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Elevator Traffic Flow Model Based On Dynamic Passenger Distribution

Zhifeng Pan, Fei Luo, Yuge Xu
College of Automation Science & Engineering
South China University of Technology
Guangzhou, China
folsompan@163.com

***Abstract*—Elevator traffic flow is fundamental in elevator group control systems. Accurate elevator traffic flow model is crucial to the elevator system configuration and the dispatching of elevator group control systems, especially to the elevator system configuration in yet-to-be-commissioned new building. Based on dynamic passenger distribution of building, importing the over-loading modulus of the passenger distribution capability of building, a new elevator traffic flow model is found and has a new form of origin vector and origin−destination matrix. The traffic flow data which based on the new traffic flow model shows that the new model is practical and useful. Simulation test also shows that the elevator traffic flow based on new model is more reasonable than the traditional elevator traffic flow model.**

Keywords-elevator group control systems; elevator traffic flow model; dynamic passenger distribution

I. INTRODUCTION

With the development of high-rise buildings, the demand for elevator group control systems has been increased rapidly. The service quality and performance level for the elevator group control systems have also been increased. As a result the elevator traffic flow model is one of the most important factors that affect the performance of the whole elevator system. Accurate elevator traffic flow model is very significant to the elevator system configuration and the elevator dispatching policies in different traffic situations, especially in yet-to-be-commissioned new building. It will greatly improve service quality and system performance in elevator group control systems.

Butcher and Wilson [1] (1993, p. 3-2) pointed out that "the difficulty in planning lift installation is not in calculating its probable performance, but in estimating the likely passenger demand". Researchers have done some work on the elevator traffic model. In recent years, artificial neural network algorithm [2], least squares support vector machines (LS-SVMs) [3], wavelet neural networks [4] have been applied to elevator traffic prediction. These means have gained some achievements, but they all need the real elevator traffic flow data to train their model, if the building is a yet-to-be-commissioned new building, it is impossible to acquire the real elevator traffic flow data and it is incompetent for these means to make suitable elevator system configuration and elevator dispatching policies. Some other researchers presented some elevator traffic models [5] [6], they are all based on Monte Carlo method, here we name them traditional elevator traffic flow model. However, because they all based on static passenger distribution of building, they have fallacious origin vector and origin − destination matrix and will generate unreasonable traffic flow: after a long time of up-peak traffic pattern, there may be more passengers on one floor than the passenger distribution capability of that floor; after a long time of down-peak traffic pattern, the number of passenger who has left one floor may be more than the passenger distribution of that floor, at that time, the number of people stay in that floor is negative.

Based on dynamic passenger distribution of building, importing the over-loading modulus of the passenger distribution capability of building, a new elevator traffic flow model is found and has a new form of origin vector and origin−destination matrix. With the simulation and analysis, it is proved that the new elevator traffic flow model is more reasonable and accurate.

This paper is organized as follows:

Section Ⅱ presents the traditional elevator traffic flow model. Section Ⅲ introduces the new form of origin vector and origin−destination matrix. Section Ⅳ shows the new elevator traffic flow model. Finally, some discussions and conclusions end this paper.

II. TRADITIONAL ELEVATOR TRAFFIC FLOW MODEL

Passenger arrivals are random events, they are assumed to Poisson distribution.

$$p = \frac{(\lambda T)^n e^{-\lambda T}}{n!} \qquad (v = 0,1,\cdots) \tag{1}$$

Here, p denotes the probability of that there are n passengers arrive during the time T ; λ is the rate of passenger arrivals.

So passenger arrivals time is as follow:

$$t_0 = t_b \quad t_i = t_{i-1} - \frac{\ln(r)}{\lambda} \qquad (i = 1,2,\cdots) \tag{2}$$

Where the t_b is the beginning time; t_i is the arrival time of the ith passenger; r is a random data between 0 to 1.

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It is also a random event that passengers come from which floor and go to which floor. Two parameters must be introduced, including $ORIGIN$ vector (ratio vector of floor of passenger origin) and OD matrix (ratio matrix of floors of passengers' origin and destination). Given the parameter of the traffic pattern: A, B and C (A denotes the percentage of passengers coming into the lobby, B means the percentage of passengers departing from the lobby, C is the percentage of rest passengers), $ORIGIN$ vector can be gained as follow:

$$\begin{cases} ORIGIN(1) = 100A \\ ORIGIN(i) = 100(B+C)\rho_i \\ (i = 2,3,\cdots,N) \end{cases} \tag{3}$$

$$\rho_i = POP(i) \Big/ \sum_{i=2}^{N} POP(i) \tag{4}$$

$POP(i)$ denotes the passenger distribution capability of the ith floor; N is the floor number of building; $ORIGIN(i)$ means the ith data of ratio vector of floor of passenger origin.

Similarly, OD matrix is given by:

$$\begin{array}{c} \\ \textit{from} \\ \textit{the} \\ \textit{ith} \\ \textit{floor} \end{array} \left\{ \begin{array}{c} \\ 1 \\ 2 \\ \vdots \\ N \end{array} \right. \begin{array}{c} \overbrace{\begin{array}{cccc} 1 & 2 & \cdots & N \end{array}}^{\textit{to the jth floor}} \\ \begin{pmatrix} OD(1,1) & OD(1,2) & \cdots & OD(1,N) \\ OD(2,1) & OD(2,2) & \cdots & OD(2,N) \\ \vdots & \vdots & \vdots & \vdots \\ OD(N,1) & OD(N,2) & \cdots & OD(N,N) \end{pmatrix} \end{array} \tag{5}$$

$$OD(1,j) = \begin{cases} 0 & j = 1 \\ 100\rho_j & j \neq 1 \end{cases} \tag{6}$$

$$OD(i,1) = \begin{cases} 0 & i = 1 \\ \dfrac{B}{B+C}100 & i \neq 1 \end{cases} \tag{7}$$

$$OD(i,j) = \begin{cases} 0 & i = j \\ \dfrac{C}{B+C}100\rho_{ij} & i \neq j \end{cases} \tag{8}$$

$$\rho_{ij} = POP(j) \Big/ \sum_{\substack{K=2 \\ K\neq j}}^{N} POP(K) \tag{9}$$

III. A NEW FORM OF $ORIGIN$ VECTOR AND OD MATRIX

Based on static passenger distribution of building, the traditional elevator traffic flow model has fallacious ORIGIN vector and OD matrix and will generate unreasonable traffic flow: after a long time of up-peak traffic pattern, there may be more passengers on one floor than the passenger distribution capability of that floor; after a long time of down-peak traffic pattern, the number of passenger who has left one floor may be more than the passenger distribution of that floor, at that time, the number of people stay on that floor is negative.

For example:

Case 1: set the ORIGIN vector:

A building of ten floors (the passenger distribution of every floor is the same). When there are 6 people on the 6th floor and 1 people on the 2nd floor, it is unreasonable that these two floors have the same ratio of passengers' origin. The ratio of the 6th floor should be higher. Further more, if there are 5 people on the 6th floor and no people on the 2nd floor, it is obviously wrong that these two floors have the same ratio of passengers' origin. There is no any traffic flow origin from the 2nd floor.

Case 2: set the OD matrix

A building of ten floors (the capability of passenger distribution of every floor is 10). When there are 9 people on the 6th floor and 1 people on the 2nd floor, it is fallacious that these two floors have the same ratio of passengers' destination. The ratio of the 2nd floor should be higher. More over, if there are 10 people on the 6th floor and 2 people on the 2nd floor, it is obviously wrong that these two floors have the same ratio of passengers' destination. There is not any traffic flow destination to the 6th floor.

Through above analysis, deficiencies of the traditional elevator traffic flow model are obvious. After doing some research on the real elevator traffic flow, some conclusions can be drawn as follow:

First, ORIGIN vector is determined by the proportion between the number of people stay on every floor and the total number of people staying in the building.

Equation (4) can be revised as follow:

$$\rho_i = PIF(i) \Big/ \sum_{i=2}^{N} PIF(i) \tag{10}$$

$PIF(i)$ denotes the number of people stay on the ith floor ; N is the floor number of building.

Second, origin−destination matrix is determined by the proportion between the actual passenger distribution capability of every floor and the actual passenger distribution capability of building.

In fact, different floors with the same configuration have different passenger distribution capability for different purposes; it is illegitimate to denote the passenger distribution capability with only one parameter. Here, POP is used to denote the rating passenger distribution capability (relating to the area of the floor) and φ (between 0 to 1) is used to denote the over-loading modulus of the passenger distribution capability (relating to the purpose of the floor).

As a result, Equation (6) can be revised as follow:

$$OD(1,j)=\begin{cases}0 & j=1\\ 100\xi_j & j\neq 1\end{cases} \tag{11}$$

$$\xi_j=\frac{POP(j)*(1+\varphi(j))-PIF(j)}{\sum_{K=2}^{N}\left[POP(K)*(1+\varphi(K))-PIF(K)\right]} \tag{12}$$

And revise (8), (9) to:

$$OD(i,j)=\begin{cases}0 & i=j\\ \frac{C}{B+C}100\eta_{ij} & i\neq j\end{cases} \tag{13}$$

$$\eta_{ij}=\frac{POP(j)*(1+\varphi(j))-PIF(j)}{\sum_{\substack{K=2\\K\neq j}}^{N}\left[POP(K)*(1+\varphi(K))-PIF(K)\right]} \tag{14}$$

Where $PIF(i)$ denotes the number of people stay on the ith floor, $POP(j)$ denotes the rating passenger distribution capability of the jth floor, $\varphi(j)$ means the over-loading modulus of the passenger distribution capability of the jth floor, N is the floor number of building.

IV. ELEVATOR TRAFFIC FLOW MODEL BASED ON DYNAMIC PASSENGER DISTRIBUTION

Passenger arrival time model is the same as the one of the traditional elevator traffic flow model, referring to (1), (2).

$ORIGIN$ vector can be gained as follow:

$$\begin{cases}ORIGIN=100A\\ ORIGIN(i)=100(B+C)\rho_i\\ (i=2,3,\cdots,N)\end{cases} \tag{15}$$

$$\rho_i=PIF(i)\Big/\sum_{i=2}^{N}PIF(i) \tag{16}$$

$PIF(i)$ denotes the number of people stay the ith floor ; N is the floor number of building; $ORIGIN(i)$ means the ith data of ratio vector of floor of passenger origin.

Similarly, OD matrix is given by:

$$\begin{pmatrix}OD(1,1) & OD(1,2) & \cdots & OD(1,N)\\ OD(2,1) & OD(2,2) & \cdots & OD(2,N)\\ \vdots & \vdots & \vdots & \vdots\\ OD(N,1) & OD(N,2) & \cdots & OD(N,N)\end{pmatrix} \tag{17}$$

$$OD(1,j)=\begin{cases}0 & j=1\\ 100\xi_j & j\neq 1\end{cases} \tag{18}$$

$$\xi_j=\frac{POP(j)*(1+\varphi(j))-PIF(j)}{\sum_{K=2}^{N}\left[POP(K)*(1+\varphi(K))-PIF(K)\right]} \tag{19}$$

$$OD(i,1)=\begin{cases}0 & i=1\\ \frac{B}{B+C}100 & i\neq 1\end{cases} \tag{20}$$

$$OD(i,j)=\begin{cases}0 & i=j\\ \frac{C}{B+C}100\eta_{ij} & i\neq j\end{cases} \tag{21}$$

$$\eta_{ij}=\frac{POP(j)*(1+\varphi(j))-PIF(j)}{\sum_{\substack{K=2\\K\neq j}}^{N}\left[POP(K)*(1+\varphi(K))-PIF(K)\right]} \tag{22}$$

$POP(j)$ denotes the rating passenger distribution capability of the jth floor, $\varphi(j)$ means the over-loading modulus of the passenger distribution capability of the jth floor.

V. SIMULATIONS AND RESULTS

Based on the two kinds of elevator traffic flow model, two elevator traffic flows of ten floors are generated according to traffic pattern in the Table I, and the number of people stay on the 6th floor of two model are compared:

TABLE I. TRAFFIC FLOW PATTERN

Traffic pattern	A /%	B /%	C /%	Traffic flow amount / persons/min	Time /s
Up-peak	80	10	10	30	288
Inter-floor	35	35	30	15	288
Down-peak	10	80	10	35	288

Here, A denotes the percentage of passengers come into the lobby; B means the percentage of passengers depart from the lobby; C is the percentage of rest passengers.

The traditional traffic flow model:

Passenger distribution capability for every floor is 18 and there are 5 people at the beginning.

Elevator traffic flow data based on the traditional model is shown as Table II:

TABLE II. ELEVATOR TRAFFIC FLOW BASED ON THE TRADITIONAL MODEL

Ar-Time /s	O /f	D /f	Ar-Time /s	O /f	D /f	Ar-Time /s	O /f	D /f
0.4	1	9	43.6	1	9	73.1	1	6
0.5	1	3	47.5	1	5	74.5	1	7
6.6	1	4	49.7	1	10	75.9	1	10
10.7	1	4	49.7	1	4	77.4	1	5
16.0	1	6	50.8	1	8	79.4	1	10
18.0	3	1	51.2	1	10	84.8	1	4
18.3	8	1	53.6	7	1	88.1	3	4
22.9	1	2	58.2	4	1	99.1	1	7
28.7	1	4	60.0	1	7	100.2	1	8
31.9	1	6	60.7	1	9	103.4	1	4
33.6	1	4	63.4	1	2	103.7	1	6
35.7	1	10	65.2	1	7	104.9	1	7
36.0	3	1	66.9	1	10	107.8	1	6
36.2	1	6	67.6	1	2	109.0	1	7
37.9	1	4	70.5	1	8	110.0	1	3
38.2	1	9	70.9	1	9	111.5	1	2
39.1	9	7	71.0	1	10	112.1	1	8
39.8	1	4	71.7	1	4	112.8	1	4
41.4	1	9	71.8	1	3	113.0	1	7
43.5	1	5	72.6	1	9	…	…	…

Where Ar-Time denotes the arrive time of passenger, O denotes the origin floor and D denotes the destination floor.

The number of people stay on the 6th floor is shown as Fig 1:

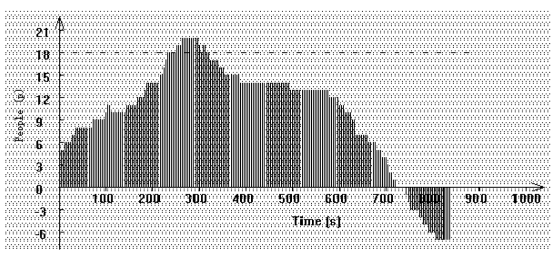

Figure 1. The number of people stay on the 6th floor based on traditional model

The new traffic flow model:

The rating passenger distribution capability of every floor, $POP = 15$, the over-loading modulus of the passenger distribution capability of the every floor, $\varphi = 0.2$, and there are 5 people at the beginning.

Elevator traffic flow data based on the new model is shown as Table III:

TABLE III. ELEVATOR TRAFFIC FLOW BASED ON THE NEW MODEL

Ar-Time /s	O /f	D /f	Ar-Time /s	O /f	D /f	Ar-Time /s	O /f	D /f
0.9	1	6	61.5	1	6	108.3	1	5
2.0	4	1	62.4	1	5	109.0	1	8
3.6	1	6	62.9	1	4	109.8	1	7
7.9	1	2	66.9	1	6	110.2	5	1
15.5	1	7	67.6	1	3	113.7	1	8
16.6	1	7	70.9	6	3	114.8	1	3
27.7	1	2	74.5	1	10	115.3	1	3
29.0	1	8	74.7	10	4	118.2	1	7
32.1	6	1	78.6	1	10	120.6	1	3
35.3	1	4	79.9	1	8	125.0	1	6
36.2	2	5	80.9	1	9	125.4	1	7
38.8	1	2	82.7	8	1	125.7	2	1
41.5	1	9	83.5	4	9	128.5	1	4
42.9	1	2	88.0	1	6	129.1	1	4
47.3	1	2	88.0	1	3	131.7	1	2
50.4	7	2	90.1	1	6	133.9	5	10
51.7	1	10	92.7	1	8	135.9	6	1
56.2	1	6	96.2	1	2	138.5	1	8
59.9	1	10	101.6	1	10	145.2	1	7
61.2	1	9	103.4	8	1	…	…	…

Where Ar-Time denotes the arrive time of passenger, O denotes the origin floor and D denotes the destination floor.

The number of people stay on the 6th floor is shown as Fig 2:

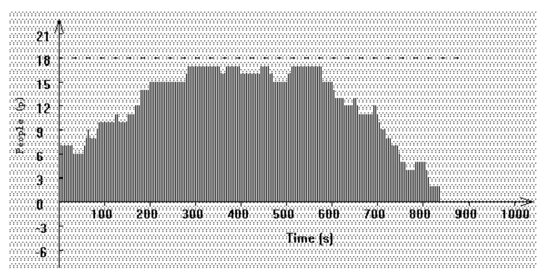

Figure 2. The number of people stay on the 6th floor based on new model

Comparing the Fig 1 to Fig 2, the differences between them are obvious: in the traditional model, since the accumulation of people in the up-peak traffic, the number of people stay in the 6th floor is more than the rating passenger distribution capability (18) at about 300 second; and because of the people reduction in the down-peak traffic, the number of people stay on the 6th floor turns to negative at about 800 second. However, this doesn't happen in the new traffic flow model. The new traffic flow model can generate more reasonable and accurate traffic flow than the traditional traffic flow model.

VI. CONCLUSION

Accurate elevator traffic flow model is crucial to the elevator system configuration and the choice of elevator group control policy. Elevator traffic flow prediction is probably more effective in choosing elevator group control policy. However, in the elevator system configuration, especially in yet-to-be-commissioned new building, the elevator traffic flow model is more useful. The elevator traffic flow model based on dynamic passenger distribution of building is of considerable practical value.

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