Network based Multi Agent Simulation Analysis
-Part 2: Model Application-

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Abstract
In the previous paper, a new analytical model was presented that incorporates ideas of network analysis and multi agent simulation. Also the advantages and potentials was discussed that could be achieved by combining those two methods. This paper looks at how the discussed potentials could be utilized in real situations. As a step of model application, this study focuses mainly on the reliability of the model in predicting actual pedestrian volume.

A meso-scale urban district called Shimokitazawa in Tokyo, Japan was selected as the target site for analysis. To validate the reliability and efficiency of the model, this paper will take the following steps: 1) A pedestrian simulation will be performed based on the information collected from target area examinations. 2) The resulting outcome of simulation will be compared to the actual pedestrian volume data for correlation analysis. 3) The model's reliability will be discussed from the correlation analysis result.

If proved reliable through this procedure, the logical ground of further studies using the proposed model will be given. Moreover, the developed model will clearly become a useful analytical tool to assess and predict pedestrian movement in real situations.

Keywords: network analysis; multi-agent simulation; street network; pedestrian traffic volume; correlation analysis

1. Introduction
This paper is about the application of the proposed model in the previous paper (Cheol-Jae Yoon, Akira Fujii, JAABE, 7 (2)) to a real urban area. The purpose of the study is to test the reliability of the model by implementing a simulation experiment based on preliminary analysis on the target site and comparing the results with an actual pedestrian volume report of the area.

This verification process of the model's reliability is an essential step for future use of the model as it will provide a logical ground not only for further studies using the model but also for any applications of the developed model in real situations.

This paper largely consists of four parts: a review of the proposed model in the previous paper; preliminary analysis of the target area; data conversion process and determination of simulation parameters; and correlation analysis between simulation outcome and the actual pedestrian volume report.

Simulation parameters are determined based on the information collected through preliminary analysis and simulation results are compared to actual pedestrian volume data of the target area.

Part I: Review of the Proposed Model
1.1 Network based Multi Agent Simulation Model
In the previous study, a new analytical modeling method combining network analysis (e.g. Space Syntax) and multi agent simulation system was proposed. These two well-known methods in the architectural and urban field have extremely opposite qualities: "static" and "dynamic". The strong characteristics of each method might produce a strong performance in cases which place a particular emphasis...
on either of these qualities but can be a weakness in the opposite case.

From this point of view, the new model in the previous paper began with the concept that combining these two methods will provide a more powerful tool. As described in Fig. 1., the developed model could carry the merits of both methods and at the same time compensate for any weak point. The resulting model will be a suitable vehicle to investigate the relations between aspects of the visible and invisible in cities, understood as static and dynamic. This approach also enables exploration of the effects of spatial structure on spatial dynamics in a general sense.

1.2 Algorithm of the Developed Model

By combining these two methods, the new model will have an advantage in its ability both to suggest structural forms for agent-based simulation which could be built, and to allow model structures to be described, compared, explored, and represented in various ways. The network-theoretic framework enables us to specify model structures concisely.

In particular, this simulation model converts urban elements into a network structure - nodes and edges and assigns them with adequate attributes. Then the model allocates pedestrian agents from fixed origins to various destinations (facilities on each street segment) and in doing so enables their assignment to the various streets which link origins and destinations together. Fig. 2. shows the algorithm of the proposed model.

2.1 Outline of Target Area

Based on the review above, let us now get into the application process of the new model. The target area is centered around the Shimokitazawa station where two railways, the Odakyu line and Keio Inokashira line intersect with each other. This area maintains a maze-like complex ante-World War II street structure with four- or five-story small buildings lining both sides of the streets.

Pathways within these small buildings are suitable for migratory pedestrian circulation and the vehicle traffic inside the target area is light as the main roads run along the perimeter of the boundary of the site. The whole target area and specific district for analysis are shown in Fig. 3.

2.2 Collection of Data

Preliminary surveys were conducted on the target site to collect information on its urban network elements and determine parameters for pedestrian behavioral patterns as follows:

a) Electronic Map

For basic information on the location and size of buildings and facilities in the target site, an electronic map published by Zenrin Co., Ltd. was used.

b) Online Research

The official website of the Shimokitazawa shopping district and other online sites (in References No. 21–24) were used for more detailed information on facilities such as the types, activities, business hours and maximum population capacity.

c) Publications on Target Site

In addition to the online research above, publications on Shimokitazawa were referenced for facility information. (in References No. 3, No. 15)

d) Field Survey

Field surveys were conducted from September to November 2006 to collect data on facilities and pedestrians. For facilities, the survey focused on information that could not be obtained from publications or online research such as connection of

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**Fig. 2. Algorithm Chart of New Model**

(Cheol-Jae Yoon, Akira Fujii, 2008)

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**Part II: Preliminary Analysis of the Target Area**

2.1 Outline of Target Area

Based on the review above, let us now get into the application process of the new model.
buildings and streets (where the entrance is located and whether there is another sub-entrance on the back side) or maximum concurrent population capacity. The focus of the survey for pedestrian information was on gender/age compositions based on each separated time zone in a day. For the field survey method, digital cameras and video recorders were used and the records were systematically documented for each purpose.
e) Reports on the Shimokitazawa Machidukuri Project
This is a series of urban planning reports commissioned by the city of Setagaya for the Machidukuri project (a town planning program) of the area around the Shimokitazawa station. The data referred to is its pedestrian traffic survey and information on the age, gender and visit purpose of pedestrians. (in References No. 16–19)
f) Other Local Pedestrian Reports
Along with the Shimokitazawa Machidukuri project reports, pedestrian reports of other local areas were also referenced to determine the characteristic patterns of pedestrian agents including propensity and visit purpose. (in References No. 11, 13, 14)
g) Lifestyle Reports
To determine parameters for the behavioral patterns of pedestrian agents according to their type and time zone and their preferences for specific activities, statistical lifestyle reports were used for reference. (in References No. 4–8, 12)

Part III: Conversion of Collected Data
In this section, the process of reorganization of collected data and determination of parameters for simulation will be described.

3.1 List of Data
Data collected in Part II should be transformed into the appropriate formats for use in simulation. In this simulation model, data is organized into several lists to be loaded onto the simulation program. The contents and uses of each list are explained below and major lists are shown in Tables 1.-4. to aid understanding.

| Table 1. Standards for Facility Categorization |
|-----------------------------------------------|
| Category                  | Facility Use     | Stay Period(M) |
| Shopping (1)              | Men’s Clothes(0) | 15 – 60        |
|                         | Women’s Clothes(1) |                |
|                         | Bags, Shoes (N)  |                |
| Shopping 2 (1)            | Super Market (0)  | 15 – 60        |
|                         | Drug Store (1)    |                |
| Restaurants (2)          | Japanese Sushi(N) | 30 – 60        |
|                         | Italian, Pasta (1) |                |
|                         | Fast Food Restaurant (N) | |
| Medical Services (N)     | General Hospital (0) | 30 – 120       |
|                         | Clinic (1)        |                |
|                         | Senior Care center (N) |        |

a) List of Standards for Facility Categorization
A list of standards to categorize facilities in the target site by their activity type. (See Table 1.)
b) Facility List
A list of information of all available facilities in the target area including floor area, business hours, maximum population capacity, reference land price\(^1\), and facility type based on the categorization standards in 3.1. a). (See Table 2.)
c) List of Agent Attributes
This list is designed to show the different behavioral patterns of the agents of each class by assigning different activity lists to each agent group determined based on the composition of age and gender. Each agent group is also given different walking speeds. (See Tables 3.-4.)
d) List of Agent Generation Ratios
Regarding the entry point of the agents in the target area, a list of rates for each agent class is provided. (See Table 2.)

Table 2. Facility List in Target Area

| Bld ID | FC ID | FA (m²) | ID | PU ID | Business Hours | MPC | RLP |
|--------|-------|---------|----|-------|---------------|-----|-----|
| 0      | 0     | 45.50   | 1  | 7     | 10:30 - 20:30 | 25  | 430 |
| 1      | 0     | 13.9    | 0  | 3     | 13:00 - 20:30 | 10  | 430 |
| 2      | 0     | 23.57   | 7  | 13    | 17:30 - 22:30 | 15  | 430 |

Table 3. Activity List 1

| Group 3 | Female in 20% Walking speed 0.9m/s |
|---------|-----------------------------------|
| Time Zone | Shopping 1 | Shopping 2 | Restaurants | Medical Services |
| 10-12    | 15 | 20 | 15 | 30 |
| 13-15    | 10 | 20 | 10 | 30 |
| 16-18    | 5  | 10 | 5  | 15 |
| 19-22    | 5  | 10 | 5  | 15 |

Table 2. Activity List 2

| CA | Facility Use | W100/M1(M1)/W20%/W5%/W2%/W1%
|----|--------------|-------------------------------|
| CA | Facility Use | W100 | M1(M1) | W20% | W5% | W2% | W1% |
| Men's Clothes (0) | 5 | 25 | 5 | 2 | 2 | 1
| Women's Clothes (1) | 15 | 5 | 15 | 5 | 5 | 2 | 2 |
| Bags, Shoes (N) | 8 | 10 | 8 | 12 | 12 | 12 | 12 |
| Convenience Store (N) | 20 | 30 | 10 | 2 | 2 |
| Japanese Sushi (0) | 15 | 10 | 10 | 5 | 10 | 10 |
| Italian, Pasta (1) | 15 | 10 | 10 | 5 | 10 | 10 |
| Fast Food Restaurant (N) | 5 | 5 | 5 | 2 | 2 | 2 |
| General Hospital (0) | 10 | 10 | 10 | 10 | 10 | 10 |
| Clinic (1) | 15 | 15 | 15 | 15 | 15 | 15 |
| Senior Care center (N) | 5 | 5 | 5 | 5 | 5 | 5 |

Table 3. Activity List 2

| CA | Facility Use | W100 | M1(M1) | W20% | W5% | W2% | W1% |
|----|--------------|------|-------|------|-----|-----|-----|
| Men's Clothes (0) | 5 | 25 | 5 | 2 | 2 | 1 |
| Women's Clothes (1) | 15 | 5 | 15 | 5 | 5 | 2 | 2 |
| Bags, Shoes (N) | 8 | 10 | 8 | 12 | 12 | 12 | 12 |
| Convenience Store (N) | 20 | 30 | 10 | 2 | 2 |
| Japanese Sushi (0) | 15 | 10 | 10 | 5 | 10 | 10 |
| Italian, Pasta (1) | 15 | 10 | 10 | 5 | 10 | 10 |
| Fast Food Restaurant (N) | 5 | 5 | 5 | 2 | 2 | 2 |
| General Hospital (0) | 10 | 10 | 10 | 10 | 10 | 10 |
| Clinic (1) | 15 | 15 | 15 | 15 | 15 | 15 |
| Senior Care center (N) | 5 | 5 | 5 | 5 | 5 | 5 |

Table 4. Activity List 2

| CA | Facility Use | W100 | M1(M1) | W20% | W5% | W2% | W1% |
|----|--------------|------|-------|------|-----|-----|-----|
| Men's Clothes (0) | 5 | 25 | 5 | 2 | 2 | 1 |
| Women's Clothes (1) | 15 | 5 | 15 | 5 | 5 | 2 | 2 |
| Bags, Shoes (N) | 8 | 10 | 8 | 12 | 12 | 12 | 12 |
| Convenience Store (N) | 20 | 30 | 10 | 2 | 2 |
| Japanese Sushi (0) | 15 | 10 | 10 | 5 | 10 | 10 |
| Italian, Pasta (1) | 15 | 10 | 10 | 5 | 10 | 10 |
| Fast Food Restaurant (N) | 5 | 5 | 5 | 2 | 2 | 2 |
| General Hospital (0) | 10 | 10 | 10 | 10 | 10 | 10 |
| Clinic (1) | 15 | 15 | 15 | 15 | 15 | 15 |
| Senior Care center (N) | 5 | 5 | 5 | 5 | 5 | 5 |
area, a total of 25 points were established considering railway stations, bus stops and car parks. (See Fig.4.) Then to each entry point, time zone based agent generation ratios were allocated individually based on the information of the field survey and pedestrian volume report.

e) List of Gender & Age Compositions of Agents
   A time zone based list of gender and age compositions by which agents will be generated from each entry point into the target area.

3.2 Network Map
   All the urban elements of the target site with information mentioned above are outlined in Fig.4. Network Map.

![Network Map of Shimokitazawa](image)

Fig.4. Network Map of Shimokitazawa

3.3 Other Parameter Settings
   Parameters not included in the lists above are determined as follows. For a detailed description of each item, refer to the previous paper (Cheol-Jae Yoon, Akira Fujii, 2008):
   a) Trip Number Curve Function
      The following log function from the related reference (Koshi Tamura, 2006) will be used for the curve graph to determine the number of agent trips:
      \[ Y = 0.4491 \ln(x) + 0.0541 \]  
   b) Coefficient of Attraction Rate Function
      From the related research (Kitano Masashi et al., 2003), the coefficient value in attraction rate function for each agent's facility selection process will be set at 0.25.
   c) Determination of Simulation Time
      There are two main considerations in determining simulation running time: 1) the proposed model is designed to analyze pedestrians who visit the target site with specific purposes. However, in the target site, there exist not only commercial areas but residential areas also; 2) unreal situations will occur in which there will be no single pedestrian in the target area at the start of the simulation.

Considering the issues above, the simulation start point is set at 10 am to exclude the early rush hours where outgoing traffic from the residential area of the target site is heavy. Moreover, the data of the first two hours after the simulation starts will be excluded. Valid data for analysis is set to be collected from noon when the pedestrian simulation has become stabilized.

Part IV: Simulation Analysis

4.1 Simulation View
   The following Fig.5. shows several capture shots of the simulation run based on the settings explained above.

![Capture Shot of Simulation](image)

Fig.5. Capture Shot of Simulation

4.2 Reliability Test of Simulation Outcome
   This section discusses the testing reliability of the developed model. Basically, simulation experiments and reliability tests were executed twice, once during a weekday and once during a weekend. However, only the reliability testing procedure of the weekday simulation results will be described in this paper.

For actual pedestrian volume data to be compared with the simulation result, the traffic survey report described in section 2.2.e) will be used. (Tonichi Consultants, Setagaya-ku, in References No. 16-19) In the reports above, the pedestrian traffic survey was conducted at 25 points in the Shimokitazawa area.
The pedestrian volume of every possible direction was counted separately based on 1-hour periods at each point. Fig. 6. left shows the 25 observation points and summary report of the pedestrian traffic survey. 

4.2.1 Correlation Analysis I

The following table provides a comparison between the simulation results and actual pedestrian survey reports of all comparable streets. The resulting plots on the left show a great similarity between actual observations and the simulation outcomes.

For a more detailed comparison, the broken-line graphs on the right were created to show the simulation outcomes and actual observations, and the correlation coefficients of the two given varieties were estimated.

In the graph, the x-axis represents each street segment, edge ID and the y-axis represents the number of pedestrians who passed the street segment.

The simulation results and actual pedestrian trip surveys were found to have significantly high

| Table 5. Simulation Outcome VS. Actual Pedestrian Volume - Result 1 |
|---------------------------------------------------------------|
| **(1) Volume in total**                                      |
| Plot of Actual Volume                                       | Plot of Simulation Outcome | Simulation Outcome VS Actual Pedestrian Volume |
| (Tonichi Consultants, Setagaya-ku, 2001, p. 364)            |                             |                                                 |
| ![Simulation Outcome VS Actual Pedestrian Volume](image)    | ![Simulation Outcome VS Actual Pedestrian Volume](image) | ![Simulation Outcome VS Actual Pedestrian Volume](image) |
| Correlation Coefficient = 0.891                             | Correlation Coefficient = 0.895 |
| **(2) Volume in peak time zone(18:00~19:00)**               |
| Plot of Actual Volume                                       | Plot of Simulation Outcome | Simulation Outcome VS Actual Pedestrian Volume |
| (Tonichi Consultants, Setagaya-ku, 2001, p. 363)            |                             |                                                 |
| ![Simulation Outcome VS Actual Pedestrian Volume](image)    | ![Simulation Outcome VS Actual Pedestrian Volume](image) | ![Simulation Outcome VS Actual Pedestrian Volume](image) |
| Correlation Coefficient = 0.895                             | Correlation Coefficient = 0.895 |
correlations of 0.891 in total volume and 0.895 during the peak time zone. (18:00–19:00)

4.2.2 Correlation analysis II
In the correlation analysis I above, the data of total flow volume through all time zones and in a specific time zone (peak time) was compared in all comparable street segments between simulation results and the actual pedestrian volume report. It was a cross-sectional analysis of pedestrian flows, which shows continuously changing patterns.

On the other hand, in the next correlation analysis II, it will be examined whether the developed simulation model might be useful in time series analysis by comparing simulation outcomes and actual pedestrian volume data for a few selected streets.

Table 6. Simulation Outcome VS. Actual Pedestrian Volume - Result 2

| Index Map | Street No. 01 | Street No. 02 | Street No. 03 | Street No. 04 | Street No. 05 | Street No. 06 | Street No. 07 | Street No. 08 | Street No. 09 | Street No. 10 |
|-----------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
|           | Correlation Coefficient = 0.812 | Correlation Coefficient = 0.842 | Correlation Coefficient = 0.856 | Correlation Coefficient = 0.74 | Correlation Coefficient = 0.733 | Correlation Coefficient = 0.952 | Correlation Coefficient = 0.853 | Correlation Coefficient = 0.755 | Correlation Coefficient = 0.859 | Correlation Coefficient = 0.755 |

The correlation analysis II below selects a number of edges that constitute consecutive streets and plots their actual pedestrian volume data and simulation results in a broken-line graph to examine their correlations with changes in the time series data.

The x-axis represents time zones while the y-axis stands for the number of the total pedestrians who passed the street. Most of the 10 sample consecutive streets show a correlation range of 0.7–0.9 with an average of about 0.8.

The overall results of correlation analysis I and II imply that the presented simulation model appropriately describes the pedestrian behavioral patterns in real situations. Especially, through the correlation analysis II, it became evident that the
presented model reflects the complex changing patterns of pedestrians efficiently.

In some samples, however, the total number of pedestrians in the simulation results was less than half the actual number of pedestrians observed. Possible causes of the discrepancies will be discussed in the following section.

5. Discussion and Conclusion

Through the course of the research from the previous to the current paper, a new analytical approach combining network analysis and multi agent simulation methods was proposed and validated its effectiveness by analyzing the pedestrian flows in a real urban area with the model. The conclusions from the research process are as follows:

1. A simulation experiment in a real urban area using the developed model was conducted to compare the results with actual pedestrian volume data of the target area for correlation analysis. The high correlation of both the cross-sectional and time-series analyses proved the sufficient reliability of the presented model.

2. The potentials and effectiveness of a new analytical modeling technique that is fundamentally different from the traditional pedestrian traffic analysis methods such as a physical count, time-lapse photography or a trajectory follow-up were indicated.

3. These achievements were made possible by combining the static and dynamic techniques of the network analysis and multi agent simulation systems. By implementing the multi agent system's strong capability of reproducing a complicated phenomenon on a network structure, the model could effectively incorporate the constant changes in pedestrian flows while facilitating the processes to alter conditions for individual network elements and derive general conclusions.

Despite the results above, possible areas for improvement were also identified, mainly in simulation settings including the listing standards for an agent's behavior rule such as preferences regarding activities, generation ratios and age/gender compositions explained in c), d) and e) of section 3.1.

Basically the simulation experiment was performed based on actual pre-published pedestrian survey data of Shimokitazawa, but to determine simulation parameters, which could not be extracted from the survey report, other related local pedestrian reports and life style reports were also used as reference.

More accurate and objective settings of these elements would require a high integrity in the initial survey data. As the aim of this research was to produce the platform for a new analytical modeling method, pedestrian survey for simulation test was not the focus of this paper. However, in the case of further experiments, this could be improved by carrying out a proper pedestrian survey for simulation on the established target site.

Another issue is the observed discrepancy between the actual pedestrian volume and the simulation results. In most cases, the number of pedestrians in simulation results was less than that of the real pedestrian traffic volume. The possible reasons for this are as follows:

1. Limited observation points in actual pedestrian survey report: The actual survey data used to determine agent generation ratios was not the result of observations in all possible entry points in the target site. It was based on a few selected entry points considered to have a large volume of pedestrian traffic. However, the target site has other numerous points, which could be the entry and exit points of pedestrians. It is certain that pedestrian inflow from these points could not be included in the simulation results.

2. Pedestrian inflow from the inside residential area of the target site: The target site is a mixed area of residential, commercial, daycare, recreation uses and so on. The presented simulation was solely designed for pedestrians who visit the site from outside with specific purposes. Therefore, the pedestrian inflow from the inside residential area could not be covered by the model and is not reflected in the simulation results.

Regardless of these factors, it has been proved that the new model is sophisticated enough to explain overall patterns in pedestrian movements. The potential of the model as a useful tool in predicting pedestrian flows has been confirmed.

With this confirmed reliability, it should be mentioned that the model can cover not only existing street networks but also new developing areas or urban development projects. As shown in Fig.7., if only the information concerning a changing environment can be achieved, it will be possible to predict the visitor's movement in future situations, which could be the significantly helpful factor in considering the pedestrian circulation, for example the location of transportation facilities, the structure of functional zonings and so on.

As a next step, a new analysis using the simulation results proven reliable in this paper will be conducted by dividing the same target site into North and South. The street networks of the north and south areas of Shimokitazawa have apparently different structures. It is expected that our main focus - to investigate the inter-relationship between geometrical factors of street

![Fig.7. Sample Image of Model Application](Background: Minato Mirai District, Yokohama, Japan)
"structure" and socio-economic "process" between urban attractors and pedestrians in pedestrian flow - will be clarified by the comparison of these two contrasting areas.

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Notes

1) In the previous paper, the definition of attraction rate function introduced three parameters of floor area, rent and sales to determine the attractiveness of facilities. But it was practically impossible to collect rent and sales data of all facilities in Shimokitazawa. A different approach was taken for this research: 1) Parameter of sales was excluded, 2) Instead of rent, reference land price data was applied. Reference land price is set on each street and refers to the price for each 1m² of standard housing lot facing the street. This is based on the concept that although the reference land price could not represent all the differences of each facility's value it could at least represent the difference based on each street segment. The data used for the simulation is based on the reference land price map in Asset Assessment Standards published in 2005 by the National Tax Agency of Tokyo. (in References No. 25)
2) This is a translation whereby its original title was officially published in Japanese. The simulation outputs in this paper are the results of numerous trial experiments and feedbacks from the actual survey data. The very first simulation experiment before applying the feedbacks produced a correlation coefficient of 0.69 for the weekday in total volume and 0.84 for the weekday during peak time zone. It might be mentioned that this result was good enough to prove the validity of the model. This research, however, implemented a series of feedback operations and adjusted the values of simulation elements to obtain and use more realistic outcomes for the next analysis. In this process, the following two weighting factors of psychological distance were considered. 1) Weighting Factor of Psychological Distance 1
   In a railway station with the highest pedestrian traffic volume in the target area, a pedestrian would choose a ticket gate that provides an easy access to his or her destination. In other words, a pedestrian who exits from the north - (or south) ticket gate would provide an easy access to his or her destination. In other words, a pedestrian who exits from the north - (or south) ticket gate would visit the facility located in the north - (or south) area in most cases.
2) Weighting Factor of Psychological Distance 2
   Street segments such as railway crossings, overpasses or crosswalks make pedestrians feel psychologically as if they were walking a far greater distance than general streets. Restrictions were established by adding a certain distance to the street segments which satisfy the conditions stated above. It is difficult to translate psychological factors into measurable numbers. But this research established 60 seconds for case 1) and 30 seconds for case 2) as appropriate estimates of the time required. Applying these estimates to the average walking speed of 0.9m/s in the target area, the simulation applied an additional 50m to the streets of case 1) and 30m to the streets of case 2) respectively.
3) Fig.8. shows the street segments to which these factors were applied.