IEE 574: Applied Deterministic Operations Research

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Facility Location For Food Distribution

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Problem Context

Frontline workers are the backbone of our society. Over the past several months, they have enabled the continued operation of hospitals, fire stations, grocery stores, etc., thereby helping us all cope with the ongoing pandemic. More than ever, it is important to return the favor and provide these workers with support. To that end, your team has resolved to apply your ingenuity and operations research skill sets to determine a cost-effective plan for delivering meals to these workers.

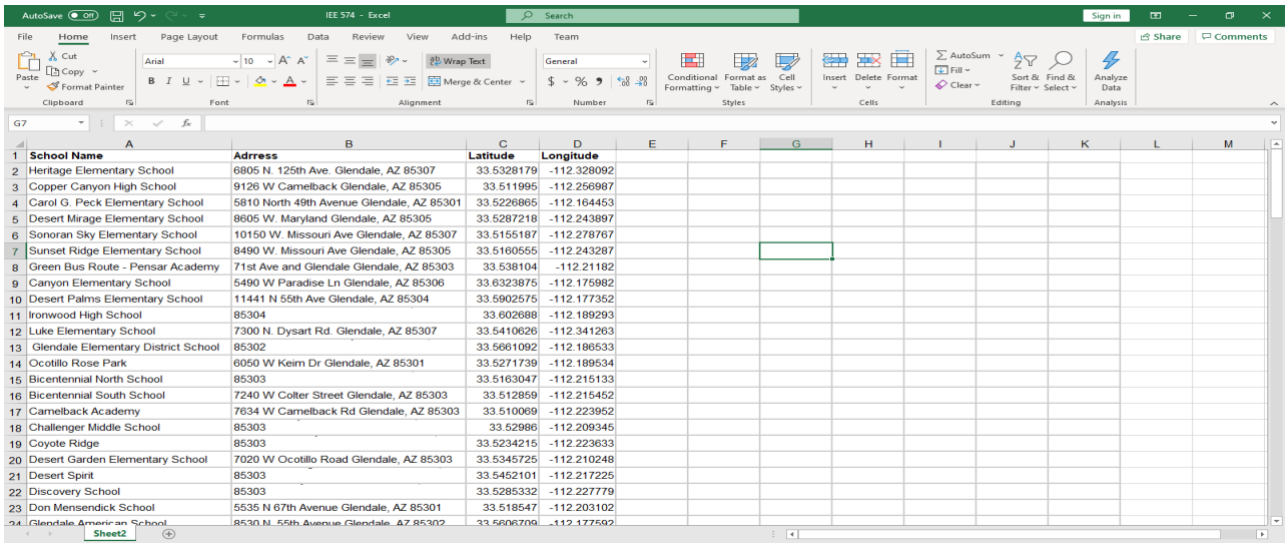
Introduction

Our objective of the project as Operations Research Consultants to “XYZ Start up” was to select 106 public institutional spaces in Glendale area, which consisted of hospitals, schools, police/fire stations, museums. We collected Data from reputable sources which are cited in the reference. In our project we used AMPL/CPLEX and Python to do the computations associated with decision making with setting up a small number of relatively inexpensive and quick-to-deploy \cloud kitchens" from which meals are to be delivered on a weekly basis to 106 worker stations. We used “Off the shelve”, ”Branch and Cut” and “Heuristics” solution methods to solve our models.

Data Collection:-

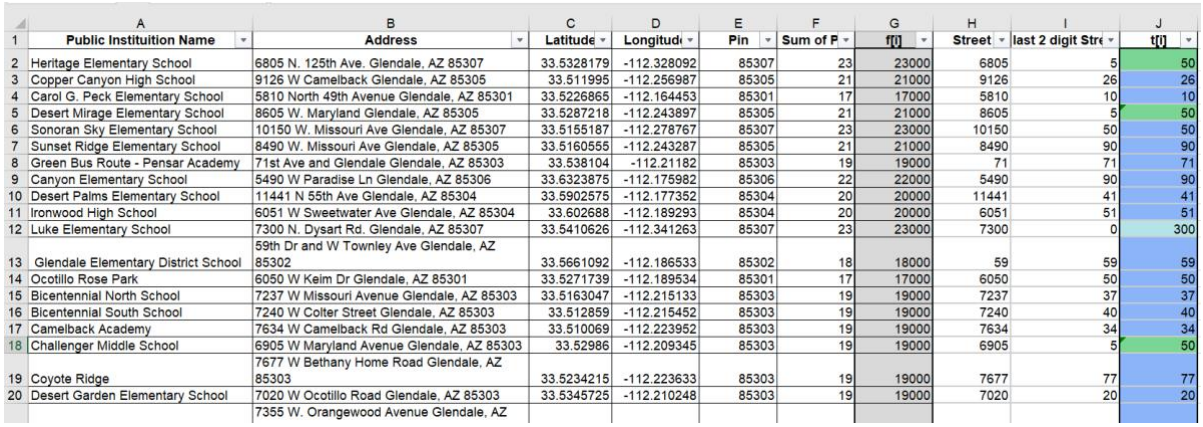
We collected data of 106 locations and we collected the “Name of Public institutions” ,”Address”, ”latitude”, ”longitude”. The data of Food Banks and Pantries from google search. The Schools data was collected from USDA website and downloaded through Summer Meal Sites data.

To get location coordinates we used Geocod website.



	A	B	C	D
1	School Name	Adrress	Latitude	Longitude
2	Heritage Elementary School	6805 N. 125th Ave. Glendale, AZ 85307	33.5328179	-112.328092
3	Copper Canyon High School	9126 W Camelback Glendale, AZ 85305	33.511995	-112.256987
4	Carol G. Peck Elementary School	5810 North 49th Avenue Glendale, AZ 85301	33.5226865	-112.164453
5	Desert Mirage Elementary School	8605 W. Maryland Glendale, AZ 85305	33.5287218	-112.243897
6	Sonoran Sky Elementary School	10150 W. Missouri Ave Glendale, AZ 85307	33.5155187	-112.278767
7	Sunset Ridge Elementary School	8490 W. Missouri Ave Glendale, AZ 85305	33.5160555	-112.243287
8	Green Bus Route - Pensar Academy	71st Ave and Glendale Glendale, AZ 85303	33.538104	-112.21182
9	Canyon Elementary School	5490 W Paradise Ln Glendale, AZ 85306	33.6323875	-112.175982
10	Desert Palms Elementary School	11441 N 55th Ave Glendale, AZ 85304	33.5902575	-112.177352
11	Ironwood High School	85304	33.602688	-112.189293
12	Luke Elementary School	7300 N. Dysart Rd. Glendale, AZ 85307	33.5410626	-112.341263
13	Glendale Elementary District School	85302	33.5661092	-112.186533
14	Ocotillo Rose Park	6050 W Keim Dr Glendale, AZ 85301	33.5271739	-112.189534
15	Bicentennial North School	85303	33.5163047	-112.215133
16	Bicentennial South School	7240 W Colter Street Glendale, AZ 85303	33.512859	-112.215452
17	Camelback Academy	7634 W Camelback Rd Glendale, AZ 85303	33.510069	-112.223952
18	Challenger Middle School	85303	33.52986	-112.209345
19	Coyote Ridge	85303	33.5234215	-112.223633
20	Desert Garden Elementary School	7020 W Ocotillo Road Glendale, AZ 85303	33.5345725	-112.210248
21	Desert Spirit	85303	33.5452101	-112.217225
22	Discovery School	85303	33.5285332	-112.227779
23	Don Mensendick School	5535 N 67th Avenue Glendale, AZ 85301	33.518547	-112.203102
24	Glendale American School	8530 N. 55th Avenue Glendale, AZ 85302	33.5606709	-112.177592

We used excel to generate parameters f[i] and t[i] from Pin code and last 2 digits of the street address respectively.



	A	B	C	D	E	F	G	H	I	J
1	Public Instituition Name	Address	Latitude	Longitud	Pin	Sum of P	f[i]	Street	last 2 digit Str	t[i]
2	Heritage Elementary School	6805 N. 125th Ave. Glendale, AZ 85307	33.5328179	-112.328092	85307	23	23000	6805	5	50
3	Copper Canyon High School	9126 W Camelback Glendale, AZ 85305	33.511995	-112.256987	85305	21	21000	9126	26	26
4	Carol G. Peck Elementary School	5810 North 49th Avenue Glendale, AZ 85301	33.5226865	-112.164453	85301	17	17000	5810	10	10
5	Desert Mirage Elementary School	8605 W. Maryland Glendale, AZ 85305	33.5287218	-112.243897	85305	21	21000	8605	5	50
6	Sonoran Sky Elementary School	10150 W. Missouri Ave Glendale, AZ 85307	33.5155187	-112.278767	85307	23	23000	10150	50	50
7	Sunset Ridge Elementary School	8490 W. Missouri Ave Glendale, AZ 85305	33.5160555	-112.243287	85305	21	21000	8490	90	90
8	Green Bus Route - Pensar Academy	71st Ave and Glendale Glendale, AZ 85303	33.538104	-112.21182	85303	19	19000	71	71	71
9	Canyon Elementary School	5490 W Paradise Ln Glendale, AZ 85306	33.6323875	-112.175982	85306	22	22000	5490	90	90
10	Desert Palms Elementary School	11441 N 55th Ave Glendale, AZ 85304	33.5902575	-112.177352	85304	20	20000	11441	41	41
11	Ironwood High School	6051 W Sweetwater Ave Glendale, AZ 85304	33.602688	-112.189293	85304	20	20000	6051	51	51
12	Luke Elementary School	7300 N. Dysart Rd. Glendale, AZ 85307	33.5410626	-112.341263	85307	23	23000	7300	0	300
13	Glendale Elementary District School	59th Dr and W Townley Ave Glendale, AZ 85302	33.5661092	-112.186533	85302	18	18000	59	59	59
14	Ocotillo Rose Park	6050 W Keim Dr Glendale, AZ 85301	33.5271739	-112.189534	85301	17	17000	6050	50	50
15	Bicentennial North School	7237 W Missouri Avenue Glendale, AZ 85303	33.5163047	-112.215133	85303	19	19000	7237	37	37
16	Bicentennial South School	7240 W Colter Street Glendale, AZ 85303	33.512859	-112.215452	85303	19	19000	7240	40	40
17	Camelback Academy	7634 W Camelback Rd Glendale, AZ 85303	33.510069	-112.223952	85303	19	19000	7634	34	34
18	Challenger Middle School	6905 W Maryland Avenue Glendale, AZ 85303	33.52986	-112.209345	85303	19	19000	6905	5	50
19	Coyote Ridge	7677 W Bethany Home Road Glendale, AZ 85303	33.5234215	-112.223633	85303	19	19000	7677	77	77
20	Desert Garden Elementary School	7020 W Ocotillo Road Glendale, AZ 85303	33.5345725	-112.210248	85303	19	19000	7020	20	20
		7355 W. Orangewood Avenue Glendale, AZ								

Distance Calculation

Since we collected the coordinates and we wanted to get the distance of all the 106 cities from one another.

To find distance matrix (106 x 106) we used Python programming language. We eventually added the distance matrix as a parameter in our model and data files. (.mod and .dat)

```
# importing libraries and loading dataset
from sklearn.neighbors import DistanceMetric
from math import radians
import pandas as pd
import numpy as np
df = pd.read_excel("IEE 574.xlsx")
df.head()
```

	School Name	Adrress	Latitude	Longitude
0	Heritage Elementary School	6805 N. 125th Ave. Glendale, AZ 85307	33.532818	-112.328092
1	Copper Canyon High School	9126 W Camelback Glendale, AZ 85305	33.511995	-112.256986
2	Carol G. Peck Elementary School	5810 North 49th Avenue Glendale, AZ 85301	33.522687	-112.164453
3	Desert Mirage Elementary School	8605 W. Maryland Glendale, AZ 85305	33.528722	-112.243897
4	Sonoran Sky Elementary School	10150 W. Missouri Ave Glendale, AZ 85307	33.515519	-112.278767

```
#converting Latitude and Logitude degree data to radians
df['Latitude'] = np.radians(df['Latitude'])
df['Longitude'] = np.radians(df['Longitude'])
df.head()
```

	School Name	Adrress	Latitude	Longitude
0	Heritage Elementary School	6805 N. 125th Ave. Glendale, AZ 85307	0.585258	-1.960495
1	Copper Canyon High School	9126 W Camelback Glendale, AZ 85305	0.584895	-1.959254
2	Carol G. Peck Elementary School	5810 North 49th Avenue Glendale, AZ 85301	0.585081	-1.957639
3	Desert Mirage Elementary School	8605 W. Maryland Glendale, AZ 85305	0.585187	-1.959026
4	Sonoran Sky Elementary School	10150 W. Missouri Ave Glendale, AZ 85307	0.584956	-1.959634

```
# using built in function to find distance in KM unit by Haversine formula

dist = DistanceMetric.get_metric('haversine')
df1 =  dist.pairwise(df[['Latitude','Longitude']].to_numpy())*6373

# creating the dataframe
df2 = pd.DataFrame(data = df1)

# displaying the dataframe
df2.head()
```

	0	1	2	3	4	5	6	7	8	9	...	96	97	98	99
0	0.000000	6.988477	15.214898	7.819788	4.961973	8.081689	10.796149	17.925717	15.363108	15.029256	...	14.883065	14.094062	13.601792	13.601792
1	6.988477	0.000000	8.663051	2.221436	2.057597	1.348363	5.096479	15.351949	11.413703	11.879974	...	8.929631	7.458468	9.776372	9.776372
2	15.214898	8.663051	0.000000	7.397031	10.630599	7.347556	4.714817	12.248706	7.610411	9.191564	...	2.249156	1.233635	7.193732	7.193732
3	7.819788	2.221436	7.397031	0.000000	3.551350	1.410010	3.151893	13.136415	9.213749	9.659192	...	7.206277	6.296759	7.560419	7.560419
4	4.961973	2.057597	10.630599	3.551350	0.000000	3.290863	6.696701	16.115728	12.549281	12.758861	...	10.705990	9.445287	10.827667	10.827667

5 rows × 106 columns

```
# dataframe to CSV file
df2.to_csv("DistanceMatrix.csv")
```

Model

Set I : The index of Public Institutions { 1 , 2, 3 ….. 106 }

Decision Variables :-

Yi : Binary variable which is 1, If the location “i” is selected as cloud kitchen., 0 otherwise.

Xij : The fraction of demand of location “j” met by cloud kitchen “I”.

Zij : Binary variable which is 1, If cloud kitchen “I” meets any fraction of demand at location “j” .

Parameters :-

ti : Number of weekly bulk meal-delivery trips needed by location j ∈ I

fi : Fixed weekly cost to operate a cloud kitchen “i”.

dij : The distance between any two locations ∈ I.

Objective Function:

The objective of is to set up a small number of relatively inexpensive and quick-to-deploy \cloud kitchens" from which meals are to be delivered on a weekly basis to 100 worker stations. We will be minimizing the total costs associated with the cloud kitchens; which can be divided into two components:

1) Fixed cost of operating cloud kitchens
2) Variable costs related to the sum of distances traveled

Minimizing Cost :

$$\sum_{i \in I} \sum_{j \in I} tj * zij * dij * xij + \sum_{i \in I} fi * yi$$

Constraints

DEMAND constraints

The demand at each locations (for every Jj) should be met.

$$\sum_{i \in I} xij = 1 \quad \text{for } j \in I$$

TOTAL-KITCHENS constraints

We can set a at least 10 and at most 15 cloud stations at these 100 locations

$\sum_{i \in I} Yi >= 10$ for every $i \in I$

$\sum_{i \in I} Yi <= 15$ for every $i \in I$

MAX-STATIONS constraints

A cloud kitchen can serve up to 15 locations

$\sum_{j \in I} Zij <= 15 * Yi$ for every $i \in I$

MAX-DELIVERIES constraints

A cloud kitchen can fulfill only upto 50% of the demand of a location

$\sum_{i \in I} \sum_{j \in I} Xij <= 0.50$ for every $j \in I$, for every $j \in I$

Other constraints

When Xij is not that Zij is not zero this means that if for facility I served to location j that is some demand is satisfied then Zij will always be 1.

$Xij <= Zij$ for every $j \in I$, for every $j \in I$

Xij is not zero then facility i can serve location/ satisfy demand if and only if Yi is 1

$Xij <= Yi$ for every $j \in I$, for every $j \in I$

Zij is not zero then facility i can serve location or satisfy demand of j if and only if Yi is 1

$Zij <= Yi$ for every $j \in I$, for every $j \in I$

Enforcing relations: We needed to make sure i. (Xij = 0 => Zij = 0) AND ii. (Xij > 0 => Zij = 1)

For ii.) we added the constraint Xij < = Zij which ensures that but It doesn't ensure i.

For ensuring i. We added Xij < Yi and Zij <= Yi and also we added the term "Zij" in the objective function which has minimization orientation, thus the minimization would ensure that in case when Xij = 0 from the two possible values of Zij { 0 , 1} the objective function would enforce Zij to be only {0} thus minimizing the objective function.

Description of Advanced Solution Methods

Off-The-Shelf

The strategy we used for Off the Shelf is as follows.

1) We solved above model with CPLEX solver.

Branch-and-Cut

The strategy we used for Branch and Cut is as follows.

1) We removed the MaxStation constrain in original model.
2) Then we checked for any violation of MaxStation constrain, which we did find.
3) Next, we started adding constrains to avoid violation of MaxStation constrain. We continued till 15 iterations.

Heuristic

The strategy we used to come up with the cloud kitchen is as follows

1) We firstly evaluated the cost of traveling from cloud station i (for every i c J) to every other city j

   That is $\sum_{j\,c\,I}$ dij*1 for every i c I

2) Then we added the F[i] values to each of the corresponding terms.
3) We got a Cost value of each cloud kitchen : $\sum_{j\,c\,I}$ dij*1 + F[i],since we collected the data of 106, we got 106 such costs associated with each cloud kitchen.
4) We sorted these 106 cost values in ascending order(Greedy).
5) We selected 10 cities with lowest cost associated to serve the locations.

Results and Recommendations

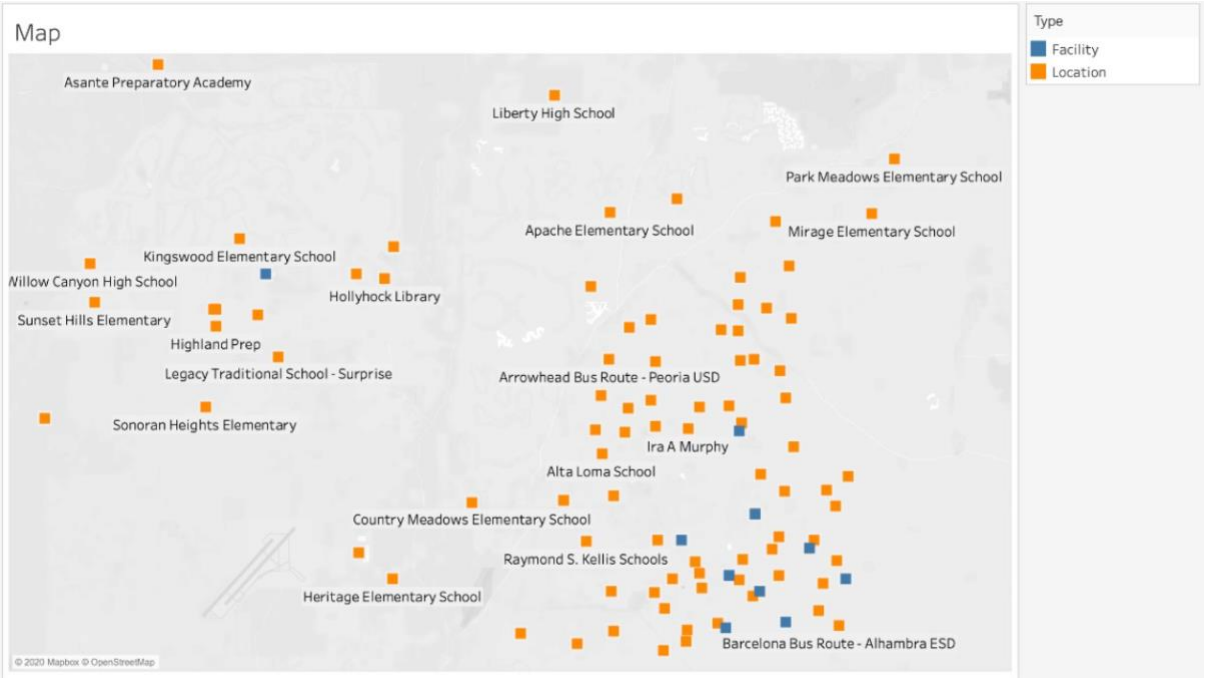
Off the-Shelf

From p-mck model

The optimal cost of setting up the cloud kitchens operations and delivery from Off the-shelf method is estimated to be 287673.3$.

We will be setting up the cloud kitchen at the following locations :

Index J	Public Instituition	Address
46	CPE Bus 4 - Pathfinder Charter School Foundation	N 65th Ave and Tuckey Lane Glendale, AZ 85301
47	CPE Bus 4 (SFSP only - Fri-Sun) - Pathfinder Charter School Foundation	N 65th Ave and Tuckey Lane Glendale, AZ 85301
48	Glendale High School	6216 W. Glendale Ave. Glendale, AZ 85301
54	Our Lady of Perpetual Help School	5614 W Orangewood Ave Glendale, AZ 85031
94	West Valley Community Food Pantry	7205 N 51st Ave Glendale, AZ 85301-2004
95	Glendale Mission and Ministry Center	6242 N 59th Ave Glendale, AZ 85301-4436
96	Salvation Army - Glendale Corps	6010 W. Northern Glendale, AZ - 85301
97	Lutheran Social Ministries West Food Pantry	7205 N. 51st Ave Glendale, AZ - 85301
99	Vinyard Food and Clothing Bank	6250 W Peoria Ave, Glendale,AZ 85302
102	Glendale Mission and Ministry Center	6242 N 59th Ave Glendale, AZ 85301-4436
103	The Salvation Army Glendale Corps	6010 W Northern Ave Glendale, AZ 85301
104	Salvation Army - Glendale Corps	6010 W. Northern Glendale, AZ - 85301
31	William C Jack School	6600 W. Missouri Avenue Glendale, AZ 85301
21	Discovery School	7910 W. Maryland Avenue Glendale, AZ 85303



Branch-and-Cut

This method resulted in the cloud kitchens at the following locations :

Index J	Public Instituition	Address
46	CPE Bus 4 - Pathfinder Charter School Foundation	N 65th Ave and Tuckey Lane Glendale, AZ 85301
97	Lutheran Social Ministries West Food Pantry	7205 N. 51st Ave Glendale, AZ - 85301
99	Vinyard Food and Clothing Bank	6250 W Peoria Ave, Glendale,AZ 85302
103	The Salvation Army Glendale Corps	6010 W Northern Ave Glendale, AZ 85301
104	Salvation Army - Glendale Corps	6010 W. Northern Glendale, AZ - 85301
31	William C Jack School	6600 W. Missouri Avenue Glendale, AZ 85301
22	Don Mensendick School	5535 N 67th Avenue Glendale, AZ 85301
49	Independence High School	6602 N. 75th Ave Glendale, AZ 85303
100	Vineyard Food and Clothing Bank	6250 W. Peoria Ave Glendale, AZ - 85302
101	West Valley Community Food Pantry	7205 N 51st Ave Glendale, AZ 85301-2004

From which 49 facility serve 106 other location hence MaxStation Constrain is violated; even after several iterations of satisfying the MaxStation constraints we didn't get a feasible solution.

Heuristic

Add Heuristics

The 10 cloud kitchens we came up didn't have a feasible solution, then we kept on adding one more cloud kitchens until we added 5 kitchens which eventually resulted in a feasible solution.

The optimal cost of setting up the cloud kitchens operations and delivery from Heuristics method is estimated to be 288,600.27$.

We got our first feasible solution by setting up 15 cloud kitchens through the Heuristics.

We will be setting up the cloud kitchens according to the heuristics at the following locations:

Index	Public Instituition	Address
14	Bicentennial North School	7237 W Missouri Avenue Glendale, AZ 85303
27	Horizon School	8520 N 47th Avenue Glendale, AZ 85302
30	Sunset Vista	7775 W Orangewood Avenue Glendale, AZ 85303
31	William C Jack School	6600 W. Missouri Avenue Glendale, AZ 85301
32	Deer Valley Ud- Route 4	57th Avenue and Grovers Avenue Glendale, AZ 85308
53	Barcelona Elementary School	6530 North 44th Avenue Glendale, AZ 85301
55	Glendale YMCA Schools	14711 N 59th Ave Glendale, AZ 85306
56	Mirage Elementary School	3910 W. Grovers Glendale, AZ 85308
62	Apache Elementary School	8633 W John Cabot Rd Peoria, AZ 85382
47	CPE Bus 4 (SFSP only - Fri-Sun) - Pathfinder Charter School Foundation	N 65th Ave and Tuckey Lane Glendale, AZ 85301
48	Glendale High School	6216 W. Glendale Ave. Glendale, AZ 85301
97	Lutheran Social Ministries West Food Pantry	7205 N. 51st Ave Glendale, AZ - 85301
101	West Valley Community Food Pantry	7205 N 51st Ave Glendale, AZ 85301-2004
102	Glendale Mission and Ministry Center	6242 N 59th Ave Glendale, AZ 85301-4436
103	The Salvation Army Glendale Corps	6010 W Northern Ave Glendale, AZ 85301
104	Salvation Army - Glendale Corps	6010 W. Northern Glendale, AZ - 85301

Swap Heuristics

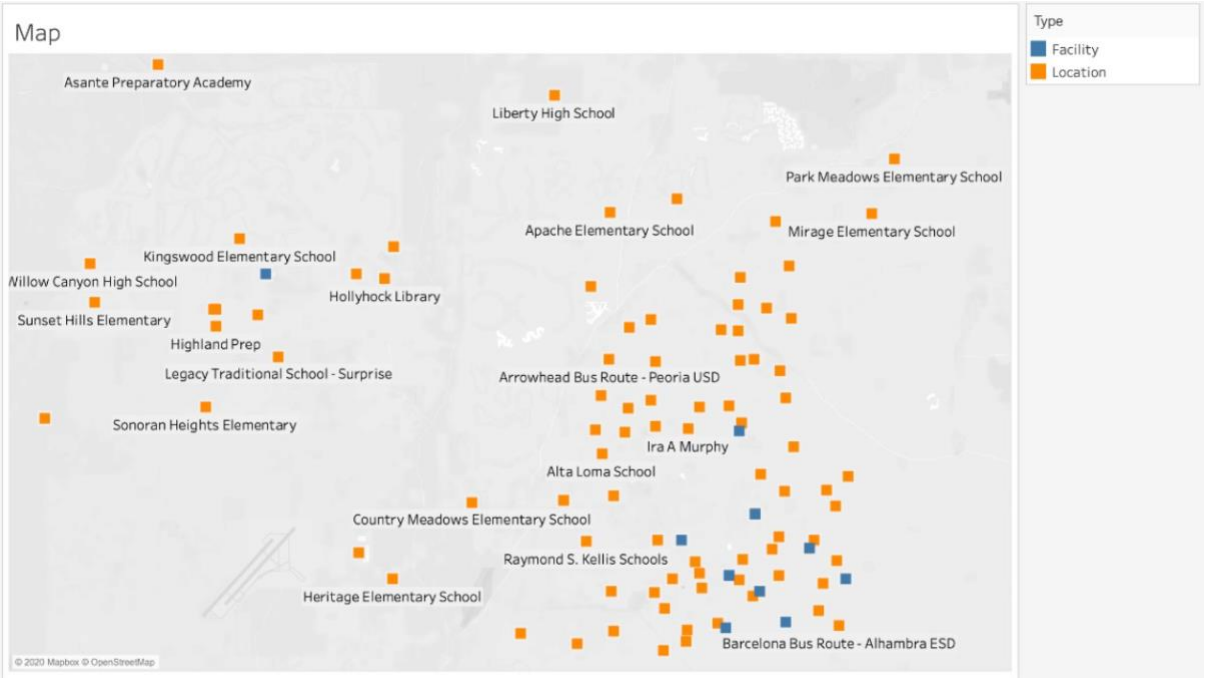
On performing SWAP heuristics, we either got a solution which was more expensive than the solution which we got through our ADD heuristics or it was infeasible. To deal with the iterations we parameterize locations y variable and changed our dat files accordingly and kept the mod file same.

Recommendations

We started our computations with off the shelve model. The model has a lot of parameters which were computationally expensive for the solver. As a result, the solver could not reach to the optimal solution in 5-6 hours, to get a solution which is closer to the desired solution we had to halt the solver.

The “Heuristics” method has been computationally very less expensive as we came up with the cloud locations from a different strategy. The “Heuristics” technique resulted in a very good optimal objective value which is close to the original optimal objective from the off the shelve method. “Heuristics” is a good way to quickly assess the feasibility and estimation of the models before a deep dive into exploring off he shelves problem of a real-world problems like on which we are working.

On exploring branch and cut we didn’t get any feasible solution even after several iterations; branch and cut may have worked well in case of different kind of constraints or perhaps lesser number of locations.



References:-

Websites:-

- https://www.geocod.io/
- https://usda-fns.hub.arcgis.com/datasets/USDA-FNS::summer-meal-sites-2020/data?geometry=-97.509%2C25.197%2C-65.868%2C31.945&orderBy=siteState&selectedAttribute=sponsoringOrganization
- https://www.foodpantries.org/