Improvement of Pedestrian Shop-around Behaviour Agent Model

Design and Implementation of 'Erratic Visit' Behaviour Model

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Abstract: We presented the following three research results: 1) we classified pedestrian shop-around behaviour in a commercial district by the phase axis and process axis, and defined "Erratic Visit". Next, we constructed an Erratic Visit Model where all facilities and routes are known. Then, we simulated the shop-around behaviour in the Osu district using ASSA2.0 with an implemented Erratic Visit Module, and confirmed that the performance of ASSA was improved.

1. RESEARCH BACKGROUND AND OBJECTIVES

In large modern cities, the behaviour patterns of visitors to commercial districts have become increasingly diversified. For this reason, when we plan to promote a 'bustling' commercial district, it is important to analyze pedestrians' micro behaviour, based on the bottom-up approach. In such an analysis, pedestrian shop-around behaviour within the commercial district is the key factor to focus on, because, it is clear that each pedestrian's shop-around behaviour consists of multiple levels of activity; at first planned action in accordance with a preference pattern of the visitor, and later improvised action, such as the search for alternative facilities or information

gathering. Furthermore, the behaviour patterns of visitors are closely related to the accumulation of facilities and their spatial layout in a commercial district. Accordingly, development of a simulation model of pedestrian shop-around behaviour in a commercial district can be a useful tool for analyzing the composition of a commercial district.

One of the major characteristics of pedestrian shop-around behaviour is premeditation and improvisation. That is, each pedestrian ranks the facilities they will visit and plans a proposed route before the visit, whilst in the commercial district they will respond flexibly and change their plan according to the situation. In the construction of our shop-around behaviour model we considered it important to place emphasis on incorporating this key characteristic. Therefore, our model evolved into a non-Markov model that inevitably differed from the existing models using the Markov chain. Moreover, Agent-Based Social Simulation (ABSS) involving an autonomous individual with intelligence, was selected as the best technique to reproduce these behaviours.

Taking into account the above points we are developing an ASSA (Agent Simulator for Shop-Around) with the functions of Planned Action and Improvised Action, and we have already succeeded in the development of a basic model, ASSA version 1.0 with the functions of 'Planned Action' and 'Alternative Visit' (Yoshida and Kaneda, 2007a, 2007b).

In this paper, we examine an aspect of improvised action that we have called "Erratic Visit", and we give an outline of ASSA version 2.0 that incorporates this Erratic Visit function into ASSA1.0. Moreover, we also verify the validity of this model by comparing our simulations with the results of shop-around behaviour analysis in the Osu District of Nagoya City, a busy shopping district with a wide variety of shops and high visitor numbers.

2. AN OUTLINE OF ASSA1.0

2.1 Examination of the Characteristics of Pedestrian Behavior

In this chapter, we give an outline of ASSA1.0, the shop-around behaviour agent model we developed before ASSA2.0.

Firstly, we examined Planned Action and Improvised Action, Table 1. shows the functional features of shop-around behaviour. Planned Action is carried out by a visitor before they visit the commercial district and involves scheduling the order and time of the facilities to be visited, followed by a

review of the plan. In contrast to this planned behaviour, the series of non-scheduled events generated by various factors and experienced by the visitor are called Improvised Action.

Taking the above into account, we tried to resolve the problem of shop-around behaviour by the use of 2 axes: process, and phase. We thought that we could divide the shop-around behaviour into 4 phases on the phase axis. That is, a) Plan Phase: make a plan before the visit; b) Do Phase: review that plan; c) Accident Phase: any non-scheduled event caused by an external factor; d) Revise Phase: modify the plan in response to the result of an event or the result of a non-scheduled act. Using this framework we considered we could divide the behaviour into 2 phases on the process axis: the visited facility, and the walked route. In this resolution, a) Plan Phase and b) Do Phase are classified as Planned Action, and c) Accident Phase and d) Revise Phase are regarded as Improvised Action.

Table 1. Functional Resolution of Pedestrians' Shop-Around Behaviour

Phase	Process		Meaning
	Facility Visit Decision	Path	
Plan Phase	Planned Action I (Planning)	Path Planning	Schedule
Do Phase	Planned Action II (Action)	Following Planned Path	Digest
Accident Phase	Erratic Visit	Detour Action	Insert
Revise Phase	Alternative Visit	Path Adjustment	Re-schedule

2.2 Concept of ASSA1.0

ASSA version 1.0 is a pedestrian agent behaviour model that incorporates 3 Phases: Plan Phase, Do Phase, and Revise Phase as shown in the previous section. To incorporate the 3 Phases, we designed our agent model to include the following three sub-models: (1) *Planning Model* at home; (2) *Shop-around Model* in the commercial district; and (3) *Travel Model* between home and the district.

Figure 1. shows the concepts for the agent behaviour model. (1) *Planning Model* actualizes the Plan Phase. In this model, a variety of errands and a time-budget are given to each agent; based on this given information and their own knowledge an agent generates the date and time to visit the commercial district, and makes a preliminary plan for their behaviour in the commercial district. (2) *Shop-around Model* actualizes the Do Phase and Revise Phase (in ASSA2.0 mentioned later, also includes an Accident Phase). In this model, in accordance with the plan generated in (1), each agent who visits the district walks to each of the facilities to complete each of their errands (Do Phase). If the agent fails to achieve their errand, Alternative Visit occurs in which their plan is changed as required (Revise

Phase). Moreover, based on the results of their behaviour within the district, the agent updates their own knowledge base and makes use of it for future visits to the district. Model (3) connects the above (1) and (2), and expresses a round trip between the agent's home and the district.

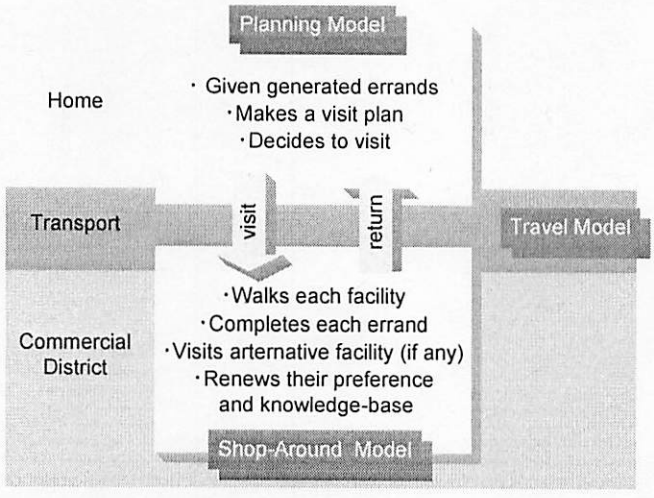

Figure 1. Concept of ASSA's Agent Behaviour Model

2.3 Assumptions Introduced to Develop ASSA1.0

To develop the model, we introduced the following assumptions:
(1) The city model has only one unipolar commercial district, and there is no other prominent commercial district in any other district.
(2) Direct interaction between agents does not occur.
(3) All agents already know all facilities and routes.
Our future research aims to improve these assumptions.

2.4 Behaviour Model of ASSA1.0

This section describes in detail the Planning Model and Shop-Around Model that are the major components of the agent behaviour models of ASSA1.0. The Planning Model consists of the following 4 modules:

(1) Errand Generation Module: generates errands that are to be carried out in the commercial district.
(2) Commercial District Visit Decision Module: makes decisions concerning the visit according to the number of errands.
(3) Time-Budget Generation Module: generates a time-budget that consists of the visit day and the possible time-bands for the visit.
(4) Plan-Making Module: generates a plan to efficiently complete the accumulated errands within the constraints of the time-budget.

By (4), the function of Planned Action I and Path Planning in Table 1. are completed.

The Shop-Around Model consists of the following 4 modules:

(1) Trip to Facility Module: expresses the moves each agent in the commercial district makes by applying the Dijkstra Method.
(2) Errand Achievement Module: decides the success or failure of an errand that the agent attempts.
(3) Alternative Visit Action Module: if the agent fails to complete the errand a decision is made whether to carry on with the errand, search for an alternative facility, or modify the plan.
(4) Post-Action Processing Module: after completion of the errands a decision is made concerning the return to home and preferences are updated.

The following functions are completed: Following Planned Path by (1), Planned Action II by (2), and Alternative Visit and Path Adjustment by (3).

3. VERIFICATION OF ASSA1.0: CASE STUDY OF THE OSU DISTRICT

3.1 Application of ASSA1.0 to Osu District

In order to evaluate the validity of ASSA1.0, We executed simulations based on existing research data (Oiwa, Yamada, et al., 2005), using a case study of the Osu District, Naka-ku, Nagoya City (Figure 2.). In this chapter, we explain the results and analysis of this simulation.

The Osu District was modelled as shown in Figure 3., with 35 streets, including 12 crossroads, 7 facility types and 685 facilities.

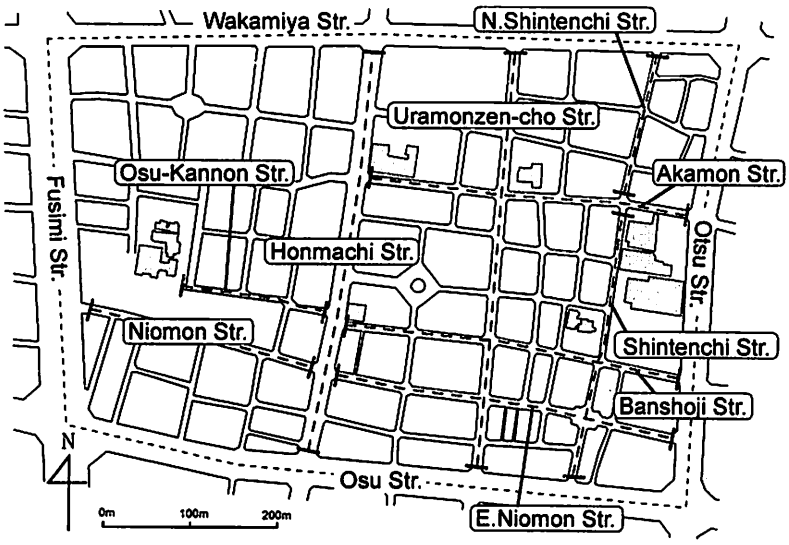

Figure 2. Osu District, Nagoya City

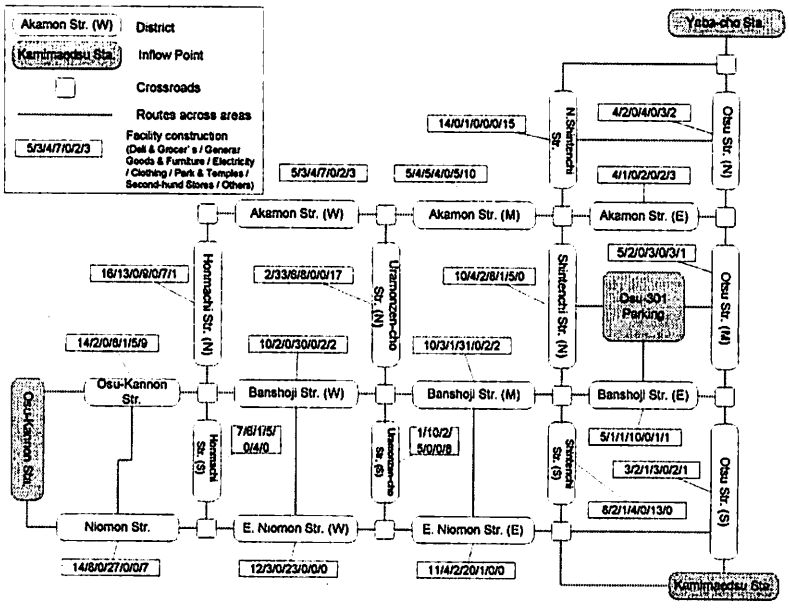

Figure 3. Spatial Model of the Osu District

3.2 Illustration of Observed Simulation Agent Behaviour

This section illustrates the validity of the model by observing each agent's behaviour that was obtained from a simulation using the previously described model.

For example, Figure 4. shows the behaviour locus when on the 70th day an agent No.65 visited the commercial district. This agent is a housewife in her 30s or 40s and resident in the long distance zone; the agent planned to visit Facilities (1): Appliances, (2): Deli & Grocer's, (3): Deli & Grocer's, (4): Second-Hand Store and (6)Deli & Grocer's and travelled to the commercial district by car. When checking the behaviour results, after the agent parked her car in the "Osu-301 Parking Lot", she visited (1) and in this facility failed to complete her errand; improvised action then chose (5), as an alternative facility. This alternative reorganization of the plan resulted in (5) being inserted between (4) and (6). The agent then visited (2), (3) and (4), and in Facility (4) she again failed to complete her errand and an alternative facility, (7) was chosen. She then visited (5) and completed the errand originally planned for (1); moreover, the agent visited (6) and (7) and left for home from the "Osu-301 Parking Lot", her original entry point.

From these results, it was found that the model expresses the following situation: according to the success or failure of an errand, the agent generates improvised action and while rearranging the behaviour plan, the agent walks around the district. From those behaviour results, it was confirmed that planned action and improvised action, which are key features of random behaviour, are expressed in the model and it can be confirmed that these functions of ASSA1.0 achieve this objective.

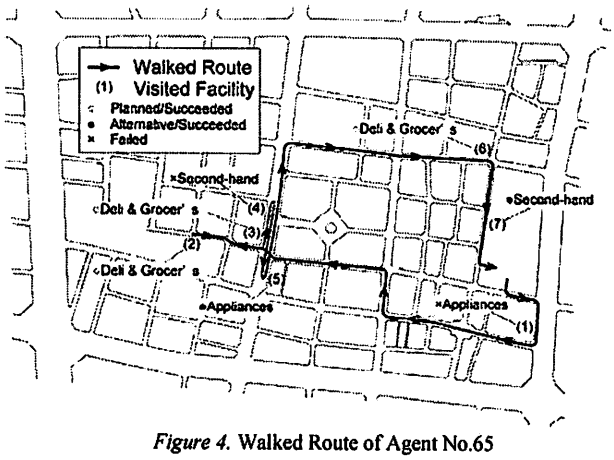

Figure 4. Walked Route of Agent No.65

3.3 Comparative Analysis Between the Simulation Results and the Survey Result

This section presents the analysis of the results of the agents' behaviour we obtained from the simulation and by comparing them with the survey results of the actual district, checks the operation, and verifies the validity of the model. When the simulation was conducted, we established a condition of 2,500 agents living in the city and conducted a 10-day trial run; we then ran the simulation for 120 days, and calculated the average daily values of pedestrian behaviour in the district as shown in the figure.

Table 2. shows the comparison between the simulation result of using ASSA1.0 and the survey result by Oiwa, Yamada, et al. (Researched in 2003). Concerning the number of facilities visited, the simulation result is less than the survey result, but overall it nearly corresponds to the number of scheduled visited facilities. They show that non-scheduled stopping of the simulation result is less than that found in the survey, this could be accounted for by the lack of Erratic Visit and Detour Action – more improvised behaviours. With regard to the walking distance distribution, the simulation adopted time distance and the result is shown as a reference. Generally a pedestrian's unrestricted walking speed is taken to be about 1.2 to 1.5m/s, giving a simulation distance of about 1.13 to 1.41km.

Table 2. Comparison between ASSA1.0 Simulation Results and the Survey Results

	ASSA1.0 Simulation Results	Survey Results
Stay Time in the District	142 min	148 min
Walk Distance	15.7 min	1.15 km
Number of Visited Facilities	3.17 places	5.00 places
Number of Visited Facilities (scheduled)	2.17 places	2.18 places

4. CONSTRUCTION OF ERRATIC VISIT MODEL

4.1 Erratic Visit in Shop-around Behaviour

This section presents an examination of the Erratic Visit function and its implementation. In this paper, Erratic Visit is defined as "an impromptu visit to a facility in the commercial district, that is neither Planned Action nor an Alternative Visit." Erratic Visit expresses the completely spontaneous behaviour of an agent; such behaviour is not found in the original plan and is a response to an unknown stimulus. Therefore, this behaviour can be

classified by motive as shown in Table 3. However in a broad sense, Type-II can be included in Planned Action and Alternative Visit, because in this case it possibly refers to potential motives known before the plan was drawn up. Consequently, in the following, Type-I defined Erratic Visit in a narrow sense, and unless specially mentioned it can be assumed that we dealt only with this type.

Table 3. Classification of Erratic Visit by Motive

Type-I	Impulse visit generated to recognize the target facility by passing by or seeing its signboards or posters	
	Ia	Target facility is unknown before recognition
	Ib	Target facility is already known before recognition
Type-II	Visit in the event that motive was generated after the plan was drawn up	
	IIa	Generated motive specifies the target facility
	IIb	Generated motive does not specify the target facility

4.2 Assumptions Introduced to Develop the Erratic Visit Model

As mentioned above, in ASSA1.0 we have assumed that all agents already know all facilities and routes. When developing the Erratic Visit model, we continuously used this assumption, so there is no guarantee that Erratic Visit Type-Ia will occur. Therefore, only Type-Ib is implemented in this model.

4.3 Outline of Erratic Visit Model

This section describes the developed Erratic Visit model in detail.

First, each agent that stays in a street in the commercial district receives facility information value I_{FC} from each facility located on that street. I_{FC} is a value to express the appeal of each facility.

Next, the received I_{FC} is modified by W_{FT}. W_{FT} is a value unique to each agent and expresses the facility preference of that agent. But all this information is not automatically reflected in the agent's behaviour. Each agent assesses the information up to the highest n pieces with a sequentially high value gained from this information, and this is then reflected in their actions.

Then, motivated by I_{AVE}, and by considering γ, an agent decides whether to choose Erratic Visit to determine whether or not to visit a facility. I_{AVE} is an average value of I_{FC} of n pieces, and γ is the margin time rate for action. At this time, γ is defined as follows.

a) When there is a fixed constraint* in the next errand

$$\gamma = t_R / t_A$$

t_R: remaining time possible to stay
t_A: total time possible to stay

b) When there is no fixed constraint* in the next errand

$$\gamma = 1 - \frac{t_L}{t_C - t_N}$$

t_L: time distance to destination
t_C: time constraint of next errand
t_N: current time

*fixed constraint: reserved time necessary to complete that errand

If Erratic Visit is decided by the above criteria, each agent decides which facility to visit. When this decision is made, the agent considers the picked up I_{FC} and W_{FC}. W_{FC} are values to express their preference for each facility. Moreover, if modification of the visit plan is needed during this visit, the agent changes the plan using the Alternative Visit function. Figure 5. shows that algorithm described above.

So, we implemented the above-mentioned model as an Erratic Visit Module to the Shop-Around Model of ASSA1.0, and we named this model ASSA version 2.0.

5. A SIMULATION USING ASSA2.0 AND VERIFICATION OF ITS RESULTS

5.1 An Outline of The Simulation using ASSA2.0

We executed the simulation intended for the Osu district and verified the validity of ASSA2.0 as well as the time of ASSA1.0. When the simulation was executed, we made it equal to the one that used ASSA1.0 to allow comparison.

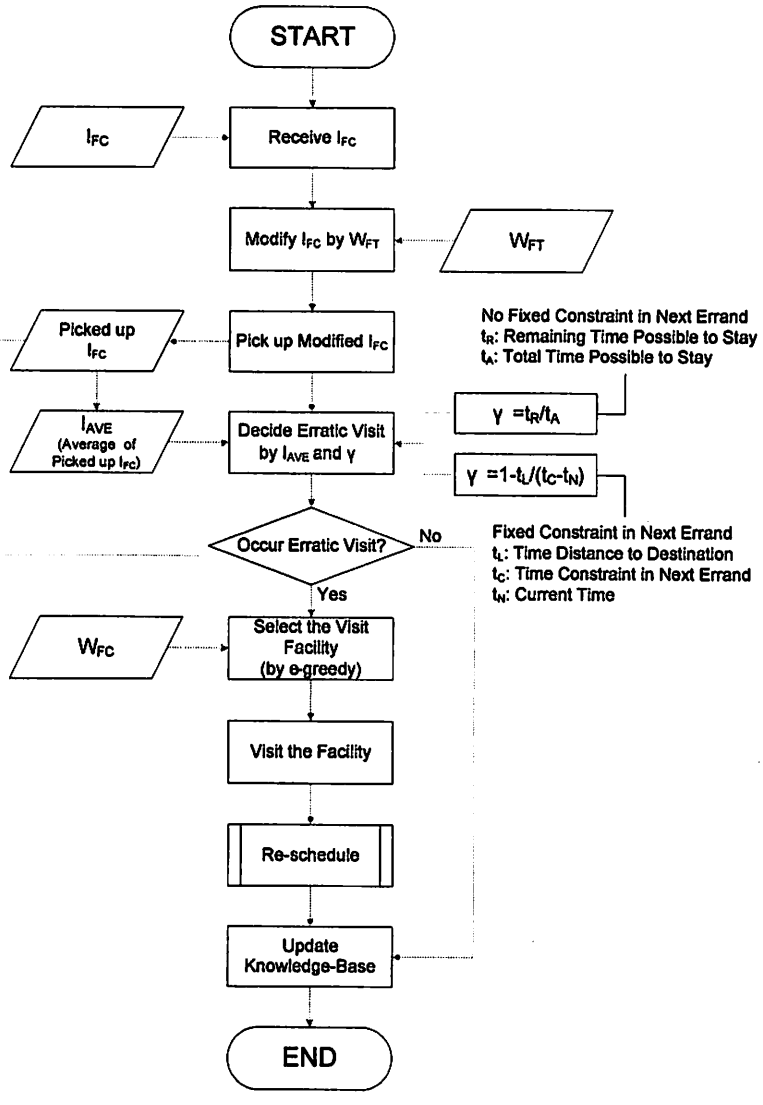

Figure 5. Algorithm of Erratic Visit Model

5.2 Verification of the Erratic Visit Function by an Illustration of Agent Behaviour

This section illustrates the results of verification of the Erratic Visit Module by observing each agent's performance from the results of a simulation using ASSA2.0. As a sample, Figure 6. shows the behaviour locus when agent No.1433 visited this district on the 18th day. He is a male agent, more than 50 years old, resident in the middle distance zone, and travelled to the district by train. He had a schedule to visit facilities (3) and (2) (both Clothing Stores) in turn in his plan, but in his actual action, he also visited (1) Park & Temples and (4) Deli & Grocer's. Just after his visit to (1), he reversed the visit order of (2) and (3) in his original schedule; the route was also modified with his new visit order. The visits to (1) and (4) are due to Erratic Visits, because these visits occur without any relation to the pre-scheduled two visits. The reason why the visit order is modified, he didn't want to delay his reservation in his visit to (2), and then he made the visit to (3) to delay.

From these results, it can be found that the Erratic Visit model simulates the following situation: the agent generates Erratic Visits within the commercial district, and the agent's plan after that time is modified in connection with Erratic Visit, and the implementation of the Erratic Visit function which is the objective of ASSA2.0 was successfully verified.

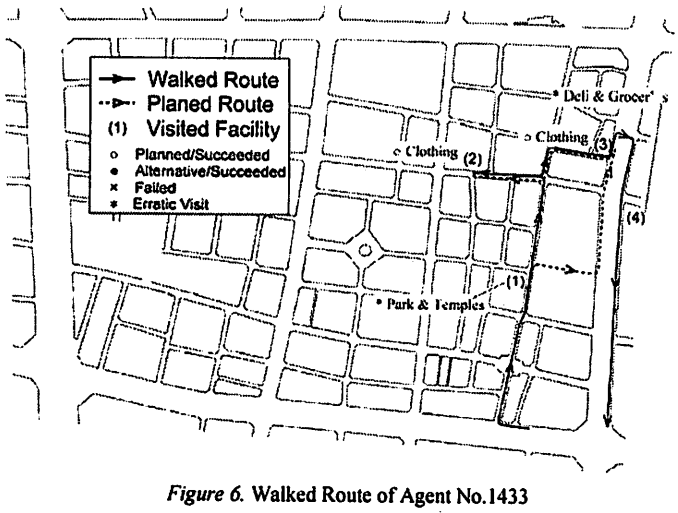

Figure 6. Walked Route of Agent No.1433

5.3 Verification of Usefulness of ASSA2.0 Seen from the Behaviour Result of Agent Group

This section presents the comparison of the ASSA2.0 and ASSA1.0 simulation results and the survey results, and verifies the validity of ASSA2.0.

Table 4. shows the comparison results (the execution conditions of ASSA2.0 were made equal to that of ASSA1.0 in section 3.3). In the ASSA2.0 simulation results, the stay time in the commercial district increased by 4 minutes, and the number of visited facilities increased by 1.48 places more than ASSA1.0. These increases are due to all Erratic Visit functions because there is no change in the number of scheduled visited facilities. On the other hand, the average walk distance decreased to 0.7 minute, converting to a distance of nearly 50~60m. Because the margin time decreased by generating Erratic Visit, a possible reason for this difference is each agent chose closer facilities when searching for facilities in Alternative Visit.

From this result, it can be confirmed that the fit of the simulation result improved in both the stay time in the commercial district and the number of facilities visited. Especially, we also achieved an excellent fit with the number of visited facilities. From this point, it can be said that this extension improved the performance of ASSA.

Table 4. Comparison of ASSA2.0 Simulation Results and Other Results

	ASSA2.0 Simulation Results	ASSA1.0 Simulation Results	Survey Results
Stay Time in the District	146 min	142 min	148 min
Walking Distance	15.0 min	15.7 min	1.15 km
Number of Visited Facilities	4.65 places	3.17 places	5.00 places
Number of Visited Facilities (scheduled)	2.17 places	2.17 places	2.18 places

6. CONCLUSION AND FURTHER WORKS

In this Paper, we presented the following three research results: 1) we classified pedestrian shop-around behaviour in a commercial district by the phase axis and process axis, and defined the Erratic Visit function of this behaviour, 2) Next, we constructed an Erratic Visit Model where all facilities and routes are known, 3) Then, we simulated the shop-around behaviour in the Osu district using ASSA2.0 with an implemented Erratic Visit Module, and confirmed that the performance of ASSA was improved.

Our next step is to continue reviewing the assumptions made to date and improve the construction of ASSA by building models with functions which are not modelled in classified shop-around behaviour.

We will also consider the evaluation system of the shop-around behaviour and will try to express the interaction between visitors and facilities by the construction of a facility agent model.

REFERAENCES

Borgers, A.,Timmermans, H.A., 1986, "A Model of Pedestrian Route Choice and Demand for Retail Facilities within Inner-city Shopping Areas", *Geographical Analysis No.18*, p. 115-128

Kaneda, T., Yokoi, S., Takahashi, S., 2001, "Development of Pedestrian Shop-around Behavior Model Considering Transition between Facilities", *Simulation & Gaming volume 11*, p. 17-23 (in Japanese).

Kurose, S., Borgers, A., Timmermans, H.A., 2001, "Classifying Pedestrian Shopping Behavior according to Implied Heuristic Choice Rules", *Environment and Planning B No.28*, p.405-418.

Oiwa, Y.,Yamada, T., Misaka, T., Kaneda, T., 2005, "A Transition Analysis of Shopping District from the View Point of Visitors' Shop-around Behaviors", *Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan No.22*, p. 469-474 (in Japanese).

O'kelly, M., 1981, "A Model of the Demand for Retail Facilities, Incorporating Multistop, Multipurpose Trips", *Geographical Analysis No.13-2*, p. 134-148.

Saito, S., Ishibashi, K., 1992, "Forecasting Consumers' Shop-around Behaviors in an agglomerated within a City Center Retail Environment after its Redevelopments using Markov Chain Model with Covariates", *Journal of City Planning Institute of Japan No. 27* p. 439-444 (in Japanese).

Saito, S., Kumata, Y, Ishibashi, K., 1995 "A Choice–based Poisson Regression Model to Forecast the Number of Shoppers –Its Application to Evaluating Changes of the Number and Shop-around Pattern of Shoppers after City Center Redevelopment at Kitakyushu City-", *Journal of City Planning Institute of Japan No. 30*, p. 523-528 (in Japanese).

Sakamoto, T., 1984, "An Absorbing Markov Chain Model for Estimating Consumers' Shop-around Effect on Shopping Districts", *Journal of City Planning Institute of Japan No. 19*, p. 289-294 (in Japanese).

Takadama, K., 2000, "Multiagent Learning –Exploring Potentials Embedded in Interaction among Agents-", *Corona Publishing Co., Ltd.*, (in Japanese).

Yoshida, T. and Kaneda, T.,2007a, "An Architecture and Development Framework for Pedestrians' Shop-Around Behavior Model inside commercial district by using Agent-Based Approach", *Computers in Urban Planning And Urban Management 2007*, No.135.

Yoshida, T. and Kaneda, T., 2007b, "A Simulation Analysis of Shop-around Behavior in a Commercial District as an Intelligent Agent Approach -A Case Study of Osu District of Nagoya City-" *Agent-Based Social Systems Sciences 2007*, p. 210-221.