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A Study on Energy Consumption of Elevator Group Supervisory Control Systems using Genetic Network Programming

Lu Yu, Shingo Mabu, Tiantian Zhang, Kotaro Hirasawa
Graduate School of Information, Production and Systems,
Waseda University
Hibikino 2-7, Wakamatsu-ku, Kitakyushu, Fukuoka, 808-0135, Japan
E-mail: yulu1006@fuji.waseda.jp, mabu@aoni.waseda.jp,
zhangtt@ruri.waseda.jp, hirasawa@waseda.jp

Tsuyoshi Ueno
Central Research Institute
of Electric Power Industry
2-11-1, Iwado Kita, Komae-shi,
Tokyo, 201-8511, Japan
E-mail: ueno@criepi.denken.or.jp

***Abstract*—Elevator group supervisory control system (EGSCS) is a traffic system, where its controller manages the elevator movement to transport passengers in buildings efficiently. Recently, Artificial Intelligence (AI) technology has been used in such complex systems. Genetic Network Programming(GNP), a graph-based evolutionary method extended from GA and GP, has been already applied to EGSCS. On the other hand, since energy consumption is becoming one of the greatest challenges in the society, it should be taken as criteria of the elevator operations. Moreover, the elevator with maximum energy efficiency is therefore required. Finally, the simulations show that the elevator system has the higher energy consumption in the light traffic, thus, some factors have been introduced into GNP for energy saving in this paper.**

***Index Terms*—Elevator Group Supervisory Control System, Energy Consumption, Genetic Network Programming**

I. Introduction

Elevator Group Supervisory Control System (EGSCS) is a traffic control system that manages three or more elevators in order to efficiently transport the passengers in buildings [1]. The assignment of elevators to hall calls is a kind of optimization problem in transportation systems [2]. With the increasing demand for EGSCS, the service quality and performance level of EGSCS have also been increased. Meanwhile, the energy crisis is becoming the reality. Energy saving requires complex elevator management systems that realize a control to satisfy conventional passenger demands and also ensure energy efficiency.

In recent years, various approaches in Artificial Intelligence (AI) have been applied to such complex problems [3,4]. Evolutionary optimization is a subfield of AI, whose search procedures are based on the mechanism of natural selection and genetic operations. A new evolutionary computation named Genetic Network Programming (GNP) [5] has been proposed as an extension of Genetic Algorithm (GA) [6] and Genetic Programming (GP) [7] ten years ago by employing a directed graph as its genes. In this paper, we use GNP to solve EGSCS with energy consumption.

The paper is organized as follows. Section 2 and 3 give an overview of EGSCS and GNP. Section 4 explains EGSCS with energy consumption using GNP. Section 5 shows the simulation conditions and results. Conclusions are provided in section 6.

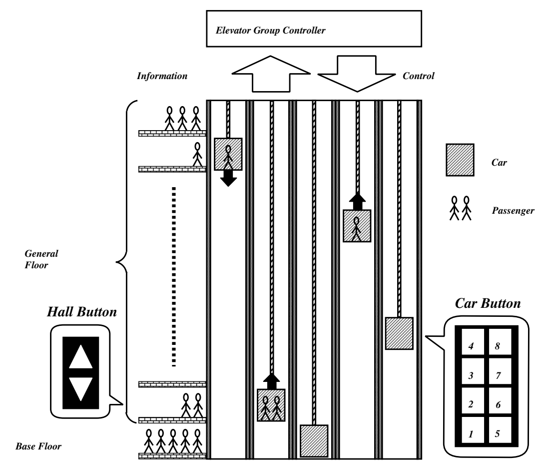

Fig. 1. Outline of EGSCS.

II. Elevator Group Supervisory Control Systems (EGSCS)

Elevator Group Supervisory Control System (EGSCS) is a traffic control system that manages multiple elevators in buildings in order to efficiently transport the passengers. The outline of EGSCS is shown in Figure.1 The system assigns a service car for a new passenger waiting at a hall. The assignment is a kind of real-time scheduling problem for transportation systems.

The performances of the elevator system are measured by several criteria such as the average waiting time of passengers, percentage of passengers waiting for more than 60 seconds and energy consumption [8]. The elevator system manages elevators to minimize the evaluation criteria. In this paper, the following four criteria are used.

1) **Average waiting time(AWT)** is the average time until the service elevator arrives at the floor after a passenger presses a hall call button.
2) **Average Traveling Time(ATT)** is the average time until a passenger drops off at the destination floor after he/she gets into the car.
3) **Long Waiting Percentage(LWP)** is the percentage of the passengers waiting over 60 seconds after a passenger presses a hall call button until he/she enters into a car.
4) **Energy Consumption(EC)** is the total energy of all the elevators during their operation.

The elevator traffic flow affects the elevator system configuration and the elevator dispatching policies significantly [9]. In the typical office buildings, the traffic is divided into three traffic patterns(Regular Traffic, Up-peak Traffic and Down-peak).

In elevators, a heavy counterweight balances the load of the elevator car, so the motor has to lift only the difference between the car load and the counterweight load. The counterweight also increases the ascending acceleration force and decreases the descending acceleration force to reduce the amount of horsepower needed by the motor. Both the elevator cars and the counterweights have rollers attached to them to prevent irregular movement and provide a smoother ride for the passengers. The counterweights typically weigh the car plus about the half of its maximum load. So, a full elevator needs the help from the motor to carry people to upper floors, but an empty elevator needs energy to descend instead, because it takes energy to move up and down the weight difference between the empty elevator and its counterweight. Conversely, the full descending elevator and empty rising one yield potential energy that is dissipated as heat if it cannot be used as electricity.

III. Genetic Network Programming

A. Basic Structure

As an extension of GA and GP, GNP has a network structure which is shown in Figure.2. GNP program is composed of one start node and plural judgment nodes and processing nodes. Start node has no functions and no conditional branches. Judgment nodes have decision functions with conditional branches. Each judgment node returns a judgment result and determines the next node to be executed. Processing nodes work as action functions. In processing nodes, actions are conducted to environments. The node transition begins from a start node, but there is no terminal node. After the start node, the current node is transferred according to the node connections and judgment results.

As shown in Figure.2, GNP can be illustrated by its "Phenotype" and "Genotype". Phenotype GNP shows the directed graph structure, while Genotype GNP provides the chromosomes encoded into bit-strings. The structure of the gene of node i is set as shown in Figure.2. The chromosome NT_i identifies the node type such as start node, judgment node and processing node, while NF_i denotes the function label. d_i is the time delay spent on the judging or processing of node i.

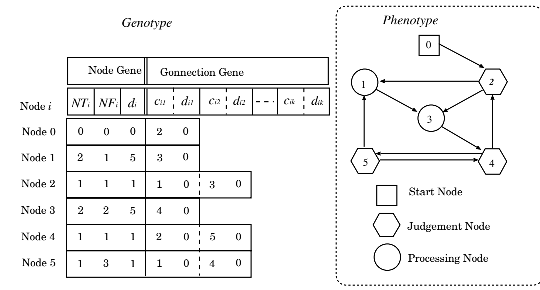

Fig. 2. Basic structure of GNP.

C_{ik} indicates the node number connecting from the kth branch of node i, and d_{ik} shows the time delay for its transition.

B. Evolution of GNP

In evolutionary computation, each individual is evaluated and has the same number of nodes. Then, a number of the offspring who can survive at the next generation are decided by their fitness. In each generation, the elite individuals are preserved and the rest are replaced with the new ones generated by crossover and mutation. Mutation operator affects one individual. All connections of each node are changed randomly by mutation rate of P_m. Crossover operator affects two parent individuals. All the connections of the uniformly selected corresponding nodes in two parents are swapped each other by crossover rate of P_c.

The outline of evolution is described as follows:

- Generate initial population and calculate the fitness of initial population;
- Execute genetic operations to individuals and generate new individuals;
- Calculate the fitness and select the individuals for the next generation based on the fitness;
- Iterate 2-3 until the terminal condition.

IV. Elevator Group Supervisory Control Systems using Genetic Network Programming

EGSCS can be built by an evolutionary method with mutation, crossover and selection, which could develop new efficient and effective rules. The structure of EGSCS using GNP is shown in Figure.3. In the system, GNP can realize a rule based EGSCS due to its directed graph structure of the individual, which makes the system more flexible. The proposed method includes Elevator System and GNP controller. When a hall call occurs, System Information and Car Information are collected. Then, the GNP Controller uses these data, does some calculation and evaluation. The GNP Controller consists of the System Information Judgment Part, Car Selection Part, Car Judgment Part and Car Assignment Part.

A. Evaluation Items

In our proposed method, 5 evaluation items are defined and employed to construct GNP considering the features of EGSCS.

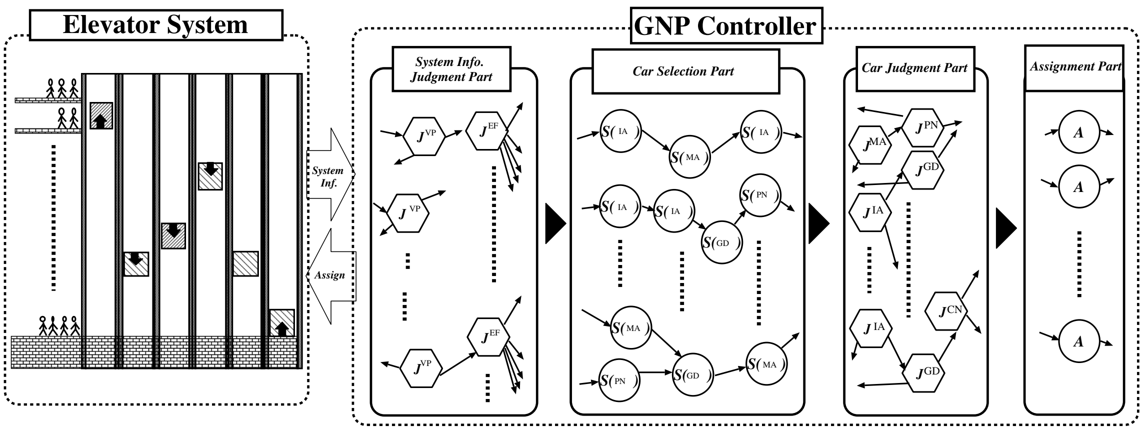

Fig. 3. Structure of EGSCS using GNP.

- IA: Arrival time of the assigned hall call to the car including the incremental arriving time of the already registered hall calls
- MA: Maximum of the arrival time of the assigned hall call and arrival time plus elapsed time of the already registered hall calls since their assignment of the hall calls
- PN: Number of passengers in the car
- CN: Number of assigned hall calls to the car
- GD: Service index considering registered calls and distance between the hall call floor and the current floor of each elevator.

B. Assigning Algorithm

In GNP controller, firstly, the information is transferred to the System Information Judgment Part. In this part, the new hall call is classified based on the following two terms, i.e., the degree of the variance of the elevator positions VP, the floor and direction of the new hall call EF. VP is used for the binary judgment whether the degree of the variance of the elevator positions is less than the average over the past 5 minutes or not. EF is used for the judgment of the floor and direction of the new hall call.

Secondly, a candidate car with the minimum value of the evaluation function is selected in the Car Selection Part. A candidate car is selected by the following procedure. First, the car evaluation function $e(i)$ of car i is calculated by Equation(1).

$$e(i) = \sum_{p \in P} w_p \cdot x_p(i), \quad (1)$$

The normalized value $x_p(i)$ of the evaluation item X of car i at the car selection node p is calculated by Equation(2)

$$x_p(i) = \frac{X_p(i)}{X_{AveMax}}, \quad (2)$$

where,

P : set of suffixes of nodes transited in the car selection part (P is determined by evolution)

w_p: weight of car selection node p (w_p is optimized by evolution)

$x_p(i)$: normalized value of evaluation item X of car i at car selection node p

$X_p(i)$: value of evaluation item X of car i at car selection node p

X_{AveMax}: maximum value of averaged evaluation item X over the past 5 minutes among cars

Then, the candidate car d is selected by Equation (3)

$$d = arg \min_{i \in I} e(i), \quad (3)$$

where, I: set of car IDs

After that, the selected candidate car d is evaluated again by individual evaluation items in the Car Judgment Part. Equation(4) is carried out in the car judgment node $j \in J$.

$$y_j(d) \leq r_j^Y, \quad (4)$$

where,

$$y_j(d) = \frac{Y_j(d)}{Y_{AveMax}},$$

J: set of suffixes of nodes in the car judgment part

$y_j(d)$: normalized value of item Y of car d at car judgment node j

$Y_j(d)$: value of evaluation item Y of car d at car judgment node j

Y_{AveMax}: maximum value of averaged evaluation item Y over past 5 minutes among cars

Finally, in the Car Assignment Part, the new call is assigned to the candidate car. After that, the same procedures are executed for the next call.

C. Node Function

The following node functions are provided in each part of the GNP controller.

<System Information Judgment Node (2 kinds)>

J^{VP}: Judge the variance of the elevator position (2 branches)

J^{EF}: Judge the emerged floor and direction of the new hall call (5 branches)

<Car Selection Processing Node (5 kinds)>

In the processing nodes, there are totally 5 kinds of nodes.

$S(X)$: select evaluation item X from 5 items by the node transition in the car selection part and calculate Equation (1)

$X \in \{IA, MA, PN, CN, GD\}$

<Car Judgment Node (5 kinds)>

$J^Y(d)$: Judge whether $y_j(d) \leq r_j^Y$ is satisfied or not

$Y \in \{IA, MA, PN, CN, GD\}$

<Car Assignment Processing Node (1 kind)>

$A(d)$: Assign car d to the new hall call

D. Fitness Function

The fitness function of GNP individual is calculated by the weighed sum of the waiting time, maximum waiting time, number of loops of GNP and energy consumption. Therefore, the fitness function is defined as follows:

$$Fitness = (1-\alpha)\left(\frac{1}{N}\sum_{n=1}^{N} {t_n}^2 + w_t \cdot (t_{max})^2 + w_l \cdot l^2\right) + \alpha \cdot w_{ec} \cdot EC^2,$$

where,

N : the total number of passengers

t_n : waiting time of the nth passenger

t_{max} : maximum waiting time among N passengers

l : the number of loops of GNP per an hour evaluation

EC : energy consumed

α: energy consumption balance parameter

w_t, w_l, w_{ec}: weighting coefficient

α can be adjusted between 0 and 1, and it shows the balance between the importance of energy consumption and other criteria during the evolution processing. When α = 0, the energy consumption can not affect the controller at all.

V. Simulation

A. Simulation Conditions

We have studied the effectiveness of the proposed GNP controller with energy consumption in a typical office building, which has 10 floors and 4 elevators running at the speed of 1.5 m/s. Table I shows the specifications of the system simulator. Simulations are executed under 10 kinds of random sequences considering the probabilistic feature of EGSCS. As shown in Table II, simulations are implemented in terms of three kinds of traffic flows, "Regular Traffic", "Up-peak Traffic" and "Down-peak Traffic". The row of the table represents the floor where passengers emerge, and the column represents the floor where passengers plan to go. Here, passengers emerge at the "Lobby Floor" or "General Floor (Gen.)".

We use the database of the energy consumption shown in Figure 4. Each curve corresponds to the different number of floors the car travels without stop, and X axis represents the number of passengers in the elevator. We here ignore the energy consumption of the lighting and controlling the equipments. The energy consumption statistics are used for upward and downward, respectively. The parameters for evolving GNP are set as shown in Table III. The size of generation and population is set at 200 generations and 300 individuals. Each of the individuals has 67 nodes.

TABLE I
SPECIFICATIONS OF ELEVATOR SIMULATOR

Items	Value
Number of Floors	10
Floor Distance $[m]$	4.8
Max. Velocity $[m/s]$	1.5
Max. Acceleration $[m/s^2]$	0.4
Jerk $[m/s^3]$	0.4
Cage Capacity $[person]$	10
Time spent on	
—Opening Door $[s]$	2.0
—Closing Door $[s]$	2.3
—Riding $[s/person]$	1.0
Passenger Density $[person/hour]$	1250

TABLE II
OD RATIO (ORIGIN/DESTINATION) OF VARIOUS TRAFFIC FLOWS

	Regular		Up-peak		Down-peak	
	Lobby	Gen.	Lobby	Gen.	Lobby	Gen.
Lobby	–	30	–	80	–	10
General	30	40	10	10	80	10

B. Results and Discussion

1) Experiment 1: In experiment1, we studied how the average waiting time (AWT), average traveling time (ATT), percentage of the passengers waiting over 60(s)(LWP) and total energy consumption (EC) change depending on the passenger density in regular, up-peak and down-peak traffic, respectively. In experiment 1, $\alpha = 0$ is used. The evolution completes around 200th generation. After that, we use the best individual to evaluate the performances of the proposed method from light to heavy load. One hour evaluation is implemented for 10 times in the range of 250 – 2000 [person/h] at intervals of 125[person/h]. Figure.5 – Figure.8 show the average waiting time (AWT[s]), average traveling time (ATT[s]), percentage of

TABLE III
EVOLUTIONAL CONDITIONS OF GNP

Items	Value
Generation	200
Population Size	300
—Crossover	120
—Mutation	170
—Elite	10
Node Size	66+Start Node
Crossover Rate P_c	0.1
Mutation Rate P_m	0.01
Evaluation Time $[h]$	1
w_t, w_l, w_{ec}	0.007, 0.6, 0.2

TABLE IV
PERFORMANCES OF AWT AND EC IN THE LIGHT TRAFFIC FOR VARIOUS NUMBER OF ELEVATORS.

<500[persons/h]>

Num. of	Regular		Up-peak		Down-peak	
elevators	AWT[s]	EC[Wh]	AWT[s]	EC[Wh]	AWT[s]	EC[Wh]
2	45.8	3304	65.6	5634	40.2	4013
3	36.9	6584	36.4	9217	23.8	8799
4	22.1	11937	26.9	12977	16.9	11716

<375[persons/h]>

Num. of	Regular		Up-peak		Down-peak	
elevators	AWT[s]	EC[Wh]	AWT[s]	EC[Wh]	AWT[s]	EC[Wh]
2	53.2	4034	48.5	5906	31.7	5388
3	29.2	7339	30.3	9734	19.2	9113
4	17.4	10984	20.4	12900	15.0	10525

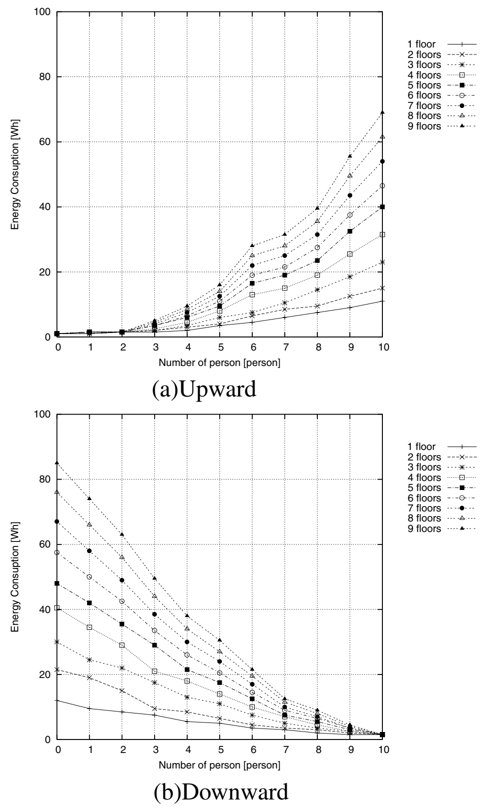

Fig. 4. Database of Energy Consumption.

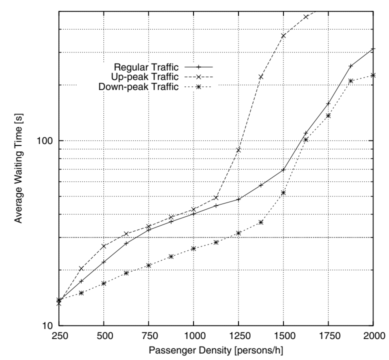

Fig. 5. Average Waiting Time[s] of Performances.

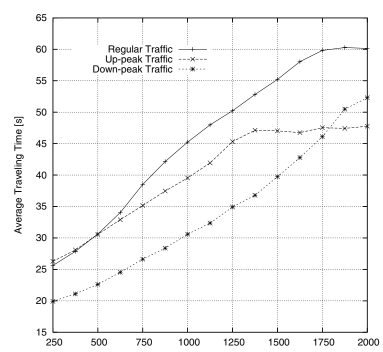

Fig. 6. Average Traveling Time[s] of Performances.

the passengers waiting over 60[s] (LWP[%]) and total energy consumption (EC[Wh]) in three kinds of traffics.

In all kinds of traffics, the proposed method obtains AWT in the rage of 10 – 30 seconds and LWP is less than 20% during the low traffic density. In up-peak traffic, cars are filled at the entrance floors, and they are forced to serve all the calls in sequence. Car load factor in other traffics is smaller than that of up-peak traffic. So, AWT increases faster when the passenger density increases and LWP reaches the saturation earlier in up-peak traffic than other traffics.

In ATT, the performance is less than 40 seconds during the low traffic density. Most of the passengers emerge at the lobby floor in up-peak traffic, and they have the same destinations in down-peak traffic. In those cases, the service load is lighter than regular traffic. Therefore, the cars must stop more times and the traveling time would be longer in regular traffic than others during the heavy traffic.

On the other hand, the system has the higher energy consumption in the lower traffic density, especially around 500 [person/h]. It is because an empty elevator needs energy to descend.

2) Experiment 2: We stopped the operation of some elevators in the low traffic density with 375[persons/h] and 500[persons/h] in order to study the energy saving operations.

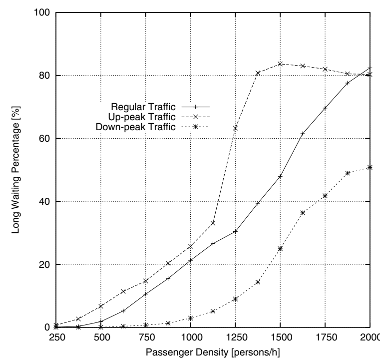

Fig. 7. Long Waiting Percentage[%] of Performances.

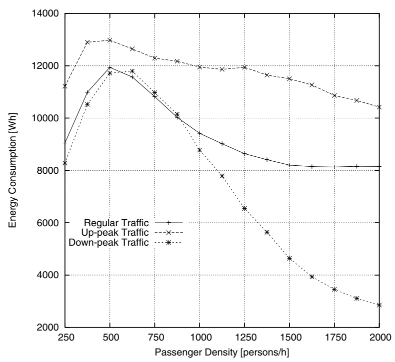

Fig. 8. Energy Consumption[Wh] of Performances.

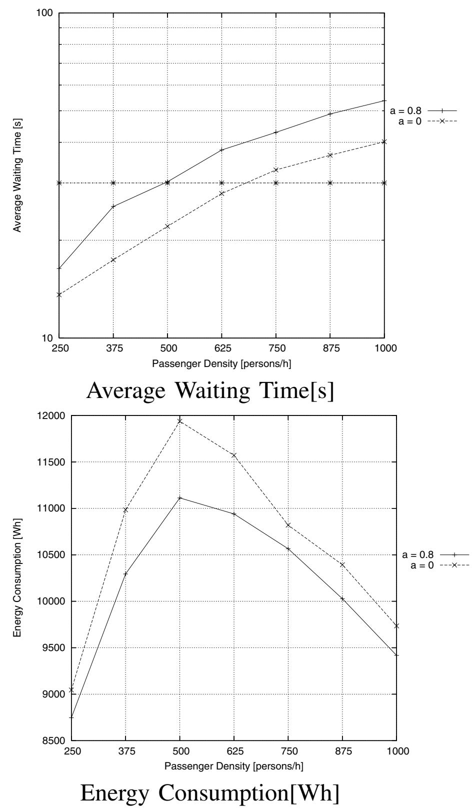

Fig. 9. Performances with different values of energy balance parameter.

In experiment 2, we also used $\alpha = 0$. The results are shown in Table IV. Usually, AWT around 30 seconds could satisfy the passengers' demands, so, in the density of 500[persons/h], we could reduce the number of elevators from 4 to 3 for energy saving only in the down-peak traffic. However, in the density of 375[persons/hour], stopping the operation of one elevator in the up-peak and regular traffic could reduce the energy consumption by 24 – 33%, and stopping the operation of two elevators in the down-peak traffic could save the energy by about 50%. It indicates that reducing the number of elevators in the light traffic for energy saving is useful.

3) Experiment 3: Simulations were implemented using different values of energy balance parameter (α = 0 and 0.8) in the fitness function using the regular traffic. The results are shown in the Figure.9. When α = 0.8, i.e. considering the energy saving during the training time, the energy consumption is saved at the risk of the increase of AWT. Therefore, the energy balance parameter could be adjusted to different values depending on the different demands of different building managers. Then, the elevator systems work with the maximum energy efficiency satisfying the passengers' demands in the light traffic.

VI. Conclusion

In this paper, GNP has been used to solve the energy saving problem of EGSCS. It has been found from simulations that the elevator systems use more energy in the light traffic than heavy traffic, because the empty elevators needs energy to descend. It is also found that the unnecessary elevators could be shut down for energy saving in the lower traffic density. The proposed method could adjust the balance between energy saving and passengers' requirement for waiting time.

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