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A structured flexible transit system for low demand areas

Seyed Mohammad Nourbakhsh, Yanfeng Ouyang *

Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801, United States

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ABSTRACT

Public transit structure is traditionally designed to contain fixed bus routes and predetermined bus stations. This paper presents an alternative flexible-route transit system, in which each bus is allowed to travel across a predetermined area to serve passengers, while these bus service areas collectively form a hybrid "grand" structure that resembles hub-and-spoke and grid networks. We analyze the agency and user cost components of this proposed system in idealized square cities and seek the optimum network layout, service area of each bus, and bus headway, to minimize the total system cost. We compare the performance of the proposed transit system with those of comparable systems (e.g., fixed-route transit network and taxi service), and show how each system is advantageous under certain passenger demand levels. It is found out that under low-to-moderate demand levels, the proposed flexible-route system tends to have the lowest system cost.

1. Introduction

Traditionally, transit systems are designed to contain fixed bus routes, and passengers move to predetermined stations to gain access to the system. The bus network design problem were studied as early as in the 1960s, and the search for a cost-minimizing urban transit system structure (e.g., route positions and headways) explored possible grid networks (Holroyd, 1965), radial systems (Byrne, 1975), hub-and-spoke systems (Newell, 1979), and general bus network design (e.g., Ceder and Wilson, 1986). Wirasinghe et al. (1977) found the optimal network parameters that minimize transit operating cost and passenger travel time in coordinated rail and bus transit systems. Desaulniers and Hickman (2007) summarized a variety of optimization problems that are related to public transit, while a number of other studies focused on specific aspects of transit network design, such as express transit design (Barnett, 1970), bus priority at signalized intersections (Balke et al., 2000), and bus lane priority (Eichler and Daganzo, 2006). Very recently, Daganzo (2010) proposed an innovative transit network design framework that determines the adequate structure of the network as well as the optimal headway for a range of transit modes. It was shown that such a hybrid network structure (see Fig. 1) nicely inherits the advantages of both a hub-and-spoke structure (e.g., low infrastructure investment) and a grid structure (e.g., low travel time).

Fixed routes in a transit system provide clarity and regularity to the transit service, and it is known to work very well for densely populated cities (i.e., with high passenger demand) in general. However, in low demand regions (e.g., sprawled suburban areas), the optimal spacing between bus routes often tends to be relatively large so as to reduce the total system cost. As such, the transit system exposes passengers to the open (sometime adverse) environment for a long time while they walk to and from the bus stops. In such cases, adding flexibility to transit route and schedule seems desirable. For example, Quadrifoglio et al. (2006) demonstrated the potential advantages of allowing transit vehicles to travel within a low-demand geographical region to pick up and drop off passengers. Properties of such operations (e.g., bounds on the maximum longitudinal velocity) are obtained, often via simulations, and incorporated into the overall network design via mixed-integer

* Corresponding author. Tel.: +1 217 333 9858.
E-mail address: yfouyang@illinois.edu (Y. Ouyang).

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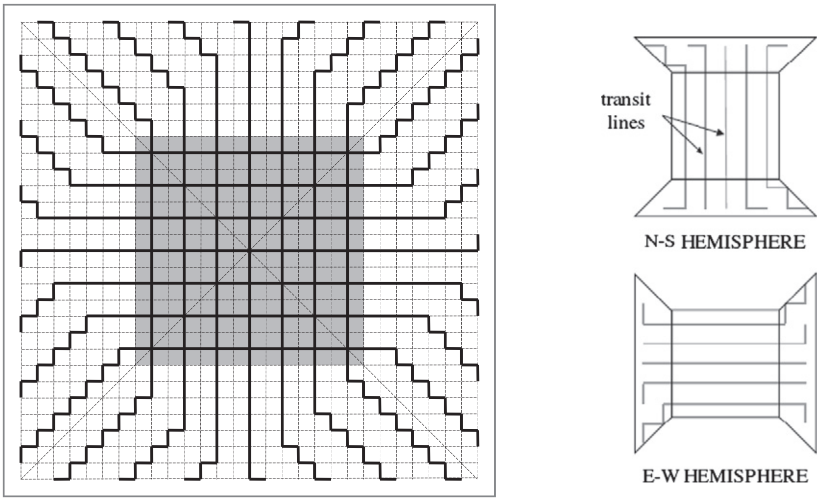

Fig. 1. A hybrid network structure (adapted from Daganzo (2010)).

programming models (e.g., Quadrifoglio et al., 2008). For feeder buses, the suitable demand density for the flexible-route operation is also studied (Quadrifoglio and Li, 2009, among others).

This paper aims to integrate these interesting ideas (e.g., hybrid network structure, flexible route) into the design of a new structured "flexible-route transit system." Individual buses operate without fixed routes or predetermined stops, but rather they can travel around within their own service regions to pick up or drop off passengers. At the macroscopic level, however, the buses (or their service regions) collectively form a suitable network structure to provide reliable spatial and temporal service coverage to the entire demand area. In this paper, instead of relying on complex mathematical programs to determine the optimal network structure numerically, we express the system's operating performance into analytical functions of a few key design variables, and solve for the optimal design as a simple constrained nonlinear optimization problem. These analytical functions also cast important insights into the impacts of these design variables on the overall system performance. Numerical examples and comparison with comparable alternative systems (e.g., the fixed-route transit system and taxi service) show that the proposed flexible-route transit system is advantageous under a range of low-to-moderate demand levels. This is encouraging because the proposed transit system can be used in a number of real-world applications. One possibility, for example, is to let the transit system switch among different operating modes according to the demand level at specific hours (e.g., at night or during weekend). In addition, the flexible network can be used for design of "safe ride" or "dial-a-ride" systems (Daganzo, 1984) in which passengers call and wait for pick-ups.

The exposition of this paper is as follows. Section 2 introduces the notation, concept and formulation of the flexible-route transit system. Section 3 examines other transit system structures (including the fixed-route transit system and a taxi system) that are comparable to the proposed one. In Section 4, the proposed system is numerically compared with the other systems at different demand levels. Finally, Section 5 provides conclusions.

2. Methodology

2.1. Notation and definition

Similar to Daganzo (2010), we consider a square service region of side D (km) that generates λ passenger trips per hour per unit area. The trip origins and destinations are uniform and independently distributed in the region according to a homogeneous spatial Poisson process. The local streets in this service region align along a grid network with constant spacing s.

We consider designing a new flexible transit system to provide service to the passengers when λ is relatively small. Unlike the traditional transit system where buses travel along a fixed route and make stops at predetermined stations, in the flexible transit system buses pick up passengers at their origins or drop them off at their destinations. Each bus now serves the passengers in a narrow elongated area, which we call it a "bus tube," as shown in Fig. 2a. The bus makes lateral movements while sweeping longitudinally back and forth through the tube. The exact bus trajectory obviously depends on the realization of passenger locations, but fixed transfer points are planned along each bus tube, and we assume buses always stop at those points.

Fig. 2b shows the grand overview of the structured flexible-route transit system, including the layout of tubes and the location of transfer points. Based on the intended service level, the whole demand area can be divided into the central square and the peripheral quadrants. The transit system includes N–S and E–W hemispheres each containing N equal transit tubes