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Translating research to practice: Implementing real-time control on high-frequency transit routes

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A B S T R A C T

On high-frequency routes, buses tend to bunch together, creating gaps in service and causing undue passenger waiting time. There are many approaches to solving the bus bunching problem in the literature but there lacks empirical analysis on practical implementation. In this study, a real-time holding method from the literature was implemented on three high-frequency transit routes, the Atlanta Streetcar and the Georgia Tech Red Route in Atlanta, GA, and the VIA Route 100 in San Antonio, TX. The performance of the method was evaluated in terms of headway stability, holding time, and mean passenger waiting time. The method was found to improve headway stability compared to the schedule, but required longer holds in some cases. Overall, the holding method reduced the waiting time of passengers at stops in all three case studies. The challenges associated with location data quality, prediction accuracy, the human element and the surrounding environment are discussed and strategies to address them are recommended.

1. Introduction

On high-frequency transit routes, passengers tend to arrive at stops without using a schedule (Fan and Machemehl, 2009). At each stop, the number of passengers waiting for a bus is proportional to the time since the last vehicle left; as the headway of a bus grows, so does the number of passengers boarding and alighting at each stop and *vice versa*. Boarding these passengers further delays lagging vehicles. Long headways tend to get longer and short headways tend to get shorter. Eventually, vehicles bunch together and travel as a platoon, creating large gaps in service that cause undue passenger waiting time.

Although passengers on high-frequency routes tend to disregard the schedule (Fan and Machemehl, 2009), time-tabling vehicle departures from time-points[1] along the route is still the method used by almost all transit agencies. To allow lagging vehicles to recover from potential delay, planners include buffer time in their schedules and set departure times as a high percentile of historical running time (Furth et al., 2006). As a result, vehicles systematically waste time holding at control points when operating conditions are fluid, and consistently miss their scheduled departure times when operating conditions are congested. The schedule is therefore not useful for passengers who arrive randomly at stops nor effective for transit agencies who strive to stabilize headways.

Since the early 1970s researchers have developed innovative methods to stabilize headways on high-frequency routes using real-time information (Osuana and Newell, 1972; Barnett, 1974; Newell et al., 1974). It was not until recently, however, that vehicle location data collection could be automated, which made real-time holding methods feasible. A rapidly growing body of literature,

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[1] Time-points are control points where vehicles wait for their scheduled departure time.

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which is reviewed by Ibarra-Rojas and collaborators, has emerged since the early 2000s (Ibarra-Rojas et al., 2015).

The method in Berrebi et al. (2015) takes a global approach to the bus bunching problem. The method probabilistically identifies the vehicle with the most delay on the route, and holds each preceding vehicle to diffuse large gaps in service. The method uses the probability distribution of vehicle arrival times as input. In Berrebi et al. (2017), the authors compared closed-form holding methods used in practice and recommended in the literature based on data from TriMet Route 72 in Portland, OR. The study found that the holding method in Berrebi et al. (2015) can dispatch vehicles with more stable headways than other closed-form methods used in practice and recommended in the literature with the same mean holding time. Although there are prediction methods in the literature that can generate distributions, such as Hans et al. (2015), it is simpler to generate predictions deterministically as expected arrival times. Therefore, the first step to implement the holding method proposed in Berrebi et al. (2015) is to derive its deterministic equivalent.

Transit agencies who wish to use the method recommended in Berrebi et al. (2015), or any other method to stabilize headways on their high-frequency routes need insights on the performance of such methods in realistic settings, and the main challenges to implementation. Several studies have used simulation to compare holding methods and test their sensitivity to various route characteristics (Berrebi et al., 2015; Xuan et al., 2011; Cats et al., 2011; Daganzo and Pilachowski, 2011). Even in the most realistic frameworks possible, however, simulation experiments cannot consider all the small perturbations that tend to accumulate and lead to the destabilization of a route. A live implementation, on the other hand, can represent the compounded effects of the holding methods on transit operations. In particular, the following factors cannot be considered in a simulation experiment but may cause severe disruption in reality:

- In the simulation experiment, vehicle location data is assumed to be always accurate and always available. In reality, however, the GPS signal wanders and sometimes even gets lost for minutes at a time. In addition, vehicle location data is made available at a set frequency, thereby creating a lag between the time of recording and the time when the data becomes available. This lag can affect the prediction accuracy and the communication synchronization with operators.
- The dwell time at a control point can be affected by physical and human factors. If the dwell time at the control point is not explicitly considered, recommended holding times may be unrealistically short. The delay can undermine the ability of the holding method to maintain stable headways.
- In a simulation experiment, operators can perfectly follow holding instructions. In reality, however, transit vehicles are operated by human beings, whose perception, cognition, and behavior affect operations. Operators may not adhere to unclear or impractical instructions, which may disrupt the route. On the other hand, operators can use their intuition, which is informed by unique live information and experience, to amplify the impact of the holding method.
- Transit vehicles that run in mixed traffic are particularly prone to bus bunching because they have to compete for capacity and are subject to random disruptions. Some of these disruptions are periodically recurring, others are discrete events; some are localized, others span the entire route. Although these disruptions can affect the capacity of a holding method to stabilize a high-frequency transit route, they often cannot be modeled explicitly in a simulation.

Research that remains at a theoretical stage leaves a gap too great to have a real-world impact. In order to fully solve the bus bunching problem, and help agencies reduce passenger waiting time, the practical implementation of holding methods is a necessary final step. Based on the lessons learned from these experiments, agencies can be fully equipped to use these methods on their own. In this paper, the holding method from Berrebi et al. (2015) is applied in its deterministic form on three high-frequency transit routes: the Atlanta Streetcar and the Georgia Tech Red Stinger Route in Atlanta, GA, and the VIA Route 100 in San Antonio, TX.

To evaluate the performance of the holding method in realistic settings and assess challenges to implementation, a deterministic version of the method recommended in Berrebi et al. (2015) was derived analytically. An open-source tool called DynamicTime was created to predict vehicle arrivals, compute holding times and communicate instructions. The performance of the method was compared to the performance of the schedule that was currently in use in all three case studies. The impact of data and prediction quality on the performance of the method and ease of implementation were assessed. In addition, the level of adoption by supervisors, dispatchers and operators and their effect on compliance were analyzed. The effect of the route environment on the implementation was also evaluated. Finally, the study discusses the lessons learned from implementing a real-time dispatching method in high-frequency transit systems.

2. Literature review

Although the literature on holding methods to avoid bus bunching is abundant, there are few studies on the implementation of these methods in live experiments. Several implementation studies have focused on a simple holding method that aims to equilibrate the forward and backward headways as proposed by Turnquist (1982). Different versions of the method were implemented on multiple Tri-Met routes in Portland, OR (Strathman et al., 2000), on the CTA Route 20 in Chicaco, IL (Pangilinan et al., 2008), and on the MBTA multi-branch Green Line in Boston, MA (Fabian et al., 2018). In each case, supervisors were stationed at control points and communicated instructions to operators. Cats (2012) implemented a similar method on Lokaltrafik Line 1 in Stockholm, Sweden, using a CAD-AVL system communicating instructions directly to operators. The studies found that the simple holding method is more effective at stabilizing headways than the Naive Schedule (typical schedule-based service) and Naive Headway (fixed-headway service).

Bus bunching has been shown to be just as pervasive on corridors where several bus routes overlap than on corridors with a single