methodology development is required to combine formal mathematical and informal empirical procedures.

- Conference Organisers should be praised for their efforts to introduce workshop format to the present series of Symposiums. Informal discussions have proved to be very important, and feedback received on Workshop from Conference delegates seems to be quite positive. It is desirable that workshop structure is preserved at the following Symposiums with other topics of common interest open for discussion.

Finally, I would like to thank Conference Organisers for providing an opportunity for this informal discussion, Workshop speakers for their invaluable efforts and all participants for their enthusiastic input into discussion.

I hope we would be able to continue our discussions at the next Symposium in Australia.

Human Behavior

HIDEMASA YOSHIMURA
Graduate School of Engineering, Osaka University, Japan

Human behavior in fire is dependent on complexity of egress routes, familiarity with built-environment, spaciousness/closedness, fire and smoke spread, light, alarm signals, fire detector activation time, legibility of way guidance signs, etc. This paper presents a mini-review on human behavior and its modeling, mainly focusing on Japan.

1. Surveys and experiments on human behavior in fire

For fire safety planning of buildings it is essential to clarify human behavior in fire. In 1932 a fire broke out at Shirakiya Department Store in Tokyo, resulting in 14 victims. Architects and building engineers were very surprised at this fire because they believed reinforced concrete buildings would not burn up. Within a month after the fire the first scientific survey was made on the salesclerks inquiring their escape behavior during fire [1]. The findings were that most of them made for staircases they habitually used, and that some occupants who were driven into a corner by smoke and heat courageously or recklessly climbed down tied ropes, connected cloths, chimney, flagpole, down pipe, etc. Since this fire, human behavior in fire has been scientifically surveyed and analyzed by many fire scientists and environmental psychologists.

In order to supplement the weak point of questionnaire surveys and interviews, various experiments on human behavior have been made. In Japan the first experiments on human behavior in fire date back to 1970s. Dr. Jin made successful experiments on walking speed in very dense and irritant smoke environment and in complete darkness [2]. Recent experiments use computer graphics and virtual reality simulator [3] [4] [5].

2. Findings on human behavior in fire

Through various observations, surveys and experiments, considerable part of human behavior in fire is already clarified. The findings are as follows.
1) They use familiar doorways, corridors and stairs.
2) When they face danger, they trace back their own routes to familiar area.
3) They make for light, or brighter, more spacious side.
4) They instinctively avoid and elude irritant environment or danger such as smoke and fire.
5) They follow other evacuees when they lose their judgement.

6) They tend to make for stairs or corridors which they see first.
7) They choose the nearest stairs, linear corridors or stairs which they can see far ahead along.
8) Some of them show unexpectedly strong power and courage such as jumping to a tree through a window, climbing down the connected cloths, when they have no other alternatives.

3. Crowd flow analysis and its application to evacuation estimation

We often experience in the crowded stations or on busy streets that the walking speed gradually decreases as the crowd gets denser, and sometimes we are forced to walk with gliding steps or to stop walking. The first mathematical analysis of this phenomenon was made in as early as 1937[6]. After several years' interruption by World War II, the study of crowd flow was resumed for easing hectic congestion in large railway stations due to the rapid postwar restoration.

Dr. Togawa's mathematical analysis of crowd flow in terms of concentration, detention, and outflow [7] was epoch-making, and Togawa's theoretical analysis developed during 1960s. In Japan 1960s are a memorable decade for fire scientists in that the number of building fire rapidly increased and that the first skyscraper in Japan, *Kasumigaseki Building*, was completed in 1968. In preparation for the upcoming skyscraper era, evacuation safety for super high-rise buildings was carefully studied based on Togawa's theory. Nowadays Togawa's theory still plays an important role in evacuation estimation and evacuation simulation.

4. Evacuation estimation

One of the important purposes of evacuation estimation is to check the width of doorways and fire exits, and the capacity of safety compartments and staircases. In Japan the authorized guideline of evacuation planning [8] has been improved several times by the Building Center of Japan. In the authorized guideline, the process of evacuation estimation is described in detail using the graph model, and the process is given as follows.

4.1 The proposition of evacuation estimation

Occupants in a fire building are expected to evacuate as follows.
1) Occupants initially distribute uniformly in the room at specified density given in the guideline.
2) All occupants except those in fire occurrence room start evacuation at the same time.
3) Occupants evacuate along the specified evacuation routes as if they knew the overall floor plan, that is, they never get lost even in unfamiliar or very complicated buildings.
4) Occupants neither get ahead of others, nor go back.
5) Occupants travel at a constant walking pace.
6) The amount of crowd flow is restricted at the narrow doorways according to the specified flow rate of 1.5 person/m/s.
7) Detained occupants wait their turns in calm and quiet state even if smoke is just around the corner.

4.2 Process of Evacuation estimation

The specific process of evacuation estimation is described in the authorized guideline are as follows.

1) Estimate the initial distribution of occupants according to the building type, use of rooms, room area, or the number of initially planned seats and chairs.
2) Imagine the point of fire ignition in the critical point on the critical floor in terms of evacuation, or in the room whose fire occurrence ratio is statistically very high.
3) Specify their escape routes for the room occupants to evacuate along the safe and shortest routes to escape stairs. Doorways and corridors which will be immediately blocked by smoke spread cannot be used. The problem is that this important step is sometimes made at the planner's will.
4) Three speed of movement, 0.5m/s, 1m/s, 1.3m/s, are selectively used according to the evacuees' mobility or crowd density.
5) Occupants in a fire room start evacuation 30 seconds after fire outbreak, before those in non-fire rooms start evacuation.

The wider the room is, the longer the allowable evacuation time becomes. Allowable evacuation time of a room whose ceiling height is more than 6 meters is 1.5 times as long as that of a low ceiling room. In these ways the influence of smoke spread on evacuation behavior is indirectly taken into consideration. However, in the year 2000 evacuation estimation is being revised with the introduction of performance-based fire safety code to the Building Standard of Law in Japan.

But these suppositions apparently don't agree with the evacuation in real fire. If a fire suddenly broke out in fully occupied auditorium, will all the occupants evacuate just like the way they perform do in the annual evacuation drill? The role of evacuation simulation is not to describe the fire scenario as realistic as possible, but to find potential danger in evacuation. Therefore if some problems are found in evacuation estimation, the original plan should be completely looked over again because in such a case, evacuation in real fire is sure to fall into great confusion.

5. Evacuation simulation using computer

We have 30 years history of evacuation simulation since late 1960s, and many types of evacuation simulation models have been developed. Reviews of methodologies used in the computer simulation models help us improve and develop simulation models [9] [10].

5.1 Modeling of human behavior

In evacuation simulation, there are two types of mathematical modeling of human behavior. One is transaction model and the other is fluid model. Transaction model treats occupants as individuals and assign them unique characteristics including physical, psychological and physiological response. Transaction model is good for reproducing movement of each evacuee as realistic as possible. Fluid model handles large number of occupants as if they are flowing water or rolling ball bearings. Fluid model is good for taking wide view of evacuation process in fire. In both models, walking speed is given according to the crowd density. Some advanced models can change walking speed according to the restriction of visual field, psychological condition, smoke density, etc.

The algorithm of path choice behavior is classified into three types.

(1) Shortest path model
Evacuees travel along the shortest paths to stairs or fire exits eluding smoke spread area as if they knew all of the floor plan. At an early stage of development many simulation models had this type of behavioral rules only, but recent models describe more realistic escape behavior.

(2) Transition probability model
Moving directions are given by the transition probability which depends on the distance to stairs, psychological condition, etc.

(3) Field-dependent model
Field-dependent model simulates human behavior like material points behave in the field of force. Magnetic force model can simulate pedestrians' movement and their interaction with each other [11]. Object-oriented model gives evacuation direction by synthesizing attractive force from the goal and repulsive force from smoke [12].

5.2 Modeling of Spatial Elements

Evacuation simulation using computer requires modeling of space, human behavior, and smoke behavior. Many spatial models have been developed and improved since late 1960s', and they can be categorized at least into three types.

(1) Coordinate system model
Coordinate system model can precisely describe the physical dimensions and the location of each spatial element, and occupants' movement in coordinate space. But it takes much time, memory, cost and energy in feed-backing process.

(2) Mesh model
Mesh model divides building floors into equal-sized square mesh elements. Floor plans with one large space like department stores and exhibition halls are good for mesh modeling. Occupants in a mesh move in groups to adjacent meshes. Mesh model is appropriate for macro analysis due to its easy data processing and handling.

(3) Network model
Network model describes spatial elements as nodes and paths. Evacuees travel and smoke spreads along the paths via nodes. Network model is suitable for buildings with corridors and small rooms such as hotels, hospitals and schools.

6. Concluding remarks for the future breakthrough

Modeling of human behavior has developed, and is still developing, but we still have many problems yet to be solved. For example when should we make the occupants start evacuation? How do they react to the built environment, light, smoke, heat, congestion, others' behavior, and other human decision factors? Can we predict the spread of fire and smoke correctly?

And what if the aged, or the challenged such as wheelchair users, visually-impaired, hearing impaired are mingled with the evacuees? [13]. There are so many uncertainties which cannot be supported by adequate and reliable data.

Evacuation safety is assured by predictive models which are created by collaboration of specialists in fire physics, fire chemistry, structural behavior, risk assessment, and human behavior. Some models are very practical and excellent, but they still have much room for improvement. In order to quantify and integrate human factors issues into engineering fire safety design, exchanging ideas and information in the international symposium is very important for the breakthrough in the 21st century.

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