Bike-Share Toronto Stochastic Simulation

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1 Background

Bike-sharing has become increasingly popular in cities worldwide as a sustainable and affordable mode of transportation. Without having to worry about bike maintenance or theft, bike-sharing allows customers to take a bike from a station and return it to any other station in the city within 30-minute intervals - going overtime will lead to additional costs. Bike-Share Toronto offers 24/7 access to 7,185 bikes and 630 stations spanning 200 km^2. In a city such as Toronto which has a growing population and heavy traffic congestion, commuters are looking for reliable and efficient ways to get to work or school, and bike-sharing can offer a solution. However, the issue of bike overpopulation at certain stations during rush hour remains a challenge. The Toronto Parking Authority (TPA), which owns bike-share Toronto, reallocates bikes overnight to address this issue. However, during peak hours, the flow of bikes can become unbalanced, leading to frustration for customers who arrive at an empty dock or cannot return a bike due to a station reaching maximum capacity. This can be a concerning issue for customers and the TPA to ensure that bike-sharing remains a reliable and convenient mode of transportation for commuters in Toronto. Although the destination of a specific bike is stochastic, the process of stations being under/overpopulated can be simulated to provide practical insight toward an optimal solution.

2 Literature Review

This project will be based on [1] and [2] among many papers tackling the bike-sharing literature rebalancing problem. [1] uses Citi Bike NYC data from December 2015 that is fed to a discrete-event simulation model which is an adaptation of [2] simulation model. The problem statement is to minimize the expected number of "unhappy" customers due to poor bike allocation. [1] proposes a variety of a gradient-like heuristic method that can improve any given allocation based on the discrete-event model. Moreover, this paper explores how the system may behave during different times of the day such as morning and afternoon rush hours. The paper then uses simulated optimization heuristics to optimize bike and dock allocations during the different times of the day. [2] focus on rebalancing problems that take traffic during bike reallocation time into account. When rebalancing the system during rush hours, the paper focuses on the optimal way to rebalance with limited resources and real-time problems, such as traffic. Aspects of both papers will be presented in this project.

3 Proposal

This project will follow the methods used in [1] to simulate and optimize bike and dock allocation applied to the Bike-Share system in Toronto. Using open-source bike-share data from the city of Toronto [3], the aim is to replicate [1] work to minimize the expected number of customers that would arrive at a station being under or over-populated. Using real trip data containing 705150 trips from August 1st - September 1st, 2022, a discrete-event simulation will be used to analyze the behaviour of the bike-share system. This time was chosen due to the peak season being in July and August in Toronto, thus proper bike allocation has a greater impact during this time.

The discrete-event simulation model will follow [1] version where the arrival times of potential bikers at each station is a time-varying Poisson process with a lognormal trip duration. And the probability of arriving at a certain station given the departure from a specific station follows a multinomial distribution. Using this logic, new data can be extrapolated and fitted to these distributions such that optimization heuristic methods can be performed in 'real-time'. Furthermore, simulating the cost of moving bikes can be taken into account such that the cost of transporting bikes from station A to station B may be dependent on TPA's limited resources/vehicles that can transport bikes at a given time. Thus the expected cost of optimizing both bike and dock allocation may be a performance measure of interest, as well as potentially minimizing the cost of transporting bikes while optimizing both bike and dock allocation - although minimizing the cost of transporting bikes may not be feasible within the time frame for this project. Additionally, being able to successfully optimize using gradient-like heuristic methods might be challenging due to the lack of experience in this field. To conclude, the goal of this is to provide a comprehensive analysis of how bike-share Toronto can sustain a surge in usage during peak hours, which would allow developers to have better insight into future development.

Bibliography

[1] Nanjing Jian et al. “Simulation optimization for a large-scale bike-sharing system”. In: *2016 Winter Simulation Conference (WSC)*. IEEE. 2016, pp. 602–613.

[2] Eoin O’Mahony. “Smarter tools for (Citi) bike sharing”. In: (2015).

[3] City of Toronto. *Open data dataset*. URL: `https://open.toronto.ca/dataset/bike-share-toronto-ridership-data/`.