THIRTEENTH MEETING OF THE UJNR PANEL ON FIRE RESEARCH AND SAFETY, MARCH 13-20, 1996

VOLUME 1

Kellie Ann Beall, Editor

Assessment of Clarity of Egress Route in Buildings

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ABSTRACT

A framework of a new fire safety design method based on a concept of performance-based design is now in preparation in Japan[1]. In this paper, the authors turned their attention to the clarity of the egress route as an important performance for assuring the life safety of occupants in buildings, and intensively discussed its assessment. The relevant previous work on the evaluation of the clarity of the egress route was reviewed and studied. The clarity of the egress route was considered dependent upon the physical measure which could quantitatively evaluate how quickly occupants could escape from buildings or how easily they could find exits or safety zones in floors. In this point of view, the travel distance during the emergency evacuation was one of the effective and quantitative measures of the clarity of the egress route. The assessment of the travel distance based on some probabilistic assumptions of the occupant's evacuation behavior was introduced. The network modeling technique was utilized to represent the configuration of the egress route and to calculate the expected value of the travel distance. Through numerical computations, an effective configuration was discussed in such a way that the average of expected travel distance in a floor was minimized among possible layouts of the egress route. Finally, it was concluded that the proposed procedure with an emphasis on the clarity of the egress route was based on the minimization of the travel distance and it could provide a practical basis for the new fire safety design of buildings.

1. INTRODUCTION

Buildings in Japan tend to become large and complex according mainly to the variety of usage. Most of the existing regulations of the fire safety design in Japan were established by means of empirical judgments, which were not always solidly based on any engineering or scientific basis[2]. Under these circumstances, it is necessary to grope for new and effective strategy in the fire safety design or the evacuation planning for the new type of large-scale and complex buildings. A performance-based design system of buildings was proposed to the Building Community of Japan as a new fire safety design system. Ministry of Construction launched the five year research project to make clear the detail of the building design regulations based on the concept of the performance-based design system.

In this paper, one of the ideas how to establish a regulation concerning the egress route design in the performance-based design is introduced. The authors turn their attention to the assessment of the clarity or the complexity of the egress route in buildings. It is considered that

the clarity of the egress route have to be evaluated from the two points of view. One is the effectiveness of evacuation that means the assessment with regard to the occupant's evacuation behavior. Another is the simplicity of the structure which is constructed by routes in a floor that means the assessment of the geometrical relation or the configuration of routes (Figure 1). In other words, the state, that the clarity of the egress route is maintained in way-finding or decision-making during an emergency evacuation, may be the one that the travel distance will be in the appropriate level for assuring the life safety, according to the scale of buildings. In this point of view, the relation between the travel distance and the clarity of the egress route is discussed. At first, two existing works on the evaluation of the clarity or the complexity of the route[3,4,5] is reviewed and discussed from the viewpoint of their applicability to the measure of clarity of the egress route in the performance-based design system. After that, some calculation result of the travel distance is introduced, under a probabilistic assumption on the choice of egress route at a T-junction or a crossroads in the occupant's evacuation behavior. The calculation results are provided by applying the network modeling technique to modeling of the egress route in the floor. Through the calculation results, the effective factors to minimize the expected travel distance in the layout of egress route with the emphasis on the assessment of the clarity of the egress route can be measured by the assessment of the expected travel distance. Finally, we mention about the future subjects in this field.

2. NETWORK MODELING OF EGRESS ROUTE

The network modeling technique is applied to representing the configuration of the egress route in buildings. The network model consists of nodes and links. The node represents a point at which some judgment is required to the occupant during the emergency evacuation along the route in the floor. The link, which has the length as a variable, represents a relation between the points represented by the nodes with regard to the connection of the routes. The node is constructed based on the several rules, as follows:

     i) the point of parting of routes (for example a crossroads or a T-junction)
     ii) the point of making a right angle or a blind curved corner
     iii) the end point of a route
     iv) the indoor temporary safety zone (this means a kind of exit in a floor)
     v) the point in front of the door which connects the room and the corridor.

Figure 2 shows an example of the network model of an existing office floor in Japan.

3. REVIEW OF EXISTING MEASURES OF CLARITY OF EGRESS ROUTE

Two existing measures which are used to evaluate the clarity of the egress route using the network model are introduced. One was proposed by Yoshimura[3,4], the other was by Donegan[5]. Figure 3 shows the concept of these measures. Yoshimura's measure indicates that if the value is close to 1.0, the clarity of the egress route is maintained. In the case of Donegan's measure, if the value is close to 0.0, it is maintained. These measures were applied to existing office floors in Japan. Figure 4 shows the relation between two measures, and the relation between each measure and the index which is assumed to represent the characteristics of the network model. Each measure is discussed by using the average value of the measures of all the origin and the destination pairs in the floors. The clear correlation is found in the relation between Yoshimura's measure and the total number of degrees of nodes, and in the relation between the Donegan's measure and the total number of links. Each measure is basically proposed as the value of evaluating the relation between the nodes, in short, the relation between the origin and the

destination, in consideration of the shortest route between them. Thus, it is convenient to compare the clarity of the route among various relations between nodes. But it is unclear that what level is sufficient to assure the clarity of the egress route. In this point of view, these measures are not so applicable to assess the clarity of the whole structure of route.

4. ASSESSMENT OF CLARITY OF EGRESS ROUTE USING TRAVEL DISTANCE

The applicability to assess the clarity of egress route using the travel distance is discussed. The reason why the travel distance is proposed as the measure of the clarity of the egress route is that it is supposed to be easy to handle in the fire safety design of buildings by the designers or the planners. In this section, we make clear the effect of the number of exits or safety zones and the layout of them on the travel distance. In the numerical calculations of the travel distance, basically it is assumed that the each direction on the corner, the T-junction and the crossroads has the same probability on the choice of egress route, including a backward motion. In the calculation steps, first the expected travel distances of all origin and destination pairs of nodes in the network model are determined, and then the average of expected travel distance is determined by averaging all expected travel distances.

4.1 EFFECT OF NUMBER OF EXIT ON TRAVEL DISTANCE

Figure 5 shows examples of the network models for studying the effect of the number of the exits on the travel distance. Each link in the network model has unit length, and all links in the network model are assumed to have the same length. Figure 6 represents the results of the relation between the number of exits and the average of expected travel distance. The average of expected travel distance and the value of the total length of the route divided by the total degree of exits are correlated. A similar tendency toward the correlation is shown between the network models constructed by the existing floor plans and the assumed network models. This result means that it is possible to control the travel distance by the number of exits which are arranged in a floor corresponding to the total length of routes.

Figure 7 shows the change of the expected travel distance between the node and the exit due to the change of the probability of the backward motion. The x-axis indicates the probability ratio of the occurrence of the backward motion to the probability of the choice of other directions. Here, the value of 0.0 indicates the case that the backward motion is not considered with the exception of the node which corresponds to the end of the route. The dashed line indicates the minimum travel distance to the exit from the node. Through the calculation results, it is pointed out that the probability of the backward motion has the effect on the expected travel distance. However, this effect is different from the characteristics found in the relation between nodes and the structure of the network model. In the case of the network model without loop structures, the expected travel distance is larger than the case of the network model with loops. This result indicates that the number of the end points has some effect on the expected travel distance, and it is supposed to be important to control the number and the layout of the end points of the routes in the floor.

4.2 EFFECT OF LAYOUT OF EXIT ON TRAVEL DISTANCE

In this section, the effect of the layout of exits on the travel distance is studied from the two kinds of viewpoints. One is the centralized layout of exits, the other is the distributed layout. Figure 8 shows the examples of the network models used in this study. The same assumption on the length of the link in the network model, which is described in the previous section, is applied.

Figure 9 shows the relation between the number of exits and the average of expected travel distance. It is understood that the distributed layout of exits is effective for minimizing the average of expected travel distance compared with the centralized layout. It is also understood that the effective number of exits for minimizing the average of expected travel distance exists, depends on the structure of the network model.

Figure 10 shows the example of the distribution chart of the travel distance used in the assessment of the expected travel distance between the nodes. The expected travel distance between nodes is close to the distance which has the high probability of occurrence. In the case of the centralized layout, the distribution of the travel distance has a tendency to become wide. This effect appears that the expected travel distance becomes larger compared with the case of the distributed layout. Therefore, it is important to control the distribution of the travel distance for minimizing the expected travel distance.

5. CONCLUSIONS

The assessment of the clarity of the egress route using the travel distance is discussed. In the evacuation planning, the existing regulation of the maximum travel distance during emergency evacuation plays an important role for assuring the safe egress routes or the life safety of occupants. So, it is supposed that the assessment of the clarity of the egress route based on the travel distance is easy to accept, and also easy to understand as a quantitative measure by designers. The average of expected travel distance, which is directly calculated from the network model of routes based on a probabilistic assumption of the occupant's evacuation behavior, is studied in two ways. The first is to regulate the number of safety zones or exits in a floor. The second is to regulate their layout in the floor. It is confirmed that the appropriate number of exits in the floor exists corresponding to the scale of the floor or the total length of the routes, and it is better to distribute the exits in the floor for minimizing of the average of expected travel distance. It is also confirmed that the travel distance is applicable to assess the clarity or the complexity of the egress route in the floor. Figure 11 proposes a flow chart to regulate the egress route in which the clarity is considered. The first step is set up with the aim of minimizing the average of expected travel distance corresponding to the scale of the floor. In this point of view, it is considered that the important factor is to control the number and the layout of exits, safety zones, and end points in the floor. On the other hand, even if two networks have similar characteristics in the total length of the route, this dose not necessarily mean two models are identical, for example the distribution of the length of links in the network model. It is considered that these characteristics between the network models have to be taken into account in discussing from an equal point of view about the assessment of the clarity of the egress route using the travel distance. In this point of view, the assessment of the simplicity of the structure of the network model will be required, and it is necessary to assess the simplicity by using parameters which characterize the network model, for example the number of nodes or links, and the average length of the links. The second step is established for the purpose of an improvement of reliability in applying the average of expected travel distance to the measure of clarity of the egress route.

The calculation result of the expected travel distance is affected by how to construct the network model based on the floor plan. Therefore, it is necessary to make clear the rules for the constructing the network model based on the floor plan. At the same time, in the case of applying the travel distance as the quantitative measure of the clarity of the egress route, it is necessary to collect the data which is used for determining the probability on the choice of route during the emergency evacuation, including the choice of a straight or a wide egress route and so on. If the

data, which have high reliability, are obtained from the survey of occupant's evacuation behavior, it is possible to confidently treat the travel distance as the assessment measure of clarity of the egress route.

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4) Yoshimura, H: A Metrical Evaluation of the Arrangement of Fire Escapes by Goal Programming, A Study on Arrangement of Fire Escape in a Buildings Part 2, Journal of Architecture, Planning and Environmental Engineering, Transaction of AIJ (in Japanese), No. 403, 1989. 9
5) Donegan, H. A., Pollock, A. J. and Taylor, I. R.: Egress Complexity of a Building, Fire Safety Science - Proceedings of the Fourth International Symposium, 1994
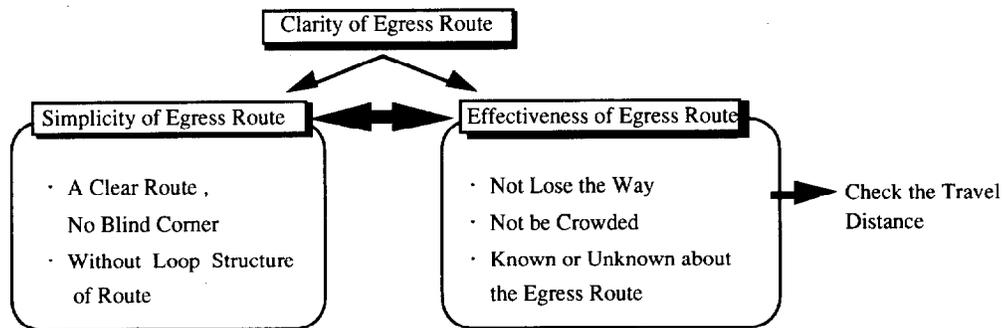
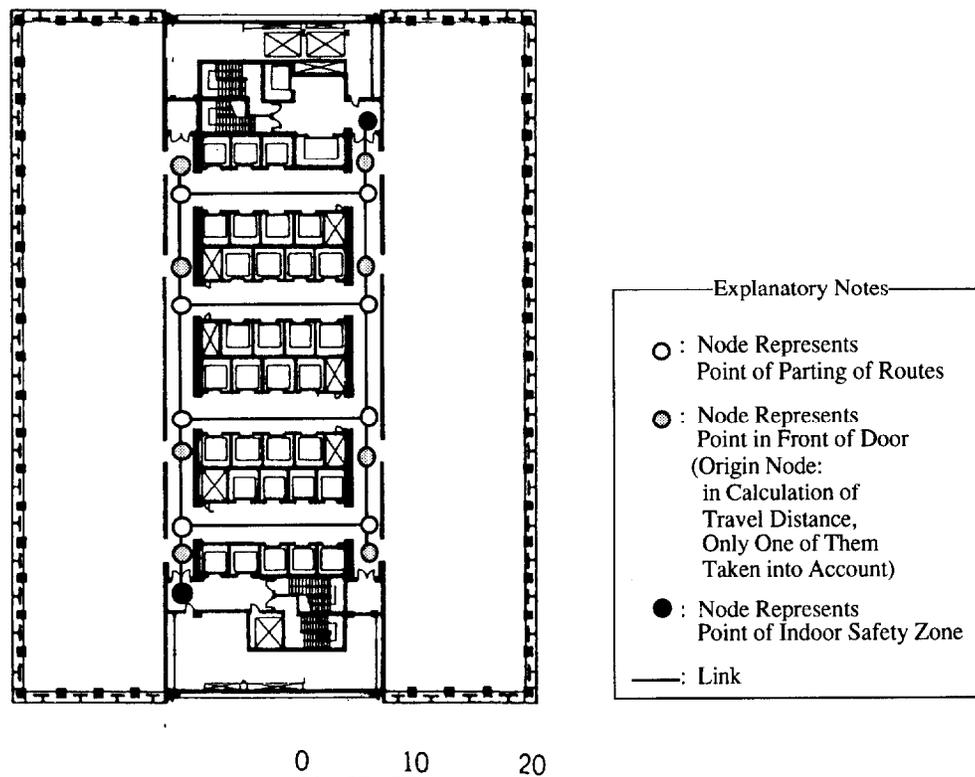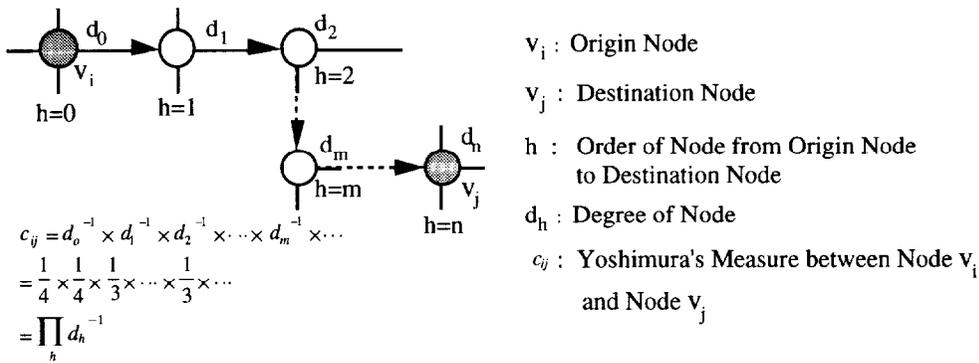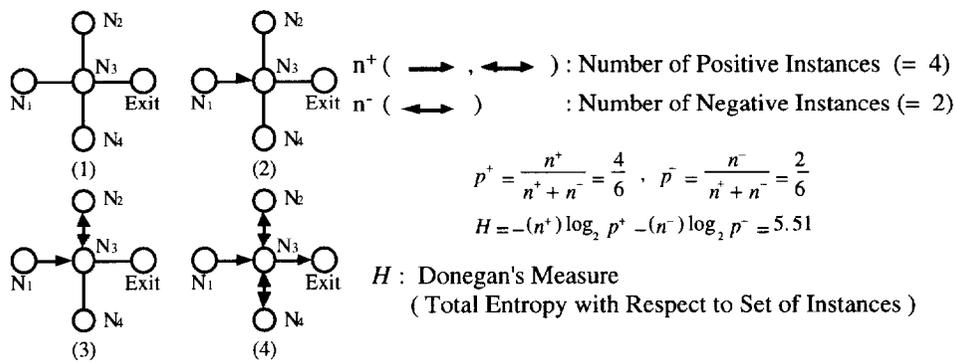Figure 1 Concept of Assesment of Clarity of Egress Route

0   10   20

Figure 2 Example of Network Model of Office Floor

4 7

$$c_{ij} = d_o^{-1} \times d_1^{-1} \times d_2^{-1} \times \cdots \times d_m^{-1} \times \cdots$$
$$= \frac{1}{4} \times \frac{1}{4} \times \frac{1}{3} \times \cdots \times \frac{1}{3} \times \cdots$$
$$= \prod_h d_h^{-1}$$

v_i : Origin Node

v_j : Destination Node

h : Order of Node from Origin Node to Destination Node

d_h : Degree of Node

c_{ij} : Yoshimura's Measure between Node v_i and Node v_j

(a) Yoshimura's Measure

n^+ ($\longrightarrow$, $\longleftarrow$) : Number of Positive Instances (= 4)

n^- ($\longleftrightarrow$) : Number of Negative Instances (= 2)

$$p^+ = \frac{n^+}{n^+ + n^-} = \frac{4}{6} , \quad p^- = \frac{n^-}{n^+ + n^-} = \frac{2}{6}$$

$$H = -(n^+)\log_2 p^+ - (n^-)\log_2 p^- = 5.51$$

H : Donegan's Measure
(Total Entropy with Respect to Set of Instances)
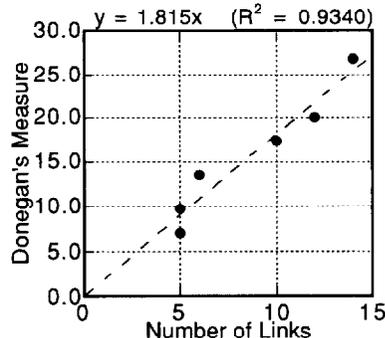
(b) Donegan's Measure

Figure 3 Existing Measures of Clarity of Egress Route
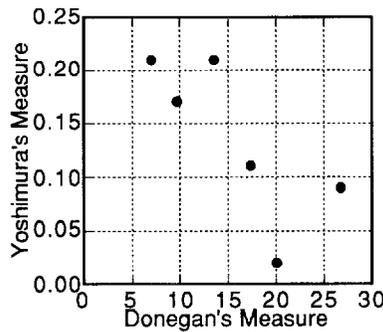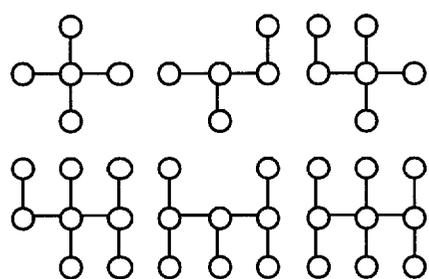

(a) Relation between Two Measures
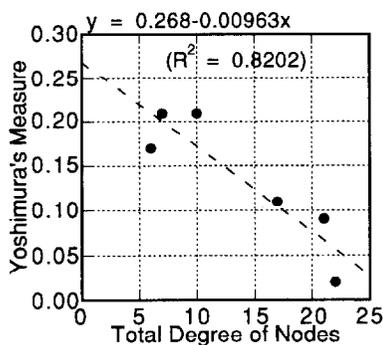
(b) Relation between Yoshimura's Measure and Total Degree of Nodes
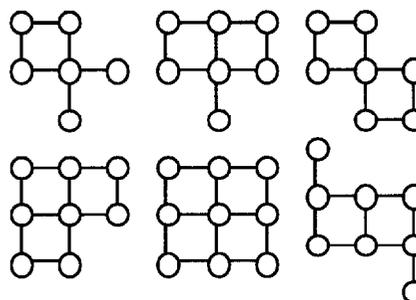
(c) Relation between Donegan's Measure and Number of Links

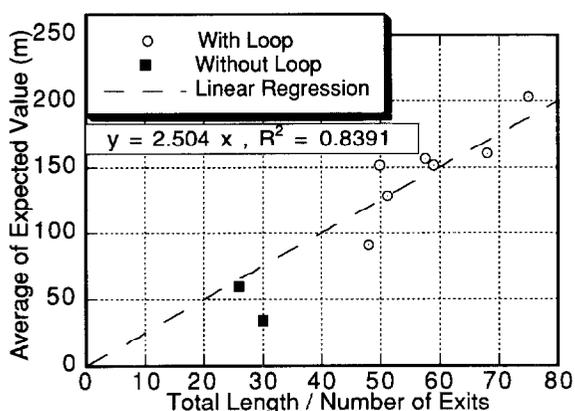Figure 4 Calculation Results of Two Measures

(a)   Network Models
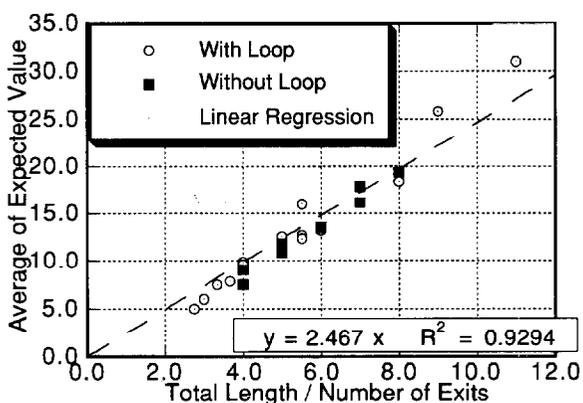Without Loop Structure

(b)   Network Models
With Loop Structure
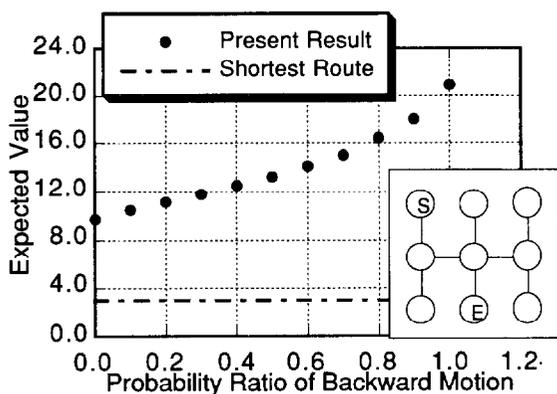
Figure 5 Examples of Network Models

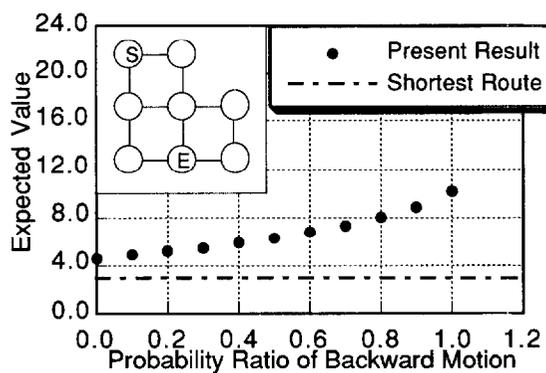(a) Network Models of Existing Floors

(b) Assumed Network Models

Figure 6 Calculation Results of Average of Expected Travel Distance

(a) Without Loop Structure

(b) With Loop Structure

Figure 7 Change of Expected Travel Distance Due to Change
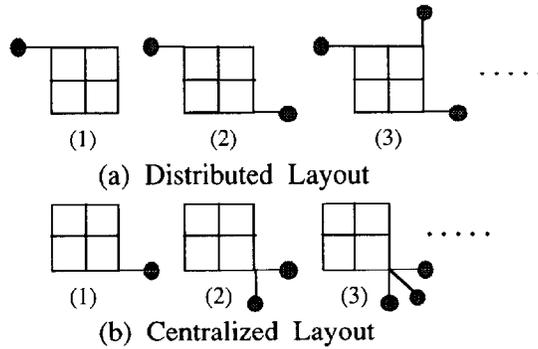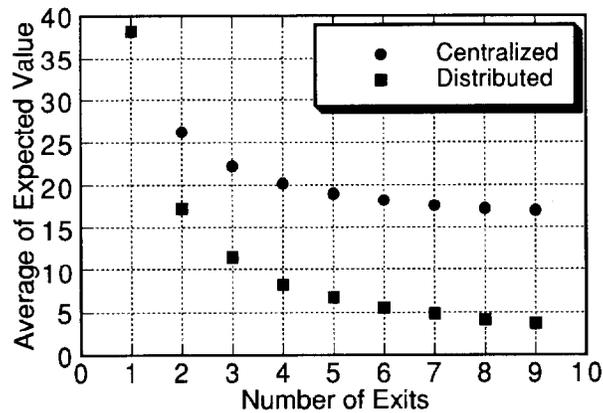of Probability of Backward Motion

(1) (2) (3) . . . . .

(a) Distributed Layout

(1) (2) (3) . . . . .

(b) Centralized Layout

Figure 8 Examples of Exits Layout

Figure 9 Relation between Number of Exits and
Average of Expected Travel Distance

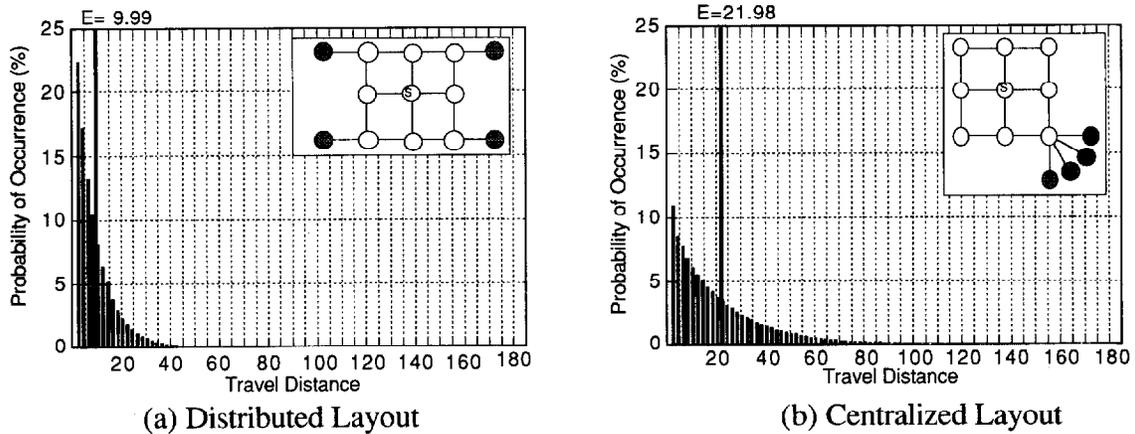(a) Distributed Layout   (b) Centralized Layout

Figure 10 Examples of Distribution Chart of Travel Distance

Effectiveness of Egress Route

·Check the Number and the Layout
 of Exits (or Safety Zones)
·Check the Number and the Layout
 of End Points of the Routes

To Minimize the Average of
Expected Travel Distance

Simplicity of Egress Route

·Check the Number of Nodes
 and Links
·Check the Total Degree of Nodes
·Check the Distribution of
 the Length of Links

To Improve the Reliability of
the Average of Expected Travel Distance

The State Maintained
the Clarity of
Egress Route
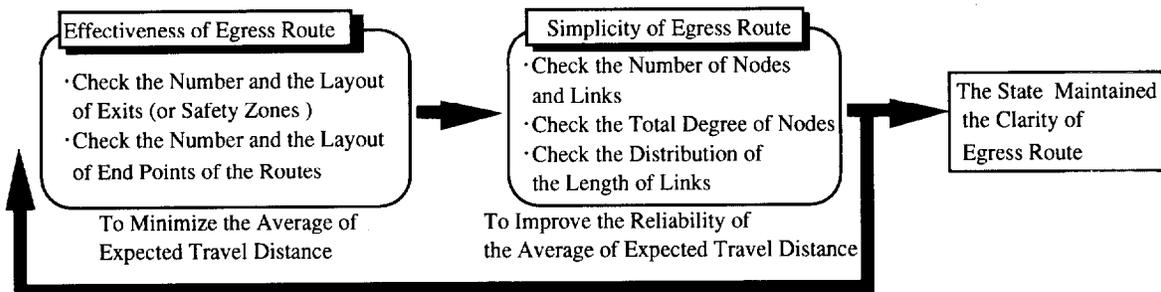
Figure 11 Flow Chart to Regulate Egress Route in Consideration of Clarity

Discussion

Tokiyoshi Yamada: Is it possible to add in smoke movement in the near future?

Manabu Ebihara: At this moment, we are not considering taking of smoke movement into consideration because smoke movement itself is probabilistic. So that it is very difficult to take that factor into consideration.

Brian Meacham: It seems to me that both the smoke movement issue and the number of people in a room are variables and the question would be how do you handle the weighting of the variables? Do you have a statistical background?

Manabu Ebihara: At this moment, we do not have any data with respect to route selection, and we do not have data on smoke movement either. So in order to weight the various different variables, first of all, we have to collect the necessary data so that we can weigh them properly.

Takeyoshi Tanaka: I'm afraid there is some misunderstanding here. This particular model is not an evacuation model. This is a model to determine whether the evacuation route is simple or complicated in terms of distance and speed and so forth. So this does not take into consideration smoke movement or other variables which can be used in an evacuation model.

Masahiro Morita: So if that was the case, it is not the shortest range, rather it has to be shortest time using maximum flow.

Manabu Ebihara: This does not deal with the shortest distance, rather, this model is to get an expected value for different nodes. Then if this value is small, the evacuation time would be shorter. Of course, we can assess the walking speed at certain levels when we make calculations. So for that reason, as Mr. Tanaka mentioned earlier, we are not taking into consideration, at this time, density and smoke movement.

John Rockett: Perhaps my question is more directed at the assembly of the papers rather than yours in particular. When you have high population densities, and particularly if the evacuation routes are limited, you would expect queuing to occur. When queuing occurs with a large population density, a signal should propagate up the line that a particular route is being successful. Do any of these models take that kind of effect into account?

Manabu Ebihara: No, those things are not taken into consideration. In this model we only took into consideration the horizontal data. And just by using such data, we try to give some kind of indicator for the degree of clarity of the routes. And that was the purpose of this paper so that we did not take into consideration factors such as density.