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Calculation of mixed evacuation of stair and elevator using EVACNET4

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Abstract

Elevator mode in EVACNET4 is used for mixed evacuation of stair and elevator in a high-rise building. It is shown that EVACNET4 always produces an optimal evacuation of the building. Each evacuation is optimal in the sense that it minimizes the total evacuation time and makes good balance of the usages between stairwells and elevators. Calculations in several scenarios are carried out to study the influences of different amounts of people on the evacuation time and usage percentages between these two escape methods. It is shown that elevator is a better choice due to its faster movement, while there are only a few people to be evacuated. When evacuees increase, the more evacuees are, the bigger costs of elevator usages are. Mixed evacuation is competitive. Double deployment is also considered to show potential abilities of elevators in safety evacuations.

Keywords: Mixed evacuation; Stair; Elevator; EVACNET

1. Introduction

According to incomplete statistics, there are more than 160,000 high-rise buildings in China, more than 1,500 of which are higher than 100m. Along with the development of cities and high-rise buildings, elevators in China are increasing rapidly. At the end of 2008, according to the statistics from Shanghai Fire Brigade, there are more than 13,800 high-rise buildings and 10.7 million elevators in Shanghai. Such a large number of elevators can be huge potential resources for safety evacuations in emergency. 492 m high World Financial Center, with 101 floors above ground, 3 floors underground and more than 120 elevators inside, helps more than 10 thousand people up and down every day. If they can help in rapid evacuation in emergency, it would be a breakthrough to the high-rise building evacuation problem.

Apparently elevator scan be used in evacuations safely in several emergency situations, such as hazardous chemicals leakages, explosions, typhoons and nuclear/biological/chemical terrorist attacks. They don't affect elevators' normal operations. As for fire emergencies, researches have been done since 1970s [1-3] and elevators can still be helpful if under several conditions and with right protections [4, 5]. Moreover, even if fires affected elevators' normal functions in one building, people allocated in the neighboring buildings can still get benefits from elevators inside these buildings.

Along with experimental studies of protection equipment to elevators, there are some simulation researches of elevator movements for evacuation plan design. Major elevator companies and manufacturers have developed their own elevator simulation models such as Elevate [6] and BTS [7].The calculated elevator movement time is used for product design. Some evacuation simulation packages such as STEPS [8] also have an elevator module. Most of them are commercial software. Here the classic free network model software EVACNET4 is used to study the mixed evacuation of stairs and elevators in high-rise buildings.

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2. EVACNET4

EVACNET+, the former of EVACNET4, was developed by Francis and Kisko in 1984, under the sponsorship of National Bureau of Standards, Center for Fire Research. EVACNET+ ran on a 16 bit platform and had a memory limit of 640k. Thereafter Thomas Kisko enhanced EVACNET+ to EVACNET4. EVACNET4 is now free and available on Kisko's website [9].

EVACNET4 requires a network description of building and information about the initial placement of occupants at the beginning of evacuation. The network model, which is called EVACNET4 network model, consists of a set of nodes and arcs. The nodes represent the building components such as rooms, halls, stairs, and lobbies. The initial contents (people) in each node must also be specified. It is the distribution of evacuees at the beginning of an evacuation. The arcs represent passageways between the building components. For each arc, two attributes, arc traversal time and arc flow capacity, must be supplied. It takes evacuees the traversal time to traverse the passageway the arc represents. The arc flow capacity is the upper limit on the number of people that can traverse the passageway the arc represents per time period. The concept of time in EVACNET4 is divided into time periods of fixed length. The length of each time period is user-definable, which is 5 seconds by default. Traversal times and flow capacities are based on this time period.

EVACNET4 uses node types to represent different building structures, e.g., "WP" for workplace, and "SW" for stairwell. Node type names can be defined by users, although there are some name conventions. EL is a special node type in EVACNET4, which represents the elevator object. If you want to simulate an evacuation where elevators are involved, EL nodes and arcs should be added in your building model. The elevator node can be thought as the people loading point and the elevator arc as people unloading point.

Elevator nodes have three attributes: capacity, time steps of first departure and priority. Elevator arcs have 2 attributes: time steps to travel "down"(including loading and unloading operations) and time steps to travel "up". Each elevator node requires exactly one arc (which is referred to as the elevator arc) departing from it. Elevator arcs must originate from elevator nodes and cannot point to "DS" (destination) nodes or other "EL" (elevator) nodes. Complete usage information can be referenced in the software's user guide [10] or several related papers [11, 12].

3. Calculation

We use EVACNET4 to calculate mixed evacuations in a 10-storey building. There are 100 people to be evacuated on the 10th floor. There is a stairwell at the west of the building, and an elevator at the east. A central corridor connects the west to the east. The north and south of the central corridor are workplaces. To simplify the scenario, the walk time of people from workplaces into the central corridor is ignored. Here we focus on the vertical traveling abilities of stairs and elevators. The illustration and specific parameters of the model are as follows:

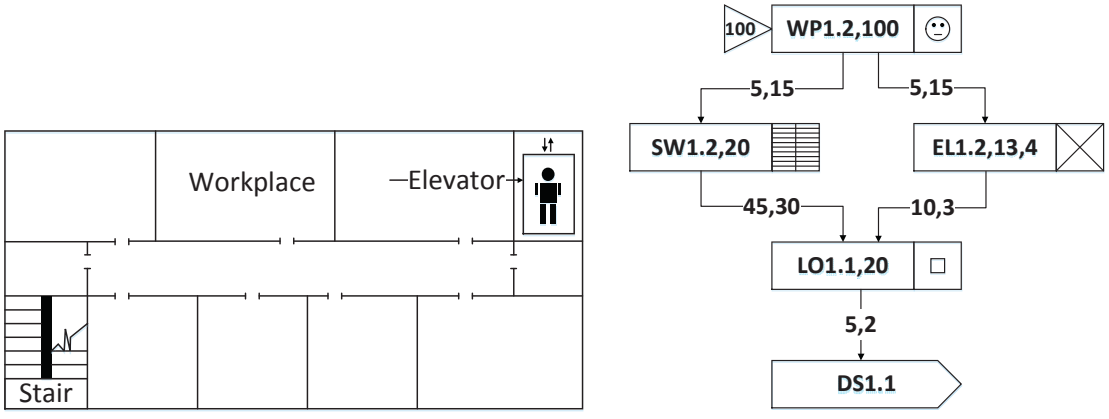

Fig. 1. Illustration of demo building model of EVACNET4.

3.1. Optimal usage between stairwell and elevator

For evacuees in the scenario above, there are two ways to evacuate. Different usages between the stairwell and the elevator result in different evacuation time. In EVACNET4, the evacuation route for each person is dynamically chosen by

the underlying model. Therefore, in order to predetermine the usage percentages of the stairwell and the elevator before evacuation and make them fixed during the process afterwards, a little modification (see Fig. 2) to the model above is conducted to separate evacuees into 2 groups, each uses one way only. Let X be the number of people evacuate using the stairwell, then the remains 100-X people evacuate using the elevator.

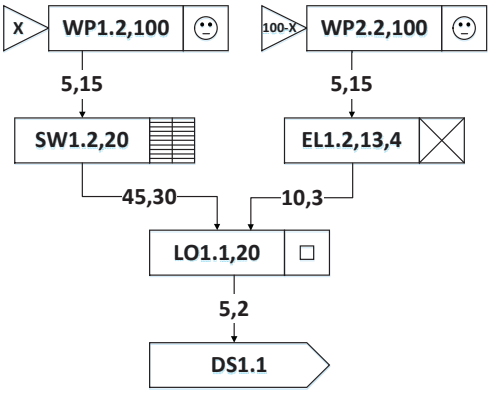

Fig. 2. Modified building model of EVACNET4 for evacuation way usage study.

Evacuation time results for different X values are plotted in Fig. 3. The case in which all the people evacuate using the stair only dose not win the competition, nor the case where all the people using the elevator. The best strategy with the minimum mixed evacuation time is approximately 60% of the crowd use the stairwell in the considered scenario. This gives a clue that fine cooperation between these two common escape ways could make real evacuations better and safer.

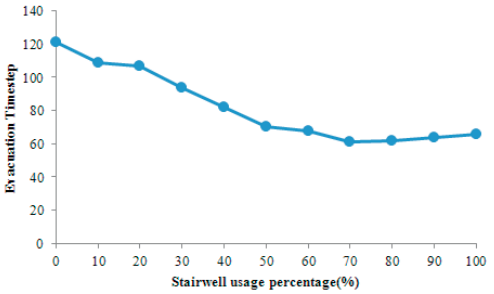

Fig. 3. Evacuation time for different stairwell usage percentage.

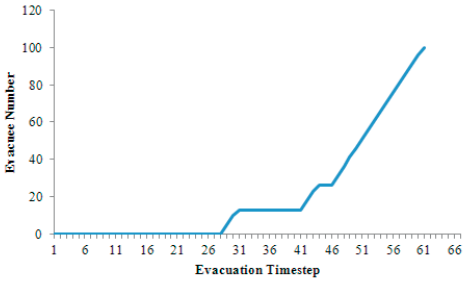

Fig. 4. Illustration of building evacuation profile for 100 evacuees from 10th floor.

Then we let EVACNET4 itself make the route choice for each evacuee. Back to the original network model in Fig. 1, the mixed evacuation takes 61 time steps (1 time step is set to 5 seconds by default). There are 39% of the total people using the elevator and 61% using the stairwell. Building evacuation profile, *i.e.*, the number of evacuated people along with the evacuation time is shown in Fig. 4. The first two up rise occurrences in the curve represent 2 groups of evacuees who get down to the destination using the elevator at the early stage of the evacuation, while at that time people using the stairwell have not came out yet.

The comparison of results from two cases above (usage percentages are determined by the user before the calculation and by the software itself during the calculation) shows the software makes good choices automatically during the calculation. Actually EVACNET4 is designed to produce results that describe optimal evacuations of given building models. Each evacuation is optimal in the sense that it minimizes the time to evacuate the building. People are evacuated as quickly as possible. So the results shown above can be considered as a reasonable percentage usage between the stairwell and the elevator. In a sense, the software can be used to obtain the best route strategy for evacuation plan design under a given model.

3.2. Different amount of people

Simulations with different amount of evacuees are calculated, and results are shown in Fig. 5. People are allocated on the same floor (the 10th floor) as before.

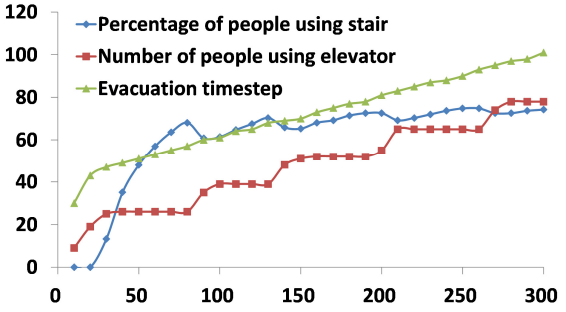

Fig. 5. Illustration of scenarios with different amount of evacuees.

When the total amount is less than 20, all the evacuees should escape with the help of the elevator. It's a better plan since elevators run faster than people run downstairs. With the increase of the total amount of people, as we can see, the stair usage percentage increases while the elevator usage percentage decreases. The more total evacuees are, the bigger cost of elevator evacuation is, because of the considerable increases of round trips, people loading, unloading and waiting time. In such situations stairs would be a better choice.

It should be noticed that after a steep rise up, the increase of the stair usage percentage gets slower and relies around 70%. It means when the amount of evacuees is considerable large, a little fluctuation of population does not make large difference on the optimal evacuation plan. It ensures the effectiveness and robustness of the optimized mixed evacuation plan for buildings with fixed staff and random but not many customers, which are common cases in our daily life.

Another interesting thing is, in the optimal mixed evacuation strategy, the number of people choose to escape with the elevator is about a multiple of its capacity. In the context scenario, 26, 39, 52..., are multiples of the elevator's maximum load 13. From this perspective, EVACNET4 does produce an optimal route plan that maximizes the effective use of elevators.

3.3. Double deployment

Another stairwell and elevator are equipped in the model to make a double deployment. Its influence is shown in Fig. 6. Similar results are generated. Along with the increase of the crowd, the total evacuation time increases steadily. When the total amount is less than 50, all the evacuees should escape with the help of elevators. The advantages of elevators get impaired when the population gets larger. The impaired point was delayed compared with 20 in the previous situation due to the added elevator.

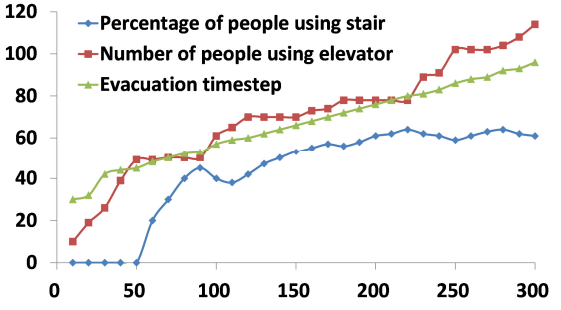

Fig. 6. Illustration of scenarios with double deployment.

Then again, with the increase of the total amount of people, the usage percentage of stairs increases while the usage percentage of elevators decreases. After a steep rise up, the increase of the usage of stairs gets slower, and relies around 55%, which is lower than previous (70%). It is shown that, in the battle of elevators vs. stairwells, elevators are more powerful than stairs. Percentage usage of stairs still gets down even when the number of elevators and stairwells are both doubled.

In the optimal mixed evacuation strategy, the number of people choose to escape with elevators is also found to be segments; each is around a multiple of the elevator's capacity.

4. Conclusions

EVACNET4 still is a free and easy-to-use tool among several choices, for calculations of evacuations from buildings with stairs and elevators. The elevator mode in EVACNET4 is demonstrated and some mixed evacuation scenarios are considered. It is shown that EVACNET4 can maximize the efficiency of these two escape ways and make an optimal usage balance. It can be used to design reasonable plans of mixed evacuations with stairs and elevators in such situations. The mixed evacuation with the optimized plan evacuates fastest. The influence of the amount of evacuees is studied. When there are a few evacuees, elevators are better than stairs because of the higher vertical movement speed. When evacuees become more and more, evacuations through elevators need more round trips and waiting time, which slow down the efficiency. Thus mixed evacuation is observed and competitive. When the amount of evacuees is considerable large, the stair usage in the optimal plan increases very slowly. Results of double deployment make it obvious that when the power of elevators grows, the best strategy is to use elevators more.

Acknowledgements

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