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O.R. Applications

Dynamic optimization of the operation of single-car elevator systems with destination hall call registration: Part II. The solution algorithm

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Abstract

In this study we consider the elevator operation problem of single-car elevator systems with destination hall call registration. In this part we construct a branch-and-bound algorithm to solve the dynamic operation optimization problem formulated in the first part. To calculate lower bounds of the subproblems generated in the course of the branch-and-bound algorithm, we first relax some of the constraints of the subproblems and decompose the relaxed subproblems into three parts. Then, we apply the Lagrangian relaxation method to the decomposed subproblems.

Keywords: Transportation; Elevator operation; Destination hall call registration; Branch-and-bound algorithm; Lagrangian relaxation

1. Introduction

In this part of the study we propose a branch-and-bound algorithm to solve the dynamic optimization problem of elevator operation with destination hall call registration formulated in the first part.

The problem size, i.e, the number of passengers to be served, or the number of floors to be visited depends on how heavy passenger traffic is. During heavy traffic, it is inevitable to solve dynamic optimization problems in that the car is full and there are at least as many waiting passengers as on-board passengers; the number of passengers is at least twice as large as the car capacity ($\geqslant 30$), or the number of floors to be

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visited is at least three times as large as the car capacity ($\geqslant 45$). Moreover, since the algorithm must be applied every time when a new hall call is registered, such problems must be solved many times. Therefore, the computational time for a problem of this size should be at most a few seconds even for simulation purposes.

In the framework of elevator operation problems, a static operation problem for multiple-car elevator systems where all the information about passengers is known a priori was studied by Inamoto et al. [1]. They proposed a branch-and-bound algorithm and showed some computational results, but their algorithm is so slow that it can solve only small size problem instances (around 20 passengers) even in the case of a single-car system. Moreover, the operation problem that they treated was such a simplified one that the load/unload time is independent of the number of passengers loaded or unloaded, the car travels at a constant speed, and so on. Therefore, their algorithm cannot be applied directly to our problem.

It is also possible to treat this problem in the framework of vehicle routing problems (VRPs). Our problem has a close similarity to variants of VRPs such as the school bus routing problem [2], the pickup and delivery problem and the dial-a-ride problem [3] in that the objective is to determine routes and schedules of vehicles (cars) to transport loads (passengers) from locations to locations. This type of problems is in general harder than our problem since car routing for two-dimensionally distributed locations should be considered in contrast to car routing for floors (one-dimensionally distributed locations) in the elevator operation problem. Therefore, the studies on these problems are mainly on heuristic algorithms (cf. Refs. in [2,3]) and strict solution algorithms have not been studied extensively. The algorithms for the dial-a-ride problem based on dynamic programming were proposed in [4,5], but only instances of small size (10 requests) can be solved by these methods. Dumas et al. [6] proposed the algorithm based on column generation for the pickup and delivery problem with time windows, and Ruland and Rodin [7] applied the branch-and-cut technique to the ordinary pickup and delivery problem. Although medium size instances (30 requests) were optimally solved in [6], the calculation time depends on restrictive time window constraints. Therefore, it might not be fast enough for the larger number of requests if time window constraints are not so restrictive. On the other hand, only small size instances (15 requests) were optimally solved in [7].

Of course, our single-car (vehicle) problem is easier than the multi-vehicle problems [6,7], but the objective functions considered there are to minimize the travel cost (such as the travel distance) of vehicles although it is much more important to improve service quality for passengers in elevator operation problems. Furthermore, elevator specific constraints that arise from psychological limitations such as reversal are not taken into account. It would be hard to handle such objective functions and complicated constraints in their frameworks. Therefore, these methods cannot be applied directly to our problem, either.

In this study we apply a branch-and-bound algorithm to solve the formulated dynamic optimization problem since it works efficiently even when the problem has complicated constraints. The efficiency of branch-and-bound algorithms depends much on the efficiency of lower bound calculation; how good lower bounds are and how fast they can be calculated. To achieve these two requirements, we first relax some of the constraints of subproblems generated in the course of the branch-and-bound algorithm, and decompose the relaxed subproblems into three parts corresponding to passenger loading and unloading, car stops and car floor-to-floor travel. Then, we calculate an optimal solution and lower bounds of the three subproblems separately. We apply the Lagrangian relaxation method to calculate lower bounds of the subproblems, where Lagrangian multipliers are adjusted heuristically to give better lower bounds.

As shown in the first part of this study, our algorithm can solve problems with 50 or 60 floors to be visited within only a few seconds. Although it is not fast enough for real-time operation optimization, it is enough for simulation based analysis, which was performed in the first part.

The outline of this part is as follows. In Section 2 we will restate the dynamic optimization problem considered here that was formulated in the first part of this study. In Section 3 the branch-and-bound algorithm will be constructed for this problem. How to calculate the lower bounds of the subproblems will be given in Section 4.