ISE3230 Project - LinkNYC Optimization

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Introduction

With the dramatic increase of personal device usage and the reliance on internet availability, public access to Wi-Fi and charging stations has outgrown many cities and regions infrastructure and ability to provide these services to residents. One program that has been trying to provide access to residents and visitors is the LinkNYC communication network in New York City. This program which is brought to residents by the City of New York and CityBridge gives access to free public Wi-Fi, phone calls, device charging, and a tablet to access city services, maps, and directions. The program costs roughly $200 million through funds acquired through advertising. The kiosks are continuing to being added in the 5 boroughs, but one major problem that arises with this project is site selection to make sure the services are equitable for NYC residents and visitors that would need them.

We will be looking at census tracts throughout NYC, which are small subdivisions of counties, in which there are 2168 census tracts within NYC. Our goal is to determine if kiosks should be installed in these census tracts and determine how many to install. We will assume that there is a constant cost for each borough a census tract is located in. The method of determining these costs was by looking at the population and number of points of interest. A point of interest is a location considered to be a common place by the city agencies. An area with a high population and high number of points of interest would likely have a lot of traffic, so we assume it will cost more to build a kiosk in this location. A less busy area might still see some use; however, the space is likely less competitive, so the cost would be lower. The number of kiosks currently in a census tract will also be considered, to ensure that there are not too many kiosks currently in place.

Optimization Model

Problem Description

We aim to optimize the installation of LinkNYC kiosks across census tracts in New York City. The objective is to minimize installation costs while ensuring adequate kiosk coverage for the population and meeting specific constraints.

Model Formulation

Constants:

- **P**: Vector of populations for each census tract (P_i for tract i).
- Cost: Vector of installation costs per kiosk for each census tract (c_i for tract i, determined by the borough it belongs to).
- POI: Vector of points of interest for each census tract (POI_i for tract i).
- **K**: Vector of current kiosks for each census tract (K_i for tract i).
- ρ: Minimum population per kiosk per census tract.
- MinPOI: Minimum number of points of interest required to consider installing kiosks.
- k: Maximum number of kiosks to install.
- β: Population threshold per kiosk per borough.
- b: One borough (5 total).
- CT_b: Set of census tracts in borough b.

```
# Get vectors and change nan pois to 0
geoid = df['GEOID']
kiosks=df['kiosks'].to_numpy()
pop=df['population'].to_numpy()
pois=df['pois'].to_numpy()
cost=df['Cost'].to_numpy()
borough=df['COUNTYFP']

pois = np.nan_to_num(pois, nan=0, posinf=1, neginf=0)
```

```
# Constants
n = len(geoid)
min_pois = 15
max_kiosks = 2000
min_pop = 10000
```

```
borough_pop = 5000
```

Decision Variables:

- x_i: Number of new kiosks to install in census tract i ($x_i \geq 0, x_i \in \mathbb{Z}$).

```
X = cp.Variable(n, integer=True)
```

Objective Function:

$$\text{Minimize } Z = \sum_{i}^{2327} c_i \cdot x_i$$

Where c_i is the cost assigned to the borough where tract i is located.

```
obj_fun = cp.sum(cp.multiply(cost, X))
```

Constraints:

Population Coverage:

$$x_i \leq \frac{P_i}{\rho} \cdot 10 \quad \forall i$$

```
constraints.append(X <= pop/min_pop*10)
```

```
# For every 3000 people can have max 7 kiosks CT
```

$$\sum_{i \in CT_b} \frac{P_i}{\beta} \leq \sum_{i \in CT_b} (K_i + x_i)$$

```
b in [5, 47, 61, 81, 85]: # For Each borough
lt = len(geoid[borough==b]) # numer of CT in burough
# average population in the borough divided by 5000 <= average total kiosks
# On average over each CT in a borough 1 total kiosk for 5000 people
constraints.append(sum(pop[borough==b]/borough_pop)/lt <= cp.sum(kiosks[borough==b]+X[borough==b])/lt)
```

POI Coverage:

$$x_i \leq \frac{\text{POI}}{\text{MinPOI}} \cdot 5 \quad \forall i$$

```
constraints.append(X <= pois/min_pois*5)
```

```
# Can have maximum of 2000 kiosks total ($2 million max budget)
```

Non-Negativity and Integer Constraints:

$$0 \leq x_i \leq k, \quad x_i \in \mathbb{Z}$$

```
constraints.append(X>=0)
constraints.append(X<=max_kiosks)
```

```
X = cp.Variable(n, integer=True)
```

Complete Formulation

Objective:

$$\text{Minimize } Z = \sum_i c_i \cdot x_i$$

Subject to:

$$x_i \leq \frac{P_i}{\rho} \cdot 10 \quad \forall i$$

$$\sum_{i \in CT_b} \frac{P_i}{\beta} \leq \sum_{i \in CT_b} (K_i + x_i)$$

$$x_i \leq \frac{\text{POI}}{\text{MinPOI}} \cdot 5 \quad \forall i$$

$$0 \leq x_i \leq k, \quad x_i \in \mathbb{Z}$$

Results

```
print("Total Kiosks added: ", sum(X.value))
print("Total cost: ", obj_fun.value)

for b in [5, 47, 61, 81, 85]:  # Adjust number of boroughs as needed
    # Sum kiosks added in this borough
    kiosks_in_borough = np.sum(X.value[borough == b])
    cost_for_b = np.sum(np.multiply(cost[borough==b], X.value[borough==b]))
    print(f"Borough {b} : Kiosks added = {kiosks_in_borough}")
    print(f"Borough {b} : Cost = {cost_for_b}")
```

```
Total Kiosks added:  459.0
Total cost:  566900.0
Borough 5 : Kiosks added = 82.0
Borough 5 : Cost = 123000.0
Borough 47 : Kiosks added = 204.0
Borough 47 : Cost = 204000.0
Borough 61 : Kiosks added = 0.0
Borough 61 : Cost = 0.0
Borough 81 : Kiosks added = 124.0
Borough 81 : Cost = 186000.0
Borough 85 : Kiosks added = 49.0
Borough 85 : Cost = 53900.0
```

Our problem had a very high number of dimensions, because the number of kiosks to install in each of the 2168 census tracts was its own decision variable. Costs were previously split up into boroughs, so we summed the results for each census tract into their respective boroughs.

	The Bronx	Brooklyn	Manhattan	Queens	Staten Island	***Total***
Existing Kiosks	362	339	1220	355	50	2,306
# to Add	**82**	**204**	**0**	**124**	**49**	**459**
Cost	**$123,000.00**	**$204,000.00**	**$0.00**	**$186,000.00**	**$53,900.00**	**$566,900.00**

The table above shows us that 459 kiosks should be added across the five boroughs. We estimate the cost of this expansion to be $566,900.00. The cost per kiosk we estimated in Brooklyn was the cheapest, so it makes sense the optimal solution is to build more kiosks in that borough. This increase will also make it the borough with the second highest number of kiosks, with 543 kiosks. Manhattan's result is also interesting, since the optimal solution has zero kiosks built in that location. We can infer the large number of kiosks currently installed in Manhattan means that there is not as much room to expand, and the coverage of the kiosks is already optimal. As our results show, it is more worthwhile to look at other boroughs, because they are cheaper, and the added coverage will have a greater impact than another kiosk being added to Manhattan. Staten Island's kiosks will double but still only have a relatively small expansion; however, this is to be expected due to the lower population of the borough.

The increase in the spread of the kiosks will also benefit LinkNYC as well. As the Wi-Fi service they provide is free, their method of earning money is entirely through advertising. Since our solution seeks to minimize the cost, while maximizing coverage, this means that it also increases the areas that it can offer advertisements. The increase in advertising offerings at a minimum cost could also lead to increased profits which can be put towards future expansions of the service as well.

This problem will also be able to provide optimal solutions in the future, as the population changes, as well as kiosks and points of interest being built or demolished. A similar model could also be used to solve for the implementation of LinkNYC's relatively new offering of Link5G kiosks. LinkNYC can also serve as a blueprint for other US cities to implement their own Wi-Fi services, and models like ours will also be important for those as well. As technology furthers, and internet becomes a greater part of our lives, projects such as LinkNYC will become more important, and our model will help to increase its reach.

Appendix

Video Link:

https://youtu.be/Ix3OL3hpUh8

GitHub Repository:

https://github.com/bsosu/ISE3230_Group17_Project/tree/main

Team Member Contributions:

Catherine Ling.273: Model conceptual formulation, model mathematical formulation, constraint decisions, CVXPY coding, report writing, PowerPoint writing, result tables, introduction

Benjamin Strong.241: Model conceptual formulation, constraint decisions, CVXPY coding, report writing, result section/analysis interpretation, presentation recording

Jaden Thomas.4504: Model conceptual formulation, project proposal, data pre-processing, CVXPY coding, PowerPoint writing, result tables, kiosk graphic

Sources:

https://www.census.gov/programs-surveys/acs

https://data.cityofnewyork.us/City-Government/Points-Of-Interest/rxuy-2muj

https://github.com/bsosu/ISE3230_Group17_Project/blob/main/final-project-ise.R