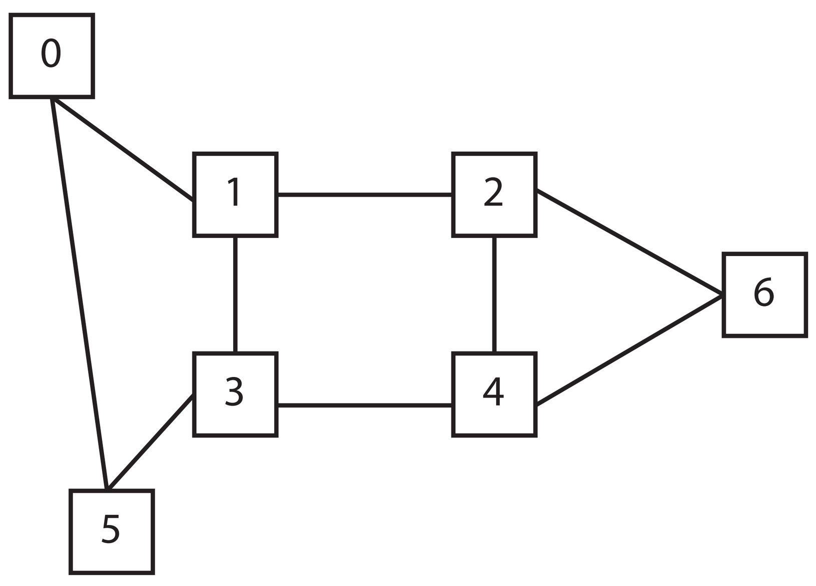
Methodology

Summary of Overall Algorithm



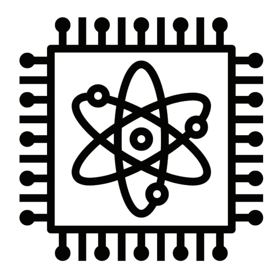
Visual depiction of original road network with bus stops

Pre-processing

Candidate routes
$$\begin{bmatrix} [4, 3, 1, 2] \\ [0, 1, 2, 6] \\ [5, 3, 4, 2] \end{bmatrix}$$

↓

Mapping of candidate routes to binary variables
$$\begin{bmatrix} q_1 = 0 \text{ or } 1 \\ q_2 = 0 \text{ or } 1 \\ q_3 = 0 \text{ or } 1 \end{bmatrix}$$



Quantum algorithm

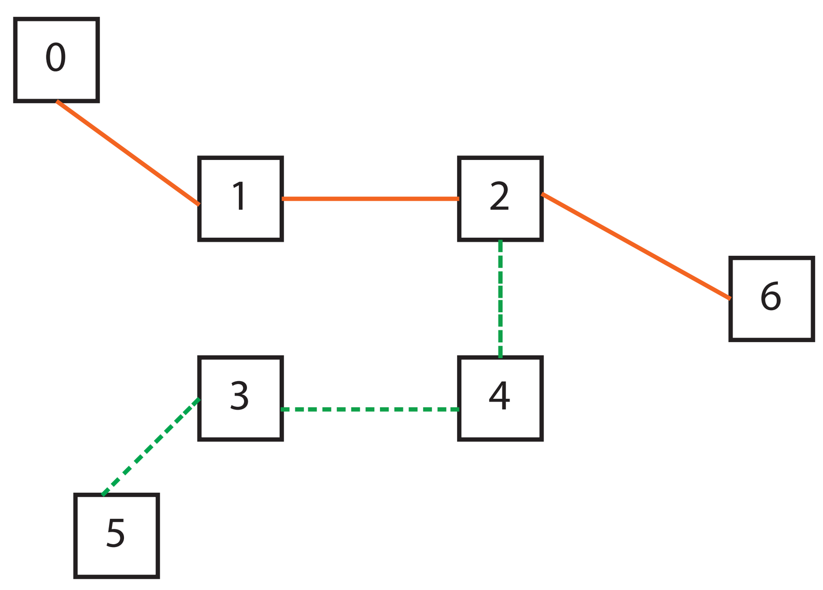
Post-processing

$$\begin{bmatrix} 0 \\ 1 \\ 1 \end{bmatrix}$$
Output of optimized binary variables

↓

[0, 1, 2, 6]
[5, 3, 4, 2]

Binary variable output translated to final route set



Visual depiction of optimized route set

Quantum Algorithm

Quadratic Unconstrained Binary Optimization (QUBO) model:
- model for representing combinatorial optimization problems, like the UTRP
- has the form:

$$Obj(x, Q) = x^T * Q * x$$

where x is a list of binary variables and Q is a 2D matrix

↓

Benefit of QUBO: all problem information can be stored in one 2D matrix

UTRP QUBO Objective Function:

Novel cost function | Route constraint function

$$Obj = \sum_{v,w \in G} \left(\sum_{q_{ij} \in B_{vw}} TT_{vw} d_{vw} q_{ij} \right)^2 + \lambda \sum_i \left(\sum_j q_{ij} - 1 \right)^2$$

bus stop indices; set of bus stops in road network; binary variable; route # index; candidate route index; Set of candidate routes that don't contain v or w; travel time; demand; scaling factor

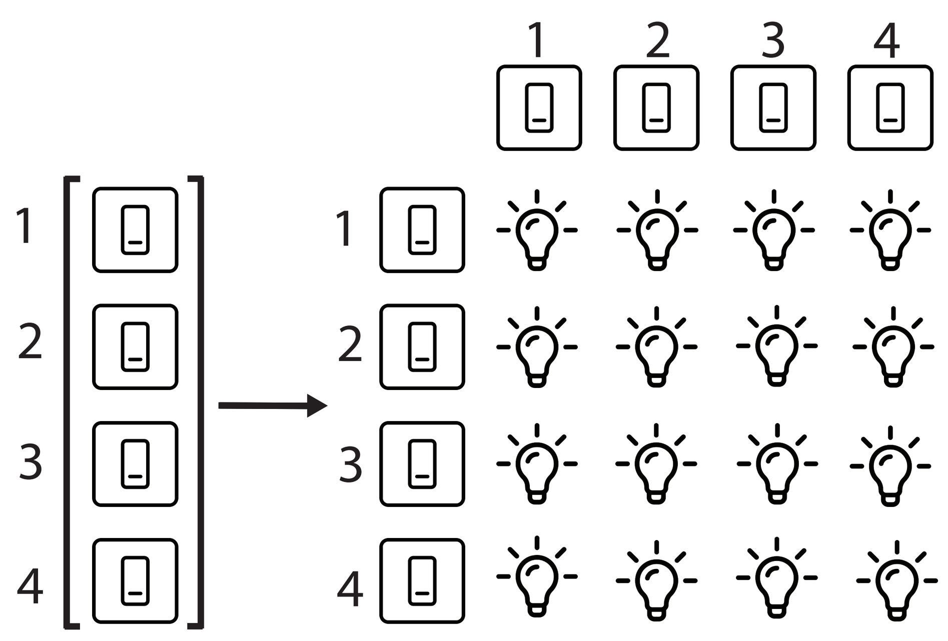
↓

Purpose of UTRP Objective Function

routes that meet more demand weighted low → rewards routes that meet a high level of demand

routes that meet less demand weighted high → punishes routes that meet a low level of demand

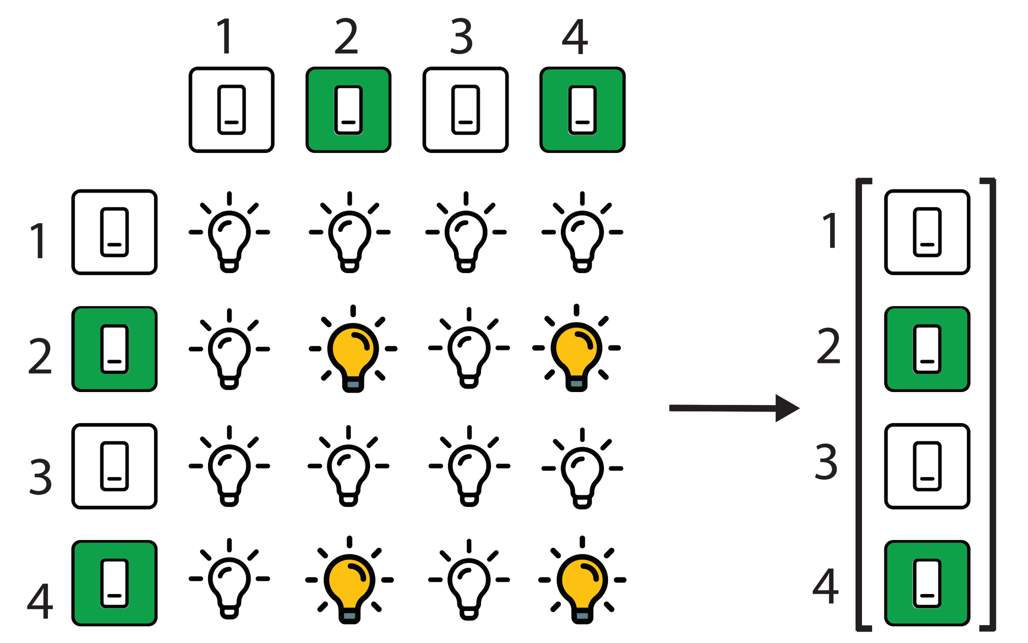
→ creates route set that meets high levels of demand with short travel time between bus stops -> low ATT for final route set



Binary variables as lightswitches

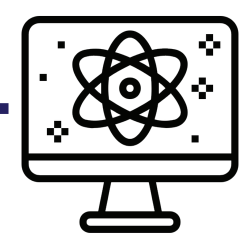
Grid wiring of lightswitchs (each switch wired to each bulb in row/column) with different levels of brightness -> some bulbs are brighter than others

Goal: Choose 2 lightswitches that turn on the lightswitches that make the brightest room



Quantum computer optimized configuration of lightswitches to make brightest room

Optimized light switches = optimized candidate routes



D Wave's Quantum Computer

Goal: Choose 2 binary variables/candidate routes that create the lowest sum

$$\begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \end{bmatrix}$$

Binary variables as candidate routes

$$\begin{array}{c|cccc} & q_1 & q_2 & q_3 & q_4 \\ \hline q_1 & -2 & 3 & 9 & 5 \\ q_2 & 3 & -6 & 3 & 1 \\ q_3 & 9 & 3 & -3 & 4 \\ q_4 & 5 & 1 & 4 & -8 \end{array}$$

Q matrix, created by applying novel objective function to candidate routes

$$\begin{array}{c|cccc} & q_1 & q_2 & q_3 & q_4 \\ \hline q_1 & -2 & 3 & 9 & 5 \\ q_2 & 3 & -6 & 3 & 1 \\ q_3 & 9 & 3 & -3 & 4 \\ q_4 & 5 & 1 & 4 & -8 \end{array}$$

Quantum computer optimized Q matrix with lowest total sum

$$\begin{bmatrix} 0 \\ 1 \\ 0 \\ 1 \end{bmatrix}$$

Output of binary variables = optimized candidate routes

Results

Research Question/Engineering Goal #1

Algorithms	ATT (min)	Total Travel Time (min)
Simulated Annealing (Fan et. al)	11.37	177,031
Genetic Algorithm (Mumford et. al)	11.90	185,283
Particle Swarm Optimization (Kechagiopoulos et. al)	10.71	166,755
Differential Evolution (Buba et. al)	10.36	161,305
My quantum algorithm	10.11	157,413

~ 4,000 min decrease in total travel time

↓

My quantum algorithm outperformed current best UTRP algorithms

Research Question/Engineering Goal #2

Existing route set in downtown Seattle, plotted using OSMnx

Optimzed route set created by quantum algorithm

Route Set Type	ATT (min)
Existing downtown Seattle bus routes	7.08
Optimized routes created by my quantum algorithm	3.33

53% decrease in ATT

A Quantum Optimization Algorithm to Efficiently Route Public Transportation in Cities

Ashwin Kaliyaperumal | Nikola Tesla STEM High School, Redmond WA | HS-ETSD-0277

All tables, pictures, and graphs created by me unless otherwise cited

Introduction

Motivation

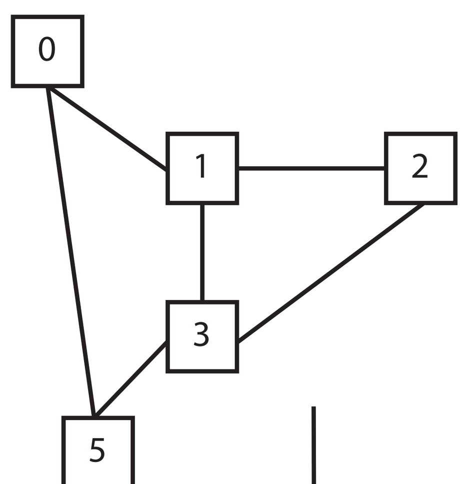
Buses in downtown Seattle are slow and unrealiable → King County Metro buses show up late 23% of the time normally, most of Metro's 195 buses are late during rush hour (Gutman 2017)

Solution: Remodeling existing bus routes in downtown Seattle can help increase reliability of buses

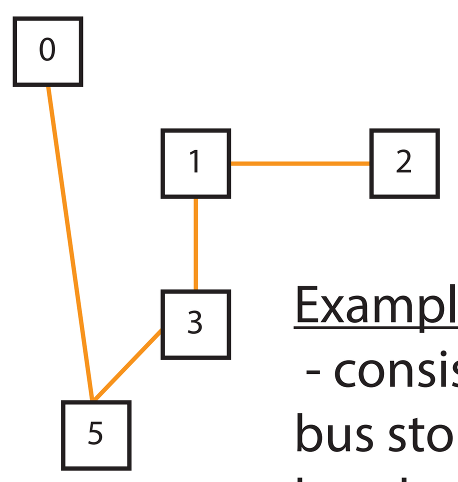
However, There are many factors to take into account -> demand and travel time between stops, traffic, operating costs

Urban Transit Routing Problem (UTRP)

- Simplified model to design efficient route sets from a road network with existing bus stops

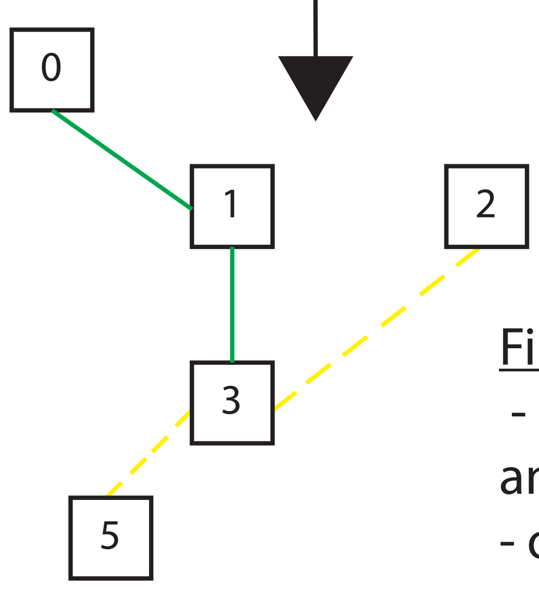


Map of small city:
- existing bus stops numbered from 0-5
- all connections between bus stops shown



Example route:
- consists of all bus stops visited by a bus
- also represented as [0, 5, 3, 1, 2]

Goal of UTRP -> create a route set that minimizes the average travel time (ATT) of a passenger traveling between any two bus stops



Final route set:
- made up of two routes: green and yellow
- output of UTRP solvers

Problem: Current UTRP solvers don't perform well on benchmarks + haven't been tested on real world applications

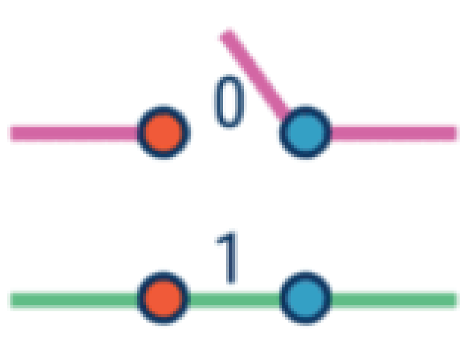
Research Questions/Engineering Goals

Research Questions:
- Can a quantum computing approach to the Urban Transit Routing Problem (UTRP) produce a route set with a lower average travel time (ATT) than classical algorithms?
- Can a quantum computing algorithm to solve the UTRP produce routes with a lower ATT than an existing bus route set in downtown Seattle?

Engineering Goals:
- Produce route set for Mandl Swiss benchmark that has an ATT less than 10.36 minutes
- Create route set for downtown Seattle road network that has an ATT 20% faster than existing bus route set

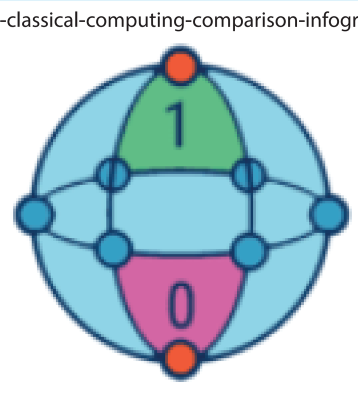
Quantum Computing vs Classical Computing

Images taken from https://www.cbinsights.com/research/quantum-computing-classical-computing-comparison-infographic/



- Classical computers use bits to store info
- Bits can only store a 0 or 1 at a time

→



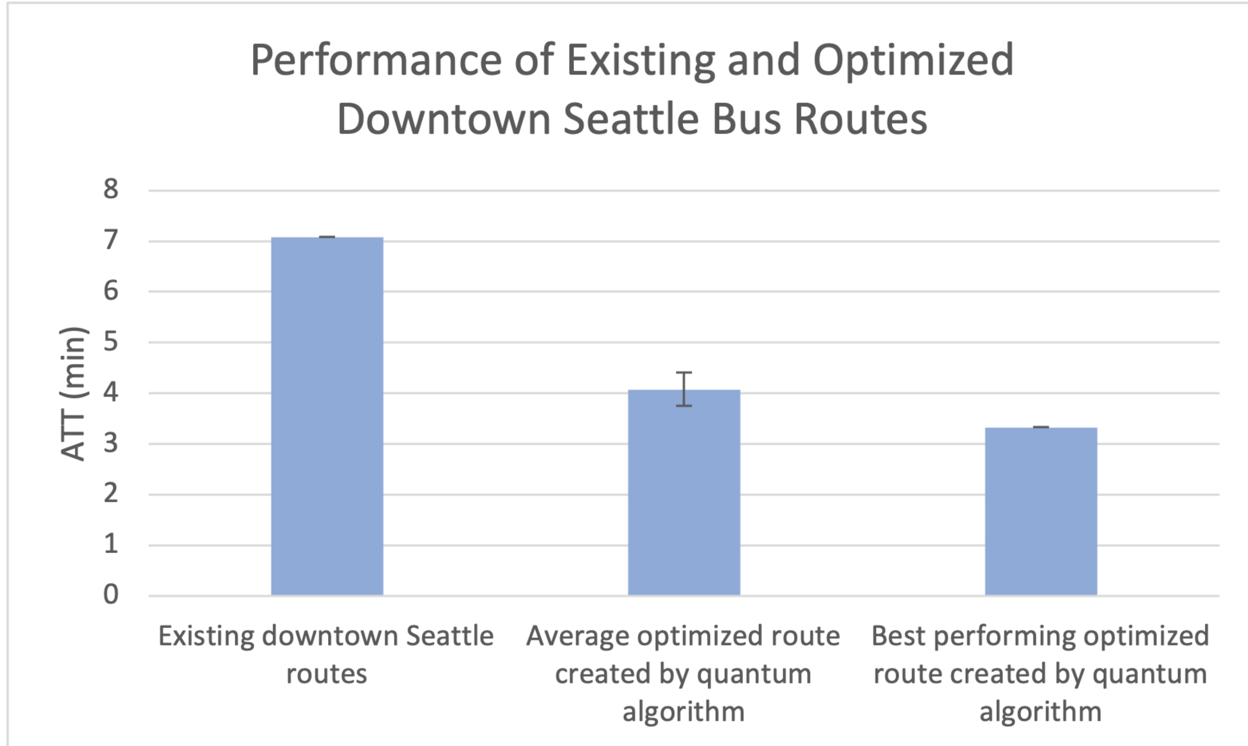
- Quantum computers use qubits to store info
- Qubits can be 0 or 1 at the same time

Benefits:
- can search through more solutions quicker
- better suited to optimization tasks
- hasn't been used to solve UTRP before

Hypothesis: Quantum computing algorithms to solve the UTRP will produce solutions with a significant decrease in ATT through their theoretical superiority in solving optimization problems.

Results (cont.)

Research Question/Engineering Goal #2



Expected decrease in ATT with optimized routes

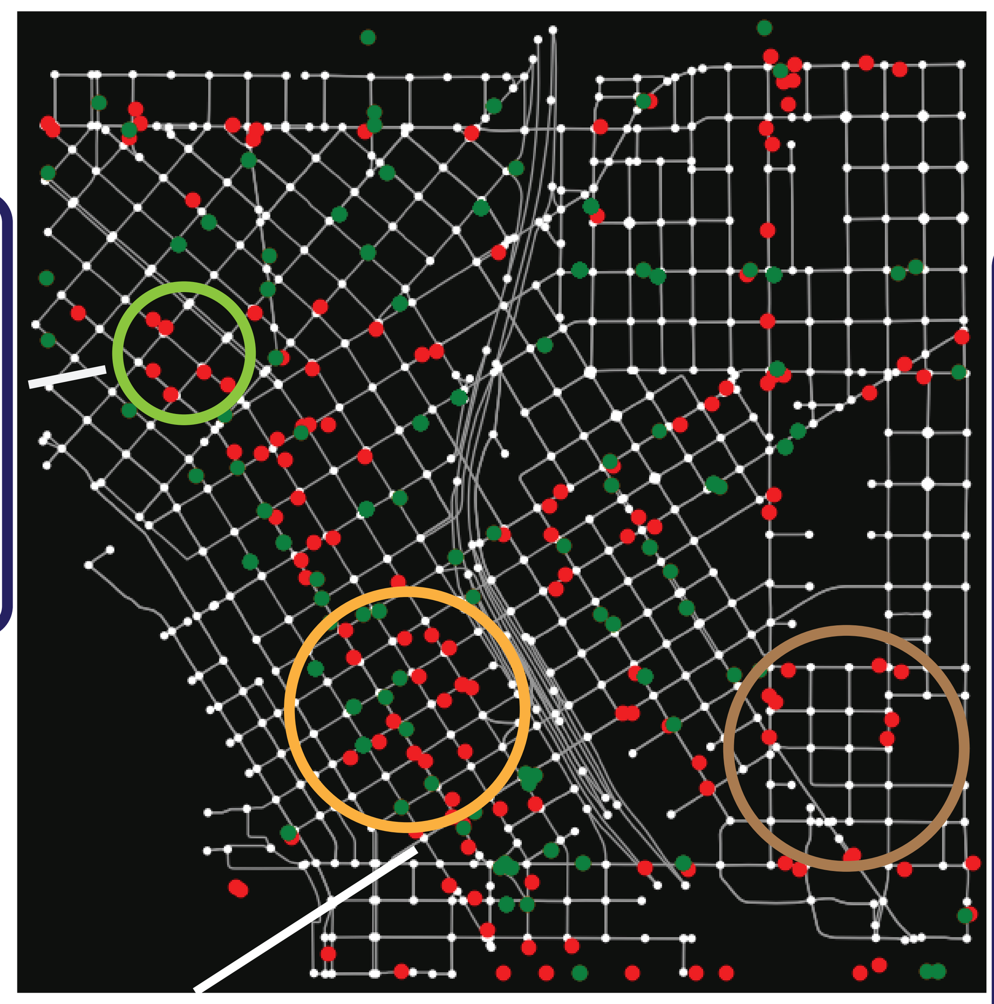
↓

This was observed

↓

Algorithm was able to significantly decrease ATT consistently

Analysis of Missing Bus Stops



Not enough demand -> Annual Average Weekday Traffic (AAWDT) was only ~5,000 here, while in city center it was > 13,000

Problem: limited demand data -> algorithm thought no one wanted to go to these bus stop -> didn't include in final route set

↓

Solution: use more accurate demand data -> can use more recent traffic flow data

Too many bus stops in small area: more stops in route -> slower transit system → Getting rid of unnecessary or redundant stops -> less overall travel time in routes

Conclusion

- My quantum computing algorithm outperforms classical algorithms in solving the UTRP
- My algorithm drastically reduced ATT for bus stops covered by optimized route set in downtown Seattle

Future Steps

Improve algorithm → - Take into account other aspects of route generation, like construction projects blocking roads or demand from lightrails/trains

Other ways of reducing late buses → - Frequency setting -> optimizing number of buses needed per route
- Timetable development - creating optimized bus schedules

Testing on other cities → - Can quantify more accurately my algorithm's effectiveness
- Could be applied to routing other forms of public transportation

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All icons from Flaticon.com

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