A STUDY OF SIMULATION MODEL FOR PEDESTRIAN MOVEMENT WITH EVACUATION AND QUEUING

Shigeyuki Okazaki[1)] and Satoshi Matsushita

1) Department of Architecture and Environmentall Design, Architecture and Environmentall Engineering, Kyoto University, Yoshidahonmachi, Kyoto, 606-01 Japan
2) Department of Architecture and Civil Engineering, Faculty of Engineering, Fukui University, 3-9-1, Bunkyo, Fukui, 910 Japan

ABSTRACT

The objective of this study is the development of a computer simulation model for pedestrian movement in architectural and urban space. The characteristic of the model is the ability to visualize the movement of each pedestrian in a plan as an animation. So architects and designers can easily find and understand the problems in their design projects.

In this model, the movement of each pedestrian is simulated by the motion of a magnetized object in a magnetic field. Positive magnetic pole is given to each pedestrian and obstacles like walls and columns. Negative magnetic pole is located at the goal of pedestrians. Each pedestrian moves to his goal by the attractive force caused by the negative magnetic pole at his goal, avoiding collisions with other pedestrians and obstacles by repulsive forces caused by the positive magnetic poles.

The effectiveness of the simulation model is shown by the following two kinds of simulation examples.

(1) Evacuation from an office building

In this model pedestrians walk along the route from each starting point to the exit in case of evacuation. The example shows the places where stagnations and heavy congestions occur, and designers can see if the evacuation routes are appropriate.

(2) Movement of pedestrians in queue spaces

Three types of queuing behavior is classified in this model: movement in front of counters, movement passing through ratches, and movement of getting on and off in elevator halls. Simulation examples in a railway station and in a main floor of a resort hotel are shown where several kinds of queue spaces are included and complicated movements of hundreds of pedestrians occur.

1. INTRODUCTION

In these days a lot of large complicated architectural and urban spaces have been built all over the world. In these spaces, it is quite difficult for designers to understand the relation between space and human behavior by only their senses and experiences.

Computer simulation of pedestrian movement is a useful method to help designers to understand the relation between space and human behavior. This research is a proposal of application of a computer simulation model to the analysis of pedestrian movement. The model tries to simulate the movement of each pedestrian to the motion of a magnetized object in a magnetic field (1). The characteristic of this model is the ability to visualize the movement of every pedestrian in the plan of a design project as an animation. In this simulation model, each pedestrian is displayed at each 0.1 second at the appropriate location in the plan on computer display. This model can show the flows and stagnations of pedestrians in the plan. So designers can understand where stagnations and congestions are occurring and where the dangerous place is, and then they can use the result of simulations to improve their design projects.

In this paper, first the outline of the magnetic model is explained, and then application examples are shown. Regarding the application of the simulation model, fire safety and queuing problems are mainly discussed. These two problems often happens in a lot of architectural and urban spaces. The simulation examples show that this model can be reasonably applied to those problems and that they are effective for improvement of design projects.

2. OUTLINE OF THE SIMULATION MODEL

The simulation model, first, reads the data of the plan of a building and the data of pedestrians. Data of a plan contains the information of the elements in the plan like the location of walls, columns, exits, and queue spaces. Data of pedestrians contains the initial information of each pedestrian which indicates the location of the starting point, walking velocity, time to start walking, orientation, destination, and so on.

The movement of each pedestrian is simulated by the motion of a magnetized object in magnetic field which exerts attractive force on the different kind of magnetic poles and which exerts repulsive force on the same kind of magnetic poles. In this model each pedestrian has positive pole, obstacles like walls, columns, and handrails have positive pole, and negative poles are assumed to be located at the goal of pedestrians. In this magnetic field, pedestrians move to their goals and avoid collisions.

2.1. Input Data

The data of a plan and the data of pedestrians are given as initial input data to execute the simulation. The simulation model begins calculation after the input of these data.

2.1.1. Data of a plan

The data of walls and openings in a plan are given as input data of a plan, and the simulation model displays the plan on computer screen by these data. The data of walls includes handrails and other obstacle objects. The data of openings includes the elements of openings in the plan like doors, exits, and windows.

Walls — The data of walls are given as sequences of vertexes which are described by xy-coordinates on the plan of a building. Walls are drawn as lines which connect the sequences of vertexes on the computer screen.

Openings — The following kinds of openings are given by numerals. 3,4,and 5 are data of queue spaces.

- 0 boundaries among zones like smoke zones
- 1 doors and exits
- 2 windows
- 3 counters
- 4 ratches and gates
- 5 exits of vehicles like elevators and trains

Corners — Vertexes on walls which are salient to the inside of a plan are automatically recognized as corners. In a complicated plan where pedestrians cannot directly move to their goal, they assume those corners as temporary goals which lead them to their final goal. The walking route of each pedestrian is constituted by a sequence of corners.

2.1.2. Data of a Pedestrian

The following data are given to each pedestrian as initial input data. If a lot of pedestrians should appear in the plan, pedestrians are divided into groups and data are given to each group. Each group has common destination, orientation, start time, and method to walk. Velocities are decided by random values which are generated by normal distribution. Positions of pedestrians are decided by uniform random values in the areas which are set to each group.

Destination — Final goal of each pedestrian is given by an opening number.

Position of a pedestrian — The position of each pedestrian are given by xy-coordinates on the plan. Initially, the position of the starting point of each pedestrian is given as input data.

Velocity — If a pedestrian would move to the goal simply by the force from the magnetic field, his velocity would increase unlimitedly by the acceleration according to Coulomb's Law. So maximum velocity of walking is given by this data.

Orientation — The orientation of each pedestrian to walk

Time to start — Time to start walking is given to each pedestrian.

Method to walk — The model has three kinds of method to walk as following. Examples in this paper use only indicated route method.

- indicated route — A sequence of corner numbers is given and a pedestrian walks along them.
- the shortest route — A pedestrian automatically walks along the shortest route from the starting point to the goal (2).
- wayfinding — When a pedestrian does not know the route to the goal, he walks seeking for the goal (3).

2.2. Magnetic Forces among Pedestrians and Elements of a Plan

Magnetic force which acts on a pedestrian from a magnetic pole is basically calculated by equation (1) according to Coulomb's Law.

$$F = (k*q_1*q_2 / r^3)*r \qquad (1)$$

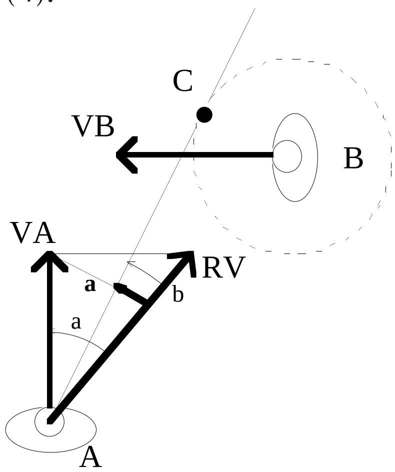
F : magnetic force (vector)
k : constant value

q_1: intensity of magnetic load of a pedestrian
q_2: intensity of a magnetic pole
r : vector from a pedestrian to a magnetic pole
r : length of r

Another force acts on a pedestrian to avoid the collision with another pedestrian. In the example of Figure 1 where Pedestrian A tries to avoid the collision with Pedestrian B, the force exerts acceleration **a** on Pedestrian A. Acceleration **a** is calculated by equation (2).

$$\mathbf{a} = \mathbf{VA} * \cos a * \tan b \tag{2}$$

In Figure 1, Acceleration **a** acts on pedestrian A to modify the direction of **RV** to the direction of Line **AC**. Line **AC** is a contacting line from the position of Pedestrian A to the circle around Pedestrian B. This circle is the Pedestrian Area Module of which the radius is set to 60cm (4).



A: a pedestrian
B: a pedestrian
VA: velocity of pedestrian A
VB: velocity of pedestrian B
RV: relative velocity of pedestrian A to pedestrian B
a: angle between **RV** and **VA**
b: angle between **RV** and **AC**

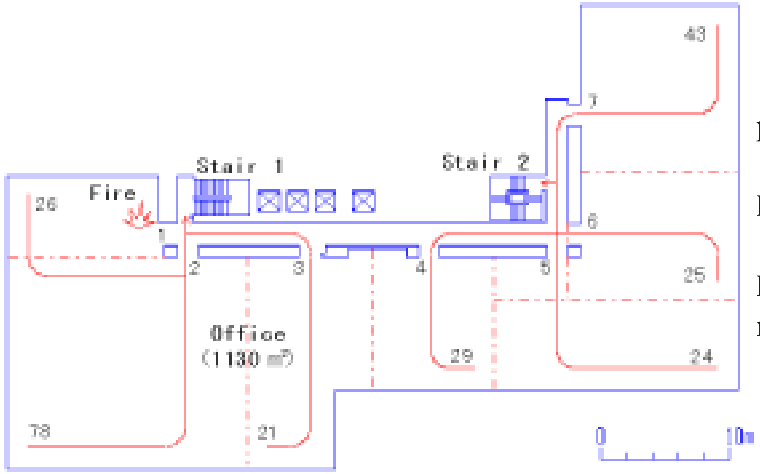
Figure 1. Acceleration a acts on pedestrian A to avoid a collision with pedestrian B.

Total of above forces from goals, walls, and other pedestrians acts on each pedestrian, and it decides the velocity of each pedestrian at each time. The average velocity, density, and flow volume of pedestrians differ according to situations. This model can deal with those variation. If large values are given to parameters of intensity of magnetic loads of elements and pedestrians, the intensities of repulsive forces become larger. Then pedestrians keep longer distances from other pedestrians and obstacles like walls, and consequently density and flow volume of pedestrians become smaller. In the opposite case, density and flow volume become larger.

3. SIMULATION EXAMPLE OF EVACUATION

Figure 2 shows an example of fire escape in a real floor plan of an office building. Conditions of executing simulation are as following.

All pedestrians in a room start at the same time.
Average velocity of pedestrians is 1.0 m / second.
Pedestrian flow volume at bottle necks (doors) is set to 1.5 pedestrians / m*second.
Pedestrians take closest doors, exits, and stairs to escape.
Total number of pedestrians is 246.



The fire occurs at the indicated place.

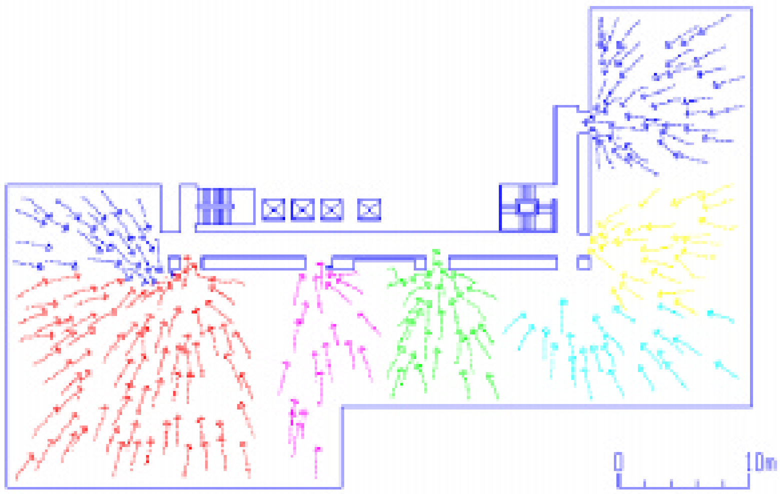
Exit 1 is not used.

Pedestrians escape along the routes indicated by broken lines.

Figure 2. Plan of an office building.

69.00 second

246 pedestrians have started escaping. They started escaping at 67.3 second.



80.00 second

At exits 2, 5, 6, and 7, stagnations are occurring as the crowd in the corridor prevent the pedestrians in the office room from coming out. Especially a lot of pedestrians are gathering at exit 2. Real pedestrians would move to exit 3.

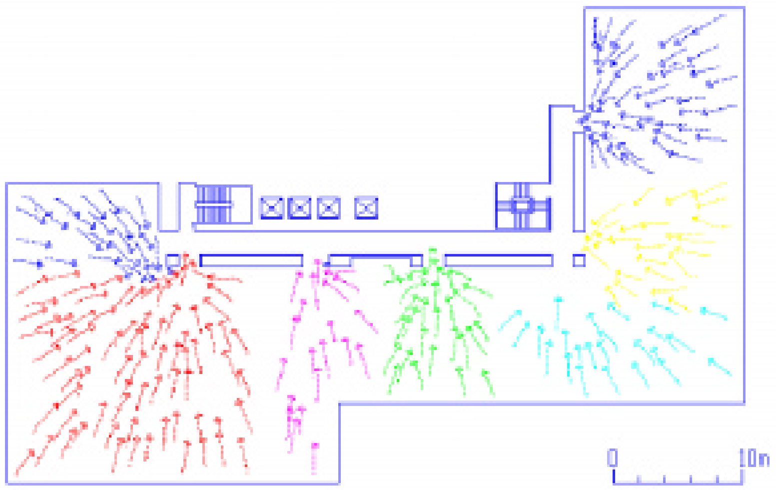


Figure 3. Simulation example of fire escape.

This simulation shows where and how congestions and stagnations are occurring, and how congestions and stagnations make influences on the whole movement of pedestrians in the plan. Furthermore, stagnations lasted for long time at exits 2, 5, 6, and 7, which means that the escape route was not appropriately assigned to the pedestrians in the office room.

4. QUEUING

In queue spaces, the number of waiting people and waiting time can be calculated by Queuing Theory. However, Queuing Theory cannot deal with extremely heavy congestion and complicated movement of pedestrians as shown in this section. In large urban spaces, a lot of kinds of movement of pedestrians are merging and intersecting. In many cases queue spaces are also a circulation spaces. Some pedestrians form queues, and others only pass through queue spaces. Even in forming a queue, several steps of movement are observed; approaching to queues, standing in queues, moving forward, getting services, and getting out of queues. This simulation model simulates these complicated movement of pedestrians in large spaces including queue spaces (5) in detail.

4.1. Classification of queuing behavior

Three types of queuing behavior in Table 1 were classified on the basis of the observation of the movement of pedestrians in airports, railway stations, department stores, and office buildings. In addition to these three types, Type 3 can be classified into 2 types (Type 3-1 and Type 3-2) as Table 2.

Table 1
Three types of movement in queue spaces

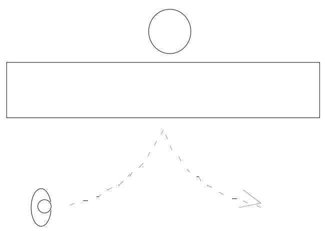
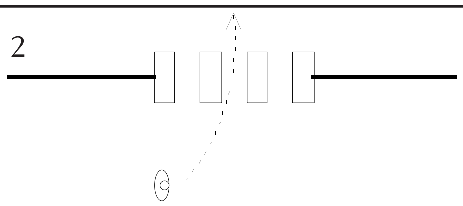
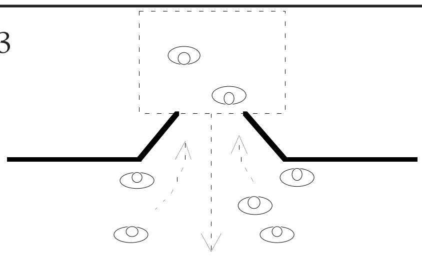
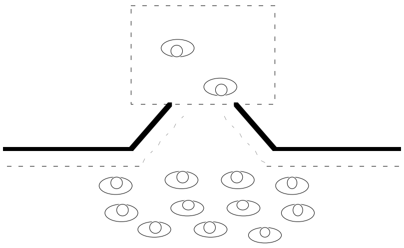
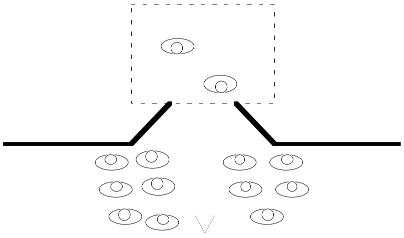
Type 1		Pedestrians form queues in front of a counter. Pedestrians approach to the queue, stand in the queue, move forward, get the service, and get out of the queue. This type of movement can be seen at the reception counters in stations, department stores, hotels, banks, and so on.
Type 2		Pedestrians form queues in front of gates and ratches pass through after they get services. This type of movement can be seen at the ratches in railway stations, entrances of theaters, museums, and so on.
Type 3		Pedestrians form queues in front of the doors of vehicles. When a vehicle arrived, pedestrians wait for the inside passengers to get off the vehicle and then get on it. This type of movement can be seen at elevator halls, platforms of railway stations, bus stops, and so on.

Table 2
Two types of movement in platforms for vehicles

Type 3-1		Pedestrians gather in front of the entrance without leaving the way for inside passengers to get off the vehicle.
Type 3-2		Pedestrians leave the way for inside passengers to get off the vehicle.

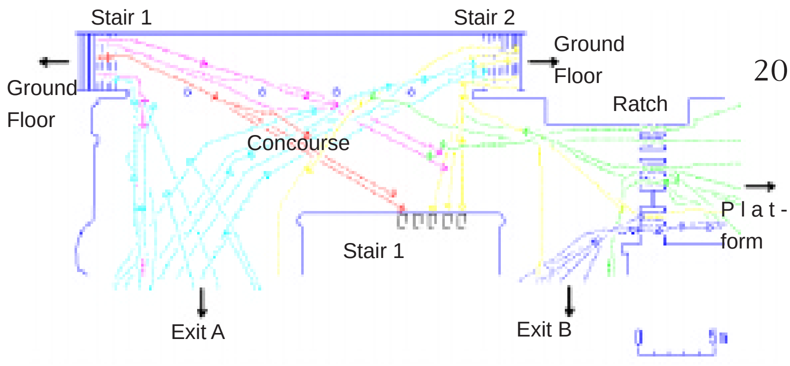
4.2. Simulation Example in a railway station

This is an example of the movement of pedestrians in a part of the concourse of an underground railway station (Figure 4). This plan includes two kinds of queue spaces: ticket venders (type 1) and ratches (type 2).

Total of 240 pedestrians walk in this plan. The number of pedestrians of each group and the route of them are shown in Table 3. Some pedestrians buy tickets and pass through ratches, and others only pass through concourse without any relation with these queue spaces.

Table 3
Pedestrians and routes of each group

Group	Number of Pedestrians	Route
1	60	Stair 1 -> Ticket Vender -> Ratch
2	10	Stair 1 -> Concourse -> Exit A
3	10	Stair 1 -> Concourse -> Ratch
4	60	Stair 2 -> Ticket Vender -> Ratch
5	10	Stair 2 -> Concourse -> Exit A
6	10	Stair 2 -> Concourse -> Exit B
7	10	Stair 2 -> Concourse -> Ratch
8	10	Ratch -> Concourse -> Stair 1
9	10	Ratch -> Concourse -> Stair 2
10	10	Ratch -> Concourse -> Exit A
11	10	Ratch -> Exit B
12	10	Exit A -> Concourse -> Stair 1
13	10	Exit B -> Concourse -> Stair 2
14	10	Exit B -> Ratch
Total	240	



20.0 second

Some pedestrians form queues in front of ticket venders and passing through ratches. Other pedestrians pass through the concourse without forming a queue. The trace of pedestrians shows clearly the intersection of their movements.

85.00 second

A lot of pedestrians are standing in the queue in front of the ticket vender.

Figure 4. Simulation example in a railway station.

4.3. Simulation Example in a hotel at ski resort

This example shows the movement in the main floor of a hotel in a ski resort. The site of the building is so small that the main floor of the building cannot get enough area for entrance hall, lobbies, elevator hall, and ski locker rooms. By this reason, the front lobby is located on the upper floor. Figure 5 shows the plan of the main floor in which front lobby is also displayed. Front lobby is displayed on the same plan as the ground floor in order to execute the simulation on one plan. This plan includes the following queue spaces:

Front Lobby (Type 1),
Ski Locker Rooms (Type 1),
Lobby 1 (Type 1), and an
Elevator hall (Type 3).

Table 4 shows the number of pedestrians of every group and the route to walk. Groups 1 through 4 are new visitors who put their luggages at Lobby 1 temporarily, then take the route indicated in Table 4. Groups 5 through 8 are staying skiers who are coming back from the skiing area to the hotel. Figure 5 shows the movement of total of 178 pedestrians go up and down between two floors, and visit queue spaces on each floor. The behavior that pedestrians stop walking for a short time to put their luggage in Lobby 1 and ski locker room is simulated by queuing type 1.

Table 4 Number of pedestrians and routes of each group

Group	Number of Pedestrians	Route
1	32	Main Entrance -> Lobby 1 -> Front Lobby -> Lobby 1 -> Ski Locker Room 2 -> Elevator Hall
2	48	Main Entrance -> Lobby 1 -> Front Lobby -> Lobby 1 -> Ski Locker Room 1 -> Elevator Hall
3	12	East Entrance -> Lobby 1 -> Front Lobby -> Lobby 1 -> Ski Locker Room 2 -> Elevator Hall
4	18	East Entrance -> Lobby 1 -> Front Lobby -> Lobby 1 -> Ski Locker Room 1 -> Elevator Hall
5	20	West Entrance -> Ski Locker Room 1 -> Front Lobby -> Elevator Hall
6	20	Main Entrance -> Ski Locker Room 1 -> Front Lobby -> Elevator Hall
7	14	West Entrance -> Ski Locker Room 2 -> Front Lobby -> Elevator Hall
8	14	Main Entrance -> Ski Locker Room 2 -> Front Lobby -> Elevator Hall
Total	178	

After this simulation, the designers of this hotel modified the plan. They located the front lobby on the ground floor.

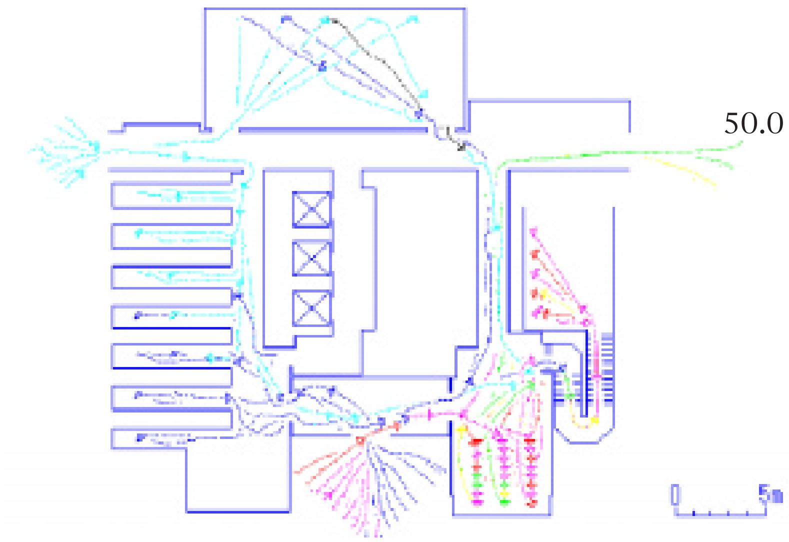
5. CONCLUSION

In this paper a simulation model for pedestrian movement has been proposed as a tool to help designers to find problems of their design projects visually. Simulation examples have shown that this magnetic model can be effectively applied to the following problems.

1. The model can be applied to the movement in case of fire escape, and observers can see how long it takes for all pedestrians to escape from the building. So designers and planners can see if their design projects have problems regarding fire safety.

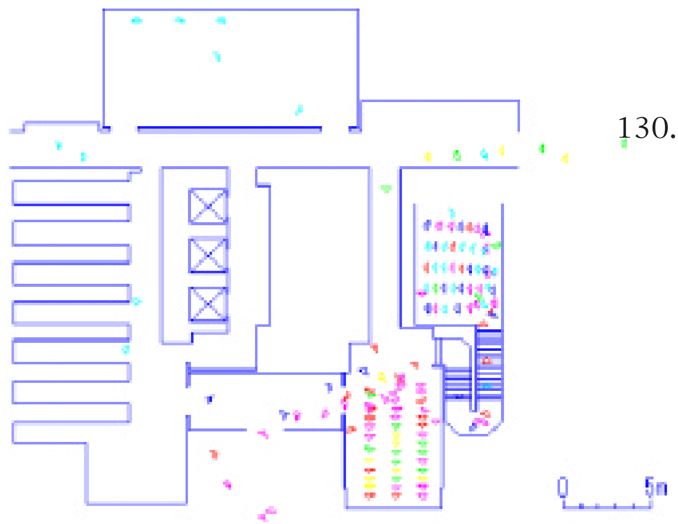
2. The model can simulate the movement of pedestrians in queue spaces. This model can simulate not only the number of waiting people and waiting time but also the detailed process of movement in queue spaces like approaching to queues, standing in queues, and getting out of queues.

3. The model can simulate the merging and intersecting movement of a number of kinds of pedestrians. Figures 4 and 5 showed such complicated movement.



50.0 second

Pedestrians are forming queues in lobbies and ski locker rooms.



130.0 second

Front lobby is full of people. Calculation stopped as no more queue space was available.

Figure 5. Simulation in the plan of a hotel

6. REFERENCES

1 S. Okazaki, A Study of Simulation Model for Pedestrian Movement in Architectural Space, Part 1: Pedestrian Movement by the Application of Magnetic Models, Transactions of Architectural Institute of Japan, 283 (1979) 111.

2 S. Okazaki, A Study of Simulation Model for Pedestrian Movement in Architectural Space, Part 3: Along the Shortest Path, Taking Fire, Congestion and Unrecognized Space into Account, Transactions of Architectural Institute of Japan, 285 (1979) 137.

3 S. Matsushita and S. Okazaki, A Study of Simulation Model for Wayfinding Behavior by Experiments in Mazes, Journal for Architecture, Planning, and Environmental Engineering, No. 429 (1991) 51.

4 J. J. Fruin, Pedestrian Planning and Design, Kajima Institute, Tokyo, 1974.

5 S. Matsushita, A Study of Simulation Model for Pedestrian Movement with Queuing, Journal for Architecture, Planning, and Environmental Engineering, No. 432 (1992) 79.