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Energy-saving scheduling optimization under up-peak traffic for group elevator system in building

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ABSTRACT

Energy-saving group scheduling is a significant challenge for multi-elevator system in building. Among various traffic patterns in building, most energy is consumed under up-peak traffic pattern. To save unnecessary energy consumption and realize optimal scheduling, an energy-saving scheduling optimization method for up-peak pattern is proposed. The optimization objective is minimizing the scheduling energy price of the group system. The up-peak energy price function is defined first, both of picking and traveling energy are considered in it. Based on that, scheduling Robust Optimization model is built to handle elevator scheduling under uncertain up-peak traffic flow. The key point of optimization is a dual energy-saving mechanism. One is adaptive configuration, choosing fewer but enough number's elevator to transport waiting passengers on the lobby floor. Another is optimization selection, choosing which elevators to serve according to minimum energy price after the number of dispatched elevators is decided. In practice, elevators in group system are dispatched by scheduling decision of the optimization to realize system energy-saving operation under up-peak pattern. In simulation, compared with the scheduling performances of other algorithms under different up-peak flows in several buildings, effectiveness of the method proposed is verified.

1. Introduction

Scheduling operation of building transportation systems has profound societal impact such as in improving efficiency and reducing costs [1]. Scheduling of a group of elevators in a building has long been recognized as an important issue, since elevator service ranks second after heating, ventilation and air conditioning (HVAC) as the main complaints of building tenants [2]. For group elevator system in building, a major challenge is developing a scheduling optimization algorithm for deciding which one or more elevators should be dispatched to carry waiting passengers on different calling floors based on specified scheduling criteria [3,4]. Effective elevator scheduling algorithms must meet certain scheduling performances [5]. In elevator scheduling, passenger waiting time is the prevalent performance. This is the time from when a passenger enters the system (hallway) until that passenger can board an elevator. Many scheduling algorithms have been developed to minimize the time performance, e.g., minimizing waiting time algorithm [3], exact calculation of expected waiting time algorithm [6], group elevator scheduling with advance information [7]. Currently, we have paid more attention to energy-saving elevator scheduling in building. Recent statistics suggest that the global energy use contributed by buildings is about 40% [8], and the overall electricity consumption of a building contributed by elevators is about 3–8% and rising [9,10]. How to reduce the energy consumption of the whole elevator system effectively is a challenging issue. The energy performance which indicates the quality of elevator system in energy use should be considered in scheduling algorithms [11]. Elevator energy costs are different under different traffic patterns. There are three traffic patterns in building, peak, inter-floor and idle pattern. Most energy is consumed under up-peak pattern because of the numerous passengers during up-peak. The up-peak traffic pattern occurs during the morning rush hour at a typical office building, when hall calls occur at the lobby only and result in car calls to all floors [5]. Energy-saving dispatching of group elevator system is not handled by most peak scheduling algorithms [12–15]. The ideal way of optimal scheduling is balancing the trade-off between energy performance and time performance. In this paper we propose an energy-saving scheduling optimization method for up-peak traffic pattern for minimizing elevator system dispatching energy and keeping time performance acceptable.

Elevator group scheduling is a typical combinational optimization problem [16], we can solve energy-saving elevator scheduling by optimization approaches. Recent studies on multi-elevator energy conservation algorithms yield limited success. Yu [17] proposed an energy consumption group control method based on Genetic Network Programming (GNP), considered energy in the

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fitness function of GNP, but mathematical expression of energy cost was not given. And our previous work, Zhang [18] developed an energy-saving scheduling strategy based on Ant Colony Optimization (ACO), the optimization object is minimizing multi-elevator system consumption. However, only picking energy (energy consumed by elevator from current position to calling floor) was studied in its energy price function, traveling energy (energy consumed by elevator from calling floor to destination floor) was neglected in it. Precise objective function of scheduling energy price is important for scheduling optimization, we can design energy-saving scheduling algorithms with the optimization objective of minimizing the energy price function. In this paper, we make two improvements on the basis of work in [18] to handle up-peak dispatching. First, both of picking and traveling energy are considered in the energy price function, the two energy constitute the whole energy consumption of group elevators. Second, the energy function in [18] is a general one for all traffic patterns in building, here the new function is built specially for up-peak pattern, and applied to peak scheduling.

Based on the energy price objective function, Robust Optimization (RO) scheduling model is built in this paper. RO theory provides a framework to handle uncertain programming [19,20], and has been applied in scheduling optimization areas [21–23]. Here RO method is introduced to handle uncertain energy-saving dispatching optimization. Scheduling under uncertain traffic flows is always a challenging issue in group elevator system, passenger flows uncertainty influences scheduling seriously, unnecessary energy is consumed by unreasonable dispatching. Recent studies on uncertain group scheduling focus on elevator traffic flow recognition by increasing hardware, e.g., dispatching based on video monitoring scanner/camera [24,25] or destination registration device [26–28]. However, it is not realistic to upgrade all existing multi-elevator system by hardware. The goal of our work is to explore a novel energy-saving elevator scheduling optimization method which is immune to the traffic flows uncertainty, and we only change the scheduling algorithm in the group scheduling controller without new hardware investments.

Besides, we consider adaptive adjustment of operating elevator number in the RO up-peak scheduling model. In most cases of up-peak scheduling, it is no need to dispatch all elevators in group to take and carry passengers, dispatching fewer elevators to serve can save energy to some extent. And during up-peak, the waiting time of lobby waiting passengers has close relationship with the number of elevators dispatched. Because more operating elevators lead to more carrying capacity, less round-trip time for elevators and less waiting time for passengers, but more electricity consumption. It is feasible to choose a proper operating elevator number to balance the trade-off between energy and time performance. The pioneer research was proposed by Nagatani [29]. However, there is an ideal assumption in [29], all passengers get in elevators in the lobby and get off on the top floor of the building. Thus it is no need to determine which cars to move after the decision of operating cars number in scheduling, because the states of all dispatched elevators are same. Nevertheless in practice, scheduling algorithms have to decide, not only dispatching how many cars to move, but also dispatching which cars to move, and the ideal condition does not exist. To handle the two-stage optimization, a dual energy-saving mechanism is proposed in our RO model. On one hand, adaptive configuration, choosing how many cars need to be scheduled according to up-peak traffic, commanding dispatched elevators to be active and un-dispatched ones to be dead. Active and dead are two states defined for each elevator. On the other hand, optimization selection, choosing which cars to be dispatched. During up-peak, elevator state changes between active and dead according to optimal energy-saving dispatching solution.

The remainder of this paper is organized as follows. In Section 2, basic idea of energy-saving up-peak scheduling problem is shown. In Section 3, scheduling energy price function is derived, with consideration of picking and traveling energy. In Section 4, up-peak energy-saving scheduling RO model with dual energy-saving mechanism is built to minimize the scheduling energy price, up-peak energy-saving strategy is proposed. Section 5 gives performance results to demonstrate the efficacy of our algorithm. Finally, conclusion is drawn in Section 6.

2. Problem formulation

The passenger flow of up-peak traffic pattern is called up-peak flow. During up-peak, all passengers arrive only at the first floor and move up from the first floor to their requested destinations [12]. More energy is consumed under up-peak pattern than other traffic patterns because of the numerous upwards passengers. Research on up-peak energy-saving scheduling has great significance for group system energy-saving operation. In fact, there is always a contradiction between system energy consumption and passengers waiting time. We cannot only emphasize the energy and neglect passengers feeling. How to reduce the energy consumption effectively and keep acceptable time performance is a challenging issue. The pioneer work studied the coupling relationship between energy and time in group elevator scheduling [29]. We can save elevator system energy and keep passengers waiting time not to exceed some specified value, by choosing an optimal number of operating cars in up-peak dispatching. After deciding the number of dispatched cars, we further determine which cars to be chosen by minimum scheduling energy criteria. This is the basic idea of dual energy-saving mechanism proposed in the following scheduling optimization model. First, adaptive configuration, choosing the number of operating cars as few as possible to serve waiting passengers in the lobby to save energy costs, commanding dispatched cars to be active and un-dispatched cars dead, for making full use of every car's loading capability, avoiding the situation passengers aboard all elevators in the lobby dispersedly, and keeping passenger waiting time acceptable. Second, optimization decision, choosing which cars to be dispatched according to minimum scheduling energy. In this paper, the energy price contains not only picking energy, but also traveling energy, considers not only "energy from waiting to loading", but also "energy from loading to unloading".

For illustration, Fig. 1 is given. In the system with three cars installed, in a scheduling during up-peak, if dispatched two elevators is enough to satisfy waiting time performance, and dispatching one elevator cannot meet the time demand, for the purpose of system energy-efficient operation, the scheduling algorithm will dispatch two cars to serve the waiting people on the first floor. After choosing the number of dispatched cars, the algorithm will decide which two cars to be scheduled. From the example, car number 2 is static now, car number 1 and 3 are moving towards, and the current position of car 1 is higher, its final top destination is lower. It is assumed, present people number inside car 1 and 3 are same, there is only one destination floor of car 1 and 3, and the waiting passengers on the first floor will be distributed to each dispatched car uniformly. Based on minimum scheduling energy (picking and traveling energy) criteria, car 1 and 2 will be dispatched to take the waiting passengers on the lobby floor.

Moreover, according to the above scheduling decision, three elevators' running states will be different and typical. Car 1 (Active Before Active After) is loading passengers upwards before this scheduling and dispatched this scheduling, thus the car will transport the passengers inside to their destinations first, and return to lobby to transport new waiting people. Car 2 (Dead Before Active After) is stopping and a dead car now, after receiving the scheduling