Transportation Research Part E 79 (2015) 201–212

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

Generation and design heuristics for zonal express services

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ARTICLE INFO

Article history:
Received 15 September 2014
Received in revised form 24 April 2015
Accepted 26 April 2015
Available online 22 May 2015

Keywords:
Public transport
Network design
Route design
Express services
Zonal services
Bus Rapid Transit

ABSTRACT

A methodology is presented for designing zonal services for a bus corridor, in which buses visit all stops in a route's initial and final segments, skipping all stops in between. Two heuristics are described, one for congested (binding capacity) and other for uncongested cases. An experiment on a bidirectional corridor shows that the heuristics can find savings in social costs of 6.6% and 10.3% when compared to an express-service-only solution. We also show that, in some cases, the zonal service design problem can be solved analytically, outperforming the heuristics. This suggests the two approaches could be employed in tandem.

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1. Introduction

Recent decades have witnessed increasing demands on public transport bus systems to improve levels of service while cutting dependence on the public purse. Such pressures have driven the emergence since the early 2000s of a concept of high-quality bus service known as Bus Rapid Transit (BRT). Often seen as a cost-effective competitive alternative to Metro-type systems, BRT is generally associated with a set of specific features including segregated bus lanes, centralized fare collection systems, modern bus stops and stations with unobstructed boarding (Levinson et al., 2002).

According to Global BRT Data (www.brtdata.org), 168 cities around the world have implemented BRT services on their streets. Around 80% of these systems have been inaugurated since the year 2000, and about half of them are less than seven years old. However, if BRT is truly to provide a fast and high-capacity service it must be configured with passing lanes that permit the running of express services. This is the case with the Transmilenio system in Bogotá, Colombia, which carries up to 48,000 passengers per hour per direction and has an average operating speed over 25 km/h, according to the same source mentioned before.

Services which by design skip some of the stops along their routes, usually known as express services or limited-stop services, can benefit both users and operators. For users, they enhance service levels by reducing travel times thanks to fewer stops and higher between-stop speeds. If frequencies are high enough, these time savings will exceed the extra waiting time some users may face due to the splitting of the fleet into express and regular services. For operators, meanwhile, shorter bus cycle times mean demand can be met with fewer vehicles and therefore lower costs. As shown by Larrain et al. (2010), express services are especially useful for boosting service levels in high-demand situations. In systems such as Transmilenio (Bogota, Colombia), Transantiago (Santiago, Chile), and Metro Rapid (Los Angeles, California), express services have proved to be highly attractive to users.

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http://dx.doi.org/10.1016/j.tre.2015.04.008
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In this paper, we propose a methodology to design a particular type of express operation we call zonal service. This configuration visits all stops in the initial and final zones of a route while skipping all stops in the middle zone. The time savings generated by such a setup would be attractive to users travelling from a stop in the initial zone to one in the final zone. It could also be useful for relieving the load on the critical arc (the arc with maximum passenger load) of a regular service when capacity is binding since the lower cycle time would result in a frequency increment on that link. Moreover, because of the simplicity of a zonal service's structure, analytical expressions for its optimal frequencies are easily derived.

According to Desaulniers and Hickman (2007) and Jordan and Turnquist (1979) were the first to address the express service design problem for buses. Assuming a "many-to-one" demand type, this is, that every trip shares a common destination, the authors determine the optimal zoning of the corridor using a dynamic programming model. Every zone in this solution is associated to an express bus service, which operates locally inside its zone and then runs non-stop towards the final destination. This type of service was further studied by Tsao and Schonfeld (1983), who derived some general system design guidelines, and Furth (1986), who extended the analysis for bidirectional and branching corridors. Similar zoning schemes have also been studied for rail (Eisele, 1968; Ghoenim and Wirasinghe, 1986) and even for elevators (Powell, 1975). It is worth noting that many of these authors refer to the type of service described above as zonal service. Our proposed definition of zonal service can be understood as a generalization of this case: instead of connecting one zone to a single terminal, our zonal services connect a zone to another zone.

A number of publications have reported case studies of express services for buses, such as Ercolano (1984), Silverman (1998), Tétreault and El-Geneidy (2010), El-Geneidy and Surprenant-Legault (2010), and Scortia (2010). Although they offer certain guidelines for the design of express services, none of these works attempt to optimize the stops to be served and/or the service frequencies.

Two recent works that propose models for the express service design problem for a corridor are Sun et al. (2008) and Chiraphadhanakul and Barnhart (2013). The first one presents a model which designs and optimizes three services: a regular service, an express service, and a zonal service, which is defined in the same way as we do in this work. This work assumes that users will wait for the single service that minimizes their expected travel time, and does not deal with vehicle capacity. The second work proposes a model that optimizes an express service operating in tandem with a regular service. This model considers that the demand for the express service is a function of the travel time savings it offers, and imposes bus load capacity as a direct constraint on their optimization model. Neither of these models allow passenger transfers.

Leiva et al. (2010) presented a methodology for designing express services along transit corridors with capacity constraints that minimizes social costs. This formulation considers that users can make transfers and choose a set of attractive lines to minimize their expected travel times at each trip segment. However, this approach assumes knowledge of a set of possible services from which those to be used are chosen. Strictly speaking, therefore, it is a frequency-setting model for express services rather than a design model as such since it does not actually specify the stop configurations. Larrain et al. (2010) applied this methodology to determine on what type of corridors express services work better, concluding that they are particularly attractive in corridors with high demand, long trips, and monotonically increasing or decreasing profiles.

The express service design problem defines which stops should be visited or skipped by every service at a planning stage. However, skipping stops can be also conceived as a control strategy. This strategy, known as stop-skipping, was first studied by Li et al. (1992), who defined the stops to be served by a bus at the moment of its departure from the terminal. Sun and Hickman (2005) developed a model to solve this problem in real-time for en-route buses.

In what follows, we present a method for the design of unidirectional zonal services over a bidirectional corridor that can be fed to the frequency optimization model. The method produces a social cost function for each possible service configuration so that the best possible zonal service can then be chosen for any particular scenario. As regards the buses' passenger load capacity, two different cases are considered: uncongested and congested. In the uncongested case, we study the zonal service design problem for a corridor with buses big enough that capacity is not binding; in the congested case, we assume that capacity is often reached.

The remainder of this article consists of five sections. Section 2 develops a frequency optimization model and presents a heuristic to deal with bus capacity. Section 3 introduces the heuristics *ZONAL-U* for the uncongested case and *ZONAL-C* for the congested case. Section 4 reports on simulation experiments that were carried out to test how these heuristics perform on a simple forty-stop bidirectional corridor scenario. Finally, Section 5 presents our conclusions and some indications for further extensions.

2. Frequency optimization model

We begin by developing a frequency optimization model for a bidirectional corridor that will permit us to compare the savings generated by different zonal service configurations. Based on Leiva et al. (2010), this model determines the optimal frequencies for a set of predefined services $\mathcal{L}$. These services provide the trips T_w specified by a stop-to-stop origin–destination (O/D) matrix for the corridor, where $w \in \mathcal{W}$ and $\mathcal{W}$ is the set of O/D pairs.

The model can be stated as follows:

$$Min\left[\sum_{l\in\mathcal{L}} c_l f_l + \theta_{WT}\sum_{w\in\mathcal{W}} T_w \frac{\lambda}{\sum_{l\in\mathcal{L}} f_l^w} + \theta_{TT}\sum_{w\in\mathcal{W}} T_w \frac{\sum_{l\in\mathcal{L}} t_l^w f_l^w}{\sum_{l\in\mathcal{L}} f_l^w}\right] \tag{1}$$

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