Research on Elevator Optimization Scheduling Based on Statistical Analysis

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Abstract. Aiming at the problems of low elevator full load rate and high energy consumption, an energy-saving priority elevator scheduling algorithm based on statistical analysis is proposed. The statistical control results are used to control the elevator control domain and extra waiting time in time to realize the off-site elevator dispatching. The scheduling algorithm introduces the energy consumption of the elevator before and after the operation. Experiments show that only 2 elevators save energy 28291.4J within 1 h, and the optimization ratio is 1.4%.

Introduction

As an important factor affecting building energy consumption, elevators have an important significance for improving the energy consumption of building resources and improving energy and environment [1]. In addition to improving hardware equipment, the core of controlling elevator energy consumption is also reflected in its scheduling algorithm. Common elevator scheduling algorithms include traditional and improved [2]. The traditional elevator dispatching algorithm aims to minimize the waiting time of the waiting person, and immediately responds to the elevator call service to complete the call at the fastest speed, providing higher convenience to the waiting person, but the elevator carrying rate is low [3]. No energy saving measures were considered. The improved elevator scheduling algorithm includes scheduling algorithms based on artificial intelligence technology such as fuzzy control, expert system, genetic algorithm and particle swarm optimization algorithm [4]. It introduces energy-saving optimization control, and no longer simply pursues elevator service efficiency, but also considers service efficiency and energy efficiency control, and dynamic scheduling optimization based on mission characteristics such as traffic volume and peak passenger flow, improving elevator resource utilization. Based on statistical analysis, this paper proposes an elevator external dispatching algorithm based on energy saving, taking into account the wait time of waiting people and introducing dynamic waiting time, which has a significant effect on reducing the energy consumption of elevators.

Energy-Saving Priority Elevator Scheduling Algorithm Flow

Figure 1 is a flow chart of an energy-saving priority elevator scheduling algorithm. Specifically, the method includes: calculating the equivalent load of each floor in different time periods, selecting the elevator total control domain by using the floor equivalent load as the weight, and adjusting the elevator service unit based on the selected control domain to prioritize the efficiency and determine the elevator control domain. The elevator service unit performs secondary adjustment according to each elevator control domain, and determines the extra waiting time of each elevator according to the traffic volume.

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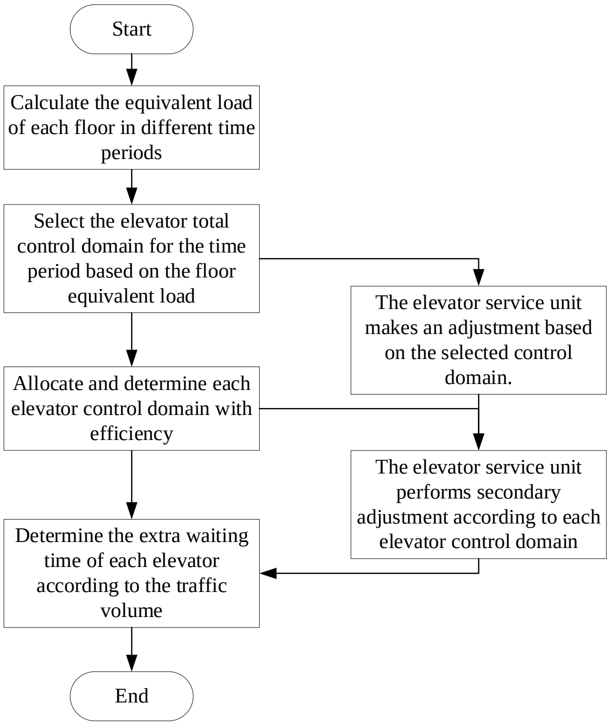

Figure 1 Flow chart of energy-saving priority elevator scheduling algorithm

Elevator Scheduling Algorithm Principle

The total number of floors is N_{floor}, the height of floor L_x is H_x, the number of elevators is N_{rated}, the rated passenger capacity is N_{rated}, the rated load is W_{rated}, the elevator door is opened/closed once, the average time of people is one, the average time is t_{door}, t_{swap}, and the single average quality is W_{solo}.

Calculate the Equivalent Load of each Floor in each Period. The elevator running task consists of the elevator basic service unit $U(i)$. The elevator basic service unit $U(i)$ is the elevator moving from the floor $L_{on}(i)$ to the floor $L_{oiff}(i)$ at the start time $t_{on}(i)$ to the stop time $t_{off}(i)$, and the process load is $W(i)$, that is, $U(i): H_{on}(i) \xrightarrow{W(i):t_{on}(i) \to t_{off}(i)} H_{off}(i)$. All service units constitute a complete set U, the total number of service units is $N_{service}$, according to the starting time $t_{on}(i)$ from small to large, all elevator basic service units $U(i)$ are sorted, and the elevator basic service unit can be sorted.

For the service unit $U(j)$, if it meets:

$$\begin{cases} i < j \\ t_{on}(j) \le t_{off}(i) + N_{rated} t_{swap} + t_{door} \\ H_{on}(j) = H_{off}(i), H_{off}(i) \ne 0 \,\&\, H_{off}(i) \ne H_{N_{floor}} \end{cases} \tag{1}$$

It is indicated that after the elevator completes the service unit $U(i)$ on the floor $L_{off}(i)$, the personnel enters and exits and continues to execute the service unit $U(j)$. For two closely connected service units like this, if the elevator comes out $n_{out}(i)$ persons after the completion of the service unit $U(i)$ on the floor $L_{off}(i)$, and enters $n_{in}(j)$ persons, the formula for estimating the number of people entering and leaving is:

$$\begin{cases} n_{out}(i), n_{in}(j) \in N \\ n_{out}(i) \le N_{rated}, n_{in}(j) \le N_{rated} \\ [n_{out}(i) + n_{in}(j)] \dfrac{t_{swap}}{2} \approx t_{on}(j) - t_{off}(i) - t_{door} \\ \left| W(i) - W(j) - [n_{out}(i) - n_{in}(j)] W_{solo} \right| < W_{solo} \end{cases} \tag{2}$$

The floor L_x equivalent load W_{eq_L} is the sum of the elevator quality in and out of the floor L_x in the time period Δt, namely:

$$W_{eq\_L_x} = \sum \left\{ \left\{ W(i) \left| U(i) \in \left(\bar{U}_{swap\_L_x} \cap U_{L_x} \right) \right. \right\} + \left\{ [n_{out}(i) + n_{in}(i)] W_{solo} \left| U(i) \in U_{swap\_L_x} \right. \right\} \right\} \tag{3}$$

In the formula, U_{L_x} is to start or stop the service unit set on the floor L_x, and the $U_{swap\_L_x}$ belongs to the set U_{L_x} and satisfies the service unit set of the formula (1). The larger the equivalent load $W_{eq\_L_x}$, the greater the mass of the elevator entering and exiting the floor L_x during the time period Δt, and the stronger the energy saving effect and convenience when the total control domain of the elevator includes the floor L_x.

Elevator Total Control Domain Selection and Service Unit Adjustment. The total control domain of the elevator needs to save energy and ensure the convenience of the elevator. Therefore, according to the equivalent load $W_{eq\_L_x}$ of each floor, the first n floors are selected as the total control domain of the elevator in the time period Δt to cover 80% of the service unit $U(i)$. The total control domain of the rear elevator is $D = \{L'_x(1), L'_x(2), \cdots, L'_x(n)\}$, namely:

$$\sum_{i=1}^{n} U_{L'_x}(i) \ge 0.8 \sum_{i=1}^{N_{service}} U(i), n \le N_{floor} \tag{4}$$

After the optimization of the total control domain of the elevator is completed, all service units U are adjusted and fitted according to the control domain, so that the adjusted service order $U'(i)$ starting floor $L'_{on}(i)$ and stopping floor $L'_{off}(i)$ are all in the control domain D. Service unit adjustment adopts the principle of proximity, namely:

$$\begin{cases} L'_{on}(i) \in D, L'_{off}(i) \in D \\ \left| H_{on}(i) - H'_{on}(i) \right| \le \left| H_{on}(i) - H_x(k) \right| \quad (k = 1, 2, \cdots, n) \\ \left| H_{off}(i) - H'_{off}(i) \right| \le \left| H_{off}(i) - H_x(k) \right| \quad (k = 1, 2, \cdots, n) \end{cases} \tag{5}$$

Elevator Control Domain Allocation and Service Unit Secondary Adjustment. After one adjustment, the service unit needs to be assigned to each elevator. Since a single service unit is actually associated with two floors, the secondary adjustment of the service unit is realized by assigning the elevator control domain. The control domain allocation adopts the principle of equalization to make full use of the elevator resources. The primary selection floor must meet the highest relevance of the current candidate floor, and the two-floor correlation is measured by the total energy consumption transmitted between the floors, namely:

$$\rho_{L_x L_y} = \sum_{U'(1)}^{U'(i)} W'(i) g \left| H'_{off}(i) - H'_{on}(i) \right| \tag{6}$$

Since the number of elevators is N_{lift}, each elevator control domain contains the $N_{domain} = \left[\dfrac{n}{N_{lift}} \right]$ floor (the remainder is placed in the last elevator), and the elevator m control domain $D_{lift}(m) = \left\{ L_{lift\,m}(1), L_{lift\,m}(2), \cdots, L_{lift\,m}(N_{domain}) \right\}$, it meets:

$$\sum_{i=1}^{N_{domain}} \sum_{j=1, j\neq i}^{N_{domain}} \rho_{L_{lift\,m}(i)L_{lift\,m}(j)} \geq \sum_{i=1}^{N_{domain}} \sum_{j=1, j\neq i}^{N_{domain}} \rho_{L_x(i)L_y(j)} \tag{7}$$

So far, the control domain division of each elevator in the time period Δt has been completed. After one adjustment, the service unit needs to be adjusted twice according to each elevator control domain, and the task unit cannot be completed in any elevator according to the principle of one adjustment, and the principle of proximity is adopted. The fitting adjustment is such that the service unit start floor and the stop floor of the secondary adjustment are all in the same elevator control domain.

Elevator Extra Waiting Time. The extra waiting time of the elevator is the additional waiting time before the elevator starts under normal conditions, and the extra waiting time is introduced, which helps to increase the full load rate of the elevator, reduce the number of elevator start/stop times, and reduce the running mileage of the elevator, thereby reducing the energy consumption of the elevator. The extra waiting time $t_{add}(m)$ of the elevator m is related to the amount of elevator traffic in the current time period Δt. In addition, the maximum extra waiting time $t_{add\,\max}(m)$ needs to meet the normal psychological tolerance of human beings, while the normal person tolerates for 50s, so $t_{add\,\max}(m) = 50$.

Elevator m service unit set $U_{lift\,m}$, service unit number is $N_{lift\,m}$, and the service unit is $U_{lift\,m}(i) : N_{on\_lift\,m}(i) \xrightarrow{W_{lift\,m}(i):t_{on\_lift\,m}(i)\rightarrow t_{off\_lift\,m}(i)} H_{off\_lift\,m}(i)$, additional waiting time $t_{add}(m)$ is added, the essence is to increase the elevator full load rate to achieve energy saving, so after the $t_{add}(m)$ join, the service unit expects at least 80% of the full load run:

$$\begin{cases} t_{add}(m) \leq t_{add\,\max}(m) \\ t_{add}(m) = \dfrac{t_{add\,\max}(m) \sum_{i=1}^{N_{lift\,m}} W_{lift\,m}(i) g \left| H_{off\_lift\,m}(i) - H_{on\_lift\,m}(i) \right|}{0.8 \sum_{i=1}^{N_{lift\,m}} W_{rated}(m) g \left| H_{off\_lift\,m}(i) - H_{on\_lift\,m}(i) \right|} \end{cases} \tag{8}$$

Case Study

Evaluation Index. The performance of the scheduling algorithm is measured by the energy consumption of the elevator under its control. Therefore, the experiment uses the energy consumption of the elevator as the evaluation index, and calculates the energy consumption $E_{initial}$ of the elevator under the original service unit, and the operating energy consumption E_{algol} optimized by the scheduling algorithm.

The energy consumption of the elevator operation includes the energy consumption of the elevator start/stop and the energy consumption of the running process. To simplify the calculation, it is assumed that the energy consumption $E_{on/off}$ of the elevator is set/stopped each time, so the start/stop energy consumption $E_{on/off}$ is only related to the number of elevator starts and stops. And the process energy consumption is affected by the running load. It can be obtained that the original service unit elevator operating energy consumption $E_{initial}$ is:

$$E_{initial} = N_{service} E_{on/off} + \sum_{i=1}^{N_{service}} W(i) g \left| H_{off}(i) - H_{on}(i) \right| \tag{9}$$

The operational energy consumption E_{algol} optimized by the scheduling algorithm needs to be calculated according to the secondary adjustment and the service unit after the additional waiting time. Increase the start time $t_{on\_lift\,m}(i)$ of the service unit $U_{lift\,m}$ after the second adjustment to $t_{on\_lift\,m}(i) = t_{on\_lift\,m}(i) + t_{add}(m)$, if the service unit $U_{lift\,m}(j)$ satisfies:

$$\begin{cases} i < j \\ t_{on\_lift\,m}(i) \ge t_{on\_lift\,m}(j) \\ L_{on\_lift\,m}(i) = L_{on\_lift\,m}(j) \end{cases} \tag{10}$$

Then, the service units $U_{lift\,m}(i)$ and $U_{lift\,m}(j)$ are combined to obtain $U'_{lift\,m}(i)$ and $U'_{lift\,m}(j)$. Then the service unit $U'_{lift\,m}(j)$ repeats the formula (10) until all the service units are traversed, and finally the service unit set $U'_{lift\,m}$ is obtained, so the running energy consumption E_{algol} is optimized after the scheduling algorithm is:

$$E_{algol} = \sum_{m=1}^{N_{lift}} \left(N'_{service\,lift\,m} E_{on/off} + \sum_{m=1}^{N'_{service\,lift\,m}} W'_{lift\,m}(i) g \left| H'_{off\_lift\,m}(i) - H'_{on\_lift\,m}(i) \right| \right) \tag{11}$$

Parameter Setting and Result Analysis. Parameter setting: $N_{floor} = 12$, $H_x = 3(x-1)$, $N_{lift} = 2$, $N_{rated} = 12$, $W_{rated} = 900$, $t_{door} = 6$, $t_{swap} = 1.5$, $W_{solo} = 75$, $E_{on/off} = 60$, $g = 9.8$. Table 1 shows the original elevator service unit, where $N_{service} = 60$.

Table 1 Original Elevator Service Unit (9:00-10:00)

i	1	2	3	4	5	6	7	8	9
$t_{on}(i)$	00:00	00:22	00:52	01:11	01:33	01:48	02:22	02:48	03:11
$t_{off}(i)$	00:12	00:26	01:00	01:19	01:41	02:00	02:38	03:04	03:19
$H_{on}(i)$	0	6	18	24	30	21	15	0	15
$H_{off}(i)$	9	9	24	27	21	12	3	12	21
$W(i)$	755	611	607	156	380	526	457	911	756
...									
i	52	53	54	55	56	57	58	59	60
$t_{on}(i)$	46:06	48:31	52:10	52:32	54:34	55:03	55:18	55:30	57:55
$t_{off}(i)$	46:42	48:59	52:26	52:52	54:58	55:11	55:22	55:58	58:15
$H_{on}(i)$	27	0	27	15	0	18	24	24	0
$H_{off}(i)$	0	21	15	0	18	24	21	0	15
$W(i)$	152	376	231	226	0	77	226	529	158

Table 2 Elevator 1 final service unit (9:00-10:00)

i	1	2	3	4	5	6	7	8	9
$t_{on}(i)$	00:30	02:18	02:52	03:18	03:41	05:27	06:34	06:58	08:20
$t_{off}(i)$	00:42	02:30	03:08	03:34	03:49	05:35	06:50	07:06	08:28
$H_{on}(i)$	0	21	15	0	15	21	0	12	21
$H_{off}(i)$	12	12	0	12	21	12	15	21	15
$W(i)$	755	526	457	911	756	453	831	603	378
...									
i	27	28	29	30	31	32	33	34	35
$t_{on}(i)$	37:51	44:05	45:50	46:36	49:01	53:02	55:04	56:00	58:25
$t_{off}(i)$	38:19	44:17	46:30	47:12	49:29	53:22	55:28	56:28	58:45
$H_{on}(i)$	0	21	12	21	0	15	0	21	0
$H_{off}(i)$	21	12	21	0	21	0	21	0	15
$W(i)$	453	154	0	152	376	226	0	529	158

Table 3 Elevator 2 Final Service Unit (9:00-10:00)

i	1	2	3	4	...	10	11	12	13
$t_{on}(i)$	01:10	01:51	04：13	04；40		13:23	39:00	52:28	55:21
$t_{off}(i)$	01:18	01:59	04：21	04:48		13:31	39:40	52:44	55:29
$H_{on}(i)$	18	30	24	30	...	24	30	24	18
$H_{off}(i)$	24	18	30	24		30	9	18	24
$W(i)$	607	380	227	156		156	153	231	77

From the formula (1) to the formula (3), the 1-12 equivalent load of the floor is 8486, 1288, 1216, 3339, 4707, 3867, 2877, 6518, 3342, 2139, 2271, 1668 kg, combined with the formula (4). The total control domain of the elevator is D={1,4,5,6,7,8,9,11}, so each elevator control domain consists of 4 floors. According to equations (6) and (7), the control fields of elevators 1 and 2 are 1, 5, 6, 8, and 4, 7, 9, and 11, respectively. After the elevator service unit is adjusted twice, the additional waiting times of the elevators 1 and 2 are respectively 30 s and 18 s according to formula (8) and (9). Thereby, the final service unit adjusted by each elevator service unit according to the extra waiting time size can be obtained.

According to formula (9) and (11), the energy consumption of the elevator under the original service unit is 202,3426.5 J, and the energy consumption under the control of the scheduling algorithm is 1995135.1 J. Therefore, energy is saved only within 1 hour from 9:00 to 10:00. The elevators 1 and 2 under the control of the priority elevator dispatching algorithm saved a total energy of 2,8291.4 J, accounting for 1.4% of the original operating energy consumption.

Conclusion

This paper proposes an energy-saving priority elevator scheduling algorithm. Based on statistical analysis, the equivalent load of each floor is calculated in different time periods to realize the selection of the elevator total control domain and the allocation of each elevator control domain to improve the elevator resource utilization effect. The dynamic extra waiting time is introduced, which improves elevator full load rate and reduces elevator energy consumption. Experiments show that with the elevator scheduling algorithm, only 2 elevators run for 1 hour, and the energy consumption saves 28291.4 J, and the optimization ratio can reach 1.4%.

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