Network based Multi Agent Simulation Analysis  
- Part 1 : Model Development -

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Abstract
This study begins with a hypothesis that pedestrian movement can be considered as an outcome of two distinct components - (1) the configuration of street network and (2) the location of specific attractions (urban facilities - shops, offices, public buildings etc.) within a network. The objective of this research is to investigate the relationship between geometrical factors of street network and socio-economic process between urban attractors and pedestrians. With this purpose, a new analytical model will be developed, whereby two well-known analytical methods of spatial analysis in architectural or urban field is combined - network analysis and multi agent system. Mainly centrality measures of network analysis will be compared to the volume of pedestrian flow from the agent simulation model. This comparison will generate a picture that demonstrates the existence of two types of factors in the performance of urban spaces. - 1) from the street network which is geometrical, static, predictable, 2) from the process which is relatively probabilistic, complex and unpredictable.

This paper is the 1st step of continuous research, to determine the necessary concept through critical review of the two methods, establish an outline of the new model, and simulation of a small virtual street network.

Keywords: network analysis; graph theory; centrality measure; multi agent simulation; pedestrian walking flow

1. Introduction
Pedestrian movement in urban area has attracted not only urban planners or government officials but also retailers and those who are involved in management of urban space. The reason why to comprehend pedestrian movement has great importance is, those interests in measuring and modeling pedestrian movement for understanding the way people move in urban setting could maintain and enhance the vitality and attractiveness of the town centers.

With this concept, it becomes important to understand how those two radical components of pedestrian movements are related to each other. One is referred to as a spatial structure, which focuses on physical structure, tends to be considered as having a similar fluidity and obeying the same laws that are contained in and governing the functional structure of the city. On the other hand, another view is that there exists a non-visible process, a dynamic relationship between socio-economic activities and distribution of attraction devices in a certain territory.

A large number of researches have been conducted in order to answer these questions, but they appear to have no consensus on the answer and some researches seem to be rather too much biased to one side extremely.

This research begins with a basic hypothesis from the viewpoint of generating spatial usage patterns, these two controversial factors working simultaneously and the interrelationship between these factors might produce an unpredictable result. Based on this hypothesis, a new analytical modeling method, combining both network analysis and multi agent system will be proposed.

First, network analysis is the most well-known analytical method in the field of geometrical configuration by simplified expression of interrelation among all the entities. There have been a great number of researches in the related field, and various analytical measures such as connectivity, accessibility, centrality are widely accepted.

However, these methods remain resolutely static. It is almost impossible to expect the influence of ‘time’. One can say that it is a snapshot within the circulation of time series in one system. Furthermore, spatial
configuration is sometimes assigned an almost mystical importance.

Second, agent based simulation system is an increasingly popular method with the rapid growth of computational techniques. Recent advances in computing power and the acquisition of fine scale digital data such as GIS mean that we might be able to attempt to understand and predict such phenomena with the focus being in spatial modeling.

However, it is still difficult to retract a very general conclusion from the models, especially in views of architectural or urban case, due to the lack of descriptive tools needed to recognize similar outcomes in spatially distinct contexts. (Sullivan, 2000)

From this point of view, a new analytical model might be needed that can grasp the interrelationship between structure and process in pedestrian movement phenomenon. This study aims to expand the concept of both structure and process as a key component for lively urban street environment. Focuses are on investigating the relationship between these two factors and the streets as an evolving structure that holds components of the city altogether.

The entire research consists of following stages : 1) model development, 2) reliability test of the developed model, 3) investigation of the relationship between two components of pedestrian movement through the use of the developed model. This paper is the 1st part of the series which begins with the theoretical background and describe the outline of new model. It will be followed by a case study in which the developed model will be applied to a small virtual street network.

In the remaining steps, the model described in this paper will be applied to real meso-scale urban district, Shimokitazawa in Tokyo, Japan. Based on this model application process, the reliability of the developed model will be questioned by comparing the results received from the simulation and the actual pedestrian volume report. Then we will attempt to conclude the final purpose of our continuous research - to find the interrelationship between two major factors of pedestrian movement.

Through these steps, it will be clear that our newly developed analytical model in this research might be used as a more realistic analytical tool to assess and predict pedestrian movement in an urban setting.

Part I : Theoretical Background
1. Critical review of the two methods
1.1 Network analysis

In an architectural or urban context, a network means a diagram which consists of a set of nodes and edges. By the method of simplifying the structure of a complicated spatial configuration, network has been widely used. (Steadman 1983, Hillier and Hanson 1984)

A network representation can capture many of the structural properties of architectural and urban spatial arrangement. Network theoretical measures of the resulting representation allow its structural features to be determined and described with some precision.

Another advantage of network representations is the wide range of measures which have been developed in a number of disciplines to assist in understanding their structure for example, centrality, accessibility, connectivity and so on. (Wasserman S. and Faust K., 1994) The network theory literature is extensive, and in many case highly technical and mathematically clear.

But, broadly speaking, it is the fixed structure of the relations between the objects of interest in any given situation which a network analysis allows us to examine. The issue is that any (kind of) snap shot is the outcome of a historical process, thus it has merit only over time-scales where the configuration can be regarded as fixed. It also decomposes space into elements which may be extremely varied in size and shape, but are treated similarly in the analysis. (Sullivan, 2000)

Furthermore, for any kind of measure related to accessibility (such as centrality, integration from Space Syntax) we would expect the highest flow rates in the most accessible locations. These accessibility measures providing indices associated with forecasting trip volumes are not based on the models which simulate processes of movement and thus do not provide methods for predicting the impact of the location changes on patterns of pedestrian flow. In short, although these indices can show changes in flow due to changes in the geometry and location of entire streets, they are unable to account for comprehensive movement patterns which link facilities at different locations to one another. (Batty, 1998)

Therefore, it might be suggested that the examination of cases where no or only poor correlations are found might be more revealing.

1.2 Multi agent system

This type of model is the one in which the basic unit of activity is the agent. Each agent autonomously acts according to its behavior rules to achieve its goal. The outcomes of the model are determined by the interactions of the agents. Autonomous agents thus cover a wide variety of behaving objects, from humans...
and other animals or plants to mobile robots, creatures from artificial life, software agents, and even particle systems in physics. (Haklay, 2001)

In essence, agents are objects that do not have fixed locations but act and interact with one another as well as the environment in which they exist, according to some purpose. In this research, for our purpose to investigate spatial performance, an agent in this research will imply a (artificial) pedestrian.

Pedestrian movement models have been developed since the 1970s. There have been some remarkable models, such as StarLogo language (Resnck, 1994), STREETS (Sullivan, 2001), PEDFLOW (Kerridge, 2001).

To model such kind of human movement is the processes over series of time. During that process, local and individual behaviors grow to global patterns, which may or may not show us a predictable result. This is entirely consistent with recent developments in complexity theory where the complexity of the system emerges in global and structural terms from actions, each of which are simple in themselves, of relatively autonomous agents, acting with their own self-interest in mind, without appeal to any grand design or response to any overall global rationality or utility.

Nevertheless, still this modeling method raises some points of problem where it is hard to attempt any general conclusion, as the structure itself does not have the elements-based literature like network analysis. This causes another difficulty to put weight or other variables according to the attributes of each spatial entity. (Sullivan, 2000)

1.3 Need for a new analytical model

As mentioned above, the development of a new model that could carry the merits of both methods and at the same time compensate for any weak point might be needed.

Both the network and multi agent system permits well-developed ways of describing model structure and process dynamics, therefore the simultaneous use of these two methods may form the basis of a research program into the elusive relations between the two factors of pedestrian movement - structure and process. The 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.

From this point of view, the combining of these two methods will provide a more powerful tool. Thus, we might seek to determine the relationships between the centrality of vertices in the network and the time-sequence of states prevailing at those vertices. 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. The approach also enables exploration of the effects of spatial structure on spatial dynamics in a general sense, and this is the major focus of this study.

Part II : Model Development

2. General Concept

The new model is based on the requirement that pedestrian movements are important to predicting how many individuals are attracted to different attractors within a certain geometrical structure. In essence, the model allocates pedestrian agents from fixed origins to various destinations and in doing so enables their assignment to the various streets which link origins and destinations together.

In this chapter, the basic structure of the model will be described in detail and followed by a discussion of
2.1 Model's description 1 – Structure

2.1.1 Network elements

As described above, the main frame of the model is based on network structure which decomposes spatial unit into a simple diagram - nodes and edges, according to their interrelation. In basic, agents will move along these nodes and edges during a simulation process.

In this model, several modifications have been made to the basic concept of conventional network analysis. The model should be available to describe the relationship of pedestrian and urban attractors, thus it requires another element which binds together the urban facilities within a network. Two additional elements can be found out in the below picture - "Point" and "Tie".

Urban elements expressed by network structure in this model are as follows.

a) Point(urban facility) : All urban facilities are expressed by point elements. A point element does not need to be a single facility but one building. In other words, although it is described in a 2 dimensional map, a point may carry information on several facilities such as the type of facility, duration of pedestrian's stay, maximum population capacity, business hours, floor area, land price, rent and so on. Such information will work as important parameters in which it influences the pedestrian behavior. These mechanisms will be explained in detail in the description part of agent's behavior rule.

b) Edge(street segment) : a unit segment of streets between one intersection and another.

c) Tie(link between facility and street segment) : interrelating elements which link a point element from street segment to an entrance or exit of a building.

d) Vertex(intersection of street segments) : A node that several edges share.

Fig.5. Network Elements

As for the two newly added elements, a point element means various types of urban facilities in a defined area and will be the destination point of an agent. When applying point elements to urban facilities, all attributes are expected to be assigned in accordance with each facility's feature. As mentioned above, during the entire simulation process, these information will work as important variables in matching process between a pedestrian agent and a point element as a destination point. Details will be described in the next chapter.

A tie is an abstract element which means a link between buildings and street segments. A single facility may have one or more tie elements according to the number of entrances or exits of the building.

2.1.2 Centrality of street network

When network structure is being built, it is possible to calculate "Centrality" of street network. Through Krafla(1994), we refer to the concept of centrality as follows.

Centrality of an edge could be defined as a measure of accessibility consisting of the capacity of falling on the shortest routes between every pair of vertices in a particular system. The most central place will be the one which falls on the largest number of shortest paths in the system. In the proposed model this centrality is measured by considering the relationship between each pair of nodes as a tension, whose value is equally distributed among all edges which form the shortest path(s) linking all vertices of network. The sum of all bits of tension generated by all pairs of vertices gives a general measure of centrality.

From this concept, centrality indirectly represents different degrees of accessibility among all the paths within a system. The measure counts how many geodesics, shortest paths from each node to every other node or pass on each individual links. The higher number of dijkstra's shortest paths on an edge, the more central it is within the whole network. In the other instance, we can also consider the centrality as an expression for the degree of compact 'linkage-ability' for which each link contributes to the whole network.

Edge centrality = "the total number of shortest paths between every pair of nodes on that edge in particular network system"

In terms of geometrical view, the general hypothesis adopted is that edges holding high degrees of centrality, are also the ones with higher accessibility and connectivity in the system. Consequently, we could expect that the paths with high centrality measures will express the more frequently passed by people than others.

2.2 Model's description 2 – agent's behavior rule

Previously, model's 'structural' part has been described. Now, we will outline the 'dynamic' part, the movement rule on the built network structure. The emphasis will be on simulating the pedestrian flow between origins and destinations.

However, there are numerous types of environment and problem context which require different variables in modeling pedestrian behavior thus it must be determined the issues we consider or otherwise we
ignore. Focuses in this model will be next two points.

First, we understand that the nature of pedestrian behavior is distinguished by their demand and supply nature, as well as by the attractiveness each of those activities attains in the urban system. In this version, each point of the network system, representing urban facilities, will be labeled as an 'origin' or a 'destination' which restricts the choice of possible pairs between which to search for the shortest paths allows us to proceed with any other calculations. (Krafta, 1996)

Secondly, pedestrian movement generally terminates or initiates a chain of linked activities, and if it treated in detail, a single pedestrian movement is found to include a considerable number of subjourneys from one location to another. (Kerridge, 2001)

In this sense, the variants of the model that we illustrate here will not apply to movements in residential neighborhoods or in work trip contexts. In this model, we focus on pedestrians who have several object activities in a target area.

In the next section, based on these hypotheses, we will outline the key issues that characterize the agents' movement we will simulate, illustrating the rudiments of the model and the way these can be articulated.

2.2.1 Set Entry Point

First, there needs to be a setting where agents will be discharged into the built network - called "Entry point". Among network elements of this model, both vertex or point elements might be transformed to entry points. Entry points will be allocated in accordance to the real situation in a target area, such as car parks, subway stations, bus stations and others.

Entry points will also be where agents finish their movement and disappear from the system. We could assume that at each entry point, individuals change their transportation mode from car, bus or subway to walk.

Related to this assumption is the fact that all agents return back to the entry point from which they entered the system. This means each agent will use the same transportsations when they exit that area.

For each entry point, variant agent generation ratio will be given individually in accordance to the real situation of a target area.

2.2.2 Generating agents

After entry points have been determined, agents are released into the district. At this time, when emerged from entry point, agents are given several attributes at once. These attributes play as the main factors in allowing the agents to have different characteristics and show various behavioral patterns. Determining factors for agent's type are as follows.

a) Agent's class type (age and gender)

Each agent has its own class type under two categories - age and gender. This is from the concept that general behavioral pattern of pedestrian shows distinct difference according to their gender and age.

Each agent's class type is defined by random (or by pre-determined rate) combination of gender and age.

b) Activity list

For each class type, specific pre-determined activity list will be given. "Activity list" is a probability table containing each object activity that agents will choose and execute. These activities such as shopping, eating, drinking are transformed from every facility within a target area. In short, from the activity list, agents will get to choose their object activity based on probability of each activity.

In this model, focus must be paid to the fact that the probability of each activity is not fixed but is of a changing value according to divided time period of a single day. This allows the model to analyze the influence of time on behavioral pattern of pedestrians.

c) Agent's walking speed

Agent's walking speed is also defined by its own class type, which is a constant value but works as an another parameter exhibiting different characteristics of each agent's class.

d) Agent's trip number

With various attributes from class type as above, each agent will now be given its own trip number. Trip number is the number of target places each agent must visit. In related research (Saburo Saito, 1998, Akira Yuzawa et al., 1993), an interesting result has been reported that there exists the following interrelationship between an agent's trip hazard probability and trip's step number t.

From the picture above, \( h(t) \) is the function of hazard probability curve representing the probability of an agent quitting one's trip and leaving the area at step number t and this \( h(t) \), the statistical function will be derived from pedestrian's trip survey in a target area. From another related research (Mizuo Kishita, 2001), we found out that in most trip survey cases, \( h(t) \) tends to show similar curve to above graph.

In the model, an agent's trip number will be determined from this \( h(t) \) curve graph.

2.2.3 Destination Choice & Route Find

With the given attributes, now each agent is ready to start its own trip into town area. When a trip begins, each agent will select certain activity from its own activity list. But the agent still needs to choose one specific destination point among all facilities which provide the same activity.

In this model, an attraction rate function has been contrived which measures each facility's strength that
influence the destination selection procedure. To define this attraction rate function, we referred to a related research (Kitano Masashi et al., 2003). However, in the selected reference, the attraction rate of a certain facility is only defined from its floor area. It may require additional parameters which may act as an influencing factor of each facility. In this model, 2 more objective data will be added.

Let the agent's current point $i$, target facility's point $j$, then the attraction rate function is defined to be:

$$P_{ij} = \exp(-\alpha d_{ij}) \times (A_j + B_j + C_j)$$  \hspace{1cm} (1)

($d_{ij}$: distance between $i$ and $j$, $A$: floor area, $B$: rent, $C$: sales)

Here, for parameters $A$, $B$, $C$, converted index values ranging between 0 to 1 will be applied by statistical normalization method.

With this mathematical function, an agent could find out the most attractive location.

2.2.4 Route Find
To find path to destination point, dijkstra's shortest-path determination algorithm is used to define the agents' route.

2.2.5 Move, Task accomplishment, Extinction
When the destination point and the path are set, each agent starts moving toward its own destination point. Arriving at the destination point, each agent will stay for a certain period defined by type of the facility. From this procedure, the agent has carried out one expected activity.

However, there exist two conditions of destination facility whereby the agent can not fulfill its goal regardless if they have reached the destination point successfully.

1) Target facility is not in business hours
2) Target facility is fully occupied by other agents

In such cases, the agent returns back selecting an activity and must choose a different activity.

Following these procedures, after one activity is executed the agent checks the remaining task number (= trip number). When all tasks are finished and there are no more trips left, the agent returns back to the original entry point then disappears. If there remains any task number, the agent repeats to the very first step of choosing a destination, then moves along its destination points and accomplish activity.

2.2.6 Count pedestrian volume
Based on these rules above, agents are allowed to travel around the target area. At a given simulation time period, the pedestrian volume at each street in the system is evaluated. By comparing this result to centrality index defined 2.1.2, it could be possible to find out the relationship between structure and process.

Part III : Model Application

3. Case Study
With these general ideas and concepts of model, a simulation program by using a C++ programming language has been developed. The first experiment involves the simplest case - a small virtual street network with several types of attraction facilities. The focus is how the pedestrian movement can be varied as

![Model's Flow Chart, Model's General Diagram](image_url)
various parameters controlling the interaction between pedestrian agents and urban attractors. From this case study we investigate how well developed model can reflect the pedestrian movement phenomenon.

3.1 Virtual street network

A virtual street network will be applied around 120m ×120m. All facilities within this network is classified into seven categories and randomly distributed.

| Type ID | Activity                          |
|---------|-----------------------------------|
| 0       | Shopping 1 (Fashion, Hobbies)     |
| 1       | Shopping 2 (Grocery, daily goods) |
| 2       | Eating (Restaurants)              |
| 3       | Rest (Cafe, coffee shop)          |
| 4       | Beauty (hair, skin, nail)         |
| 5       | Drinking (Pub, bar)               |
| 6       | Amusement (Game center, karaoke)  |

3.2 Activity List

A 2-hour period probability table below will be applied for the agent's activity list. The probability for each activity doesn't have reality but is the changing value at least by time lapse like in a real life situation.

| Type ID | 12-14 | 14-16 | 16-18 | 18-20 | 20-22 |
|---------|-------|-------|-------|-------|-------|
| 0       | 15    | 30    | 40    | 15    | 0     |
| 1       | 15    | 20    | 10    | 15    | 0     |
| 2       | 40    | 10    | 0     | 20    | 10    |
| 3       | 10    | 20    | 20    | 10    | 20    |
| 4       | 10    | 10    | 20    | 10    | 0     |
| 5       | 0     | 0     | 20    | 50    |
| 6       | 10    | 10    | 10    | 10    | 20    |

Total(%) 100 100 100 100 100

3.3 Other parameter's setting

Case study parameters are set up simply as follows:
- One agents type (same gender and age)
- Number of entry points is 3. (see figure above)
- Agents generation ratio of each point is equally set up by 5per/min
- Agents' trip number is randomly determined in the range of 1 to 5
- Walk speed of agent is 1.0m/s
- Attraction rate function's parameters and agents' capacity, stay period of every facility with same type is equally setup
- Simulation time will be from 12 o'clock to 22 o'clock.

3.4 Tracing single agent

In this section, a trip executed by a single agent will be traced to demonstrate the application of the developed model. Among 3 entry points, an agent generated from entry point 01 will be followed. Figure 9 shows the trace.log.txt file which is automatically saved and the movement trajectory of the agent.

An agent's movement can be traced which started from the entry point→(2)→(15)→(13)→ back to the entry point before it disappears. By tracing the sequential movement of a single agent, it could be said that the developed simulation program appropriately describes the concept in which pedestrian movement consists of a chain of linked subjourneys.

3.5 Simulation result of the Case study

Now let us get into the analysis of the case study simulation result. As mentioned above, our interest here is not the correct estimation or controversial discussion of factors to pedestrian's movement but confirmation of how well the model shows the changing aspect of pedestrian flow.

Table 3. shows the 1-hour time period simulation result representing each edge's prevalence by relatively different width. From the figures below, we find out the changing pedestrian's flows on each street segment and there exists a time-series process between pedestrian's behavioral pattern and urban facilities as attractors.

![Fig.8. Virtual Street Network](image1)
![Fig.9. Trace Map of a Single Agent's Movement Path](image2)

4. Discussion and Conclusion

In this study, we proposed a new simulation model by explaining the initial concept to the detail of pedestrian movement model, and by applying the developed model to a small virtual network for our case study.

The conclusion of case study is as follows:
1. By tracing single agent's movement procedure, constructed simulation program describes the model's concept accurately.
2. From the result of case study, it became clear that proposed model could describe changeable pedestrian's movement pattern appropriately.
3. As for the interface, in virtue of network's simple structure, it becomes easier to allot attributes to each urban component which makes influence to control agent's movement and to derive the simulation result as well.
In the 1st step of this continuous research, the focus of this paper was to describe the theory of the model and its general concept. The most important point mentioned constantly is that these results are attained by combining two methods.

For further steps, in the next paper, we will challenge to analyze a street network within a real urban area by using the proposed model and discuss further in regards to the advantages of the new model. To find out the inter-relationship between geometric structure and economic process in pedestrian flow, our final purpose of this research will be discussed in the last part of the continuous research.

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Endnote
1) This is a translation whereby its original title was officially published in Japanese.

Table 3. Plot of 1-hour Period Simulation Result