ELEVATORS FOR OCCUPANT EVACUATION AND FIRE DEPARTMENT ACCESS

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Abstract

This paper will present a study of the potential for elevators to reduce occupant egress time and fire department access time for fires in tall buildings. Potential reductions in egress and access times will be compared for some specific cases where times for current procedures are available. The paper will review past research in elevator usage and the structure of existing models for elevator evacuation. From this review, the assumptions and limitations of the current elevator and egress models will be discussed, and future plans for improvement of the existing egress prediction techniques will be presented.

Keywords: Elevators, evacuation, firefighter lifts, elevator evacuation, evacuation models

1. Introduction

The recent events have caused fire safety experts to question the adequacy of phased evacuation plans for high-rise buildings. Also, the issue of lengthy travel times and physical exertion of firefighters ascending stairs of a high-rise building to reach the fire floor is a concern. Inquiries of fire departments following the incident indicates that most have adopted access by elevator policies for buildings exceeding 6 stories, but there are currently no provisions for firefighter lifts in the U.S. elevator codes. During total evacuation of a tall building, it is likely that there would be significant congestion in the stairways with a larger number of occupants, when compared with occupant numbers during phased evacuation, at the same time as firefighters traveling against the flow. Increasing the number or width of the stairwells in a building represents an extremely expensive option, especially for existing buildings. A viable option is to design elevators capable of providing a safe exit route out of the building for occupants and safe access to the fire area for firefighters. Several issues concerning elevator use in emergencies, such as human behavior, control, training, equipment reliability, and communication, should be addressed before this mode of vertical transportation can be implemented.

1.1 Current Requirements for Firefighter Lifts

Firefighter lifts are protected elevators provided in tall buildings for use by the fire department for moving people and equipment to the fire area and which also may be used by the fire department to provide evacuation assistance to people with disabilities. The provision of lifts dedicated to fire department use in an emergency is required in at least 12 countries around the world. As a recent survey by the ISO TC178 committee shows[1] operating procedures for fire department use of elevators are similar. For example they are generally required in buildings taller than 30 m, are provided with enclosed lobbies on each floor, and are housed in a two hour smoke protected shaft. Emergency power to the controllers and motor is required and the cars are operated under manual control by a firefighter.

British Standard 5588, Part 5 entitled Code of Practice for Firefighting Stairs and Lifts[2] describes what is referred to as a *firefighting shaft*. This is a dedicated, protected elevator with lobbies on every floor and an associated stairway fitted with a standpipe. The procedure is to move people and equipment to the lobby three floors below the fire. The hose team then advances up the stairs from the elevator drop-off position, connects to the standpipe, and proceeds with the attack. Enough firefighting shafts are required so that any point on a floor can be reached with 60 m of hose. The commentary describes several advantages to fire department dedicated lifts, such as reduction of travel time to the access floor, preservation of the building for a longer period of time, and increased safety to the occupants of the building. The standard also recognizes that firefighters who climb several flights of stairs outfitted with heavy gear and equipment may lose needed energy to fight the fire by the time they reach the fire floor.

In the US, ASME A17.1-2000, the Safety Code for Elevators and Escalators[3], does not provide for the use of elevators in emergencies either by firefighters or by occupants (except as noted below). Since 1973, A17.1 has contained emergency procedures that take the elevators out of service if smoke is detected in any lobby or in the machine room or hoistway. Under this condition the elevators are directed immediately to the ground floor where the doors open and the elevators are locked out (called Phase I recall). Subsequently, the responding fire department can reactivate individual cars under manual control using a special key (Called Phase II operation). U.S. building regulations require that buildings taller than three floors and likely to be used by people with disabilities be provided with an accessible elevator protected in a manner similar to that described for firefighter lifts. A means of summoning assistance from the fire department is required and they would use that elevator under Phase II operation to evacuate the disabled person.

The use of elevators for fire department access would enable the firefighters to ride to a specific floor, depending upon what is specified by the department's Standard Operating Procedures (SOPs)[4]. Examples of U.S. City Fire Department's SOPs[5] state that the elevators would take firefighters from the lobby to the floor two floors below the fire floor while others, e.g. the Chicago Fire Department[6], state that the elevator would stop three floors below the fire. In either case, the firefighters from an engine company, for instance, would exit the elevator on the designated floor, travel via stairs to establish a hose line one to two floors below the fire floor, and continue stair travel with the hose line to the fire floor.

1.2 Research on Egress Elevators

In a fire emergency, elevators are not only the focus for fire department access, but for evacuation purposes as well. Work was done in the early 1990s at the National Institute of Standards and Technology (NIST)[7,8,9,10,11] on the use of elevators for evacuation in which pros and cons were established that still exist today. The advantages noted for elevator evacuation are the following:
- Occupants usually exit buildings the same way that they enter
- Elevator evacuation takes less physical effort
- Stair congestion is an unpleasant experience
- Overall evacuation time is decreased
- Elderly or disabled occupants may rely on elevators as their only option

On the other hand, with an elevator evacuation plan, there are many issues to consider and prepare for in an emergency. First, the 30 year campaign cautioning the public against using elevators in the event of a fire could severely lessen the occupants' confidence in the elevator system. Also, occupants could become impatient and overcrowd the elevator, which causes the car to stop functioning and remain at the floor indefinitely[10]. One way for these issues to be addressed is through a training program and extensive evacuation plan for the building. The evacuation plan of a single rise elevator system could involve, for example, the use of elevators by the higher floors of the buildings, stairs used by the lower floors, and fire wardens on each floor directing his/her occupants to the correct evacuation route[8]. Since training may not be as helpful for visitors of the high rise building, the use of fire wardens becomes even more important in elevator evacuation.

For an 88-floor residential building in Melbourne, Australia, an evacuation strategy has been used in the building design to allow for elevator use during evacuation. The Eureka Place Tower[12] is separated, according to the elevator arrangement, into vertical evacuation zones. The plan states that occupants within the vertical zone that includes the fire floor would evacuate via the stairs until they reach the next transfer floor. At the transfer floors, which are located on levels 24 and 52 of the Eureka Place Tower, the occupants would then take the express elevators to the ground floor. The express elevators will be located in separate shafts in order to avoid water and smoke damage, and will be accompanied by other lifts provided for firefighter access.

Along with an evacuation plan, a reliable voice communication system can provide information on the progress of the fire and evacuation system[8]. Also, a decision made on the appropriate control of the elevator system (manual or automatic) in an emergency lends itself to certain advantages and disadvantages presented in the literature[13,14,15].

1.3 Elevator Evacuation Models

In order to capture the differences in evacuation by stairs only, elevators only, or both, evacuation modeling and calculations can be done. ELVAC[7] is the only commonly available model dedicated to the calculation of evacuation time by elevators. Other elevator models, typically used for elevator design within a building, can also be used to calculate the transit time of the last person to reach the lobby, which is ultimately the evacuation time of the building. These models have limitations when using them to simulate total evacuation of a building, as well as make assumptions, which will be addressed later in this report.

The three topics covered in this report focus on a firefighter lift case study, the U.S. General Services Administration (GSA) building evacuation case study, and a review of current elevator evacuation models. The case studies will be used to estimate the ultimate reduction in travel time by incorporating elevators into the evacuation plan for occupant evacuation and fire department access. For the firefighter lift study, firefighter travel via stairs will be compared to travel by elevator to a designated floor accompanied by continual travel via stairs to the fire floor. In the GSA evacuation study[8], several ELVAC and stair evacuation calculations were made to show the reduction in travel time when both elevators and stairs are used simultaneously for evacuation, instead of stairs only. Finally, the limitations and assumptions of current elevators models will be discussed as well as future needs in the area of elevator evacuation modeling.

2. Firefighter Lift Case Study

For this case study, the commercial building used was designed by a Dallas architectural firm and stretches 40 stories above ground and 4 parking levels below. A typical floor of the building contains approximately 3000 m^2 of floor space, with 500 m^2 occupied by the core space. The core contains elevators, 2 stairwells, bathrooms, mechanical closets, etc.

The stairs are located diagonally across the core area from each other, each measuring 1.2 m (3.9 ft) wide with 26 7/11 steps per flight. The 7/11 terminology refers the height of the riser followed by the depth of the tread in inches, meaning that for each step, the riser height is 17.8 cm (7 in) and the tread width is 27.9 cm (11 in). The height of each floor is 4.5 m (15 ft), creating a travel distance of 11 m (36 ft) per flight of stairs, including the landing distance.

The elevators for a commercial building are assumed to have a speed of 5.08 m/s (1000 fpm), per Table 10.7 of the Vertical Transportation Handbook[16], and average acceleration of 1.5 m/s^2 (5 ft/s^2). For this case study, it is also assumed that a crew of 5 firefighters and their equipment will be traveling in the elevator and stairs together at one time. There are other characteristics that were assumed for the elevators that only affect the outcome of this case study in a trivial manner, such as the full car load, type of door, the door inefficiency, and door closing time.

For this case study, the fire is placed on the 35th floor. Two groups of five firefighters are analyzed in their attempts to reach floor 35. Group 1 traverses 34 flights of stairs from the lobby to floor 35. Group 2 takes the elevators to the 33rd floor and travels the stairs an additional 2 flights. Hand calculations were made for firefighter travel up the stairs, while hand calculations and the ELVAC model were used to calculate the one-way elevator travel time from the lobby to the 33rd floor. ELVAC is primarily a model used to calculate gross elevator evacuation time from buildings, and the hand calculated one-way elevator travel time was used to check ELVAC results.

To obtain firefighter travel speeds on stairs and horizontal building components, adjustments were made to data already recorded from people movement studies[17,18,19]. Frantzich's data show a range of velocities for upstairs movement from (0.5 to 0.75) m/s, Fruin gives values of (0.5 to 0.65) m/s and Predtechenskii and Milinskii state a range of (0.33 to 0.92) m/s for low density situations. On one hand, these values may be low if studied during nonemergency situations, but alternatively, firefighters are typically equipped with heavy gear and equipment, on the order of 25 to 45 kg per firefighter, which should be accounted for. The primary walking speed used in this case study for firefighter travel up stairs is 0.35 m/s (adjusted from 0.5 m/s for heavy gear). Another velocity used came from the

New York Fire Department's rule of thumb that states firefighters average 60 seconds per floor (unobstructed flow), which is not sustainable throughout the ascent of high-rise buildings. 60 seconds per floor will be used as the conservative ascent time and 0.35 m/s will be used as the other extreme. For horizontal building component speed, again the standard value of 1.2 m/s[20] was adjusted to a conservative value of 0.8 m/s for gear and heavy equipment.

The breakdown of the elevator calculations are as follows (multiple values indicate a range of travel speeds for that calculation):

Group 1:
- o   The time to traverse 34 flights of stairs = 17 min at 0.35 m/s; 34 min at 60 seconds per flight (more conservative)

Group 2:
- o   The one way travel time of the elevator from the lobby to the 33rd floor = 45 s with 5.08 m/s elevator speed
- o   The horizontal travel time from the elevator to the stairs on the 33rd floor = 30 s at 1.2 m/s; 45 s at 0.8 m/s (more conservative)
- o   The time to traverse two flights of stairs = 60 s at 0.35 m/s; 120 s at 60 seconds per flight (more conservative)

The travel times calculated for both Groups in this case study neglect firefighter response time to the building, travel to the elevator or stairs from the building entrance, and time spent on the floor locating the point of attack, since both need to perform these activities in a fire situation.

After performing an additional calculation of adding the elevator travel, horizontal travel, and stair travel times together for Group 2, the results are as follows:
- Group 1: 17 to 34 min
- Group 2: 2.5 to 3.5 min

It may seem obvious that an elevator would give some advantage in speed over stair use. But, when other factors, such as heavy gear and equipment and increased elevator technology play a role, elevators substantially become a more viable and constructive option. The difference between use of stairs (Group 1) and elevators (Group 2) for firefighter ascent is approximately (15 to 30) minutes. This is a large difference in time lost due to stair use, especially when a fire can grow significantly in a matter of minutes. By using elevators as the primary means of ascent, Group 2 was able to reach the fire at least 15 min earlier in this case study. In fifteen minutes, the environment can be less toxic for the occupants, the fire smaller, and the property less damaged. Also, Group 2 would have more energy to exert on fire fighting activities on the floor, when compared to Group 1. The limitation associated with the calculation was the estimation made in the firefighter movement speed, as shown by the range of results in both Groups.

3. Elevator Evacuation Study

In the early 90s, four GSA buildings were analyzed as potential applications to incorporate elevator evacuation[8]. The four selected were the Hoffman Building II (Virginia), White Flint North Building (Maryland), Jackson Federal Building (Seattle), and General Services Building (Washington, DC), and were chosen to gather different building heights, elevator capabilities, and architectural characteristics.

For each building, evacuation times were calculated for the following conditions: 1) Total evacuation of the building by stairs only; 2) Total evacuation of the building by elevators only; and 3) Total evacuation of the building by various distributions of occupants to stairs and elevators (the optimal time value is shown in Table 1). For the stair calculations, Klote et al.[8] used the people movement methodology laid out by Nelson and MacLennan[21]. For these calculations, people on each floor were assumed to be waiting at the door to the stairs as soon as evacuation begins. For the elevator calculations, the ELVAC model[7] was used which simulates 2-stop elevator trips until the entire building has been evacuated. Again, for these calculations, people were assumed to be waiting at the closest elevator lobbies as soon as evacuation began. Table 1 shows the characteristics of each building,

including the number of floors, the number of stairs and elevators used, and the total population of each building. Also, the table shows the total evacuation time of the building (minutes) if only stairs were used, the total evacuation time if only the elevators were used, and the last column shows the optimal (fastest) gross evacuation time when a combination of stairs and elevators are used. Additionally, the Hoffman building and the White Flint North Building's analysis did not use the full capacity of elevators available to the building. The Hoffman building used 5 out of the 6 elevators in each group and the White Flint building used 4 out of the 6. This was due to the fact that the existing elevator lobbies were incapable of holding as many people as would be discharged from all elevators simultaneously, and in that case, the evacuation capacity of the elevators was restricted by the size of the lobby.

Building	Floors	Stairs/ Elevators	Total Population	Evac. Time by Stairs	Evac. Time by Elevators	Optimal Time by Both
Hoffman	13	2/ 2 groups of 5	3506	14.9 min	24.3 min	11.2 min
White Flint	18	2/ 1 group of 4	1425	14.3	28.6	12.0
Jackson	36	2/ 3 rises of 6	3021	23.1	16.5	12.8
GSA	7	6/ 6 groups of 2	3621	7	17	6.3

Table 1: Summary of GSA buildings and modeling results

In each of the four buildings analyzed, the optimal time was reached by designing for a combination of floors or percentage of the floor dedicated to elevator usage while the other portion of the building evacuated by stairs. The use of elevators for evacuation made the largest contribution for the tallest building, which was the Jackson Federal building equipped with low, mid, and high rise elevators. The elevator designation that provided the optimal result for this building was the following: 65 % of occupants from the mid and high rise floors, all occupants from floors 11 through 14, and only 3 % on floors 1 through 13. All others in the Jackson building used the stairs. For the single rise elevator systems in the Hoffman, White Flint, and GSA buildings, the elevator designation that provided the optimal result was for total elevator evacuation from the upper floors of the building and stairs from the lower floors. Overall, it was shown that by using a combination of evacuation systems, stairs and elevators, the total evacuation time of the building can be reduced by a substantial amount, especially with taller buildings. This study is limited by the averaged movement calculations used, and the assumption that all occupants were waiting at the stair or elevator lobbies as soon as the evacuation began. Also, another limitation is that occupants were not studied using both stairs and elevators during a single evacuation route, as performed in the evacuation plan for the Eureka Place Tower.

4. Elevator Evacuation Modeling

While the GSA calculations were made using the ELVAC model, there are certainly limitations associated with this and other current elevator evacuation models. Due to the fact that elevators are rarely used for occupant evacuation, other than by the fire department in Phase II, few evacuation models are available that incorporate evacuation via elevators. The commercial models presently being used to simulate building evacuation in a fire situation typically model movement by stairs only, with or without the incorporation of behavior simulation. There has yet to be a commercially-available, complete simulation package to describe the entire fire scenario, including premovement and action decision making, environmental conditions inside the building, occupant behavior, and movement throughout the building via stairs, escalators, and elevators. The limitations of the current models extend beyond the obvious lack of elevator simulation. There is also a lack of data on occupant behavior during elevator use in evacuation. The uncertainties on whether or not occupants will feel comfort in using elevators arise from the lack of data on occupant overcrowding of cars on a floor, impatience due to long waits in the elevator lobby, and behavior around their particular social unit (for example, will groups remain together and let an elevator pass if there is not enough room in the car for the entire group?). Another modeling uncertainty is how the model will simulate the evacuation plan that will take place in the building. The model may need to incorporate fire wardens, manual and automatic control of the elevators, and multi-use of stairs and elevators by the same group of occupants.

As mentioned earlier, ELVAC[8] is a model dedicated to the simulation of building evacuation by elevator only. ELVAC, as will be explained, only gives the gross evacuation time of the building, and along with its assumptions, may cause the model to lose accuracy in calculation, especially when compared to a complete simulation model. The model uses the 2-stop evacuation approach, meaning that the car travels from the lobby to a specific floor and then back down to the lobby, independent of the number of tenants occupying the car. ELVAC also assumes that all occupants using the elevators for evacuation are waiting at the elevator lobbies as soon as evacuation begins. Changes could be made to ELVAC to move towards more of a simulation model, such as equipping the elevators with load sensors, which most have, that would recognize when a car has additional space and enable the car to pick up more occupants on the way down to the lobby. Also, in an actual evacuation, it is certain that people would be arriving at the elevator lobby at different times, and the load sensor device would aid in evacuation of stragglers to the lobby area after most of the occupants have been evacuated. ELVAC, by giving only the gross evacuation time, does not simulate the car movement from floor to floor and the times associated with these movements. In an actual fire evacuation, it is most likely that the cars will move to the fire floor (and floors above and below) to evacuate these occupants first. By incorporating car simulation into ELVAC, evacuation times by elevators may be more accurate, especially for worst case scenarios when the fire is on a high floor of the building. Lastly, ELVAC does not account for the actual design of the control of the elevators. This difference in control may cause delays in start-time if operated by a human, instead of computer.

ELEVATE and the Building Traffic Simulator (BTS) are both models used to design the elevators for buildings, including the number and size of the cars, for normal daily operation. ELEVATE, a commercial model, can be used to indirectly calculate total evacuation time by identifying the time that the final person has arrived at the ground floor from the elevators[22,23]. The user must specify a destination to the ground floor as 100 % and the arrival rate (persons per 5 minutes) of the building's occupants to the elevator lobbies. As of now, evacuation modeling procedures are not specified in the users manual. BTS[24,25], on the other hand, is a currently noncommercial model capable of simulating evacuation via the building's transportation devices, which includes elevators (with different control methods), escalators, and stairs. The model uses input of the building's floor shape, position of the transportation devices, passenger traffic (e.g. arrival rates to the lobbies), passenger selection of transports, and passenger walking speeds (to simulate tenants who may need to walk from one transportation device to the other during movement and/or movement on stairs) to model an evacuation. According to its developers[24,25], evacuation can be modeled defining the occupant's walking speed, space requirement, and decision on which transportation mode(s) to use throughout the evacuation. Both ELEVATE and BTS provide a step toward simulation evacuation models, since these models are continually aware of occupant loads and positions (in elevator cars or stairs, depending on the model) in time throughout the evacuation. On the other hand, like ELVAC, there is no introduction of fire conditions and human behavior, as a complete simulation evacuation package could include. Also, for each of the three models, occupants are either automatically waiting at the elevator lobbies (ELVAC) or given an arrival rate (people/time period – ELEVATE, BTS) for appearing at the designated transport device, which neglects specific behavior and movement time delays occurring from their original position to the location of the transport device.

The three elevator models discussed in this report, ELVAC, ELEVATE, and BTS, all have advantages and disadvantages for using each for evacuation simulation purposes. ELVAC gives the gross evacuation time of the building by elevators only and assumes that all occupants are waiting at the elevator lobbies as soon as the evacuation begins. ELEVATE will simulate down-peak (evening rush hour for the building, for example) elevator movement with 100 % probability of movement to the ground floor, and BTS will also simulate down-peak movement of the occupants using elevators, escalators, and stairs during their exit journey. The simulation models, ELEVATE and BTS, have the extra advantage of continual data on the current position of the cars and occupants, as well as an attempt to model premovement behavior through the use of occupant arrival rates to the elevator lobbies. However, none of these models incorporate specific behavior and movement time delays that occur before reaching the transport device, human behavior in relation to elevator and stair use during a fire, and the condition of the fire in the building during the evacuation. These are main reasons why a complete evacuation simulation package would be a valuable asset for evacuation design. It should be noted that relevant literature in human behavior is sparse[26,27,28,29]; because elevators are not commonly used for design of the evacuation system of a building, data on humans and elevator use is lacking for this simulation package.

5. Conclusions

Elevator use in emergency situations can make a significant time saving contribution to travel towards the fire for the fire service and the evacuation of the occupants in the building. The calculations done for the firefighter case study showed that firefighters traveled to the fire floor (15 to 30) min faster via elevators when compared to stair access. The stair travel calculation, using two different estimates for the firefighter walking speeds, resulted in a range of travel time values differing by a factor of two. Research is needed in the area of firefighter movement to assess which travel times within the calculated range (17 to 34 min) are more accurate.

Also, the evacuation time of occupants using a combination of stair calculations and ELVAC calculations for the elevators shows improvement over stair or elevator movement alone for the GSA examples studied. This is especially true for the taller building with multi-rise elevators. With these calculations, assumptions were made that the occupants were waiting at the elevator lobbies and staircases as soon as evacuation began. Also, the occupants were assumed to use only the stairs or the elevators during their descent, unlike the evacuation plan of the Eureka Place Tower, in which a resident could use a combination of the two during egress.

Lastly, there is a need for a complete simulation package that includes movement of the occupants on stairs, elevator movement of the cars and occupants, environmental conditions in the building due to the fire, the contribution of the building to fire and egress, and human behavior and movement during the entire evacuation. Currently, there are evacuation models that focus on all of these aspects except elevator usage, and elevator models that neglect these aspects of building evacuation except for elevator usage. Unfortunately, much data is lacking about the behavior of occupants using elevators during an emergency, which needs to be addressed.

Overall, elevators lessen the travel time of firefighters and occupants to their prospective destinations, if used properly and with an appropriate emergency plan. There are many obstacles which need to be met in order for these plans to work properly. Recently, there has been an awakening to the importance of research in these areas for eventual use in buildings all over the world.

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