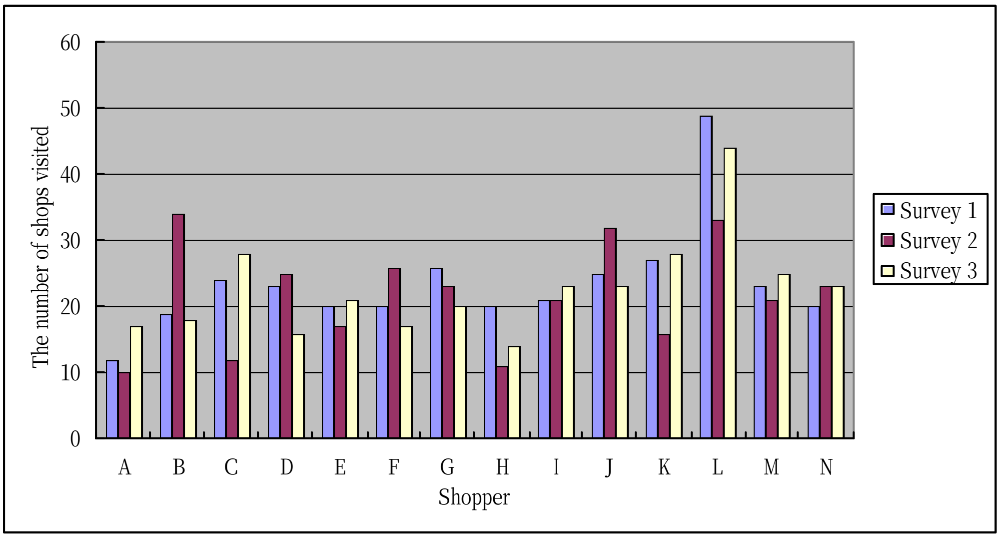


Figure 4. The number of shops visited by each shopper during 3 surveys

It was found that the shops within the category of Preference 1 amount to 80% of all shops that were visited during survey 1. Furthermore, information obtained from the interview about shopping attitudes revealed that most shoppers repeatedly visit the same shops, which are visited regardless of the objectives or tasks of the shopping trip. Then, we set up another category within the category of Preference 1. Shoppers show high brand loyalty to the shops fall into this new category. The graph in Figure 5 illustrates percentage of each shop category, which is the average of 3 surveys. It can be clearly seen tha t the shops with high loyalty were steadily chosen as a destination during shopping.

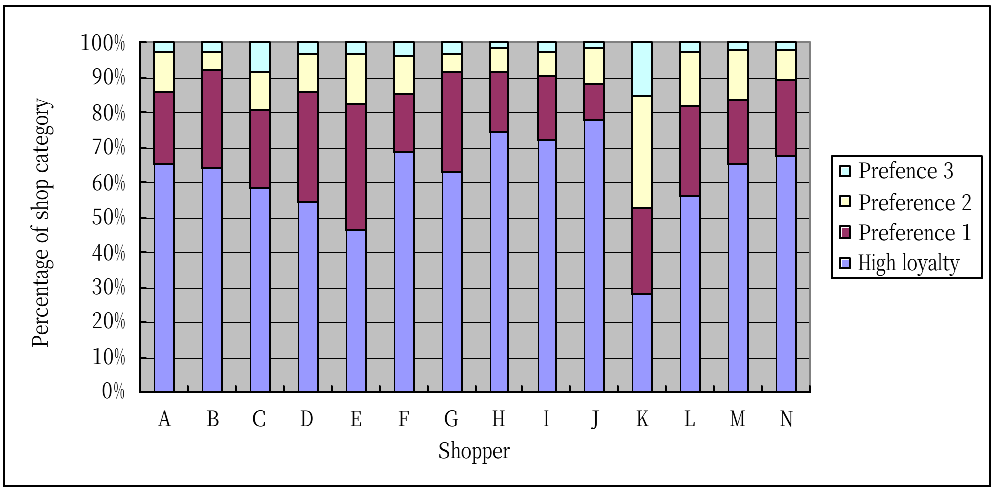


Figure 5 The number of shops visited by each shopper during 3 surveys

On the other hand, frequencies of visiting the same shop during surveys were not so high. It can be interpreted in two ways. The first interpretation is that shoppers had to prioritize visiting another shops is the category of Preference 1 over visiting the same shop again due to the time restriction. This can be regarded as a consequence of *Resource allocation*. The second interpretation is that the attractiveness of shops might decrease after they are visited. Since shoppers have already known the shop's assortment and that their task cannot be achieved, it will be impossible for the shop to attract shoppers until other tasks arise.

Other possible factors that have influence on the choice of destination were suggested from the interview; impressions or images of shops, additional information obtained during trip, and fatigue. For instance, 74% of the shops that gave positive impression to shoppers were visited again during surveys. It was found that most shoppers stopped shopping when all the tasks are completed. However, some shoppers were willing to continue shopping even after they had completed all tasks. It turned out that the prime reason for them to stop shopping is content or satiety. It follows from this that the attractiveness of shops should decrease because of diminishing of *marginal utility* after visiting other shops.

Two migration patterns can be derived from analysis on the routes; traveling in a regular route and a random walk. In the former pattern, shoppers seldom swerve from the prefixed course. While those who take the latter is susceptible to external stimuli such as additional information.

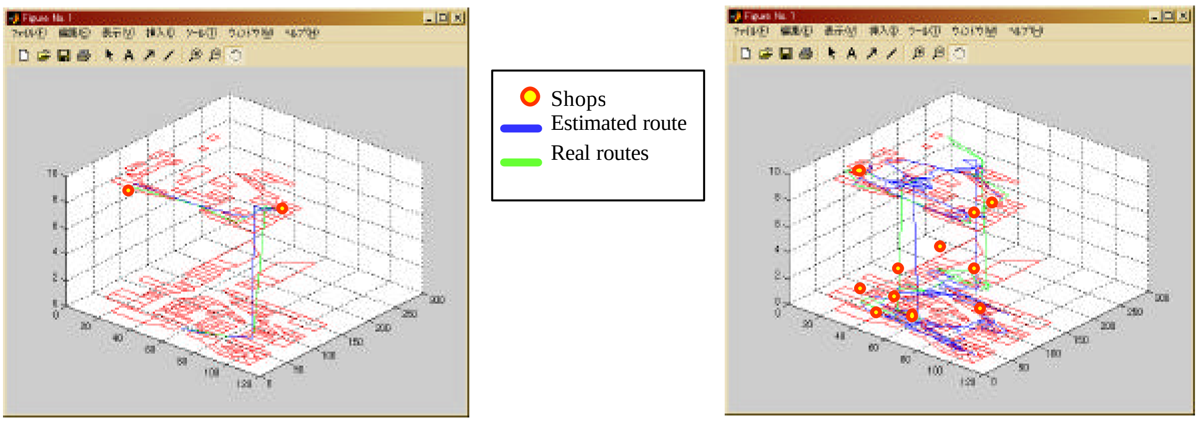
Based on the results and discussions above, it is suggested that behavioral patterns in the routes model should be examined more closely focusing on the 4 groups of shoppers listed below. They are categorized by combination of 2 elements of human behavior; tendencies to take regular routes and the matter of highest priority during shopping such as achievement of tasks and enjoying shopping itself by gathering new information.

- Shoppers who fix destinations at the beginning of their trip and follow almost the same route every time
- Shoppers who fix destinations and routes . The route differs each time according to the tasks
- Shoppers who have rough or no prefixed routes but search for a certain products
- Shoppers who have rough or no prefixed routes and enjoy window-shopping itself without any purposes of the trip

4. THE RESULTS FROM SIMULATION

Figure 6 shows the estimated routes by a simulation system using *Genetic algorithm* and the real routes obtained in the experiments. *The utility maximization principle* was used as a behavioral rule for estimation of spatial movements of shoppers of the first group mentioned above. It is assumed that each shopper goes the rounds of all scheduled shops in the shortest route.

Comparison of actual trajectories with the results of simulations shows the effectiveness of *utility optimization principle* to represent migration behavior in short period. Although the model did not fit to the whole route of 120-minute migration, the result suggested that shopper's spatial behaviour might consist of a number of segments in which shoppers follow the same principle while each of which criteria of calculation of utility is different.



Routes for 10 minutes

Routes for 120 minutes

Figure 6 Results of simulation and observed routes (First shown in *Tanaka, H.*, 2003)

5. CONCLUSION AND FUTURE WORKS

This paper proposed a framework of modeling migration behavior of shoppers and examined one of generic models. The results from the analyses on data obtained from surveys partly support the validity of the model and indicated the other influential factors. It turned out that the idea of *marginal utility* and *utility optimization* in conjunction with *Mixed Logit model* is effective to explain spatial behavior of shoppers. At the same time, high correlation between the preference of the shops and choice of destination can be seen. Each shopper's loyalty to a certain shop has an influence on their routing. What pedestrians already know about the environment or impression of each shop is also important to decide routes. Additional information that is obtained during trip and physical restrictions such as fatigue should be taken into account. Thus, it is necessary for the new framework to include these factors. The framework should be improved by more detailed analyses on behavioral patterns in the routes. It might be useful to focus on the 4 groups of shoppers categorized by combination of tendencies to take regular routes and the matter of highest priority. For further development of the model, a foreseeable extension of this research would be to include spatial data mining on shopper's movements to search other patterns.

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