The Effect of Transit Signal Priority on Headway Adherence for Bus Rapid Transit

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Abstract

This is where the abstract should go.

1. Questions

Transit signal priority (TSP) is a technology that allows traffic signals to change their timing plans to accommodate transit vehicles. This may involve extending a green phase until the vehicle passes, triggering an early green if there is a vehicle waiting at the light, or even running specific transit-only phases if the transit vehicles must make a turn across the automobile traffic lanes. TSP is an important tool in helping transit vehicles maintain on-time performance [citations]. Often, TSP will only be triggered at a specific signal if the vehicle is running some amount behind its schedule, thus maximizing green time for automobiles and minimizing automobile delay when the bus is otherwise on schedule.

In high-frequency transit systems where the goal is not schedule adherence but rather *headway* adherence, the specific vehicle schedule might not be published for transit riders. The specific vehicles might follow an internal schedule, but it is not clear whether headway adherence can be improved with a schedule-based TSP regime. The research questions are therefore:

- Does TSP improve headway adherence for rapid transit systems?
- Does the improvement change by time of day or for particular portions of a rapid transit route?
- Is there an average improvement, or is there a reduction only in extreme delay?

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2. Methods

```r
library(tidyverse)
```

2.1. Data

```r
# this dataset was constructed from raw data using the script in R/datamaker.R
# the processed data cannot be stored because it is too big for git
uvx_time_points <- read_rds("data/uvx_timepoints.rds")
```

In 2018, the Utah Transit Authority (UTA) launched a Bus Rapid Transit (BRT) system in Provo, Utah, United States. Known as the Utah Valley eXpress (UVX), the system was highly successful prior to the onset of the COVID-19 pandemic with more than 10,000 riders per average weekday [cite]. The system connects two commuter rail stations, two major universities (Brigham Young and Utah Valley), and commercial retail districts in Orem and Provo. The system includes X miles of dedicated lanes on its X-mile route, and 18 stations with a mix of center and side boarding, all at level floors. The system has been free for all riders since its opening.

Bus Rapid Transit (BRT) systems are increasingly used by cities around the world due to their ability to address high passenger demand without exorbitant upfront costs. The cost savings come from the fact that BRTs operate on Right-of-Way category B (ROW-B) facilities with separated designated lanes that are subject to traffic control at intersections. In this way, buses have an unimpeded corridor on which to complete trips. However, the subjection to traffic control creates variability in the operating times of these systems, and several strategies have been developed and implemented to increase their reliability and operating times.One such strategy is the use of Transit Signal Priority (TSP), which alters priority at signalized intersections to provide for reduced running times between stops and a more even distribution of headways. In general, TSP seeks to improve operations by increasing the efficiency with which buses navigate signalized intersections, but it can be distinguished by a few classes [4]:

1.Active or passive priority. Active priority involves timing adjustments made according to real-time data. Passive priority involves offline measures, such as optimized cycle lengths, based off of historical data.

2.Total, partial, or relative priority. In total priority, control actions such as phase jumping, phase insertion, green extension, or early termination of the red seek to create zero delay for buses. Partial priority limits control actions to those that provide less interruptions to other traffic, such as green extensions and early termination of the red. In relative priority, buses compete with general traffic at lights for priority.

3.Unconditional or conditional priority. Unconditional priority means buses receive priority at all times whereas conditional priority only provides buses with needed control measures when the buses are late.

Adaptive signal priority involves real-time control adjustments made in order to optimize the throughput of both buses and general traffic,in which the delay of each is considered and a controller decides on a response most pertinent to the current traffic conditions. Ni et al. [7] compares adaptive signal priority with active and passive priority, whereas Al-Deek et al. [1] groups it with unconditional and conditional priority.

Many studies have been done to determine the effects of various TSP strategies and configurations. In general, TSP strategies have been found to improve performance of transit systems such as BRT in a number of ways, including reduced delay, improved reliability, and mitigated effects on general traffic.

Ishaq and Cats [5] used a set of trip data from a BRT system in Haifa, Israel to study the relation between service reliability, fleet management, and service utilization. They found that full and unconditional traffic signal priority given at all signals led to an 18% reduction in total vehicle trip time and contributed to a 60% reduction in the standard deviation of trip time. Similarly, Al-Deek et al. [1] found that compared to several other TSP strategies, BRT with unconditional TSP provided the best travel time, speed, number of stops, and delay enhancements but resulted in significant crossing street delays, especially at major intersections with high traffic demand. While the unconditionalTSP strategy was found effective in termsof the delay of the BRT system, concerns rise over the effects on side-street traffic if unconditional priority consistently gives right of way to the buses. Liu et al. [6] clarified that "signal priorities are provided more efficiently and on a more informed basis, with fewer impacts on other traffic operations than the use of unconditional TSP."The implementation of unconditional TSP may only be practical where crossing street volumes are low, and must reasonably be done in conjunction with studies of how non-transit traffic is effected, as each system's corridors have differing needs based off of demand and geometry.

Liu et al. [6] performed a study using transit operation data from a bus route found in Salt Lake County, Utah. A microscopic simulation was used to test GPS-based TSP scenarios. GPS-based TSP uses a GPS to achieve real-time (active) bus locating and advanced wireless communication technologies to achieve comprehensive analysis of operating information. Then a data-driven optimization method was implemented to understand the effects of flexible granting of signal priority across several models. They found that overall, BRT travel time decreased in all models where TSP was employed when compared to the base BRT model. Al-Deek et al. [1] also used simulation models to compare several scenarios. Using field data from a corridor in Orlando, Florida, they found that BRT with conditional TSP that was engaged when the buses were 3 minutes behind experienced significantly improved travel times, average speed, and average total delay per vehicle, with minor effects on crossing street delays, when compared with BRT systems with no TSP or 5-minute conditional thresholds.These results indicate that TSP methods are effective in reducing delay. However, they ignore the important aspect of system reliability, which is critical to improving running times and maintaining ridership.

Yang et al. [8] performed a study of a pre-detective TSP strategy for BRT with active priority coordination between primary and secondary intersections using data from Changzhou, China. Using microscopic simulation, they tested three scenarios (traditional TSP, pre-detective TSP, and pre-detective TSP with coordination) against a no TSP base scenario. They found that pre-detective signal priority with coordination was most effective, with bus intersection delay decreasing by 67.4% and headway adherence improving by about 40% when compared with a no TSP strategy, while reducing normal traffic delay.

Delgado et al. [4] studied station and interstation control jointly to determine an optimal control strategy for a single-service transit corridor applied to a high-frequency transit system, with the goal of evaluating effects over the whole corridor. A strategy of green extension with holding buses at stops was shown to produce a greater reduction in waiting times for users, as well as reducing variability and improving headway adherence.

Ni et al. [7] performed a study of passive TSP control for a BRT system in Taichung, Taiwan. Microsimulation incorporated with a genetic algorithm was developed to coordinate signal offsets along an arterial with BRT operations, with the purpose of balancing improvements in BRT system delays and changes to LOS of other traffic. They found that passive TSP control can reduce approximately 22% of transit delay, with the smallest delay experienced in conjunction with a strategy of a three-minute scheduled headway. Additionally, the 3-minute departure headway scenario exhibited the best service reliability among the scenarios, with a headway stability near 100%.

These studies indicate the need to view BRT system performance in terms of both system delay and reliability. Especially when viewed across an entire system, it is possible for running times to remain consistent while reliability of individual buses is low. In particular, a bunching phenomenon may occur from a positive feedback loop of fluctuations in passenger demand and traffic conditions (Delgado et al. [4]).In scenarios where bunching is a problem, it may not be sufficient to base control strategies off of a schedule, rather on reliable operations. This may prove difficult in implementation. For instance, Ishaq and Cats [5] noted that the procurement agreement between the public transport authority in Israel and the incumbent operator implies that a schedule-based control strategy is required, as opposed to a headway-based (reliability-based) control strategy. However, when TSP control strategies are reliability-based, measures of reliability increase and the bunching phenomenon can be reduced.

Cats [2] performed a study of a regularity-driven operation scheme in Stockholm, Sweden to improve reliability and mitigate bus bunching. Using a series of field experiments and measuring performance with regularity indicators such as headway coefficient of variation, headway adherence, and average excess waiting time, he determined that a headway-based control strategy was effective in not only narrowing the headway distribution from the previous schedule-bases strategy, but also reducing waiting times, more evenly distributing dwell times, and maintaining running times. Chen et al. [3] also performed a headway-based study to measure the effects of real-time preventive operations control. They found that reliability is improved with lower permitted headway deviations and lower fluctuations of running times. When real-time information is used to predict service reliability and trigger preventive control, such as reduced dwell time and speed adjustments, bus bunching can be reduced.

Both of these studies effectively demonstrate that solutions to bunching and other reliability-based operational problems are most effectively addressed through reliability-based control strategies. However, little has been done to evaluate the relationship between methods of TSP in a reliability-based control strategy. A study of TSP strategies with a focus on headway distribution could prove useful in gauging the benefits of TSP in a headway-based system, such as the UVX BRT system in Utah Valley.

3. Findings

References

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