Transportation Research Part A 59 (2014) 204–221

Contents lists available at ScienceDirect

Transportation Research Part A

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

Access and the choice of transit technology

Karthik Sivakumaran [a,*], Yuwei Li [b], Michael Cassidy [a], Samer Madanat [a]

[a] Institute of Transportation Studies, University of California, Berkeley, 109 McLaughlin Hall, Berkeley, CA 94720, United States
[b] College of Transport and Communications, Shanghai Maritime University, 1550 Haigang Avenue, Shanghai 201306, PR China

ARTICLE INFO

Article history:
Received 20 June 2012
Received in revised form 5 June 2013
Accepted 19 September 2013

Keywords:
Trunk
Feeder
Transit
Transit-oriented development

ABSTRACT

An urban transit system can be made more cost-efficient by improving the access to it. Efforts in this vein often entail the provision of greater mobility, as when high-speed feeder buses are used to carry commuters to and from trunk-line stations. Other efforts have focused on the creation of more favorable land-use patterns, as occurs when households within a Transit-Oriented Development (TOD) are tightly clustered around trunk stations. The efficacy of these mobility and land-use solutions are separately examined in the present work. To this end, continuum approximation models are used to design idealized transit systems that minimize the generalized costs to both the users and the operators of those systems.

The assessments unveil how the choice of transit technology for the trunk-line portion of a transit network can be influenced by its access mode. If transit is accessed solely (and slowly) on foot, then the optimal spacings between lines, and between the stations along those lines, are small. This can place capital-intensive rail systems at a competitive disadvantage with transit systems that feature buses instead. When access speeds increase, the optimal spacings between lines and stations expand. Hence, if accessed by fast-moving feeder buses, Metro-rail or bus-rapid transit can become preferred trunk-line options.

By comparison, the influence of altered land use patterns brought by TODs tends to be less dramatic. We find that clustering households around Metro-rail stations justifies larger spacings between the stations. Yet, this produces only modest reductions in generalized costs because the larger spacings penalize transit users who reside outside of the TODs.

1. Introduction

The choice of transit technology is an important decision when planning either a new urban transit system, or extensions to an existing one. This choice for any city would be based in part on the city's characteristics; e.g. its spatial dimensions, the demand for travel within its boundaries, and the socio-economic attributes of its citizens. When accounting for these factors, previous studies find that capital-intensive rail systems tend to be less cost-effective than bus-rapid transit (BRT) or ordinary bus systems (Cox, 2002; Daganzo, 2011; Estrada et al., 2011; Tirachini et al., 2009). However, these earlier comparisons typically assume that access to a city's transit system would occur entirely by walking and that demand for travel would be distributed more-or-less uniformly over the city.

One wonders if these assumptions unfairly place rail at a competitive disadvantage. After all, a rail system is usually designed with large spacings, both between its lines and between the stations along those lines. To design a rail system otherwise would often be prohibitively expensive. A question therefore emerges: can the use of a faster-moving access mode (e.g. feeder buses) render rail a more economically feasible option for a large, hierarchical transit system? Similarly, can

* Corresponding author. Tel.: +1 510 642 3585; fax: +1 510 643 3955.
E-mail address: ksivakum@berkeley.edu (K. Sivakumaran).

0965-8564/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.tra.2013.09.006

clustering the demands for travel around its stations (e.g. so-called transit-oriented development or TOD) render rail systems more economically viable?

These questions are examined in the present paper. To this end, continuum approximation models are used to estimate the generalized costs imparted to both the users and operators of certain idealized transit systems. These costs are compared across three technology options for trunk-line service: heavy rail, BRT and ordinary buses. The effects of augmenting access to rail and BRT systems via feeder buses are explored. The influence of TOD when planning rail systems is examined as well.

Background information is furnished in the following section. Generalized costs are compared across the three alternatives for trunk-line technology in Section 3. Effects of designing a rail network to suit TOD are explored in Section 4. Implications of the present findings are discussed in Section 5.

2. Background

This section presents: the general structure of a hypothetical trunk-line transit network to be used for baseline analysis; the cost models, objective function and input parameters that will be used in these analyzes; and preliminary explorations of the transit technologies that are optimal for our baseline network. First, we offer the reasoning behind our modeling approach.

2.1. Continuum approximation

Transit systems are sometimes designed using very detailed cost models (Kuah and Perl, 1989; Martins and Pato, 1998; Uchimura et al., 2002). Required inputs in these instances tend to be both voluminous (e.g. travel demands are specified by means of possibly time-dependent origin–destination matrices) and case-specific, such that even details of a city's topography might be included in the analysis (Shrivastava and O'Mahony, 2006). These models therefore tend to take complex forms. Solutions often come via heuristic methods, which means that the design process is necessarily limited to the exploration of few and narrowly-defined alternatives.

In contrast, continuum approximation (CA) models of cost use as their inputs small numbers of continuous functions; e.g. travel demand is expressed as a density, while lines and stations are specified in terms of the spacings between them (Daganzo, 1996; Newell, 1973). As a result, optimal design solutions often take the form of simple, closed-form expressions that readily unveil the kinds of relations between inputs and outputs that are useful for high-level decision-making. Additionally, the CA modeling approach often yields a convex optimization problem, which in turn provides a globally optimal solution. The designs obtained in these ways are optimal for idealized assessments, and deploying these designs in real settings requires that lines and stations be altered to suit actual topographies and travel patterns. Happily, these altered designs still tend to produce near-optimal costs, since costs tend to depend more on factors such as total network length and service frequency rather than on the circuity of individual lines (Estrada et al., 2011).

Given their advantages, CAs have been used: to compare costs across distinct service strategies for feeder systems (Chang and Schonfeld, 1991; Chang and Yu, 1996; Chien et al., 2002; Clarens and Hurdle, 1975; Diana et al., 2007; Kuah and Perl, 1988; Li et al., 2009); to explore broader design alternatives for hierarchical trunk and feeder systems where the transit technologies to be used were specified a priori (Aldaihani et al., 2004; Wirasinghe et al., 1977); and as previously noted, to compare various transit technology alternatives for trunk networks under the assumption that users access these networks on foot (Cox, 2002; Daganzo, 2011; Estrada et al., 2011; Tirachini et al., 2009). Past research has also compared the costs of various combinations of transit technologies (bus and rail) for trunk services. However, efforts of this latter type assumed that all trunk-line trips occur along a single corridor (Fisher and Viton, 1975; Keeler and Small and Associates, 1975). Moreover, previous works have not examined how the redistribution of trip-making demand via TOD can affect the choice of transit technology for a planned transit system.

We will now use CAs to address the literature's above-cited limitations, by first exploring the influence of access mode. The intent is to assess the influence of users' access speed on the optimal choice of transit trunk-line technology (and not to evaluate the merits of all possible means of access). Thus, we will examine the impacts of accessing transit on foot and via feeder buses. In this way, we distinguish the effects of slow- and fast-moving access. We thereafter explore how TODs can influence the choice of transit technology.

2.2. Idealized network

Consider the rectangular-shaped city in Fig. 1. Assume for now that the origins and destinations of trips to be made via transit occur uniformly and independently over the city's area $L \times W$ [km^2], and at total rate λ [trips/hr], providing an overall trip-making density of $\rho = \frac{\lambda}{LW}$ [trips/km^2-hr].[1] Further assume that the trunk network of the city's transit system takes the form of a rectangular grid, such that all trips within the network can be made with a single transfer. Its parallel lines, running

[1] We will relax the assumption of uniform O–D's in Section 4. Also recall that a transit system designed from our idealized O–D pattern and modeling approach can be adjusted to accommodate a city's real demand patterns with relatively small deviations in cost (e.g. see Estrada et al., 2011). Further, travel demand is assumed as exogenous to the transit system's design. We note in this regard that the system-optimal solution given in our analysis might be achieved by suitably pricing transit and the alternative travel modes (Daganzo, 2012).