IS 590PR Final Project Report
Bus Transit Simulation with Focus on Bunching Reduction

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Background

Bus transit systems often face the problem of bunching where buses that are scheduled to be equally spaced in time tend to arrive at a stop at the same time. This is often due to the snowballing effect of delays for a bus which causes it to pick more passengers leading to more delays. The bus behind, on the contrary, needs to pick up fewer passengers and typically tends to speed up. This project considers a few hypothesis for reduction of this bunching phenomena and verifies them with simulation. With a bus route prone to bunching as our baseline system, we simulate our hypothesis strategies and observe if bunching is reduced.

Introduction

Bus bunching reduction has been a topic of interest for many researchers. Several technique have been adopted and put to use in public transit systems especially those routes where bunching scenarios occur frequently. This project aims to analyse and compare two popular reduction techniques by modelling and simulating a bus transit system. This modelled system can be configured to account for variability and uncertainty using monte carlo simulation method where the variable and uncertain factors obtain their values from their expected probability distributions.

The working theory behind this is that if a bus is delayed, it will pick up an increased number of passengers compared to the regular load because it will have to accommodate the passengers which would have taken the next bus. This causes a further delay in the bus that's already behind schedule.

In this project, we aim to investigate the causes of bus bunching, develop, test, and compare the following hypotheses using the Monte Carlo Simulation technique:

- Overtaking a delayed bus reduces bunching
- Stopping for a minimum time at every stop irrespective of passenger presence reduces bunching.

According to the hypothesis 1, if a slower bus is allowed to overtake by a bus behind, the faster bus tends to pick the passengers at the next stop thus reducing the onboarding delay for the bus that's running behind schedule.

According to hypothesis 2, we ensure a minimum dwell time for each bus at key stops irrespective of passenger presence. This technique helps to maintain the bus headway distance closer to the optimal required distance and prevents a bus from running faster than its schedule.

Monte Carlo Simulation method allows us to see the distributions and results by running both the hypothesis so that we can arrive at a clear conclusion as to which technique is better under various scenarios.

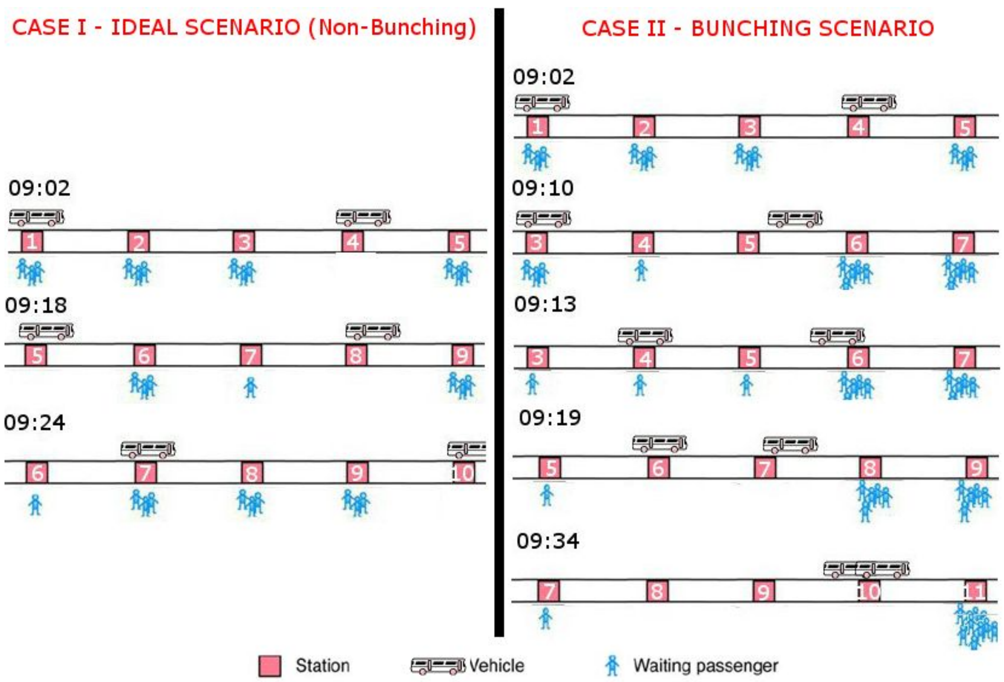

Figure 1: Illustration of Bus Bunching adapted from Luis Moreira-Matias et al., 2014 [1]

Methodology

Monte Carlo simulations are used to quantify outcomes for models containing one or more random variables. It is a technique used to understand risk and impact of uncertainty in predictions for such models.

Technique:

In order to simulate the bus bunching scenario, we have considered various deterministic and non deterministic factors for modelling a transit system.

Deterministic Parameters	**Probabilistic Parameters**
• No. of Stops/Waypoints on route • No. of Buses on route • Bus capacity	• Passenger arrival rates • Passenger destinations • Travel times between stops • Dwell times at stops (Time bus stops to onboard passengers)

Table 1: Various deterministic and probabilistic parameters used for simulation.

Probabilistic Parameters Modeling

- *Passenger arrivals* at stops are modeled using a *Poisson distribution*. This assumes passengers arrive independently from each other at a specified rate. The rate at which passengers arrive combined the time between buses at a stop is used to model the number of passengers waiting at the stop via a Poisson distribution. Poisson distribution is used as it is a popular choice for simulating arrivals in various queuing systems.
- For passengers waiting at a given stop, all other stops are considered *equally likely* destinations. Hence the waiting passengers can be split by destination using a *multinomial distribution* with equal probabilities for remaining stops.
- Travel times between stops are assumed to be asymmetric triangular in distribution with a longer right tail. So the bus is more likely to be delayed than arrive early.
- Dwell times at stops are assumed to be a *deterministic function* of number of passengers on-boarding and alighting perturbed by a *uniform positive random noise*.

The simulation itself is implemented in an event driven fashion rather than using regular time increments. The model generates realizations of the various random parameters and uses these to simulate bus movement. Using this logic, the simulation can fast forward till the time a bus reaches a stop at which point book-keeping is done and new realizations are generated for onward travel.

An *implicit assumption* of the current implementation is that the headway between buses is at most the trip time divided by number of buses plying on the route. This ensures that the simulation can be initialized with evenly spaced buses at a single stop.

Results and Conclusion

The model was simulated 1000 times with deterministic and probabilistic parameters set to value which resulted in bunched scenarios at bus stops for most of the runs. The baseline simulation was configured to simulate an environment with 4 buses each starting from the first bus stop with a headway time of 10 minutes. The probabilistic factors were set to standard values that are generally expected for most bus transit systems.

The figure 2 below shows the aggregate statistics for baseline simulation and simulation with overtaking enabled. The results are promising and concur with our first hypotheses. There was an overall reduction of around 32% in the overall mean of bunching scenarios over 1000 simulations.

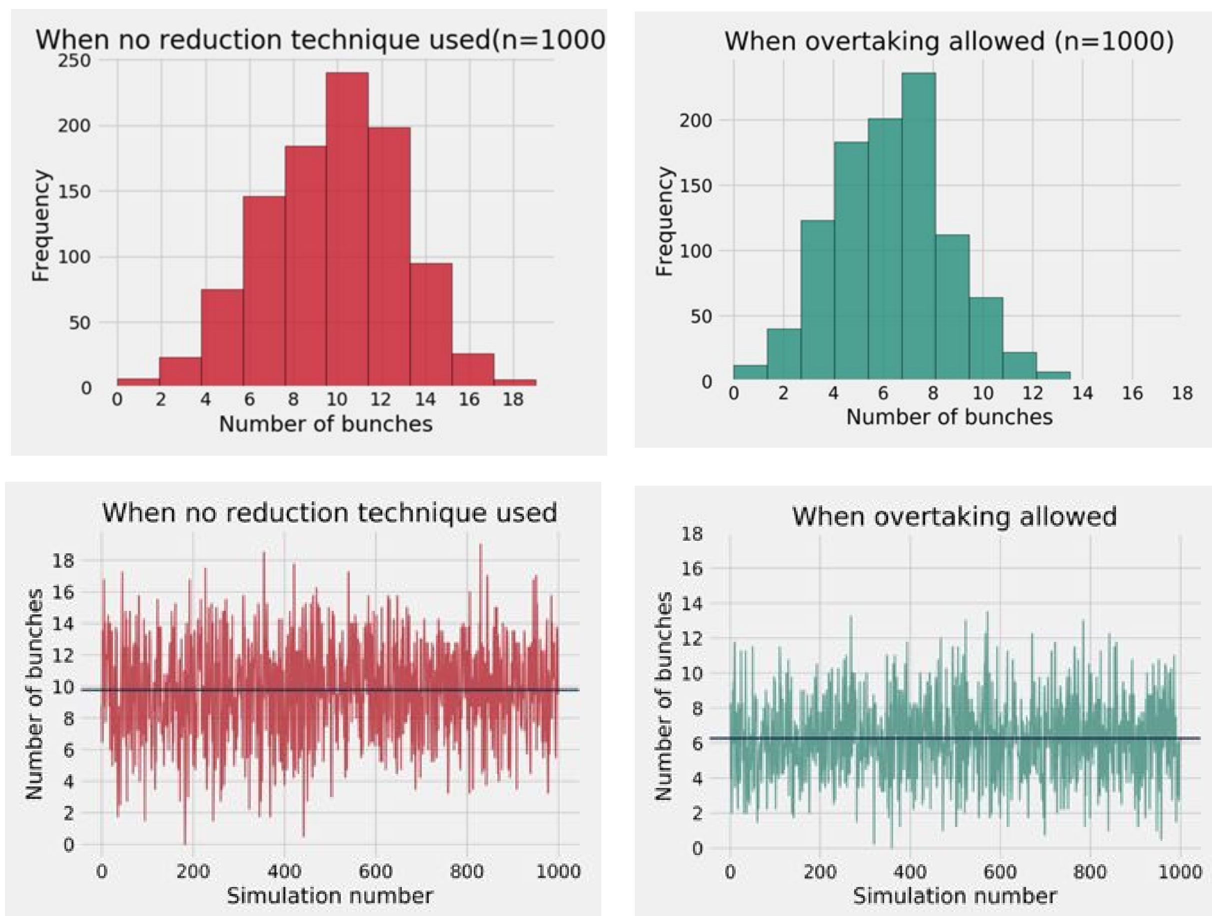

Figure 2: Comparison of bus overtaking technique with baseline simulation. Results show a 32% reduction in the mean number of bus bunching occurrences over 1000 simulations.

Future Work

The distributions used in the current simulation are currently not data driven. Next steps include using Massachusetts Bay Transportation Authority Data to simulate a notorious bus route in Boston (Route 66) [2] and infer the efficiency of the proposed hypothesis in limiting bunching. Data for passenger arrival, alighting and travel times has been sourced [3]. Distributions need to be fit from the data. Hypothesis 2 also needs to be implemented and results compared.

References

[1] Moreira-Matias, L., Gama, J., Mendes-Moreira, J., & Sousa, J.F. (2014). An Incremental Probabilistic Model to Predict Bus Bunching in Real-Time. *IDA*.

[2]https://www.bostonglobe.com/metro/2018/11/25/minutes-for-one-bus-minutes-for-next-why-some-mbta-trips-run-back-back/cURtH3GQKuiwxfLXH5P0UL/story.html

[3] http://www.mbtabackontrack.com/performance/index.html#/download

[4] Pilachowski, J. M. (2009). *An approach to reducing bus bunching* (Doctoral dissertation, UC Berkeley).