Data Science Practice :

Shenzhen Metro System Optimization

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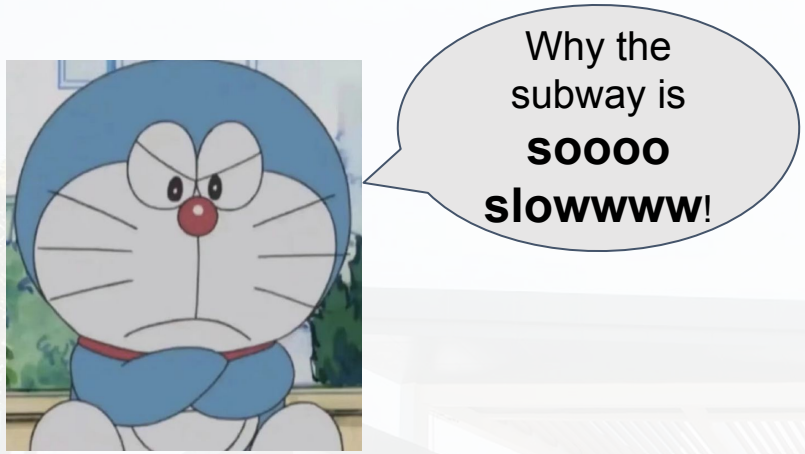
Motivation & Background



- Shenzhen's metro system faces significant challenges during peak hours, including overcrowding and long waiting times.
- Line 5 is the main line running east to west, with a daily passenger volume of 1.0262 million, making it the busiest metro line in Shenzhen.
- **Optimization approach**: Through algorithm optimization, certain trains will be designated to skip specific stations during peak hours to reduce overall commuting time across the network.

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CATALOGUE

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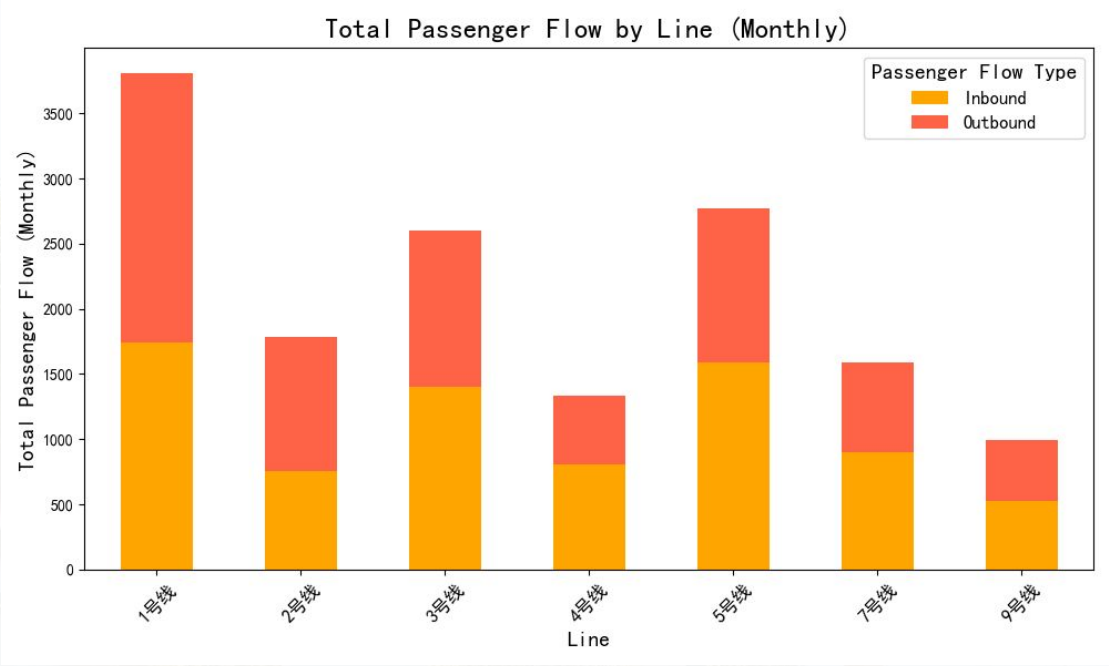
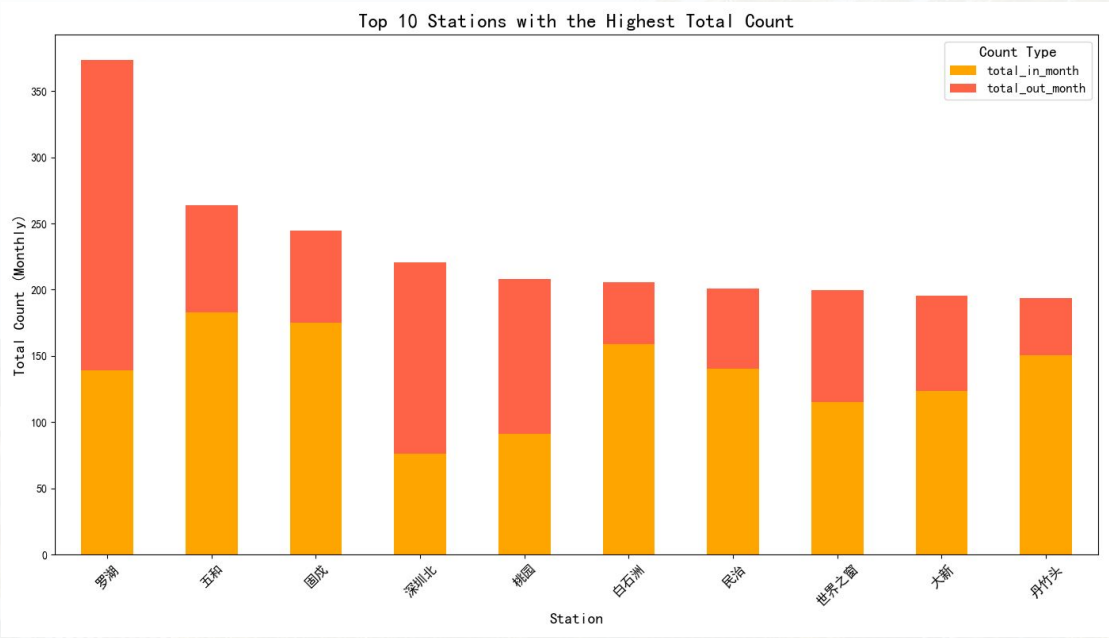
01

EXPLORATORY DATA ANALYSIS

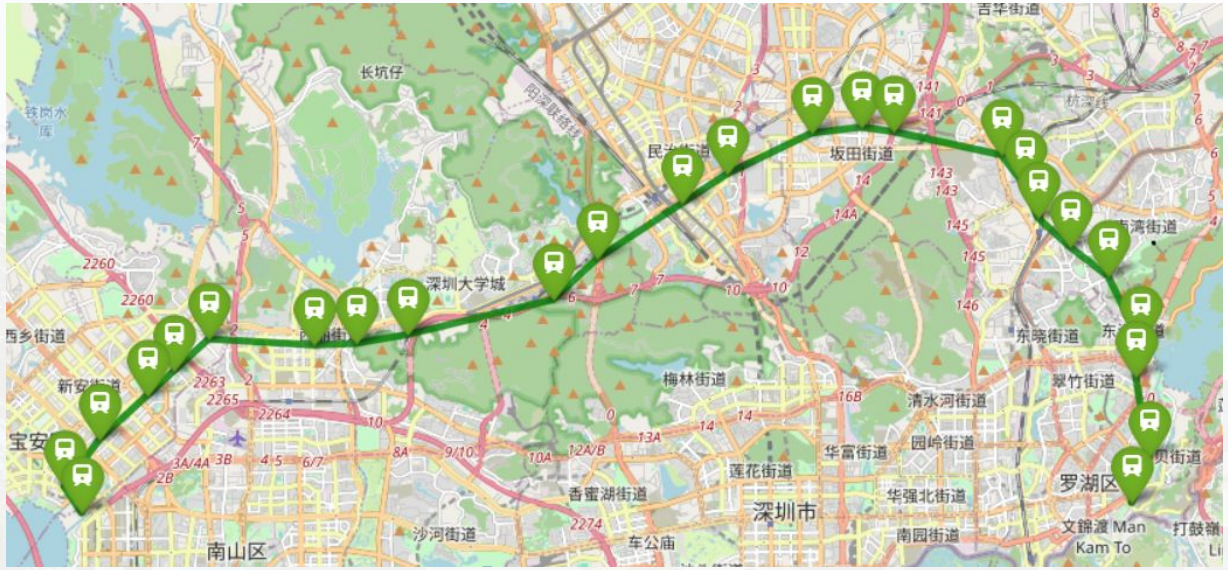
Data introduction and visualization.

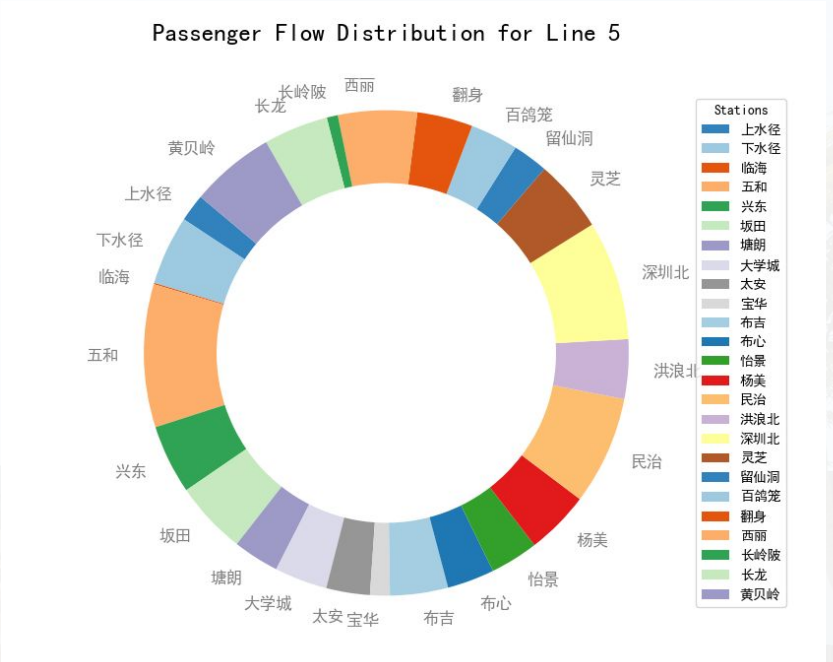
Passengers flow of different stations & lines are different





- Total passenger flow ranking for different lines: line 1 > line 5 > line 3
- Total passenger flow ranking for different stations: Luohu > Wuhe > Gushu





- Shenzhen Metro Line 5 follows an M-shaped route from southeast to northwest to southwest with a total length of 47.393 kilometers and 34 stations.

- The three busiest stations on Line 5 are: Wuhe, Shenzhenbei Station, and Minzhi Station.

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02

ALGORITHM DESIGN

Greedy algorithm and local search.

Model Assumptions

- The time saved remains constant for each station if a station is skipped.
- The distance between each neighboring station is constant.
- Subway crashes are not considered since we are optimizing scenarios with two subway railroads.
- There is a fixed capacity for each subway. This allows us to discuss situations where too many people are entering the subway.

Problem Formulation

parameters	pure simulated	Shenzhen data
station_interval	2	1.5
skipped_saved	1.5	1.2
station_N	20	25
train_N	28	27
passengers_max	110	75
N	20,000	10,000

Table 1: parameter table

ID	start	end	time
0	2	7	110
1	9	18	23
2	16	13	152
...	...	...	...
N-1	16	10	152

Table 2: input passengers flow

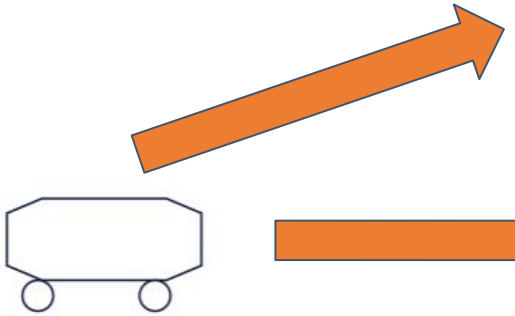
station_0	station_1	station_2	...	2*station_N
0	1	1	...	1
1	0	1	...	1
1	0	1	...	0
...	...	...	...	...
1	1	0	...	1

Table 3: output subway schedule

Greedy Algorithm

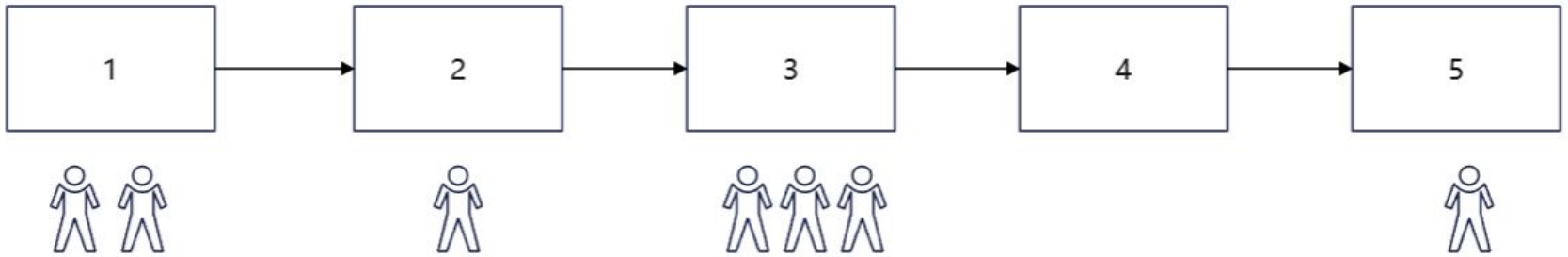
ID	start	end	time
0	2	7	110
1	9	18	23
2	16	13	152
...	...	...	...
N-1	16	10	152

Skip?



Stop √

ID	start	end	time
0	2	7	110
1	9	18	23
2	16	13	152
...	...	...	...
N-1	16	10	152

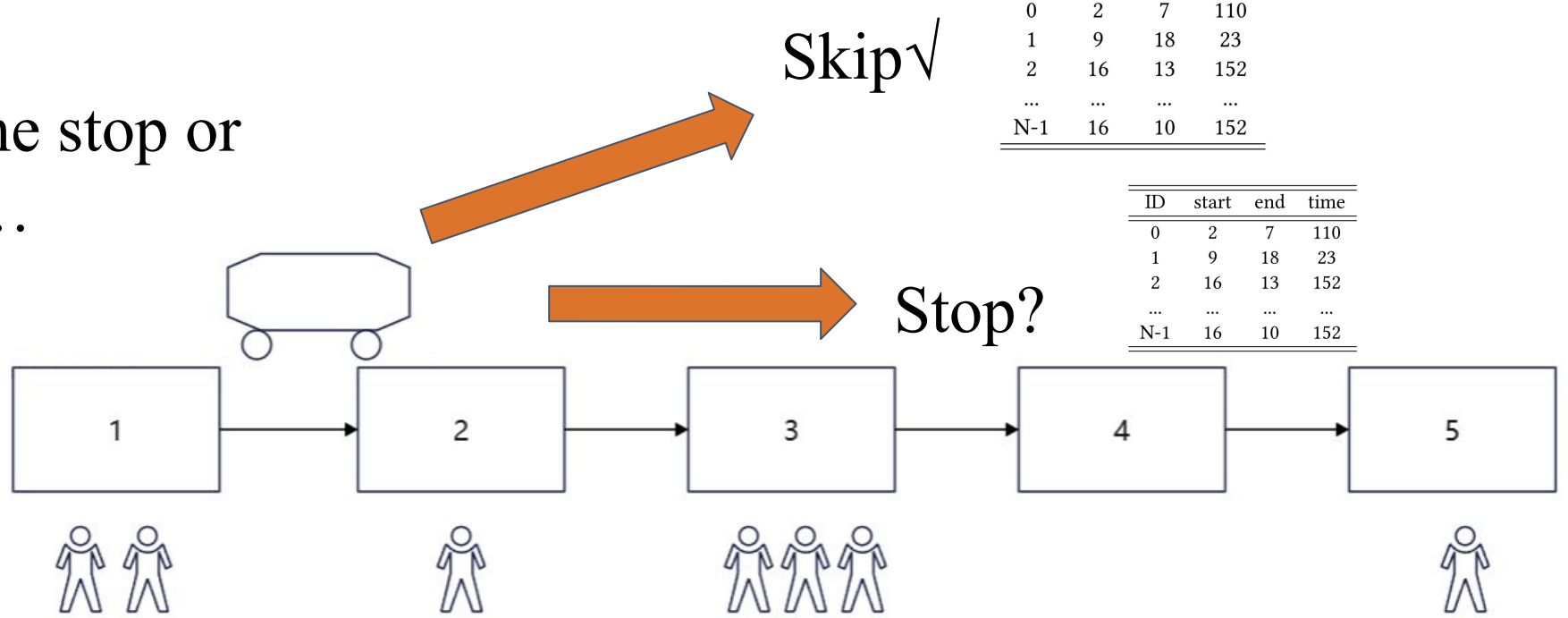


Initial Stage	stop	stop	stop	stop	stop
Improved Stage..	stop				

Greedy Algorithm

Keep asking the stop or skip question…

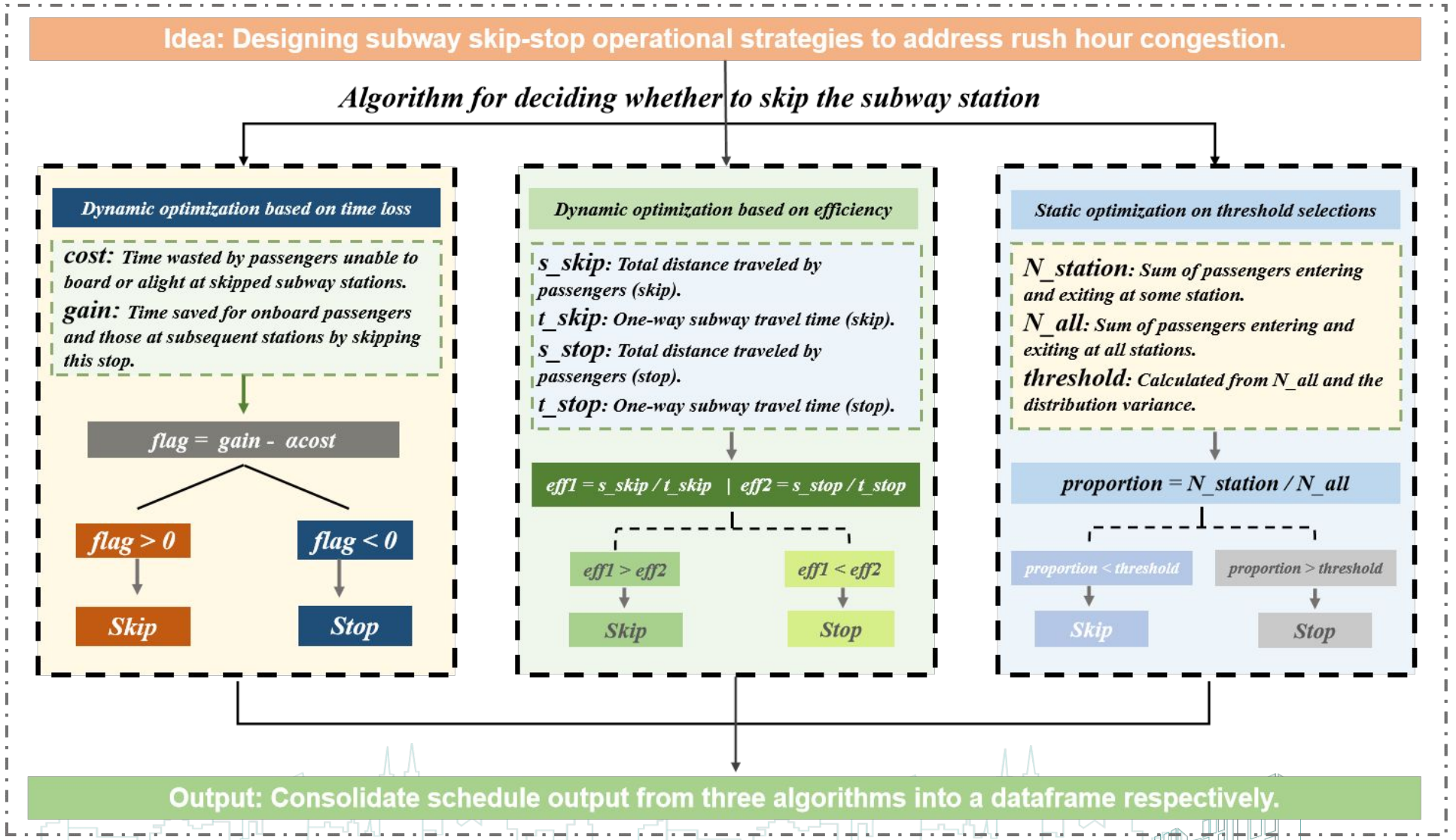
ID	start	end	time
0	2	7	110
1	9	18	23
2	16	13	152
...	...	...	...
N-1	16	10	152



ID	start	end	time
0	2	7	110
1	9	18	23
2	16	13	152
...	...	...	...
N-1	16	10	152

Initial Stage	stop	stop	stop	stop	stop
Improved Stage..	stop	skip			
Improved Stage	stop	skip	stop	skip	stop

Greedy Algorithm



ID	start	end	time
0	2	7	110
1	9	18	23
2	16	13	152
...	...	...	...
N-1	16	10	152

Table 2: input passengers flow

Implementation of Local Search

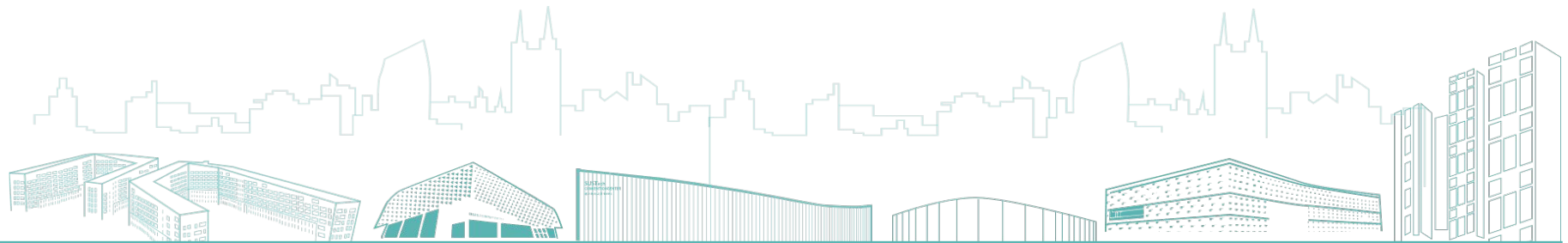
- **Optimization Objective**: Minimize total passenger commuting time.

- **Process**:
  - Evaluate neighbors of the current schedule.
  - If a better neighbor is found, update the current schedule.
  - If not, retain the current schedule.

station_0	station_1	station_2	...	2*station_N
0	1	1	...	1
1	0	1	...	1
1	0	1	...	0
...	...	...	...	...
1	1	0	...	1

Table 3: output subway schedule

- **Neighbors Definition**: Based on Hamming distance of the schedule matrix.
  - Maximal neighbourhood distance set to 3.



Local Search

Why Local Search?

- **Complexity of Advanced Methods**:Other algorithms require extensive computation.
  - Example: Calculating total waiting time for 100,000 passengers takes ~2.5 minutes.
  - Running 1000 iterations could take 41.7 hours.

- **Computational Constraints**: The schedule matrix for the morning peak contains over 2,500 elements.
  - 1,000 iterations are not enough to reach global optimal

- **Efficiency of Local Search**:
  - Local Search provides a relative good feasible solution without excessive computational time.

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03

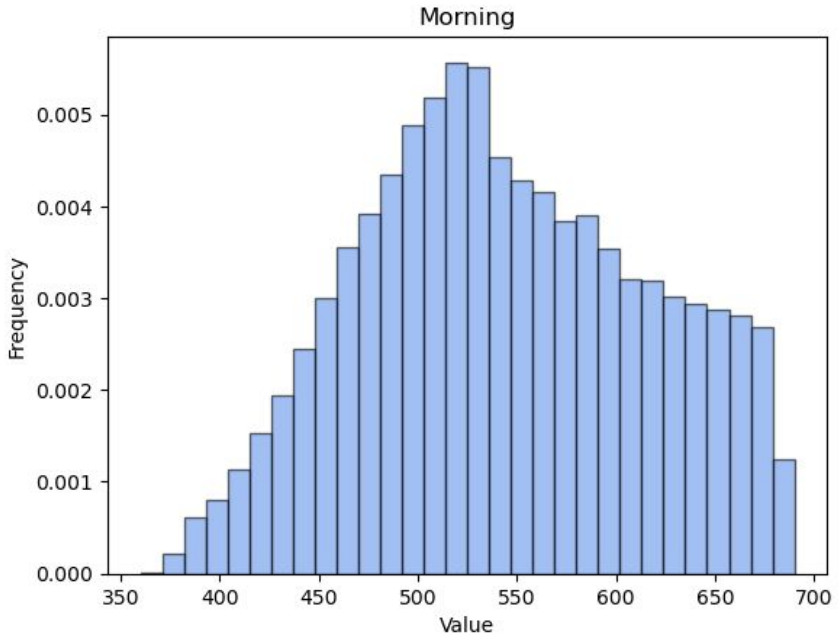
EXPERIMENT

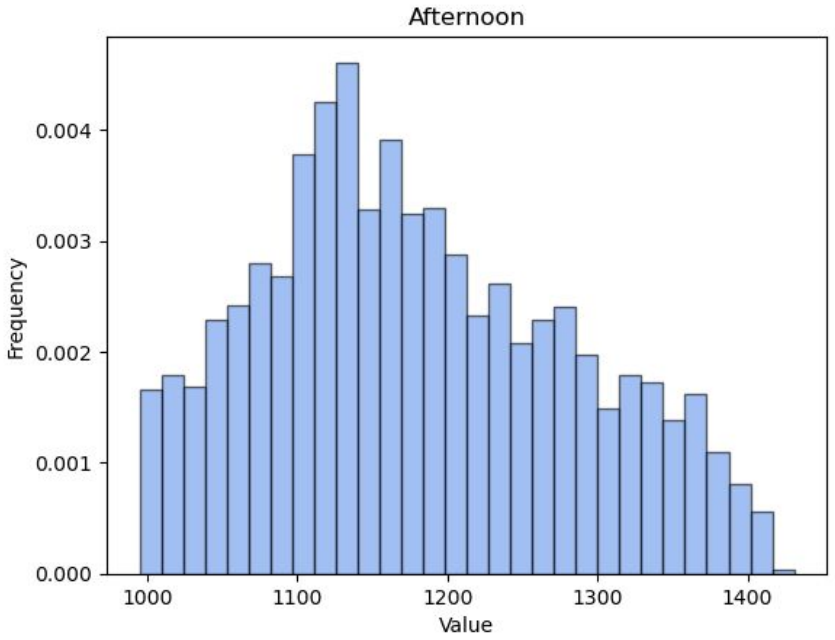
Experiment conduction and results.

Experiment

- **Simulated Data Generation**
  - Based on Real Data
  - Probability Generating Data
- **Experiment Results and Performance Comparison**
  - Commuting Time Distribution
  - Local Search (searching for optimal)
  - Analysis of Commuting Time Improvement
  - Algorithms' Feature Analysis
  - Algorithm Sensitivity Analysis

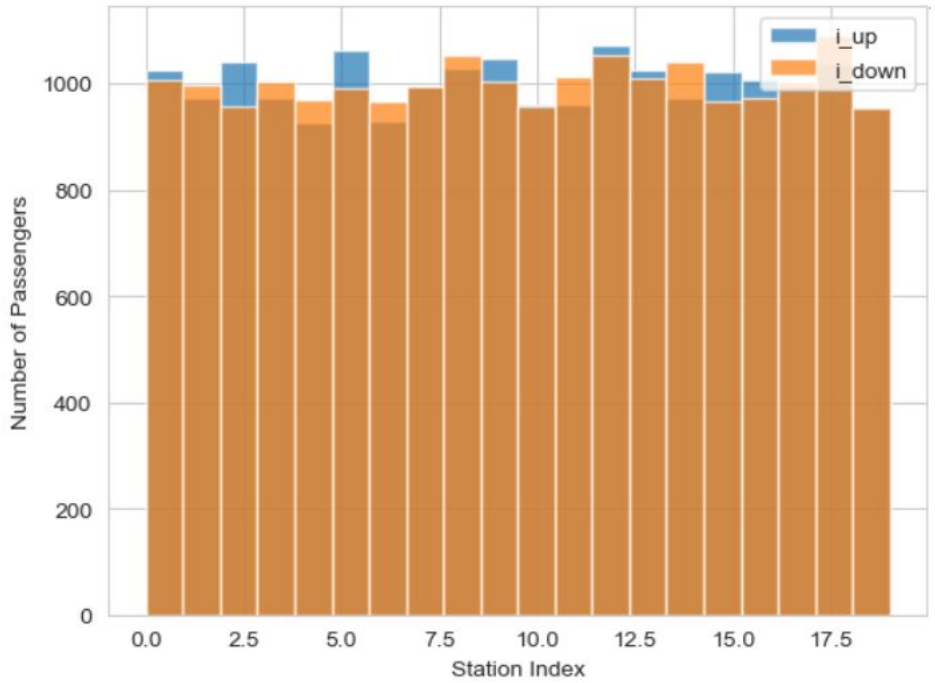
Based on Real Data

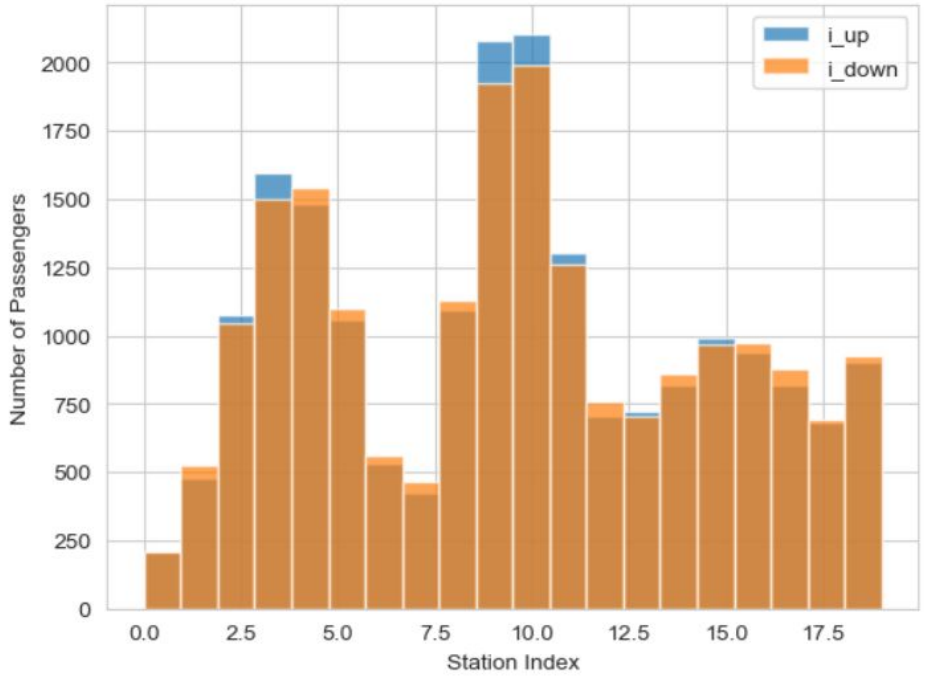




- Generate the simulated data based on the distribution of real data.

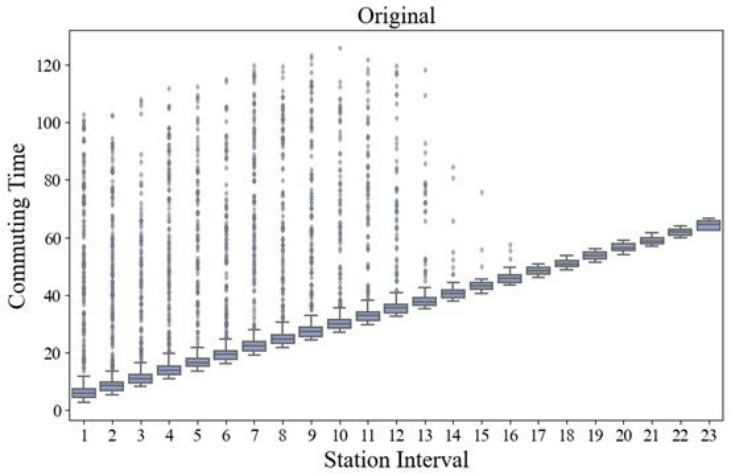
Probability Generating Data





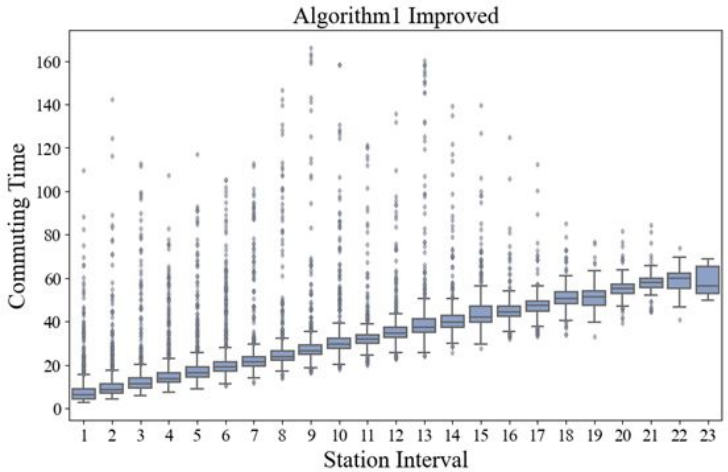
- We used uniform distribution and normal distribution to first generate a simulation Data

Commuting Time Distribution ~ Time Interval

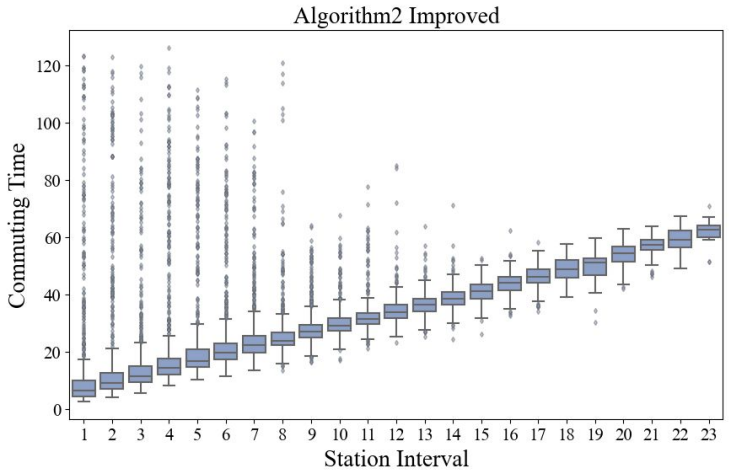


- Larger distance means longer commuting time
- Almost Linear
- Outliers are those who meet the train at morning peak

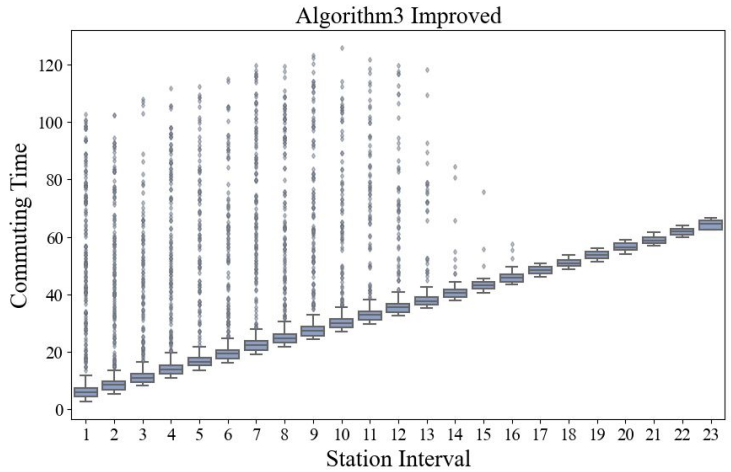
NOT OBVIOUS…



Algorithm 1

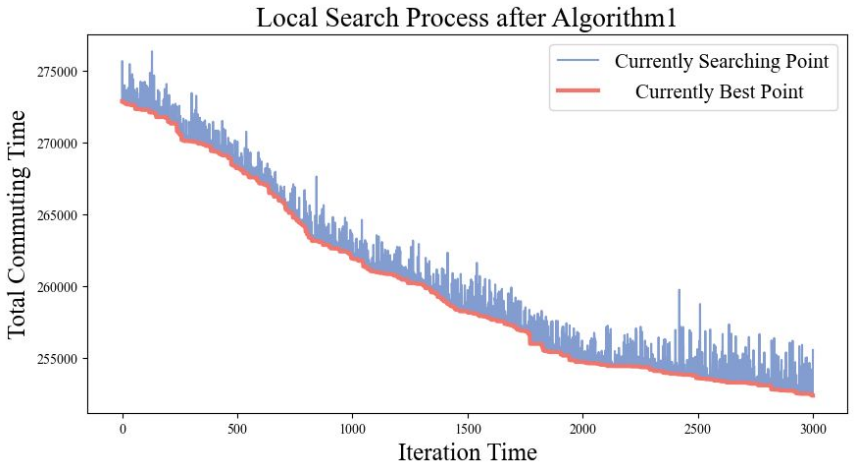


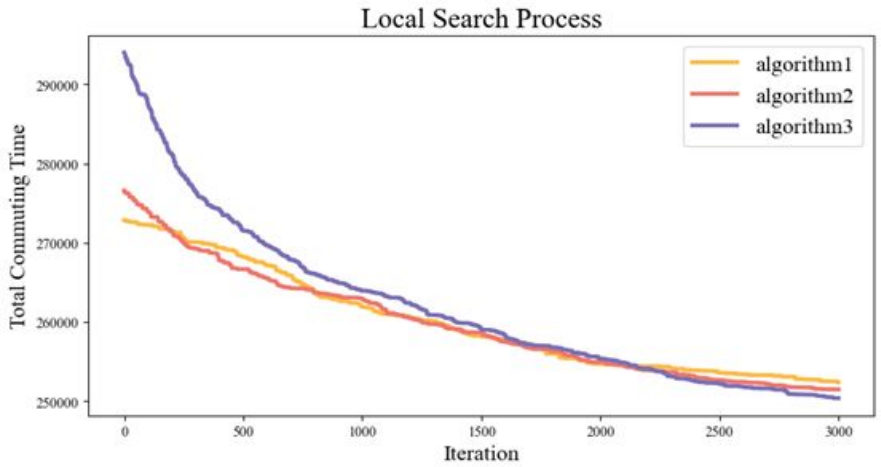
Algorithm 2

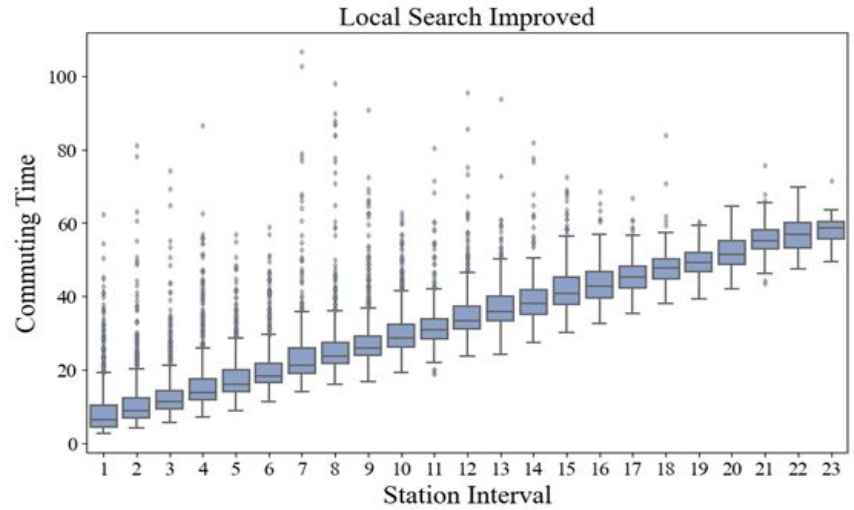


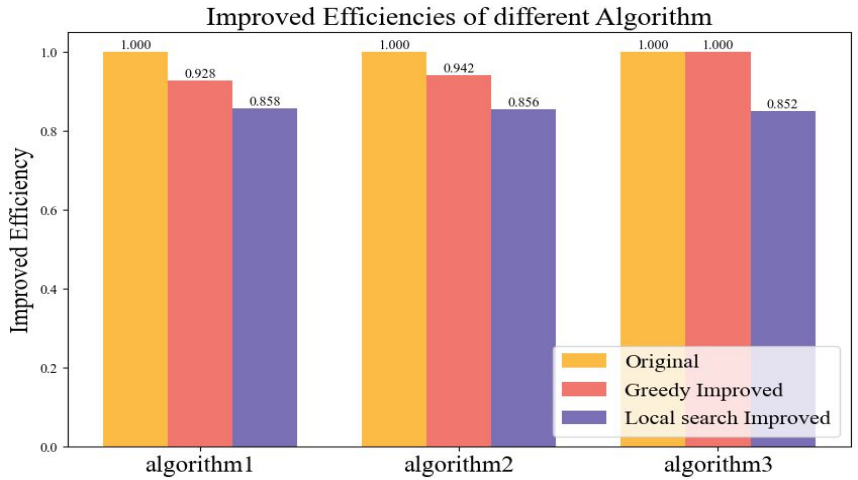
Algorithm 3

Local Search (searching for optimal)



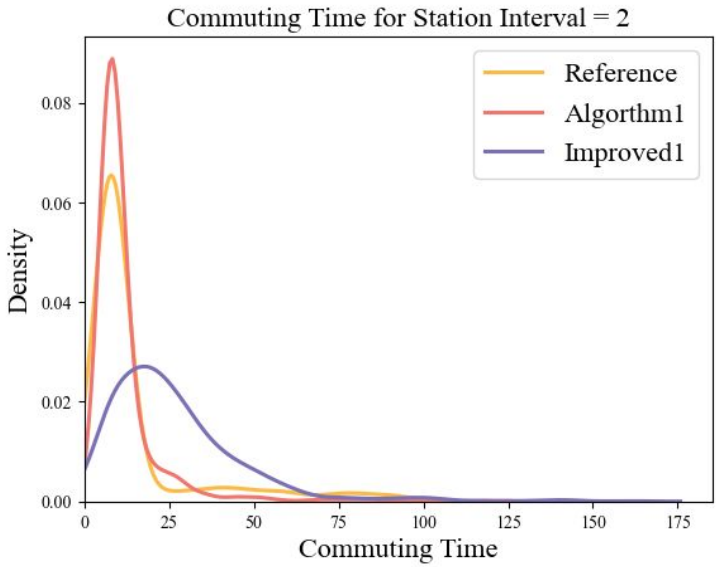


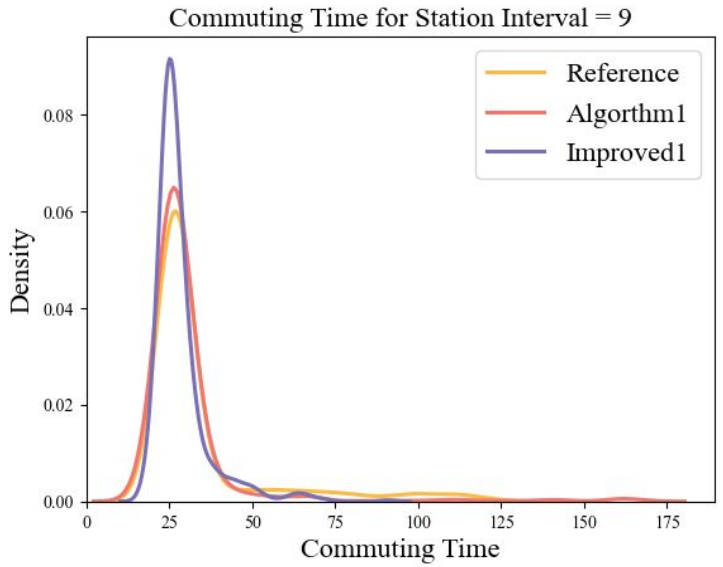


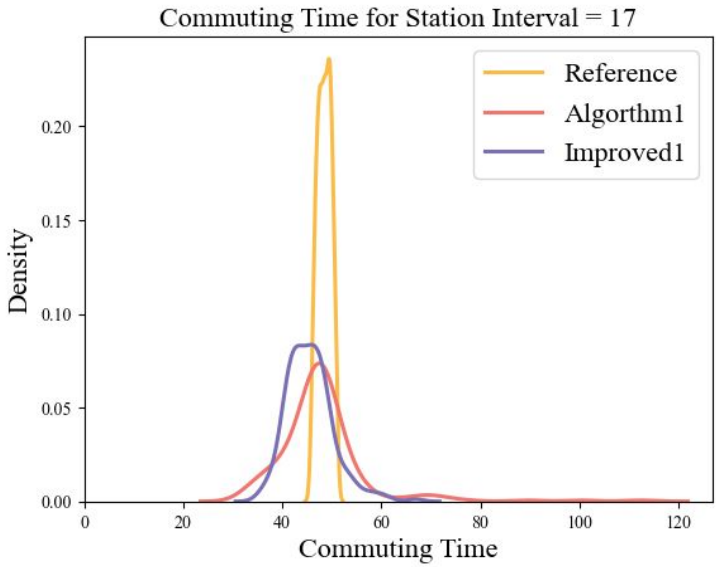


- Local search consistently elevates the total saved commuting time to approximately 15%.

Analysis of Commuting Time Improvement







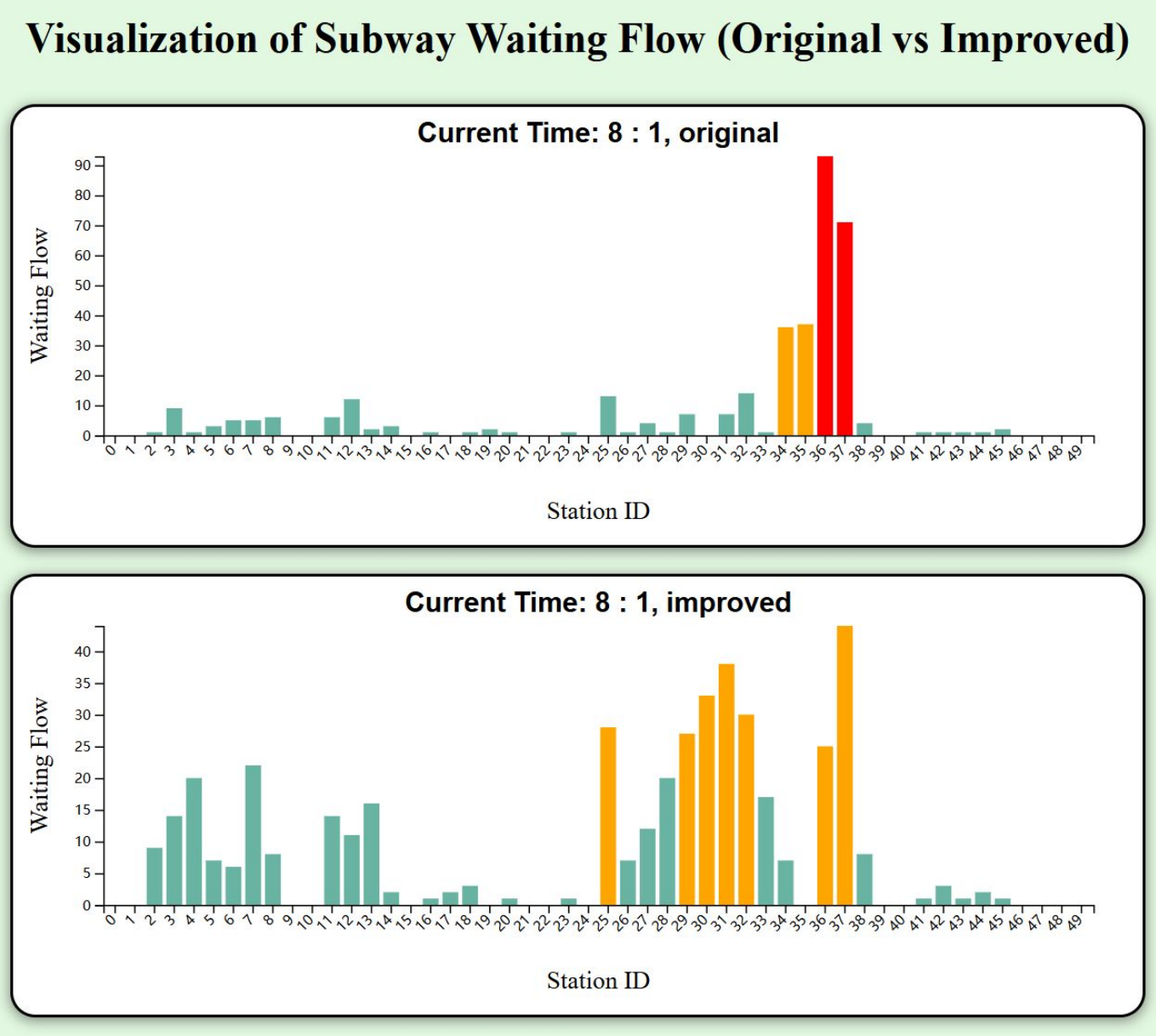
Station Interval = 2

Station Interval = 9

Station Interval = 17

- MORE TIME IS SAVED AS STATION INTERVAL INCREASES!

A short display of the performance visualization



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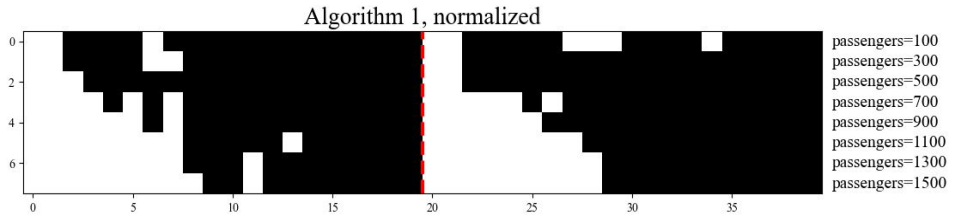
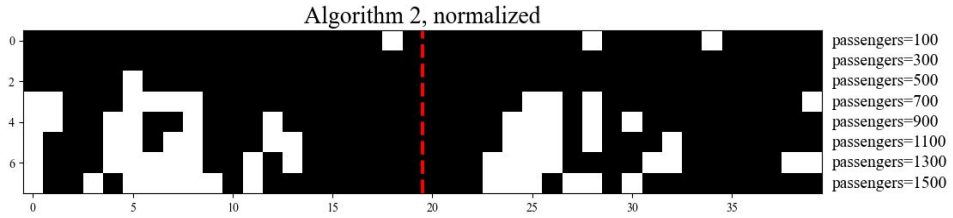
Algorithms' Feature Analysis

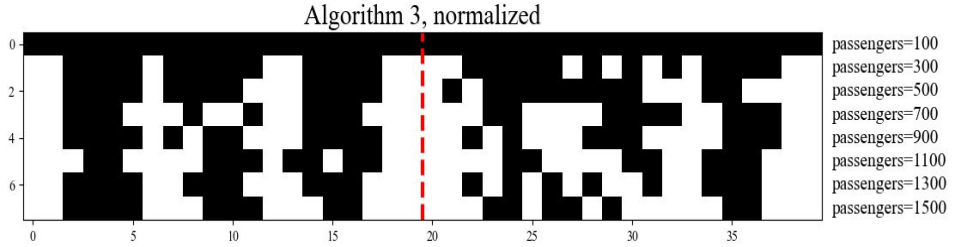
Algorithm 1

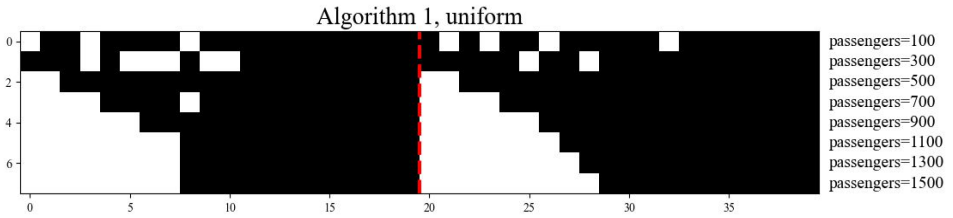
Algorithm 2

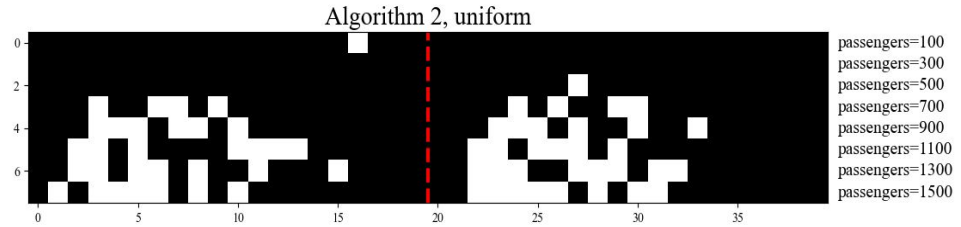
Algorithm 3

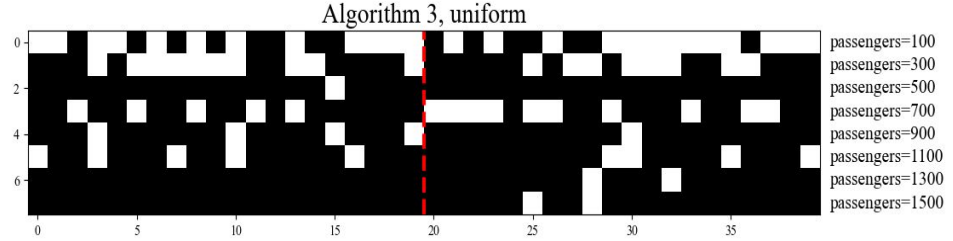












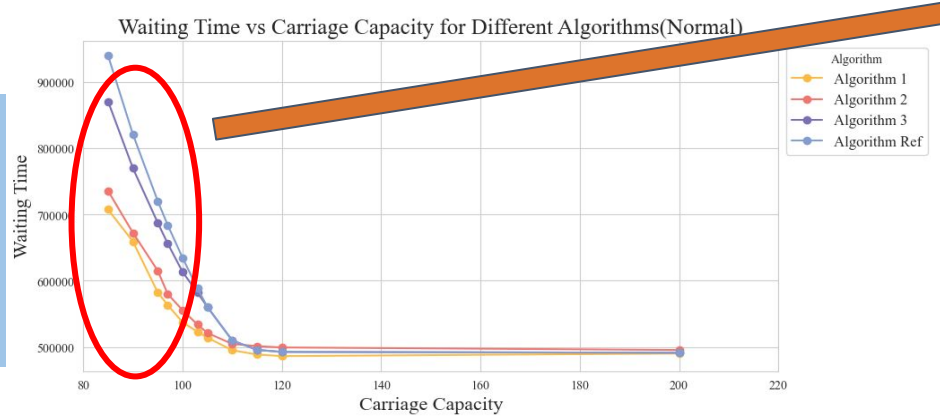
Normal distributed data

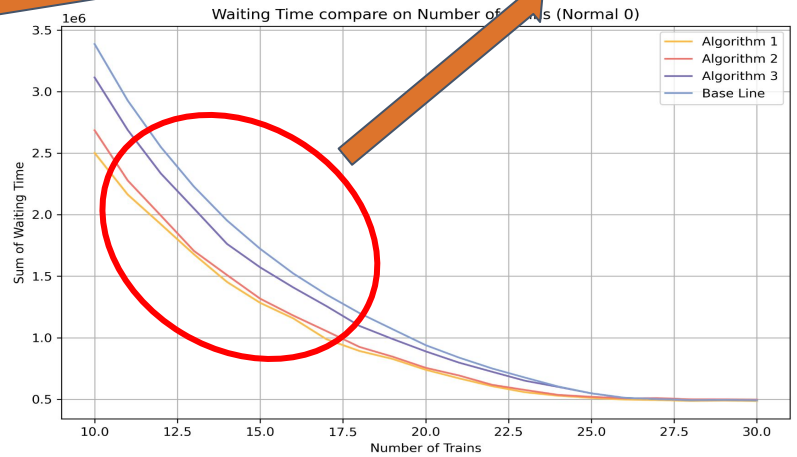
Uniform distributed data

Algorithms' Sensitivity Analysis

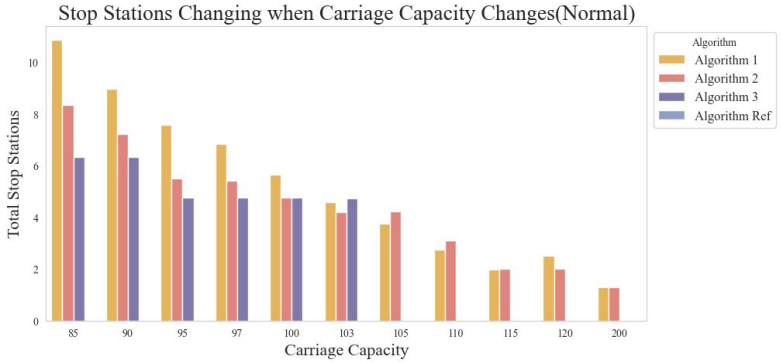
Know the risk!

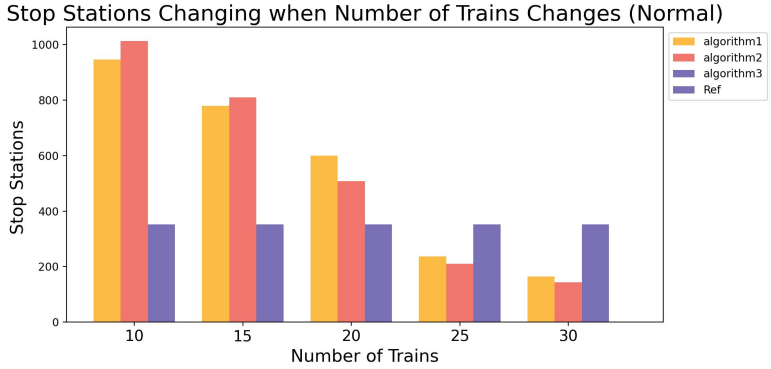
Total Commuting Time





\# Skipped Stations





Carriage Capacity

\# Trains

- IMPROVEMENTS ARE GREATER WHEN THE SYSTEM IS CROWDED

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04

CONCLUSION

Strategy in real life and further dissemination.

Conclusion

- **Model application results**
  - An average decrease in travel time of approximately 15%.

- **Effectiveness of dynamic optimization strategies**
  - Effectively balancing passenger loads across different stations not only alleviates congestion at key nodes but also ensures a smoother and more reliable commuting experience.
  - Example: Passenger congestion at key interchange stations such as Shenzhenbei and Minzhi has decreased by 20%.

- **Sensitivity analysis**
  - The adjustability of parameters allows for customization of the model to various subway lines in Shenzhen, and it may also be applicable to other cities facing similar urban transportation obstacles.

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THANKS FOR WATCHING!