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Design of limited-stop bus service with capacity constraint and stochastic travel time

Jingxu Chen [a,b,1], Zhiyuan Liu [a,b,*], Senlai Zhu [a,c], Wei Wang [a,b]

[a] Jiangsu Key Laboratory of Urban Intelligent Transportation Systems, Southeast University, Si Pai Lou #2, Nanjing 210096, China
[b] Jiangsu Province Collaborative Innovation Center of Modern Urban Traffic Technologies, Si Pai Lou #2, Nanjing 210096, China
[c] School of Civil Engineering, Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907, USA

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ABSTRACT

This paper develops a mathematical model for the optimal stopping design of limited-stop bus service, which allows each bus vehicle to skip some stops. To better reflect the reality, this paper considers the vehicle capacity and stochastic travel time. Also, vehicles are all allowed to skip stops whereas any stop is not allowed to be skipped by two consecutive vehicles. A hybrid artificial bee colony (ABC) and Monte Carlo method is developed to solve the optimal stopping strategy. Finally, the model and solution method are validated by a numerical example, and a sensitivity analysis is performed on the passenger demand.

1. Introduction

In many urban cities, the transit system keeps expanding over the last two decades in order to meet the growing travel demand. However, it has been well recognized that expansion of the transit infrastructure is not a sustainable and effective way for good transit serviceability. Hence, the transit operation control strategies are usually used to improve the efficiency and reliability of transit systems (Yang et al., 2001; Lin et al., 2008; Ibeas et al., 2010; Tétreault and El-Geneidy, 2010; Tirachini et al., 2010; Huo et al., 2014; Niu et al., 2015; among many others). For a bus service, such sorts of strategies include dedicated bus lanes, signal priority, operational stopping, high frequency and adequate timetables (Ceder, 2007; Leiva et al., 2010; dell'Olio et al., 2012; Tirachini et al., 2013; Herbon and Hadas, 2015). The bus operational stopping problem plays a pivotal role in coping with the variation of demand at different stops along the bus route and different time periods (the peak and off-peak period during the day), which is addressed in this paper.

Three different operational stopping strategies are commonly used in urban bus operations (Furth and Day, 1985): (1) short turn: some vehicles only serve the route segment with high demand; (2) deadheading: empty vehicles do not stop at any intermediate stops and return to the depot in the low-demand direction and merely operate in the high-demand direction; (3) limited-stop service: vehicles only dwell at a subset of the stops along the bus route. This paper addresses

* Corresponding author at: Jiangsu Key Laboratory of Urban Intelligent Transportation Systems, Southeast University, Si Pai Lou #2, Nanjing 210096, China. Tel.: +86 18662483667; fax: +86 25 83794102.

E-mail addresses: chenjingxu1989@gmail.com (J. Chen), jszodiac@gmail.com (Z. Liu), zhusenlai@163.com (S. Zhu), wangwei@seu.edu.cn (W. Wang).

[1] Tel.: +86 15850609186; fax: +86 25 83794102.

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the limited-stop service, where different vehicles serving the same bus line may have different stopping plans, as shown in Fig. 1. The objective of stop skipping is to reduce the vehicle dwell time and hence increase the operating speed. To avoid a long waiting time at any bus top, each stop is not allowed to be skipped by two consecutive bus vehicles (of the same bus line). Consequently, the passengers will wait at most two headways at each stop.

The limited-stop strategy will decrease the passengers' in-vehicle travel time and the bus company's operating cost. On the other side, a negative impact of the limited-bus service is on those passengers whose origin or destination stop is skipped, because it increases their waiting time. Thus, a methodology is needed to investigate the trade-off between the two sides, and get the optimal stopping plan with lowest total social costs. In practice, the bus operation is often influenced by many random external factors, including the weather, signal lights, and traffic conditions, which lead to the uncertainty of bus travel time. In addition, due to the limited vehicle capacity, the bus operation is largely affected by the demand level, in view that a saturated vehicle will have much longer boarding time. To better represent these actual circumstances of bus operation, the following factors are incorporated in the optimization models in this paper: (a) stochastic bus travel time, (b) vehicle capacity, and (c) the effects of in-vehicle congestion on dwell time.

1.1. Literature review

Operation management for bus service is a way to handle the unbalanced demand and to increase the bus serviceability. The operational stopping strategy is one of the most common and effective control strategies for bus operation management.

A number of previous studies have been conducted on the design of bus stopping. The work of Kikuchi and Vuchic (1982) was among the early studies on the qualitative analysis of bus stopping. This study first proposed three typical stopping patterns in bus operations: (1) demand stopping: buses stop at any location along the bus line if any passenger wants to board or alight; (2) on-call stopping: bus stops are provided but buses stop only when required; and (3) fixed stopping: buses stop at all stops along the bus line. Vuchic (2005) and Tirachini (2014) extended this work to further analyze the differences of these three stopping patterns. They found that the selection of any above stopping pattern is mainly determined by the demand levels: when the demand is very low, it is recommended to provide demand-stopping service, but as the demand grows it becomes more convenient to group passengers in a limited number of bus stops via the on-call stopping and fixed stopping.

Apart from the qualitative analysis, the most common approach is the formulation of different microeconomics models with different objectives, to get the optimal stopping strategy. As aforementioned, three operational stopping strategies are often used in bus operations, namely short turn, deadheading and limited-stop service (Furth and Day, 1985). Among these, there are numerous optimizations models that have been dedicated to short turn (e.g. Furth, 1987; Ulusoy et al., 2010;

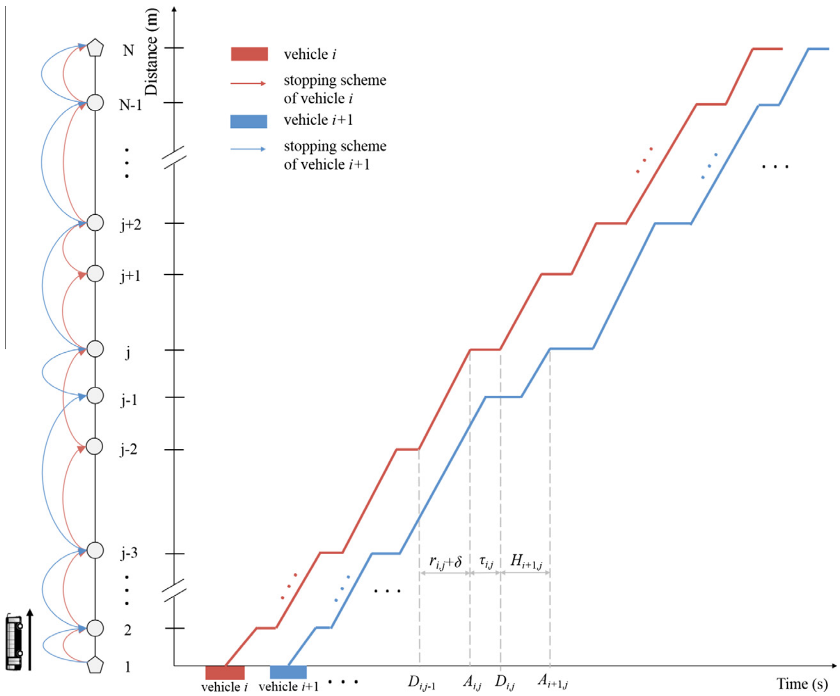

Fig. 1. The space–time diagram of a limited-stopping bus service.