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A simulation study of demand responsive transit system design

Luca Quadrifoglio, Maged M. Dessouky *, Fernando Ordóñez

Daniel J. Epstein Department of Industrial and Systems Engineering, University of Southern California,
Los Angeles, CA 90089-0193, United States

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Abstract

In this paper we study the impact on productivity of specific operating practices currently used by demand responsive transit (DRT) providers. We investigate the effect of using a zoning vs. a no-zoning strategy and time-window settings on performance measures such as total trip miles, deadhead miles and fleet size. It is difficult to establish closed-form expressions to assess the impact on the performance measures of a specific zoning practice or time-window setting for a real transportation network. Thus, we conduct this study through a simulation model of the operations of DRT providers on a network based on data for DRT service in Los Angeles County. However, the methodology is quite general and applicable to any other service area. Our results suggest the existence of linear relationships between operating practices and performance measures. In particular we observe that for each minute increase in time-window size the service saves approximately 2 vehicles and 260 miles driven and that a no-zoning strategy is able to satisfy the same demand by employing 60 less vehicles and driving 10,000 less total miles with respect to the current zoning strategy.

Keywords: Dial-a-ride; Simulation; Time-windows; Zoning; Performance measures

1. Introduction

The passage of the Americans with Disabilities Act (ADA) has changed the landscape for demand responsive transit systems. First, the demand for this type of transit service has experienced tremendous growth. In Los Angeles County alone more than 5000 vans and 4200 cabs provide service, generating 8 million trips per year. Second, besides creating a larger demand, ADA also set strict guidelines for the providers on trip denials and on-time performance (Lewis et al., 1998). In essence, transit agencies today are expected to provide better services while experiencing increased usage for demand responsive transit systems.

The National Transit Summaries and Trends (NTST) report for 2002 indicates that the average cost per passenger trip for DRT systems is \$20.8 with fares ranging from \$1.5 to \$3.00. By way of contrast, the average cost per trip for fixed-route lines is \$2.4 with fares being roughly 25% of the cost. Therefore, DRT services are

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[*] Corresponding author. Tel.: +1 213 740 4891; fax: +1 213 740 1120.
E-mail address: maged@usc.edu (M.M. Dessouky).

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still a highly subsidized service and it is imperative for agencies to analyze and investigate their current practices to identify possible cost reductions or productivity improvements.

To measure productivity and cost of the DRT system we consider different performance measures, such as fleet size, total miles and deadhead miles. The deadhead miles are defined as the *empty* trip miles driven by the vehicle between the drop-off point of a customer to the pick-up point of another customer. Note that with ridesharing a vehicle may not be empty driving from a drop-off point to a pick-up point and the miles driven in these cases would not count as deadhead miles. A reduction in deadhead miles can either cause a reduction in the total number of miles driven by a vehicle (hence reducing cost) or allow a vehicle to serve more customers on a given day (hence increasing productivity).

Some studies outline the potential positive impacts of Advanced Public Transportation Systems (APTS) on productivity and cost (Stone et al., 1994; Goeddel, 1996; Ben-Akiva et al., 1996; Chira-Chavala and Venter, 1997; Wallace, 1997; Schweiger and McGrane, 1999; Higgins et al., 2000; Stone et al., 2000). Palmer et al. (2004) show also how financial incentives and penalties can have a negative impact on productivity. That is, providers may schedule in an inefficient manner in order to ensure that they are on time to receive the incentive or avoid the penalty. But there are other factors that have an influence on the performance of DRT systems and the objective of this research is to study the impact on productivity and cost of specific operating practices currently used by DRT providers. They are the *time-window setting* and the *zoning*.

The length of the time-window that specifies the time range in which the provider must pick-up the customer is an important factor impacting productivity and cost. For example, a time-window of 20 min and a scheduled pick-up time of 3:00 pm would mean that the vehicle must pick-up the passenger by 3:20 pm at the latest to be considered on-time. Typically, providers have financial incentives or penalties for meeting on-time goals. Naturally, customers prefer small time-windows. However, in order to maintain small time-windows, transit agencies may have to decrease the ridesharing and increase their fleet size, contributing to increased cost and less productivity. Therefore, the setting of the time-window size needs to balance customer service with the impact on productivity and cost. Currently, Access Service Inc. (ASI), the agency responsible for coordinating paratransit DRT service in Los Angeles County, uses a 20 min time-window whereas many other agencies use a 30 min time-window.

A number of DRT agencies divide their service area into regions contracting the service in each of them to a different provider to simplify the management of the service. This practice, known as *zoning*, is also motivated by the drivers' preference to be assigned to a smaller region instead of the whole service area. This is a common practice for DRT agencies (paratransit, taxi services, etc.) all over the US especially when the service area is large. We distinguish between a *centralized* vs. *decentralized* control depending upon the number of regions in the service area. In centralized control, the service is aggregated into a single region; in decentralized control multiple regions are created. For example, ASI utilizes a decentralized control strategy dividing its service area into six regions (see Fig. 1). The pick-up location of the customer request determines the region and the corresponding provider responsible for the service. It is not uncommon that the pick-up and drop-off locations of a request are in different regions. In fact, according to the data provided by ASI, around 20% of the trips originating in the Northern region of Los Angeles County have a drop-off location outside that region. Hence, the return trip will be done by a different provider regardless of the dwell time of the customer at their drop-off location coming at the expense of a significant number of deadhead miles. Furthermore, in this situation, the customer is required to make two different reservations, one for each provider. In contrast, a hurdle toward implementing a more centralized strategy is that the Computer Aided Dispatching (CAD) systems of the different providers need to efficiently communicate among themselves in order to effectively manage such a design.

Although there is a significant body of work in the literature on scheduling and routing DRT systems (see e.g., Ioachim et al., 1995; Savelsbergh and Sol, 1995; Toth and Vigo, 1997; Borndörfer et al., 1999; Desaulniers et al., 2000; Diana and Dessouky, 2004; Lu and Dessouky, 2004, 2006), there has been no research performed comparing the performance of a centralized controlled DRT system with a decentralized one. Diana et al. (2005) developed analytical equations to determine the fleet size as a function of the time-window for a square service area. However, no similar equations exist for general service areas and for estimations of the total and deadhead miles. Thus, the effect of the time-window size on productivity and cost in general has also not been quantified. This paper addresses this gap by studying the impact of these issues on the operations of a representative large-scale DRT service.