

Dynamic planning of office building elevator scheduling

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Abstract. Every morning rush hour is the most crowded time for elevators in office buildings, and many office workers will be late because they can't wait for the elevator. How to reasonably call the existing elevator resources has become a problem we need to pay attention to. In this paper, we will discuss the modeling of elevator scheduling optimization problem for office buildings. In this paper, the background and significance of the research is firstly explained, and then the elevator group linkage control system is briefly understood and analyzed, and the evaluation indexes are determined according to its multi-objective and diversified characteristics, and then the group control method focusing on making the elevator run time the shortest is adopted, and the principle of the ratio of elevator running period/total running time equal to the number of passengers transported/total passengers transported by the elevator in one cycle is followed to compare several common elevator running methods, and the results are summarized in the following table. Common elevator operation methods are compared, the most effective way to arrive at, and finally use dynamic programming to solve the partition point, to establish the optimal scheme of elevator scheduling for the office building division. Since it is not possible to expand the elevator in the office building, reducing the number of stops of each elevator to shorten the time required for the elevator to carry passengers becomes the most feasible method. After comparing the common elevator operation methods, it can be found that zoning can shorten the final average arrival time of passengers more than no zoning. That is, the elevators in an office building are divided into different zones, and each zone has a designated elevator serving a designated floor segment. In order to solve the floor segment allocation problem, the shortest path algorithm is used in this paper. The paper concludes with a summary and future outlook of the resulting optimization model.

Keywords: Dynamic Programming, Data Sifting, Exhaustive Law, Shortest Paths.

1. Introduction

In 1853, American Eliza Graves Otis showed the world his invention, the elevator, at the World's Fair held at the Crystal Palace in New York. This lifting device invented by Mr. Otis changed the way people get around, replacing to some extent the traditional means of elevation, the staircase, and has become an important means of transportation for most of today's high-rise buildings [1].

At first, most of the buildings are used in a single elevator, but with the continuous development of society, a single elevator gradually unable to meet the needs of the people, so the emergence of a group of elevators composed of multiple elevator linkage control system.

Then, how to effectively use multiple elevators has become a consequent problem. As the population rises, the number of jobs and the number of people required increases, the problem of long waiting time

and long travel time during the peak period of elevator use becomes more and more significant, especially during the morning and evening rush hours on weekdays.

Given that most office buildings are unable to expand the number of elevators, optimizing elevator scheduling is the most logical solution.

2. Case Study

An office building in Beijing has 22 floors above ground and 3 underground buildings, a total of six elevators. The maximum carrying capacity of each elevator is 20 normal adult mass. Assume that the underground building portion is not considered. The average dwell time of each elevator on the first floor is 20s, the average running time between floors is 3s, and the average dwell time on floors 2-22 is 10s, and all the elevator passengers can enter and exit the elevator within the average dwell time. Our goal is to rationalize the design of the elevator operation scheme so that all office workers can reach the office floors in the shortest time during the morning peak period. The number of office workers corresponding to each floor is shown in the table below.

Table 1. Amount of workers in each floor.

Floor	Number of office workers	Floor	Number of office workers	Floor	Number of office workers
1	0	9	225	17	274
2	220	10	281	18	279
3	292	11	235	19	265
4	247	12	197	20	283
5	231	13	217	21	246
6	206	14	252	22	233
7	209	15	187		
8	283	16	217		

3. Model assumptions and notation

3.1. Model Assumptions

- (1) Employees working in this office building take the elevator, not the stairs
- (2) During the morning rush hour, there are only people going up the elevator and no people going down the elevator
- (3) Every floor within the elevator's transportation range (except for the 1st floor during the morning rush hour) has passengers exiting the elevator
- (4) There are no accidents in the elevator during operation

3.2. Notation

- n : the maximum number of floors to be transported by the elevator in a single cycle;
- t_1 : average running time of the elevator between each floor;
- t_2 : average dwell time of the elevator per stop;
- t_3 : average dwell time of the elevator on a floor;
- T_{avg} : average passenger arrival time;
- i : number of sequences in the service area;
- T_i : arrival time per cycle for elevator i in the service area;
- $T_i(n)$: arrival time per cycle of service area i elevator at $s_i = n$;
- P_i : total number of people in service area i ;
- s_i : the highest floor that service area i elevator is responsible for transporting;
- $T_A(i)$: arrival time of the i th passenger;

W_p : the total number of passengers on the elevator;
 $W_p(i)$: the total number of elevator rides in service area i ;
 $T_w(i)$: waiting time of the i th passenger for the elevator;
 $T_t(i)$: elevator ride time of the i th passenger.

4. Introduction to elevator group linkage control system

4.1. System structure

Elevator group linkage control system is a fairly complex system, involving hundreds of signals sent and received, processing. Elevator group control has a variety of ways to achieve, but their control system principle is the same, the structure is similar. The following figure shows a basic structure of the elevator group control system block diagram [2].

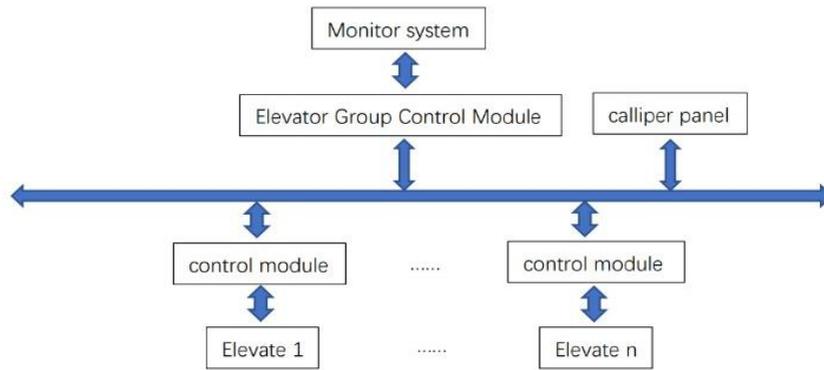


Figure 1. Elevator group control system

4.2. System features

(1) Uncertainty

The elevator group linkage control system has a very large number of uncertainties, such as the internal environment of the elevator and external environmental factors, the target floor of the occupants and the call location, etc. These uncertainties will have a large impact on the prediction of the average arrival time of the elevator, resulting in model errors.

(2) Multi-targeting

The operation of the elevator group to achieve a number of goals: short average waiting time for passengers, short average passenger ride time, the comfort of the passengers in the elevator should be guaranteed and so on. Such objectives affect the development and measurement of the model evaluation criteria.

(3) Disturbance

Elevator operation will be disturbed by a number of factors, for example: passengers enter the elevator and mistakenly press the floor, resulting in the elevator running time elongated; passengers due to their own physical reasons lead to the slow speed of the elevator, prolonging the waiting time of other passengers; passengers mistakenly touch the elevator alarm button, resulting in the elevator stopping and so on. These disturbing factors will make the model produce errors [3].

(4) Non-linear

The operation of the elevator is not linearly correlated, in different traffic operation modes, the priority of the elevator response will change; once the elevator reaches the full capacity of the number of people, it will not respond to calls from other floors in this cycle. The nonlinear characteristics will bring obstacles to the prediction of the model [4].

(5) Incomplete information

The elevator is unable to intelligently estimate the number of people boarding the elevator and the target floors of the passengers and is not good at predicting the degree of crowding in the elevator. This

fuzzy information will likewise bring difficulties to the design of the model.

4.3. Model evaluation metrics based on system characteristics

To sum up, this paper will set the evaluation index of the model as "to make the final average arrival time T_{avg} shortest", so this paper will take "to make the final average arrival time T_{avg} shortest" as the goal of modeling, to solve the optimal operation of the elevator program, where

$$T_{avg} = \frac{\sum_{i=1}^{W_p(i)} T_A(i)}{W_p},$$

$$\sum_{i=1}^{W_p(i)} T_A(i) = \sum_{i=1}^{W_p(i)} T_w(i) + \sum_{i=1}^{W_p(i)} T_t(i).$$

The precondition for model establishment is assumed that the errors and disturbances caused by the characteristics of elevator group linkage control system do not exist.

5. Analysis of elevator passenger traffic patterns and scheduling

5.1. Upward peak traffic patterns

The upward peak traffic pattern mostly appears in the morning rush hour, with the operation pattern of conveying passengers from the ground floor (because this article does not consider the underground part of the building, so the bottom floor is the first floor) to the floors above the first floor. When the upward peak period comes, the office elevator is faced with the problem of how to quickly transport all passengers to the designated floor. Because it is the morning rush hour, convergence in the lower floors of the staff are to take the elevator to go up, so we can think of the morning rush hour only the upward movement of people, there is no downward movement of people and each floor has people leaving the elevator.

5.2. Comparison of common elevator operation methods

In order to simplify the model without loss of generality, two elevators are assumed to operate independently at the same time in the comparison, transporting all passengers from one floor to the specified floors. There are various criteria for comparing elevator operation schemes, but here the optimal scheme is selected based on the criterion of "total elevator operation time", and T [5]. is calculated based on the ratio of elevator operation period/total operation time equal to the number of passengers transported by the elevator in one cycle/total number of passengers transported. (Assume that the number of people working on each floor is 100 and there are 10 floors. The maximum capacity of the elevator is 20 persons, the average dwell time of each elevator is 20s on the first floor, the average running time between floors is 3s, and the average dwell time on floors 2-9 is 10s.)

(1) Tiered Approach

Each elevator stops at each floor.

$$\frac{40}{900} = \frac{164}{T}$$

Thus, $T = 3690s$

(2) Single- and Double-Stacking Method

One elevator stops only at the 1st and odd-numbered floors, and the total time used is T_1 ; the other elevator stops only at the 1st and even-numbered floors, and the total time used is T_2 .

$$T_{total} = T_{max}(T_1, T_2)$$

$$\frac{20}{400} = \frac{108}{T_1}, \quad \frac{20}{500} = \frac{124}{T_2}$$

$$\text{Thus, } T_1 = 2160s, T_2 = 3100s$$

$$T_{total} = T_{max}(T_1, T_2) = 3100s$$

(3) Segmentation Scheme

With six floors as the dividing line, the first elevator is responsible for transporting floors 2-6 and the total time used is T_1 ; the second elevator is responsible for transporting floors 7-10 and the total time used is T_2 .

$$\frac{20}{500} = \frac{100}{T_1}, \quad \frac{20}{400} = \frac{114}{T_2}$$

$$\text{Thus, } T_1 = 2500s, T_2 = 2280s$$

$$T_{total} = T_{max}(T_1, T_2) = 2500s$$

(4) Combination of Layering and Segmentation

Using the fifth floor as the dividing line, the first elevator is responsible for transporting floors 5-10, and the total time used is T_1 ; the second elevator makes stops at each floor, and the total time used is T_2 . On average, each passenger has a 50% chance of choosing each elevator.

$$\frac{20}{300} = \frac{134}{T_1}, \quad \frac{20}{600} = \frac{164}{T_2}$$

$$\text{Thus, } T_1 = 2010s, T_2 = 4920s$$

$$T_{total} = T_{max}(T_1, T_2) = 4920s$$

In summary, the segmented operation method is more reasonable and efficient.

5.3. Dynamic programming to solve partition points

5.3.1. Artificial Preliminary Subdivision. If the elevator group linkage control system is used to implement segmented operation for 6 elevators, it is necessary to specify the partition point. In this paper, the 6 elevators in the office building are divided into 3 service areas, and each service area has 2 elevators running within the specified range. According to the distribution of the number of office workers in the office building, the preliminary partition is shown in the following table:

Table 2. Preliminary partition

Service Area Number	i_1	i_2	i_3
Elevator Number	S1&S2	S3&S4	S5&S6
Service Area	1-8	9-15	16-22
Total number of service	1688	1594	1797
Number of Operation Cycles	85	80	90
Arrival time per cycle	1212s	1254s	1296s
Total Arrival Time	102999s	100278s	116577s
Arrival time per capita in this service area	61.02s	62.91s	64.87s
Arrival time per capita	62.98s		

Total time to complete transportation of all passengers.

For service area i , the sum of arrival times of all passengers:

$$W_i = \left\lceil \frac{P_i}{20} \right\rceil \times T_i - 3(s_i - 1)$$

Where $P_i (i = 1,2,3)$ denotes the total number of passengers that the service area is responsible for transporting, and $\lceil \cdot \rceil$ is rounded upwards, since the time of descending from the highest to the lowest level after the last transportation is completed does not need to be taken into account, and is therefore subtracted by $3(s_i - 1)$.

5.3.2. *Dynamic Programming Modelling for Optimal Solutions Based on Preliminary Partitioning.* In this paper, the per capita arrival time of the three service areas cannot differ by more than 5s as a constraint, and the dynamic planning model is established to further optimize the partitioning scheme on the basis of the preliminary partitioning.

$$T_i(n_1) = 400 + 10 \times \frac{(40 - (n_1 - 2) \cdot \left\lceil \frac{20}{n_1 - 1} \right\rceil) \cdot (n_1 - 1)}{2} + 3 \times 2(n_1 - 1)$$

$$T_i(n_2) = 400 + 10 \times \frac{(40 - (n_2 - n_1 - 1) \cdot \left\lceil \frac{20}{n_2 - n_1} \right\rceil) \cdot (n_2 - n_1)}{2} + 3 \times 2(n_2 - 1)$$

$$T_i(n_3) = 400 + 10 \times \frac{(40 - (22 - n_2 - 1) \cdot \left\lceil \frac{20}{22 - n_2} \right\rceil) \cdot (22 - n_2)}{2} + 3 \times 2(22 - 1)$$

$$T_{avg}(n) = \frac{T_i(n) \cdot \left\lceil \frac{W_p(i)}{20} \right\rceil}{W_p(i)}$$

Since the difference in per capita arrival time between the three service areas was no more than 7s, it was derived by programming (see appendix for code):

$$n_1 \in \{8,9,10\}$$

$$n_2 \in \{15,16,17\}$$

$$n_3 \in \{22\}$$

In this regard, the problem is transformed into a problem of solving the shortest path:

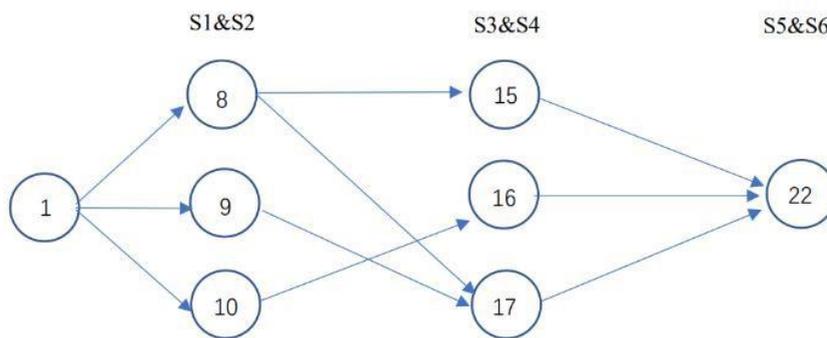


Figure 2. Shortest path

So, there are the following four plans:

Table 3. Plans

	S1&S2	S3&S4	S5&S6	Total Arrival Time	T_{avg}
Plan 1	102999s	100278s	116577s	319854s	62.98s
Plan 2	102999s	127632s	74253s	304884s	60.03s
Plan 3	115944s	116760s	74253s	306957s	60.44s
Plan 4	129113s	71895s	88891s	289899s	57.08s

In summary, the optimal solution for the elevator operation model in the morning peak period is:

Table 4. Optimal solution

	Service Area 1	Service Area 2	Service Area 3
Service Floor	2-10	11-16	17-22
Total Arrival Time	129113s	71895s	88891s
Per capita arrival time in this service area	58.85s	55.09s	56.26s
Arrival time per capita	57.08s		

6. Conclusion

6.1. Advantages of the model

The purpose of the research is clear; first, the research significance and background of this topic is explained, then the common elevator operation system - elevator group linkage control system is analysed, and according to its characteristics, the evaluation indexes of this paper's model are formulated, i.e., the objective function is determined. Next, this paper mathematically analyses the common elevator operation mode, and determines that the segment operation method is the most effective operation mode. On this basis, this paper first gives a feasible solution, and then based on the preliminary partition using dynamic programming (combined with the C language) to solve the reasonable partition point, and then use the shortest path principle to derive the optimal solution, for the office building planning elevator scheduling has a suggestive work.

6.2. Shortcoming of the model

The assumptions about the behavioural patterns of the elevator occupants are not realistic enough, such as all people take the elevator instead of the stairs, no down-travellers during the morning rush hour, etc. The preconditions are ideal, circumventing the errors caused by the characteristics of the elevator group linkage control system, which will have a certain impact on the model results, and do not take into account the underground building portion.

6.3. Prospects

Consider more objective factors in the model; collect the number of people taking the stairs and their target floors in the morning rush hour every day, fit the data to the actual number of people taking the stairs every day, and simulate the flow of people with MATLAB simulation algorithms; take the underground building into account to enhance the practicality of the model.

References

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- [3] Nikovski, Daniel, and Matthew Brand. "Decision-Theoretic Group Elevator Scheduling." ICAPS. Vol. 3. 2003.
- [4] Ahn, Sungyong, Soyoon Lee, and Hyokyung Bahn. "A smart elevator scheduler that considers dynamic changes of energy cost and user traffic." *Integrated Computer-Aided Engineering* 24.2 (2017): 187-202.
- [5] Luh, Peter B., Bo Xiong, and Shi-Chung Chang. "Group elevator scheduling with advance information for normal and emergency modes." *IEEE Transactions on Automation Science and Engineering* 5.2 (2008): 245-258.

Appendices

```
#include <iostream>
#include
<math.h> using
namespace std;
double tn1(int n1)
{ double t,r1;
t=ceil(20.00/(n1-
1));
r1=400+5*(40*(n1-1)-t*(n1-2)*(n1-1))+6*(n1-1);
return(r1);
}

double tn2(int n1,int n2)
{ double t,r2;
t=ceil(20.00/(n2-
n1));
r2=400+5*(40*(n2-n1)-t*(n2-n1-1)*(n2-n1))+6*(n2-1);
return(r2);
}

double tn3(int n2 )
{ double t,r3;
t=ceil(20.00/(22-
n2));
r3=400+5*(40*(22-n2)-t*(22-n2-1)*(22-n2))+6*21;
return(r3);
}
```

```
int abs(double r)
{
    if (r>=0) return
    r; else
    return(r*(-1));
}

int main()
{

    int sc;
    cout<<" Please enter the ideal time difference:";
    cin>>sc;
    int m1,m2,i;
    //m1:2-21
    //m2:2-21 m1<m2
    double r1,r11,r2,r22,r3,r33;
    int p1,p2,p3;// The sum of the number of people in the service area
    int w1,w2,w3;
    int
lcrs[22]={0,220,292,247,231,206,209,283,225,281,235,197,217,252,187,217,274,279,265,283,246,2
3
3};// Number of people on each floor
    for (m1=2;m1<=21;m1++)
    {
        r11=tn1(m1);
        p1=0;
        for (i=1;i<=m1;i++)
            p1=p1+lcrs[i-
            1];
        r1=r11*ceil(p1/20.00)/p1;
        w1=ceil(p1/20.00)*r11-3*(m1-
        1);
        //cout<<" Number : "<<p1<<" , The average number of people is rounded
        upwards "<<ceil(p1/20.00)<<" ,tn1="<<r11<<endl;

    for (m2=m1+1;m2<=21;m2++)
    {// Second service
        area
        r22=tn2(m1,m2);
        p2=0;
        for
            (i=m1+1;i<=m2;i+
            +) p2=p2+lcrs[i-
            1];
```

```
    r2=r22*ceil(p2/20.00)/p2;
    w2=ceil(p2/20.00)*r22-3*(m2-
1);
    //cout<<"    Number : "<<p2<<" , The average number of people is rounded
upwards "<<ceil(p2/20.00)<<" ,tn2="<<r22<<endl;

    // Third service area
    r33=tn3(m2);
    p3=0;
    for
        (i=m2+1;i<=2
        2;i++)
            p3=p3+lcrs[i-
            1]
            r3=r33*ceil(p3/20.00)/p3;
    w3=ceil(p3/20.00)*r33-3*(22-
1);
    //cout<<"    Number : "<<p3<<" , The average number of people is rounded
upwards "<<ceil(p3/20.00)<<" ,tn3="<<r33<<endl;

    if ( (abs(r1-r2)<=sc) && (abs(r1-r3)<=sc) && (abs(r2-r3)<=sc) )
        {
            cout<<" First service area cap ="<<m1<<" , Second service area cap ="<<m2<<" ;The time
difference is, respectively "<<abs(r1-r2)<<"s,"<<abs(r2-r3)<<" , "<<abs(r1-r3)<<"s;"<<endl;
            cout<<"    w1="<<w1<<" ,w2="<<w2<<" ,w3="<<w3<<" ,sum of
w="<<w1+w2+w3<<endl; cout<<"
                p1="<<p1<<" ,p2="<<p2<<" ,p3="<<p3<<" ,number="<<p1+p2+p3<<endl;
            cout<<"average time="<<(w1+w2+w3)*1.00/(p1+p2+p3)<<endl;
        }
    }
}
}
}
```