



Study on Group Control Strategy of Multiple Elevators and Its Efficiency Evaluation

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Abstract

With the rapid development of modern society, large buildings are springing up like mushrooms in every city. The huge passenger flow demands more and more intelligent buildings. The carrying capacity of cluster elevators is one of the important factors. The carrying efficiency of elevators directly determines whether the vertical traffic is crowded, whether the building is energy-saving and whether the building is intelligent. Therefore, the group control strategy of cluster elevator is very important. Firstly, the paper expounds the characteristics of elevator, introduces the configuration of software and hardware of Programmable Logic Controller (PLC) and the production and use of WinCC, in order to realize the program design of elevator control. Then, relying on the elevator simulation training system EET-2017035, three elevator group control algorithms are designed for the ten-story integrated office building equipped with six elevators, and five most common passenger flow modes are equipped according to the functions of the building. Three kinds of group control strategies are tested. Several cumulative indicators measured by simulation platform are used as evaluation indicators. After dealing with each indicator, evaluation functions are constructed. The evaluation values of three kinds of group control strategies in five-passenger flow modes are calculated, and the comparison of group control strategy algorithms is completed.

Subject Areas

Mechanical Engineering

Keywords

Elevator Control, PLC, Group Control, Elevator Traffic

1. Introduction

1) *Research background*

Nowadays, for the public, the requirements of service indexes have been more and more. The study of the elevator in large buildings indicates that the key point of the elevator carrier systems is meeting the endurance physically and mentally for the passengers. However, in the theory, there are lots of group control strategies of cluster elevators, and various group control strategies have different carrying capacity and satisfaction of passengers. Besides, the strategies have different strengths, weaknesses, and application scenarios. For example, some group control strategies apply in the lower floor rather than upper and some apply in fewer stairs building rather than more stairs building. Consequently, aiming at some specific scenario, there will be a more suitable group control strategy relatively.

Aiming at different scale building, there will always be a better strategy in kinds of group control strategies of cluster elevators. Even though at the same building, the same is true in the different application scenarios and time. To appropriately choose the most suitable group control strategy, the experience of people and the carrying capacity of elevators in some time are not enough to assess. So, there should be a set of the entire assessment system. Jian Chen [1] took a series of accumulation as kernel potential variables of passenger satisfaction. This is similar to the construction of the efficiency indicator system of the elevator group control strategy. Focused on the different carrying environment and conditions, the quantitative analysis should be used to assess the quality of multiple group control strategies. So, the efficiency assessment is widely used.

2) *Research status of efficiency assessment*

For a relative and quantitative system efficiency, specific application scenarios and objectives should be considered. Assessment of system efficiency aims at design, analysis, optimization, and assessment. If in the management system, there are different symptoms and the indicators measured deviate from the default range, the relative indicators will change. According to the reasonable classification and definition of the range of the indicator, the levels of current assessment can be obtained [2].

With the analysis of multiple objective decisions, Jinwei Guo *et al.* [3] thought that the weight was affected by many factors, such as the effect of the subjective factors on the weight configuration, reasonable configuration proportion. Currently, there are a lot of ways to configure the weight. After normalization, the 5-minute load factor was used as a significant reference to find the best elevator. Dongmei Song *et al.* [4] suggested an objective weighting method. The part of this method was based on the CARTTI method and entropy method and considered sufficiently the discreteness, correlation, and contrastive intension of data.

Shixin Gong *et al.* [5] found that if the failure model was assessed directly, the solution of the failure model would be invalid because the complete assessment system was lacked. Víctor Giménez [6] analyzed from 2 static and temporary perspectives to assess the total factor productivity (the hospital performance changing)

in the whole time and the changing of its component. Referring to these components, it would help to define the variables and parameters in the system. For constructing the application scenario, it was a critical process.

2. Elevator System Analysis

1) *Elevator model introduction*

A traction elevator is a relatively complicated device. The elevator usually, from the structure, is divided into the elevator machine room, elevator shaft, lift car, lift hall, and so on. This paper aims at 6 ten-floor elevators model. The floors are composed of first-floor lobby supermarket, second and third floors mall, fourth and ninth-floor office, and tenth-floor lounge. The whole structure of the elevator simulation model is shown in **Figure 1**.

2) *Classification of elevator transportation modes*

When the elevator is working, the passenger flow is continuously changing. The most suitable group control scheduling algorithm can be chosen only by getting the passenger flow change and determining the elevator transportation modes. The ten floors medium comprehensive office building (the floors are composed of first-floor lobby supermarket, second and third floors mall, fourth and ninth-floor office, and tenth-floor lounge) is used as the research object in this design. Referring to the change of passenger flow in different time, the transportation mode is divided into 5 types: morning peak mode, lunch hour peak mode, afternoon peak mode, normal low passenger flow mode, and evening peak mode.

According to the scoring system of the simulation platform, shown as **Figure 2**, the following points will be composed as an assessment system.

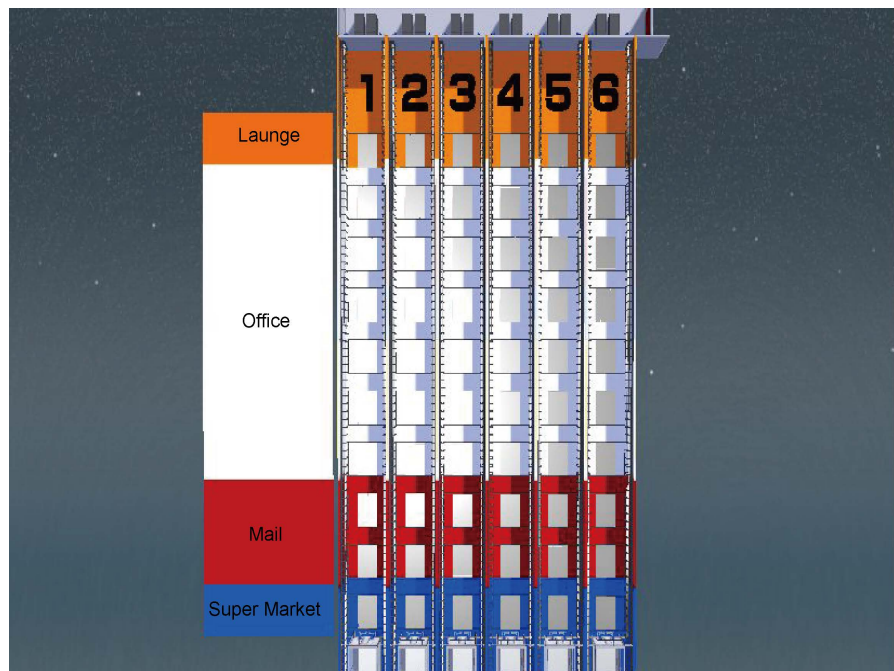


Figure 1. Entire structure of elevator simulation model.

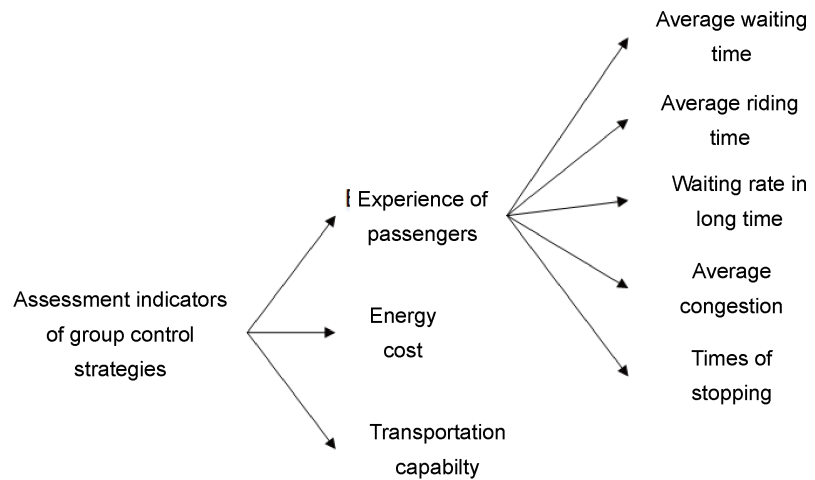


Figure 2. Assessment indicators of the group control algorithm.

3. Design of Group Control Algorithm

Multiple elevator group control systems will generally generate several assessment indicators referring to the different demands for building and passengers. There are several types of indicators and several factors in EGCS and the main object needs to intensify as much as possible; for the EGCS with more comprehensive considerations, the assessment standard is relatively higher. Conversely, when the consideration is less, the standard is relatively lower. In this design, several indicators will be used as consideration to analyze the multiple performance indicators and influence parameters of the EGCS. What's more, two methods have been determined: the shortest distance scheduling algorithm and minimum waiting time scheduling algorithm (in the following, they will be simplified as the shortest distance and minimum waiting time).

3.1. The Shortest Distance Scheduling Algorithm

The scheduling principle of this algorithm is that when there is a call, according to the evaluation function to calculate the distance between this floor and each elevator and to compare these distances, the call signal will allocate to the elevator with the shortest distance to the floor.

Because the floor distance between every floor is equal, the difference of floors can be used to replace the distance. The following factors should be considered in the shortest distance:

- 1) N_{OUT} : Call floor
- 2) N_{CAR} : The floor of the lift car
- 3) N_{ICAR} : Improve the present floor
- 4) N_{DIF} : The floor distance

The up-call algorithm will be used as an example (the following is same).

1) *Calculating the real distance*

a) When the elevator goes up and the No. 1 elevator high-speed contactor is set 1, the elevator is going up certainly and it will arrive on the upper floor soon.

The improvement numbers of floors will be added 0.5, shown as **Figure 3**.

$$N_{ICAR} = N_{CAR} + 0.5 \tag{3-1}$$

b) The absolute difference of floors will be calculated and that is to say the absolute distance between the call floor and lift car (**Figure 4**).

$$N_{DIF} = |N_{OUT} - N_{ICAR}| \tag{3-2}$$

2) The floor difference adjustment

Taking the No. 1 elevator as an example, if No. 1 elevator, at this time, is going down or up, but the real floors, at this time, are more than call-floors. This is a long time waiting situation, and it is not suitable to allocate. So 100 floors will be added to compare rather than calculating the precise difference of the floors, shown as **Figure 5**.

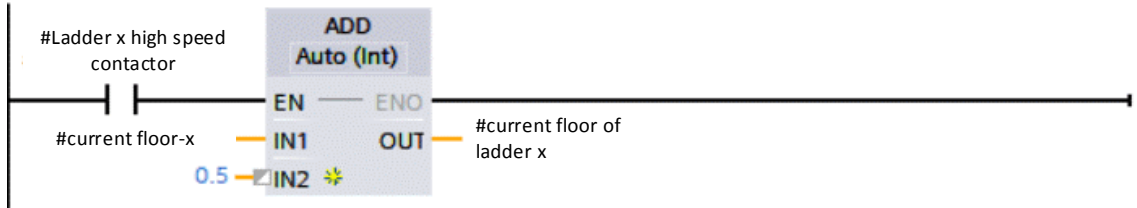


Figure 3. Floor solution with high speed.

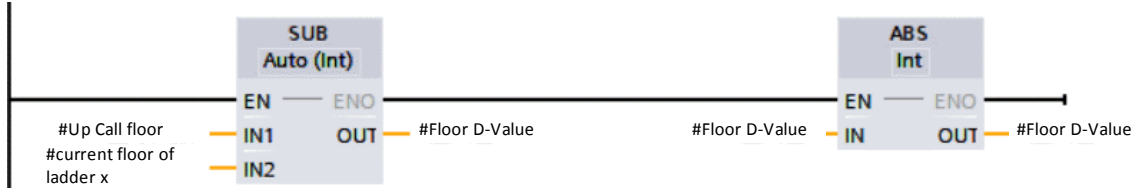


Figure 4. Difference calculation of real floors.

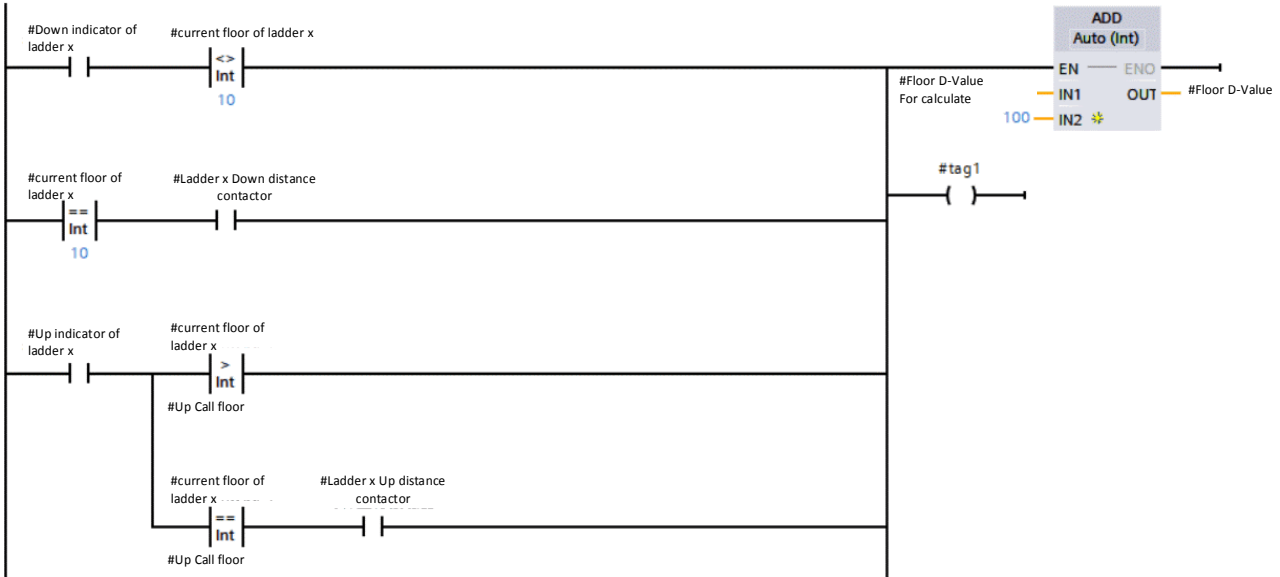


Figure 5. The floor difference adjustment.

3.2. The Minimum Waiting Time Scheduling Algorithm

This algorithm needs to precisely calculate the uniform working velocity of the elevator and the time through one floor with uniform velocity. It needs to calculate each stopping time as well, including acceleration and deceleration, door opening and closing, and personnel entry and exit time. The speed of AC two speed elevators from start to stop is always constant, and the door opening and closing motor is DC motor, so the opening and closing time is also constant. The all above can be measured by the timer and the results are much precise. After analyzing every kind of factor, the multiple-object mathematical model will be built. And this model will be solved to find the best scheduling scheme. The following factors should be considered in the minimum waiting time:

- 1) N_{STOP} : Number of the elevator stopping
- 2) N_{DIF} : Difference between floors
- 3) T_{USP} : Time to pass one floor with uniform velocity
- 4) T_{STOP} : Time of stopping once
- 5) T_{TOT} : Total working time
- 6) T_{TST} : Total stopping time
- 7) T_{EMP} : False waiting time
- 8) T_{REL} : Real waiting time

1) Calculating the difference between the real floors

a) As the same when the elevator goes up, and the No. 1 elevator high-speed contactor is set 1, the elevator is going up certainly and it will arrive on the upper floor soon. The improvement numbers of floors will be added 0.5.

b) When the elevator goes up, and the No. 1 elevator high-speed contactor is set 0, the elevator must be at leveling or arrives at leveling as soon. And at this time, nothing is added, shown as **Figure 1**. It is the same for the elevator goes down.

c) Calculation floors difference: it can be obtained by using call-floors subtracts the present floors. And then it is convenient to compare by taking the absolute value of the difference, shown as **Figure 5**.

2) Waiting time

$$T_{EMP} = T_{TOT} + T_{TST} \quad (3-3)$$

a) Total working time

According to timing, the time of passing one floor with uniform velocity is 4s. Taking second-floor call-up as an example, if the second-floor call-up has been allocated to the No. 1 elevator when there is a call-up above the second floor again, the number of stopping should be added 1.

Total working time calculation(s):

$$T_{TOT} = N_{DIF} \times 4 \quad (3-4)$$

b) Total stopping time

According to timing, the time of each stopping is about 12s.

Total stopping time calculation(s):

$$T_{TST} = N_{STOP} \times 12 \quad (3-5)$$

3) Waiting time adjustment

Taking the No. 1 elevator as an example, if the No. 1 elevator is going down or going up, but the real floors are more than call floors, this will be a long time waiting situation and it will not be suitable to allocate. So 10000s will be added to compare rather than calculating the precise waiting time.

After calculation and comparison, the call will be allocated to the elevator of minimum waiting time.

4. System Configuration and Efficiency Assessment

The elevator control system consists of PLC S7-1214C, communication module, call-button, control loop, Three-phase AC asynchronous motor, LED digital tube, PC STATION/WINCC RT ADVANCE and so on, shown as Figure 6.

The Control system mainly includes a PLC host and power module (Table 1 and Figure 7).

Wincc and S7-1200CPU of PC, and the elevator simulation system were connected by the ProfiNET Industrial Ethernet. This would come into being an entire simulation process finishing on the coaxial cable.

1) Passengers configuration

The passenger table would be set and the test time was all 10 minutes (Table 2).

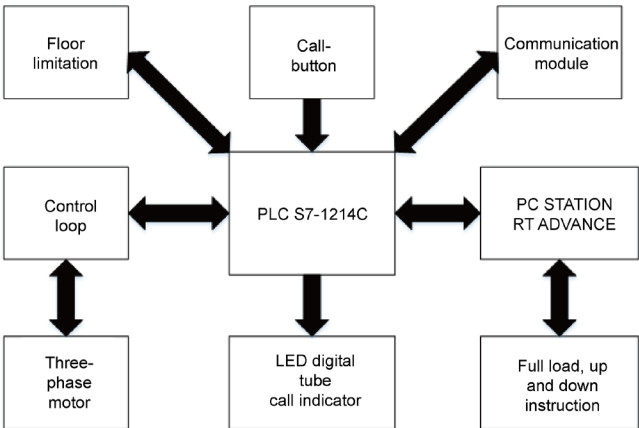


Figure 6. The structure diagram.

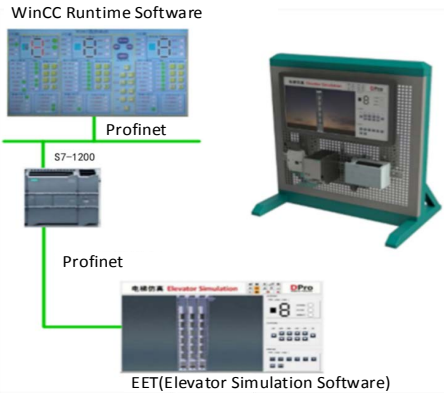


Figure 7. EET network topology.

Table 1. Equipment selection table.

Name	Type	Amount	Explanation
CPU	S7-1200 CPU 1214C DC/DC/DC	1	Master controller
Power module	PM1207	1	Provide stable voltage to master controller
Ethernet communication	ProfiNET cables and connectors	1	Communicate with CPU and GPU

Table 2. Passenger setting table.

	Total passengers	Number of people from the first floor to the office	Number of exchanges between floors	Number of people from the office to the top floor	Number of people from the top floor to the office	Number of people from the office to the first floor	The range of passengers weight (kg)
Normal low passenger flow	100	8	79	4	7	2	49 - 88
Moring peak	200	161	30	3	2	4	49 - 88
Lunch time peak	200	1	20	171	3	5	49 - 88
Afternoon peak	200	5	27	3	164	1	49 - 88
Evening peak	200	4	28	2	3	163	49 - 88

2) Weight configuration

The weights of above 6 indicators are represented as $W_1 \sim W_6$. The goal of the algorithm design in the elevator group control system is to achieve the shortest waiting time outside the hall, reduce the long waiting rate of passengers, shorten the travel of each elevator, allocate the elevator response reasonably, prevent the clustering and uneven busy and idle, so as to meet the requirements of comfort, safety and economy. However, there may be conflicts in the above conditions. For example, the pursuit of the minimum waiting time must cause a certain degree of energy loss. Therefore, this paper will be divided into two cases for weight distribution. It focuses on the psychological indicators of passengers and energy consumption indicators, and adopts the method of average distribution for non important influencing factors.

At the normal low passenger flow mode, the elevator will not overweight basically, because the passengers distributed on every floor are relatively less and the exchange of passengers is mainly between floors. Therefore, at this time, the energy conservation indicator will be considered significant and put at first [7]. At the peak mode, the first goal is transforming the passengers to the target floor quickly. At this time, the key indicators will be the average waiting time of passengers, ride time, and waiting rate in a long time. These indicators will directly affect the experience of passengers, so the energy cost will not be the first goal to consider. The weight configuration shows in **Table 3**.

3) Efficiency assessment results

The above 6 indicators are represented as formulation:

$$S(i) = W_1 \frac{\min(A_{HT}(i))}{A_{HT}(i)} + W_2 \frac{\min(A_{CT}(i))}{A_{CT}(i)} + W_3 \frac{\min(P_{CHT}(i))}{P_{CHT}(i)} + W_4 \frac{\min(L_{YX}(i))}{L_{YX}(i)} + W_5 \frac{\min(T_S(i))}{T_S(i)} + W_6 \frac{T_A(i)}{\max(T_A(i))} \quad (4-1)$$

The indicator parameters show as **Table 4** and all the maximum and minimum indicators are the indicators of the best reference model.

The test results of 6 cumulative amounts in the simulation platform are taken into the evaluation function to calculate. The calculation results are shown as follow **Table 5**.

The assessment result will be shown in a histogram to compare the assessment indicators conveniently and directly, shown as **Figure 7**. But these 6 indicators are different in unit and order of magnitude, the data in the figure are all the result of normalization.

- 2) Lunch hour peak mode (**Table 6**)
- 3) Afternoon peak mode (**Table 7**)
- 4) Normal low passenger flow mode (**Table 8**)
- 5) Evening peak mode (**Table 9**)

Table 3. Weight configuration table.

	W_1	W_2	W_3	W_4	W_5	W_6
Low passenger flow	0.2	0.1	0.1	0.2	0.2	0.2
Peak mode	0.2	0.2	0.2	0.1	0.1	0.2

Table 4. Indicator parameters.

Indicators	Meaning	Indicators	Meaning
$A_{HT}(i)$	Average waiting time	$\min(A_{HT}(i))$	Minimum average waiting time
$A_{CT}(i)$	Average riding time	$\min(A_{CT}(i))$	Shortest riding time
$P_{CHT}(i)$	Waiting rate in a long time	$\min(P_{CHT}(i))$	Minimum waiting rate in long time
$L_{YX}(i)$	Total distance	$\min(L_{YX}(i))$	Shortest total distance
$T_S(i)$	Times of stopping	$\min(T_S(i))$	Minimum times of stopping
$T_A(i)$	Number of transporting passengers	$\max(T_A(i))$	Maximum number of transporting passengers

Table 5. The assessment result of morning peak mode.

Algorithm	Average waiting time/s	Average riding time/s	Waiting rate in long time/%	Total distance/m	Times of stopping	Number of transporting passengers	$S(i)$
Shortest distance	52.05	86.08	0.27	755.65	239	162	0.84
Minimum waiting time	42.50	86.56	0.27	796.39	254	155	0.85

Table 6. The assessment result of lunch hour peak mode.

Algorithm	Average waiting time/s	Average riding time/s	Waiting rate in long time/%	Total distance/m	Times of stopping	Number of transporting passengers	$\mathcal{S}(j)$
Shortest distance	51.67	84.07	0.21	799.32	259	182	0.89
Minimum waiting time	49.21	82.42	0.21	811.05	260	185	0.91

Table 7. The assessment result of afternoon peak mode.

Algorithm	Average waiting time/s	Average riding time/s	Waiting rate in long time/%	Total distance/m	Times of stopping	Number of transporting passengers	$\mathcal{S}(j)$
Shortest distance	42.04	66.08	0.24	729.22	217	154	0.88
Minimum waiting time	60.46	65.66	0.4	849.77	240	164	0.75

Table 8. The assessment result of normal low passenger flow mode.

Algorithm	Average waiting time/s	Average riding time/s	Waiting rate in long time/%	Total distance/m	Times of stopping	Number of transporting passengers	$\mathcal{S}(j)$
Shortest distance	43.37	54.66	0.17	370.43	139	91	0.88
Minimum waiting time	34.61	51.34	0.17	401.81	142	90	0.89

Table 9. The assessment result of evening peak mode.

Algorithm	Average waiting time/s	Average riding time/s	Waiting rate in long time/%	Total distance/m	Times of stopping	Number of transporting passengers	$\mathcal{S}(j)$
Shortest distance	51.67	84.07	0.21	799.32	259	182	0.89
Minimum waiting time	50.01	82.08	0.24	808.22	262	185	0.87

5. Conclusions

According to the calculation, the assessment value of 2 group control strategies can be obtained in 5 passenger flow modes. The results are as follow:

1) In the 5 passenger flow modes, the assessment values of the shortest distance and minimum time are very close to each other. And the latter is slightly higher than the former because the total working time and total stopping time were considered accurately in the minimum time. Compared to the former, the consideration was more specific.

2) In the normal flow passenger low mode, it is similar for the energy conservation indicators of 2 type group control strategies and the assessment results are similar too. Because, at this time, the energy conservation indicator takes more proportion, and other indicators are weakened. The advantages of group control strategies cannot appear easily.

3) In this design, aiming at the morning peak mode, the most representative mode, in the 5 passenger flow modes, the number of transporting the passengers measured in this mode is not ideal, because this is to be more in line with reality.

The type of passenger was set as No Patient, and they would leave when the waiting time was so long. So this would lose some passengers and make the number of transporting passengers to be lower than other conditions.

To sum up, the scheduling algorithm of the minimum waiting time is the best, and one of the highlights of the algorithm is: in the peak passenger flow, such as class peak, as long as it is in the peak state, the first floor passengers do not need to press the up call button, the elevator will also give priority to alleviate the first floor congestion.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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