Translating Research to Practice: Implementing Real-time Control on High-Frequency Transit Routes

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Abstract 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 empirical analysis on practical implementation is limited. In this study, a real-time holding method from the literature is 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 is evaluated in terms of headway stability and holding time. The method is found to improve headway stability compared to the schedule on all three case studies, but requires longer holds in some cases. Most critically, the challenges of implementing real-time control are discussed.

Keywords: Public transport · Holding method · Real-time prediction · Control strategy · Bus bunching
1 Introduction

On high-frequency transit routes, passengers tend to arrive at stops without using a schedule (Fan, et al. 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 (Verbich, et al. 2016). 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.

Since the early 1970's researchers have developed innovative methods to stabilize headways on high-frequency routes using real-time information (Osuana and Newell 1972; Barnett 1974; Newell 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, which is reviewed by Ibarra-Rojas and collaborators (2015), has emerged since the early 2000's. In particular, the holding method developed by the authors takes a global approach to the bus bunching problem (Berrebi, et al. 2015). It identifies probabilistically the vehicle with the most delay on the route, and holds each preceding vehicle to diffuse large gaps in service. The method was found to yield the most advantageous trade-off between headway stability and holding time in a wide range of operating conditions when compared to holding methods used in practice and other closed-form methods from the literature (Berrebi, et al. 2017).

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. Pangilinan, et al. (2008) implemented a dispatching method on CTA Route 20 in Chicago, IL. Argote, et al. (2015) implemented an on-route control method in San Sebastian, Spain, along a busy corridor where two unsynchronized bus routes overlap. Lizana, et al. (2014) implemented a holding method on Transantiago Route 210 in Santiago de Chile. The implementations in the literature report the performance of holding methods, but they lack analysis about the factors of success. To support widespread implementation of real-time control, transit agencies need further insights about the role of data quality, prediction accuracy, human factors, and the surrounding environment.

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 save their passengers' 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. The performance of the method is compared to the schedule that was currently in use. In addition, lessons learned from implementing a real-time dispatching method in high-frequency transit systems is discussed.

2 Methodology

In this research, a real-time holding method was implemented on three frequent transit routes. The holding method is a simplified version of the method developed by the authors, where expected arrival times are treated as discrete probability distributions (Berrebi, et al. 2015). The method holds vehicles at control points along the route to equilibrate headways. The researchers developed an open-source dispatching software called DynamicTime. Each time a vehicle arrived at the control point, the DynamicTime dashboard started showing a green countdown and made a sound to notify the dispatcher. When the countdown reached zero, another sound was emitted to instruct dispatchers that the vehicle should depart the control point. Vehicle location data from the implementation were collected and compared to historical data. The main factors influencing the implementation of a real-time control method were recorded and analysed.

The holding method was implemented on the Atlanta Streetcar, the VIA Primo 100 Route, and the Georgia Tech Red Stinger Route. The Atlanta Streetcar is a 2.7 mile transit line running in mixed traffic through the Downtown and Sweet Auburn neighbourhoods. The Atlanta Streetcar usually runs two vehicles based on a schedule with 15-minute headways, but for the experiment, the City of Atlanta agreed to run three vehicles simultaneously at 10-minute headways. The VIA Route 100 is a 22-mile high-frequency line connecting Downtown San Antonio to the South Texas Medical Center. During the implementation, eleven vehicles ran simultaneously at 10-minute headways. The Red Stinger Route is a 2.5 mile loop with four vehicles serving students, faculty and staff on Georgia Tech campus at six-minute headways.

3 Results

The proposed holding method reduced headway variability in all three implementations. Results are presented for Atlanta Streetcar and San Antonio VIA. The proposed method was only implemented for 77 minutes on the Georgia Tech Red Stinger Route due to defective GPS units, but still reduced headway variability compared to historical data before the implementation.

3.1 Atlanta Streetcar
The holding method was successfully implemented for two days in March, one in April, and one in May. During the study period, vehicles were dispatched with relatively stable headways with some fluctuation in the first hour and a half and
much less in the second part. Most of the fluctuation was caused by the discrepancy between recommended and actual holds caused by the actuated traffic signal located at the control point. Operators often missed their permissive phase and had to wait for the entire 120-second cycle. On average, vehicles held for 107 seconds longer than recommended by the DynamicTime dashboard.

Figure 1 shows a histogram of headways at departure from the control point as dispatched by the schedule (white) and by the real-time holding method (black). The schedule method dispatched vehicles with a wide range of headways; 39% of headways were shorter than 480 seconds and 12% were greater than 780 seconds. Under the holding method, the distribution of headways was more compact with 60% of vehicles dispatched with headways between 540 and 660 seconds. The method, however, dispatched buses with slightly longer headways, 622 seconds on average, compared to 584 seconds for the schedule method.

![Fig. 1 Histogram of headways at departure from the control point on Atlanta Streetcar](image)

**3.2. San Antonio VIA**

The real-time method was successfully implemented on VIA Route 100 for two days, Tuesday, May 9 (shown in Figure 2) and Friday, May 12, 2017. Figure 2 shows the headway Coefficient of Variation squared over several days prior to and one during the implementation period. The days that started with high CV² remained disrupted and the days that started with a low CV² maintained stable headways. On January 17 and 31, the Route 100 was already severely bunched at 2:30 PM with a CV² close to 0.8. On these days, the schedule was unable to stabilize headways and CV² remained close to or above 0.5 until 5:30 PM. On January 3 and May 3, the route was relatively stable at 2:30 PM with CV² at approximately 0.2 for both methods. On both January 3 and May 9 around 4 PM, a long headway caused the route to quickly destabilize. On May 9, the real-time holding method was able to recover stable operations and yielded the lowest CV² for 2:24 hours of 3 hours. Overall on VIA Route 100, 80% of the time, headways had the lowest coefficient of variation under the proposed method, when compared to three days of historical data under the schedule.
4 Conclusion

In this paper, a real-time holding method was successfully implemented on three high-frequency transit routes. In each case study, the real-time holding method has helped reduce headway variability compared to the schedule that was currently used.

Most critically to the industry, we found that the success of implementations hinges on four main factors: data, predictions, human element, and surrounding environment.

1. The DynamicTime software was able to function when Automatic Vehicle Location (AVL) data were lagged or had low polling frequency, but not when it lost AVL feed for extended periods of time.
2. The prediction accuracy in DynamicTime was found to be sufficient for this implementation. The data accuracy, lag, and frequency were not found to substantially affect predictions.
3. Operators have a sense of ground-level operations that may be unperceivable to the holding method, and even to a dispatcher who is away from the field. We found that indirect lines of communication can introduce layers of error.
4. The surrounding environment can condition the capacity of vehicles to hold at control points. In particular, the physical design of control points and the presence of adjacent traffic signal affected instruction adherence.

As academic researchers, we often limit real-world implementations to smaller systems and those most convenient in location. These systems provide an opportunity to test the research in a safe environment, but they rarely face the same scale of problems as larger transit agencies. This research has shown that full-scale implementation can put the research to a true test and allow it to solve real problems. Through this research, we have gained insights on the factors that
condition the successful implementation of a real-time holding method on high-
frequency routes. The next step is to conduct more sophisticated sensitivity analyses
on these factors. The quantity of data required for these tests would require a
permanent implementation of the holding method.

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