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Integration of conventional and flexible bus services with timed transfers

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ABSTRACT

Conventional bus services, which have fixed routes and fixed service schedules, and flexible bus services, which provide doorstep services, have different advantages and disadvantages, with conventional services being generally preferable at high demand densities and flexible services being preferable at low densities. By efficiently integrating conventional and flexible services and thus matching service type to various regions, the total cost of transit services may be significantly reduced, especially in regions with substantial demand variations over time and space. Additionally, transit passengers must often transfer among routes because it is prohibitively expensive to provide direct routes for among all origin–destination pairs in large networks. Coordinating vehicle arrivals at transfer terminals can greatly reduce the transfer times of passengers. In this paper, probabilistic optimization models, which are proposed to deal with stochastic variability in travel times and wait times, are formulated for integrating and coordinating bus transit services for one terminal and multiple local regions. Solutions for decision variables, which include the selected service type for particular regions, the vehicle size, the number of zones, headways, fleet, and slack times, are found here with analytic optimization or numerical methods. The proposed models generate either common headway or integer-ratio headway solutions for timed transfer coordination based on the given demand. A genetic algorithm is proposed as a solution method and tested with numerical examples.

1. Introduction

In urban bus transit networks, passengers must commonly transfer among routes because it is prohibitively expensive to provide direct routes among all origins and destinations with conventional bus services, which have fixed routes and fixed schedules. Since transfers are important in public transportation services, it may be beneficial to coordinate (i.e. synchronize) bus arrivals at transfer stations (terminals) so that such "timed transfers" help minimize wait times and passengers can reliably catch their next bus. Because bus travel times and dwell times are usually stochastic, a probabilistic optimization model is needed for determining buffer (slack) times that help provide reliable connections among buses.

Different bus services have different characteristics. Conventional services can carry numerous passengers at low average costs per round trip, but their average costs are very high at low demand densities. Flexible services, which are defined here

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as demand-responsive services having flexible routes with different pick-up and drop-off stops on each successive "tour", typically carry fewer passengers than conventional services. Flexible services may offer door-to-door service (subject to the physical accessibility of those doors) and are generally preferable for low demand densities. Thus, by effectively integrating conventional and flexible services the overall system cost may be significantly reduced in comparison with pure conventional or flexible services (Chang and Schonfeld, 1991; Kim and Schonfeld, 2012; Kim and Schonfeld, 2013), especially when the demand density varies considerably over time and space.

In this paper we explore the potential reductions in system costs that are achievable by combining coordinated timed transfers with the integration of conventional and flexible services. The resulting system costs are compared with those of uncoordinated conventional and flexible services. To do this we develop a probabilistic optimization model for timed transfers with integration of conventional and flexible bus services. Uncoordinated and coordinated bus operation models are also formulated and compared through numerical analyses. The optimization model for uncoordinated operations finds solutions for the service type selection, vehicle size, headway, fleet size, and number of zones for both conventional and flexible services. In order to efficiently coordinate vehicles for timed transfers, common headways or integer-ratio headways are found numerically. For integer ratio headways, a round travel time is an integer multiple of a base cycle.

2. Literature review

Kyte et al. (1982) present a timed-transfer system in Portland, Oregon, which provides services since 1979, including its planning history, implementation, and evaluation. This system provides timed transfers to the suburban areas in which demand densities are low, and provides grid-type bus services for higher demand regions. The authors also discuss the performances and results of the implemented system. They use two indicators, which are a successful meet and a successful connection, to analyze the transfer reliabilities. A successful meet is defined as all buses arriving as scheduled at a given time, and a successful connection is a direct transfer connection that results from two routes arriving as scheduled. The authors point out that weekday ridership increased by 40 percent after one year of operation, and local trips using this system increased dramatically. However, the 40% increase of ridership results not only from the timed transfer system, but also from new route designs. Bakker et al. (1988) similarly study a multi-centered time transfer system in Austin, Texas, and confirm that such timed transfers systems are particularly applicable for low-density cities.

Abkowitz et al. (1987) study timed transfers between two routes. They compare four policy cases, namely unscheduled, scheduled transfer without vehicle waiting, scheduled transfers with the lower frequency bus being held until the higher frequency vehicle arrives, and scheduled transfers when both buses are held until a transfer event occurs. In other words, they compare scheduled, waiting/holding, and double holding transfer strategies. They note that the effectiveness of timed transfers varies with route conditions. However, they find that the scheduled transfers are effective (over the unscheduled) when there is incompatibility between headways and the double holding strategy outperforms the other time transfer strategies when the headways on intersecting routes are compatible. They also note that slack time should be built into the schedule so that vehicle holding does not cause significant delays to passengers.

Domschke (1989) explores a schedule coordination problem with the objective of minimizing waiting times. He provides a mathematical programming formulation which is generally applicable to public mass transit networks such as those using subways, trains and/or buses. The formulation is a quadratic assignment problem. With four routes and five transfer stations in a very simple network, this paper uses heuristics and a branch and bound algorithm. The heuristics include a starting heuristic, which is based on rigid regret heuristic, and then a heuristic improvement procedure. Lastly, simulated annealing (SA) is applied to improve the solutions. For SA, the quality of the initial solution is important. The author finds that problems with more than 20 routes cannot be solved with exact solution methods.

Knowppers and Muller (1995) provide a theoretical note on transfers in public transportation. Their main objective is to minimize the passengers' transfer time. They find that when the frequency on the connecting lines increases, the benefit of transfer coordination decreases. Muller and Furth (2009) seek to reduce passenger waiting time through transfer scheduling and control. They provide a probabilistic optimization model, and discuss three transfer control types, namely departure punctuality control, attuned departure control, and delayed departure of connecting vehicles. They confirm that by increasing a buffer (slack) time, the probability of missing the connection decreases. However, a larger buffer increases the transfer time for riders who do not miss their connection. They also find that if the control policy allows a bus to be held to make a connection, the optimal schedule offset, which is the time between the arrival time of the feeder vehicle and the departure time of the connecting vehicle, decreases.

Shrivastava et al. (2002) first discuss existing algorithms for solving nonlinear mathematical programming, because transit scheduling problems are often nonlinear. The existing algorithms are generally gradient-based, and require at least the first order derivatives of both objective and constraint functions with respect to the design variables. Gradient-based methods can identify a relative optimum closest to the initial guess of the optimum design. However, there is no guarantee of finding the global optimum if the design space is known to be non-convex. In such a case, exhaustive and random search techniques such as random walk or random walk with direction exploitation are quite useful. The main drawback with these methods is that to reach a good solution they often require thousands of function evaluations, even for the simplest functions. They also note that genetic algorithms (GAs) are based on exhaustive and random search techniques, and are robust for optimizing nonlinear and non-convex functions. Thus, they apply a genetic algorithm (GA) to schedule