# Dynamic Partition of Elevator Group Control System with Destination Floor Guidance in Up-peak Traffic

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*Abstract*—**This paper presents a new modeling of elevator group intelligent scheduling system with destination floor guidance. The traditional input mode of separate hall call registration and the destination selection is improved to a single-input mode. On this basis, dynamic partition method in up-peak traffic is studied. This method means dynamically adjust division of floor region based on flow rate and distribution of passenger. Dynamic programming algorithm is used to solve this problem. Through regroupment and classification for ensemble of hall call communication, prediction of multi-objective evaluation items is proposed. Fuzzy Neural Network is constructed and applied further to realize the optimal scheduling policy. Simulated results show that the presented elevator model is effective and the optimized scheduling algorithm has advantaged improvement for overall performance of elevator system.**

*Index Terms*—**elevator group control system, destination floor guidance, dynamic programming, dynamic partition, up-peak traffic**

## I. INTRODUCTION

Elevator group control system (EGCS) is a typical discrete event dynamic system which modeling, analysis, and optimization are complex to some certain extent. The dilemma of the traditional EGCS with scheduling policy is imperfection and nondeterminacy of state information, randomness and nonlinearity of system, diversity and of control objective. Consequently, although some scheduling algorithms to point against traditional elevator passenger flow pattern have some effect to improve the system performance such as the minimization average waiting time algorithm [1], zoning algorithm [2], and Artificial Intelligent control techniques [3], they cannot completely resolve the restriction of traditional system itself. However EGCS with destination floor guidance (DFG) can effectively resolve such dilemma. It fundamentally changes the basic pattern to elevator passenger flow management and challenges the traditional elevator traffic management mode and the traditional traffic analysis methods. Through maximized utilization for the integrated and reliable hall call information it can effectively reduce the system's travelling disturbance and optimize scheduling policy. At the present time, many scholars have done some systemic researches on the algorithm of single-car elevator system with DFG [4-5]. Through their study, the operation efficiency of the single-car elevator system was improved remarkably under heavy passenger flow patterns. Aiming at EGCS with DFG, many scholars have put forward multi-objective control method. Through their research it is obvious that EGCS with DFG has its distinct advantage and the scheduling algorithm of EGCS was optimized by combinatorial optimization to objective function and intelligent algorithm such as cellular automation theory and Fuzzy Neural Network (FNN).

Besides, up-peak traffic means the most or entire passengers enter in elevators from entrance hall and transport upwards in the building and its characteristic is that traffic intensity is strong and passenger flow is concentrated. Up-peak traffic is a very important traffic pattern and it is also main pattern used for measuring the performance of EGCS. Thus the research for EGCS with DFG is of extremely important significance in up-peak traffic. But the research in this field is preliminary. The validity and optimization should be studied in-depth concerning modeling and scheduling policy of EGCS with DFG.

In this study, the modeling EGCS with DFG is built up. Dynamic programming algorithm is used to solve the problem of dynamic partition for EGCS in up-peak traffic. Predication algorithm of evaluation items is designed as the inputs of FNN. Through the construction of FNN the optimal scheduling policy could be selected and the optimal value function of dynamic programming could be validated. Simulation experiment results show that this

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algorithm can realize harmonious and effective scheduling control in up-peak passenger flow pattern.

## II. ELEVATOR GROUP SYSTEM (EGCS) WITH DESTINATION FLOOR GUIDANCE (DFG)

The management pattern of passenger flow information to traditional EGCS adopts twice-input method for hall call application which means direction selection of hall call registration outside the elevator halls and destination selection inside the elevator halls. This method leads to that the destination floor information of hall call application is uncertain before the passengers enter the elevator and the amount of waiting passengers for each hall call application is also unpredictable. This easily results in the phenomenon of "crowding centralization" and "over-capacity to loss", especially in up-peak traffic, which reduces the efficiency of scheduling policy. DFG of EGCS is designed to amalgamate the hall call registration and the destination selection to be a single-input mode with specified floor figure buttons outside the elevator halls for realizing the one-off management which is called destination call registration. Based on it, the system can attain nearly complete and reliable information aggregation in advance, which includes the information such as origination floor, destination floor and the number of passengers for the same destination call registration. Meantime at one hand the particular guidance function can indicate the assigned elevator ID timely, at the other hand it can settle running route. So that passengers cannot randomly, whereas systematically enter into the specified elevator in terms of the systemic notification. It is obvious that EGCS with DFG has distinct improvement in terms of branching off the peak passenger flow and reduce the elevator congestion degree. The scheduling model of EGCS with DFG is shown as Fig. 1.

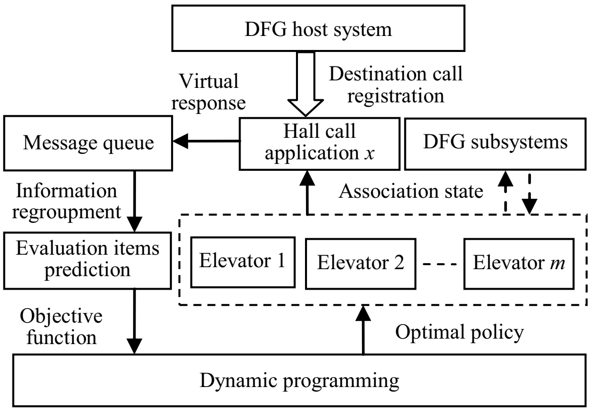

Figure 1. Scheduling model of EGCS with DFG.

As the show of Fig. 1, DFG system includes the host system and the subsystems. DFG host system realizes the function of collection, storage, and management for destination call registrations and produces a relevant hall call application *x* to every valid destination call registration. DFG subsystems realize the operation and scheduling control for elevator group.

In EGCS with DFG, the implementation procedures to destination call registration are formulated as follows:

(1) At any time $t_n$, when a destination call registration which is from floor *i* to floor *j* appears, DFG host system collects and stores it immediately then produces a hall call application *x*.

(2) The assignment of hall call application *x* is responded virtually and then joined in the message queue.

(3) Dynamic partition based on all the hall call applications which have not been responded yet by the means of information regroupment and classification, evaluation items prediction, and dynamic programming.

(4) According to the optimal policy and the destination floor *j* of hall call application *x*, elevator *k* is selected and exported. Then the output and the hall call application *x* are shielded immediately to wait for the next destination call registration.

(5) According to the feedback of assignment information *k*, DFG subsystems convert the relevant scheduling status of elevator *k*. Then procedure turns into the pretreatment phase.

(6) After elevator *k* arrives at the floor *i*, DFG subsystems amend the relevant scheduling status of elevator *k*. Then procedure turns into the executing phase.

(7) After elevator *k* arrives at the floor *j*, DFG subsystems reverts the relevant scheduling status of elevator *k* and then releases the memory space of hall call application *x*.

## III. Dynamic Programming Partition

In the traditional up-peak traffic mode, each elevator serves all the floors which inevitable leads to the number of required stop is huge, the round trip time is long, and the efficiency of passenger transporting is low during the operation of each elevator. In order to optimize the scheduling policy, the conception of partition is proposed which means each elevator only serves on some certain concentrated floors of a region, also the elevators serving high-rise regions provide the high-speed round trip services between the lowest floor of assigned region and the entrance hall.

At present, there are three main methods for the partition of elevators in high-rise buildings: static partition, planning time partition, and dynamic partition. Static partition works through settling a fixed group of elevators to serve on some certain adjacent floors of a region. Planning time partition works through experience to temporarily arrange elevators to serve on the different regions as the predetermined time. While the partition region of dynamic partition lies on the distribution of passenger flow which is adjusted dynamically with the changes of passengers flow. In regarding to the up-peak traffic, the distinct characteristic is that the one-way passenger flow is significant, the inter-floor traffic is rare, and they have the common initial floor. When the change of passenger flow is intense, the steady partition algorithm is not fit for such condition and its scheduling policy is less effective. While dynamic partition is perfectly adaptable to the characteristic of up-peak traffic, through concentrated service the number of required stop is decreased and the passenger waiting and journey time is reduced.

Chan and Lam, and others proposed analytic method to resolve the problem of dynamic partition [6], but because of the complexity of objective function, the computation of partial derivative is intensive and the real-time performance is limited. Search algorithm adopts numerical solution through a series of iteration to generate the sequence of points, and then approach optimization step by step [7]. Search algorithm simplified the computing process which makes programming easier and computing speed quicker than analytic method, but in that each point of search algorithm needs to be searched, the time of search is too many and the amount of computing is large. In this paper, we propose dynamic programming algorithm based on ballman and others' principle of optimality to resolve the problem of dynamic partition in up-peak traffic. Dynamic programming only solves the key paths of every step, not need to search all the paths, so it can obtain the overall optimal path more efficiently.

In order to explain the idea of dynamic partition using dynamic programming algorithm, the modeling of dynamic programming of EGCS with DFG is given as Fig. 2.

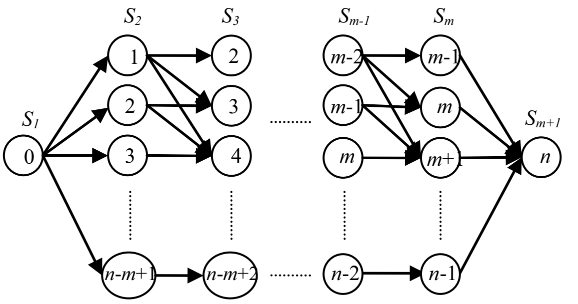

Figure 2. Modeling of dynamic programming of EGCS with DFG.

As the show of Fig. 2, the EGCS with DFG consists of *n* floors and *m* elevators. According to the spatial feature of dynamic partition in up-peak traffic, namely region, to divide the step of dynamic programming, each region is a step and each elevator serves on a region. The initial floor is 0 expressed by $S_1$ and the highest floor is *n* expressed by $S_{m+1}$, so from $S_1$ to $S_{m+1}$ there are *m* steps. Using the letter *k* to represent step variable, that is $k=1,2,...,m$.

The state of dynamic programming model is the lowest floor of assigned region of each step. The set of value of state variable in the $k^{\text{th}}$ step is $X_k$, and $x_k$ represents the determined state value of the $k^{\text{th}}$ step. The region represented by the $k^{\text{th}}$ step is the interval $[x_k, x_{k+1}]$ and the set of state variable in each step is show as follows:

$$\begin{aligned} &X_1=\{0\} \\ &X_2=\{k \mid 1\le k\le n-m+1\} \\ &X_3=\{k \mid 2\le k\le n-m+2\}\cdot \\ &\quad\vdots \\ &X_m=\{k \mid m-1\le k\le n-1\} \\ &X_{m+1}=\{n\} \end{aligned} \tag{1}$$

When the state of each step is determined, there are various choices transferring to a certain state of next step and this choice is called decision. Using $u_k(x_k)$ to represent the decision variable of state $x_k$ in the $k^{\text{th}}$ step. All the paths between the $k^{\text{th}}$ step and the $(k+1)^{\text{th}}$ step composes the set of decision variable $U_k(x_k)$. Giving the value of $x_k$ and $u_k(x_k)$, the state in the $(k+1)^{\text{th}}$ step can be determined through equation of state transition.

$$x_{k+1}=T_k(x_k,u_k(x_k))\,. \tag{2}$$

The dynamic partition problem of EGCS is actually an optimal control problem which purpose is to find a policy making the scheduling policy optimal. The sequence composed by decisions is called policy. Using $p_{1n}(x_1)$ to represent the entire decision process from the initial state $x_1$, the equation is that $p_{1m}(x_1)=\{u_1(x_1),u_2(x_2),...,u_m(x_m)\}$, the policy of rear part decisions is represented as $p_{km}(x_k)$ from the state $x_k$ of the $k^{\text{th}}$ step to the final state $x_m$ and the equation is that $p_{km}(x_k)=\{u_k(x_k),u_{k+1}(x_{k+1}),... ,u_m(x_m)\}$.

Objective function is the quantitative index to measure the superiority and inferiority of policy. Using $V_{km}(x_k, p_{km}(x_k))$ to represent objective function from the $k^{\text{th}}$ step to the final state $x_m$. In the up-peak traffic, objective function should do its utmost to correspond with passenger demand, hence through analyzing hall call communication, selecting and prediction fit evaluation items, and constructing FNN to ensure that the policy determined by objective function not only fulfill centralization and homogenization of passenger service in all the regions, but also maximize the improvement of overall service quality of EGCS. Thus the optimization objective function is optimal value function which is shown in (3).

$$f_k(x_k)=\underset{u_k(x_k)\in U_k(x_k)}{opt}(V_{km}(x_k,p_{km}(x_k)))\,. \tag{3}$$

In up-peak traffic, the basic concepts of dynamic programming partition are that recursive optimization backward begins from the final state $S_{m+1}$ step by step, that means the optimal path from a certain state $S_k$ to $S_{m+1}$ would be involved in the computation of next step, in other words, the resolving of each sub-problem uses the optimal solution of previous sub-problem, then the optimal solution of the last sub-problem is just the optimal value of dynamic programming. In conclusion, the basic function of dynamic programming is shown in (4).

$$\begin{cases} f_k(x_k)=\underset{u_k(x_k)\in U_k(x_k)}{opt}(v_k(x_k,u_k)+f_{k+1}(x_{k+1})) \\ \qquad k=m,m-1,\cdots,1 \\ f_{m+1}(x_{m+1})=0 \end{cases}\,. \tag{4}$$

Taking Fig. 2 for example, at first it need to acquire the optimal path from $S_m$ to $S_{m+1}$. There are *n-m+1* states in the $m^{th}$ step and each state has only one path to $S_{m+1}$, so they are all involved in the computation of next step from $S_{m-1}$ to $S_{m+1}$. There are also *n-m+1* states in the $(m-1)^{th}$ step, hence there must be *n-m+1* paths to be involved in the next step. But between $S_{m-1}$ and $S_{m+1}$ there are many paths, e.g. from $S_{m-1}(1)$ to $S_{m+1}$ there are $n-m+1$ alternative paths, it must exist a path is the optimal one which would be selected to the next step. Likewise, there are $n-m$ alternative paths from $S_{m-1}(2)$ to $S_{m+1}$, and it can select only one path to the next step etc. According to this method, finally it can obtain an optimal path from $S_1$ to $S_{m+1}$ which are also the optimal partition points in up-peak traffic.

## IV. ENSEMBLE OF HALL CALL COMMUNICATION

The ensemble of hall call communication mainly includes hall call application information and elevator running state information. The characteristics of elevator running state determine its own parameters. Simultaneously, all elevator running states are returned to hall call application in real time as the influence factors of scheduling policy. The entire cycle period of hall call application starts when the destination call registration is produced, then passes through the period of scheduling response and execution until the course is over. The parameters of hall call application are determined by the characteristic of the entire cycle course. The parameters of elevator running state and hall call application are shown in Table I and Table II.

TABLE I.
RUNNING STATE PARAMETERS OF ELEVATOR *M*

| Parameter | Specification |
|---|---|
| $d_m$ | Running direction of elevator *m* |
| $f_m$ | Real-time floor ID of elevator *m* |
| $t_{ma}(i)$ | Time when elevator *m* arrives at floor *i* |
| $t_{ml}(i)$ | Time when elevator *m* leaves from floor *i* |
| $n_{me}(i)$ | Number of passengers whose origination floor is *i* for elevator *m* |
| $n_{mo}(i)$ | Number of passengers whose destination floor is *i* for elevator *m* |
| $n_{mc}$ | Real-time number of carrying passengers of elevator *m* |
| $C_m(i,j)$ | Scheduling state from floor *i* to floor *j*, $i,j \in n$,<br>(*n* is floor ID) |

TABLE II.
PARAMETERS OF HALL CALL APPLICATION *X*

| Parameter | Specification |
|---|---|
| $f_{xb}$ | Origination floor ID of hall call application *x* |
| $f_{xt}$ | Destination floor ID of hall call application *x* |
| $t_{xb}$ | Occurring time of hall call application *x* |
| $n_x$ | Number of passengers for hall call application *x* |
| $ID_x$ | Assignment ID of hall call application *x* |

From the Table I and Table II, it is known that hall call application *x* is related to elevator *m* by $ID_x$ that means $ID_x=m$, and converts the scheduling state $C_m(f_{xb}, f_{xt})$ of elevator *m*. The parameters $n_{me}(i)$ and $n_{mo}(i)$ can be acquired by consulting $n_x$ of hall call application *x* whose parameters are $f_{xb}=i$, $f_{xt}=i$ and then $n_{mc}= n_{(m-1)c}+ n_{me}(i)-n_{mo}(i)$.

For realizing optimal assignment to hall call application and reasonable dynamic partition to EGCS, the parameter $C_m(i,j)$ ($i,j=1,2,\ldots,n$ and $i\neq j$) of elevator *m* is classified following the rules of assignment state. The classification is shown as follows:

(1) CR: assignments which have already been scheduled and are also being executed;

(2) CU: idle assignments;

(3) CD: assignments which have already been scheduled but not been responded;

(4) CE: assignments which are being executed and then are scheduled again.

Further, classifying the hall call applications assigned in $C_m(i,j)$ which belong to CR, CD, CE following the rules of executing order.

(1) $m_1$: hall call applications corresponded with the assignments which have already been scheduled and are also being executed, in other words all of the assignments CR and CE;

(2) $m_2$: hall call applications corresponded with the assignments CD whose parameters are $f_{xb}>f_{xt}$, $d_m$ is downwards and $f_m>f_{xb}$ or $f_{xb}<f_{xt}$, $d_m$ is upwards and $f_m<f_{xb}$;

(3) $m_3$: hall call applications corresponded with the assignments CD whose parameters are $f_{xb}>f_{xt}$ and $d_m$ is upwards or $f_{xb}<f_{xt}$ and $d_m$ is downwards;

(4) $m_4$: hall call applications corresponded with the assignments CD whose parameters are $f_{xb}>f_{xt}$, $d_m$ is downwards and $f_m<f_{xb}$ or $f_{xb}<f_{xt}$, $d_m$ is upwards and $f_m>f_{xb}$.

## V. EVALUATION ITEMS PREDICTION

In up-peak traffic, the control objectives of EGCS embody in two aspects. They are service quality (low waiting time and journey time) and service quantity (strong capacity of carrying passengers). Obviously it is a typical problem of multi-objective optimization. The selection of control objectives should conform to requirement of dynamic partition in up-peak traffic. So according to the characteristics of passenger flow pattern and self requests of EGCS, we adopt four evaluation items including the average waiting time ($T_w$), the average journey time ($T_r$), long waiting percentage ($P_{lw}$), and power consumption ($R_{pc}$). Furthermore the prediction functions of evaluation items can modeling exactly on the basis of regrouping and classification to the ensemble of hall call communication.

### A. Average Waiting Time ($T_w$)

Waiting time means the time interval between the production of a destination call registration and the arriving of assigned elevator to origination floor. $T_w$ prediction algorithm considers the waiting time of all the destination call registrations in the relative service region which have already been scheduled but not been executed and also including the new destination call registration if its destination floor belongs to this relative region. The prediction of real-time waiting time for each hall call application can be calculated by surveying the practical range ability and required stop floor ID between the current floor of elevator and the origination floor of hall

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call application. In the meantime characteristic parameter defined as waiting influent factor is proposed which indicates the influence for waiting passengers in the relative region.

If defining $t_w(x)$ as the waiting time of hall call application $x$, $t_w(x)$ prediction equation is shown in (5) and (6).

$$t_w(x)=\begin{cases}\left[\left|f_m-f_{xb}\right|-n_s(f_m,f_{xb})\right]\times T_h+\left[n_s(f_m,f_{xb})-1\right]\times T_s & ,x\in m_2\\ t_1+\left[\left|f_1-f_{xb}\right|-n_s(f_1,f_{xb})\right]\times T_h+\left[n_s(f_1,f_{xb})-1\right]\times T_s & ,x\in m_3\\ t_2+\left[\left|f_2-f_{xb}\right|-n_s(f_2,f_{xb})\right]\times T_h+\left[n_s(f_2,f_{xb})-1\right]\times T_s & ,x\in m_4\end{cases}. \tag{5}$$

Where,

$$\begin{cases}t_1=\left[\left|f_m-f_1\right|-n_{s1}\right]\times T_h+n_{s1}\times T_s\\ t_2=t_1+\left[\left|f_1-f_2\right|-n_{s2}\right]\times T_h+n_{s2}\times T_s\end{cases}. \tag{6}$$

$n_s(i,j)$: Required stop number for elevator from floor $i$ to floor $j$;

$f_1$: Highest or lowest reverse floor ID for elevator the first time which can be calculated by all the $f_{xt}$ of hall call applications which belong to $m_1$, $m_2$ and all the $f_{xb}$ of hall call applications which belong to $m_3$;

$n_{s1}$: Required stop number for elevator from current floor to $f_1$;

$f_2$: Highest or lowest reverse floor ID for elevator the second time which can be calculated by all the $f_{xt}$ of hall call applications which belong to $m_3$ and all the $f_{xb}$ of hall call applications which belong to $m_4$;

$n_{s2}$: Required stop number for elevator from $f_1$ to $f_2$;

$T_s$: Time for every time required stop of elevator which can be estimated by passenger flow;

$T_h$: Time for elevator passing a floor not required stop.

For a new time of dynamic partition, $T_w(k)$ prediction equation in the $k^{th}$ step is shown in (7).

$$T_w(k)=\frac{\sum\limits_{x\in m_2,m_3,m_4}(t_w(x)\times n(x))}{\sum\limits_{x\in m_2,m_3,m_4}n(x)}\qquad k=1,2,\cdots,m. \tag{7}$$

### B. Average Journey Time ($T_r$)

Journey time means the time interval between the arriving of assigned elevator to origination floor and to destination floor. $T_r$ prediction algorithm considers the journey time of all the destination call registrations in the relative service region which have already been scheduled but not been executed and also including the new destination call registration if its destination floor belongs to this relative region.The prediction of real-time journey time for each hall call application can be calculated by surveying the practical range ability and required stop floor ID between the origination floor and the destination floor of hall call application. In the meantime characteristic parameter defined as journey influent factor is proposed which indicates the influence for journey passengers in the relative region.

If defining $t_r(x)$ as the journey time of hall call application $x$, $t_r(x)$ prediction equation is shown in (8).

$$t_r(x)=\left[\left|f_{xt}-f_{xb}\right|-n_s(f_{xt},f_{xb})\right]\times T_h+\left[n_s(f_{xt},f_{xb})-1\right]\times T_s. \tag{8}$$

For a new time of dynamic partition, $T_r(k)$ prediction equation in the $k^{th}$ step is shown in (9).

$$T_r(k)=\frac{\sum\limits_{x\in m_2,m_3,m_4}(t_r(x)\times n(x))}{\sum\limits_{x\in m_2,m_3,m_4}n(x)}\qquad k=1,2,\cdots,m. \tag{9}$$

### C. Long Waiting Percentage ($P_{lw}$)

$P_{lw}$ means the percentage of passengers whose waiting time is longer than 60s in the sum of current waiting passengers. For a new time of dynamic partition, $P_{lw}(k)$ prediction equation in the $k^{th}$ step is shown in (10).

$$\begin{cases}P_{lw}(k)=\dfrac{\sum\limits_{x\in m_2',m_3',m_4'}n(x)}{\sum\limits_{x\in m_2,m_3,m_4}n(x)}*100\% & k=1,2,\cdots,m\\ t_w(m_j')>60 & m_j'\in m_j,j=2,3,4\end{cases}. \tag{10}$$

### D. Power Consumption Ratio ($R_{pc}$)

$R_{pc}$ mainly embodies in the process of acceleration and deceleration of elevator, thus energy conservation could be realized by reducing the number of required stop. In dynamic partition of EGCS with DFG, $R_{pc}$ prediction algorithm contains two aspects, $R_n$ and $R_o$.

$R_n$ means the ratio of the new increased number of floor for elevator $m$ compared the new service region with the practical range ability of destination call registrations which have already been scheduled to elevator $m$ but not been executed to the relative new increased number of hall call passenger.

$R_o$ means the product of the lapped number of floor between the new service region and the practical range ability of destination call registrations which have already been scheduled to elevator $m$ but not been executed and relative number of hall call passenger.

$$R_{pc}(k)\approx R_n(k)/R_o(k). \tag{11}$$

Obviously, the lower of $R_n$ and the higher of $R_o$, the fewer required stop number is and the lower waste of energy is.

## VI. MODELING OF FUZZY NEURAL NETWORK (FNN)

Every time EGCS receives a new hall call application, firstly it is responded virtually and joined in the message queue. Then all the service regions would be dynamically re-zoned based on both the new hall call application and all the destination call registrations which have already been scheduled but not been executed. According to the idea of dynamic programming the new partition would

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choose an optimal policy from $S_1$ to $S_{m+1}$ which can be validated through optimal value function. The decision of each step is determined by information regroupment and classification, evaluation items prediction, finally through the construction of modeling of FNN making the prediction of each decision cost more precise. Finally, according to the new optimal policy and the destination floor $j$ of new hall call application, selecting the relative elevator to serve, meantime the new hall call application is joined in scheduled queue.

Thus we settle four evaluation items as the inputs of FNN and the decision variable $u_k(x_k)$ as the only output of FNN. These inputs are numerical variables and need to be fuzzified, which are described as large, middle or small in the fuzzy language. Then for fuzzy rule $R_j$ ($j=1,2,\cdots,l$), the fuzzy modeling of inputs and outputs is that:

IF $T_w$ is $A_{j1}$, $T_r$ is $A_{j2}$, $P_{lw}$ is $A_{j3}$, and $R_{pc}$ is $A_{j4}$
THEN $u_l = w_{j0} + w_{j1} * T_w + w_{j2} * T_r + w_{j3} * P_{lw} + w_{j4} * R_{pc}$

The overall output of modeling could be represented as in (12).

$$u = \frac{\sum_{j=1}^{l} \lambda_j u_j}{\sum_{j=1}^{l} \lambda_j}. \tag{12}$$

$$\lambda_j = \mu_{A_{j1}}(T_w) \wedge \mu_{A_{j2}}(T_r) \wedge \mu_{A_{j3}}(P_{lw}) \wedge \mu_{A_{j4}}(R_{pc}). \tag{13}$$

Equation (13) represents fuzzy logic 'AND' calculation, $\mu_{A_{ji}}(x_i)$ represents $x_i$ membership function value to $A_{ji}$ fuzzy subset. $A_{ji}$ is represented by Gaussian function.

$$A_{ji} = \exp\left[-\left(\frac{x_i - c_{ji}}{b_{ji}}\right)^2\right]. \tag{14}$$

Where, $c_{ji}$ and $b_{ji}$ is the centre and width of membership function. The structure of five layers FNN is shown as Fig. 3.

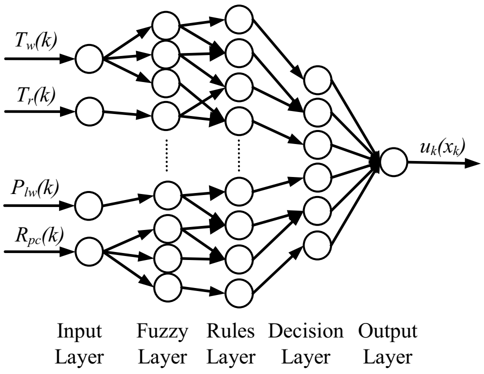

Figure 3. Structure of FNN.

The first layer is input layer and each node represents a characteristic parameter.

$$u_i^1 = \alpha_i^1 = x_i. \tag{15}$$

The second layer is fuzzification, each node represents a fuzzy subset and inputs variable are fuzzified by membership function $f(*)$.

$$\alpha_j^2 = w_{ij}^2 u_i^1, \quad u_j^2 = f(i_j^2). \tag{16}$$

The third layer is rules layer and each node represents a fuzzy logic rule. Thus all the nodes constitute a fuzzy rule base through logic 'AND' calculation.

$$\alpha_l^3 = \prod_j w_{jl}^3 u_j^2, \quad u_l^3 = \alpha_l^3. \tag{17}$$

The forth layer is decision layer and each node executes logic 'OR' calculation to integrate some similar rules.

$$\alpha_k^4 = \sum_l w_{lk}^4 u_l^3, \quad u_k^4 = \min\left(1, \alpha_k^4\right). \tag{18}$$

The fifth layer is defuzzification which fulfills to revert numerical variable of output from fuzzy value based on membership grade of fuzzy subset of output parameter.

$$\begin{aligned} \alpha^5 &= \sum_k w_{kl}^5 u_k^4 = \sum_k \left(m_k \sigma_k\right) u_k^4 \\ y = u^5 &= \frac{\alpha^5}{\sum_k \sigma_k u_k^4} \end{aligned}. \tag{19}$$

FNN inherits the learning capacity of Neural Network and meantime can automatically dispose fuzzy information, summarize fuzzy rules, adjust membership function, and fulfill fuzzy reasoning. The training of FNN is divided to three steps based on obtained sample data. The first one, obtaining membership function from sample by applying modified SOM method to learn; the second one, obtaining fuzzy rules from sample data through membership function of the first step; the last one, optimizing and adjusting membership function in terms of error back propagation algorithm.

## VII. SIMULATION AND ANALYSIS

In example of common office building, simulation is done under the simulation environment of EGCS with DFG and the condition parameters are set in Table III. The passenger flow pattern selects complex up-peak traffic which parameters are shown in Table IV. The density of passenger flow is continuing increased with time and the sample data of up-peak traffic is generated by Poisson distribution and Monte Carlo random testing method.

TABLE III.
PARAMETERS OF SIMULATION CONDITION

| Item | Value |
|---|---|
| Number of Floors | 16 |
| Height of Entrance Hall (*m*) | 4.0 |
| Height of Other Floors (*m*) | 3.0 |
| Number of Elevators | 4 |
| Max. Velocity (*m/s*) | 2.5 |

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| | |
|---|---|
| Max. Acceleration (*$m/s^2$*) | 0.7 |
| Jerk (*$m/s^3$*) | 0.7 |
| Elevator Capacity (*person*) | 15 |
| Time for Opening and Closing Door (*s*) | 4.0 |
| Average Transfer Time for Passenger (*s*) | 1.0 |

TABLE IV.
PARAMETERS OF PASSENGER FLOW IN UP-PEAK TRAFFIC

| Item | Value |
|---|---|
| Average Passenger Density (*person/ 5min*) | 150 |
| Time of System Simulation (*s*) | 1200 |
| Percentage of Upward Passenger Flow from Entrance Hall (*%*) | 100 |

At first the network is trained based on the principle of overall minimum error. The number of original sample in training package is 25, the learning rate is 0.47 and the precision of training error is $10^{-3}$. Then after 330 times training, the network can meet the range of permissible error. Then through the test of five samples, the generalization ability of network is confirmed. The network training error curve is shown as Fig. 4.

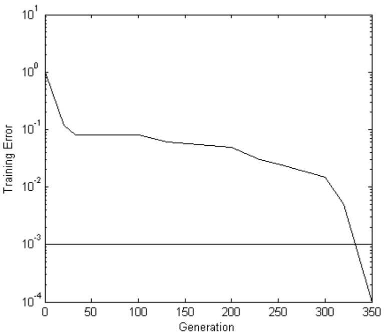

Figure 4. Network Training Error Curve.

In the same simulation condition, compare and analyze dynamic programming partition algorithm based on DFG (DPP) with minimization average waiting time algorithm (MT), static zoning algorithm (SZ), and multi-objective optimization algorithm [8] (MO). The scheduling performances are shown in Table V.

TABLE V.
SCHEDULING PERFORMANCES OF DIFFERENT ALGORITHMS

| Algorithm | $T_w$ *(s)* | $T_r$ *(s)* | $P_{lw}$ *(%)* | $R_{pc}$ *(%)* |
|---|---|---|---|---|
| MT | 52.4 | 67.2 | 56.2 | 75 |
| SZ | 36.1 | 41.6 | 13.3 | 49 |
| MO | 37.4 | 36.0 | 14.6 | 44 |
| DPP | 29.3 | 34.4 | 9.6 | 53 |

In up-peak traffic, the scheduling performances of DPP and MO based on DFG are better than the scheduling performances of the MT and SZ based on traditional elevator system. Where, MT algorithm controls as the principle of minimization waiting time of every passenger. But it cannot consider the changing feature of passenger flow pattern, so MT is not fit for the complex up-peak traffic. Compared with MT, SZ algorithm considers the characteristic of up-peak traffic and divides the crowd of high arrival rate to generate multiple waiting queues, only the passengers whose destination floor is in the service region of a certain elevator can enter in this elevator which is an indirect way to obtain the information of destination floors. Otherwise in EGCS with DFG, it is obvious to know that the performance of DPP is superior to the performance of MO. Although $R_{pc}$ of DPP algorithm is a little higher than some others, but in up-peak traffic the sacrifice of $R_{pc}$ quality is worthy to improve the overall performance.

In the entire control process of DPP algorithm, two primary evaluation items both $T_w$ and $T_r$ also get well control in each elevator. The control curves $T_w$ and $T_r$ are shown as Fig. 5 and Fig. 6. In them, four elevators are represented by E0, E1, E2, and E3 respectively.

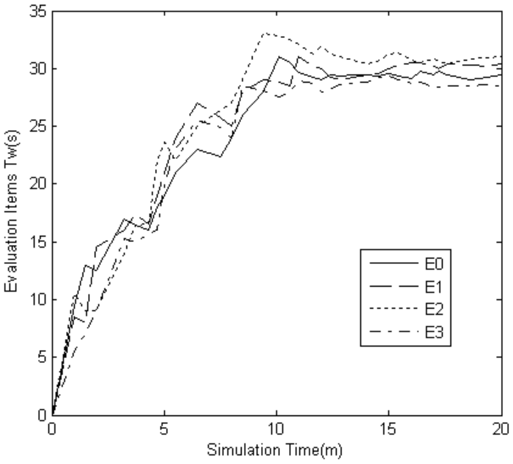

Figure 5. Control Curves of $T_w$.

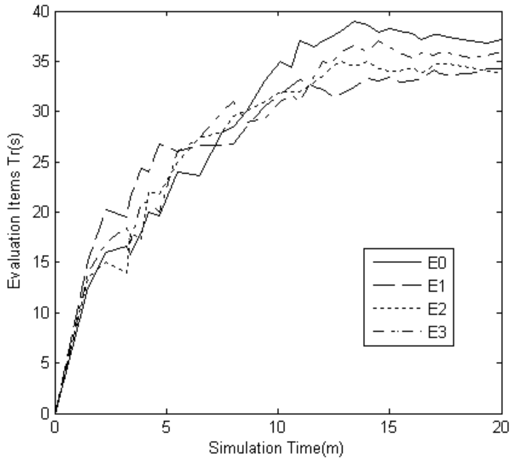

Figure 6. Control Curves of $T_r$.

From the above figures we can know that along with the increment of time, the intensity of passenger flow is gradually strengthened which result to the overall trend of $T_w$ and $T_r$ is rising, especially in $t_n \le 10min$, the amount of passenger flow is obviously increased. Then along with the stability of passenger flow, $T_w$ and $T_r$ all come up to the stable state gradually. In the stable period such as

$t_n \in [13, 20]$, it is obvious that the control process of $T_w$ and $T_r$ for four elevators is balanced and complementary, meantime the final control values for four elevators are similar with each other which indicates that DPP algorithm could effectively schedule all the elevators making the service quality of each region average. Through comparing between the both two figures, the fluctuation process of $T_w$ and $T_r$ for each elevator is mostly on inverse trend. This changing regularity corresponds with the practical elevator scheduling condition, in other words, $T_w$ and $T_r$ are a pair of conflicting evaluation items. DPP algorithm based on DFG could well control $T_w$ and $T_r$ to avoid influencing one of them appear wide fluctuation for stabilizing the other. To sum up, it is confirmed that DPP algorithm based on DFG has better performance in up-peak traffic.

## VIII. CONCLUSIONS

In this paper, EGCS with DFG is proposed. This new type of passenger flow management pattern resolves the problem of imperfection and nondeterminacy about hall call information in traditional elevator system. Through dynamic programming algorithm, service region of EGCD is dynamically divided to fit for up-peak traffic. Under the mechanism of DFG, ensemble of hall call communication is effectively regrouped and classified to ensure the precision of prediction for evaluation items. Based on this, FNN is used to realize optimal decision of dynamic partition.

In the simulation experiment, through comparing the performances of DPP algorithm with other scheduling algorithms then analyzing the control process of evaluation items, a large amount of improvement of EGCS with DFG in up-peak traffic is confirmed which indicates the advantage of DFG modeling and the effectiveness of DPP algorithm.

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## REFERENCES

[1] D. Nikovski and M. Brand, “Exact Calculation of Expected Waiting Times for Group Elevator Control,” *IEEE Trans. Automatic Control*, Vol. 49, No. 10, pp. 1820-1823, Oct. 2004.

[2] A. T. P. So, J. K. L. Yu, and W. L. Chan, “Dynamic Zoning based Supervisory Control for Elevators,” *1999 Proc. IEEE Int. Conf. Control Applications*, Vol. 2, pp. 1591-1596, Aug. 1999.

[3] Li Dong, Wang Wei, and Shao Cheng, “Elevator Group Supervisory Control Systems and Intelligent Control Techniques,” *Control and Decision*, Vol. 16, No. 5, pp. 513-517, Sep. 2001.

[4] S. Tanaka, Y. Innami, and M. Araki, “A Study on Objective Functions for Dynamic Operation Optimization of a Single-Car Elevator System with Destination Hall Call Registration,” *2004 IEEE Int. Conf. Systems, Man and Cybernetics*, Vol. 7, pp. 6274-6279, Oct. 2004.

[5] H. N. Psaraftis, “Dynamic Programming Solution to the Single Vehicle many-to-many Immediate Request dial-a-ride Problem,” *Transportation Science*, Vol. 14, No. 2, pp. 130-154, May 1980.

[6] W. L. Chan, A. T. P. So, and K. C. Lam, “Dynamic Zoning for Intelligent Supervisory Control,” *International Journal of Elevator Engineering*, Vol. 4, pp. 47-59, 1995.

[7] T. Beielstein, C. P. Ewald, and S. Markon, “Optimal Elevator Group Control by Evolution Strategies,” *GECCO 2003-LNCS 2724*, Vol. 4, pp. 1963-1974, 2003.

[8] Luo Fei, Xu Yuge, and Cao Jianzhong, “Modeling and Control in Elevator Group Control System with Destination Registration,” *Control and Decision*, Vol. 21, No. 10, pp. 1159-1162, Oct. 2006.

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