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Bus stop-skipping scheme with random travel time

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ABSTRACT

When a bus is late and behind schedule, the stop-skipping scheme allows the bus vehicle to skip one or more stops to reduce its travel time. The deadheading problem is a special case of the stop-skipping problem, allowing a bus vehicle to skip stops between the dispatching terminal point and a designated stop. At the planning level, the optimal operating plans for these two schemes should be tackled for the benefits of bus operator as well as passengers. This paper aims to propose a methodology for this objective. Thus, three objectives are first proposed to reflect the benefits of bus operator and/or passengers, including minimizing the total waiting time, total in-vehicle travel time and total operating cost. Then, assuming random bus travel time, the stop-skipping is formulated as an optimization model minimizing the weighted sum of the three objectives. The deadheading problem can be formulated via the same minimization model further adding several new constraints. Then, a Genetic Algorithm Incorporating Monte Carlo Simulation is proposed to solve the optimization model. As validated by a numerical example, the proposed algorithm can obtain a satisfactory solution close to the global optimum.

1. Introduction

Transit system, especially the urban bus system, is of considerable significance for the sustainable development of transport systems and also the robust operation of the entire society (Karlaftis, 2004; Kepaptsoglou and Karlaftis, 2009; Estrada et al., 2011; Mesbah et al., 2011; Yan et al., 2013). Infrastructure expansion and upgrading are never sufficient for a vibrant and reliable bus system (Yan et al., 2012). On the other hand, the bus operation control strategies can largely improve the efficiency and reliability of bus systems, which are taken as important instruments by the transit planners and operators. These strategies include dedicated bus lanes and signals, vehicle holding, stop-skipping and deadheading. This paper focuses on the stop-skipping and deadheading problems.

Bus stop-skipping is to allow those vehicles that are late and behind schedule to skip certain stops to avoid the associated dwell times and increase operating speed. The deadheading problem can be taken as a special case of stop-skipping, from the viewpoint of theoretical analysis. A deadheading bus is a bus that usually departs empty from a dispatching terminal point to a designated stop, skipping stops between the dispatching terminal point and this designated stop. This strategy could reduce both passengers' waiting time at the stop beyond skipped ones, and the headway irregularity Fu et al. (2003).

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The bus stop-skipping scheme can be analyzed both at the planning level and at real-time operation level (Sun, 2005). It may largely influence those passengers with either their origin or destination stop skipped, in view that they have to wait for at least one more headway to be served. Moreover, the stop-skipping of one bus would also affect the total trip time of other buses, hence influencing the operating cost of the bus company. Many previous studies on bus stop-skipping only concern reducing the waiting time of passengers at the bus stops, without considering the passengers' in-vehicle travel time and the bus company's operating cost. Thus, a systematic analysis is necessary for the stop-skipping problem considering its effects on each type of stakeholders, which is addressed in this paper.

To better describe the practical circumstances of bus operation, the travel time of each bus between two stops is rationally assumed to be a random variable. This assumption, however, has increased the challenge of analyzing, formulating and solving the addressed stop-skipping problem.

1.1. Literature review

Bus operations in urban environments are often subject to significant variations because of a variety of complex factors such as dynamic and stochastic traffic congestion. These variations, if not offset by control actions, will cause bus gapping or bunching, and eventually increase the passengers' wait time and operation costs. Management on bus operations is a way to ameliorate the effects of such variations. Among many bus control strategies, stop-skipping and deadheading are two of the effective and common strategies that can be used to regulate bus operations.

Stop-skipping has been studied by many authors using different assumptions and solution methodologies. Li et al. (1991) formulated a 0–1 stochastic programming model to solve the real-time scheduling problem for stop-skipping control, considering both schedule deviation and unsatisfied passenger demand. Eberlein (1995) formulated the stop-skipping problem as an integer nonlinear programming with both quadratic objective function and constraints. The solutions of Eberlein (1995) were based on simplified formulation. Lin et al. (1995) investigated the combined strategy of stop skipping and holding, and suggested that tight controls can increase passengers' travel time and therefore should be avoided. The model measured the system performance in terms of passenger in-vehicle time and waiting time; bus travel time and headway regularity analyzed the effects of bus holding control and stop-skipping control on the effectiveness measures, while estimating the costs to users and suppliers and providing real-time information on bus movements and on-board passengers to control centers. In the study of Lin et al. (1995), a minimum headway could not be guaranteed, especially at some O–D pairs with low travel demand, because no limitation was imposed on dispatching patterns. Fu et al. (2003) argued that if a vehicle was going to skip stations, then the next bus had to serve the entire route, which simplified the problem and provided a minimum level of service for passengers waiting at skipped stations. The authors minimized the costs associated with both operators and passengers. A simulation model called SimTransit was used for modeling stop-skipping to perform sensitivity analysis. Sun and Hickman (2005) investigated stop-skipping for a service disruption of varying length, occurring in the middle of a route, as a means of responding to the disruption more rapidly. They constructed a policy alternative such that the control vehicle could still drop off passengers at stops in the skipping segment. The stop-skipping strategy was formulated separately for both policies as a nonlinear integer programming program. The problem solution used an exhaustive search method by taking advantage of the relatively small scale of the problem.

Deadheading as a pre-planned strategy has been studied by a limited number of authors. Furth and Day (1985) and Furth (1985) suggested applying this concept to corridors with unbalanced demand between directions (in which deadheaded buses skip the entire low demand direction). According to the findings, the strategy reduced both the operator cost – by means of savings in fleet size – and the user cost – by reducing the waiting time of passengers. Three objective functions were explored: the minimization of fleet size; and the sum of operator and user costs. Ceder and Stern (1981) and Ceder (2003) considered the insertion of an empty trip between two terminals (deadheading trip) in order to reduce the fleet size subject to satisfying a given schedule of bus departures from the terminals. Eberlein (1995) and Eberlein et al. (1998) investigated the deadheading problem in the context of real-time transit controls. The objective was to determine which vehicle to deadhead and at which stations. Both problems were formulated as nonlinear quadratic programs. They only accounted for the waiting time in the objective function, obtaining a very complex formulation. Cortés et al. (2011) developed a model that combined short turning and deadheading in an integrated strategy for a single transit line, where the optimization variables were both of a continuous and discrete nature: frequencies within and outside the high demand zone, vehicle capacities, and those stations where the strategy begins and ends.

Three gaps are identified from the previous studies. Firstly, most of the stop-skipping and deadheading optimization models in the above literature review assumed deterministic travel time and constant headway. However, these assumptions are, to some extent, unrealistic because bus travel time is largely influenced by the corresponding road traffic conditions. To reflect variability of the road traffic condition, it is rationale to assume that travel time between two consecutive bus stops of a bus route is a continuous random variable. Secondly, previous studies usually investigated the stop-skipping and deadheading problems separately. Deadheading is actually a special case of stop-skipping from the theoretical viewpoint. Thirdly, the objective functions of many models built in the literature did not consider the effects of bus stop-skipping on different stakeholders involved in the bus operation, including both the passengers and the bus companies, which are taken into account in this paper.