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A slack arrival strategy to promote flex-route transit services

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ABSTRACT

Flex-route transit, which combines the advantages of fixed-route transit and demand-responsive transit, is one of the most promising options in low-demand areas. This paper proposes a slack arrival strategy to reduce the number of rejected passengers and idle time at checkpoints resulting from uncertain travel demand. This strategy relaxes the departure time constraints of the checkpoints that do not function as transfer stations. A system cost function that includes the vehicle operation cost and customer cost is defined to measure system performance. Theoretical and simulation models are constructed to test the benefits of implementing the slack arrival strategy in flex-route transit under expected and unexpected demand levels. Experiments over a real-life flex-route transit service show that the proposed slack arrival strategy could improve the system performance by up to 40% with no additional operating cost. The results demonstrate that the proposed strategy can help transit operators provide more cost-efficient flex-route transit services in suburban and rural areas.

1. Introduction

Over the past few decades, an increasing number of suburban areas with low population density have been established as a consequence of economic growth and urban sprawl. This trend has led to new travel patterns that require transit services to be more flexible. Flex-route transit, which is also referred to as route deviation (Potts et al., 2010; Lu et al., 2015), mobility allowance shuttle transit (MAST) (Quadrifoglio et al., 2006) and demand adaptive transit system (DAS) (Crainic et al., 2012), has experienced dramatic growth in recent years. According to the investigation by Koffman (2004) and Potts et al. (2010), among the many types of flexible transit services, flex-route transit is by far the most widely used.

Traditional fixed-route transit is inconvenient in low-demand areas because of the lack of flexibility, as the locations of pick-up or drop-off stations do not correspond to the needs of individual riders. Pure demand-responsive transit could provide the flexibility desired by customers, but such a system tends to be considerably more expensive; therefore, it is largely limited to specialized operations such as paratransit for the elderly and disabled (Dikas and Minis, 2014). The flex-route transit service combines the low-cost operability of fixed-route transit with the flexibility of demand-responsive transit. It operates along the base route with mandatory checkpoints located in high-density demand zones with fixed departure times; it can also deviate from the base route to serve curb-to-curb requests, which make reservations in advance. Actual operational data from New Jersey have shown that flex-route transit is more cost-efficient than pure demand-responsive transit (Fittante and Lubin, 2015) and it is also considered more convenient than regular bus routes (Becker et al., 2013).

So far, relatively few studies have focused on flex-route transit. Quadrifoglio et al. (2006) evaluated the upper and lower bounds

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of the maximum longitudinal velocity of service vehicles and proposed scheduling algorithms of flex-route transit for both static and dynamic scenarios (Quadrifoglio et al., 2007, 2008). A sensitivity analysis was also performed over different service area shapes (Quadrifoglio and Dessouky, 2008). Zhao and Dessouky (2008) analyzed the relationship between the service cycle time and the length and width of the service area. Crainic et al. (2012) estimated the optimal cycle length using probabilistic approximations theory. Nourbakhsh and Ouyang (2012) developed a new structured flex-route transit system that performs better than fixed-route transit under a range of low-to-moderate demand levels. Alshalalfah and Shalaby (2012) investigated the feasibility and benefits of replacing fixed-route feeder transit with flex-route service in Toronto. Yang et al. (2016) presented a methodology to select the optimal route of a flex-route transit service based on the lowest operating cost per passenger. Qiu et al. (2014) proposed a dynamic station strategy to eliminate the rejection of curb-to-curb requests at unexpectedly high demand. Qiu et al. (2015a, 2015b) explored the feasibility of replacing fixed-route transit with flex-route operating policies and derived the switching demand densities between the two competing policies. Frei et al. (2017) conducted a stated-preference survey between regular bus transit, private cars and flex-route transit, the results of which can help transit planners identify potential users and guide the design of flex-route transit.

As an innovative operating policy, flex-route transit has considerable potential for shaping new travel patterns in low-demand areas. However, according to the investigation conducted by Potts et al. (2010), only a small percentage of transit agencies apply flex-route policies due primarily to the uncertain travel demand in suburban or rural areas (Velaga et al., 2012). In flex-route transit, the slack time allocated for deviation service in each route segment is predetermined based on the expected demand level, which is quite fragile in real-life operation because the actual demand may vary over time. Some of the requests have to be rejected when the predetermined slack time is used up. Moreover, the passengers on board may experience idle time at the checkpoints if the actual demand is lower than expected. Both scenarios would definitely degrade the service level of flex-route transit systems.

To utilize the unused slack time and improve the acceptance rate of the flex-route service, this study proposes a slack arrival strategy in which the fixed time constraints of some checkpoints are relaxed to some extent. In this strategy, the redistribution of slack time among segments enables more curb-to-curb customers to be served without affecting the overall service cycle of flex-route transit systems.

In this paper, we study the feasibility of applying the slack arrival strategy to promote the performance of flex-route service at both expected and unexpected demand levels. Theoretical and simulation models are developed to evaluate the system cost, including the vehicle operation cost and customer cost. The optimal slack time window is also investigated in the implementation of the slack arrival strategy in an actual flex-route transit service. This work provides a new strategy option for transit planners and could assist them in determining the suitable design and operation policy for flex-route services.

2. System description

The service area can be generally modelled as a rectangle of width W and length L. There are C checkpoints located at high-density demand areas or major connection points (see Fig. 1). The checkpoints can be identified as $c = 1,2\ldots,C$. In each ride, the vehicle moves back and forth, starting from one terminal and ending at the other one after visiting all checkpoints one by one. The scheduled departure times at the checkpoints are fixed, which is generally regarded as an inviolable constraint in operation.

The demand outside the checkpoints is assumed to be uniformly distributed within the service area. We also assume that checkpoints locations and the travel demand among checkpoints are uniformly distributed along the base route. There are four main types of passengers in the service area with proportions of η_1, η_2, η_3, and η_4 ($\eta_1 + \eta_2 + \eta_3 + \eta_4 = 1$) as follows:

Type I: Pick up and drop off both at checkpoints.
Type II: Pick up at checkpoints, and drop off not at checkpoints.
Type III: Pick up not at checkpoints, and drop off at checkpoints.
Type IV: Pick up and drop off both not at checkpoints.

Type I passengers use the service as a regular fixed-route transit. Therefore, they simply show up at their pick-up checkpoint without booking. However, the other three types of passengers must make a reservation to schedule their non-checkpoint stops using smartphones or the Internet. The maximum allowable deviation width from the base route is $W/2$.

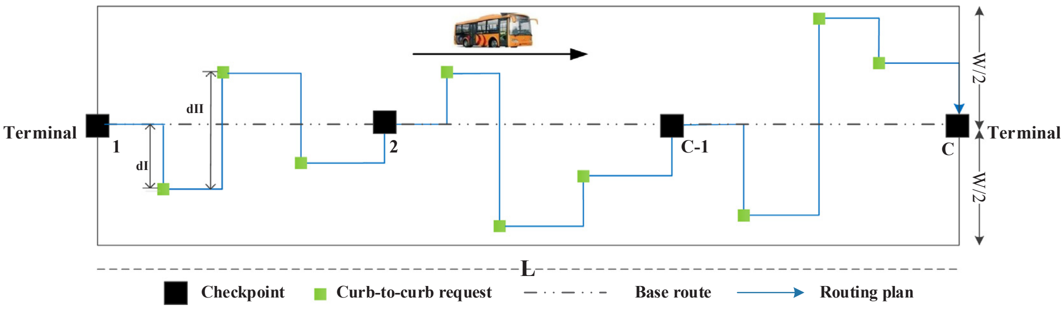

Fig. 1. Flex-route transit service.