



Feasibility Validation of Launching LA Metro Bike Relocation Service using Stochastic Programming



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Data Configuration

- Metro Bike share open-data consists of 14 columns (with each data type):

- Trip ID (int)
- Duration (float)
- Start Time (object)
- End Time (object)
- Starting Station ID (int)
- Starting Station Latitude (float)
- Starting Station Longitude (float)
- Ending Station ID (int)
- Ending Station Latitude (float)
- Ending Station Longitude (float)
- Bike ID (int)
- Plan Duration (float)
- Trip Route Category (string)
- Passholder Type (string)

- Trip data from July 2016 to June 2017
- Trip Duration (in seconds)
- 64 Stations
 - Station Latitude and Longitude
- Bike ID
- Plan Duration :
 - 1 day, 30 days, 365 days
- Trip Route Category :
 - One Way, Round Trip
- Passholder Type :
 - Walk-up, Monthly Pass, Flex Pass, Staff Annual
- 112427 rows

trip_id	duration	start_time	end_time	start_station	start_lat	start_lon	end_station	end_lat	end_lon	bike_id	plan_duration	trip_route_cat	passholder_type
32815764	18	2017.6.25 19:53	2017.6.25 20:11	3047	34.039982	-118.2664	3005	34.0485	-118.25854	4727	30	One Way	Monthly Pass
32821341	25	2017.6.25 20:35	2017.6.25 21:00	3005	34.0485	-118.25854	3020	34.031052	-118.26709	4727	30	One Way	Monthly Pass
31652471	10	2017.6.16 8:41	2017.6.16 8:51	3023	34.050911	-118.24097	3005	34.0485	-118.25854	4727	30	One Way	Monthly Pass
31700167	4	2017.6.16 17:39	2017.6.16 17:43	3005	34.0485	-118.25854	3051	34.045422	-118.25352	4727	30	One Way	Monthly Pass
31717085	17	2017.6.16 20:17	2017.6.16 20:34	3051	34.045422	-118.25352	3005	34.0485	-118.25854	4727	0	One Way	Walk-up



Data Preprocessing

- Excluded... (112427 rows → 88266 rows)
 - 11177 rides with any NaN value
 - 3225 rides by LA Metro 'Staff Annual'
 - 10459 rides of 'Round-trips'
 - Station 4108 (Outlier)
- Category 0 ('Walk-up') : 24241, Category 1 ('Monthly Pass' + 'Flex Pass') : 64025
- Remove non-relevant 9 columns
- Calculate the Manhattan distances in miles between starting stations and ending stations for each trip.
 - For cost estimation after the network optimization.

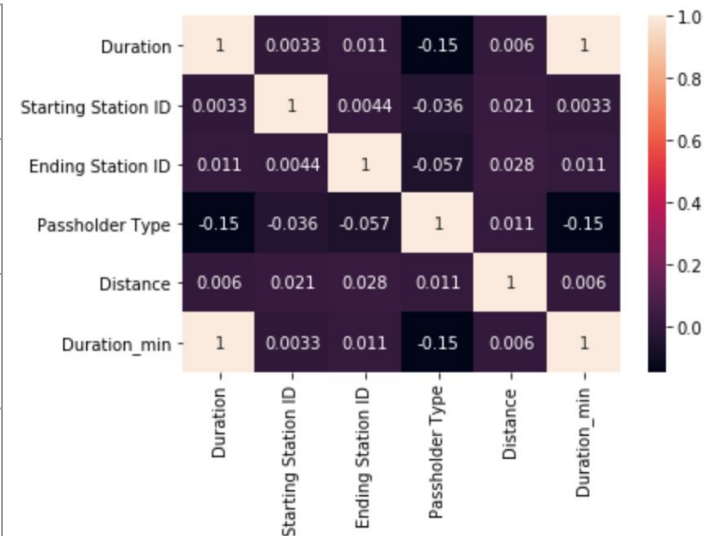
	Duration	Start Time	Starting Station ID	Ending Station ID	Passholder Type	Distance
5	780	2016-07-07T12:51:00	3021.0	3054.0	1	0.441488
6	600	2016-07-07T12:54:00	3022.0	3014.0	1	0.763951
7	600	2016-07-07T12:59:00	3076.0	3005.0	1	0.624177
9	960	2016-07-07T13:01:00	3031.0	3078.0	1	1.556036
10	960	2016-07-07T13:02:00	3031.0	3047.0	1	0.864494



Data Preprocessing

- Add Duration_min feature to the data for calculating the price for each trip.
- The current price policy is in the table below.
- The correlation between each factor are not significant.

Pass Type	Price		Category
1 Ride	\$1.75/ 30min	every 30 min.	0
Monthly	\$1.75/ 30min	first 30 min. free	1
Annual	\$1.75/ 30min	first 30 min. free	1





EDA

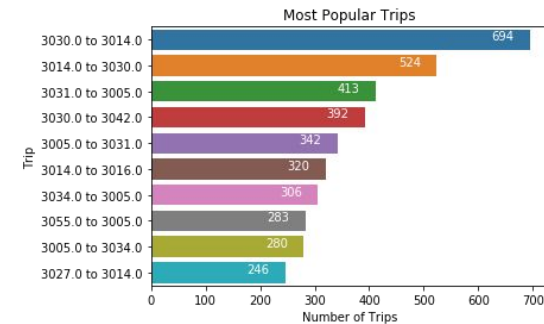
- Passholder Types according to each factor.

- Mean :

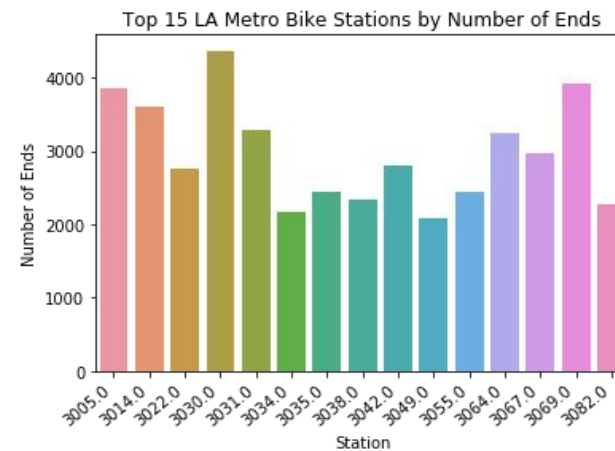
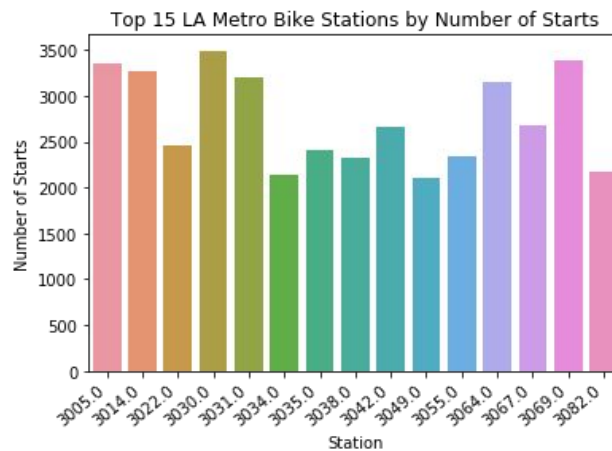
	Duration	Duration_min	Distance
Passholder Type			
0	2166.942783	36.115713	1.431571
1	771.725107	12.862085	5.347379

- Median :

	Duration	Duration_min	Distance
Passholder Type			
0	960	16.0	0.730822
1	480	8.0	0.612904



- The most frequent route : station 3030 to station 3014
- We can see there are imbalances in both starting stations and ending stations





Network Formulation - Supply and Demand

- For the relocation service, stations defined as
 - Supplying Stations : Incoming(Ending Trips) bikes > Outgoing(Starting Trips) bikes
 - Demanding Stations : Incoming bikes < Outgoing bikes
- Number of Supplying Stations and Demanding Stations

```
# Number of Supply stations and Demand stations  
print(len(s_data), len(d_data))
```

36 27

- Ex) Supplying Stations (total 36) Demanding Stations (total 27)

Net		Net	
Ending Station ID		Starting Station ID	
0	1012	2	488
1	143	4	39
3	107	7	21
5	191	14	731
6	587	16	230

- Store the data into dictionaries. (key: Station ID, value: amount)
 - s_data_constraint = {0: 1012, 1: 143, 3: 107, ...}
 - d_data_constraint = {2: 488, 4: 39, 7: 21, ...}



Network Formulation - Route Price

- Assume we discount the full price of 'Walk-up' trips and reward the full price to 'Passholders'
 - We only consider the mean duration time to get the 'full Price' for each path.

	Ending Station ID	Starting Station ID	Duration	Duration_min	Distance	Price
0	0	1	525.974026	8.766234	0.248361	1.75
1	0	2	1255.636364	20.927273	0.288265	1.75
2	0	3	1032.000000	17.200000	0.249927	1.75
3	0	4	1710.000000	28.500000	0.828233	1.75
4	0	5	2896.800000	48.280000	0.724004	3.50

- Store the full discount price into a dictionary. (key: route, value: price)
 - example : `cost_constraint = {(0,1) : 1.75, (0,2) : 1.75, ... }`
- We need 972 (36*27) pairs but we only have 838 pairs ← 124 pairs with no trips in the original dataset.
 - For these pairs, we use big M method on the constraints to get 0 moves.
- Store the missing pairs into a dictionary. (key: route, value: big M=200)
 - `missing_pairs = {(1,60) : 200, (3,7) : 200, (3,38) : 200, ...}`
- After deep-copy `cost_constraint` and update it with `missing_pairs`, we get 972 pairs.



Optimization Formulation

For each pair, parameters $Price[s, d]$ denote the maximum discount dollar-amount from the current price policy. $R_{discount} \in [0, 1]$ is defined as the discount rate for the 'Walk-ups' and $Price[s, d] \times R_{discount}$ is defined as the reward dollar-amount for 'Passholders.' Then, this becomes the company's cost for relocation service. The model solver will determine amount of bikes to be relocated over each pair, which will be represented as non-negative integer decision variables $x[s, d]$.

- The discount price for 'walk-ups' and the reward for 'passholders' are $Price[s, d] \times R_{discount}$
- By observing trade-off between discount rates and demands people will use Metro Bike, the realized demand rate is set as a function of the discount rate. Hence, the demand will become $Demand[d] \times f_{realized}(R_{discount})$
- The difference between realized demand and maximum demand (when discount rate is 1) is $(Demand[d] - x[s, d])$. This becomes cost as well.



Optimization Formulation

The problem objective is to minimize the total cost to all demanding stations from all supplying stations.

$$\begin{aligned} \text{Minimize } & \sum_{s \in \text{Supply}} \sum_{d \in \text{Demand}} \text{Price}[s, d] \times R_{\text{discount}} \times x[s, d] + (\text{price_per_mile}) \\ & \times \text{Distance}[s, d] \times (\text{Demand}[d] - x[s, d]) \\ \text{subject to } & \sum_{d \in \text{Demand}} x[s, d] \leq \text{Supply}[s] \quad \forall s \in \text{Supply} \\ & \sum_{s \in \text{Supply}} x[s, d] = \text{Demand}[d] \times f_{\text{realized}}(R_{\text{discount}}) \quad \forall d \in \text{Demand} \\ & x[s, d] \text{ is integer.} \end{aligned}$$

Relocation demands from all sources can not exceed the supplying capacity.
Relocations to each station must satisfy their demand with respect to the discount rate.



Optimization Objective

- Find the optimal discount rate for the launch of relocation service.
- Find the routes (Starting Station → Ending Station) of relocation services and the number of discounted trips for each route.
- Find the range of outsourcing cost which makes the relocation service profitable.
 - After the launch of relocation service, the operation cost can be fluctuate.



Network Assumption

- The discount dollar amount for non-passholders and reward dollar amount for passholders are the same. (for modeling simplicity)
- The optimal moves will always be met when the price is free to users (when the discount rate is 1).
- The discount rate for prices and the relocation demand percentage for each trip is the same.
 - When the price is discounted by 10%, 10% of people on each route will use the relocation service.



Network Optimization - Basic Scenario

- There are 62 paths when relocation service is free.
 - Discount rate = 1, all the demands are met.

- Each 62 paths are...

	S	D	Optimal Moves
4	0	16	71.0
6	0	18	271.0
13	0	35	337.0
14	0	36	109.0
16	0	38	1.0
18	0	40	206.0
19	0	44	17.0
32	1	17	95.0
35	1	20	32.0
37	1	29	16.0
58	3	16	107.0
81	5	2	191.0
131	6	52	587.0

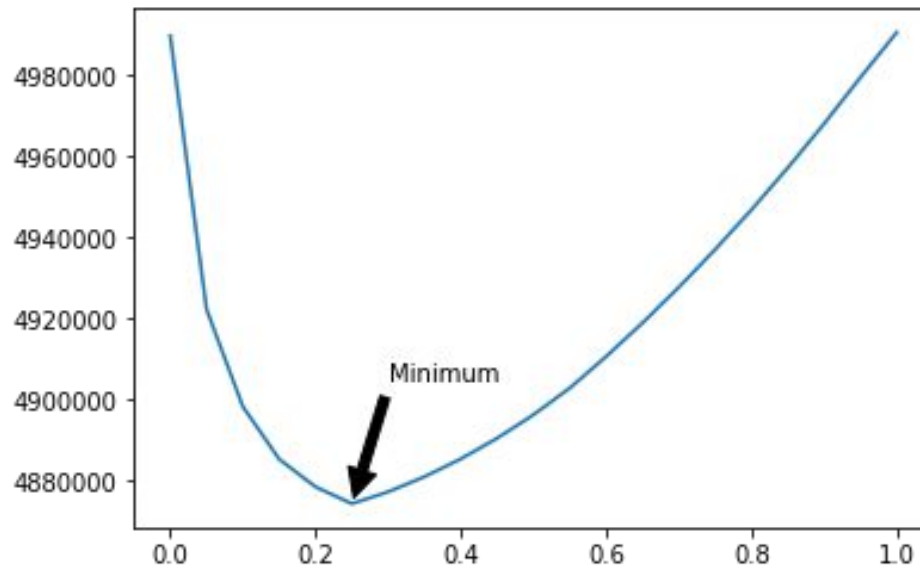
etc ...



Network Optimization (1)

- Optimal discount rate to minimize the total cost.

- Used Pyomo for network optimization and solve the problem with gurobi solver.
- Found the realistic *price_per_mile* is \$1/mile in the LA area.
- Discount rate from 0% to 100%.

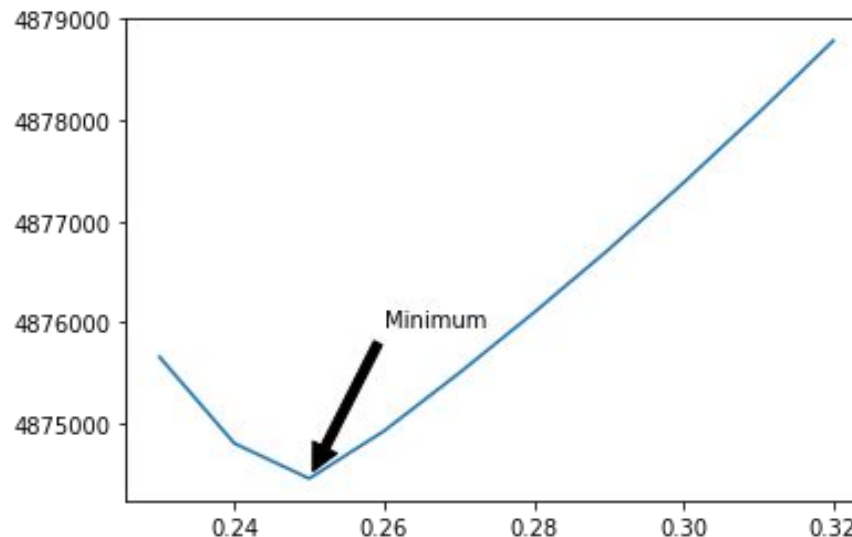




Network Optimization (1) - Detailed

- Optimal discount rate to minimize the total cost.

→ Discount rate from 22% to 32%.



→ We can conclude that the optimal discount price for minimizing the total cost is **25%**.



Network Optimization (1)

- Optimal discount rate to minimize the total cost.

- Set discount rate = 0.25
- We get the optimal solution of total cost, \$4,061,567.47
- Total relocation movements are 7663.
- The optimal moves from supplying station to demanding station are stored in 'optimal_sol.csv'

```
Solver:
- Status: ok
  Message: Gurobi 8.1.0\x3a optimal solution; objective 4061567.471694626
4; 93 simplex iterations
  Termination condition: optimal
  Id: 0
  Error rc: 0
  Time: 0.05458498001098633
..
```

```
# Store optimal solution into dataframe
optsol = []
for s in S_list:
    for d in D_list:
        optsol.append((s, d, model.x[s,d]()))
cols=['S','D','Optimal Moves']
optsol = pd.DataFrame(optsol,columns=cols)
optsol = optsol[optsol['Optimal Moves']!=0]
opts_list = optsol['S'].unique().tolist()
optd_list = optsol['D'].unique().tolist()
# optsol.to_csv('optimal_sol.csv')
optsol['Optimal Moves'].sum()
# Total movements for every route pairs.
```

7663.0

	S	D	Optimal Moves
3	0	14	103.0
5	0	17	117.0
7	0	19	15.0
8	0	20	131.0

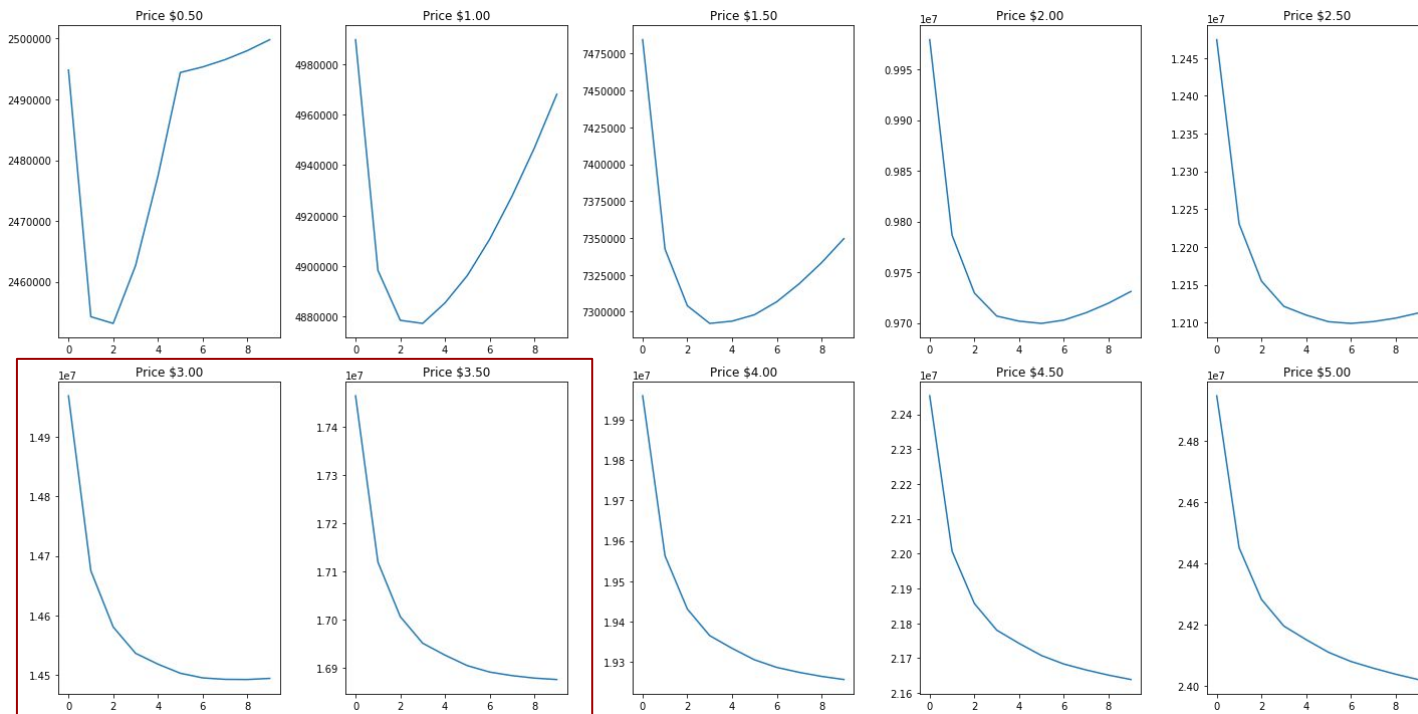
etc ...



Network Optimization (2)

- Estimation of outsourcing cost to determine relocation service feasibility.
<Criteria on the need of providing relocation service at free price.>

- Used Pyomo for network optimization and solve the problem with gurobi solver.
- Changed *price_per_mile* from \$0.50/mile to \$5.00/mile

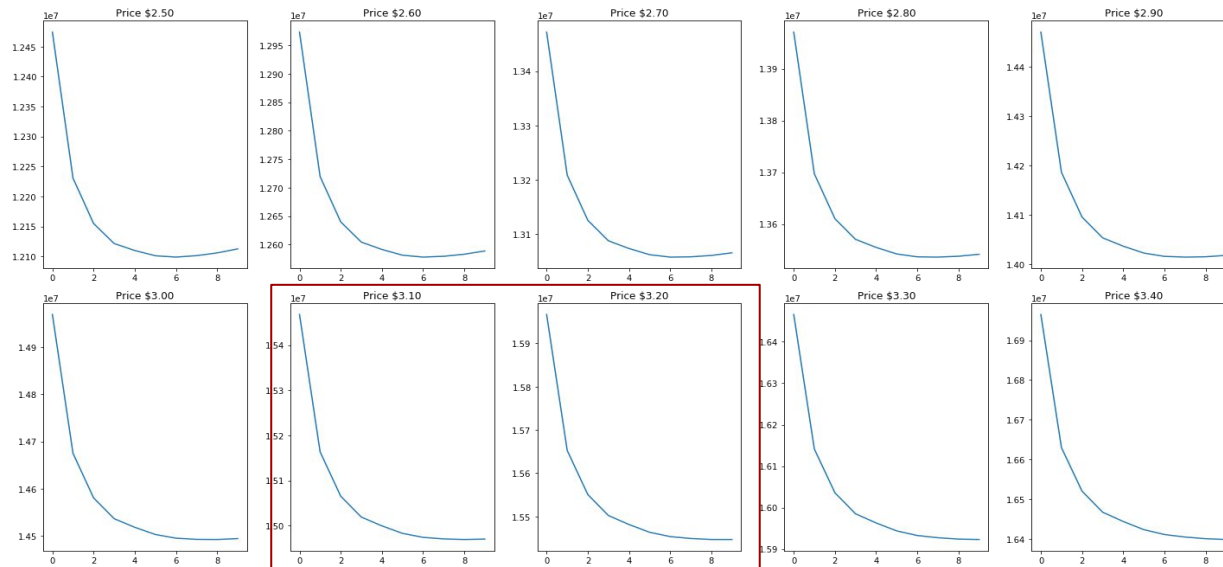




Network Optimization (2) - Detailed

- Estimation of outsourcing cost to determine relocation service feasibility.
<Criteria on the need of providing relocation service at free price.>

→ Changed *price_per_mile* from \$2.50/mile to \$3.40/mile



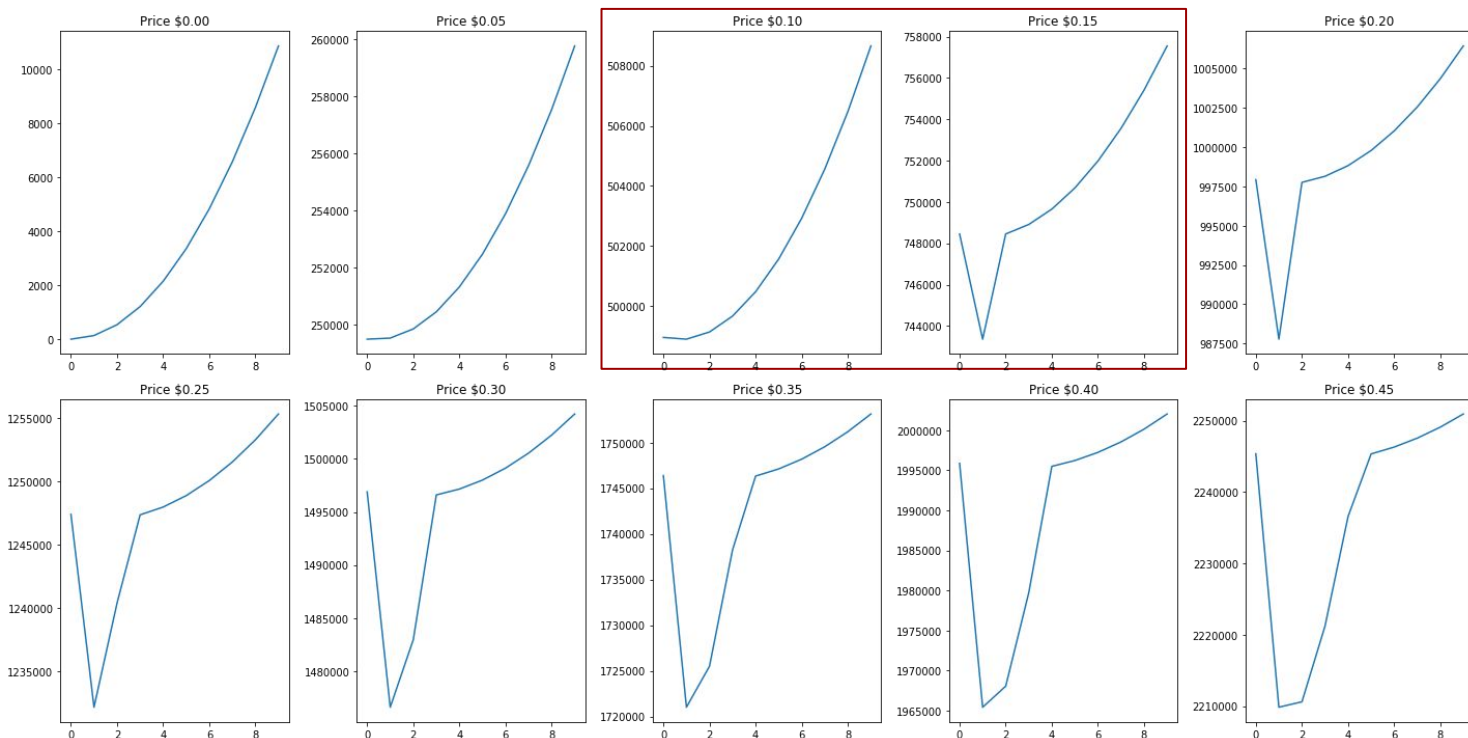
- Total cost decreases monotonically when *price_per_mile* at \$3.20/mile and increases at last when the price is \$3.10./mile
- We can observe : when *price_per_mile* is more than \$3.10/mile, it is better to launch the relocation service at free price.



Network Optimization (2)

- Estimation of outsourcing cost to determine relocation service feasibility.
<Criteria on no need of relocation service.>

- Used Pyomo for network optimization and solve the problem with gurobi solver.
- Changed *price_per_mile* from \$0.00/mile to \$0.45/mile

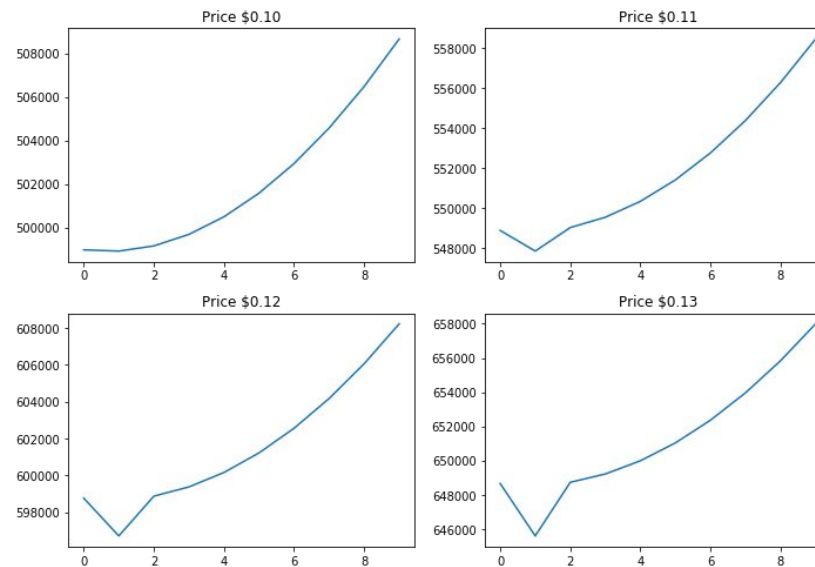




Network Optimization (2) - Detailed

- Estimation of outsourcing cost to determine relocation service feasibility.
<Criteria on no need of relocation service.>

→ Changed *price_per_mile* from \$0.10/mile to \$0.15/mile



→ We can observe : when *price_per_mile* is less than \$0.11/mile, it is better not to launch the relocation service.



Conclusion

- The optimal discount rate for relocation service is **25%**.
- The optimal routes of relocation services and the number of discounted trips are stored in 'optimal_sol.csv'.
- The relocation service is profitable when the outsourcing cost is in **between \$0.11 and \$3.10 per mile**.
 - If the operation cost is less than \$0.11/mile, it is better not to launch relocation service.
 - If the operation cost is more than \$3.10/mile, it is better to provide relocation service at free.

Detailed solution and codes :

https://github.com/yyul10/LA_metro_bike_relocation