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A Novel Method of Elevator Group Control Scheduling Based on Affinely Adjustable Robust Optimization

WANG Fang, ZONG Qun, ZHANG Jinglong, LI Junfang

College of Electric Engineering and Automation, Tianjin University, Tianjin 300072, P. R. China
E-mail: fangwang@tju.edu.cn,zongqun@tju.edu.cn

Abstract: In this paper, a group elevator scheduling (GES) method based on affinely adjustable robust optimization (AARO) is presented. The uncertain characteristics of elevator traffic flow and objective functions are analyzed. Then an uncertain GES model is established. An affine relationship between the elevator scheduling scheme and the uncertain traffic flow is constructed. And the uncertain GES model is transformed into its affinely adjustable robust counterpart (AARC). Simulation results show that the scheduling method has better scheduling performance than that of other scheduling methods.

Key Words: Group Elevator Scheduling, Affinely Adjustable Robust Optimization, Uncertain Traffic Flow

1 Introduction

Elevator group control system (EGCS) problem is a system, which is composed of many elevators. Moreover, it is uniformly controlled to reduce the waiting time of passengers and energy consumption. Nowadays, EGCS plays an important role in meeting the requirements of passengers, and GES algorithm is crucial for a good EGCS. Traffic flow has an important influence on the GES; it is the key and the basic factor for the GES, which is the common sense for all the researchers. Therefore, it is very necessary to analyze the features of the traffic flow.

There are several GES algorithms. The classic methods include minimize waiting time algorithm and the static zoning algorithm. The advanced methods include particle swarm optimization (PSO), natural network (NN), genetics algorithm (GA), and other intelligent methods [1-4]. These advanced methods improve the efficiency of the GES and satisfy the needs of passengers. In practical applications, although some intelligent methods solve the computational complexity of the GES, they do not consider the uncertainty of the passenger traffic flow (passengers who want to up and down the floor through elevator). Based on this, the articles [5-7] proposed the destination floor method, which solved the affection of uncertain traffic flow in current time to some extent. However, they did not consider the uncertainty of passenger traffic flow in the next time. Therefore, it cannot solve the influence of uncertain passenger traffic flow in the next time. Thus it may induce the case that it schedules well in current time, but it schedules badly in the next time. As a result, it needs to consider the uncertain traffic flow both in current and next time.

During a decision-making process which has uncertain parameters, if the decision variables are all certain before the uncertain parameters are determined, then the robust optimization (RO) method is effective to solve the problem. Nevertheless, for some practical problems, especially in engineering, not all of the decision invariables are determined before the realization of the uncertain parameters. That is to say, the decision variables are divided into adjustable variables and nonadjustable variables by the concept of ARO, which was proposed by Ben-Tal [8].Then the adjustable robust optimization (ARO) method is better than the RO method to solve the problem.

The main idea of ARO and RO are all to converse the uncertain optimization problem into certain problem, i.e. the feasible solution has better robustness through transforming the uncertain optimization problem into corresponding adjustable robust counterpart (ARC) or robust counterpart (RC). Moreover, for the same uncertain problem, its ARC has better feasible set and optimal objective function value than its RC, whereas the ARC is often NP-Hard. If the adjustable variables are affinely related with the uncertain parameters, then the affinely adjustable robust optimization (AARO) [8] can be used to get its non-NP-Hard affinely adjustable robust counterpart (AARC). There were many researches on the application of AARO, such as subway route design [9], emergency logistics [10], and production management [11], and multi-period inventory control [12], network design in telecommunications [13]. However, until now, there is no paper reported using AARO method in GES.

In view of operation research, GES is an optimization problem; it becomes an uncertain optimization problem when the traffic flow is uncertain. The robust optimization approach was applied to GES in the papers [14, 15], which had better performances compared with other methods including minimize waiting time and static zoning algorithm. During the elevator scheduling, the scheduling scheme (variables) adjusts itself to the uncertain passenger traffic flow. So an affinely relationship between scheduling scheme and passenger traffic flows is constructed. Then AARO method is used to transform the GES uncertain model into certain optimization problem.

2 AARO Theory

In this section, the AARO theory is mainly according to reference [8].For the general uncertain optimization problem, if the variable is determined before the realization

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of uncertain data, the variable is the non-adjustable variable. Otherwise, if the variable changed as the uncertain data change, it is called adjustable variable.

Consider the following uncertain optimization problem

$$P\left\{\min_{x}\left\{c^T x : Ax \le b\right\} : [A,b] \in U\right\} \tag{1}$$

Here, U is the uncertain parameter set.

If $x^{\mathrm{T}} = (x_1^{\mathrm{T}}, x_2^{\mathrm{T}})$, x_1, x_2 is the non-adjustable variables and adjustable variables respectively, then the formulation (1) can be written as following

$$\min_{x_1}\left\{c_1^T x_1 : A_1 x_1 + A_2 x_2 \le b\right\}_{\xi=(A_1 \quad A_2 \quad b)\in U} \tag{2}$$

The RC of formulation (2) is as following

$$\min_{x_1}\begin{Bmatrix} c_1^T x_1 : \exists x_2, \forall \xi = (A_1 \quad A_2 \quad b) \in U \\ A_1 x_1 + A_2 x_2 \le b \end{Bmatrix} \tag{3}$$

When variables include non-adjustable and adjustable variables, the ARO method can be used to transform the uncertain problem into its ARC.

And the ARC of formulation (2) is given by

$$\min_{x_1}\begin{Bmatrix} c_1^T x_1 : \forall \xi = (A_1 \quad A_2 \quad b) \in U \\ \exists x_2 : A_1 x_1 + A_2 x_2 \le b \end{Bmatrix} \tag{4}$$

ARC is often significantly less conservative than the usual Robust Counterpart (RC). For the same uncertain problem, the ARC of it has better feasible set and optimal objective function value than RC as we prove in following theorem.

Theorem 1 for uncertain problem (2), its robust counterpart (3) has a smaller feasible set than that of its adjustable feasible robust counterpart (4). The optimal value of (4) is better than that of (3).

Proof: assuming that the robust feasible set of the RC (3) and the ARC (4) is F_1 and F_2, respectively.

$$F_1 = \left\{ x_1 \middle| \begin{matrix} \exists x_2, \forall \xi = (A_1 \quad A_2 \quad b) \in U \\ A_1 x_1 + A_2 x_2 \le b \end{matrix} \right\} \tag{5}$$

$$F_2 = \left\{ x_1 \middle| \begin{matrix} \forall \xi = (A_1 \quad A_2 \quad b) \in U \\ \exists x_2 : A_1 x_1 + A_2 x_2 \le b \end{matrix} \right\} \tag{6}$$

For $\forall \overline{x}_1 \in F_1$, there exists at least one $\overline{x}_2$ to make the following true.

When $\forall \xi = (A_1 \quad A_2 \quad b) \in U$,

There is inequality $A_1\overline{x}_1 + A_2\overline{x}_2 \le b$, and for $\forall \xi = (A_1 \quad A_2 \quad b) \in U$, there exists $x_2 = \overline{x}_2$, which makes the inequality $A_1\overline{x}_1 + A_2\overline{x}_2 \le b$ true. Then $x_1 = \overline{x}_1$, That is to say, $\overline{x}_1 \in F_2$, so that $F_1 \subset F_2$.

According to the reference [8], the optimum objective value of the ARC (4) is more optimal than that of the RC (3).

But ARC is often NP-Hard; for this difficulty, Ben-Tal[8] restricted the adjustable variables to be affine functions of the uncertain data and proposed AARO, AARO method is used to transform the uncertain problem into its AARC, AARC problem is not NP-Hard problem in general. Because it equivalent to a tractable optimization problem in some cases, and in other cases, it has an approximation which is tractable. The following formulation is used to illustrate the basic theory of AARC.

If x_2 is an affine function of ξ, $x_2 = y + Y\xi$, then the AARC of formulation (2) is given by

$$\min_{x_1}\begin{Bmatrix} c_1^T x_1 : \forall \xi = (A_1 \quad A_2 \quad b) \in U \\ A_1 x_1 + A_2(y + Y\xi) \le b \end{Bmatrix} \tag{7}$$

Based on the AARO theory, the GES uncertain optimization model is studied in the following section.

3 GES Uncertain Optimization Model

The good analysis of passenger traffic flow can provide predicative direction for the GES. Passenger traffic flow includes the number of elevator passengers, passenger arrival time and passenger distribution. During the analysis of the characteristics of passenger flow, both the passengers of the current and the future time are considered, and the up outcall and down outcall passengers on every floor are regarded as the uncertainty parameters, which is the refinement in reference [14] and [15].

3.1 Uncertain Passenger Traffic Flow Formulation

Through observation and statics, passenger traffic flow is a stochastic variable, vary feature of it is similar to the cases that passengers in the bus stop in unit time, and the landing planes in an airport in unit time, they all can be predicted by the Poisson distribution.

The number of passengers in the current time and in the next time is defined as the nominal value and the disturbance, respectively. Moreover, the disturbance equals to the current passengers plus a factor, and the factor is called as uncertain magnitude in this work. In RO, the uncertain magnitude is proposed by Ben-Tal [16].

Through analyzing, the uncertain traffic flow is represented as followings,

$$P_{ui} \in U_1 = [\overline{P}_{ui}, \overline{P}_{ui} + \lambda_u \overline{P}_{ui}] \tag{8}$$

$$P_{dj} \in U_2 = [\overline{P}_{dj}, \overline{P}_{dj} + \lambda_d \overline{P}_{dj}] \tag{9}$$

P_{ui}, up outcall passengers on the *i*th floor; P_{dj}, down outcall passengers oft on the *j*th floor,

$\overline{P}_{ui}$, the number of passengers who want to go up on the *i*th floor in the current time, it also the nominal value of uncertain traffic flow; $\overline{P}_{dj}$, the number of passengers who want to go down on the *j*th floor in the current time, it also the nominal value of uncertain traffic flow,

λ_u, the uncertain magnitude of uncertain up passenger traffic flow, $\lambda_u > 0$;

λ_d, the uncertain magnitude of uncertain down passenger traffic flow, $\lambda_d > 0$,

$\lambda_u \overline{P}_{ui}$, the up (down) uncertain passengers on the *i*th floor in the current time; it is also the disturbance value of uncertain traffic flow;

$\lambda_d \overline{P}_{dj}$, the down uncertain passengers on the *i*th floor in the current time; it is also the disturbance value of uncertain traffic flow.

The uncertain passenger traffic flow in a closed and bounded interval as in (8) and (9) is defined, after the passenger traffic flow is observed and counted in an actually elevator system, the analysis and the representation is reasonable. After the passenger traffic flow is analyzed, the GES uncertain optimization model is set up.

3.2 GES Uncertain Model

For simple narration, some notations are defined:

m , building floor number,

n , elevator number,

Q, car capacity,

i , floor subscript that the elevator needs to move upward,

j ,floor subscript that the elevator needs to move downward,

k , subscript of elevator,

$i = 1,\cdots,m-1$, $j = 2,\cdots,m$, $k = 1,\cdots,n$.

R_{ui} , service cost matrix of up outcall on the *i*th floor,

R_{dj} , service cost matrix of down outcall on the *j*th floor,

$$R_{ui}^T = (r_{ui1},\cdots,r_{uin})$$
$$R_{dj}^T = (r_{dj1},\cdots,r_{djn})$$

r_{uik} , the *k*th elevator's service cost when responses to up outcall on the *ith* floor,

r_{djk} , the *k*th elevator's service cost when responses to the down outcall on *j*th floor,

x_{ui} , the *i*th floor's scheduling solution when responses to up outcall,

x_{dj} , the *j*th floor's scheduling solution when responses to down outcall,

$$X_{ui}^T = (x_{ui1},\cdots,x_{uin})$$
$$X_{dj}^T = (x_{dj1},\cdots,x_{djn})$$

x_{uik} , whether the *k*th elevator is assigned to the up outcall on the *i*th floor or not,

$$x_{uik} = \begin{cases} 0, not \quad be\ assigned \\ 1, be\ assigned \end{cases}$$

x_{djk} , whether the *k*th elevator is assigned to the down outcall on the *j*th floor or not,

$$x_{ujk} = \begin{cases} 0, not \quad be\ assigned \\ 1, be\ assigned \end{cases}$$

The objective function of the model refers to the GES service cost. Waiting time, long waiting percent are chose as the compositions of the objective function.

(1) waiting time : The time from the passengers arriving at his initial floor to the elevator's arrival and serve his call on the *i*th floor ,when the *j*th elevator serve the up outcall, the waiting time cost is $T_{wtu} = t_{wij} - t_u$, t_{wij} is the time of *j*th elevator serve the passengers on the *i*th floor, t_u is time of up calls at birth.

(2) long waiting percent : when the kth elevator is assigned to the up outcall passenger on the ith floor, the rate of the number of passengers ($N_{lwpu}(i,k)$) whose waiting time exceeds 60s compared to those of all waiting passengers ($N_U(i,k)$),

$$T_{lwpu} = \frac{N_{lwpu}(i,k)}{N_u(i,k)}$$

The total service cost of the kth elevator responses to the up outcall on the ith floor is given by

$$r_{uik} = u_1 T_{awtu}(i,k) + u_2 T_{lwpu}(i,k)$$

$0 \le u_1, u_2 \le 1$, $u_1 + u_2 = 1$, u_1, u_2 is the weighted factor of $T_{awtu}(i,k)$, $T_{lwpu}(i,k)$ respectively.

By the same way, the total service cost of the kth elevator on the jth floor responses to the down outcall is given by

$$r_{djk} = d_1 T_{awtd}(j,k) + d_2 T_{lwtd}(j,k)$$

$0 \le d_1, d_2 \le 1$, $d_1 + d_2 = 1$, d_1, d_2 is the weighted factor of $T_{awtd}(j,k)$, $T_{lwpd}(j,k)$,respectively.

So service cost for the up outcall on the i_{th} floor is as following,

$$C_{ui} = P_{ui} R_{ui}^T x_{ui}$$

And the service cost for up outcalls is given by

$$C_{UI} = \sum_{i=1}^{m-1} C_{ui} = \sum_{i=1}^{m-1} P_{ui} R_{ui}^T x_{ui}$$

Furthermore, service cost for the down outcalls on the j_{th} floor is given by $C_{dj} = P_{dj} R_{dj}^T x_{dj}$

And the total service cost for down outcalls is given by

$$C_{DJ} = \sum_{j=2}^{m} C_{di} = \sum_{j=2}^{m} P_{dj} R_{dj}^T x_{dj}$$

Then the total service cost for both up outcalls and down outcalls is as followings

$$C_T = C_{UI} + C_{DJ} = \sum_{i=1}^{m-1} P_{ui} R_{ui}^T x_{ui} + \sum_{j=2}^{m} P_{dj} R_{dj}^T x_{dj}$$

The goal of GES is to make the total service cost C_T least value in the optimal scheduling solution.

In this paper, We adopt the idea of layer dispatching, that is to say, only one elevator in GES is assigned to serve the outcall every time, $\sum_{k=1}^{n} x_{uik} = 1$, $\sum_{k=1}^{n} x_{djk} = 1$.

The GES uncertain model can be represented by the following uncertain optimization problem

$$\min_{x_{uij},x_{djk}} \sum_{i=1}^{m-1} P_{ui} R_{ui}^T X_{ui} + \sum_{j=2}^{m} P_{dj} r_{dj}^T X_{dj}$$

$$s.t.\begin{cases} P_{ui} \in [\overline{P}_{ui}, \overline{P}_{ui} + \lambda_u \overline{P}_{ui}], i = 1,\cdots,m-1 \\ P_{dj} \in [P_{dj}, \overline{P}_{dj} + \lambda_d \overline{P}_{dj}], j = 2,\cdots,m, \\ \sum_{k=1}^{n} x_{uik} = 1 \\ \sum_{k=1}^{n} x_{djk} = 1 \\ x_{uik}, x_{djk} = 0 or 1, k = 1,\cdots,n \end{cases} \quad (10)$$

In order to make simple computation and only the constraint has uncertain parameters in model (10), relaxing variable C is introduced, and then the formula (10) is rewritten as

$$\min_{x_{uij},x_{djk},C} C$$

$$s.t.\begin{cases} \sum_{ui=1}^{m-1} P_{ui} R_{ui}^T X_{ui} + \sum_{j=2}^{m} P_{dj} R_{dj}^T X_{dj} \le C \\ P_{ui} \in [\overline{P}_{ui}, \overline{P}_{ui} + \lambda_u \overline{P}_{ui}], i = 1,\cdots,m-1 \\ P_{dj} \in [\overline{P}_{dj}, \overline{P}_{dj} + \lambda_d \overline{P}_{dj}], j = 2,\cdots,m, \\ \sum_{k=1}^{n} x_{uik} = 1 \\ \sum_{k=1}^{n} x_{djk} = 1 \\ x_{uik} = 0 or 1 \\ x_{djk} = 0 or 1 \\ k = 1,\cdots,n \end{cases} \quad (11)$$

In this model, the scheduling scheme x_{uik} and x_{djk} are all realized after the uncertain passenger traffic flow, that is to say all variables are all adjustable variables.

4 AARC of GES Model

The affine relationship between scheduling scheme (adjustable variables) and uncertain passenger traffic flow (uncertain parameters) must be constructed before AARO approach is used to solve the GES problem (11).

From section 3.2, $x_{uik} = 0 or 1$ and $x_{djk} = 0 or 1$, so the affine relationship can be constructed as the followings.

The real number a_{ik}, b_{jk} can be found from the following equations

$$x_{uik} = a_{ik} P_{ui} \quad (12)$$

$$x_{djk} = b_{jk} P_{dj} \quad (13)$$

In fact, for formulation (12),

When $P_{ui} \neq 0$, i.e. there is passengers need to go upper floors,

If $x_{uik} = 0$, i.e. the kth elevator does not be assigned (there is must be one elevator to be assigned), then $a_{ik} = 0$ meet (12);

If $x_{uik} = 1$, then $a_{ik} = \frac{1}{P_{ui}}$ meet (12);

When $P_{ui} = 0$, i.e. there is no passengers need to go upper floors, Then $x_{uik} = 0$, i.e. there is no elevator needs to be assigned then a_{ik} is random real value can meet (12).

As the same way, b_{jk} can be found to satisfy the formulation (13). Thus, the affine relationship between scheduling scheme and uncertain passenger traffic flow can be obtained.

The AARC of GES uncertain model can be obtained based on AARO theory of general uncertain optimization problem and the formulation (12) and (13), the AARC of GES uncertain model is as following

$$\min_{a_{ik},b_{jk},C} C$$

$$s.t.\begin{cases} \sum_{i=1}^{m-1} P_{ui} (\sum_{k=1}^{n} r_{uik} a_{ik} P_{ui}) + \sum_{j=2}^{m} P_{dj} (\sum_{k=1}^{n} r_{djk} b_{jk} P_{dj}) \le C \\ P_{ui} \in [\overline{P}_{ui}, \overline{P}_{ui} + \lambda_u \overline{P}_{ui}] \\ P_{dj} \in [\overline{P}_{dj}, \overline{P}_{dj} + \lambda_d \overline{P}_{dj}] \\ i = 1,\cdots,m-1 \\ j = 2,\cdots,m \\ a_{ik} P_{ui} = 0 or 1 \\ b_{jK} P_{dj} = 0 or 1 \\ k = 1,\cdots,n \end{cases} \quad (14)$$

In order to gets the robust solution satisfying all the constraints under all realizations of uncertain data (8) and (9), the formulation (14) can be rewritten as

$$\min_{a_{ik},b_{jk},C} C$$

$$s.t.\begin{cases} \sum_{i=1}^{m-1} [(\overline{P}_{ui} + \lambda_u \overline{P}_{ui})] \cdot \sum_{k=1}^{n} [r_{uik} a_{ik} (\overline{P}_{ui} + \lambda_u \overline{P}_{ui})] + \\ \sum_{j=2}^{m} [(\overline{P}_{dj} + \lambda_d \overline{P}_{dj}) r_{djl}] \cdot \sum_{k=1}^{n} [b_{jk} (\overline{P}_{dj} + \lambda_d \overline{P}_{dj})] \le C \\ \sum_{k=1}^{n} a_{ik} (\overline{P}_{ui} + \lambda_u \overline{P}_{ui}) = 0 or 1 \\ \sum_{k=1}^{n} b_{jk} (\overline{P}_{dj} + \lambda_d \overline{P}_{dj}) = 0 or 1 \\ k = 1,\cdots,n \end{cases} \quad (15)$$

The GES uncertain optimization model (5) is conversed into its AARC (15) through the AARO method. If the corresponding values are given, the optimal solution of the formula (15) is a big optimization problem, which has a lot of variables and many constraints, and it can be calculated by software, such as MATLAB, LINGO (Linear Interactive and General Optimizer), and other tools.

5 Simulation

In order to evaluate the proposed scheduling method, the simulation is done under the elevator virtual simulation environment [17]. Three scheduling algorithms' scheduling performances are evaluated by VC via importing algorithms' dll (dynamic link library) program. And certain optimization problem AARC (15) is solved by LINGO software, an interface link between LINGO and VC is developed to realize the scheduling. Simulation conditions setting are shown in table 1.

Table1: Elevator Setting

Number of Elevators	4
Velocity (m/s)	1.8
Acceleration(m/s/s)	1.1
Jerk(m/s/s/s)	1
Car Capacity(person)	13
Time of Opening & Closing door(s)	4
Passenger's Transferring(s)	1.2

Table2: Building Setting

Number of Floors	16
Floor Distance(m)	3

Two kinds of peak traffic flows have been chosen to compare scheduling performances (including Average Waiting Time (AWT), Long Waiting Percent (LWP)) of AARO with other algorithms, including Minimize Waiting Time (MWT), Static Zoning (SZ), and specific settings of flows are as follows:
(1) up-peak traffic flow, 300 persons /90min, from the hall floor to upper floors,
(2) down-peak traffic flow, 300presons /90min, from the different floors to the hall floor.
The simulation results are shown in table 3.

Table3: Result of Simulation

Traffic Flow	Algorithm	AWT(s)	LWP (%)
Up-Peak	MWT	38.34	21.8
	SZ	40.23	12.42
	AARO	**35. 85**	**15.83**
Down-Peak	MWT	42.31	19.53
	SZ	35.46	15.94
	AARO	**26.43**	**10.10**

From table 3, we can see that,

For minimize waiting time algorithm: it does not consider the changes of the passenger traffic flow mode. Furthermore, it has not enough ability to solve the changes of passenger traffic flow. It makes assignment only through finding the optimal solution of the GES optimization model. Thus it does not show any prominent performances.

For static zoning algorithm: it shows the better scheduling performance during down-peak period. It distinguishes the passengers whose attained rate is very high through the zoning, so it reduces the long waiting percent.

For AARO algorithm: compared with other algorithms, it shows better scheduling performance, which because it considers the influences of traffic flow uncertainty, especially in long waiting percent. Long waiting time occurs when passengers miss the elevator, which is coming at just moment. At the former time, AARO has predicted the passengers who may show in the next time. Moreover, the corresponding measures are made for improving these indexes permanently.

6 Conclusions

The AARO scheduling method was proposed to solve the GES problem with the uncertainty of the passenger traffic flow. On the basis of AARO theory, the GES uncertain optimization model was transformed into a certain optimization problem through finding its AARC. For different passenger traffic flows, the AARO method has stronger ability to adapt to up and down peak situations. In general it improves the scheduling performance well.

References

[1] Z. H. Li, H.Z. Tan, and et al. Knowledge-based intelligent information and engineering systems. *Lecture Notes in Computer Science*, 2007, 4692: 831-838.

[2] T. Tapio, Y. Jari. Evolutionary bi-objective optimization in the elevator car routing problem. *European Journal of Operational Research,* 2006, 169(3): 960-977.

[3] H. Kotaro, T. Eguchi and et al. A double-deck elevator group supervisory control system using genetic network programming. *IEEE Transactions on Systems, Man, and Cybernetics-Part C: Applications and Reviews*, 2008, 38(4): 535-550.

[4] J. Jamaludin, N. A. Rahim, W. P. Hew. Development of a self-tuning fuzzy logic controller for intelligent control of elevator systems. *Engineering Applications of Artificial Intelligence*, 2009, 22(8): 1167-1178.

[5] S. Tanaka, Y. Uraguchi, M. Araki. A study on objective functions for dynamic operation optimization of a single-car elevator system with destination hall call registration. *Proceedings of 2004 IEEE International Conference on Systems, Man and Cybernetics.* Washington, D. C., USA: IEEE, 2004, 6274-6279.

[6] F. Luo, Y. G. Xu, J. Z. Cao. Modeling and control in elevator group control system with destination registration. *Control and Decision*, 2006, 21 (10): 1159-1162. (In Chinese).

[7] S. Tanaka, Y. Uraguchi, M. Araki. Dynamic optimization of the operation of single-car elevator systems with destination hall call registration Part I. formulation and simulations. *European Journal of Operational Research,* 2005 167(2): 550-573.

[8] A. Ben-Tal, A. Goryashko, and et al. Adjustable robust solutions of uncertain linear programs. *Math. Program*, 2004, 99(2): 351-376.

[9] O. Boni, A. Ben-Tal. Adjustable robust counterpart of conic quadratic problems. *Math Meth Opera Res*, 2008, 68(2): 211-233.
[10] F. Tang, L. Zhang, J. Huang, W.G Yang. An affinely adjustable robust optimization approach to emergency logistics. *IEEE International Conference on Industrial Engineering and Engineering Management.* Unites States: IEEE Computer Society: 2009, 1738-1742.
[11] V. Guigues. Robust production management. *Optima Eng*, 2009, 10(4): 505-532.
[12] A. Ben-Tal, B. Golany, S. Shimrit. Robust multi-echelon multi-period inventory control. *European Journal of Operational Research*, 2009, 199(3): 922-935.
[13] C. Lemaréchal, A. Ouorou, G. Petrou. Robust network design in telecommunications under polytypic demand uncertainty. *European Journal of Operational Research*, 2010, 206(3): 634-641.
[14] Q. Zong, W.J. Wang, Y Z He. Elevator group scheduling based on robust optimization. *Control Theory&Applications*, 2008, 25(4): 743-748. (In Chinese).
[15] Q. Zong, L. Q. Dou, Weijia Wang. Robust discrete optimization scheduling strategy for elevator group control system. *Control and Decision*, 2008, 23(5): 520-524. (In Chinese).
[16] A. Ben-Tal, A. Nemirovski. Robust solutions of Linear Programming problems contaminated with uncertain data. *Math. Program*, 20008, 8(3): 411-424.
[17] Q. Zong, L.H. Xue, Z.S Wang. Virtual simulation environments of elevator group control systems. *Elevator World*, 2001 (11): 90-93.