Optimal Planning for NTU YouBike Assignment

Operations Research
Final Project

Group A
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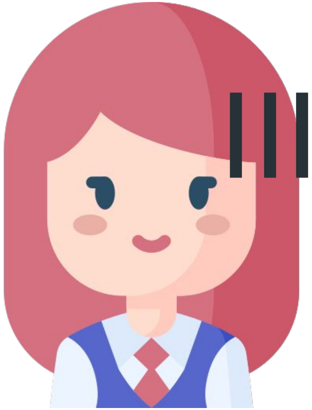
Content

Introduction

(Amy, a NTU freshman.)

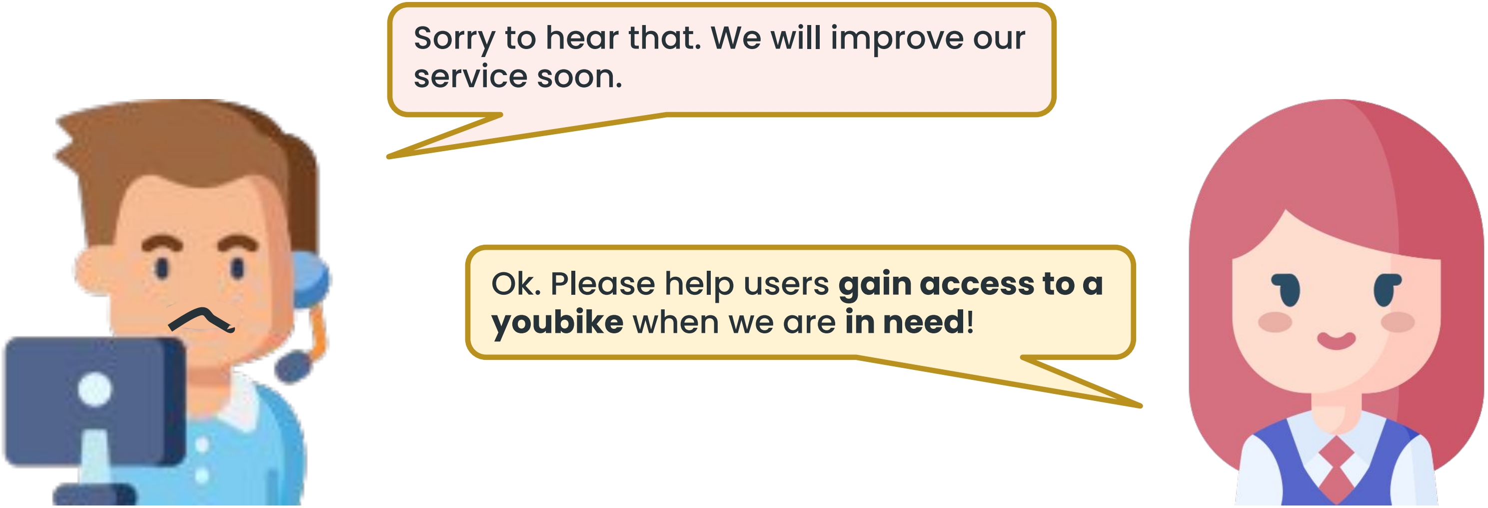
(Lunch Time.)
I'd like to have the poke bowl next to GongGuan Station.

It appears that it takes lots of time on traffic without a youbike.



This is youbike company, what may I help you with?

The service is awful! I can’t access available youbike whenever I was in need.


Sorry to hear that. We will improve our service soon.
Ok. Please help users **gain access to a youbike** when we are **in need**!

Youbike assignment is an important task.

Around NTU, there are 102 separate Spots where docks sit and 1800 docks in total.

300 ups

Expected bike capacity to meet demand for GongGuan Spot in peak time.

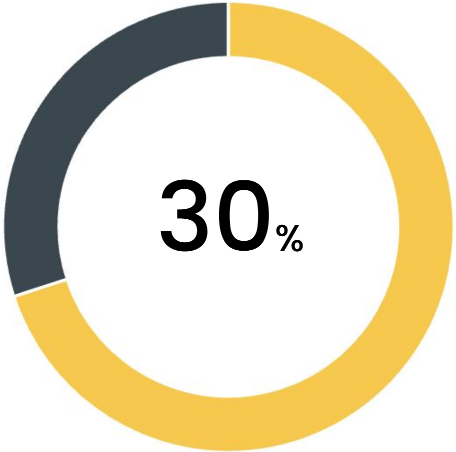
Number of bikes a shipping car could afford.

16 bikes

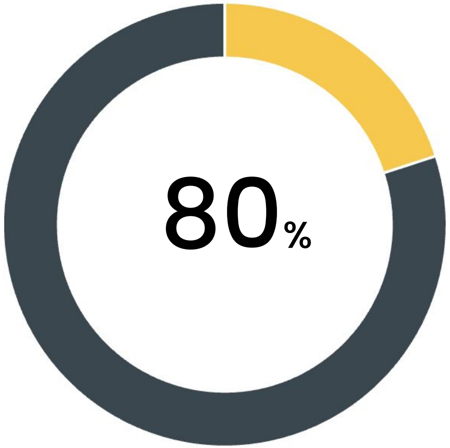
Youbike assignment is an important task.

Around NTU, there are 102 separate Spots where docks sit and 1800 docks in total.

Large Spots



Small Spots



Percentage of **spare docks** measured in peak time.

Youbike assignment is a challenging task.

TO-DO List

- Meet Real Time demand for each time slot
  by scheduling optimal **ROUTEs** for youbike shipping cars

Such that

- Percentage of spared bikes could be **Minimized**

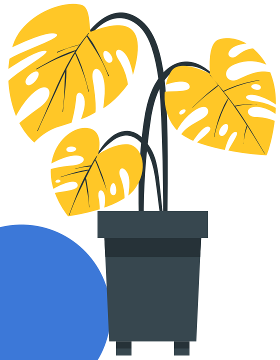
while

- Minimizing all the costs.

Now the challenge relies on the department of youbike assignment.

Problem Description

- Parameters and Decision Variables
- Objective Function
- Constraints



Parameters

A	The maximum capacity of a shipping car used for dispatching.
S_H	The upper bound of reasonable parking rate.
S_L	The lower bound of reasonable parking rate.
L	The maximum distances for a shipping car to move.
λ	Punishment coefficient used in objective function. Implemented when the parking rate of that spot is out of reasonable range.

Index 0 and index $N+1$ both stand for virtual points, which are labeled as "Start" and "End", respectively.

Parameters

C_{ij}	The distance for a shipping car to move from spot i to j. Let $C_{00} = C_{N+1,\,0} = C_{N+1,\,N+1} = 0$; $C_{0,\,N+1} < 0$	$i, j \in \{1, 2, \dots, N\}$
$Parked_i$	The number of parked bikes in spot i.	$i \in \{1, 2, \dots, N\}$
$Capacity_i$	The capacity in spot i.	$i \in \{1, 2, \dots, N\}$
M	The number of total parked bikes.	
e	The constant for ensuring the relationship between the u 's (orders)	
G	The gas price per kilometer.	
T	The cost of renting a shipping car.	

Index 0 and index $N+1$ both stand for virtual points, which are labeled as "Start" and "End", respectively.

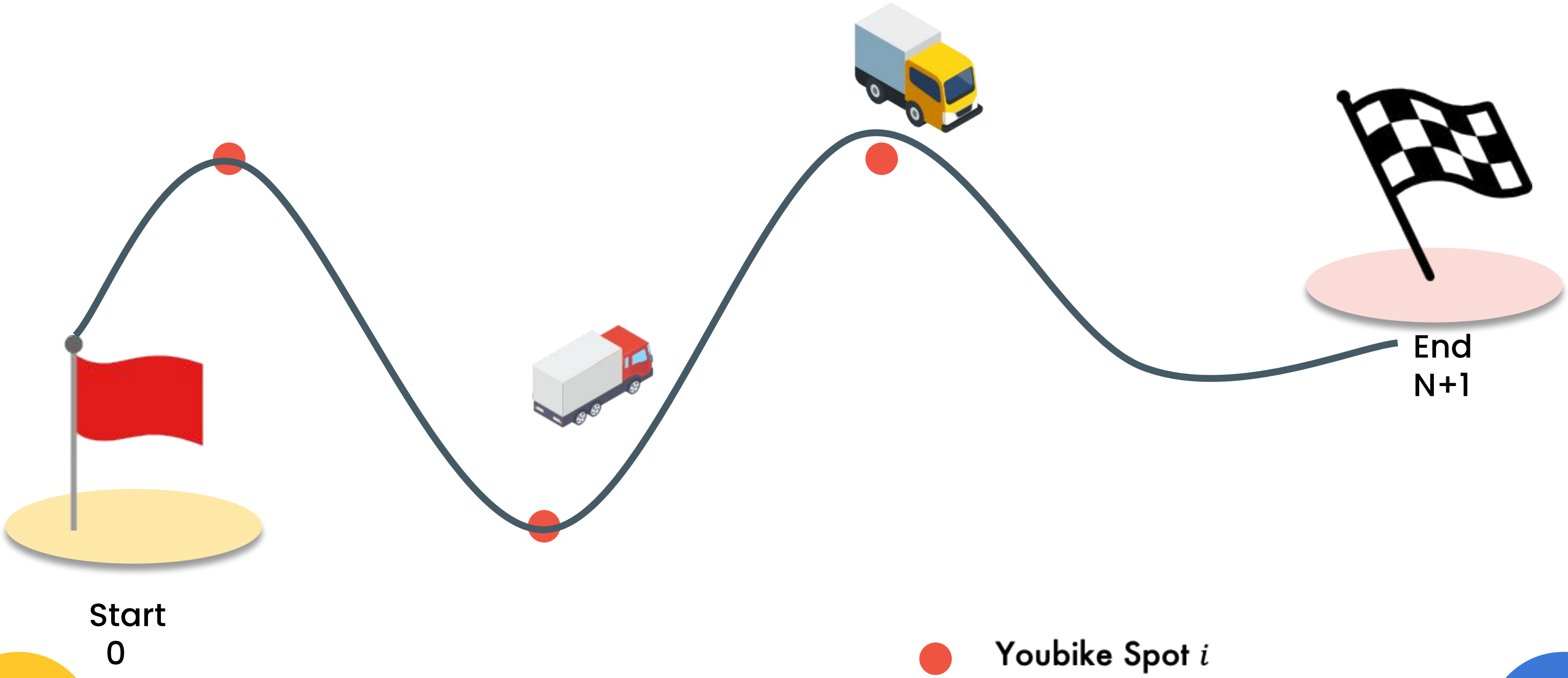
Decision Variable

a_i	The number of bikes taken away from spot i.	$a_i \geq 0$
b_i	The number of bikes dispatched to spot i.	$b_i \geq 0$
x_i	$x_i = 1$ if spot i is visited by the shipping car; $x_i = 0$, otherwise.	$x_i \in \{0, 1\}$
y_{ij}	$y_{ij} = 1$, if the shipping car moves from spot i to spot j; $y_{ij} = 0$, otherwise.	$y_{ij} \in \{0, 1\}$
p_i	The number of bikes on a shipping car when it arrives at spot i.	$p_i \geq 0$

Decision Variable

q_i	The number of bikes on a shipping car when it leave spot i.	$q_i \geq 0$
w_{iL}	The percentage shortage after dispatching to spot i.	
w_{iH}	The percentage surplus after dispatching to spot i.	
u_i	The order (number) in a shipping car's tour of spot i.	$u_i \geq 0$
v_{ij}	$v_{ij} = 1$ if spot i is visited after spot i; $v_{ij} = 0$, otherwise.	$v_{ij} \in \{0, 1\}$

Illustration



Objective Function

$$\min \quad G\sum_{i=0}^{N+1}\sum_{j=0}^{N+1} y_{ij}C_{ij} + \lambda(100\sum_{i=1}^{N}(w_{iL} + w_{iH}))^2 + T$$

Objective Function

Total Shipping costs.

The gas price per km.

The distance from spot i to j.

$$\min \quad G \sum_{i=0}^{N+1} \sum_{j=0}^{N+1} y_{ij} C_{ij} + \lambda(100 \sum_{i=1}^{N} (w_{iL} + w_{iH}))^2 + T$$

Indicating whether a shipping car moves from spot i to j.

Objective Function

Control for parking rate.

Lower/ upper bound of reasonable parking rate.

$$\min \quad G\sum_{i=0}^{N+1}\sum_{j=0}^{N+1} y_{ij}C_{ij} + \lambda\left(100\sum_{i=1}^{N}\left(\boxed{w_{iL} + w_{iH}}\right)\right)^2 + T$$

A tuning parameter.

Objective Function

$$\min \quad G\sum_{i=0}^{N+1}\sum_{j=0}^{N+1} y_{ij}C_{ij} + \lambda\left(100\sum_{i=1}^{N}(w_{iL} + w_{iH})\right)^2 + T$$

A constant value for shipping car rental.

Constraints for Routing

1 For the sake of moving from one spot to another, both spots must be visited.

$$x_i + x_j \geq 2(y_{ij} + y_{ji}), \quad \forall i, j = 0, ..., N+1$$

2 For each spot, arrival implies departure, and vice versa.

$$\sum_{i=0}^{N} y_{ik} = \sum_{i=1}^{N+1} y_{kj}, \quad \forall k = 1, ..., N$$

3 It is not reasonable for a shipping car to move from a spot to the same one.

$$y_{ij} = 0, \quad \forall i, j = 0, ..., N+1, i = j$$

4 A shipping car cannot move back to the previous spot.

$$y_{ij} + y_{ji} \leq 1, \quad \forall i, j = 0, ..., N+1$$

Constraints for Routing

5 A shipping car cannot move for more than the maximum distance.

$$\sum_{i=0}^{N+1}\sum_{j=0}^{N+1} C_{ij}y_{ij} \le L$$

6 A shipping car can only arrive at / leave a spot once.

$$\sum_{i=0}^{N+1} y_{ij} \le 1, \quad \forall j = 0, ..., N+1$$

$$\sum_{j=0}^{N+1} y_{ij} \le 1, \quad \forall i = 0, ..., N+1$$

7 A visit of a spot implies the arrival at it and / or the departure from it.

$$\sum_{j=0}^{N+1} y_{ij} + \sum_{j=0}^{N+1} y_{ji} \ge x_i, \quad \forall i = 0, ..., N+1$$

Constraints for Bikes

1 Do not take away bikes and dispatch bikes at the same time.

$$a_i b_i = 0, \quad \forall i = 0, ..., N+1$$

2 Take away / Dispatch bikes only if a spot is visited.

$$a_i \leq M x_i, \quad \forall i = 0, ..., N+1$$

$$b_i \leq M x_i, \quad \forall i = 0, ..., N+1$$

3 Penalize when there is shortage or surplus.

$$\begin{aligned}
&w_{iL} \geq S_L - \frac{Parked_i - a_i + b_i}{Capacity_i}, && \forall i = 1, ..., N \\
&w_{iL} \geq 0, && \forall i = 1, ..., N \\
&w_{iH} \geq \frac{Parked_i - a_i + b_i}{Capacity_i} - S_H, && \forall i = 1, ..., N \\
&w_{iH} \geq 0, && \forall i = 1, ..., N
\end{aligned}$$

Constraints for Bikes

4 The flow-in must be equivalent to the flow-out for each spot.

$$\sum_{i=0}^{N+1} a_i x_i = \sum_{i=0}^{N+1} b_i x_i$$

5 Dispatch bikes to a spot reasonably.

$$b_i + Parked_i \leq Capacity_i, \quad \forall i = 1, ..., N+1$$

6 Take away bikes from a spot reasonably.

$$a_i \leq Parked_i, \quad \forall i = 1, ..., N$$

Constraints for Shipping Car

1 When a shipping car visit a spot, bikes are either taken away from or dispatched to it. The following equation describes the change in the number of bikes on a shipping car.

$$p_i + a_i - b_i = q_i, \quad \forall i = 0, \ldots, N+1$$

2 The number of bikes on a shipping car when leaving a spot must equal to that when arriving at the next one.

$$q_i y_{ij} = p_j y_{ij}, \quad \forall i, j = 0, \ldots, N+1$$

3 The number of bikes on a shipping car cannot exceed the maximum capacity of it.

$$p_i \leq A, q_i \leq A, \quad \forall i = 0, \ldots, N+1$$

4 The number of bikes dispatched to a spot cannot be greater than that on a shipping car when arriving.

$$b_i \leq p_i, \quad \forall i = 0, \ldots, N+1$$

Constraints for Virtual Point

1. No bikes are taken away from and dispatched to Start.

$$a_0 = 0, b_0 = 0$$

2. No bikes are taken away from End, while it is acceptable to be dispatched to it.

$$a_{N+1} = 0, b_{N+1} \geq 0$$

3. A shipping car must visit Start and End.

$$x_0 = 1, x_{N+1} = 1$$

4. No arrival at Start, and no departure from End.

$$y_{i0} = 0, \quad \forall i = 1, ..., N+1$$

$$y_{N+1,i} = 0, \quad \forall i = 0, ..., N$$

Constraints for Virtual Point

5 No bikes are on a shipping car at Start, and no bikes are leaving End. However, when arriving at End, the presence of bikes is acceptable.

$$p_0 = 0, q_0 = 0$$

$$p_{N+1} \geq 0, q_{N+1} = 0$$

6 No penalty for Start and End.

$$w_{0L} = 0, w_{0H} = 0$$

$$w_{N+1,L} = 0, w_{N+1,H} = 0$$

Constraints for Eliminating Subtours

$$u_0 = 1$$

$$u_i \le N + 2, \qquad \forall i = 1, ..., N+1$$

$$u_i \ge 2, \qquad \forall i = 1, ..., N+1$$

$$u_i - u_j + 1 \le M(1 - y_{ij}), \qquad \forall i, j = 0, ..., N+1, i \ne j$$

$$u_i - u_j \le M v_{ij} - e, \qquad \forall i, j = 0, ..., N+1, i \ne j$$

$$u_i - u_j \ge e - M(1 - v_{ij}), \qquad \forall i, j = 0, ..., N+1, i \ne j$$

Method

- Data Collection and Description
- Introduction of Model

Data Collection and Description

政府資料開放平臺
DATA.GOV.TW

YouBike 2.0臺北市公共自行車即時資訊

https://data.gov.tw/dataset/13799

sno	sna	tot	sbi	sarea	mday	lat	lng	ar	sareaen	snaen	aren	bemp	act	srcUpdateTime	updateTime	infoTime	infoDate
500119005	YouBike2.0_臺大水源舍區 A 棟	37	0	臺大專區	2022-06-01 10:04:04	25.01493	121.53044	汀洲路三段60巷2弄...	NTU Dist	YouBike2.0_NTU ShuiYuan Dorms(A)	Aly. 2，Ln. 60，Sec. 3，Tingzhou...	37	1	2022-06-01 10:06:12	2022-06-01 10:06:51	2022-06-01 10:04:04	2022-06-01
500119006	YouBike2.0_臺大卓越研究大樓	32	0	臺大專區	2022-06-01 09:44:04	25.01466	121.52917	臺大水源舍區C南側	NTU Dist	YouBike2.0_NTU Complex for Research Excellence	NTU Prince House Chang...	32	1	2022-06-01 10:06:12	2022-06-01 10:06:51	2022-06-01 09:44:04	2022-06-01

Data Collection and Description

After organizing :

	site_id	space_total	space_occupied	space_vacant	address	sarea	lati	long
0	0	37	0	37	汀洲路三段60巷2弄路側(A舍北側)	臺大專區	25.01493	121.53044
1	1	32	0	32	臺大水源舍區C南側	臺大專區	25.01466	121.52917
2	2	18	0	18	思源街16號之1旁	臺大專區	25.01411	121.52997
3	3	10	1	9	臺大檔案展示館東北側	臺大專區	25.01391	121.52895
4	4	30	7	23	汀洲路三段60巷2弄路側(B舍北側)	臺大專區	25.01525	121.53009
5	5	42	0	42	臺大男八舍東側	臺大專區	25.01729	121.54531

Data Collection and Description

After organizing…

the distances between any two stations

(with only latitude and longitude)

	0	1	2	3	4
0	0.000000	0.131446	0.102746	0.188165	0.050099
1	0.131446	0.000000	0.101186	0.086292	0.113569
2	0.102746	0.101186	0.000000	0.1105159	0.127338
3	0.188165	0.086292	0.105159	0.000000	0.188141
4	0.050099	0.113569	0.127338	0.188141	0.000000

UNREALISTIC

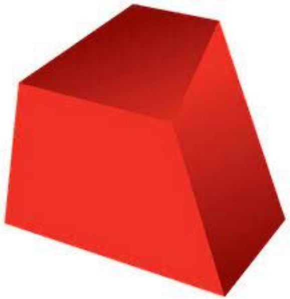
(with Google map API)

	0	1	2	3	4
0	0	0.4	0.3	0.4	0.2
1	0.4	0	0.1	0.1	0.8
2	0.3	0.1	0	0.1	0.7
3	0.4	0.1	0.1	0	0.8
4	0.2	0.8	0.7	0.8	0

Introduction of Models

K means Algorithm

Gurobi Optimizer



An algorithm to classify youbike spots based on their geographically location.
i.e. longitude and latitude.

To find an optimal solution for variables of interests.

Solution Steps

Clustering
Divide spots into groups.

Optimization
According to different number of clusters.

Visualization
Comparison.

Proposal
Performance analysis of our program.

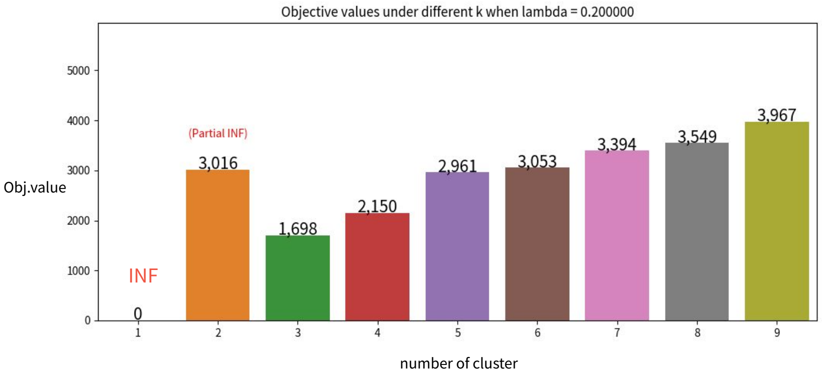
Result

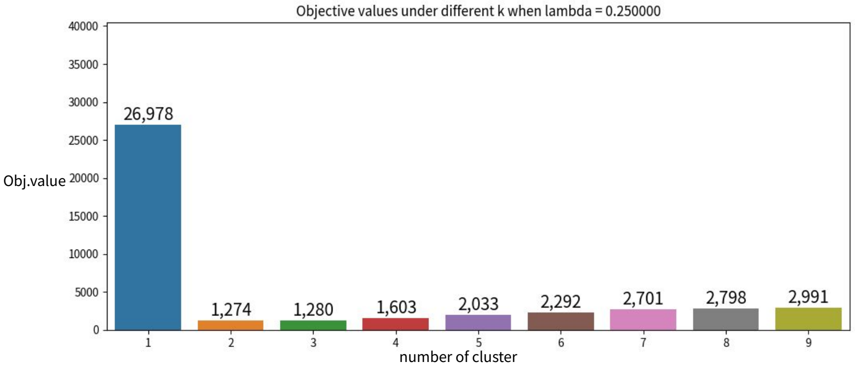
▶ **Visualization**

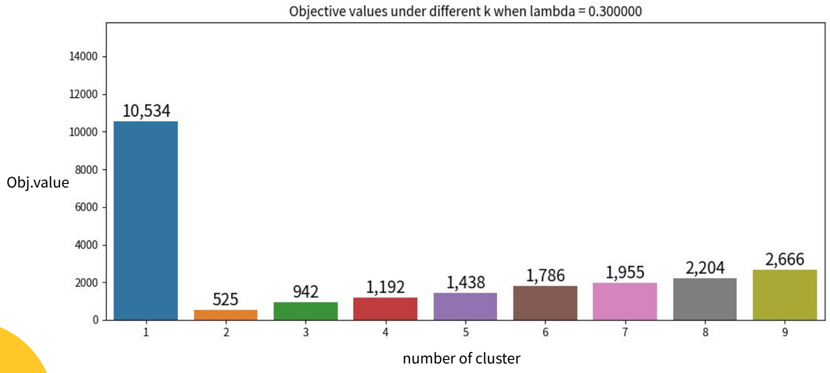
Instance 1

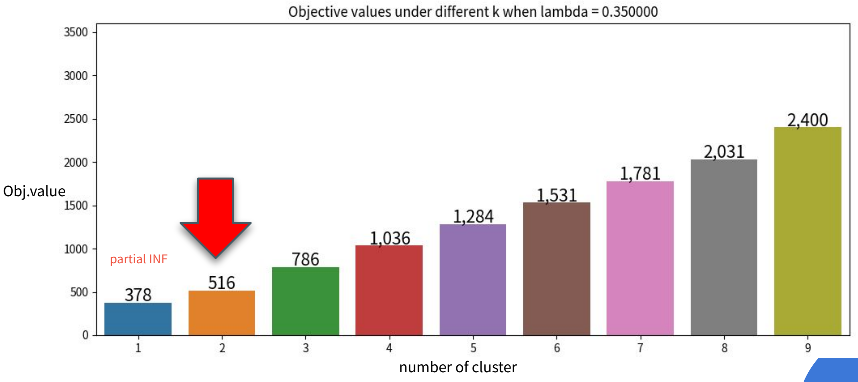
6/1 17:00

Instance 1


Objective values under different k when lambda = 0.200000
Obj.value
number of cluster
INF
0
(Partial INF)
3,016
1,698
2,150
2,961
3,053
3,394
3,549
3,967


Objective values under different k when lambda = 0.250000
Obj.value
number of cluster
26,978
1,274
1,280
1,603
2,033
2,292
2,701
2,798
2,991


Objective values under different k when lambda = 0.300000
Obj.value
number of cluster
10,534
525
942
1,192
1,438
1,786
1,955
2,204
2,666


Objective values under different k when lambda = 0.350000
Obj.value
number of cluster
partial INF
378
516
786
1,036
1,284
1,531
1,781
2,031
2,400

Instance 1

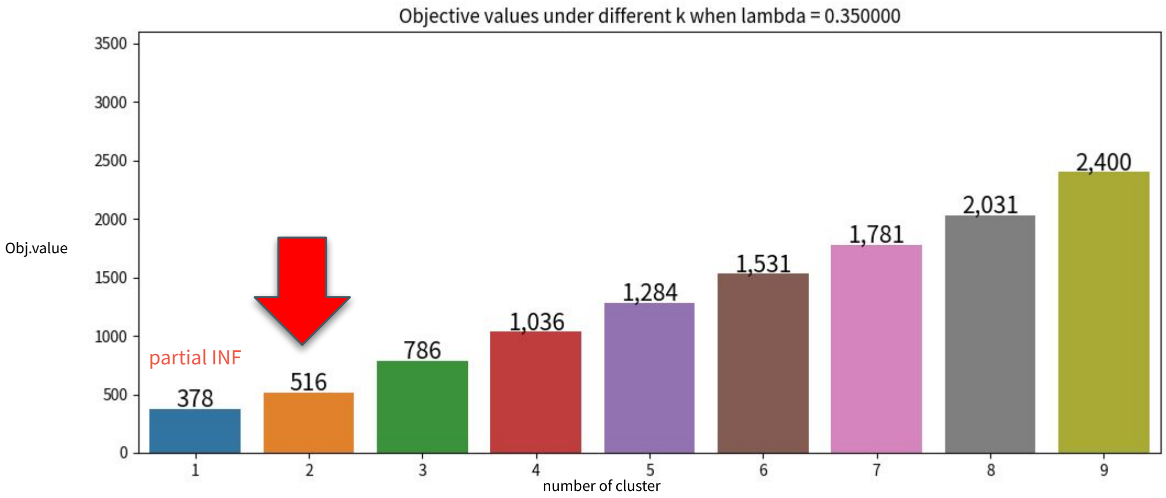


Fig 1-1. Objective values comparison with λ=0.35

Instance 1

Allocation schedule routes for Ubike 2.0 stations in NTU campus

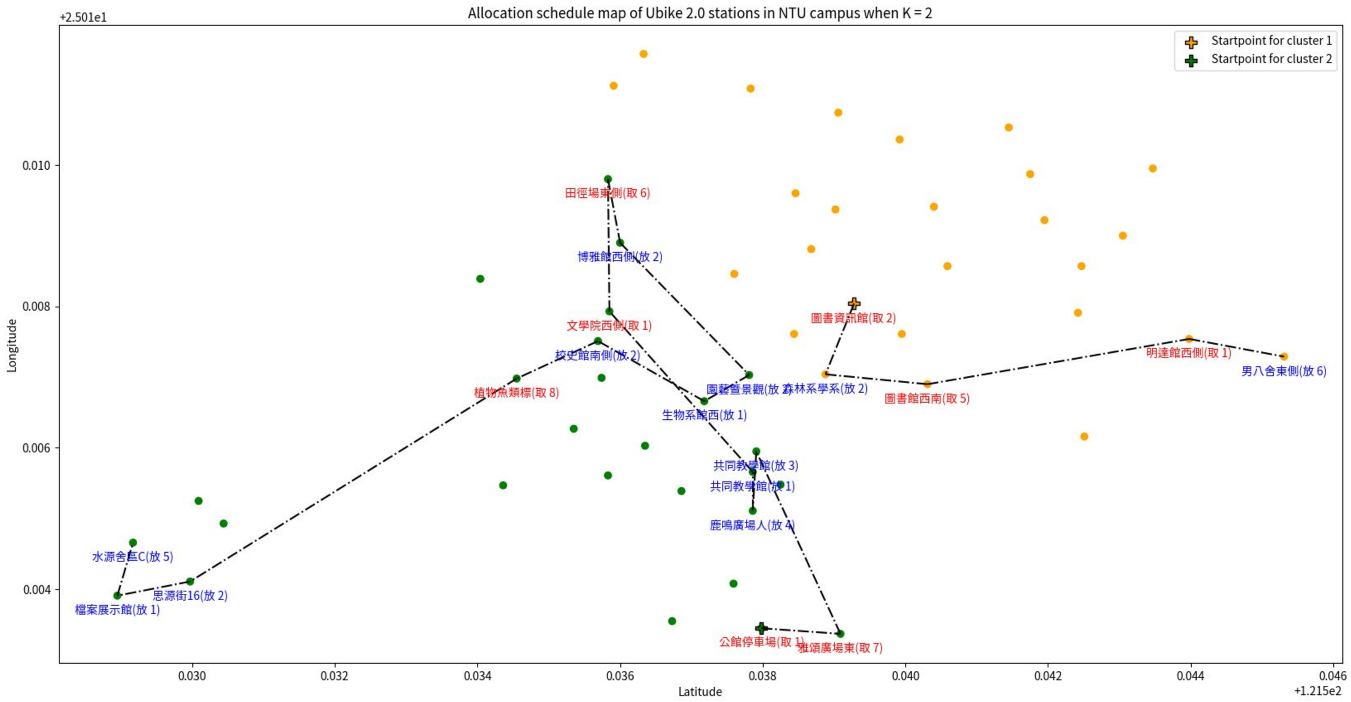


Fig 1-2. The allocation schedule map. Spot labeled red means pick up, while one labeled blue means return.

Instance 1

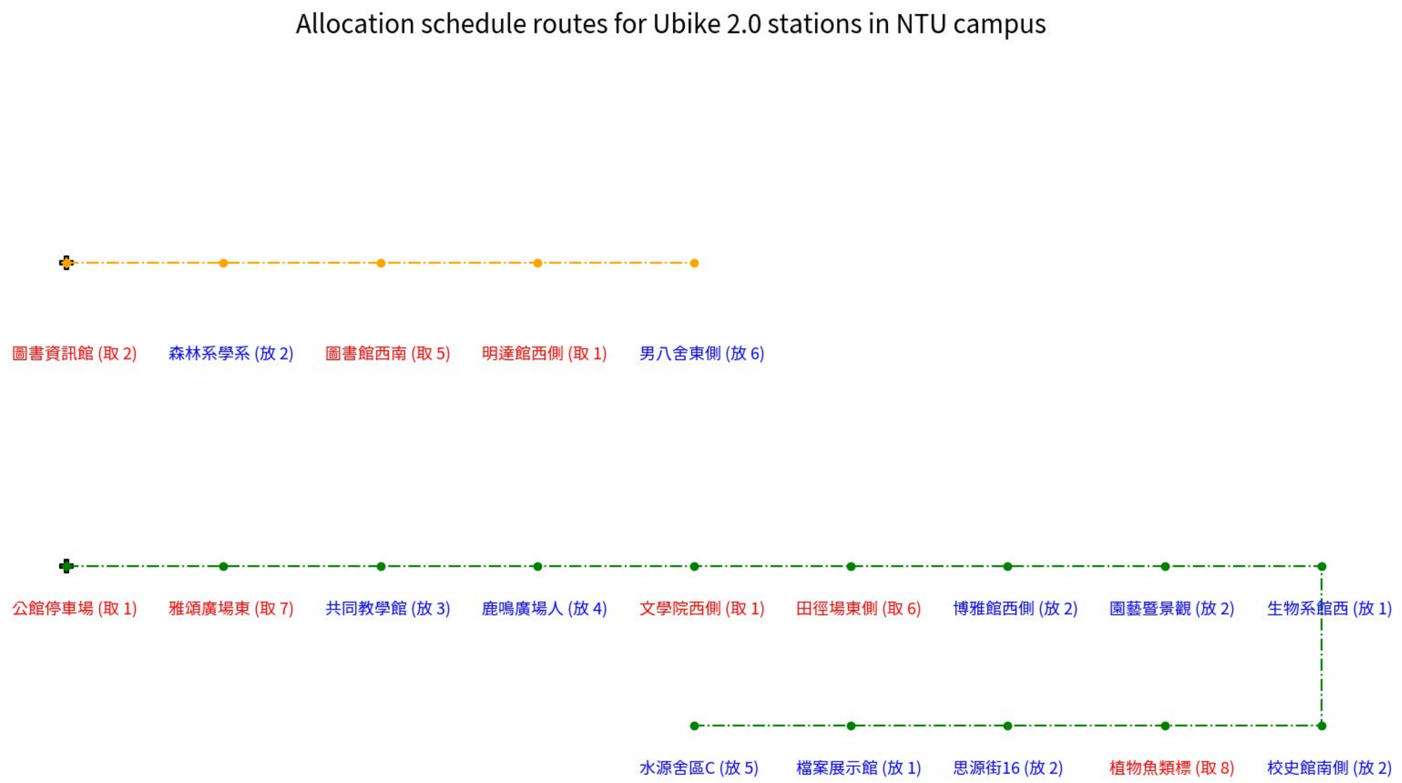


Fig 1-3. The allocation schedule routes for youbike 2.0 stations in NTU

Instance 1

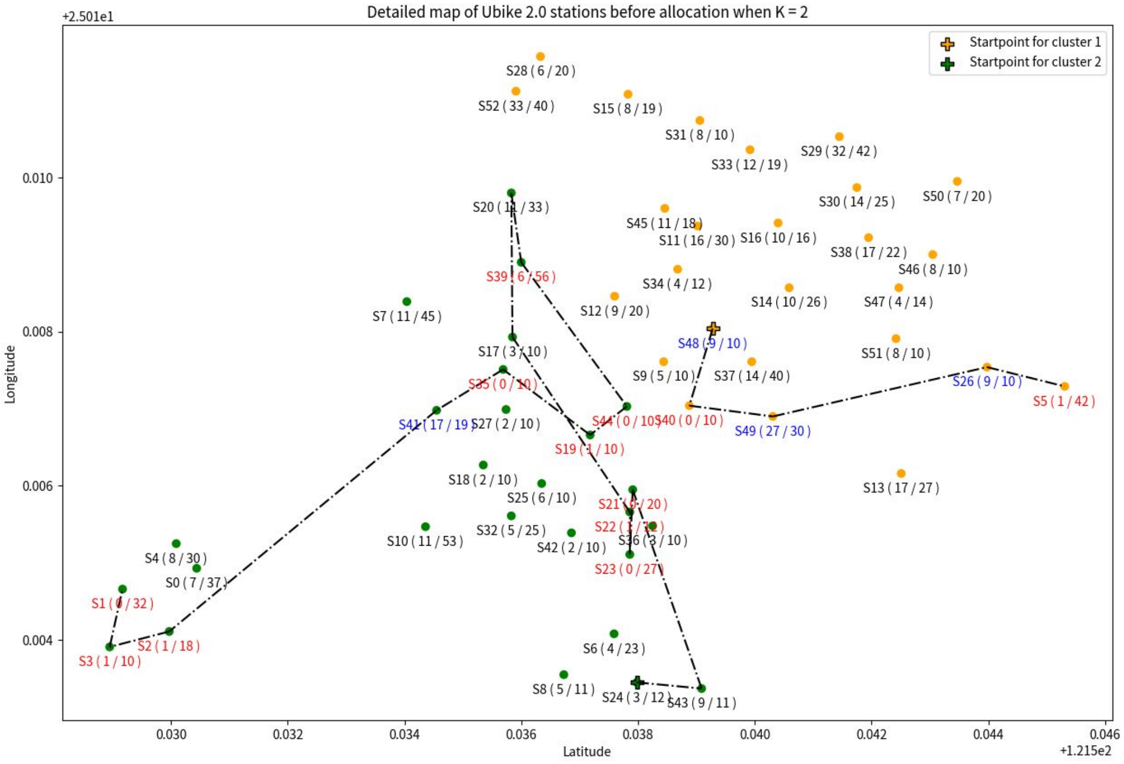


Fig 1-4. Detailed map of Ubike 2.0 stations <u>before</u> allocation

Instance 1

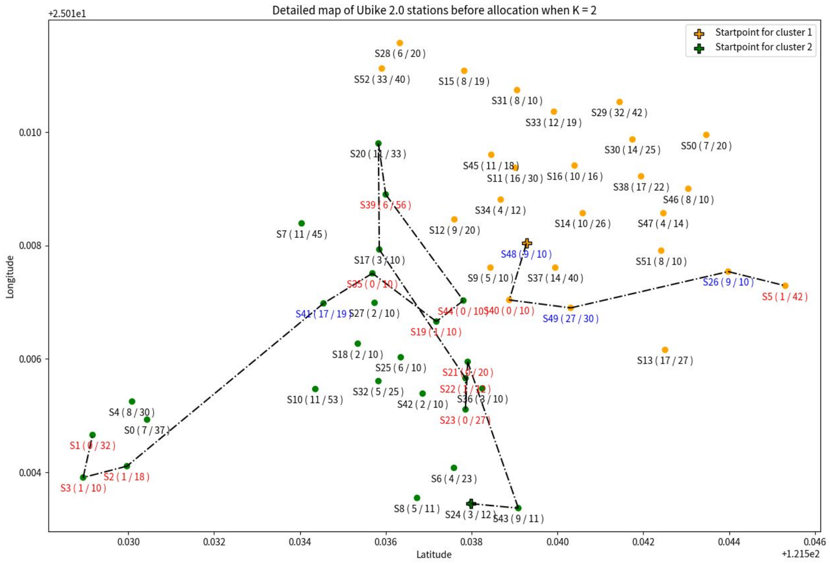


Fig 1-4. Detailed map of Ubike 2.0 stations before allocation

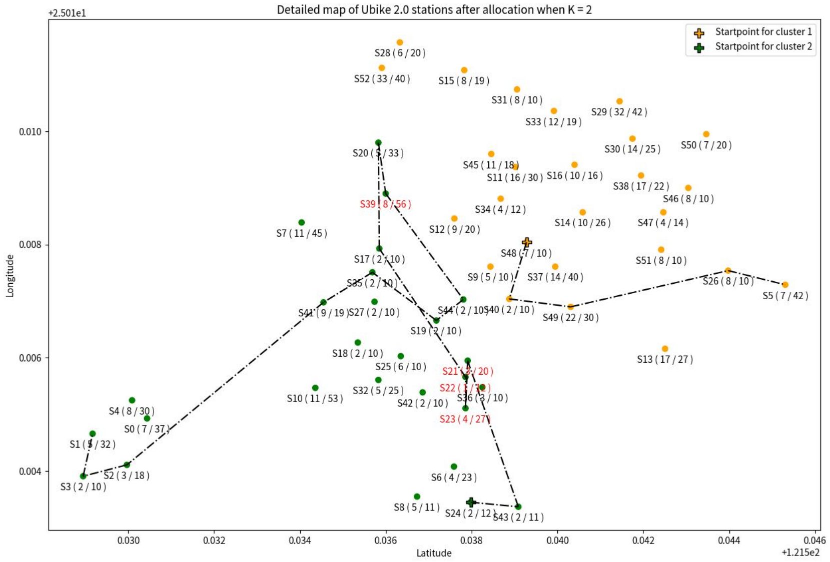
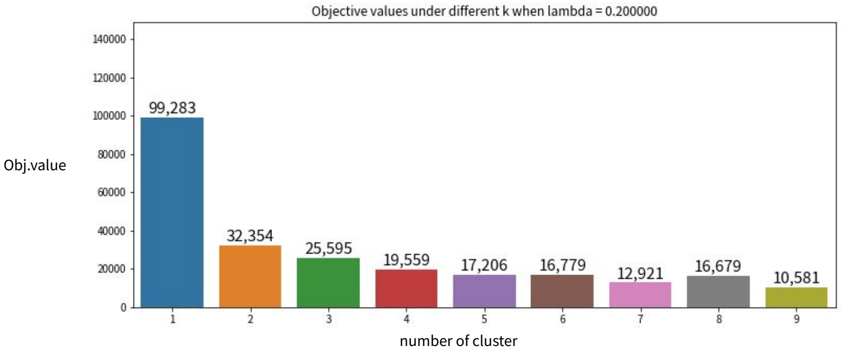


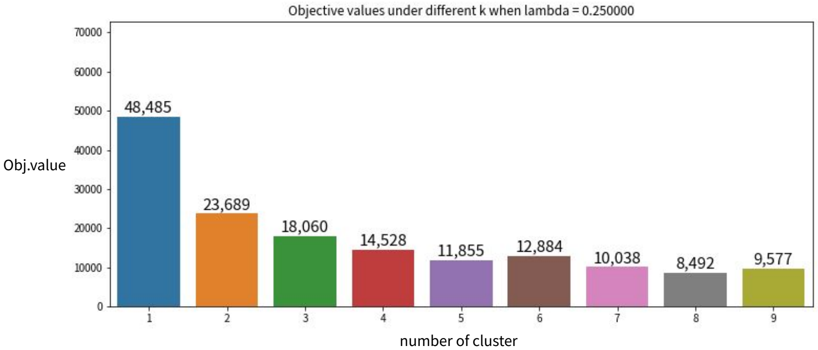
Fig 1-5. Detailed map of Ubike 2.0 stations after allocation

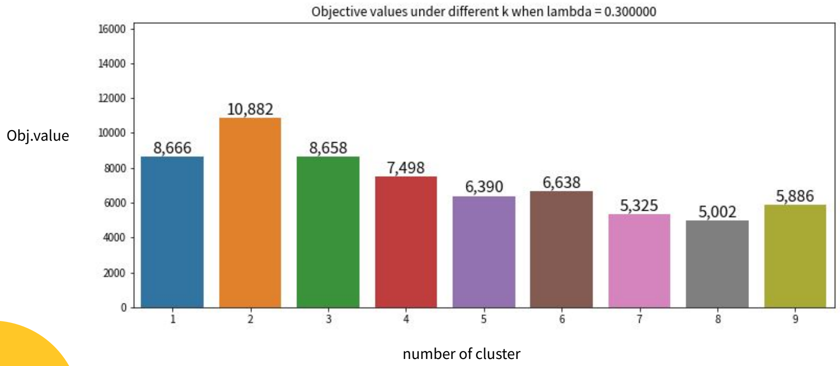
Instance 2

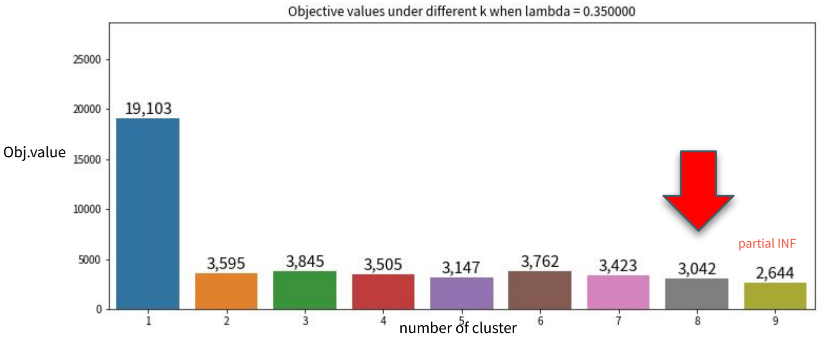
6/3 8:00

Instance 2


Objective values under different k when lambda = 0.200000
Obj.value
140000
120000
100000
80000
60000
40000
20000
0
99,283
32,354
25,595
19,559
17,206
16,779
12,921
16,679
10,581
1
2
3
4
5
6
7
8
9
number of cluster


Objective values under different k when lambda = 0.250000
Obj.value
70000
60000
50000
40000
30000
20000
10000
0
48,485
23,689
18,060
14,528
11,855
12,884
10,038
8,492
9,577
1
2
3
4
5
6
7
8
9
number of cluster


Objective values under different k when lambda = 0.300000
Obj.value
16000
14000
12000
10000
8000
6000
4000
2000
0
8,666
10,882
8,658
7,498
6,390
6,638
5,325
5,002
5,886
1
2
3
4
5
6
7
8
9
number of cluster


Objective values under different k when lambda = 0.350000
Obj.value
25000
20000
15000
10000
5000
0
19,103
3,595
3,845
3,505
3,147
3,762
3,423
3,042
2,644
partial INF
1
2
3
4
5
6
7
8
9
number of cluster

Instance 2

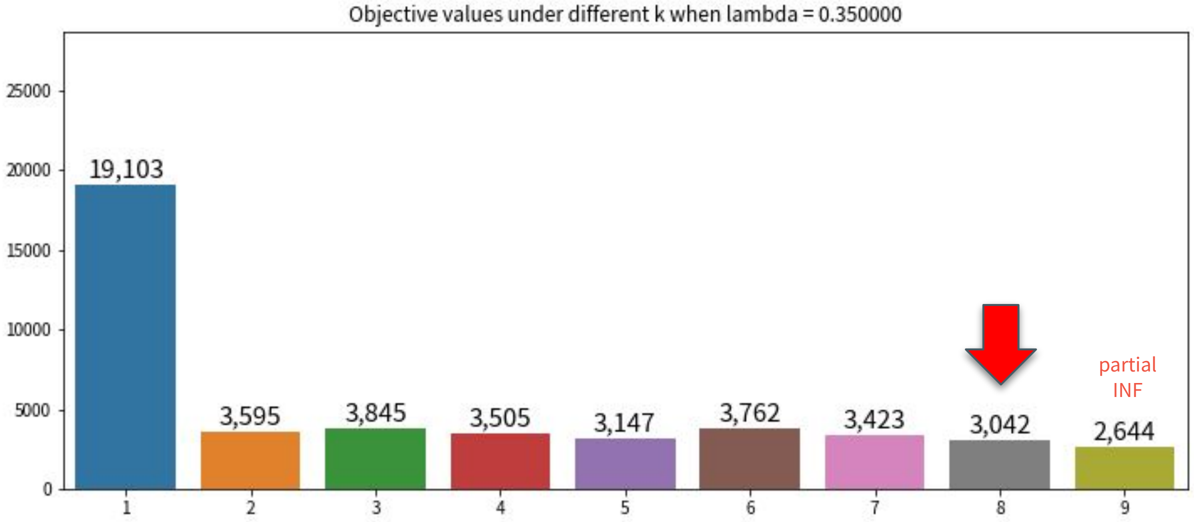


Fig 2-1. Objective values comparison with λ=0.35

Instance 2

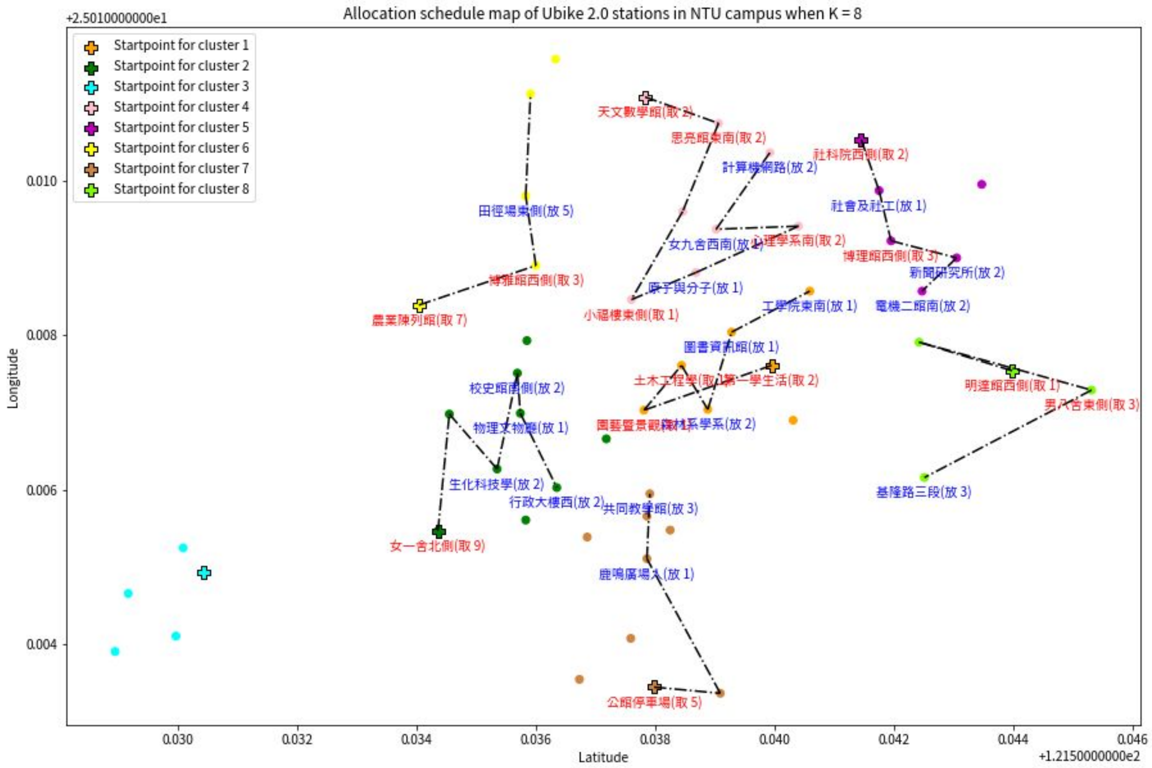


Fig 2-2. The allocation schedule map. Spot labeled red means pick up, while one labeled blue means return.

Instance 2

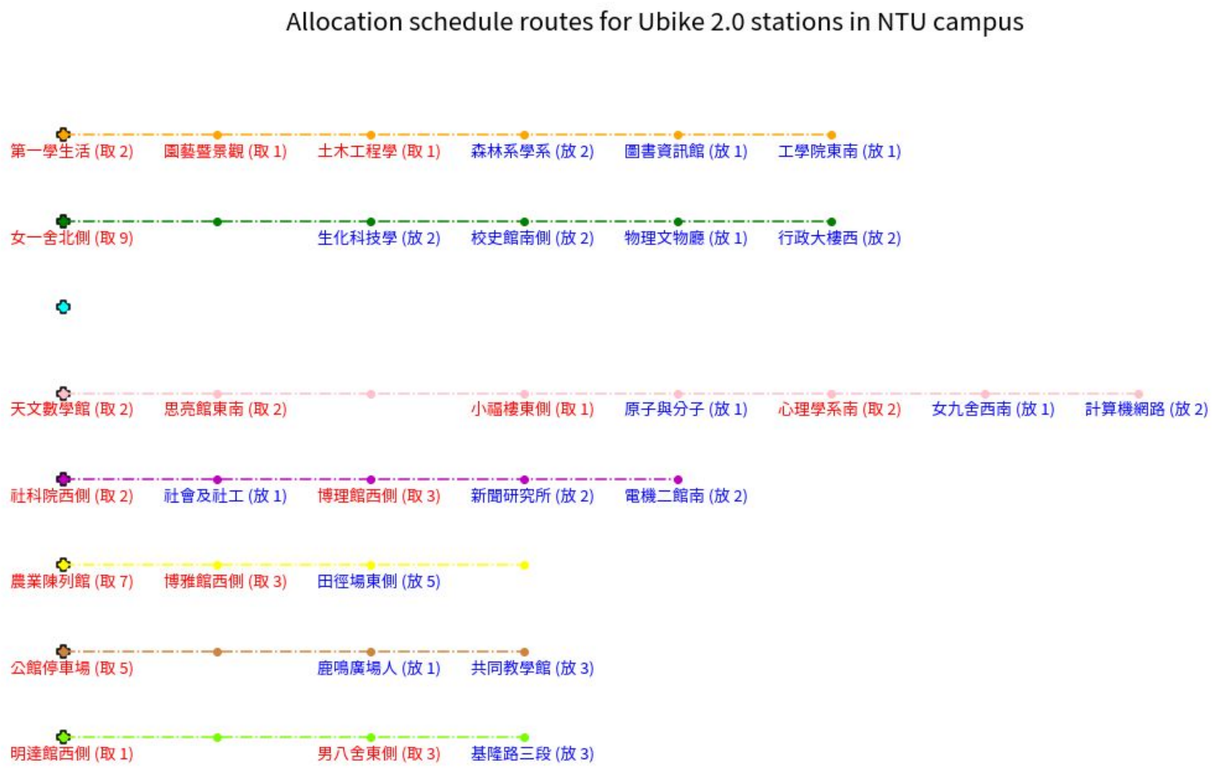


Fig 2-3. The allocation schedule routes for youbike 2.0 stations in NTU

Instance 2

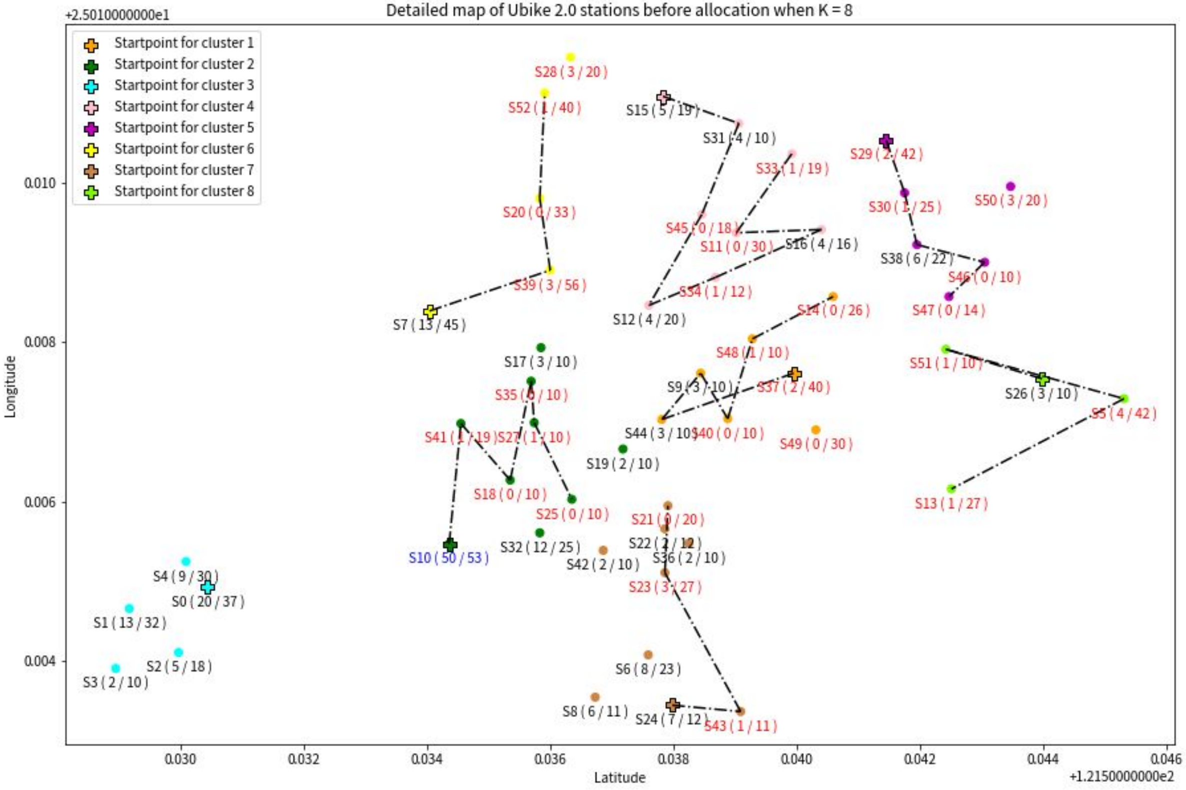


Fig 2-4. Detailed map of Ubike 2.0 stations before allocation

Instance 2

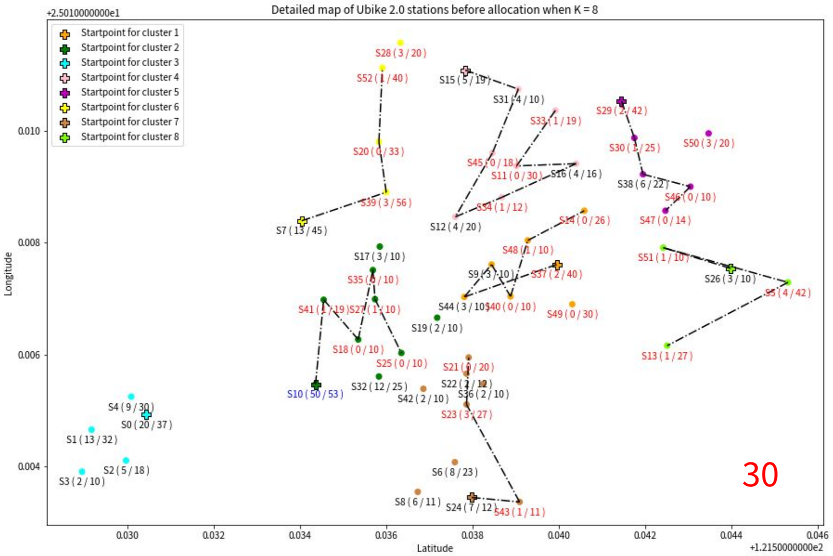


Fig 2-4. Detailed map of Ubike 2.0 stations before allocation

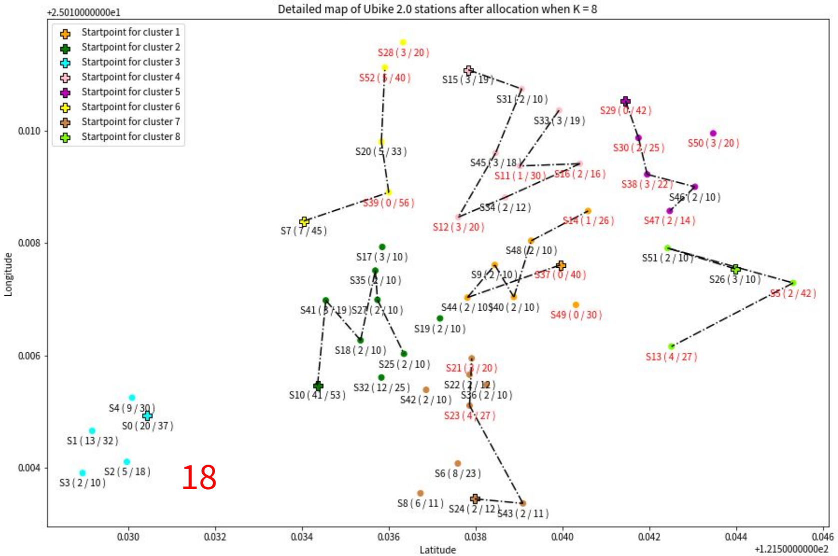
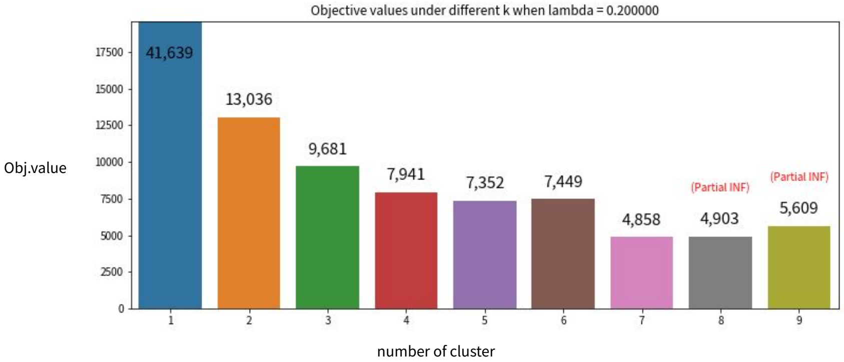


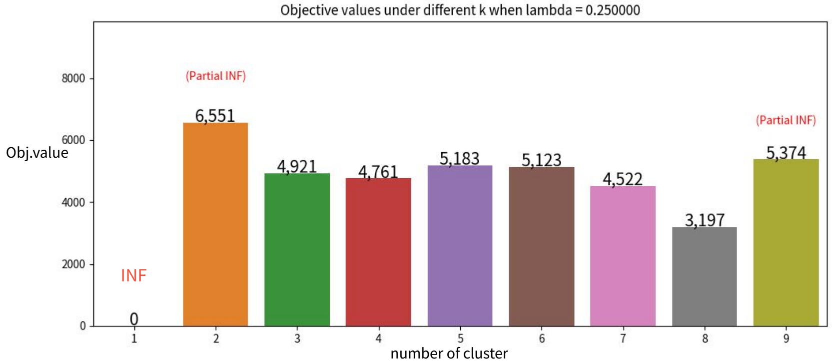
Fig 2-5. Detailed map of Ubike 2.0 stations after allocation

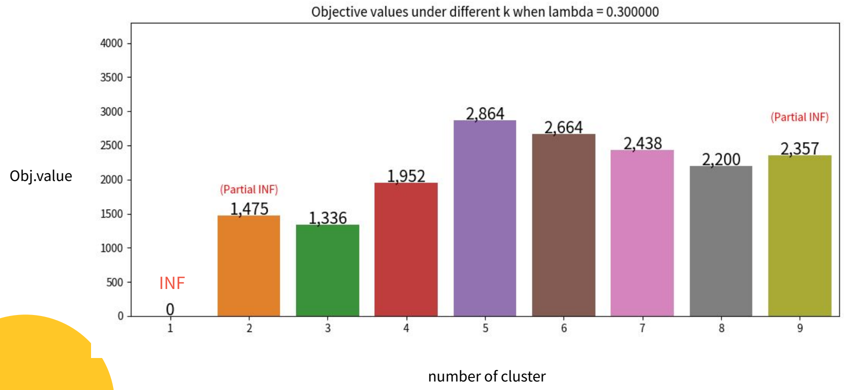
Instance 3

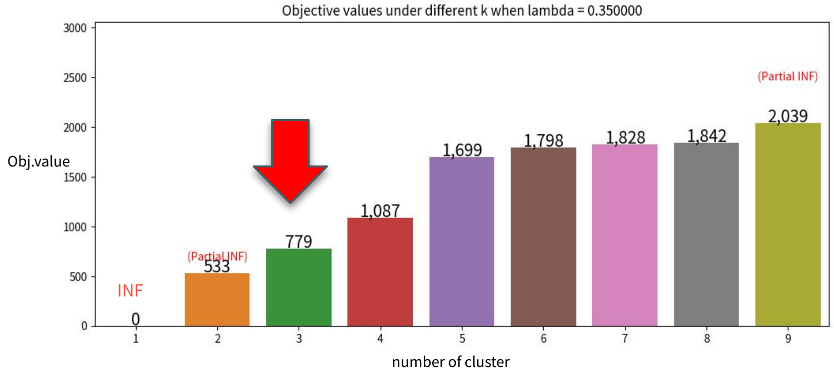
6/3 10:00

Instance 3


Objective values under different k when lambda = 0.200000
Obj.value
number of cluster
41,639
13,036
9,681
7,941
7,352
7,449
4,858
(Partial INF)
4,903
(Partial INF)
5,609


Objective values under different k when lambda = 0.250000
Obj.value
number of cluster
INF
0
(Partial INF)
6,551
4,921
4,761
5,183
5,123
4,522
3,197
(Partial INF)
5,374


Objective values under different k when lambda = 0.300000
Obj.value
number of cluster
INF
0
(Partial INF)
1,475
1,336
1,952
2,864
2,664
2,438
2,200
(Partial INF)
2,357


Objective values under different k when lambda = 0.350000
Obj.value
number of cluster
INF
0
(Partial INF)
533
779
1,087
1,699
1,798
1,828
1,842
(Partial INF)
2,039

Instance 3

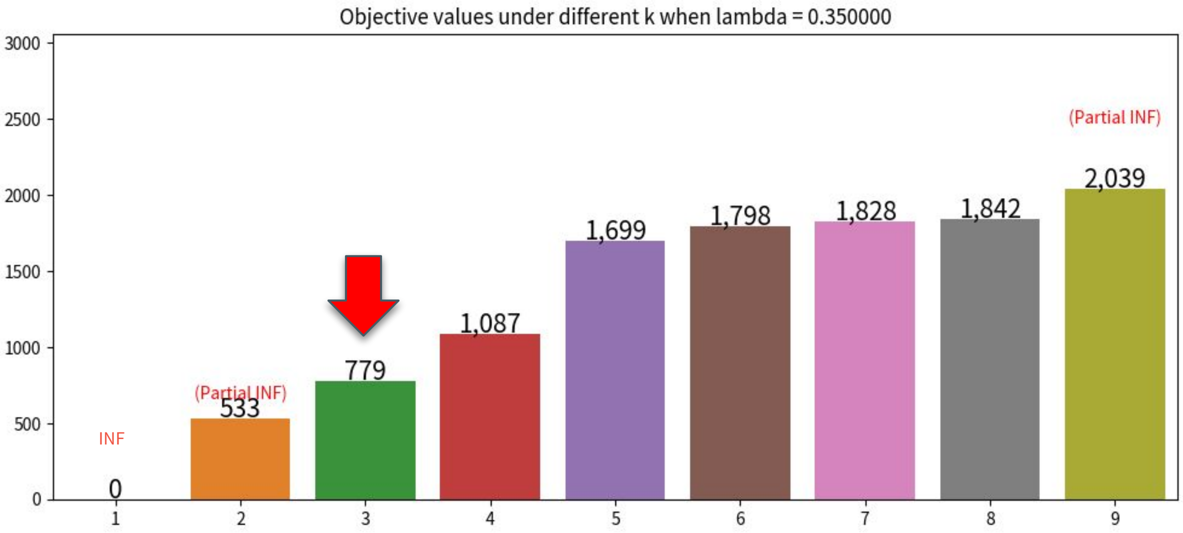


Fig 3-1. Objective values comparison with $\lambda=0.35$

Instance 3

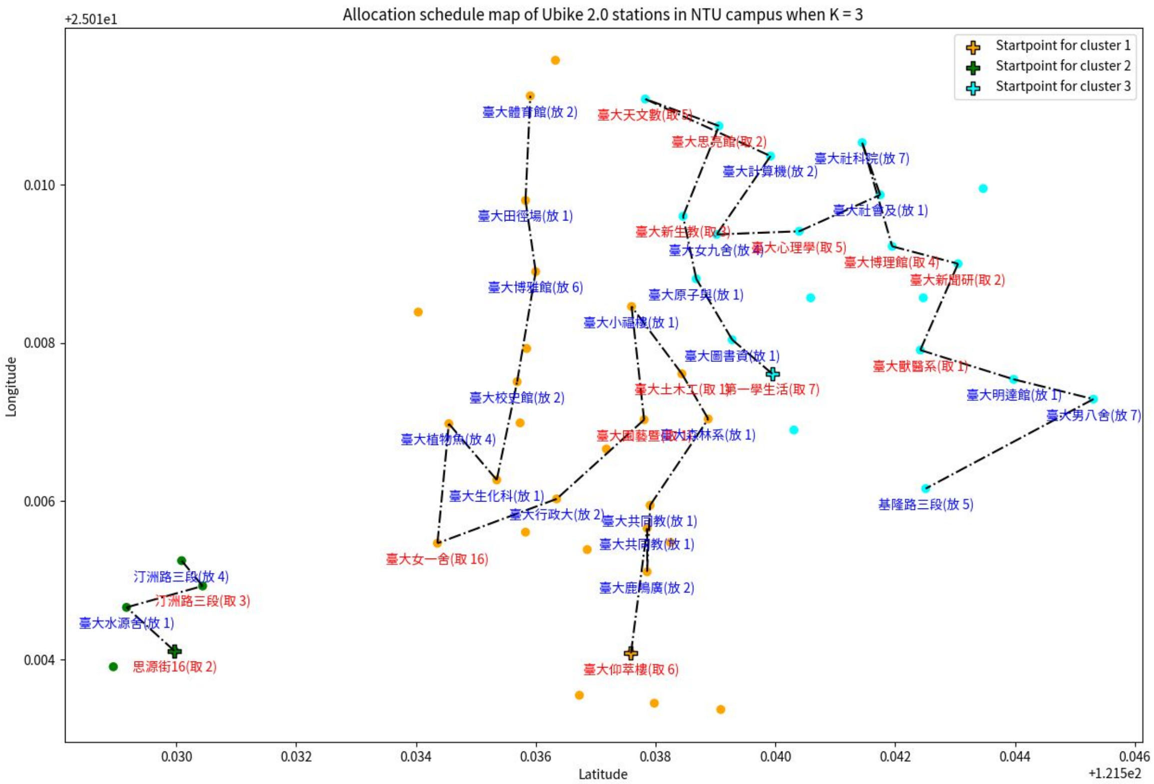


Fig 3-2. The allocation schedule map. Spot labeled red means pick up, while one labeled blue means return.

Instance 3

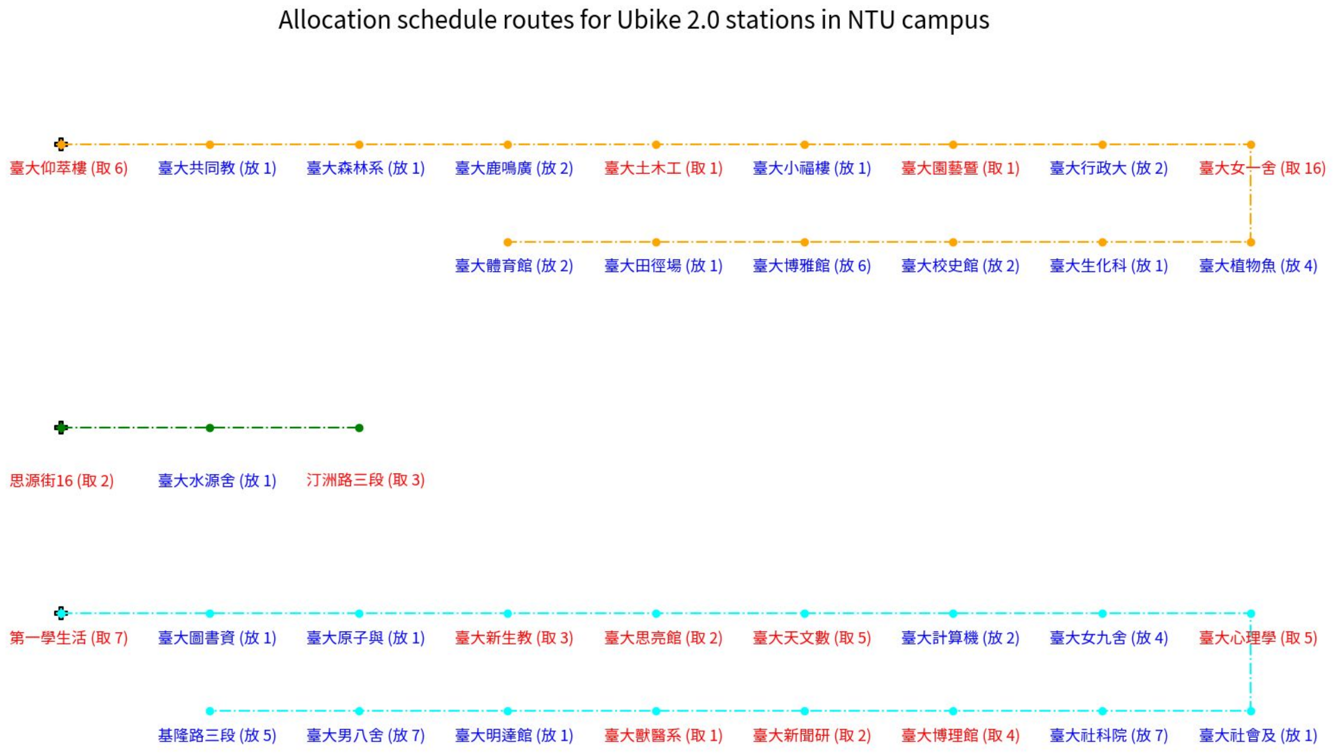


Fig 3-3. The allocation schedule routes for youbike 2.0 stations in NTU

Instance 3

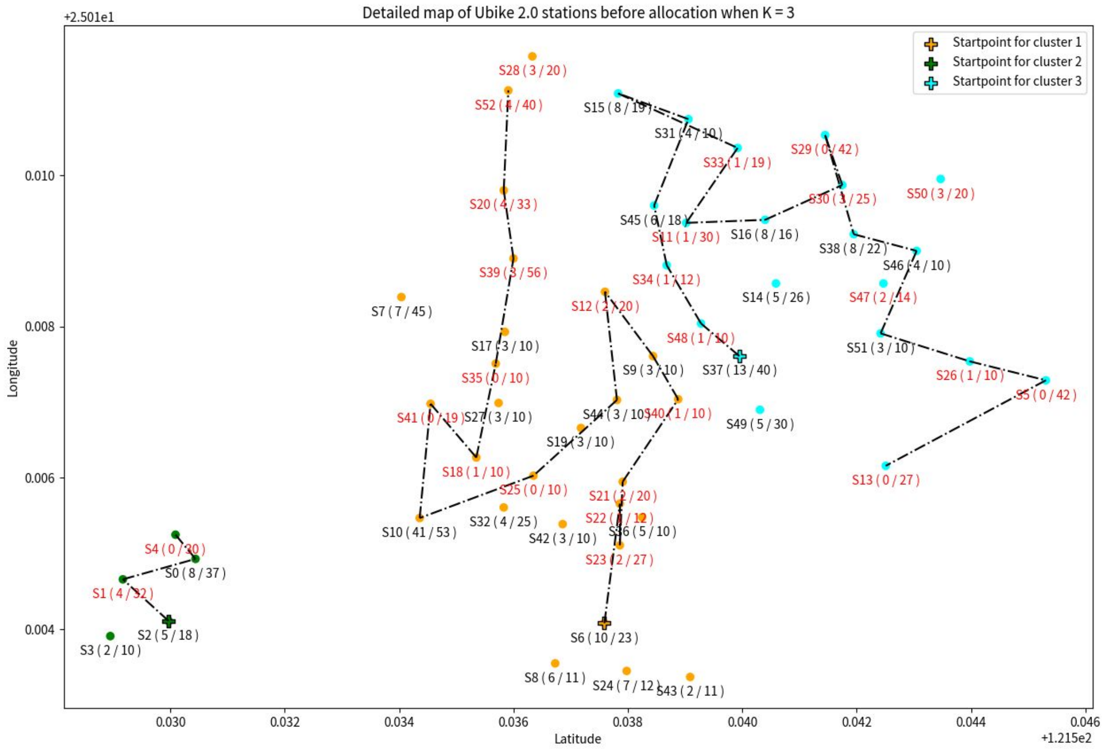


Fig 3-4. Detailed map of Ubike 2.0 stations <u>before</u> allocation

Instance 3

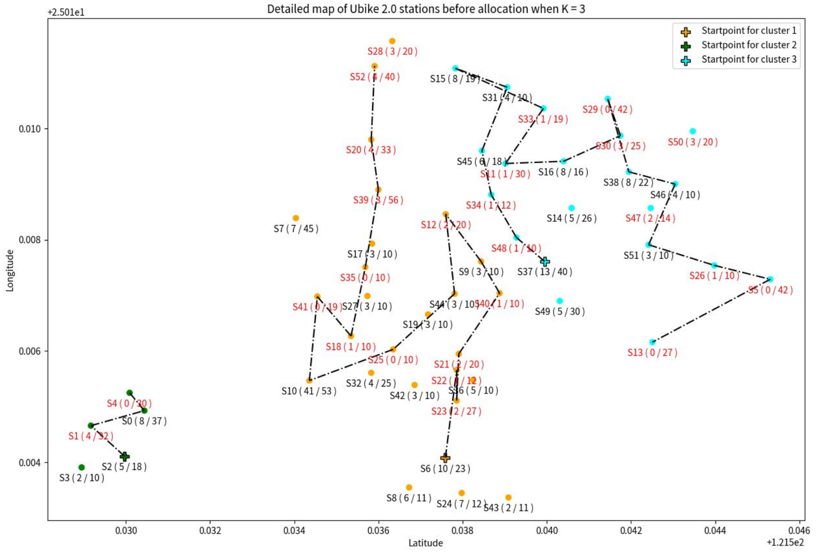


Fig 3-4. Detailed map of Ubike 2.0 stations before allocation

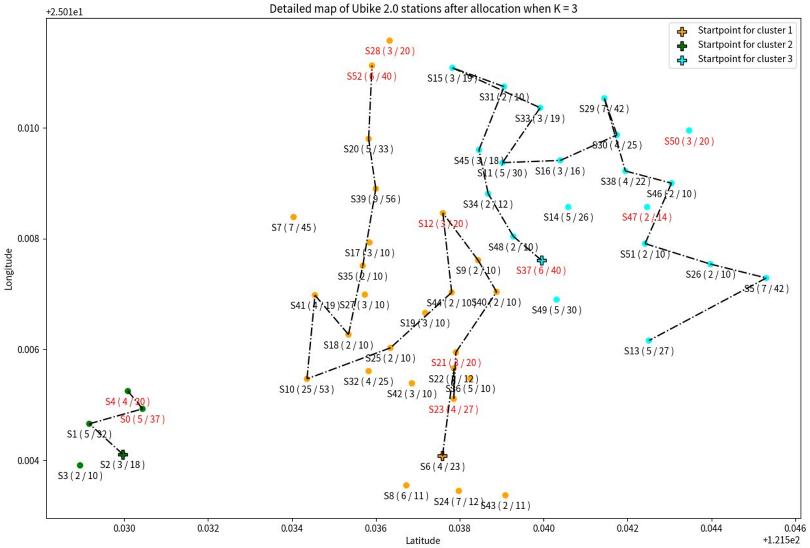
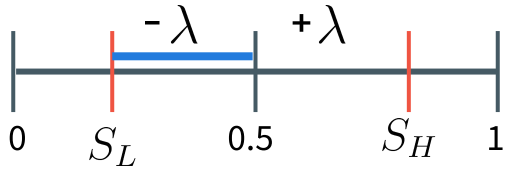


Fig 3-5. Detailed map of Ubike 2.0 stations after allocation

Conclusion



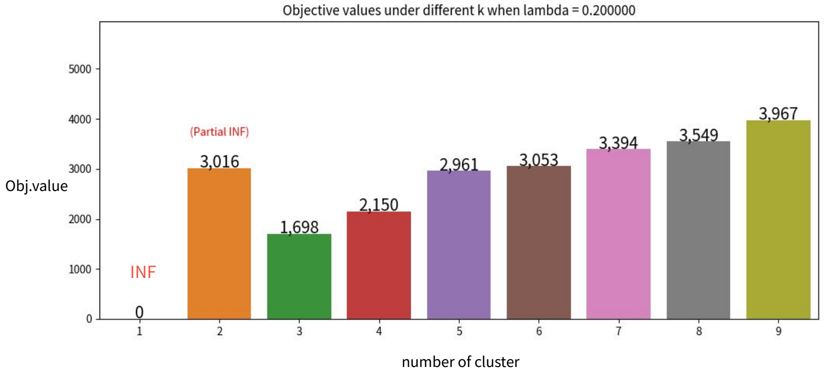
find (λ , K)
(which minimize
the objective value)

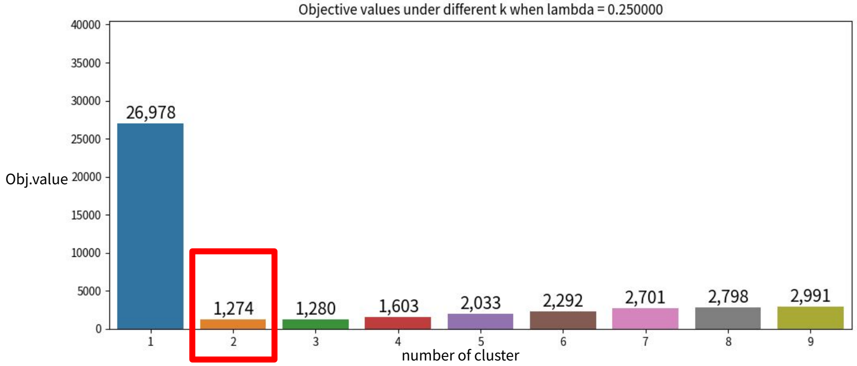
get $\begin{cases} S_H(\lambda + 0.5) \\ S_L(\lambda - 0.5) \end{cases}$

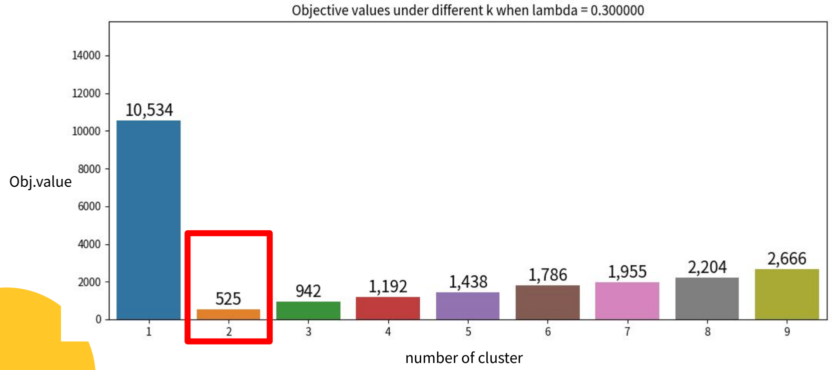
make the trade-off
between cost and service

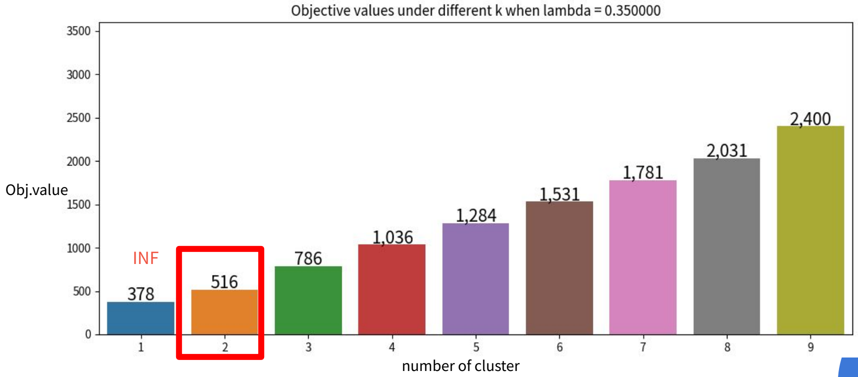
execute and generate
the schedule

Different λ in Instance 1









Future work

- The real demand without record in collected data.
- Each cluster can have more than 1 car.
- Predict the car need for next period.
- Enable moving bikes from the surplus cluster to the shortage cluster.

Thanks

Do you have any questions?

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