AN ARCHITECTURE AND DEVELOPMENT FRAMEWORK FOR PEDESTRIANS' SHOP-AROUND BEHAVIOR MODEL INSIDE COMMERCIAL DISTRICT BY USING AGENT-BASED APPROACH

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Abstract: This paper deals with our research and development plan for a simulation model of pedestrians' shop-around behavior in a commercial district using an agent-based approach; particular attention was paid to the planned actions and improvised actions of agents.

The authors think that the pedestrians' shop-around behavior can be categorized in 4 levels, and the model was designed to express the two levels of functions mentioned above. Our pedestrian agent model consists of 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. So as to more clearly represent the outflow insertion of a commercial district visitor it is modeled as a unipole-city.

In addition, we ran this model in order to use it as a prototype for application to the Osu District of Nagoya City. Based on the simulation results, the behavioral performance of some pedestrian agents is illustrated.

Keywords: Agent-Based Social Simulation, Pedestrians' Shop-Around Behavior, Planned Action, Improvised Action

1. RESEARCH BACKGROUND AND OBJECTIVES

In large modern cities, the behavior patterns of visitors to commercial districts have become increasingly diversified. For this reason, when the composition of a bustling commercial district is considered, it presents an excellent opportunity to analyze pedestrian micro behavior using a bottom-up approach. In such an analysis, pedestrians’ shop-around behavior within the commercial district is the key factor to focus attention upon. Because, it is evident that each pedestrian’s shop-around behavior consists of multiple units 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 pattern of behaviors built up is closely related to the effect of the positioning and accumulation of facilities in a commercial district. Accordingly, development of a simulation model of pedestrians’ shop-around behavior in a commercial district can be a useful tool for analyzing the composition of a commercial district.

The following research on pedestrian behavior models are all worthy of mention: an absorbing Markov chain model by Sakamoto (1984), prediction of change employing a Markov chain by Saito and Ishibashi (1992), and a fusion of a Huff model and a Markov chain model by Yokoi, et al. (2000). However, these models do not give an explicit expression of planned action and improvised action, both of which are key characteristics of pedestrian behavior. In addition, with regard to diversification in the selection patterns of facilities by visitors, a modeling method that is suitable for a greater variety of expressions should be developed. To cover this point, it would seem a valuable model is Agent-Based Social Simulation (ABSS) involving an autonomous individual with intelligence; however, a model utilizing this method has not been established yet. Therefore, there is a need for a simulation model that addresses these issues.

From the above viewpoints, the research describes a framework for the development of a simulation model employing an agent capable of random behavior and that is also equipped with both planned action and improvised action. The research also shows the simulation results of a prototype.

2. GENERAL CONCEPTS OF A PEDESTRIAN BEHAVIOR AGENT MODEL

2.1 Examination of the Characteristics of Pedestrian Behavior

First of all, planned action and improvised action, which are key characteristics of pedestrian behavior, were examined. In the research, pedestrian behavior is classified into 4 levels. Level 1 is Planned Action: before visiting a commercial district the visitor schedules their destination and the facilities to visit within a certain period of time. The remaining three levels are all categorized under the heading improvised action: Level 2 is Alternative Visit: when the visitor trips to facilities, if fails to achieve their errand then tries to visit alternative facilities. Level 3 is Erratic Visit: a visitor unexpectedly drops into other facility other than the planned or alternative ones. And Level 4 is Detour Action: the visitor deviates from the shortest route. Table.1 shows the hierarchical characteristics of the above-mentioned pedestrian behavior. The research addressed behavior model architecture for an agent that conducts Planned Action and Alternative Visit.

Table.1 Functional Levels of Pedestrians' Shop-Around Behavior

Level of action	Significance	Motivation
Detour Action(DA)	Walking out of the shortest route	Route preference, Information gathering
Erratic Visit(EV)	Visit a facility expect AV & PA	Facility preference, Information gathering
Alternative Visit(AV)	Visit an alternative facility expect PA	Try to visit another facility when the errand failed
Planned Action(PA)	Visit planned facilities	Efficient errand achievement under the constraints

2.2 Assumptions Introduced for Establishing a Model

To establish the model, the following assumptions were introduced:

(1) A 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.

- The model can express the following interactions: interactions inside the home of each agent, and group behavior with acquaintances and friends in a commercial district; such interactions, however, are not included in the model.

(3) All agents already know all facilities and routes.

- Essentially, it is preferable that an agent increases and updates their knowledge of facilities and routes through learning by themselves; however, at the present stage, to simplify the model, this process was omitted.

(4) Erratic Visit and Detour Action are not examined.

- For the establishment of the model, expression of planned action and improvised action were given priority and therefore, erratic and detour behavior, which occur spontaneously, were omitted. As our further research is to plan to include these two assumptions.

2.3 Agent Behavior Model

When a unipolar commercial district is assumed, the agent behavior model consists of the following three models: (1) Planning Model at home; (2) Shop-Around Model in the commercial district; and (3) Travel Model between their home and the commercial district. In Model (1), a variety of errands and 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 a preliminary plan for their behavior in the commercial district. In Model (2), in accordance with the plan generated in (1), an agent who visits a commercial district walks to each of the facilities for the purpose of fulfilling their errands. If the agent fails to achieve their errand, improvised action, in which the plan is changed as required, then occurs. Moreover, based on the results of their behavior within the district, the agent updates their own knowledge base and makes use of it for a future visit to the commercial district. Model (3) connects the above (1) and (2), and expresses a round trip between the agent's home and the commercial district. Fig. 1 shows the concepts for an agent behavior model as mentioned above.

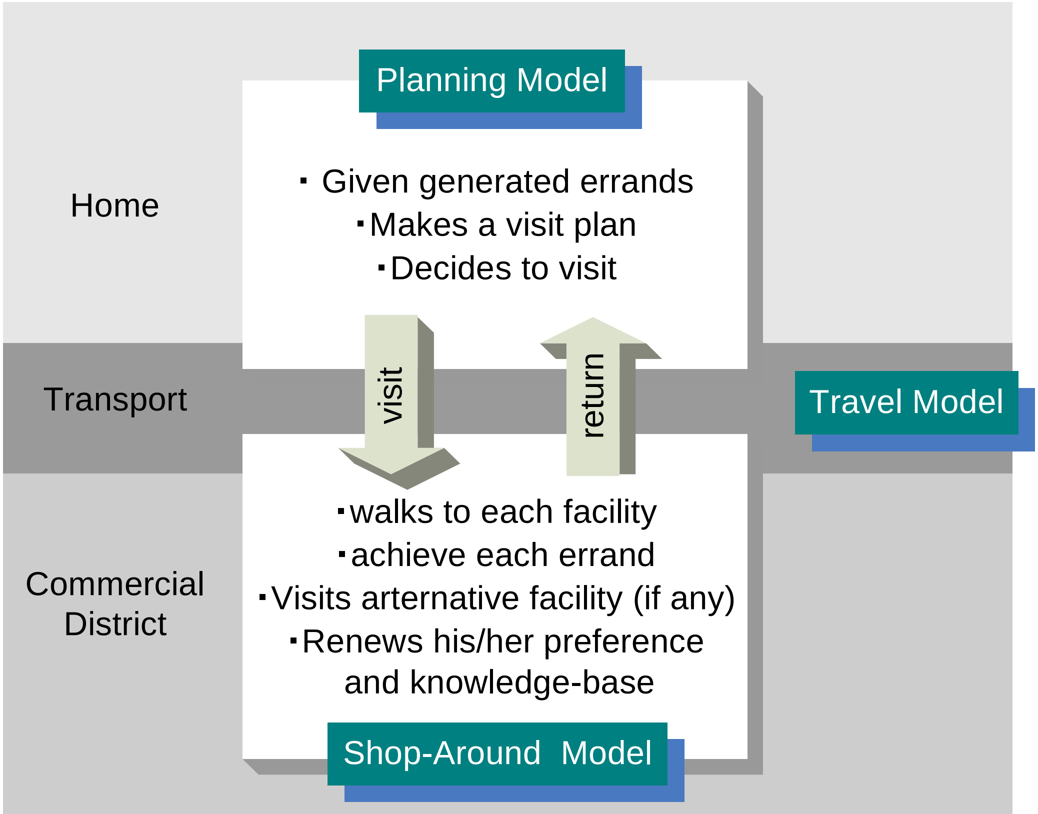

Figure.1 Concept of Agent Behavior Model

2.4 Hierarchical Model of A Commercial District

A spatial model of a commercial district is expressed as three levels of hierarchical structure made up from the following five categories: (1) Whole District Model that expresses the whole commercial district; (2) an Area Model that expresses each area of the commercial district; (3) Routes across areas that connect with other areas; (4) facilities that exists in each area; and (5) routes that connect the facilities in each area. District Model (1) holds the highest ranking within the entire model and includes Models (2) and (3). In the same way, Area Model (2) includes Models (4) and (5). Fig. 2 shows the basic concepts for a spatial model of the commercial district mentioned above.

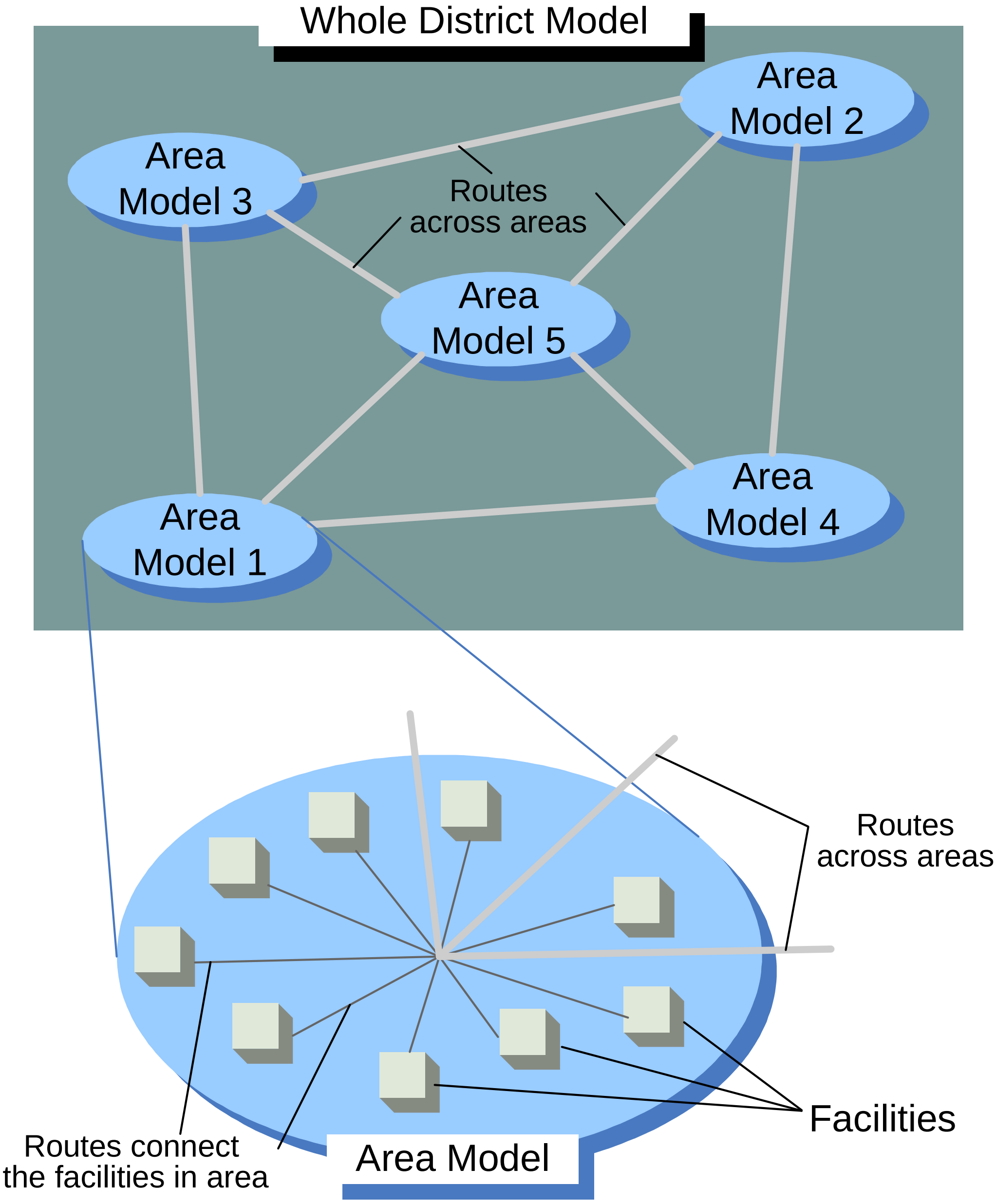

Figure.2 Concept of 3-layered District Spatial Model

3. DEVELOPMENT OF AN AGENT BEHAVIOR MODEL

3.1 Setting Attributes of An Agent

Based on the analysis results of existing behavior research, the following five criteria were set as an agent's attributes.

- Sex (Male / Female)
- Address (Short distance / Middle distance / Long distance)
- Age (Less than 30 / 30 to 49 / 50 or more)
- Occupation (Company employee / Self-employed / Housewife / Student)
- Transportation means (Railway / Car)

3.2 Planning Model

Planning Model expresses an agent's action about from given an errand to visiting the commercial district, and consists of the following four modules: (1) Errand Generation Module: a module to generate an errand, (2) Commercial District Visit Decision Module: a module to make a decision for a visit to a commercial district, (3) Time-Budget Generation Module: a module to generate a time-budget, and (4) Plan-Making Module: a module to form a plan. Fig. 3 shows this series as a flowchart.

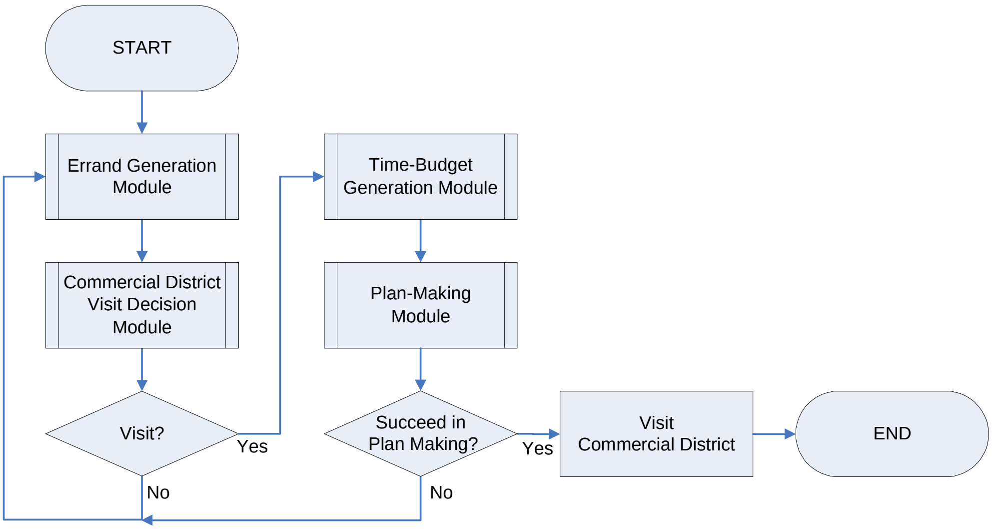

Figure.3 Flowchart of Visit Preparation Model

3.2.1 Errand Generation Module

The errand generation module is a module to give each agent errands which the agent must achieve in the commercial district; n is the number of errands per day given to each agent and is generated by using a Poisson probability with ***λ=0.17***, in accordance with reverse assumptions generated from the research results. Each errand consists of four categories of property value: type (equal to facility type), target facility, time required for achievement, and constraint type. Methods to determine each property are described below.

(1) For the type, a selection probability is found from an errand type selection matrix that follows an agent's attributes and the type is determined for each agent by using random numbers.

(2) Target facility is selected by searching the knowledge base held by each agent and finding a facility that conforms to the type determined in the foregoing paragraph. For search and selection, the ε-greedy method is implemented; it is assumed that from among the relevant facilities, a facility with the largest value of preference variable ***w*** with a probability ***(1-ε)***, will be selected. The relevant facilities are selected randomly with a probability ***ε*** (however, any facility with which ***w*** has a negative value is excluded).

(3) Time required for achievement is generated from a normal distribution with a mean of μ and a standard deviation of ρ, which are given to each errand type.

(4) For constraint type, one of the following six types is randomly given for each

errand.

1. Both-Reserved Type: both beginning and ending time of errand are reserved. (ex. concert or movie)
2. Begin Reserved Type: beginning time of errand is only reserved. (ex. restaurant or hospital appointment)
3. Both Sides Limited Type: both opening and closing time of the facility become limited within his/her stay time.
4. Open-Time Limited Type: opening time of the facility becomes limited within his/her stay time.
5. Close-Time Limited Type: closing time of the facility becomes limited within his/her stay time.
6. Free Type: there is no constraint to both beginning and ending time of errand.

Table.2 Estimated Values to calculate $\boldsymbol{\lambda_v}$

	Attribute of Agent	Value
Sex	Male	0.926
	Female	1.108
Address	Short distance	0.828
	Middle distance	1.510
	Long distance	1.884
Age	Less than 30	0.857
	30 to 49	1.184
	50 or more	0.820
Occupation	Company employee	1.107
	Self-employed	0.481
	Housewife	1.472
	Student	0.885

3.2.2 Commercial District Visit Decision Module

When the number of errands for an agent is $\boldsymbol{x}$, it is assumed that the probability $\boldsymbol{p}$ of the agent trying to inflow to the commercial district is generated from the cumulative Poisson distribution as shown below.

$$\boldsymbol{p} = \sum_{i=1}^{x} \lambda_v{}^{x} e^{-\lambda_v} / x! \tag{1}$$

Where, $\boldsymbol{\lambda_v}$ is determined according to the attributes of an agent and by using the values given in Table. 2, as shown below.

$$\lambda_v = \lambda_g \cdot \lambda_{ad} \cdot \lambda_{ag} \cdot \lambda_w \cdot \alpha \quad (2)$$

α is a constant given as the city proper parameter. The values in Table. 2 were found through the data analysis of research on behavior in Osu district, which is described later.

3.2.3 Time-Budget Generation Module

After an agent's visit to a commercial district is determined, the date of the visit is generated with Poisson probability and the allocated time period for agent behavior is generated with a normal distribution probability; these conditions are given to the agent and this is called "time-budget".

3.2.4 Plan-Making Module

This is a model to generate a behavior plan for a round-trip between the home and the commercial district and to efficiently include as many errands as possible within the given time-budget. To generate the optimum solution that satisfies any constraints applied to the errands, the following algorithm (Fig. 4) was introduced.

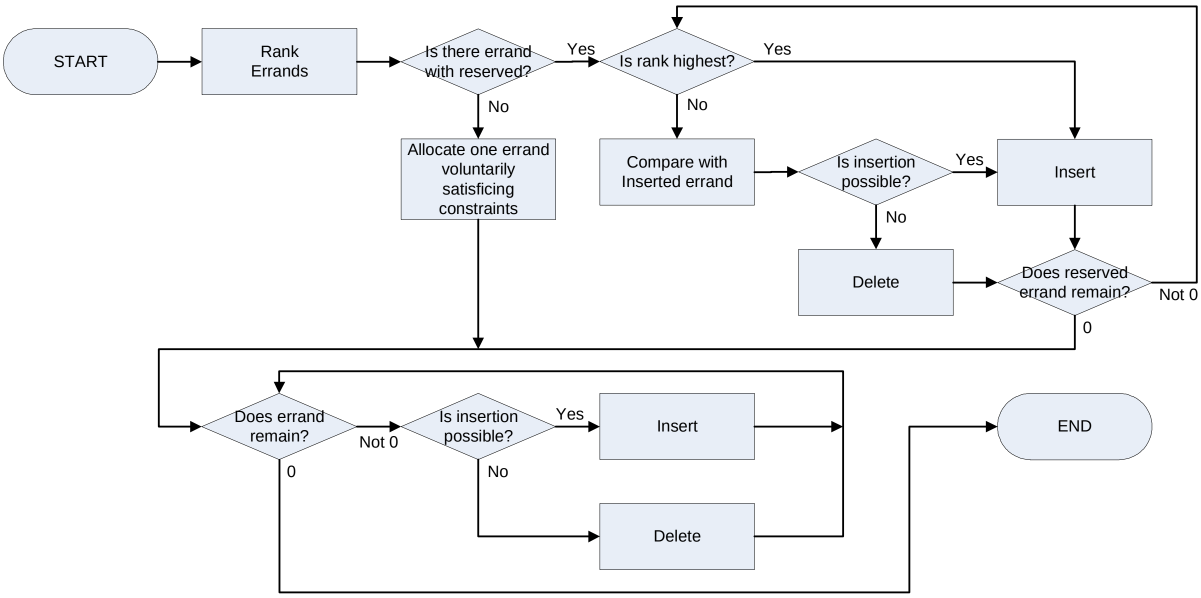

Figure.4 An algorithm of Making Plan

Step.1 All errands are randomly ranked.
Step.2a Any reserved errands are fixed first.
Step.2b When there are no reserved errands, allocate only the highest ranked errand first.
Step.3 After Step.2a or 2b have been fixed, any remaining reserved errands are assigned to any vacant slots in accordance with their ranking.
Step.4 When all errands have been assigned or it is impossible to assign any of the remaining errands, finish the allocation and alternative them in an array as a draft plan.
Step.5 Repeat Step.1 to 4 several times. (10 times in the simulation mentioned later)
Step.6 Evaluate the generated draft plans in lexicographic order by using two

variables: the number of errands and length of scheduled stay time, and select the plan with the highest value.
Step.7 Delete unselected errands.
Step.8 Select an entry point that is closest to the facility for the first errand of the plan and this is regarded as the inflow point to the commercial district.

Fig. 5 shows an example of forming a plan using the above algorithm.

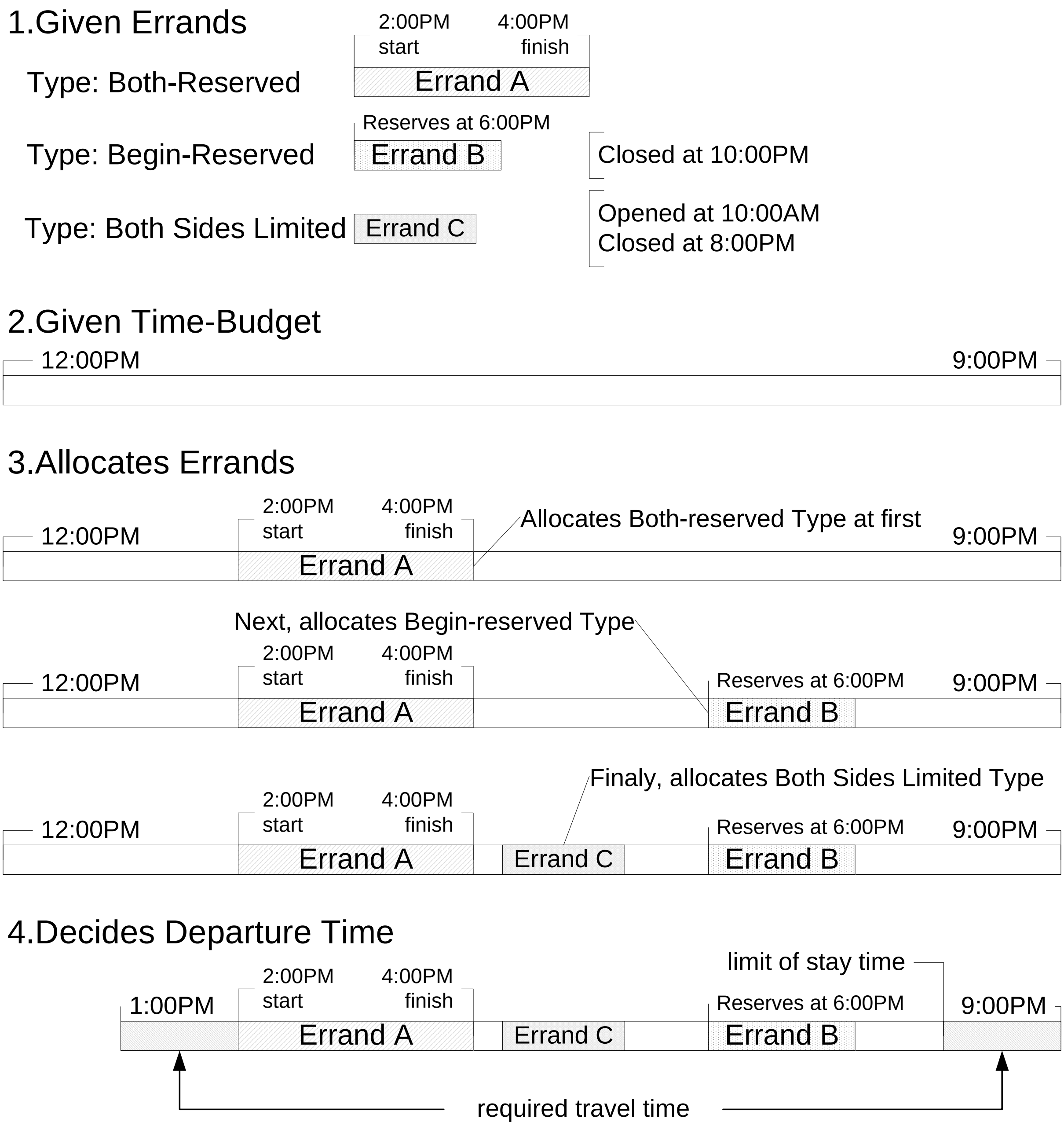

Figure.5 An Example of Plan-Making Process

3.3 Shop-Around Model in A Commercial District

Shop-Around Model in a commercial district consists of four modules: (1) Trip to Facility Module; (2) Errand Achievement Module; (3) Alternative Visit Action Module; and (4) Post-Action Processing Module. Fig.6 shows this series as a flowchart.

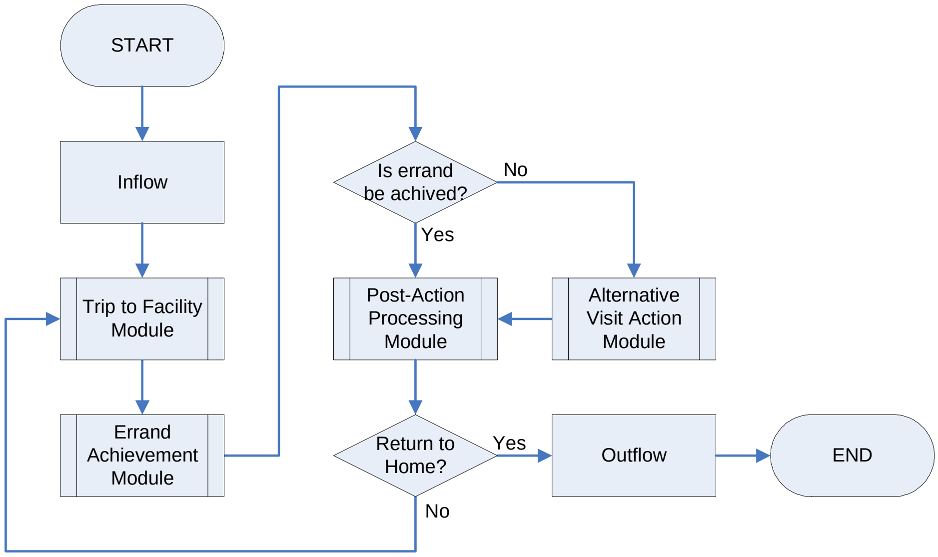

Figure.6 Flowchart of Shop-Around Model

3.3.1 Trip to Facility Module

This is a module to express the movements of an agent inside a commercial district. After each agent arrives at the commercial district, they read the properties of the facility corresponding to the first errand of the plan and set the area of the relevant facility as their destination. Then, the shortest path to the destination is calculated using the Dijkstra method, and in accordance with this calculation, the agent trips to the facility. After the agent arrives at the destination, if the time constraint is satisfied, the execution of an errand achievement module is immediately started; if not, the agent waits at the destination.

3.3.2 Errand Achievement Module

Success or failure of an errand is determined when an agent takes an action to complete an errand at a particular type of store in a facility. After the start of the execution of the errand and when the time required for achievement has ended, an achievement probability determines whether the errand is achieved or failed.

3.3.3 Alternative Visit Action Module

If the achievement of the errand is failed, a decision is made whether to carry on with the errand and a search for an alternative facility and reorganized of the plan are carried out. In the search for an alternative facility, the ε-greedy method is applied and it is assumed that the relevant facilities are randomly selected with probability ***ε*** and an alternative facility with a performance function, as shown below, being the largest value with probability ***(1-ε)***, will be selected.

$$f(l,\beta) = w \cdot \beta + (1-\beta)/(l+1) \tag{3}$$

$$\beta = t_R / t_A \tag{4}$$

- ***w*** : preference value of the chosen type of facility
- ***l*** : the distance between the agent's present location and the alternative facility (calculated from the Dijkstra method)
- t_R : remaining time in which the agent can stay in the commercial district
- t_A : total time in which the agent can stay in the commercial district

After an alternative facility is selected, the plan making module is called up and the plan is reorganized. When β is less than 0.1 in Expression 3, or a fixed constraint is given to the errand, the search for an alternative is stopped and action to achieve the next errand is taken.

3.3.4 Post-Action Processing Module

After decision for the achievement of the errand is made, this module describes the processing that is carried out for the agent. More specifically, two types of processing are carried out: (1) update of preference variable w; and (2) decide for returning home.

The update of the preference value is dependent on the success or failure of the errand achievement, and the value that follows a normal distribution with a mean of $\mu=3$ and a standard deviation of $\rho=1$ is added for the successful completion of an errand, and subtracted for a failure. This update algorithm can be considered as a form of reinforcement learning algorithm.

With regard to the decision for returning home, when the agent has achieved all errands, or the allocated time period for his/her action has ended, returning home is then selected. At this time an exit point is set: a car user returns to their car in the parking lot where they first visited the commercial district; and for a rail traveler, the nearest station from the present location.

3.4 Travel Model between Home and Commercial District

This model expresses a round-trip between home and the commercial district. In the case of a visit to the commercial district, when the agent has left home and the time set for transportation T has elapsed, the agent appears at the inflow point to the commercial district, which was set in the plan making model. Conversely, when the agent leaves the commercial district, the agent moves to the exit point that was set in the post-behavior processing model, and after the time set for transportation T has elapsed, the agent arrives home. The time set between home and the commercial district T is set in accordance with the agent's place of residence.

4. VERIFICATION OF THE MODEL WITH SIMULATION: CASE STUDY OF OSU DISTRICT

4.1 Application to Osu District

Based 491 pedestrian data (male, 47.2%, female, 52.3%) from questioning survey in 2003 (Oiwa et al, 2005), in order to evaluate the validity of the simulation model, simulation was conducted using a case study of Osu District, Naka-ku, Nagoya City (Fig. 7).

When Osu District was modeled, the whole area of Osu District was applied as Whole District Model, and each shopping street was an Area Model. This resulted in 24 areas, 7 facility types, and a total of 685 facilities (Fig. 8). For a probability of an agent visiting the commercial district, $\alpha=2.13$ was assumed in Expression 2, the standard time spent in each facility type was set in Table.3, and an errand type selection matrix was set in Table.4. The initial value of a preference variable for all facilities was set in accordance with a normal distribution, using $\mu=5$ and a standard deviation of $\rho=2$. With regard to the attribute that expresses an agent's place of residence, a short distance refers to places inside Nagoya City (it takes a half hour), a middle distance refers to places outside of Nagoya City and inside Aichi Prefecture (it takes one hour), and a long distance refers to places outside of Aichi Prefecture (it takes one and a half hours).

With regard to routes, connect the centers of each area, and each area connect each facility. In this simulation, the distance of the route in an area was assumed as all 0; therefore, there is no difference in distances between facilities in the same area.

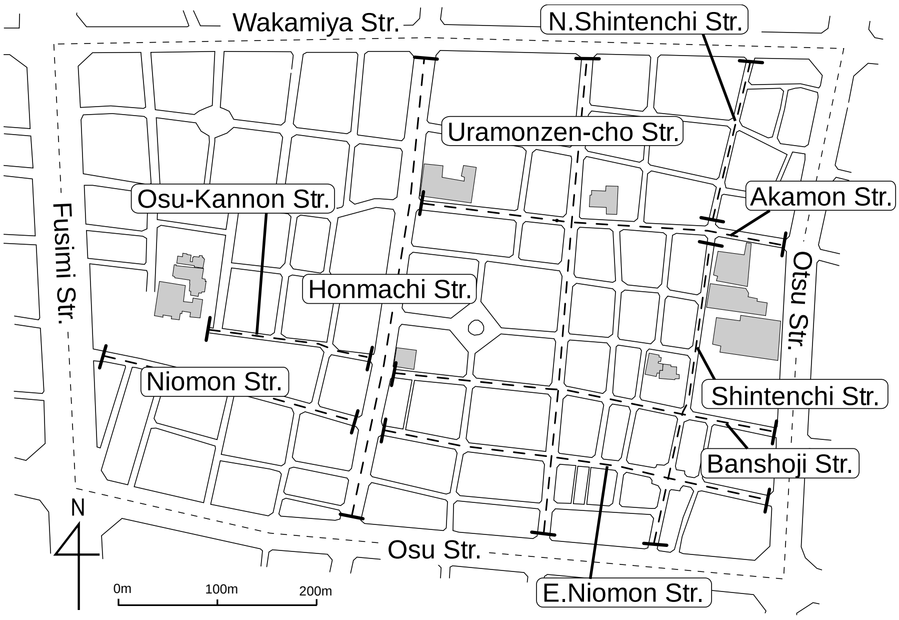

Figure.7 Osu District, Naka-ku, NagoyaCity

Table.3 Base Data of Stay Time each Facility Type

Facility Type	μ(min)	ρ(min)
Deli & Grocer’s	26.37	17.39
General Goods & Furniture	17.09	16.12
(Electric) Appliances	25.21	21.05
Clothing	25.68	54.93
Park & Temples	12.56	8.81
Second-hand Store	34.17	25.03
Others	60.75	122.26

Table.4 Errand Type Distribution

(%)

Attribute of Agent		Deli & Grocer's	General Goods & Furniture	Applian-ces	Clothing	Park & Temples	Second -Hand Store	Others
Sex	Male	21.7	10.0	38.6	7.2	5.6	10.8	6.1
	Female	25.8	13.5	8.7	21.2	8.9	14.4	7.5
Age	Less than 30	21.5	12.8	22.8	23.4	5.8	8.5	5.2
	30 to 49	25.3	11.6	26.9	11.4	6.3	13.8	4.8
	50 or more	24.6	11.8	18.7	11.0	11.0	15.4	7.4
Trans-port	Railway	23.4	11.4	22.9	15.7	5.7	13.5	7.4
	Car	25.0	10.4	27.7	14.6	5.1	11.5	5.8

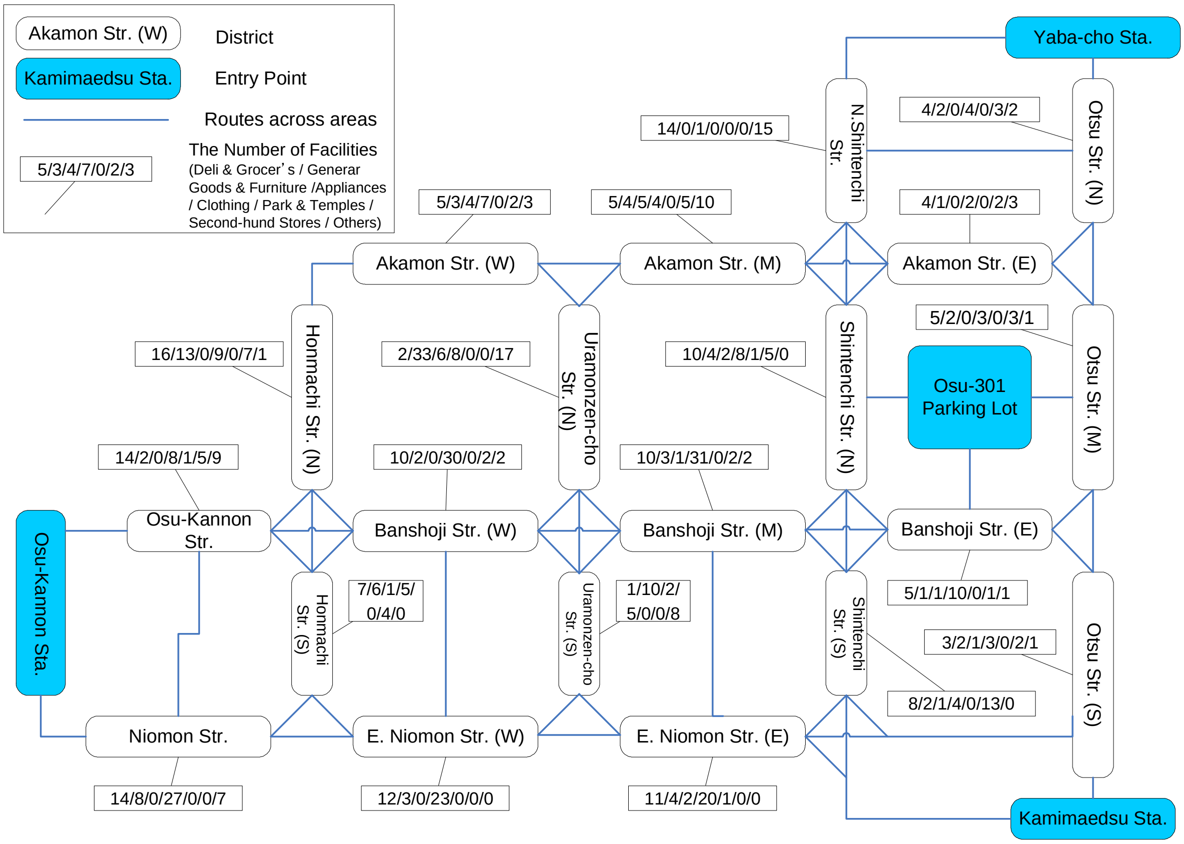

Figure.8 Osu District Spatial Model

4.2 Illustration of Simulation from Viewpoint of Agent Behavior

This section shows the results of the simulations, and illustrates the validity of the model by observing each agent's behavior that was obtained as the results of the execution of the simulation of the previously described model using the case study of Osu District.

As the first sample, Fig. 9 shows the behavior locus when Agent No.1206 visited the commercial district on the 73rd day. The agent is a male student, less than 30 years old and resident in the middle distance zone; the agent planned to visit Facility (1): Appliances and facility (2): Second-Hand Store in the figure, and took the railway to travel to the commercial district. When checking the behavior results, after the agent got off the train at Kamimaezu Station, he visited Facilities (1) and (2) as planned. The agent succeeded in completing both errands in both facilities and left from Yaba-cho Station, which is the nearest to (2) and went home.

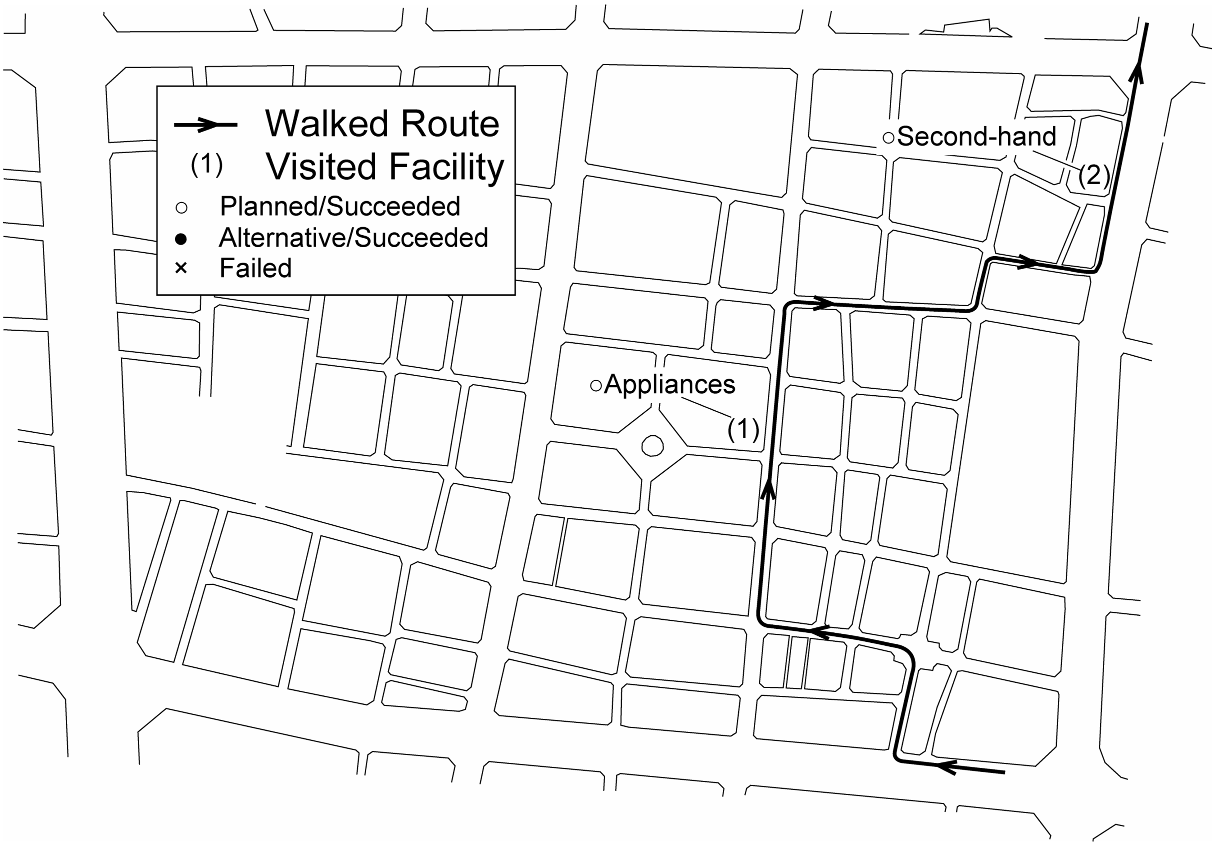

Figure.9 Walked Route of Agent No.1206

In comparison, the second sample seen in Fig.10 shows the behavior locus when on the 70th day an Agent No.65 visited the commercial district. This agent is a housewife in their 30s or 40s and resident in the long distance zone; the agent planned to visit Facilities (1): Appliances, (2), (3): Deli & Grocer's, (4): Second-Hand Store and (6): Deli & Grocer's and traveled to the commercial district by car. When checking the behavior results, after the agent parked her car in Osu 301 parking lot, she visited (1) and in this facility failed to achieve her errand; improvised action then chose (5), as an alternative facility. This alternative reorganized 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 achieve her errand and as an alternative facility, (7) was chosen. After this, she visited (5) and achieved 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 appearance point. From the 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 behavior plan as needed, the agent walks around the district. From those behavior results, it was confirmed that planned action and improvised action, which are key features of random behavior, are expressed in the model and it can be said that the objective mentioned at the beginning was achieved.

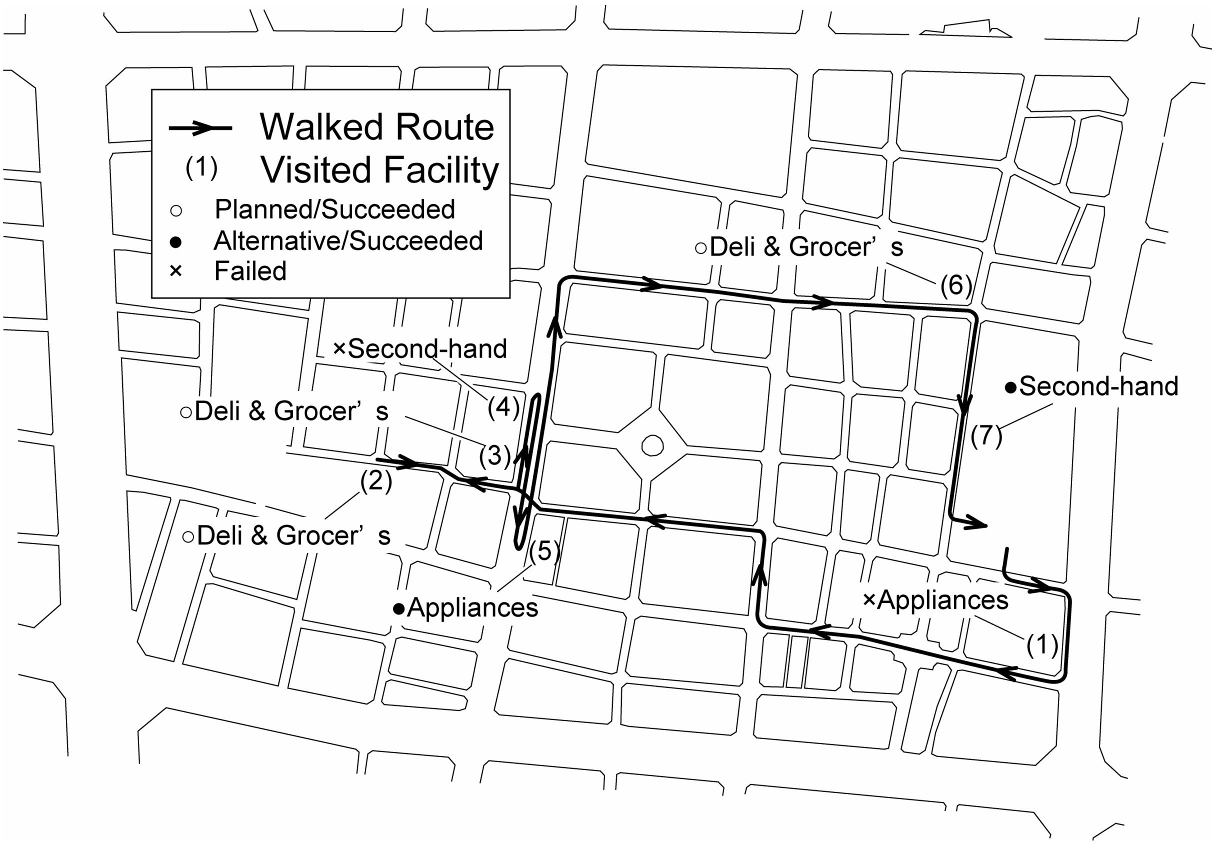

Figure.10 Walked Route of Agent No.65

5. CONCLUSION

Our research designed a pedestrian agent model that expresses Planned Action and one category of improvised action, Alternative Visit, as the first step of the development framework for a pedestrian shop-around behavior model. The model expresses planned actions in the form of solutions to the problem of satisfying constraints in scheduling, and has a reinforcement learning algorithm that updates the preference value according to the success or failure of an errand; these are key features of the model.

In addition, a simulation was run as a prototype of a model that could be applied to the Osu District of Nagoya City and behavioral performances of pedestrian agents were illustrated from the result of the simulation. Further works include the matching between the actual data and the simulation results, after the tuning of parameters is done.

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