A Mixed Robust Optimization and Multi-agent Coordination Method for Elevator Group Control Scheduling

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Abstract: An elevator group control scheduling (EGCS) method, which is combined with robust optimization (RO) and multi-agents, is proposed to deal with the uncertainty with the elevator traffic flow and the computation complexity. Considering the uncertainty of elevator traffic flow, the elevator schedule model based on RO is developed. An integrated method combined with multi-agent coordination (MAC) and RO schedule is designed to compensate for the disadvantage of RO for the EGCS problem. Simulation results show that the proposed method can improve the performance and adaptability of the EGCS.

Key Words: Elevator Group Control; Robust Optimization; Multi-Agent Coordination

I. INTRODUCTION

Elevator scheduling is a process of carrying passengers to the destination safely and efficiently. Meanwhile, the mental and physical demands of passengers should be considered seriously. When there is only an elevator in the building, the common scheduling process is based on logical control. In the case that several elevators are available in the building, the methods of EGCS will be employed. Currently, EGCS have become widely used in many types of buildings.

EGCS is a time sequence decision problem in dynamic environment[1]. At present, there are plenty of different group control algorithms for EGCS, i.e., the static zoning, the neural network, genetic algorithms, and learning algorithms, etc [2]. These advanced or intelligent algorithms have brought great improvements of performance in many aspects. However, the environment of EGCS is very complex. First of all, the uncertainty of traffic flow of buildings deteriorates the dispatching result. Secondly, searching space for optimal dispatching is very large. For instance, four elevator to serve a building with 16 floors, the number of the searching space will be about 10^{35}, which will led to a large computational complexity. Finally, the environment of EGCS is dynamically variable. Even though the dispatching is optimal at this time, it is hard to guarantee its optimization at next time. Above three complexities can be summed up as two difficult problems: the uncertainty of elevator traffic flow and computational complexity in scheduling.

However, most of current scheduling methods are difficult to deal with both of these two problems at the same time. Static zoning, neural network, and genetic algorithms have some advantage to decrease the computational complexity. But they can not solve the uncertainty of traffic flow. For this some new technology have been used, such as the destination hall call registration, the camera, etc.[3-5], and they have obtained some improvements at a certain extent. But most of EGCS do not have these functions due to the cost concern. Therefore, we present an EGCS method. In the first step, the traffic flow prediction information is taken into account for the next operation time, and the predictive error is regarded as an uncertain item. In the second step, we use the RO approach to build the EGCS model with uncertainty. In the final step, multi-agents coordination method is used to decrease the computational complexity. An integrated EGCS method based on RO and MAC is developed in this paper. Simulation results show that the proposed method can effectively improve the performance and adaptability of EGCS.

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II. ROBUST OPTIMIZATION

Definition 1: Consider an uncertain mathematical optimization problem of the form:

$$\begin{aligned} &\min \ f(x,\xi) \\ &s.t.\ \ g_i(x,\xi) \le 0, \forall \xi \in U, i = 1,\cdots,m \end{aligned} \tag{1}$$

where x is the design vector, ξ denotes the data element of the problem, U is uncertainty set, and $\xi \in U$, $g_i(x,\xi) \le 0$ is the constraints. If U is a closed and bounded set, the optimization problem (1) is called robust optimization. RO requires that all of constraints must be satisfied. Therefore, comparing with other optimization problems, RO approach emphasizes a “hard” constraint, which means that the optimal solution of RO must be feasible for all of realizations. In fact, RO is based on the worst-case optimization problem, i.e., the solution which is solved should keep the optimality in the worst case. The kernel methodology of RO is to transfer the RO problem into a certain computationally tractable optimization problem, which is called Robust Counterpart (RC). By solving the RC optimization problem, the optimal feasible solution of RO can be obtained [6-7].

Lemma 1. Considering an uncertain linear optimization problem of the following form

$$\begin{aligned} &(P) \quad \min_x \left\{ \sum_{i=1}^{n} p_i x_i \mid x_i \ge 0 \ \ p_i \in U^\theta \right\} \\ &s.t. \quad U^\theta = \left\{ p \in R^n \mid \sum_{i=1}^{n} \sigma_i^{-2} (p_i - p_i^*)^2 \le \theta^2 \right\} \end{aligned} \tag{2}$$

The RC of problem (2) can be transformed into the following optimization problem:

$$
\begin{aligned}
&(P^*) \quad \min_x \left\{ \sum_{i=1}^{n} p_i^* x_i - \theta V^{1/2}(x) \mid x \geq 0 \right\} \\
&s.t. \quad V(x) = \sum_{i=1}^{n} \sigma_i^2 x_i^2, \quad i = 1, 2, \cdots, m
\end{aligned}
\tag{3}
$$

The objective of optimization problem (P) can be transformed into its constraint. And then we can get the form of (P^*). (Please refer to [8] for the details of the proof)

Based on Lemma 1, a conclusion can be obtained that an uncertain linear optimization problem can be transformed to a certain quadratic programming problem. And currently, there are many methods to solve the quadratic programming problem[9]. (i.e., inner-point method and so on.)

III. The Model of EGCS Based on RO

This section presents RO model for EGCS. First, we analyze the traffic flow uncertainty with regard to its Poisson Process. And then define the objective function of scheduling. Based on these analysis, RO model for EGCS is built by using RO theory.

A. The traffic Flow Uncertainty

The elevator traffic flow expresses the distribution of passengers in the elevator system. In general, it is regarded as Poisson process. In a certain time phase, the probability of arriving k passengers is expressed as

$$P(k) = \frac{\lambda^k}{k!} e^{-\lambda} \tag{4}$$

where $\lambda(t)$ denotes the numbers of the average arriving passengers. With the (4), the numbers of arriving passergers at the t+1 moment can be predicted according to the numbers at the t moment. However, the predictive error is inevitable. We assume that P_i is the actual number of current passengers who make calling on the i-th floor, while P_i^* denotes the predictive number of passengers who make calling on the i-th floor. ΔP_i denotes predictive error and σ_i denotes the error's upper bound. We assume, without loss of general, that the predictive error is symmetry distribution between upper and lower bound of errors, then we have

$$P_i = P_i^* + \Delta P_i, \ \ \Delta P_i \in [-\sigma_i, \sigma_i] \tag{5}$$

The uncertainty of traffic flow is defined in a symmetry district. The above assumption holds for the real passengers' information of the elevator system with a large number of stochastic observation.

B. Decision of Objective Function

We define R as the cost of scheduling, m as the floor number of the building and n as the elevator numbers. The following symbols and parameters will be used in this part:

P_{iu} -The number of passengers making "up calling" on *i-th* floor, $i = 1, \cdots, m$;

P_{id} - The number of "down calling" on *i-th* floor;

r_{iku} - The cost of k-th elevator which is dispatched to respond the up calling of i-th floor $i = 1, \cdots, m$; $k = 1, \cdots, n$;

r_{ikd} - The cost of k-th elevator which is dispatched to respond the down calling of i-th floor;

$r_{iu} = (r_{i1u}, \cdots, r_{inu})^T \in R^{n \times 1}$; $r_{id} = (r_{i1d}, \cdots, r_{ind})^T \in R^{n \times 1}$

x_{iu} -The dispatching to service up calling of the *i-th* floor;

x_{id} -The dispatching to down calling of the *i-th* floor,

The total service cost is

$$R = \sum_{i=1}^{m} P_{iu} (r_{iu})^T x_{iu} + \sum_{i=1}^{m} P_{id} (r_{id})^T x_{id} \tag{6}$$

And it is also the objective function of elevator group scheduling. The scheduling aim is to minimize the above objective function, where r_{iu}, r_{id} can be the waiting time, the traveling time, the power consumer, or their weight average expression.

In the simulation part, we use the cost of waiting time and the cost of stop times as the total cost which can be expressed as follows: (r_{iu}, r_{id} is Up cost or down Cost, both can be calculated by formula (7))

$$r_i = \sqrt{\rho_w T_{wi}(p)^2 + \rho_c C_{ip}{}^2}, \ \ \rho_w + \rho_c = 1 \tag{7}$$

where $T_{wi}(p) = t + t_{fi} - t_p$ is the waiting time cost of the *i-th* elevator service for this floor, p is the floor, t denotes current time, t_{fi} denotes the needed time when elevator is dispatched to respond the callings, t_p denotes the moment when callings happened, C_{ip} is stop times before the *i-th* elevator services the callings of floor p, ρ_w and ρ_c are the weight coefficients of T_{wi} and C_{ip} respectively.

C. The Model of Robust Optimization of EGCS

Based on the above analysis, we can get an uncertain optimization model of elevator group scheduling as follows:

$$
\begin{aligned}
&\min \left\{ \sum_{i=1}^{m} P_{iu} (r_{iu})^T x_{iu} + \sum_{i=1}^{m} P_{id} (r_{id})^T x_{id} \right\} \\
&\text{s.t.} \ \ P_{iu}, P_{id} \in U \square U = \left\{ \sum_{i=1}^{m} \frac{(P_i - P_i^*)^2}{\sigma_i^2} \leq \theta^2 \right\}
\end{aligned}
\tag{8}
$$

where U is an ellipsoid uncertain set. By substituting (5), (8) can be rewritten as follows

$$
\begin{aligned}
&\min \{ \sum_{i=1}^{m} (P_{iu}{}^* (r_{iu})^T x_{iu} + P_{id}{}^* (r_{id})^T x_{id}) + \\
&\sum_{i=1}^{m} (\Delta P_{iu} (r_{iu})^T x_{iu} + \Delta P_{id} (r_{id})^T x_{id}) \}
\end{aligned}
\tag{9}
$$

where $\Delta P_{iu} \in [-\sigma_{iu}, \sigma_{iu}]$, $\Delta P_{id} \in [-\sigma_{id}, \sigma_{id}]$. From Lemma 1, we obtain the robust counterpart of formula (9) as formula (10):

Thus, we have set up the RO model of elevator group scheduling (i.e., (8) ~ (9)) and transformed it to a certain quadratic programming problem (i.e., (10)).

$$\min\left\{\sum_{i=1}^{m}\left(P_{iu}^{*}(r_{iu})^{T}x_{iu}+P_{id}^{*}(r_{id})^{T}x_{id}\right)-\theta V^{1/2}(x)\right\}$$
$$V(x)=\sum_{i=1}^{m}\left(((r_{iu})^{T}x_{iu})^{2}\sigma_{iu}^{2}+((r_{id})^{T}x_{id})^{2}\sigma_{id}^{2}\right) \quad (10)$$

IV. MULTI-AGENT COORDINATION OF EGCS

Multi-Agent system (MAS) is one of important research branches of intelligent control. Especially, it can efficiently resolve many scheduling problems such as the workshop scheduling, the traffic scheduling, and the power scheduling. For EGCS, dispatching is implemented via a central agent, which should deal with a large number of data processing that increase the computational complexity. To reduce the computation complexity problem, a MAC scheduling algorithm is developed.

A. Structure of Model

we assume that the elevator group contains four elevators. The structure of every elevator agent is shown in Fig.1.

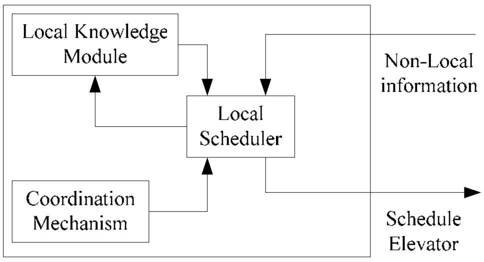


FIGURE Ⅰ STRUCTURE OF SINGLE ELEVATOR AGENT

1) Local knowledge module (LKM).

This module is a storage unit for three kinds of information: hall calls that the agent should respond to, car calls of itself, and the predictive arriving time to each floor. And it also takes on a part of calculations. Namely, it computes the arriving time of elevator at each floor based on the information stored and the local planning.

2) Local scheduler (LS).

The objective of this module is to produce and modify local scheduling. As shown in Fig.1, there are three inputs to the module. The most important part is the non-local information that comes from the other elevator agent obtained by the communication between different agents. Note that if the non-local information affects the agent's planning (i.e., new calls or dispatch conflicts), the agent must modify or re-produce it's scheduling depending on the pre-defined coordination mechanism. The new scheduling will be stored to local knowledge module, and then be used to implement elevator running.

3) Coordination mechanisms (CM).

This module is the core of the whole structure. Its functions include that how to respond new call, how to identify traffic flow, how to deal with conflicts and how to assign idle elevator, which will be introduced later.

The structure of Fig.1 denotes a single elevator Agent. And we can use it to establish the whole structure of EGCS which is shown in Fig.2. $Agent_i$ (for i=1,2,…,n) has the same structure shown as in Fig.1. The Share Data Storage (SDS) will save the local scheduling scheme for each Agent. Coordination Agent (CA) is the manager that can distribute the information in the SDS to the agent that needs the information. This enables each agent to obtain other agent's local scheduling scheme via the CA.

B. Coordination Agent

In the Fig.2, CA will analysis the mutual relations between one agent and others, and arrange multi-agent interaction depends on the relations. When the CA detects the following scenario:

1) Running direction of an elevator has been changed from Up to Down, or Down to Up.

2) An elevator remains in the idle state that Stop and No passenger.

3) Whether new call signal is sent out or not.

4) The reference zone of an elevator has been changed. (Please refer to the Fig.3)

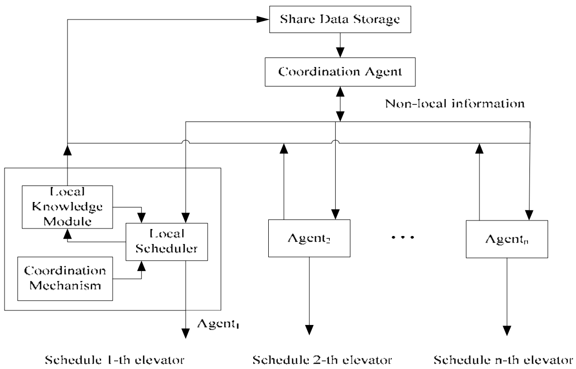


FIGURE Ⅱ STRUCTURE OF MULTI-AGENT SYSTEM

CA will inform these agents to commute the local information and schedule again.

C. Planning of Single Agent

Each agent has the ability of planning, and it can decide the scheduling of itself in terms of non-local information, coordination mechanism and the local knowledge of itself.

1) The principles of planning

The planning of an agent means to decide which call should be responded. Therefore, each agent should be intelligent, and it can calculate and decide itself. Namely, it can arrange rationally the next action. The principles include:

(1) When a new call comes, the agent should judge whether the call belongs to its dynamics reference zone or not. If the call is in its own zone, the agent will plan the call to itself.

(2) If the call doesn't belong to any zone of all agents, the CA will distribute the call by minimizing the objective function..
(3) If (1) and (2) do not hold, it complies with the coordination mechanisms.

2) Coordination mechanism

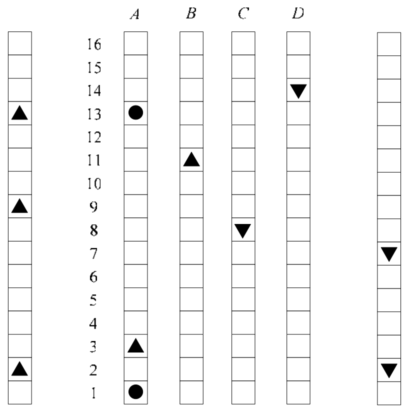
Coordination mechanism is listed as follows:
(1) When the direction of one elevator changes (Up to Down or Down to Up), all calls (include those being arranged to the other agent) that have not been responded are arranged to the elevator agent.
(2) When LS find a conflict from non-local information, which result in LS's former planning does not in according with current reference zone, it will cancel the former planning.
(3) When one elevator agent is idle, it will send request to the CA, and the CA will judge whether the agent should to help other agents or not.
(4) If none of above status holds, the agent will change its running direction, and continuous to work under the first coordination mechanism.

D. The Scheduling Process

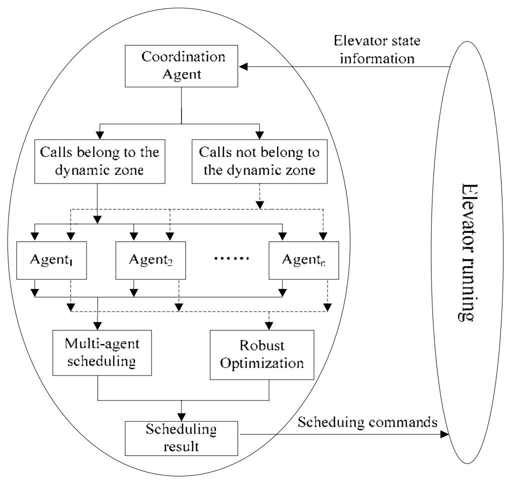
Based on above description, we can summarize the process of the scheduling as follows:
1) A local planning is formed based on each agent.
2) The local planning information is saved in SDS.
3) The CA detects all mutual relations among agents.
4) The scheduling scheme is modified or re-planned with regard to the request of CA, local planning information and the prediction to arriving time.
5) Repeating the above four steps till the task being finished

V. Elevator Group Control Scheduling Method Based on RO and MAC

By using the RO decision model presented, the problem of traffic flow uncertainty can be efficiently solved. But when the traffic flow is large or the building has much more floors, the method is not a good choice because that the single RO will face much more computation and a large decision delay may occur. The requirement of real time implementation for EGCS will be hard to meet. The decision delay can be handled by combining MAC and RO method. For this, we propose an integrated EGCS method based on RO and MAC. The scheduling process is listed as follows:
1) Based on Fig.2, build multi-agent elevator scheduling structure, and let each agent has the function of decision and computation.
2) In Fig.2, set dynamic service zones for each agent based on the following rules: We can see Fig.3.At the left, the symbol ▲ represents that the direction of the outer call is up, and at the right, ▼ represents the direction of the outer call is down, and in the center "A,B,C,D", ● denotes the inner call, ▲ or ▼ are the current location and direction of the elevator. Each elevator regards its front-elevator with the same direction as a reference. And if without the same direction front-elevator, the highest floor or lowest floor will be defined as the reference. For example, in Fig. 3, the reference of the elevator A is B, B's is the highest floor, C's is the lowest floor, D's is C. In this way, every elevator will have a dynamic zone. At current moment, A's zone is [3-10] floor, B's [11-16], C's [8-1], D's [14-9]. The calls belonging to certain zone will be distributed its relevant elevator. Therefore, every elevator agent will have a few of reactive decision ability to zone call, which avoid RO solving processing for every call. Thereby, computational complexity is decreased.
3) When an outer call does not belong to any zones, Coordination Agent will make a judgement and trigger the robust optimization process.
The whole scheduling processing is shown in Fig.4.



FIGUREIII ELEVATOR SYSTEM SCHEMATIC DIAGRAM



FIGUREIV EGCS METHOD BASED ON RO AND MAC

VI. Simulation and Analysis

To illustrate the effectiveness of the proposed scheduling approach, the simulation is finished by virtual elevator environment (VEE) of our lab[10], as be shown in Fig.5. This software can validate the performance of different algorithms, and display the performance on computer screen online. We select the following parameters for the simulation:
1) The parameter of environment
The building: 16 floors, the lobby is 4m and the others are 3m.

Elevator: 4 elevators, velocity is 1.5m/s, acceleration $1m/s^2$, capacity 12 passengers, the time of open and close 1s, load time of a passenger 1s.

Traffic flow (TR): 4 traffic flows that are respectively:

TR1: Up-peak pattern

TR2: Inter-floor pattern.

TR3: Down-peak pattern

TR4: Uppeak-Interfloor-Idle-Downpeak pattern

2) The scheduling algorithms

AL1: min waiting time.

AL2: genetic algorithm.

AL3: robust optimization and multi-agent.

3) The performance

AWT: average waiting time of passengers.

ATT: average travel time of passengers.

RWLT: rate of waiting longer time of passengers.

ACD: average crowding degree of passengers.

NSS: numbers of start-up and stop.

The results of simulation are listed in table.1.

TABLE Ⅰ RESULT OF SIMULATION

Performance: Algorithm: Traffic flow:		AWT	ATT	RWLT	ACD	NSS
TR1	AL1	29.17	49.28	15.4%	8.97	190
	AL2	22.01	50.51	5%	9.21	176
	AL3	**24.29**	**48.20**	**8%**	**9.25**	**181**
TR2	AL1	24.45	27.31	21.3%	3.71	91
	AL2	21.05	30.40	8%	2.65	87
	AL3	**18.36**	**24.10**	**4%**	**2.74**	**82**
TR3	AL1	27.65	27.38	12.5%	5.62	188
	AL2	25.33	31.32	7.4%	5.56	189
	AL3	**23.36**	**28.75**	**6.4%**	**6.26**	**176**
TR4	AL1	26.61	35.42	16.3%	5.87	431
	AL2	24.14	37.52	7.3%	5.44	418
	AL3	**21.96**	**32.03**	**6.2%**	**5.71**	**407**

Analysis: Algorithm 1 denotes a traditional method of EGCS, while algorithm 2 is an intelligent method, and algorithm 3 is the method proposed in this paper. It can be shown from table.1 that the average performance of AL3 is the best in the three kinds of algorithms, next is AL2, and the final one is AL1. Apart from the traffic flow pattern TR1, AL3 is superior to AL2 at other traffic flow pattern. The reason is listed as follows: most passengers arrive from the hall to other floors at TR1 so that the passengers arriving distribution is simple in this condition. As a result, the decision number depending on optimization is relative fewer, and moreover the capability of RO can not be used fully. However, the fuzzy method of AL2 is based on fuzzy rules, which can promptly get the scheduling result. At other traffic flow patterns, passengers arriving are relatively complex, and there are much more uncertainties. Therefore, RO method is more suitable to handle the uncertainty of traffic flow. And the multi-agent method makes up the shortage of computational complexity of RO. The data in table1 show that AL3 have almost better performance at all kinds of traffic flow pattern in spite of the changing. AL1 is a completely traditional optimization method that can not deal with the uncertainty and large computation, which result in the worst performance.

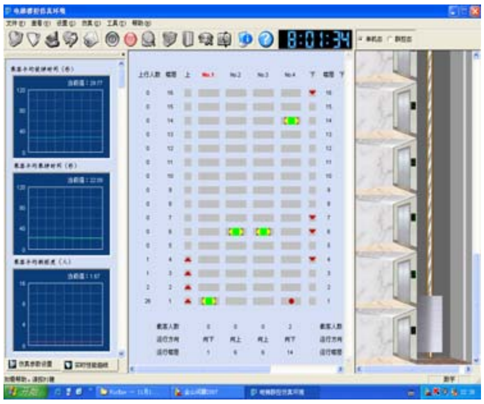


FIGURE Ⅴ VIRTUAL ELEVATOR ENVIRONMENT

VII. CONCLUSION

The key problems of EGCS are to overcome the uncertainty of traffic flow and the computational complexity. For this, the RO model for EGCS is modeled firstly to solve the uncertainty of traffic flow, and then use MAC method to reduce the computations. Based on this, we develop the integrated RO and MAC method. Simulation results show that the proposed method can improve the scheduling performances.

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