MODELLING FIRE ESCAPE OF ULTRA HIGH-RISE BUILDINGS BY ELEVATORS

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ABSTRACT

During Elevcon'96 held in Barcelona (So 1996) , a paper that summarised the issues related to using elevators for fire escape was presented. Lots of technical and psychological problems were discussed in that paper. In order to strengthen the idea to bring it to reality in the next century, a conceptual lift evacuation model was proposed. This model can be used to quantitatively evaluate the evacuation patterns of people using elevators for fire escape. Inside this model, all technical difficulties have been ignored and it is assumed that the hardware is able to resist the fire attack. It is hoped that engineers around the world will devote more time in studying this issue as buildings are getting higher and higher. Eventually, fire escape by elevators may be unavoidable.

1 INTRODUCTION

Staircases are considered as the escape routes of multi-storey buildings in accordance with the traditional prescriptive codes of practice. However, it has been found (Egan 1986) that evacuees will normally experience fatigue while travelling down in about 5 minutes (i.e. about 300 seconds). The average speed of the evacuees travelling down one storey with normal headroom of 2.5 m per floor in Hong Kong is about 16 seconds (Pauls 1987). In this connection, fatigue will occur while the evacuees have travelled about 18 storeys. For buildings over 100 storeys, people may need to have 5 stops for travelling from the topmost floor to the ground level. If an evacuee requires 60 to 120 seconds for the rest at each stop, he/she will require about 1900 to 2800 seconds for travelling from the 100th floor to ground level, which is totally unacceptable from a safety point of view. This indicates that the time for vertical movement in an ultra high-rise building is extremely extensive. Therefore, if one believes that evacuation is an essential strategy for fire safety design in buildings, mechanical means for vertical transportation appears necessary for ultra high-rise buildings. Recently, in Hong Kong, on 20th November, 1996, at Garley Building in Nathan Road, Kowloon, a fire outbreak killed 49 people and around 200 were injured. Millions of property were destroyed. Up to now, the seat of the blaze was thought to have been at the bottom of a lift shaft. The fire had burned for 21 hours. Although we still are not sure the actual cause of the fire, the situation should have been much better if the elevators had been used as a means of fire escape because the fire resistance ability of the elevator system would have been much superior compared with the current design.

Evacuation in a building can be viewed as a process which comprises behavioural and physical reactions and is continually changing in a time-dependent manner. In order to gain understanding of the process, simulation models can be built to resemble the real world situations. In complex buildings, such as those ultra high-rise buildings, the interactions of people and the built environment is very complicated and therefore, a comprehensive model is difficult to be established. Our aim is to start with a simplified model and then further develop it into a more perfect one.

2 REVIEW AND SCOPE

Despite the importance of evacuation system in buildings, the effort devoted by professionals to model the evacuation process appears limited. Earlier researchers had dealt with the evacuation problems by considering the carrying capacity of the building elements (Togawa, 1955; Predtechenskii et al, 1969; Melinek et al, 1975). They emphasised on the importance of the width and capacity of exits. Later, methods on the basis of operational research were developed to take the network topology of a building into account (Berlin, 1979; Chalmet, 1982; Choi et al, 1984). However, these methods cannot handle the behavioural reactions of the people which are considered as an important issue affecting the evacuation process. With the advancement of digital computer, refined computer programs were developed to describe the evacuation (Peacock et al, 1991; Ketchell et al, 1995; Owen et al, 1997; Thompson et al, 1997). Nevertheless, these programs are mainly developed to manipulate human movement only.

ELVAC (Klote, 1992) is a program developed by NIST to calculate the elevator evacuation time which can be regarded as a preliminary program to model the elevator evacuation process. This program is similar to some other evacuation programs in that it cannot compute the behavioural reactions of the people.

This paper aims at introducing a method in modelling evacuation process using elevators in the evacuation. A method on the basis of a multi-state evaluation technique is proposed to incorporate behavioural reaction in an elevator evacuation model.

3 LIFT EVACUATION

The idea of using elevators for fire escape is not new. Bazjanac (1973) studied the performance of elevators in high-rise buildings under emergency situations. He indicated that the automatic elimination of elevators from service in case of emergency has been incorrect. With the assistance of elevators, the evacuation time could be very much reduced. However, elevators should only be used in case of emergency when their operation is safe. With proper planning and control of evacuation process, elevators can accomplish safe evacuation for high-rise buildings, in particular, those ultra-high-rise buildings beyond 100 storeys high. Recently, many researchers have carried out the studies on elevator evacuation. For example, Klote (1993) developed a methodology (the ELVAC programme) in calculating the evacuation time by means of elevators; Croner et al (1992), Klote et al (1992) etc. studied the human behaviour of the people using elevator evacuation. Furthermore, elevator evacuation could be used for the disabled (Fox 1991; Kose 1995). In addition, the American Society of Mechanical Engineers had paid attention to this issue since 1991 by organising two national symposia on relevant topics.

The first symposium was held in February, 1991 in Baltimore, Maryland. The second symposium was held four years later in April, 1995 in the same city. The purpose of the second symposium was to continue the discussion regarding elevators, fire and accessibility in the hope of gaining even greater co-ordination between the ASME A17 and the Model Building Codes.

On the other hand, the concept of an emergency elevator evacuation system (EEES) was developed (Klote 1995) and that included the elevator equipment, hoistway, machine room, elevator lobby, as well as, protection from heat, flame, smoke, water, overheating of elevator machine room equipment and loss of electrical power. One point that is worth to note is that the EEES took into account of human behaviour so that the building occupants were willing to using and capable of operating the system during emergency.

Regarding human concerns, Levin (1995) and Holt (1995) believed that passengers would only use the elevator systems for evacuation during fire provided that good education and adequate information had been provided to the passengers so that they trust upon the reliability of the systems because passengers would always seek to minimise their risks during a fire emergency.

On the basis of such a concept, in this paper, we have proposed an evacuation system using computer vision technique. It aims at systematically evacuate the people from the designated floors in an ultra high-rise building.

4 THE USE OF DESIGNATED FLOORS

There are two kinds of problems that need consideration regarding fire evacuation using elevators, namely hardware problems and software problems respectively (So 1996). Hardware problems are associated with all sorts of technical features of elevator systems that ensure safe operation during fire emergency. But hardware problems are outside the scope of this paper. The software problems concern the behavioural reaction of the people.

Escape process involves solving spatial problem (Lo and Will 1995). Theoretical studies in psychology had reviewed that cognitive mapping played a central role in the people's ability to solve spatial problems (Passini 1984). The elevator system in a building which is the major means of vertical transportation will be stored as an image on the occupants' cognitive maps. Such image will then influence the movement of the occupants under emergency situation.

In ultra high-rise buildings, the image created by the staircases may not be clear as they are seldom used by the occupants for vertical movement during normal situation. Accordingly, in a traditional escape system, directional signs have been provided to influence the "normal" movement patterns of the occupants and divert them to the staircases. However, if the elevator system is to be adopted as part of the escape system and directional signs are also used to facilitate the use of such system, majority of the evacuees will naturally use the elevators for escape.

The capacity of an elevator system is generally designed for normal up-peak demand, say 15% if total population within a period of five minutes. During fire emergency, occupants of every floor gather in the lobby of every floor, waiting for services. Certainly, the capacity is not adequate to handle all these passengers. Normally, there are quite a number of stops within one round trip and therefore, the evacuees inside the elevators and those waiting for elevators may be frustrated when they need to wait for quite a long period of time before getting to the main terminal. It has been found that the stress level of the evacuees will be increased with time (Proulx 1993). Although the evacuees will normally not experience panic (Wood 1972; Sime 1980; Bryan 1991; Lo 1996), the increase in stress level owing to the waiting time will redefine the perceived level of threat of the evacuees. This will impair the decisional control which is one type of personal control for the people to exert over threatening circumstances (Averill 1973) and influence the evacuees' decision to rely on the elevators for the ultimate means of life saving (Lo, 1997).

It is true to say that the elevator system, designed for normal operation, cannot handle all occupants during fire emergency. It is because the 5-minute handling capacity of an elevator system is always designed to handle 10% to 15% of the population of the whole building. During an emergency situation, the passengers demanding for elevator service can be up to 100% of the total population, which is certainly beyond the system capacity. However, a fire outbreak will initially occur at a particular location instead of the whole building. Floors close to the fire source should be given priority so that elevators will serve these floors first. Of course, a good information system is definitely necessary to instruct the occupants where is the fire source and which floors are given priority to use the elevators.

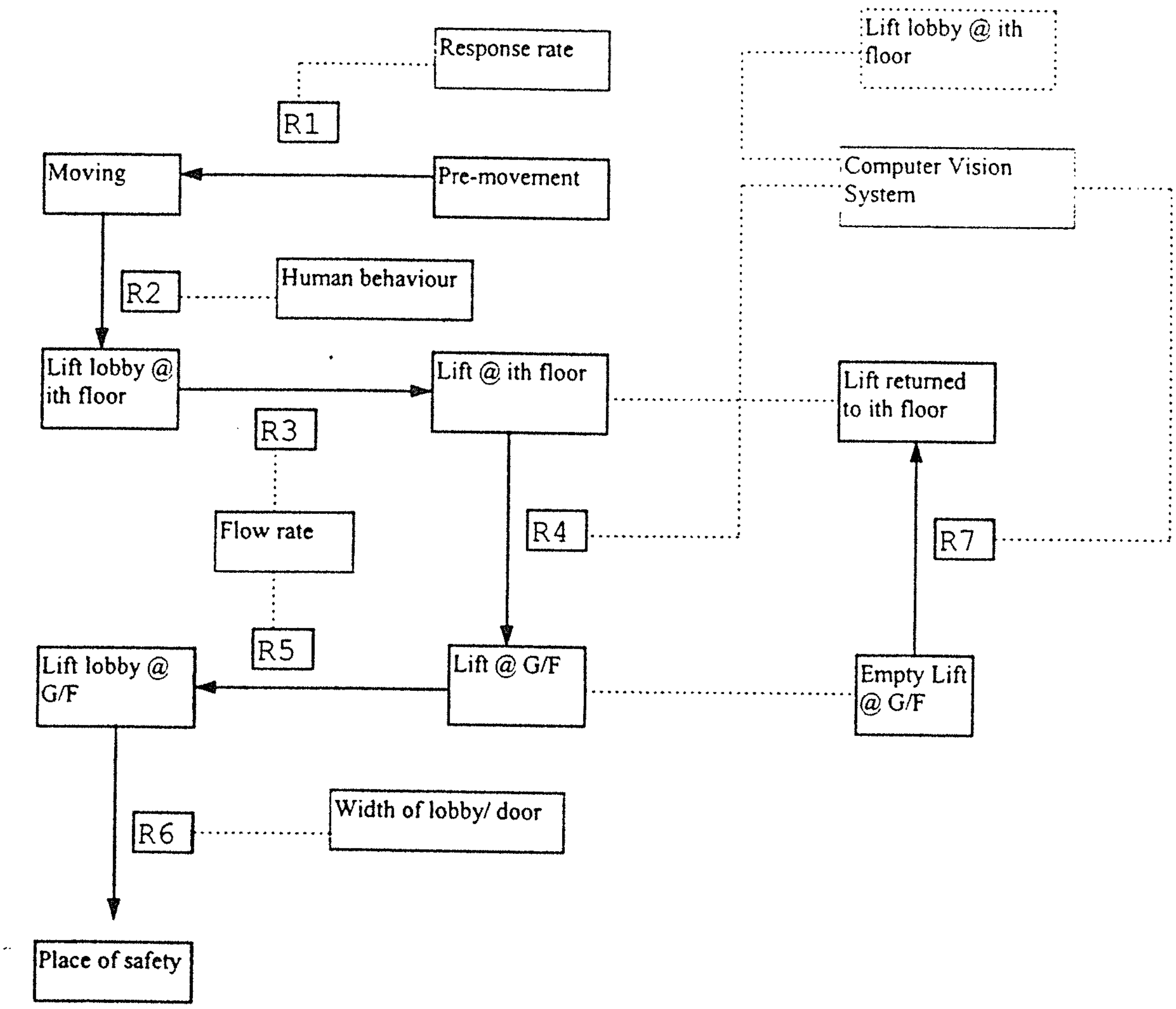
If the evacuees can stay at a place of safety, though temporarily, their stress can be psychologically reduced. The decisional control of the evacuees can assist the evacuees to escape in a rational manner (Lo, 1997). The elevator system should be considered to operate between such temporarily safe place and the ground level (discharge floor/ refuge floor). In addition, such a temporarily safe place can serve as a basis for the firemen to fight the fire. Once people have reached a temporarily safe place and see firefighting personnel there, they will be psychologically relieved and have more confidence with their personal safety. The firefighting/ rescue personnel can assist the evacuation process by using the elevator system. It is considered that a temporarily place of safety should be a designated floor which is separated from other parts of the building by adequate fire resisting and smoke checking construction. Such floors can be used as the basis for transmitting the evacuees to the ground level.

Here, the idea of using computer vision to recognise the number of passengers waiting at the lobby seems to be the only way out. Computer vision systems have been developed and implemented for elevator control (So 1992, 1993; Alani 1995). By using computer vision, it is possible to count the number of passengers waiting in a lift lobby as well as in each elevator car by means of area estimation and optical flow technology. Although the accuracy is still not up to 100% based on the current technology, a reasonably close estimation to the actual number will certainly help the whole process. The controller then decides on the number of empty cars that must be sent to serve an individual floor so that all passengers can be served simultaneously unless the number of passengers far exceeds the system capacity.

5 THE MULTI STATE ELEVATOR EVACUATION MODEL

The aforesaid arrangement at any time can be represented by numerous states which describe the number of people at various positions in a building. The following diagram, Fig. 1, can describe the interrelationship of various states at any time within a building:

Fig. 1



Remarks: .... influence lines (information flow)

⟶ flow influencing the state changes

R1 to R7 are rates governing the state changes

▭ a state

The state changes as illustrated in Fig. 1 can be approximately described by first order ordinary difference equations simplified to difference equations, selected samples being shown below:

$$\text{Pre-movement}_{[t+dt]} = \text{Pre-movement}_{[t]} + (-R1)*dt$$

$$\text{Moving}_{[t+dt]} = \text{Moving}_{[t]} + (R1 - R2)*dt$$

$$N_{i\,[t+dt]} = N_{i\,[t]} + (R2 - R3)*dt$$
where N_i is the number of people at the ith refuge floor

$$L_{i\,[t+dt]} = L_{i\,[t]} + (R3 - R4)*dt$$
where L_i is the number of people inside lift(s) at the ith designated refuge floor

$R1 = f(\text{response rate}) = \text{RANDOM}(T_0, T_R)$
where T_0 is the initial reaction time of people which depends on the type of warning system; and T_R is the response time which depends on the usage of the building.

$R2 = f$(human movement) $= f$(travel speed, density, average distance)

$R3 = f$(door width, density, capacity of lift, position of lift)

$R4 = f$(lift door operating rate, lift travelling rate)

$R5 = f$(door width, density, capacity of lift, lift lobby capacity)

$R6 = f$(lobby door width, density)

$R7 = f$(lift door operating rate, lift travelling rate, information prescribed by computer vision system)

Fig. 1 is a simplified version. By manipulating the 1st order O.D.E.'s into a computer program, the whole picture of passenger escape can be modelled. The results can be used to suggest improvement to the supervisory control of the elevator system under emergency situations. In building up a model to describe an evacuation system in a building, other building elements such as corridors, staircases, etc. should also be considered. In other words, a simulation model should be established in accordance with the layout of the building. The rates governing the changes of the states in each zone should be introduced on the basis of reasonable judgement such as the basis of experimental results or site surveying.

Once the difference equations of the system have been established, it can be executed by computer programs. The model can provide useful and constructive information to assess the adequacy of the evacuation system. The question of "what if" will arise naturally after the model has been constructed and the initial calculations have been completed. It may be necessary to check the effect of changing one or more variables in the model, e.g. the influence of lift operation algorithms. Such a sensitivity analysis needs to be carried out after each simulation.

6 CONCLUDING REMARKS

The reasons why elevators should be included as a major means of evacuation during emergency situations have been described as an introduction of this paper. A comprehensive literature survey on research works related to the issue has been carried out. Then, the conceptual considerations proposed by the authors for elevator evacuation during fire or emergency have been discussed in this paper. A multi-state model is then proposed to describe the whole process by a series of first order ordinary differential equations. As the behavioural reaction of human beings varies so much, the proposed method can satisfactory describe the pattern of state changes. The model shows an integration of a computer vision system. The information obtained from the vision system is employed to enhance the supervisory control the elevator operating system to assist the evacuation process. The algorithm of the elevator service will be determined by the computer vision system on the basis of the assessment of the number of evacuees at the lift lobbies by the CCTV system.

This paper has merely described the conceptual approach of establishing a model in describing the lift evacuation system. A more comprehensive program is being developed and the simulation results for verification will be published later.

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