CSE6730 Project III: Elevator Simulation

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***Abstract*—Simulation of elevator system is a crucial issue with regard to modern buildings, especially those with large passenger flow. With proper design and management, time cost and energy cost can be dramatically deduced. In this project, three daily processes are simulated, including workers arriving, having lunch, and being off duty. The relationship between average waiting time for an elevator and energy consumption with the number of elevators is studied, and the optimal number of elevators for different types of office buildings is achieved.**

***Index Terms*—elevator, simulation, cost efficiency**

Fig. 1: Relational schema for elevator simulation

I. Introduction

NOWADAYS, the elevator system research has aroused more and more concerns due to fast development of technology. With gigantic daily passenger flow rate, how to operate elevators most efficiently becomes a crucial problem. Generally, most research focus on different aspects of operation efficiency, such as waiting time, queue size, and energy consumption [1]. Local elevators and shuttle elevators can both be considered by Browne [2] to make it more efficient. Siikonen made simulation for the up-peak, the down-peak and the lunch hour traffic, and comparing elevator performance under different traffic intensities [3]. In addition, there exist research observing the effect of passenger behaviors and different transport methods, for instance, peoples preference on using elevators, escalators, and stairs. According to Susi [4], physical attributes, like walking speed, space demand, and ability to use certain transportation devices can all affect elevator simulation. Al-Sharif used Monte Carlo simulation instead of analytical methods under more complicated conditions, such as unequal floor populations and multiple entrances [5]. Specifically, the arriving rate of passengers is usually in Poisson distribution, which best reflects the actual change of passenger arriving rate during the day [6].

In this project, a simulation on a series of elevators in an office building is conducted. Whole-day behavior of workers is simulated for different buildings with different number of workers. Total cost for a combination of average waiting time of workers and energy consumption of elevators are regarded as the criteria for deciding the optimal number of elevator. The whole simulation consists of enhancing the model, setting parameters, varying parameters, collecting data, and analyzing results.

II. Modeling and Analysis

A. Background

The whole process of elevator simulation includes workers going to work, having lunch, and getting off work. Figure 1 vividly shows the relational schema. It is assumed that elevators are on the first floor initially. Then from 8 a.m. to 11 a.m., workers come to the first floor and go to their offices respectively by elevators. Their arriving time follows Poisson distribution, which will be introduced in details in the following section. At noon from 11 a.m. to 5 p.m., they go downstairs to the first floor for lunch at random time. Then at the end of work, they go back to the first floor again at random time from 5 p.m. to 8 p.m..

Five types of buildings with different number of workers are introduced to find their corresponding optimal number of elevators. Several parameters are recorded to find their effect to determine the number of elevators, such as total move of elevators (total number of floors they have passed), number of empty moves (without any workers inside), and average waiting time for workers.

B. Algorithm

For every single elevator, the algorithm can be summarized as follows.

- Continue traveling in the same direction while there are remaining requests in the same direction, the elevator will go to the first floor waiting for requests if there are no further requests in one direction. To fully utilize the elevator, if there are over 15 people waiting for one elevator in the queue, the first 15 people can only take the same elevator which is free. For example, if there are 20 people waiting in-line and there are two elevators available, then the first 15 people take the first elevator and go to their destinations.
- The elevator prefers to go to higher level if several levels are requesting. For instance, currently the elevator is free at first floor, and there are people waiting to go to the first floor at 20th and 15th floor. The elevator would go to the 20th floor first. If there is available room for more people, the elevator would go to 15th floor subsequently.
- If the elevator is free at one floor, then it will go the first floor automatically. But if there are requests at the floors under the floor where the elevator stops by, the elevator will take the people who call the requests.

C. Assumptions

Before enhancing our model, following assumptions need to be clarified to simplify the problem.

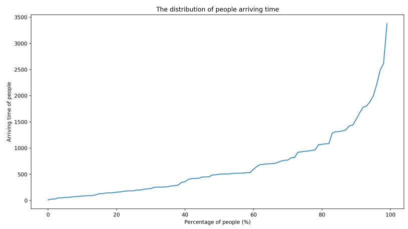

Fig. 2: Distribution of arriving time

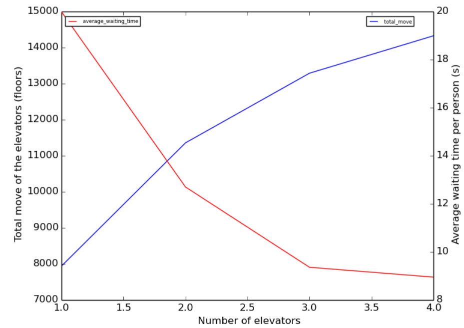

Fig. 3: Effect of total move and waiting time for building 1

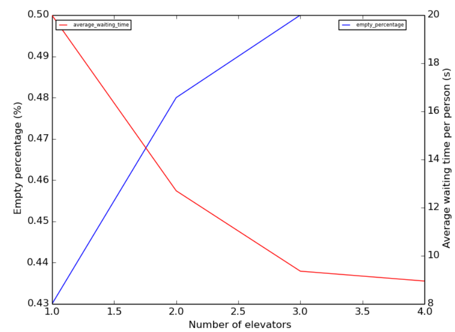

Fig. 4: Effect of empty move and waiting time for building 1

- One iteration of elevator, which is one move (one floor), is set as 4 second.
- Total simulation time is set as 43200s, which is 12 hours.
- At noon, when people are going down, they will only go to the first floor. When they finished lunch, they will go back to their corresponding floor.
- Time for people entering and exiting the elevator is ignored since it has no effect on our result.
- Initially, the arriving time of workers follows Poisson distribution.
- Each elevator has same parameters.
- Average waiting time and total move have different portion of effect on deciding the optimal number of elevators.

D. Parameters

1) Building: Table 1 lists some important parameters for the buildings.

From Table 1, it is shown that the maximum number of workers for each building is proportional to the number of floors. This helps us get the optimal number of elevators for company of different sizes, which makes our simulation more applicable.

TABLE I: Parameters for buildings

	Number of floors	Number of workers
Building 5	30	1500
Building 4	25	1250
Building 3	20	1000
Building 2	15	750
Building 1	10	500

2) Elevator: For elevators, its time for moving through one floor is set to be 4 second, which is one iteration. The total simulation time is therefore 10800 iterations, which is 12 hours. The maximum capacity for each elevator is 15 people.

3) Customer: For the first process, the arriving time for workers from 8:00 a.m. to 11:00 a.m. follows a Poisson distribution. Since each iteration is 4 seconds, people will arrive between 0-2700 iterations, and the average arriving time is set as 500 iterations. Figure 2 shows our distribution.

For the second process, workers are leaving for the first floor from 11:00 a.m. to 15:00 p.m. and then come back in one or two hours. Therefore, a leaving time will be generated randomly as between 2700 and 6300 iterations for each worker. Their back time is generated randomly as between 900 and 1800 iterations, which is one or two hours.

For the third process, workers are leaving for the first floor at a random time ranging from 8100 to 10800 iterations, which is from 17:00 p.m. to 20:00 p.m..

III. Result and Discussion

For this project, we mainly focus on the relationship between the number of elevators and average waiting time of workers as well as energy consumption of elevators. Buildings of different types as described in previous section are analyzed separately. Figure 3 and Figure 4 show the relationship for building with 500 workers.

From Figure 3, it is sure that average waiting time for workers for one ride decreases sharply with increasing number of elevators. When there are no fewer than three elevators, however, the effect of increasing number of elevators is not much obvious since there are only 500 workers in total. While for total move, its increasing trend decreases with increasing number of elevators. This makes sense since the number of workers is not so large, and the times for carrying them upwards is limited.

From Figure 4, it is shown that the percent of empty move increases with increasing number of elevators. This may due to two reasons. First, if there is no request, elevators will automatically go down to the first floor. Therefore, with more

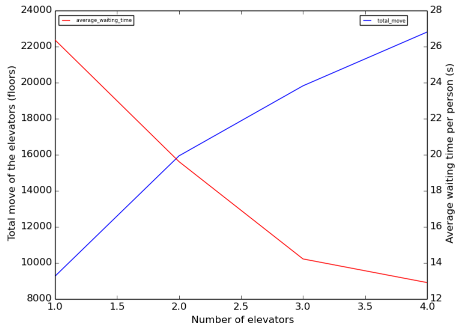

Fig. 5: Effect of total move and waiting time for building 2

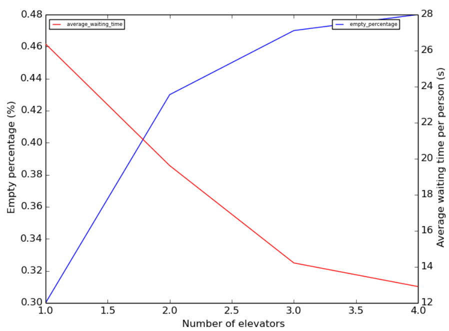

Fig. 6: Effect of empty move and waiting time for building 2

elevators, more elevators will lead to more empty moves. Second, since there are only 500 people for this building, the number of requests should be relatively small so large number of elevators is unnecessary.

To show a more vivid comparison of the number of elevators with these parameters, Table 2 lists their detailed values.

TABLE II: Result for building 1

	1 elevator	2 elevator	3 elevator	4 elevator
Total move (floors)	7940	11358	13290	14328
Empty move (floors)	3419	5506	6631	7164
Avg waiting time (s)	19.99	12.7	9.36	8.95

From Table 2, we can see that the performance of three-elevator system and four-elevator system are rather similar while four-elevator system consumes more energy. Here, we introduce the total cost as the final criteria for judging elevator's performance. Since average waiting time is generally more important than elevator's energy consumption, we assign a higher weight to waiting time as 0.7, while assigning 0.3 to energy consumption. And according to our research, people in office buildings are quite impatient, therefore waiting time should be considered as the most important attribute.

Figure 5 through Figure 12 show the relationship for building with 750, 1000, 1250, and 1500 workers.And we can see the result is similar to those in Figure 3 and Figure 4.

Table 3 is built to show the calculated cost for different buildings with different number of elevators.

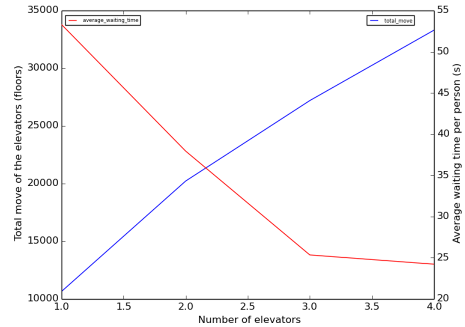

Fig. 7: Effect of total move and waiting time for building 3

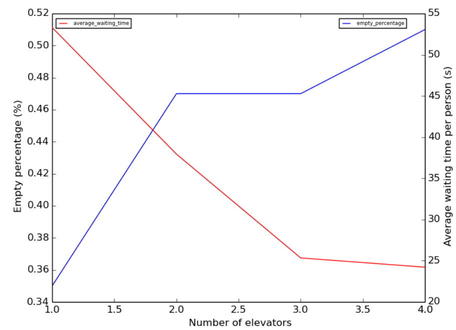

Fig. 8: Effect of empty move and waiting time for building 3

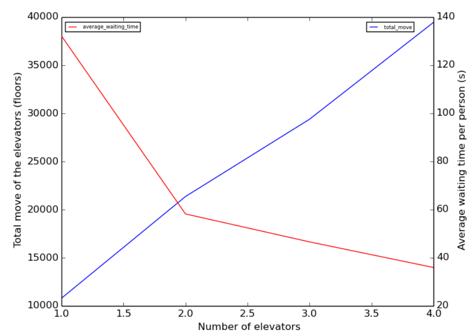

Fig. 9: Effect of total move and waiting time for building 4

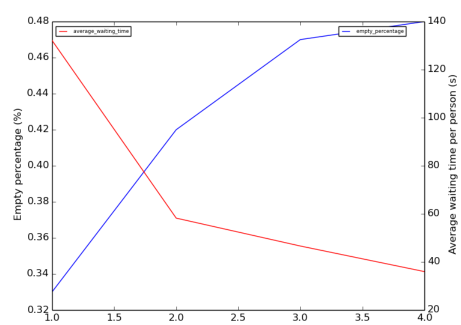

Fig. 10: Effect of empty move and waiting time for building 4

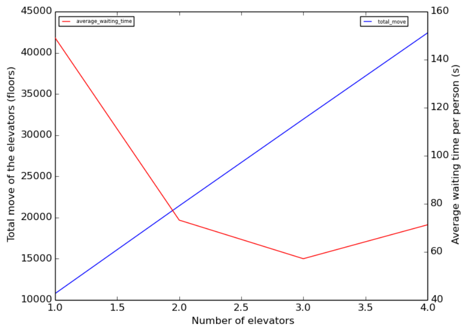

Fig. 11: Effect of total move and waiting time for building 5

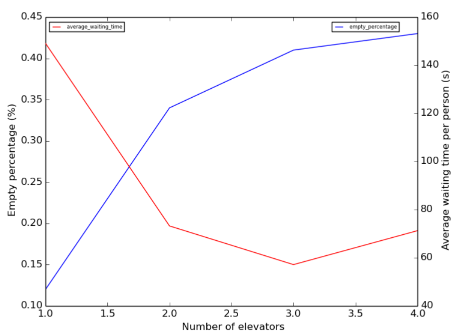

Fig. 12: Effect of empty move and waiting time for building 5

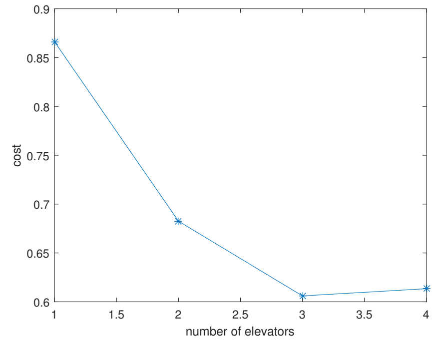

Fig. 13: Cost for building 1

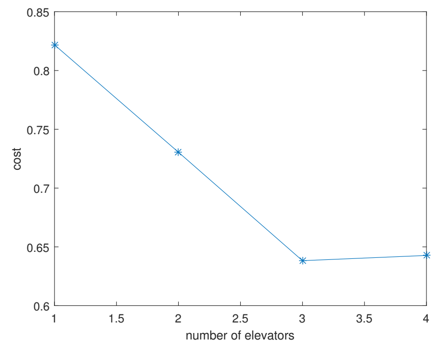

Fig. 14: Cost for building 2

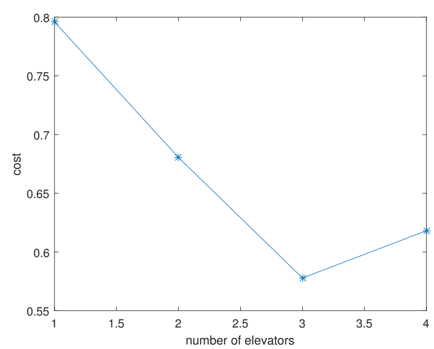

Fig. 15: Cost for building 3

TABLE III: Cost estimate for different buildings

	1 elevator	2 elevator	3 elevator	4 elevator
Building 1	0.8662	0.6825	0.6060	0.6134
Building 2	0.8218	0.7305	0.6382	0.6427
Building 3	0.7960	0.6805	0.5778	0.6181
Building 4	0.7821	0.4708	0.4704	0.4905
Building 5	0.7762	0.4953	0.4943	0.6346

Figure 13 through 17 vividly shows the trend. From these figures, it is concluded that for number of people ranging from 500 to 2500 and number of floors ranging from 10 to 30, three-elevator system performs the best at a cost of average waiting time and energy consumption.

This may due to two reasons. First, more elevators would cost more energy consumption, which is undesirable. Therefore, it cannot be directly concluded that more elevators should be better. Second, considering our number of total workers and elevator capacity, there is no need for many elevators. Although single elevator does not perform well, three elevators are enough to handle all the workers. To make our simulation more realistic, the maximum number of elevators is set to be four. Maybe this can be set larger to find further effect of increasing number of elevators and their cost.

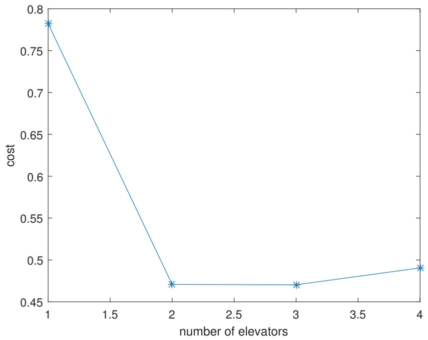

Fig. 16: Cost for building 4

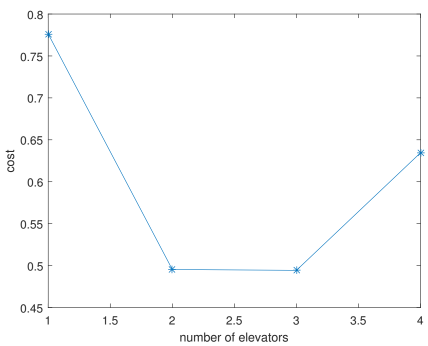

Fig. 17: Cost for building 5

Actually, it can be inferred that the number of elevators is estimated accordingly based on population to be served and passenger waiting time for an elevator, with energy consumption playing a relatively smaller role. The rate and duration of peak travel time, for instance, in the morning and in the evening, should also be considered and can make an effect. For this project, Poisson distribution for the inter-arrival time should make sense. And as mentioned above, a large number of elevators are not ideal, which can also be inferred from above figures. First, they put higher demands on electricity to run and have higher maintenance cost. Second, the initial cost for elevators can be expensive. Third, they would occupy a huge floor area which may otherwise be usable.

IV. Future Improvement

Although this model includes detailed process of elevator simulation for office buildings, many aspects are not taken into consideration since it is a simplified model. For future improvement, other factors, such as different types of elevators, different types of buildings, and various of transportation such as escalators and stairs should be considered. Besides, more realistic data, such as arriving rate and worker's behavior at noon, should be studied.

V. Conclusion

For this project, a python program with several classes is written to simulate a 12-hour elevator system for different office buildings. The relationship between total move, empty move, average waiting time, and number of elevators are studied. It is concluded that three-elevator system performs the best regarding the effect of waiting time and energy consumption. However, our simulation can be improved by considering more features such as different types of elevators and more complicated everyday process. With further refinement, this elevator simulation can be applied to decide the optimal number of elevators regarding a combination of time and energy cost.

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