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System modeling of demand responsive transportation services: Evaluating cost efficiency of service and coordinated taxi usage

Mahour Rahimi[a,*], Mahyar Amirgholy[b], Eric J. Gonzales[a]

[a] Department of Civil and Environmental Engineering, University of Massachusetts, Amherst, MA 01003, United States
[b] Department of Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853, United States

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ABSTRACT

This paper presents a continuum approximation model for the operating cost of demand responsive transit (DRT) systems in large urban networks. Applications of the proposed model shed light on ways demand and characteristics of the DRT system affect major components of cost: fleet, vehicle hours, and vehicle miles traveled. Verifying the relationship with empirical data, results show an accurate approximation of the operating cost for the paratransit system in New Jersey. Furthermore, we develop a systematic approach for evaluating the efficiency of policy implementations for DRTs. Finally, the circumstances where coordinated taxis could be a cost reduction strategy are identified.

1. Introduction

Demand responsive transportation (DRT) services are flexible public transportation services in which the routing and the schedule of vehicles operating are defined in response to the demand. The objective of DRT services is to provide mobility when: (1) the demand density is too low to support the provision of adequate and economic conventional transit services, or (2) the individuals being served have mobility limitations or conditions that would prevent them from getting access to a fixed-route transit stop (e.g. distance or lack of adequate sidewalks). DRT vehicles do not follow a fixed route but are usually restricted to a defined service area. The service characteristics of a DRT system are more complex than the headway and travel time that define the fixed-route service. Riders are affected by when they are able to schedule a trip, how long they wait to be picked up, and how long they travel within the vehicle while it may deviate to pick-up or drop off other passengers. The productivity of DRT services is related to the size of the service area, the demand inside the area, demand density, agency operating practices and whether the service is available to the general public or only to certain classes of eligible users. Compared to fixed-route services, variations in the DRT service are inherently greater, and the history of observation is far shorter; therefore, less effort has been expended to monitor and understand DRT services and their performance compared to conventional fixed-route services (Spielberg and Pratt, 2004).

Most transit agencies use DRT services to extend the reach of an existing fixed-route network, provide coverage for low-density suburbs, or enhance mobility for certain customer groups such as senior citizens or people with disabilities. Common examples of demand responsive services in the Unites States are taxicabs, smart transit feeders, senior dial-a-ride (DAR) services, and American with Disabilities Act (ADA) paratransit services. Among these, the dominant type of DRT service in the United States is ADA paratransit, which is designed to meet the travel needs of people whose mobility is limited (Schofer et al., 2003). Transit agencies in the United States are obligated to operate ADA services as a condition for eligibility for federal funding. Horn (2002) provides a general classification for transport modes that spans conventional timetabled fixed-route public transit as well as conventional single-hire

* Corresponding author.
E-mail address: mrahimi@umass.edu (M. Rahimi).

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taxis. This paper focuses on DRT serving random origins and destinations with a pickup window and no underlying route structure. Such services have operating characteristics similar to Roving Bus (free-range demand-responsive public transit) or TaxiMulti (free-range taxi service, allowing for shared rides) in Horn's classification. This is particularly applicable to ADA paratransit services or dial-a-ride services throughout the United States.

DRT services are unavoidably expensive to operate and their costs are becoming an increasing percentage of overall transit authority costs (Cayford and Yim, 2004). According to National Transit Database (NTD) statistics, demand responsive transit service accounts for 5–7% of total transportation agency's demand while contributing to 20–25% of the total agency operating costs. As the number of people aged 65 or older increases, the demand for senior dial-a-ride services and paratransit services grows, and the operating costs continually increase; therefore, if DRT service is not made more efficient, its growth will be unsustainable in both cost and scale (Kaufman et al., 2016). Thus, DRT operators are continually seeking opportunities to increase their productivity and reduce their total agency costs. Considering the high cost of on-demand trips, it is important to be able to model and estimate the performance and cost of these services and pursue different practical approaches that can increase the efficiency of the DRT system.

The demand responsive routing problem may be viewed as a Pick-up and Delivery Problem (PDP) which has been broadly studied over the years. In the PDP, the aim is to plan a set of vehicle routes capable of accommodating as many requests as possible under a set of constraints such that the cost or travel time is minimized (Savelsbergh and Sol, 1995; Desaulniers et al., 2001; Cordeau and Laporte, 2003; Laporte, 2010). Horn (2002) provides a modeling framework for assessing the performance of a multi-modal passenger transport system consisting of conventional timetabled services, taxis and other DRT services. Daganzo (1978) presents an analytical continuous approximation model to estimate the capacity of a DRT system for three different pickup and drop-off strategies. This model accounts for the effect of the order that the operator serves the requests in approximating the capacity of service as a function of demand, operation, and network variables. Amirgholy and Gonzales (2016) use this model to study the dynamics of the DRT system and approximate the generalized user's cost when the operating capacity is inadequate to serve the demand over the peak period without excess delay.

Fu (2003) uses an analytical model to optimize the total time and fleet size in the system subject to a quality of service constraint. Due to demand uncertainty, it is more realistic to develop a stochastic model to relate the fleet size to demand distribution, service area, and time window (Diana et al., 2006; Diana, 2006). Moreover, approximate models have been used to estimate the length of near-optimal tours for a certain number of vehicles to serve a number of points (Daganzo, 1984; Figliozzi, 2008). Figliozzi (2009) improves the models by considering some complementary probabilistic constraints on the number of users, tour duration, and time window. Markovic et al. (2013) develops a statistical linear regression model and an artificial neural network (ANN) model to determine the DAR capacity considering the entire day of operations. This study is extended in Markovic et al. (2016) by proposing the Generalized Linear Model (GLM) and Support Vector Regression (SVR) for predicting capacities of DAR services. Their models are calibrated for both simulated and real-world data. These models use a regression approach in which parameters are calibrated to fit the data empirically. In contrast, the models developed in this paper specify functional relationships between inputs and outputs based on the physical operations of the systems and requires only two parameters to be calibrated: a fit parameter for vehicle miles traveled and a fit parameter for vehicle hours traveled. All other inputs are physical quantities that can be measured through observation.

As demand for DRT services continues to increase, agencies must seek ways to organize services in order to minimize costs while providing sufficient mobility to customers (Chia, 2008). Therefore, there is a variety of research focused on studying the factors influencing the performance, productivity, and costs of DRT. Extensive studies have been presented for the purpose of identifying the factors affecting the DRT system's performance and productivity. The effects of dynamic and stochastic variations in travel time on scheduling reliability and system performance have been investigated by performing several experiments on a paratransit system in Edmonton, Alberta (Fu, 1999). The variation of travel time in routing can also be taken into account to achieve a more reliable and efficient system (Fu, 1999). Some studies have investigated changes in performance when the DRT system is run with various numbers of vehicles (Bailey and Clark, 1987; Feuerstein and Stougie, 2001). Fu and Ishkhanov (2004) investigate the impacts of the type and number of vehicles on performance of paratransit services. This research identifies the optimal fleet mix that maximizes the operating efficiency of a paratransit service. Moreover, models have been developed to identify the minimum fleet size for a paratransit system assuming either a fixed fleet mix or unlimited vehicle capacity (Schofer et al., 2003; Fu, 2003). Hauptmeier et al. (2000) and Lipmann et al. (2002) take traffic conditions into account to evaluate the performance of DRT systems. Haghani and Banihashemi (2002) addresses the relation between efficiency of vehicles and town size. Dessouky et al. (2005) investigates the effect of time-window size on the productivity of DRT services using linear regression models. According to this study, for the DRT service operating in Los Angeles County, each minute increase in the time-window size results in saving 2 vehicles and 260 vehicle miles, while satisfying the same demand. Diana (2006) studies the impacts of information flow on the effectiveness of scheduling process of DRT systems. The percentage of real-time requests, the interval between call-in and the requested pickup time, and the length of the computational cycle time are included in the scope of that study. The producivity and service quality of a DRT service in Harris County, Texas has been compared for different zoning strategies Quadrifoglio and Shen (2010). Moreover, the flexibility of providing transfer option for a decentralized service area has been investigated in the simulation model of a paratransit system Shen and Quadrifoglio (2011, 2012).

Research has also been done on metrics of efficiency for DRT services. (Fu et al., 2007) uses a nonparametric approach to evaluate the technical efficiency of paratransit systems. Cost per passenger trip, revenue per passenger trip, passenger trips per hour, passenger trips per employee, and vehicle miles per employee are some of the common efficiency metrics listed in his study. In addition, Shioda et al. (2008) identifies deadhead time, delay, ride time, and average trip distance as performance metrics for paratransit systems. It is important to note that different DRT organizations have different characteristics that may require additional or modified performance

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