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# Human Behavior During Emergency Evacuation

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ABSTRACT

To collect data on human behavior, a maze experiment with two different conditions was performed using 40 subjects. From the maze experiment, it was found that once a subject has lost reference positions, it takes time to recover the sense of direction. The behavior of a subject was greatly affected by brightness and smoke. The behaviors can be categorized into three patterns. The data from the maze experiment and from an actual fire were employed to examine the use of the fractal dimension in classifying evacuation paths. From these investigations, the fractal dimension is found to be a good index to quantify the complexity of evacuation behavior.

## 1 INTRODUCTION

Human behavior during evacuation is an important factor in mitigating the loss of human lives from earthquakes or fires as well as the safety of structures. Performing experiments is one way of collecting data on human behavior. Watabe (1982,1984) used a 27m X 27m grid to investigate the speed, path selection and characteristics of learning. Hokugo (1985) performed an experiment to estimate the influence of brightness and smoke on speed and on the selection at an intersection. Matsushita and Okazaki (1991) performed maze experiments and classified the wayfinding behavior into four basic patterns. These studies, however, did not determine the relationship between evacuation behavior and the characteristics of a person.

To study human behavior, it is necessary to find an adequate index to quantify the characteristics of behavior. Categorization is a simple way to treat complicated patterns like human behavior paths but it has some limitations. Subjectivity may be involved in judgment, and categorized data are difficult to process in computers.

Nowadays, fractals and fractal dimensions are applied in many fields; for example, computer graphics, chaos, earth science (Takayasu,1986; Jurgens et al., 1990). Nakagawa, et al. (1991) proposed an earthquake damage evaluation method for lifeline systems using fractal dimensions.

A maze experiment and a personality inventory were carried out on 40 subjects to estimate the behaviors and feelings in darkness when an unexpected shock is given. This paper discusses the behaviors observed during the maze experiment. It also examines the feasibility and adequacy of the fractal dimension of evacuation paths as a quantitative index of human behavior using

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the data from the maze experiment and from an actual fire.

## 2 MAZE EXPERIMENT

### 2.1 SETTING OF THE EXPERIMENT

The maze experiment was carried out using the facility of Ikebukuro Life Safety Hall, which is managed by the Tokyo Fire Department. This facility is used by the general public to study the effects of smoke during evacuation and the good posture to be taken in smoke. Figure 1 shows the plan of this maze. It consists of many doors and movable walls. On some doors, there are small windows from which light can enter. The brightness and the amount of harmless smoke in the maze are adjustable from outside at a control panel. There are many mat sensors and posture sensors in the maze which give the location and the evacuation posture of the subject.

Two experiments (hereinafter referred to as Case 1 and Case 2) with different initial conditions of brightness and smoke were conducted. Table 1 shows the experiment conditions. Each experiment used the same 40 subjects (19 men and 21 women) with ages from 23 to 57. Figure 2 shows the composition of the subjects. The subjects were sent one by one to the maze to find the exit. When the subject reached the room located at the center of the maze, the light of the whole maze was turned off to give the subject an unexpected shock. After two minutes or when the subject came near the exit, the light was turned on again. In Case 2, all windows were covered to prevent light from entering. This was done to know the effect of slight light on the evacuation. The evacuation paths and elapsed time were recorded using a video camera at the control panel. When the subject got out of the maze, he or she was asked to answer a questionnaire on his or her motivations and feelings in the maze. The Yatabe-Guilford personality inventory, which is the most popular in Japan, was also performed to investigate the correlation between the evacuation behavior and the characteristics of each subject.

### 2.2 RESULTS OF THE EXPERIMENT

Typical behaviors observed in Case 1 and 2 are shown in Figures 3 and 4, respectively. The hatched circles in the figures show the point when the light was turned off while the white circles show the point when the light was turned on again. When the light was on, the behaviors of the subjects seemed similar. They tried different possible ways and went back only when there was a dead end. When the light was off, their behaviors seemed more varied.

Some of the subjects did not lose their way and got out of the maze without fail. For instance, subject No.39 in Case 1 and subject No.17 in Case 2 walked along the wall and got out of the maze quickly. Some of these subjects knew the "right-handed (or left-handed) method" and applied it. These methods are known to be sure tactics to get out of mazes. Most of these subjects, however, did not know or remember this method. They just walked along the wall unintentionally.

On the other hand, some subjects lost their way and took a rather long time

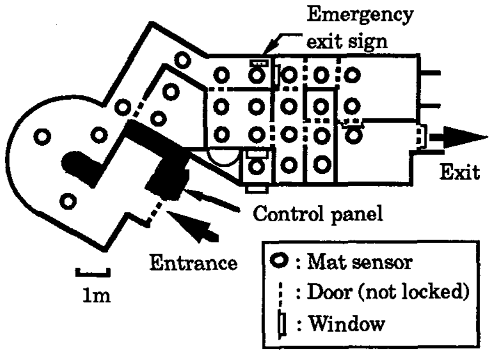



Figure 1. Plan of the maze

Table 1. Experiment conditions

| | Initial conditions | | |
|---|---|---|---|
| | Brightness | Amount of smoke | Entering light |
| Case 1 | Completely light | none | Some |
| Case 2 | Moderately light | Moderate | None |

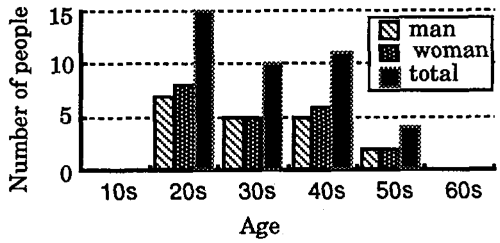



Figure 2. Composition of the subjects

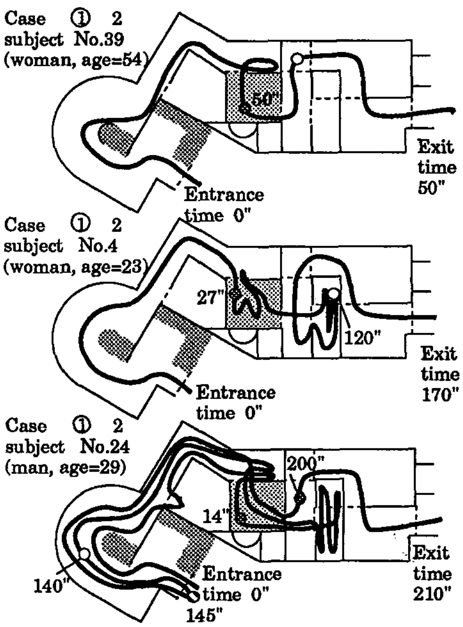



Figure 3. Typical behaviors observed in Case 1

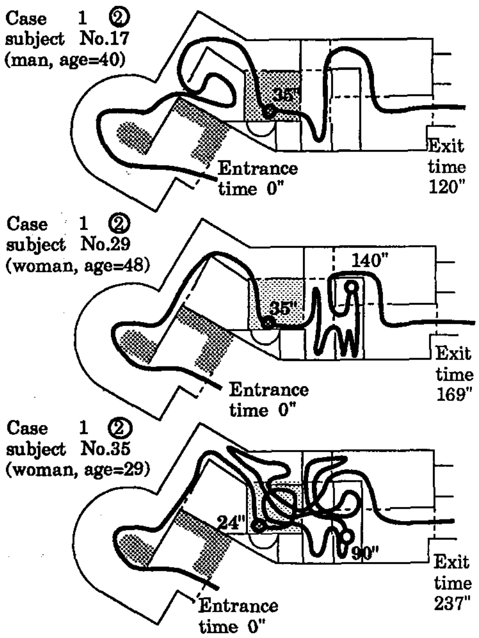



Figure 4. Typical behaviors observed in Case 2

to get out of the maze. For instance, subject No.4 in Case 1 went back to the emergency exit sign when the light went off. She also spent a rather long time at the dead end of the maze. However, she found the path to the exit quickly when the light came back. Subject No.29 in Case 2 also behaved this way but she did not go back when the light went off. These subjects did not search the exit systematically. Thus, they spent a rather long time searching for it. However, when the light came back, they found the path to the exit easily. This seems to imply that these subjects kept their sense of direction although they lost their way in the darkness.

Most of the subjects, however, completely lost their way and took a long time to get out of the maze. Eleven of the 40 subjects came back to the entrance without recognizing it (e.g., subject No.24 in Case 1). The behaviors of these subjects did not improve noticeably even when the light came back. This implies that it takes time to recover your sense of direction once you have lost your reference points.

In Case 2, some subjects got confused by the absence of light leaking from the windows. For instance, subject No.35 returned from the room near the exit. Those subjects remembered the light near the exit. When they could not find this light, they thought that they came to the wrong place and returned. In addition, some subjects pointed out the change in that room's image due to the absence of light. When the room was lit well, they did not walk carefully and mistook that room for a narrow corridor like the other part of the maze. In the darkness, however, they went groping along the wall and found out that the room was much wider than they thought.

## 2.3 EVACUATION BEHAVIOR AND THE CHARACTERISTICS OF THE SUBJECTS

The histograms of evacuation time in Case 1 (first time, no smoke) and Case 2 (second time, with smoke) are shown separately in Figures 5(a) and (b). In each case, the average of all subjects' evacuation times is about 170 seconds. However, the average evacuation times of men and the average evacuation times of women in the two cases differ. In Case 1, men are 45 seconds faster than women but in Case 2, women are 26 seconds faster than men.

Figure 6 shows the histogram of the difference of evacuation times in the two cases. The peak corresponds to the range of -30 seconds to +30 seconds. Sixty-five percent of the subjects fall in the range of -90 seconds to +90 seconds. Most of the subjects' evacuation times in Case 2 did not improve much in spite of the experience in Case 1.

The relationships between the evacuation time in the two cases and the subjects' age and sex are shown in Figure 7. No distinct difference of evacuation time between the age groups was observed in the two cases.

The behaviors of the 40 subjects may be divided into these three patterns: (1) got out of the maze without fail, like subject No.39 in Figure 3 and subject No.17 in Figure 4 (pattern 1), (2) lost their way in the darkness but kept their sense of direction, like subject No.4 in Figure 3 and subject No.29 in Figure 4 (pattern 2), (3) completely lost their way and could not get out even though the light came back, like subject No.24 in Figure 3 and subject No.35 in Figure 4 (pattern 3). The authors admit that this categorization involves some subjectivity.

Figures 8(a) and (b) show the relationships between the patterns of behavior and the subjects' sex and age. In Case 1, most of the subjects who exhibited behavioral pattern 1 were young men. Also, most of the women and half of the men exhibited behavioral pattern 3. In Case 2, dispersion becomes very wide and the distribution is almost uniform with respect to both sex and age.

## 3 HUMAN BEHAVIOR ANALYSIS USING FRACTAL DIMENSION

### 3.1 FRACTAL DIMENSION

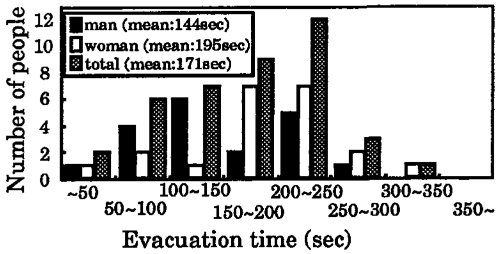
The concept of fractal, which is a general idea for figures, structures and phenomena without their characteristic length, was proposed by Mandelbrot in 1975. The characteristics of fractals are quantified by fractal dimensions. The fractal dimension of a figure expresses the degree of its complexity quantitatively.

There are several definitions of fractal dimension. In this study, the fractal dimensions of evacuation paths were determined using the box counting method. In this method, a mesh of size $r$ is placed on an evacuation path. $N(r)$, the number of squares which contain the path, is determined (Figure 9). This $r$ and $N(r)$ are plotted on a log-log scale. If $N(r)$ is proportional to $r$ on the log-log scale, the absolute value of the slope, $D$, is the fractal dimension of the path (Figure 10).

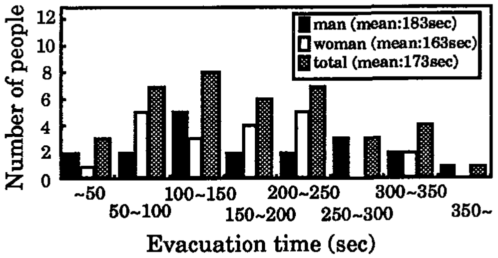
Figures 11(a)-(d) show simple examples to explain the fractal dimension of human behavior. These figures show the paths from point S to point G on a 21X 21 grid. The fractal dimensions of the two shortest paths shown in Figure 11(a) are both 1.02. The fractal dimension of a simple path with no loop or going back is quite near 1.0, which is the dimension of line. Figures 11(b)-(d) show three paths with the same length of 114. The fractal dimensions of these paths increase as their shapes become more complicated, like when the walkers had completely lost their way. This means that the fractal dimension of the path quantifies its complexity. If one lost his way during evacuation, the fractal dimension of his evacuation path becomes large.

### 3.2 FRACTAL DIMENSION AND OTHER BEHAVIORAL INDEXES

The relationships between the fractal dimension of evacuation paths and other behavioral indexes like evacuation time will be discussed. In previous studies (e.g., Matsushita and Okazaki, 1991; Okuyama et al., 1984), patterns of behavior, evacuation time, speed, evacuation path length and available area to move are used as indexes of behavior. However, these indexes do not provide enough information. For example, you cannot treat the behavior of a man who actively searched the exit and that of the one who waited to be rescued as the same behaviors even if their evacuation times were the same. The path length and the speed cannot also distinguish a man who walked a wide area from a man who went this way and that. Using the fractal dimension of the path in addition to the other indexes, the characteristics of human behavior can be quantified. The relationships between the fractal dimension




(a) Case 1




(b) Case 2

Figure 5. Histograms of evacuation time

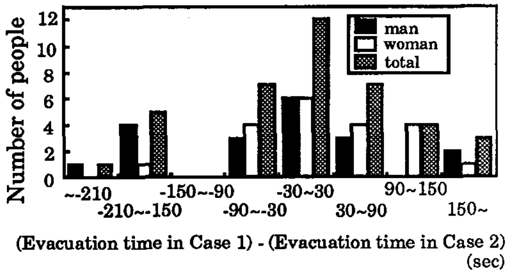
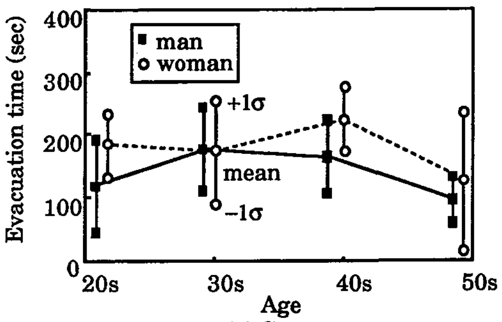
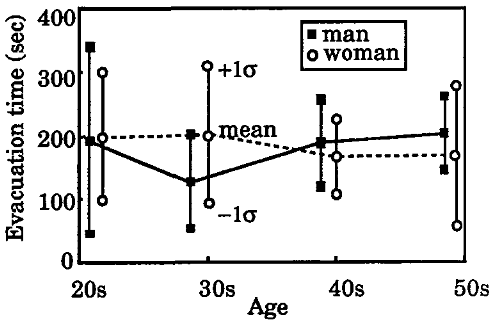



Figure 6. Difference of evacuation times in two cases

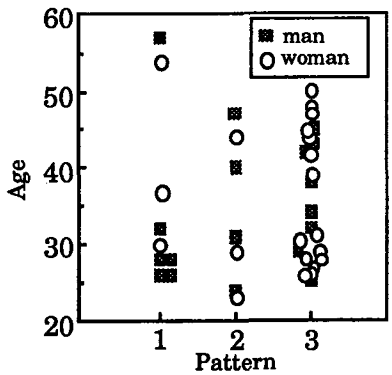



(a) Case 1

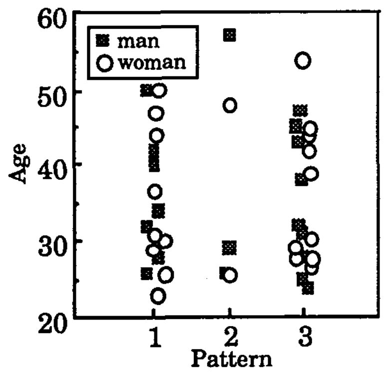



(b) Case 2

Figure 7. Evacuation time and age




(a) Case 1




(b) Case 2

Figure 8. Pattern and Age

and the other indexes are discussed using the data from the maze experiment and from an actual fire.

### 3.3 APPLICATION TO THE MAZE EXPERIMENT DATA

Figure 12 shows the relationship between the fractal dimension and the behavioral pattern. The fractal dimensions become large in the order of pattern 1, 2, 3, and they correspond with the subjective categories.

The relationship between the fractal dimension and the speed is shown in Figure 13. Most subjects had a speed between 0.2 m/s and 0.4 m/s. The average speeds of men and women are almost the same. Hokugo (1985) also reported a similar result from his experiment. This implies that the walking speed in the darkness is not affected much by the properties of the subjects.

Figures 14, 15 and 16 show the relationships between the fractal dimension of the path and the three indexes: the evacuation time, path length and area covered during evacuation (hereinafter simply referred to as area). In this study, the area is defined as the sum of the area of the unit boxes (1m X 1m) that cover the paths.

From these figures, it can be seen that these indexes: time, path length and area become larger with the increase in the fractal dimension. This tendency may be attributed to the limited freedom of movement. The maze used for this experiment is rather small and the starting point and the goal are limited to the entrance and the exit of the maze. With these limitations, the fractal dimension can be expected to correspond to the other indexes. However, the fractal dimension varies by almost the same value as those indexes.

Figure 17 shows examples to illustrate the relationship between the fractal dimension and the other behavioral indexes. The fractal dimension of path (a) is smaller than the fractal dimension of path (b), which is more complicated than path (a). Although path (a) and path (c) run through the same part of the maze, many returns are observed in path (c) indicating that path (c) is more complicated than path (a). There are only slight differences in time, path length and area between path (a) and (c). Therefore, these behavioral indexes cannot express the difference of these two paths. However, the fractal dimensions of the two paths reflect the difference of behavior.

### 3.4 APPLICATION TO AN ACTUAL FIRE

The fractal dimension is applied to the human behavior during an actual fire at the Sennichi Department Store Building in Osaka, Japan in 1972. More than one hundred people died in this fire. This study uses Morita's report (1973), which was based on the survivors' statements, as basic data. The plan of the building is shown in Figure 18.

Figure 19 shows the relationship between the fractal dimension and path length. Figure 20 shows the relationship between the fractal dimension and area. Both indexes become larger along with the fractal dimension, but the variation is rather big. In addition, the distributions of the points in the two figures are quite similar. The main part of this building is a large

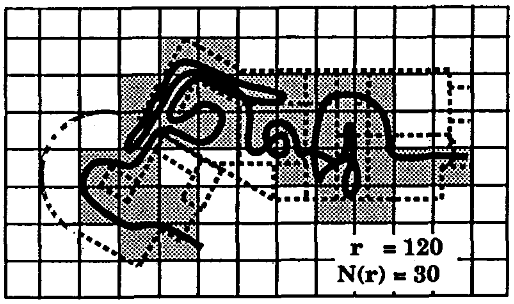



Figure 9. Determination of fractal dimension using the box counting method

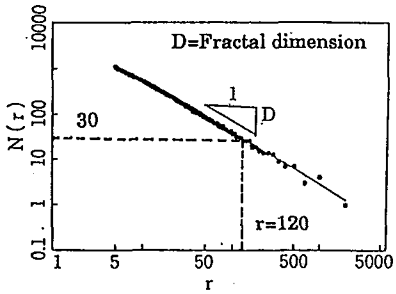



Figure 10. r-N(r) plot

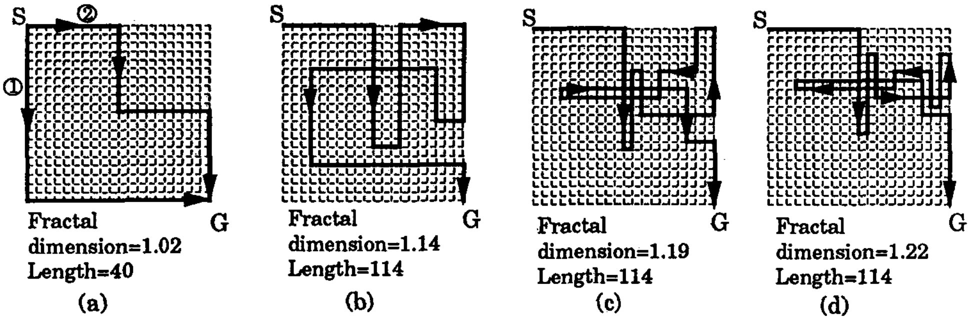



Figure 11. Different paths and their fractal dimensions

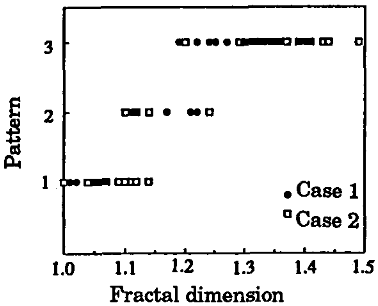



Figure 12. Fractal dimension and behavioral pattern

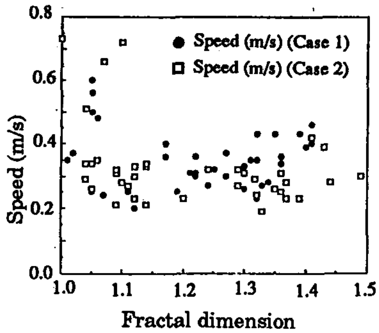



Figure 13. Fractal dimension and speed

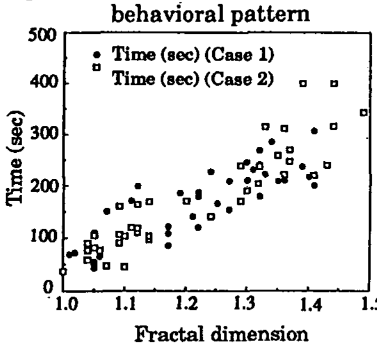



Figure 14. Fractal dimension and evacuation time for the maze experiment

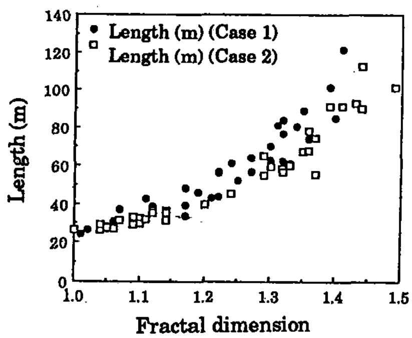



Figure 15. Fractal dimension and path length for the maze experiment

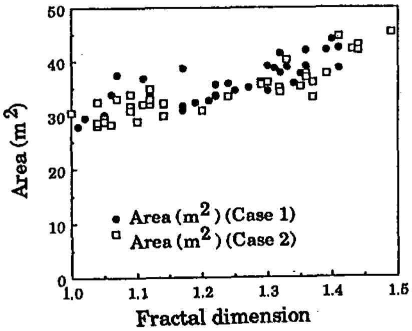



**Figure 16. Fractal dimension and area for the maze experiment**

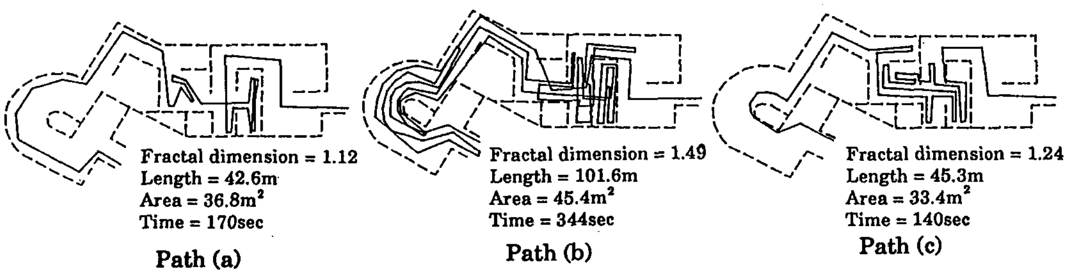



**Figure 17. Three paths observed in the maze experiment**

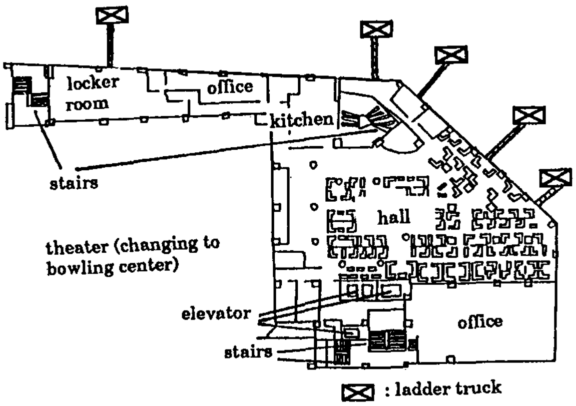



**Figure 18. Plan of Sennichi Department Store Building (Morita, 1973)**

room. Thus, people can choose many paths instead of going back to the same path. This might be the reason that the area and the path length are almost proportional.

Figures 21(a)-(f) show the evacuation paths of six survivors. The path lengths and areas are almost the same for TA and NI and for TM and MOT, but the fractal dimensions are different. In addition, though the path length and the area of YO are greater than those of MOT, YO's fractal dimension is smaller than MOT's. This shows that the path length or area is not always proportional to the complexity of the path and that these indexes cannot express the difference of evacuation behavior.

Generally, the evacuation paths are complicated. Thus, the subjective categorization of paths is often difficult. For example, the paths of TA and SA are both T-shaped and similar, but SA went back many times. It is also difficult to determine the suitable category of NI's path. Fractal dimensions of the paths can be a good index to classify this kind of complicated figures.

## 4 CONCLUSIONS

A maze experiment was conducted to collect data on the characteristics of human behavior during evacuation. Using 40 subjects, two experiments with different initial conditions of brightness and smoke were conducted. The subjects were sent one by one to the maze. When the subject reached the room located at the center of the maze, the light of the whole maze was turned off to give the subject an unexpected shock. The major findings of the experiment are:

(1) Once a subject has lost his reference positions, it takes him time to recover his sense of direction.

(2) Smoke and the absence of light can change the subject's image of a place and this change greatly affects the evacuation behavior.

(3) The behaviors can be categorized into three patterns: got out of the maze without fail, lost their way in the darkness but kept their sense of direction, and completely lost their way and could not get out even though the light came back.

To find a more objective measure of human behavior, the use of the fractal dimension was considered. The adequacy of the fractal dimension of the evacuation path was examined using the data from the maze experiment and from an actual fire. From these investigations, the fractal dimension is found to be a good index to quantify the complexity of evacuation behavior. It is also found that the complexity cannot be expressed by the evacuation time, path length and the area covered during evacuation.

## ACKNOWLEDGMENT

We are grateful to the staff of Ikebukuro Life Safety Hall and those who participated in the experiment. Special thanks are extended to Dr. Ohtsuki and Mr. Ebihara of Shimizu Construction Co., Ltd. for their cooperation during the experiment.

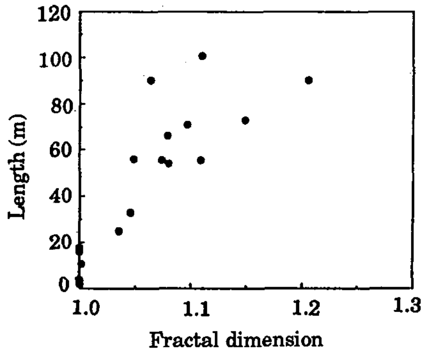



Figure 19. Fractal dimension and path length for the fire

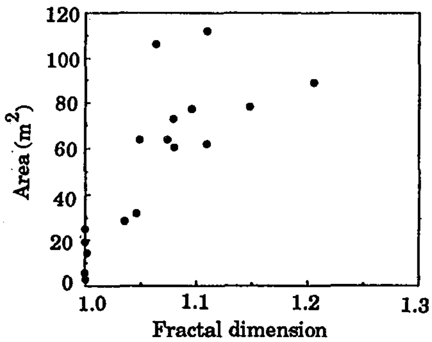
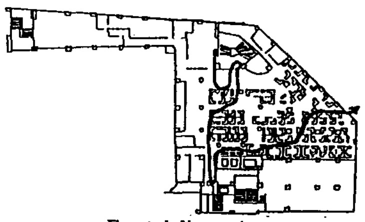
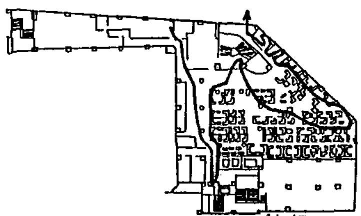


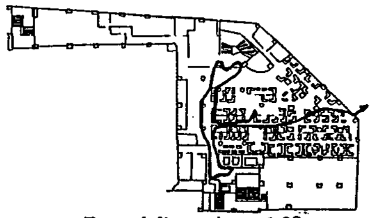

Figure 20. Fractal dimension and area for the fire



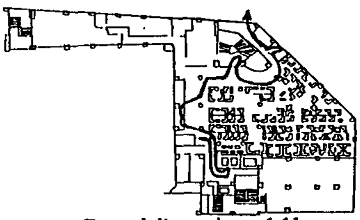
Fractal dimension = 1.05
Length = 55.7m
Area = 63.9m²
(a) TA



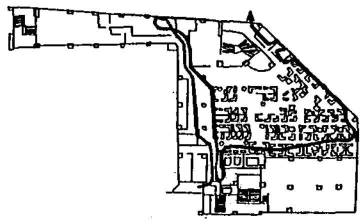
Fractal dimension = 1.06
Length = 89.7m
Area = 106.3m²
(b) TM



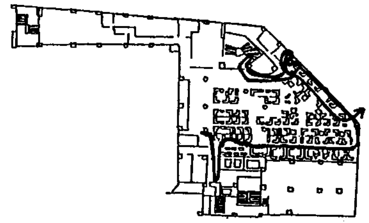
Fractal dimension = 1.08
Length = 65.9m
Area = 72.8m²
(c) SA



Fractal dimension = 1.11
Length = 55.3m
Area = 62.0m²
(d) NI



Fractal dimension = 1.11
Length = 100.5m
Area = 111.6m²
(e) YO



Fractal dimension = 1.21
Length = 89.9m
Area = 88.8m²
(f) MOT

Figure 21. Evacuation paths of six survivors in the fire (Morita, 1973)

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