Redefining Bike Balancing with Quantum Precision

Introduction

After parking her rented bike at a station outside the WQC office in downtown Toronto, Avery Reynolds, Quantum Solutions Consultant, headed into her office wondering how she would help Bike Share Toronto overcome its inability to turn a profit by implementing quantum optimization solutions. Following a new partnership with Tangerine Bank, the company must administer transformational technology to fuel its ambitious growth strategy and continue to serve the 5.7 million annual trips taken by users[1].

Bike Sharing

The first generation of bike-sharing services began in 1965 in Amsterdam, when ordinary bikes were painted white and provided for public use. The concept soon failed, with bikes being thrown into canals or stolen for private use. Bike-sharing services have since evolved and become monetized by many private companies by leveraging technology to reduce theft, secure payments, and provide better service. Due to their profound effects on increasing transit use, decreasing greenhouse gas emissions, and improving public health, local governments often provide support through sponsorship funding.

Bike Share Toronto

Bike Share Toronto is an app-based platform that rents bicycles to individuals for short-term use. It is available in twenty of Toronto's 25 wards. Bikes are docked at stations throughout the city (Exhibit 1), and riders rent a bike from one station and can return it to any others available. Bike Share is North America's fourth-largest bike-sharing agency and has expanded exponentially since its inception. Founded in 2011[2], it has grown to over 700 stations and 9,000 bikes from only 80 stations and 1,000 bicycles.

Financial turmoil

Bike Share heavily depends on corporate sponsorships to support operating costs. Following the termination of the TD Canada Trust sponsorship in 2016, it experienced $12.3M in losses from 2018 to 2022[3]. Still under development, the bike-share model struggles to generate a profit independently. Luckily, in May 2023, Bike Share signed a five-year contract with Tangerine Bank in hopes of helping restructure the company.

A dynamic approach

Balancing and predicting the number of bikes at Bike Share stations is difficult due to demand fluctuations, geographical factors, logistical constraints, data accuracy, and the operational costs

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[1] https://biketoronto.com/news/january-newsletter-2024/

[2] https://en.wikipedia.org/wiki/Bike_Share_Toronto#:~:text=The%20system%20was%20launched%20in,currently%20sponsored%20by%20Tangerine%20Bank.

[3] https://www.cbc.ca/news/canada/toronto/bike-share-toronto-new-partner-1.6651074

of redistributing bikes across the city. This system demands proper data analysis, strategic planning, and operational flexibility.

An effective way of addressing these issues is a technique known as *rebalancing*[4]. Operators can, for example, deploy a fleet of trucks to pick up and drop off bikes at different stations to balance the network at certain periods during the day. Two major challenges arise in this scheme. First, predicting the demand for bikes and stalls in the docking stations in the different locations covered by the service is difficult for a number of reasons, particularly seasonal variations and unpredictable user behaviour. Additionally, selecting the most efficient way to relocate the bikes to satisfy such a demand is difficult due to the operational challenges associated with recruiting personnel, sourcing vehicles, and limited data availability.

Dynamic rebalancing counters the static scheme common in practical bike-sharing services. It aims to increase user satisfaction by minimizing the probability of service failures, like when a user experiences an unavailability of bikes or stalls in the docking station. This decreases user satisfaction and bike share revenues. Should a Bike Share user arrive at a full station to park, they can receive a fifteen-minute time credit to travel to a new station[5]. Based on their pay-as-you-go model (Exhibit 2), this translates to $1.80 or $3.00 in lost revenue, depending on the bike model.

A dynamic rebalancing scheme must address how long a station will be self-sufficient before running out of bikes or available stalls, knowing its initial state. This is commonly known as its survival time, a metric that determines whether rebalancing is necessary. The survival time can be broken down into different datasets based on the fraction of time the system is out of service (empty or full stations), the number of daily rebalancing operations, and the daily distance covered by the rebalancing trucks.

The Quantum Advantage

Balancing the distribution of bikes in Toronto is a tough job. Imagine delivery trucks needing the quickest route to pick up and drop off bikes, so they're evenly spread across the city. This challenge is like a puzzle called the Travelling Salesman Problem (TSP). In TSP, you must figure out the shortest path to visit all the locations and return to the starting point[6]. It's a tricky problem and falls into the category of NP-hard, meaning there's no easy way to solve it with regular computer methods that work quickly for all situations.

Quantum computers can potentially address NP-hard problems, such as the TSP, more efficiently than classical computers. The key advantage lies in their ability to leverage quantum parallelism and superposition. In a classical computer, solving the TSP involves exploring all possible routes

4 https://www.mdpi.com/1424-8220/18/2/512
5 https://bikesharetoronto.com/how-it-works/
6 https://www.geeksforgeeks.org/traveling-salesman-problem-tsp-implementation/

to find the optimal one. This results in an exponential time complexity, making it infeasible for large problem instances. Quantum computers, on the other hand, can process multiple possibilities simultaneously due to superposition. Quantum parallelism allows quantum algorithms, like Grover's algorithm, to explore multiple solutions in parallel. For TSP, this means efficiently evaluating various routes simultaneously, reducing the search space.

The Challenge

Question 1: Descriptive Analytics

The data that you have been provided with includes 1 week's worth of bike routes tracked across the city. Because the purpose of solving this problem is to come up with a proof of concept, we did not include the full dataset (data is fully available from 2015-2024) but discuss how this data could be incorporated into your model.

i) As Reynolds, prepare a descriptive analysis of the current bike-sharing data in Toronto. Where are the major intersections? Are there certain intersections, times of the day or frequent path's that peak at different times?

ii) Suggest potential strategies with regard to the timing and implementation of bike rebalancing. *Hint: Analyze how bikes flow in and out of the downtown core.*

Question 2: Predictive Analytics

i) Construct a predictive model to predict supply and demand across 10 stations in the dataset for a given day. In the excel we have provided an outline for 10 potential stations. Consider what data should be included (eg. rides on weekends were not included or calculated separately as the average departures and arrivals are very different).

ii) For Union Station, King St W/Jordan St, Bay St/Wellesley St W simulate the inflow and outflow of bikes for a given day given that each intersection starts off with 10 bikes. Assuming each station has a capacity of 20 bikes and we ideally don't want to run out of bikes at a given station, determine at what time during the day a given station goes over capacity or under capacity.

iii) Provide strategic recommendations for ensuring that these stations do not go over/under capacity. Consider how this recommendation could be employed as an algorithm and discuss the important factors and variables that would be included. Should there be a minimum number of bikes at each station? When is the best time to move bikes from locations with excess to locations who don't have enough? How would your algorithm determine when rebalancing needs to occur?

Question 3: Quantum Computing Application

Bike Share Toronto has identified an opportunity within this complex problem to optimize a critical bottleneck in the rebalancing process: moving bikes from supply stations to in-demand stations. Develop a quantum inspired application to determine the optimal route (least distance traveled) for visiting stations where an excess of bikes is available, and then dropping them off where bikes are needed. Your objective is to seamlessly drop off these surplus bikes at the station in need, all while ensuring the journey begins and concludes at the company parking lot. Ensure your program is scalable so it could be deployed for a large system with multiple demand and supply stations.

Once developed, implement this program for the hypothetical situation shown in Exhibit 3. Discuss your results.

Exhibit 1: Bike Share Toronto Stations

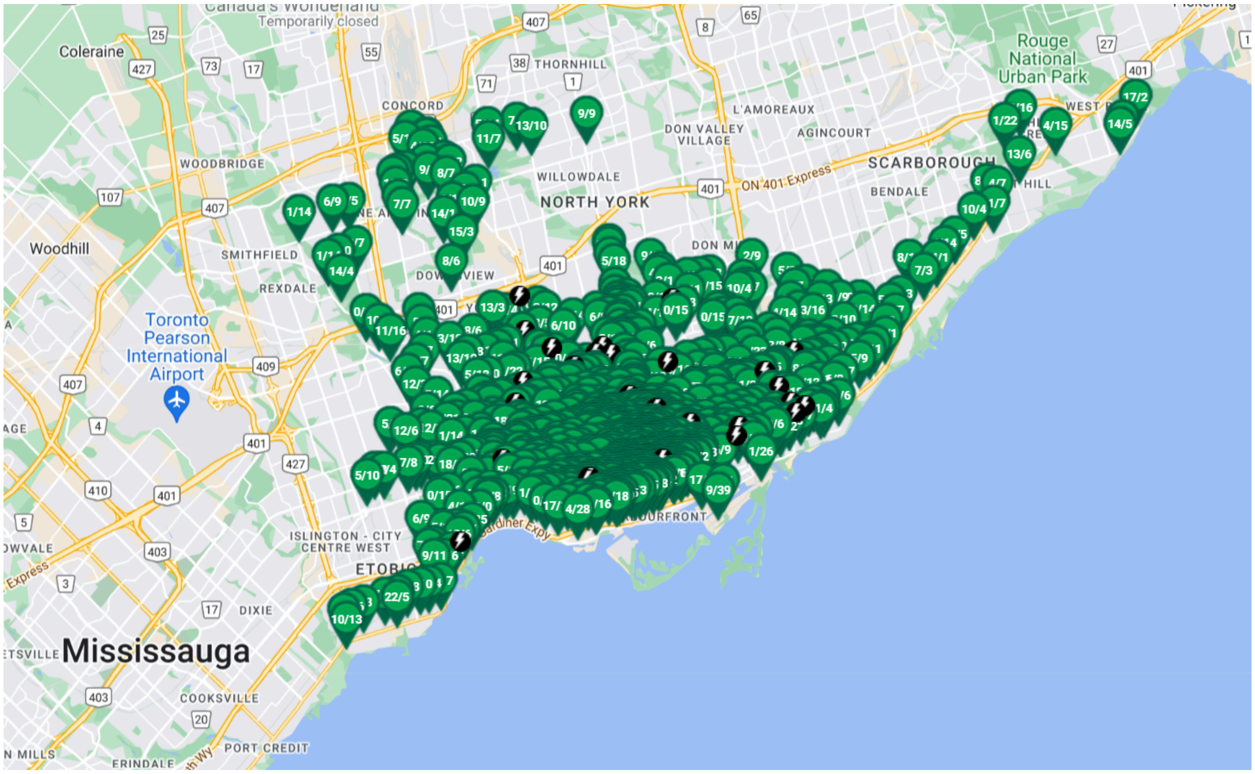

Exhibit 2: Payment Options

Model	System	Type of Rider
Pay-As-You-Go	$1 to unlock + $0.12/minute for classic bikes or + $0.20/minute for e-bikes	Ideal for first-time users, visitors, and casual users.
Day Pass*	$15 for unlimited 90-minute rides for 24 hours.	Ideal for first-time users, visitors, and casual users.
Annual 30*	$105 for unlimited 30-minute bike trips.	Ideal for locals and casual users.
Annual 45*	$120 for unlimited 45-minute bike trips.	Ideal for locals and casual users.

*E-bikes are not offered in the payment model.

Exhibit 3: Hypothetical Rebalancing Scenario

supply indicates excess bikes, and demand implies there are not enough bikes at the station