CSE 6730 – MODELLING AND SIMULATION

PROJECT 2

Simulation of the Elevator Transport in An Office Building

Daxuan Huang, Qinlan Zhang, Xu Zhang, Zheng Deng

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OBJECTIVES

In this project, we are aiming to simulate the operation of the elevators during peak time and Cloughs Undergraduate Building is the system under investigation of this simulation. Our objective is to find a balance between transport efficiency and energy consumption with different specific numbers of passengers, in order to provide some reference to the elevator operation measures of Clough Building during peak time. Then the total number of passengers and the number of elevators in operation will be set to various values, representing different situations. The simulation will end when all the passengers in the system have reached their destination floor. Thus, the time steps needed to reach the end of the simulation is an output.

MODEL DESCRIBTION

In complex buildings, the transportation system consists of several types of transports, among which the elevator transport is the most essential part, especially in high buildings. The energy consumption and the transport efficiency are actually closely related to the way the elevators operated, which is the reason and necessity to simulate the elevator traffic in a building.

To make the simulation more meaningful, we will mainly focus on the peak-time of elevator transportation in the Clough Undergraduate Building. Due to the real situation of the Clough Building, the number of floors in the building is 5. The number of elevators in operation and the number of passengers entering the system under investigation will be determined at the beginning of each simulation run, to represent different situations. In this simulation, we set the value of the number of passengers to be 150, 500,1000 or 2000. And the number of elevators in operation is set to be 2, 3 or 5. Furthermore, passengers' arrival floor and destination floor are typically generated by the random number generator which is in accordance with the uniform distribution and the weight values of different floors are based on the on-site observation of the Clough Building. At each time step, different number of people will enter the system and this number is also generated by the random number generator obeying the uniform distribution. On arrival, passengers give landing calls and wait on that floor until a car arrives. After entering the car, passengers give car calls and travel to the destination floors where they exit the car [7]. And the simulation will end when all the passengers entering the system under investigation reach their destination floor, that is to say the number of passengers waiting on each floor is zero and the number of passengers remaining in the elevators is also zero.

LITERATURE REVIEW

In order to relieve the large demand of office and residential space, more and more high buildings are constructed, with elevators equipped. For high buildings, people need to take the elevators to reach most of the upper floors, indicating the demand for the elevators in high buildings. Then when a large number of passengers exist in the high building, a congestion may occur, resulting a long wait time for the elevator. This is particularly true in high-density buildings, such as office buildings, where limited stairwell capacity would result in congestion, long delays, and could potentially prevent the safe egress of people [1]. As a result, how to improve the efficiency of elevator transportation in office buildings has become a significant problem for practical application, especially during the rush hours [3]. For the simulation of elevator operation, some features and processes are worth being discussed. For instance, the total time for passengers to reach their specific destination when taking the elevators decreases with increasing total number of elevators in operation, while leading to higher energy consumption [2]. For further consideration, the passenger flow also has obvious influence on the prediction of the whole process of taking elevator transportation. Generally, elevator traffic flow describes the main elevator traffic information, which consists of the number of passengers inside buildings, passenger's requirement and passenger's distributing status [3].

For the simulation aspect, simulation can be split into discrete event simulation and time-slice simulation when we make the lift traffic design. On the other side, calculation can be split into main categories: analytical equation-based methods and numerical methods. Moreover, the repeatability of the results is an important consideration, as well as the simplicity and calculation time of the method used. Also, when designing a lift traffic process, we will need the following four parameters: Number of lifts, Rated speed of the lifts, Rated capacity of the lifts and Group control process algorithm [4]. As described by AI-Sharif, Lutfi, et al, the concept of the HARint plane can be properly used to design an elevator, in which user needs to determine the passenger arrival rate, the target interval, the target average travelling time and the target average waiting time. This is then used to calculate the round trip time and then select the optimum number of elevators under different total number of passengers we would simulate. [5]. Furthermore, the inner service of the elevator is also a significant part of the whole simulation. The waiting time, requirements of each passenger, number of floors served, passenger traffic, elevator dispatching strategy are all involved in a series of complex function to design. The importance of these simulations in a simulator leads to the necessity to provide the optimum elevator configuration for each high building installation [6]. Additionally, when talking about the traffic in a single-occupant building on the other hand, this essay also considered the large traffic peaks at rush hours which will generate a large amount of in-and-out traffic [6]. Considering these special cases along with building features such as a cafeteria floor, a Starbuck floor and other floors that may gather much more passenger traffic in front of elevators on these floors, the elevator planner has found it necessary to treat each new or modified elevator installation [6]. In elevator traffic simulators, passenger arrival floors and destination floors are typically generated randomly following the population distribution in the building [7]. To achieve a realistic simulation, diverse traffic patterns and passenger attributes should be modeled. When simulating traffic in buildings with several transportation devices, modeling passenger behavior should also be considered as an issue [7]. For the round trip time of each elevator, the evaluation of the vertical group control simulation becomes very complicated and requires the use of advanced special condition formulae. These formulae become even more complex and difficult when a combination of the special conditions exist within the building being designed [8]. The Monte Carlo simulation is implemented to achieve this goal by Lutfi Al-Sharif, et al, as a simple and practical means to calculate the round trip time for an elevator during the peak time which has large passenger traffic conditions. This kind of round trip time is necessary to decide the number of elevators required for a building. When special conditions exist in different buildings and different time, the use of the analytical method becomes extremely complicated to simulate [8].

CONCEPTUAL MODEL

To build a simulation, we first begin by constructing a conceptual model that is representative of the real elevator operation in the building while making some reasonable assumptions to simplify the complexity of the model. In this part, we will discuss the entities involved and their interaction rules, the various inputs to the model, the outputs and the model itself.

Assumptions and Simplifications

We assume that the elevators' capacity is finite and homogeneous, that is to say, each elevator holds the same number of people. According to our observation, the capacity of each elevator in the Cloughs Undergraduate Building is 16 people. So the capacity of each elevator in our simulation is set to 16. The energy consumption and the features of each elevator are also assumed to be homogenous. Furthermore, the velocity (number of floors each elevator goes through in a time step) will be assumed to be uniform across all elevators and set to 1. And based on the observation, the time needed for an elevator to go through one floor is about 4 seconds, then we assume each time step is 4 seconds.

We make some simplifications by assuming that the elevators' stopping time at each floor, during which the passengers will leave and go into the elevators, will be 4 time steps, not affected by the number of passengers go into and leave the elevators. Besides, each elevator at each time step will be stopping at or running right through certain floors.

Also, at the beginning of the simulation there's no one in the elevators. All elevators will start at the 1st floor. All passengers will originate from one of the floors in the building and knows their destination floor in advance, with the destination floor different from the initial one. The number of elevators in operation is determined at the beginning of the simulation and will be set to different values in different simulation runs. And when a passenger reaches the destination floor, we assume the passenger has already left the system under investigation.

Finally, we only focus on the peak-time simulation process in this simulation. We will also omit the interactions between passengers, i.e. more passengers make the time entering or exiting an elevator much larger. And the passengers will only take elevators to go upstairs and downstairs, excluding any other transportation methods.

Input

The main inputs of the simulation are the number of elevators in operation and the number of passengers that will enter the system under investigation. These two values will be input at the beginning of each simulation run, representing different situations. The number of passengers entering the system may have the value of 150, 500,1000 and 2000. The number of elevators in operation will be 2,3 or 5.

There will also be some parameters predetermined and will not be changed. The number of floors in the building is 5. The capacity of each elevator will be 16 and the interval of each time step will be 4 seconds. These values are all based on our on-site observation of the Clough Building.

As discussed earlier in model description, we will assign a random number of passengers entering the system at each time step, which is originated from a random number generator obeying the uniform distribution. Furthermore, passengers' arrival floor and destination floor are typically generated by the random number generator which is in accordance with the uniform distribution and the weight values of different floors are based on the on-site observation of the Clough Building.

The state variables in this simulation include the current floor of each passenger in the system, the current floor and the direction of each elevator in operation, the number of passengers remaining in the elevator and the number of passengers leaving the system at each time step.

Output

Since the objective of this simulation is to find a balance between the transport efficiency and the energy consumption under different elevator operation situations in the Cloughs Building, one output of this simulation will be the time steps needed to reach the end of the simulation, representing the transport efficiency. Because we make assumptions that each elevator's energy consumption is the same, the total energy consumption is then proportional to the number of elevators in operation. Thus, we also use the product of the time steps needed and the number of elevators in operation as an output.

Contents

Entities

Exogenous: People entering and leaving the system

Endogenous:

●Consumer: Passengers in the system under investigation

●Resources: Elevators

●Aggregates: Pools of people waiting on each floor of the building

In this simulation, the passengers are viewed as the consumer entities, whose attributes include initial floor, destination floor and direction. And the initial floor and destination floor are different. And the elevators are the resource entities competed by the consumers. The elevator has the following attributes, the number of passengers in it, direction and current floor.

Events

- For elevators:
  - change direction: in which the direction of the elevator changes
  - move: in which the current floor of the elevator changes
  - load people: in which the number of remaining passengers in an elevator changes
- For passengers:
  - move: in which the passengers move with the elevator and the current floor of the passenger changes

Activities

- The move of the elevators
- The loading passengers and removing passengers process

APPROACH

In this section, we will discuss finer details of each of our steps in the modelling and simulation process.

Pre-simulation:

<u>Building a random number generator:</u>

We used Python default random number generator for this project. It generates a random number from (0,1).

We obtained the specific passenger distribution in Clough Building by observation as follows:

floor number	number of people	destination floor of passenger
1	74	67
2	227	234
3	150	147
4	235	225
5	68	81

The distribution is generally 1:3:2:3:1. So we generate a random number using RNG and return specific floor number according to this distribution.

Additionally, at each time step there's a flow of passenger come into this building. This number is between [0,20] according to observation and satisfies uniform distribution.

Simulation process

Fig.1 Simulation Process and Approach

Initialization:

In the initialization of the simulation, we create some objects including Customer, Pool, Building and System. Customer is the object representing the passenger, containing attributes like init_floor, dest_floor and direction. Pool is an object which is the list of passengers waiting on each specific floor, and on each floor there are two pool objects, pool_up and pool_down, representing the list of passengers who needs to go up and go down respectively. Building is an object containing a dictionary of all the pool information on each floor of the building, whose key is the number of floor and the value is the pool_up and pool_down of that floor. System contains all the elevators in operation in the building.

We load in the building with empty pools and system with empty elevators.

Assigning and updating:

At each time step, we generate a new flow of passenger and add it into each floor's pools according to passengers' start floor. Then we update the outer request list. Responding to outer request list update, we decide each elevator's direction and update them.

For each elevator, it will check the inner and outer request list to decide which floor to move before moving. Inner requests should be satisfied first and then outer requests. If there's no request, it will stay at current level until any new request occurs, which is referred as the "stay" status of the elevator.

During elevator's stopping time (4 time steps), passengers from the pool can enter the elevator unless it's full by join in elevators remain list which stores passengers in elevator.

After checking the moving direction, and loading & releasing passengers, elevator will move to next upcoming floor according its direction.

We do a parallel update at each time step to update every elevator and every passenger which means all elevators and passengers will move at the same time.

Capturing metrics:

We repeat this process until every passenger reach their destinations. At every time step, we record the total number of people left the elevator (reach destination) by increment once there's a passenger left the elevator.

As all passengers reached their destination, it will return the time step taken to finish this simulation for us to evaluate the estimated energy consumed.

THE SIMULATION SOFTWARE

Here, we briefly describe the architecture of our simulation software. We developed it entirely in Python 2.7.

Architecture

Here is a brief high level flow of the program:

- Load and initialize the building, pools, and elevator system
- At each time step:
    - If number of passengers exit the simulation less than total number of passengers:
        - Update pools with a flow of passengers coming into this building
        - Update require list
            - For each elevator:
                - Update direction according to require list
                - Check if there are requires in upcoming floor:
                    - If yes, stop at that floor:
                        - ♦ Omit passengers whose destination is this floor;
                        - ♦ Remove those passengers from simulation;
                        - ♦ Load passengers from pools until full;
                        - ♦ Wait certain time then go to next floor;
                    - If no, run through
    - If all passengers have left the simulation:
        - ♦ Return time step taken
        - ♦ End the simulation

Code Description

The code files are listed in a separate folder, with usage instructions and description of each file in a README file

Interfaces:

Here are the main attributes and methods of the different classes:

<u>Building:</u>

Total_cus: total number of passengers will enter the system

Num_of_floors: total number of floors of the building

Adict: a dictionary contains all pools at each floor

Dictioncreate(): create empty pools at each floor

Dictionupdate(): Update the dictionary contain pools' information

<u>Elevator:</u>

Cur_floor: elevator's current location

Direction: direction of moving of an elevator, "stay" or "up" or "down"

Remain_list: a list containing passengers in the elevator

RequireIn: request from passengers inside the elevator

Capacity: maximum number of passengers an elevator can load

Aimminglist: a list combining outer and inner request list

Move(): update elevator's current floor

Add_customer: Add one passenger to remain_list and add the passenger's destination to inner request list.

Cancel_customer: Remove one passenger from remain_list

<u>Customer:</u>

Init_floor: start floor of the passenger

Dest_floor: destination floor of the passenger

Direction: moving direction of the passenger

customerUpdate(): Assign initial and destination floor of a passenger

<u>Pool:</u>

Floor_num: specify which floor the pool belongs to

Pool_up: a list contains passengers going up

Pool_down: a list contains passengers going down

AlreadyIn: number of people entered the system up to now

Updatepool(): Update the pool when new passengers come

Uppoolremove(): remove passengers from pool_up

Downpoolremove(): remove passengers from pool_down

System:

Num_elevator: number of elevators in operation

Elevators: a dictionary contains all elevators

Requireout_up: a list contain outer requests moving up

Requireout_down: a list contain outer requests moving down

requireOut(): Compute and update the outer request list

DecisionDecide(): Decide every elevator's direction according to aimming list

Outdemand(): modify aiming list's outer request part according to outer request list

<u>Simulator:</u>

Building: An object holds the building information

System: An object holds the elevator information

Peoplecount: total number of passengers left the simulation

Main(): the main simulation process

Validation and Result

Validation

RNG Validation:

To lessen the error carried by the input statistic, using random number while testing our program. Random numbers are mainly used in two parts: passengers' floors information and number of passengers entering the system per time step. Basing on collected information, we build up specific algorithms for them.

1. Passengers' floors information

Passengers' floors information mainly contains two parts: initial floor and destination floor. Both of them are individual to the other one. Run its algorithm for presetting different total passengers and finally compare data distribution with collected data ratio. If there occurs notable difference, it algorithm seems fail to pass the validation process.

By our observation, the ratio of people's initial and destination floor is both about 1:3:2:3:1 (first floor to fifth floor). Following figures are simulation result for different total passengers.

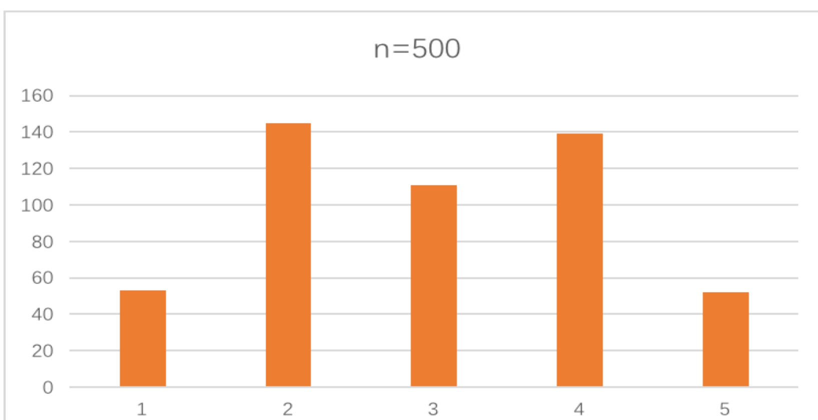

Figure. 2 Initial and destination distribution for N (total passengers) =500

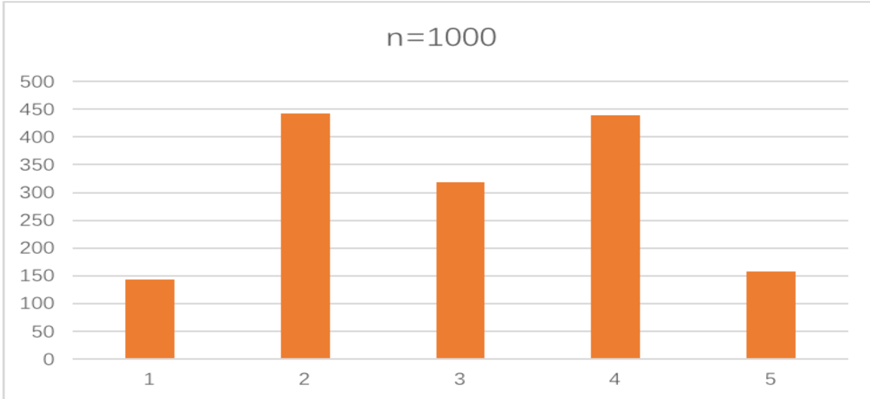

Figure. 3 Initial and destination distribution for N (total passengers) =1000

In figure 2, results show that people choosing floor 1 to 5 is about 50,145,110,145 and 50 and the ratio is 1:2.9:2.2:2.9:1. The ratio is really close to pre-obtained ratio. In figure 3, the number of people in floor 1 to 5 is about 150, 445, 315, 440 and 150 and its ratio is also similar to pre-obtained ratio. To ensure the simulation process is correct, each test is repeated about 3 times and all results are really closed. Following this test result, used algorithm for generating random initial and destination floor accords to realistic observation.

2. Entering simulation

Because the time we concentrated on is busy time, the number of passengers in one-time step willing to enter elevators should be uniformly distributed in a specific range. Following our observation in Clough building, the range is between 0 to 20. Figure 4 and 5 are the experiment results for different total passengers.

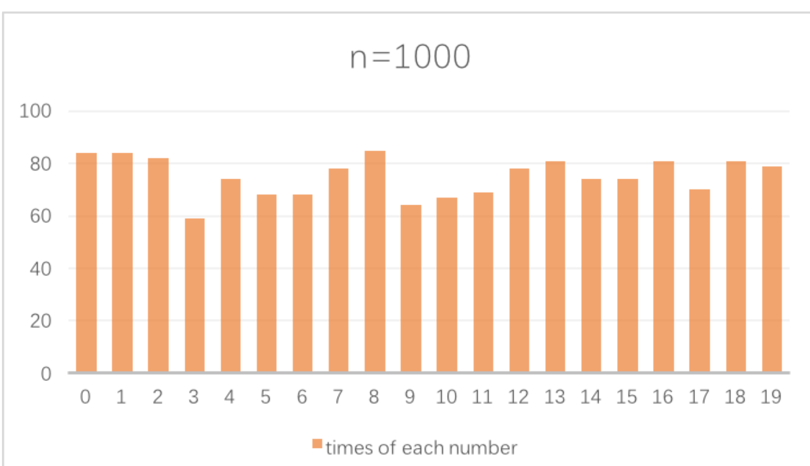

Figure. 4 Distribution for people entering system in one-time step (N=1000)

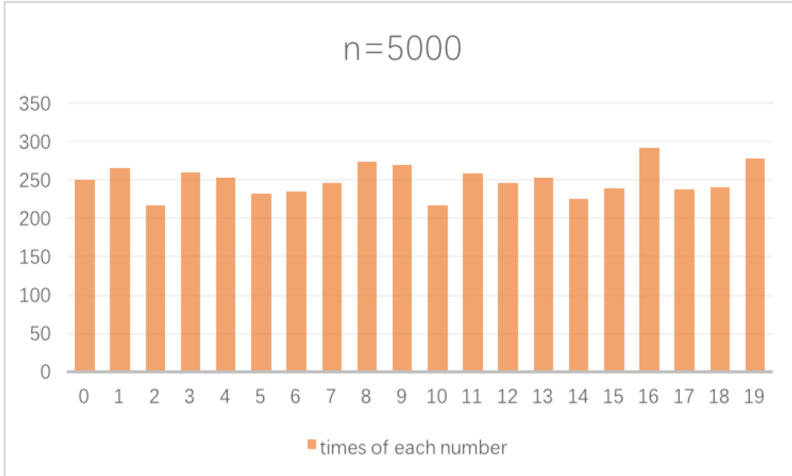

Figure. 5 Distribution for people entering system in one-time step (N=5000)

In each figure, the occurrence frequency for 0 to 20 is around 0.05 and their differences are not notable. After several times repeating, all the results are similar. So this algorithm for generating number of passengers entering system can be used in our simulation process.

Process Validation:

To ensure our project can well simulated, we print each elevator's location, occupation information and each floor's outer demand information to justify whether it accords to reality. If there exist following error means that our algorithm doesn't well in specific situations. Common errors are: 1) passengers don't enter/leave the elevator when possible; 2) Elevators response to wrong outer demand; 3) Elevators don't move or stay correctly. In our simulation experiment, passengers and elevators behavior both accord to realistic rules mentioned before. Using simple visualization method to clarify this process. Figure 6 is the location information for all elevators and from this figure can we observe that all the elevators running following specific rules, never keep moving or staying at specific floors. Concise visualization for passengers' behavior is difficult gaining, so the validation process based on the generated text results and all the passengers' behavior is reasonable.

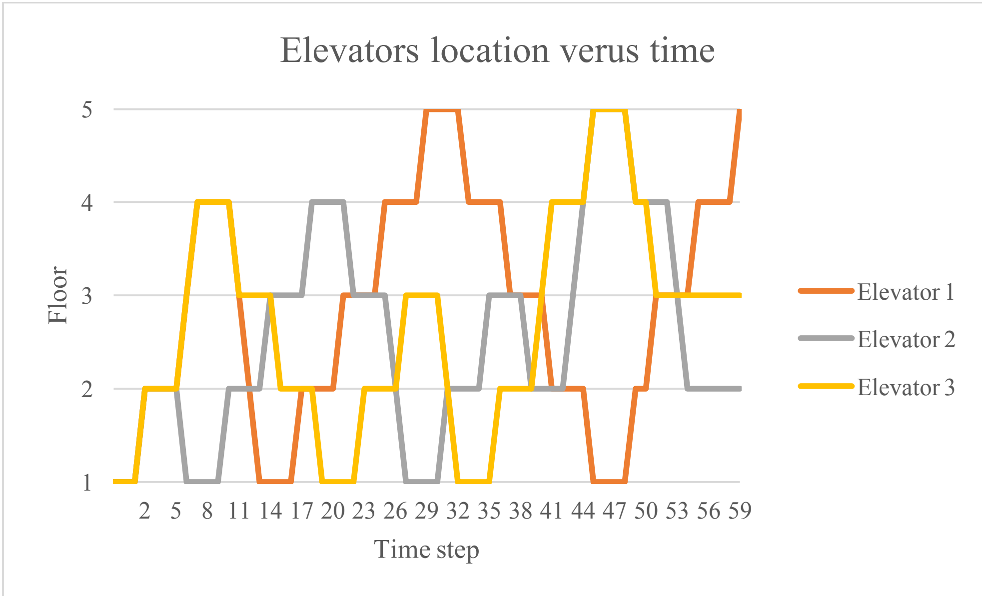

Figure. 6 Elevators running conditions while simulation (N=150)

So the model and simulation algorithms will represent realistic well.

Results

In our project, we concentration on the performance of different elevators facing same total passengers and same elevators with different passengers. Neglecting extra energy consumption while elevators moving, we assume that the value for total running time multiplies the number of elevator is proportional to total energy consumed. We running simulation program 50 times for each individual test aiming to lessen the error because of random data. Figure 7 shows that estimated energy is proportional to total involved passengers for all different elevators. Keeping total passengers stable, in our cases, less elevators will be estimated to use less energy and less passengers entering, more differences between those elevators. But from Figure 8, using more elevators will apparently shorten costing time. Balance consideration of energy and total cost time.

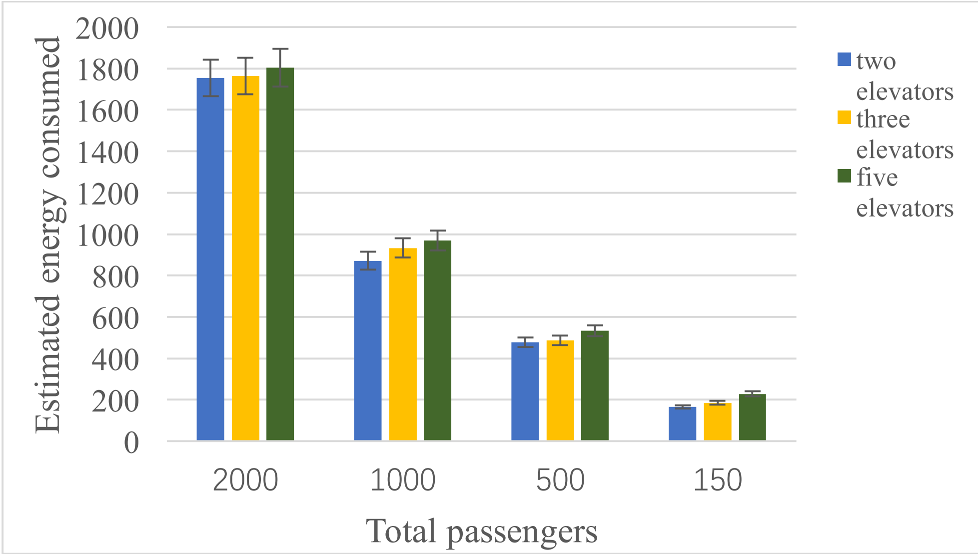

Figure. 7 estimated energy consumption for different conditions

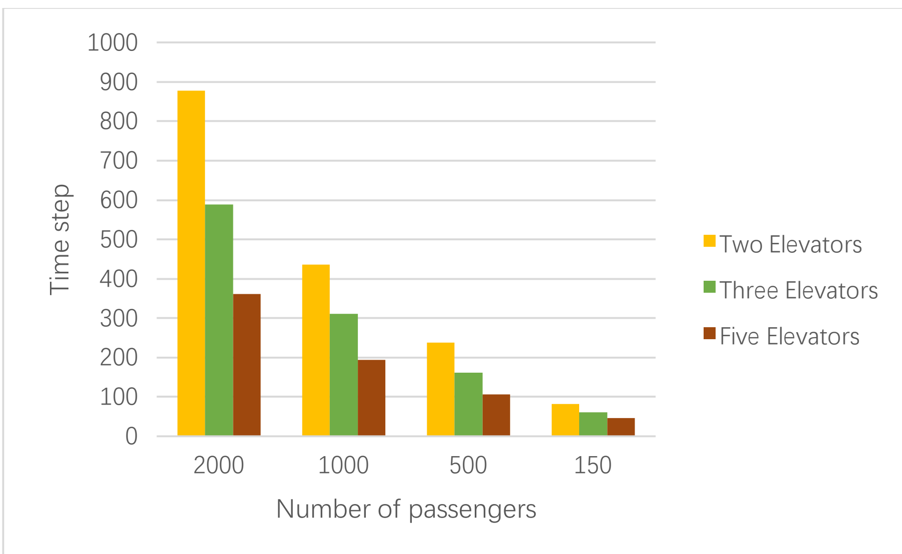

Figure. 8 Time cost for different conditions

To obtain the future information about estimated energy consumption difference, using ratio graph maybe easier to observe. In Figure 9, set information of 5 elevators as standard and all the other cases divided by it. When less passengers take part in this system, conditions with less elevators will consume less energy that is because less elevators will waste less time for waiting or other unrelated moving. If more than 2000 people will use elevators, the energy difference will not play an important role in deciding process, we need to build more elevators to shorten the using time.

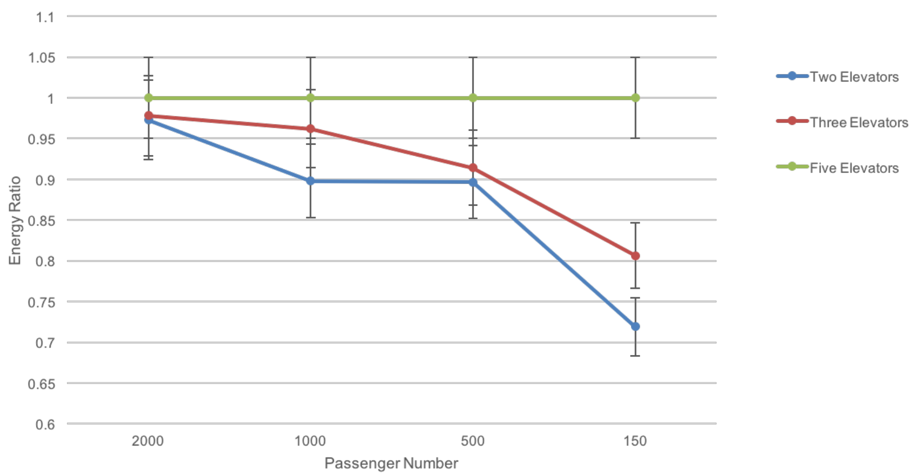

Figure. 9 Estimated energy consumed ratio for different conditions

On balance, the estimated energy is almost proportional to total passengers. When keeping total people same, using less elevators will cost less energy consumption. But if people's number is enough large, the energy difference is tiny than costing time will be the dominant parameters for selecting elevators.

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