# Food Distribution at GW's 23 Commencement

School: The George Washington University School of Business

Course: DNSC 6280 Supply Chain Analytics

Name: Chao Zhang, Danyu Zhao, Haoyang Wang, Xinyi Li

## Supply Chain Problem and Motivation

Food Distribution is a critical part of any event. To provide timely and efficient food distribution to multiple colleges with a lot of considerations on May 21st, 2023, our team has designed two scenarios for the food distribution in 23 GW's Commencement.

Generally, we list some scenarios to meet the requirements of food delivery and setting pick-up stations on campus. Besides, we design some extra constraints ourselves to meet unexpected conditions happening in reality, such as a prioritization system for food delivery based on each school's specific needs.

As for setting the pick-up stations, we combine the actual geographical location of each node building with our result and try to figure out an accessible plan for setting pick-up stations for this event, in case that canteens could not take the responsibility of delivering the food. And that is also another plan for the board of GW.

## Analytical Models and Data Collection

First, we marked and numbered 11 colleges (demand locations) to be covered by meals according to the campus map with red circles, and accordingly, marked two school canteens (origins) with green circles shown in Figure 1. And Table 1 lists the names of the colleges and canteens as well as their numbers. Then, we decided to experiment with the models shown below (Table 2), and collected real data as well as reasonably simulated data through Google map as needed for these models.


Figure 1. Location on the map

| Location | No. |
|---|---|
| Thurston Hall | 1 |
| Shenkman Hall | 1 |
| School of Medicine and Health Sciences | 2 |
| Science and Engineering Hall | 3 |
| School of Media and Public Affairs | 4 |
| Duques Hall School of Business | 5 |
| GW law School | 6 |
| Elliott school of international affairs | 7 |
| Graduate School of Education & Human Development | 8 |
| Corcoran School of the Arts & Design | 9 |
| Phillips Hall Columbian College of Arts & Sciences | 10 |
| Milken Institute School of Public Health | 11 |
| School of nursing offices | 12 |

Table 1. List of all canteens and colleges in GWU

| Scenario | Model | Data Collection |
|---|---|---|
| Logistics Planning: Food Delivery | Traveling Sales Problem (TSP) | Real distance among the marked locations searched by Google Map |
| | TSP with Precedence Constraints | 1. Real distance via Google Map<br>2. Simulation: Precedence pairs |
| | Vehicle Routing Problem | Real distance among the marked locations searched by Google Map |
| Locate Food Pick-up Stations | Set Covering Problem | 1. Real distance via Google Map<br>2. Simulation: Candidate facilities |
| | Clustering: K-mean & K-median | The latitude and longitude of each location |

Table 2. List of analytical models and data collection

**Application of the proposed models and preliminary findings**

Based on the problem description in the previous section, we decided to categorize it, adopt corresponding models and data based on different scenarios, conduct experiments, and make elaboration and comparison of the experimental results to make data-driven scientific decisions to help us accomplish our goals.

**Scenario 1: Food Delivery Problem**

**Model 1:** Travel Salesman Problem and TSP with precedence constraints (Delivery via one van)

**TSP:**

The Mathematical Model

$$
\begin{aligned}
\min \quad & \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij} \\
s.t. \quad & \sum_{i=1}^{n} x_{ij} = 1, \; j = 1, \ldots, n \\
& \sum_{j=1}^{n} x_{ij} = 1, \; i = 1, \ldots, n \\
& u_i + 1 - u_j \leq M(1 - x_{ij}), \; i \neq j, 1 \leq i \leq n, 2 \leq j \leq n \\
& x_{ij} \in \{0, 1\}, u_i \geq 0, i = 1, \ldots, n.
\end{aligned}
$$

**Data Collection**

Collect the distances(miles) from Node i to Node j via Google Map and input the data to the code. To simplify the processing of input, we use 10 times of each distance. Therefore, to get the exact result, all the outputs would be divided by 10.

As we have learned in the lecture, the distances between the nodes which are far away from each other could be regarded as an extremely huge number. But in this case, there is not a huge difference among the locations on campus. So, we only use 1000(miles) to replace the data of the distance from Node i to itself to represent that this is not an accessible solution.

**Result**

As for the case of Shenkman Hall, the optimal route is [1. 5.10. 3. 4. 6. 8.7. 9. 12. 11. 2.], that is, from Thurston Hall, to Duques Hall School of Business, to Phillips Hall Columbian College of Arts & Sciences, to Science and Engineering Hall, to School of Media and Public Affairs, to GW law School, to Graduate School of Education & Human

Development, to Elliott school of international affairs, to Corcoran School of the Arts & Design, to School of nursing offices, to Milken Institute School of Public Health, to School of Medicine and Health Sciences, and finally back to Thurston Hall. And the best objective, the total distance of the routing is 2.97 miles.

As for the case of Thurston Hall,We did the same experiment again for another canteen, Thurston Canteen and tried to find which one would be better to take the responsibility of delivering food to every college at the 23 GW's Commencement. Similarly, we have collected the data of the distance from each node to another node, that is, what we should update is to collect the new source node, Thurston Hall, to each other node. And we can share the data of distance between other nodes themselves. We can gain the optimal objective, and conclude that the optimal and minimized distance whose source node is Thurston Hall would be 3.07 miles, which is more than the optimal distance starting from Shenkman Hall.

**Conclusion**

Comparing the two departure points (2.97 < 3.07), we found that the shortest distance is from Shenkman Hall, which could meet our expectation, because we can roughly see that there are a lot of colleges around the Shenkman Hall, which might be more convenient to deliver food. So this conclusion is accessible for us. Therefore, we decided to have Shenkman do the meal preparation and delivery on the day of the graduation ceremony, and we also planned the route for this delivery to drive the least distance and finish the delivery fastest.

Based on the result of comparison, we draw the draft of the driving route below(Figure 2), whose source node is Shenkman Hall.

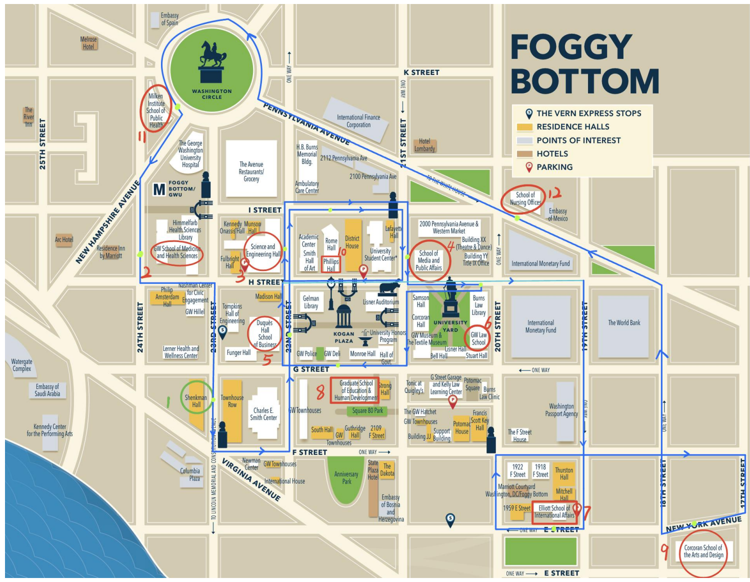


Figure 2. The Optimal route from Shenkman Hall

### Limitation

From the map, we can see that it is NOT a typical route like a loop. Because the Travel Salesman Model, which is widely applied in the broader area like planning a route in a city or in a country, would meet more delicate problems and limitations while being applied in this smaller area. And we find two explanations for that.

Firstly,  the route on campus is NOT just linking the nearest two buildings. In reality, you might see that Building A and B are more closed in the map. However, it might be the occasion that the gate of Building A located in the north is towards north, and the gate of Building B located in the south is towards south. So, to get Building B from Building A, we should spend more time than expected.

Secondly, another reason in reality is that there are a lot of single lane roads on campus. While gaining the distance of each node via Google Map, the problem was gotten rid of, and we can directly get the distance information considering these real traffic limitations.

### TSP with Precedence Constraints:

After getting the result that Shenkman Hall would be faster in the TSP, we assume that there might be some extra requirements in the food delivery.

We set that some colleges start the college event earlier, so they need to be delivered than other colleges. We suppose that we have to deliver to School of Medicine and Health Science first then Corcoran School of the Arts and Design, Graduate School of Education & Human Development first then Law School, School of Media and Public Affairs first then Elliott School of International Affairs. In mathematical way, the precedence pairs P = {(1,10), (2,9), (8,6),(4,7)}.

After modeling, the best route under the constraints is changed to [1. 5. 6. 12. 9. 7. 8. 4. 3. 10. 2. 11.], that is, from Thurston Hall, to Duques Hall School of Business, to GW law School, to School of nursing offices, to Corcoran School of the Arts & Design, to Elliott school of international affairs, to Graduate School of Education & Human Development, to School of Media and Public Affairs, to Science and Engineering Hall, to Phillips Hall Columbian College of Arts & Sciences, to School of Medicine and Health Sciences, to Milken Institute School of Public Health, which could meet the requirement of the constraints. Besides, the objective of this route will be 3.18 miles, which is longer than the objective without the constraints, 2.97 miles.

**Model 2:** Vehicle Routing Problem(delivery via more than one van)

After we conclude that Shenkman would be better while we choose only one canteen, we start to think, why not distribute the task of delivery to two canteens. Will the total amount of delivery distance be less after separating the colleges to two groups, one of them would be delivered by Thurston Hall and the other would be delivered by Shenkman Hall?

Technically, there are 11 colleges waiting for food delivery, so there would be 2^11 types of distribution. That would be a huge workload if we check all of them. To simplify the route, we can roughly separate them. Let Shenkman Hall take over the northwestern area and let Thurston Hall deliver the Southeastern area based on the location of the two canteens. The border of the distribution would be around Node 4(School of Media and Affairs), Node 8(Graduate School of Education & Human Development) and Node 12(School of Nursing Office). We can not decide which ones would be delivered by Thurston Hall or Shenkman Hall, and we would do the experiments 2^3 times to find the least distance.

Here, we only take Node 8 as an example and show how to do that, while the other 2 nodes, Node 4 and Node 12, would be distributed randomly to one canteen.

Firstly, we assume that Node 8 should be delivered by Shenkman Hall, so Node 2, 3, 5, 8, 10,11 are for Shenkman Hall, and the rest 4, 6, 7, 9, 12 are for Thurston Hall. We process the objective for the two routes individually and get the result of Shenkman Hall, 1.38 miles, Thurston Hall, 1.79 miles. So,it would take 1.38+1.79= 3.17 miles to cover all the colleges. Secondly, we assume that Node 8 should be delivered by Thurston Hall, the other dots keeping the same, that is, Node 2, 3, 5, 10,11 are for Shenkman Hall, and the rest 4, 6, 7, 8, 9, 12 are for Thurston Hall. We got the result of Shenkman Hall, 1.08 miles, and Thurston Hall, 2.09miles. So, it would take 1.08+2.09= 3.17 miles to cover all the colleges in this case.

**Conclusion**

It is coincidence that the result of these two distributions is the same, but, we can see that the best objective in the two-van delivery are both more than the best objective in the one-van delivery, the basic TSP model, whose optimal objective is 2.97 miles.

We can learn that it might not be more efficient to set more vans for food delivery, although we might think adding more work force or vans would be beneficial. Considering this extreme case, if we send one van to every dot, it is obvious that this is not an efficient way. Because the van could also deliver food to the other colleges if it passes by, and it would not take too much extra distance. We can apply this extreme case here, so we can not easily guess that two-van delivery must be more beneficial than one-van delivery.

**Limitation**

As mentioned before, in this scenario, we only take an example of Node 8 and do the experiment for the options of this node 8. We can not conclude that one-van delivery must be more efficient than two-van delivery, and it would take more effort and workload many times, if we would like to figure this out.

**Scenario 2**: Pick-up Location

In this scenario, we assumed that no meal delivery service would be provided and students would pick up their meals at a fixed location by themselves. Therefore, choosing a suitable location for picking up meals becomes our key task.

In order to solve this problem, in the first approach, we position the problem as facility location problem and introduce the set covering problem model, hoping to select the least number of pick-up locations to cover whole demands of all students through this model; In the second approach, we try to introduce the clustering algorithm in machine learning, by using two models, K-mean and K-median, so as to find the best place for picking up meals and facilitate everyone.

**Model 3:** Set covering problem

**Data Collection**

Our objective is to find minimum pick-up stations (candidate facilities) to cover all colleges ( demand locations). First, we marked 5 locations and assumed they were candidate facilities. The five blue circles in the figure below represent the candidate facilities for our simulation.


Figure 3. Representation of colleges and candidate facilities on the map

Then, we search the real distance as follows between candidate facilities and demand locations, and use it as the input data for following modeling.

| No. | Candidate Facility | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Metro Station | 0.07 | 0.1 | 0.3 | 0.2 | 0.3 | 0.6 | 0.3 | 0.8 | 0.1 | 0.1 | 0.3 |
| 2 | Shenkman Hall | 0.2 | 0.2 | 0.3 | 0.1 | 0.3 | 0.4 | 0.1 | 0.7 | 0.3 | 0.3 | 0.5 |
| 3 | Kogan Plaza | 0.2 | 0.08 | 0.063 | 0.004 | 0.1 | 0.3 | 0.06 | 0.6 | 0.08 | 0.3 | 0.3 |
| 4 | University Yard | 0.4 | 0.2 | 0.09 | 0.2 | 0.02 | 0.3 | 0.2 | 0.5 | 0.2 | 0.4 | 0.2 |
| 5 | Thurston Hall | 0.6 | 0.4 | 0.3 | 0.4 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 | 0.6 | 0.3 |

Table 3. The distance between candidate facilities and demand locations

**Formulation**

$$
\begin{aligned}
\min \quad & \sum_{i=1}^{m} f_i x_i \\
\text{s.t.} \quad & \sum_{i=1}^{m} a_{ij} x_i \geq 1, \forall j = 1, \ldots, n \\
& x_i \in \{0, 1\}, \forall i = 1, \ldots, m
\end{aligned}
$$

Where $aij$ is 0 or 1, indicating if demand location $j$ is within the coverage distance from facility location $i$.

**Modeling**

(1) Import all the data.

(2) Set the coverage distance to be 0.32 by combining the actual situation in order to find an effective solution.

(3) Introducing the set covering problem model and using Gurobi, we obtain the optimal solution.

**Result**

The minimum candidate facilities (pick-up stations) are 2, Shenkman Hall and Thurston Hall, respectively.

```
Explored 0 nodes (0 simplex iterations) in 0.01 seconds (0.00 work units)
Thread count was 1 (of 8 available processors)

Solution count 1: 2

Optimal solution found (tolerance 1.00e-04)
Best objective 2.000000000000e+00, best bound 2.000000000000e+00, gap 0.0000%
------------------------------------------
Optimal Objective Value: 2
Facility open at point 2
Facility open at point 5
```

Figure 4. The optimal solution

**Limitation**

(1) The candidate facilities are not chosen randomly around the colleges on the map, but the candidate list is first given by manual prediction and guessing which subjective accounts for more. Thus, there is a risk that more candidate pickup locations are ignored, affecting the experimental results.

(2) Since the activity is carried out around the school, the range of activity is small, and the buildings are close to each other which indicates the distance difference between the candidate facilities and colleges is similar. So when setting the coverage distance is not completely random, but needs to analyze and make a decision according to the known distance. Otherwise, it will lead to no solution.

**Model 4:** Clustering

### Data Collection

Firstly, we collect the latitude and longitude of each location, search from Google Maps and then organize the information in excel, as shown below.

| Canteens and Colleges | Latitude | Longitude |
|---|---|---|
| Thurston Hall | 38.89802389 | -77.04403504 |
| Shenkman Hall | 38.89863688 | -77.04986 |
| School of Medicine and Health Sciences | 38.90118486 | -77.0506355 |
| Science and Engineering Hall | 38.90039115 | -77.04951445 |
| School of Media and Public Affairs | 38.90013894 | -77.0462463 |
| Duques Hall School of Business | 38.89917099 | -77.0492324 |
| GW law School | 38.89871772 | -77.04506193 |
| Elliott school of international affairs | 38.89632618 | -77.04354111 |
| Graduate School of Education & Human Development | 38.89834127 | -77.04839263 |
| Corcoran School of the Arts & Design | 38.89662355 | -77.03953849 |
| Phillips Hall Columbian College of Arts & Sciences | 38.90048732 | -77.04810611 |
| Milken Institute School of Public Health | 38.90270405 | -77.05062654 |
| School of nursing offices | 38.90083459 | -77.04427794 |

Table 4. The latitude and longitude of Canteens and Colleges

### Formulation

$$W(C_k) = \sum_{i \in C_k} \|\mathbf{x}_i - \boldsymbol{m}_k\|_1$$

### Modeling

(1) Importing all data.

(2) Longitude and latitude maps of all addresses where food needs to be delivered, red dots indicate canteens (left red dot is Shenkman Hall and right ted dot is Thurston Hall ), blue dots indicate colleges.

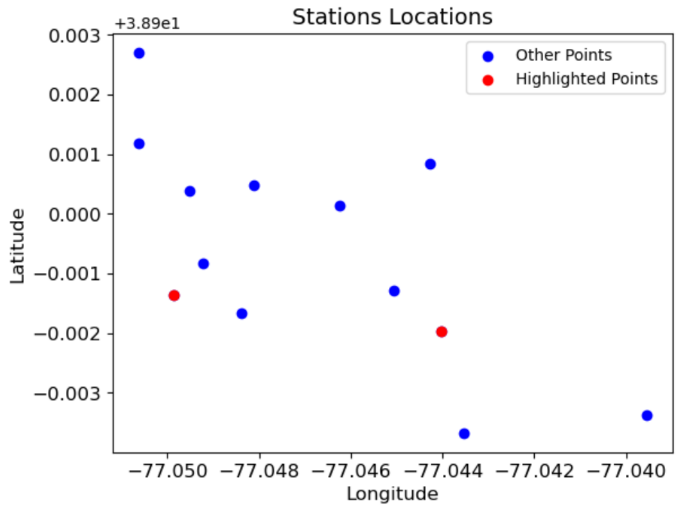


Figure 5. Visualization of locations

(3) Calculate the optimal k in this model, according to the plot we have at this point optimal k = 2.

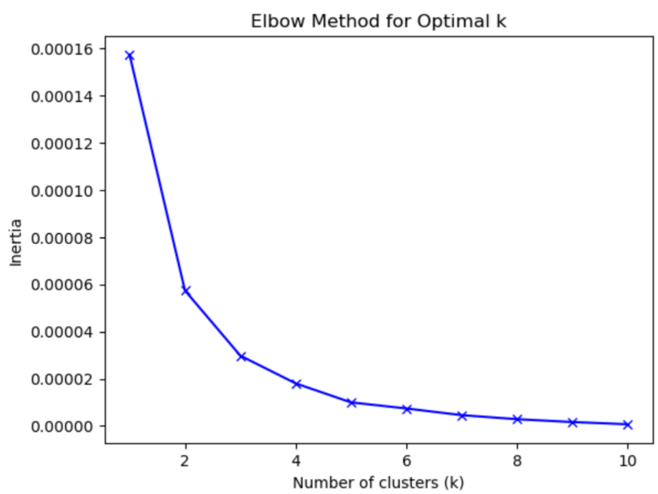


Figure 6. The elbow method for optimal k

(4) Plot the k-mean and k-median according to the model.

Based on the results of the K-mean model, we obtain the following results, the latitude and longitude of the calculated centroids are [-77.04310487, 38.89812551] and [-77.04896485, 38.90034551], where the left point is in the middle of Science and Engineering Hall and Phillips Hall, and the right point is very close to Thurston Hall.

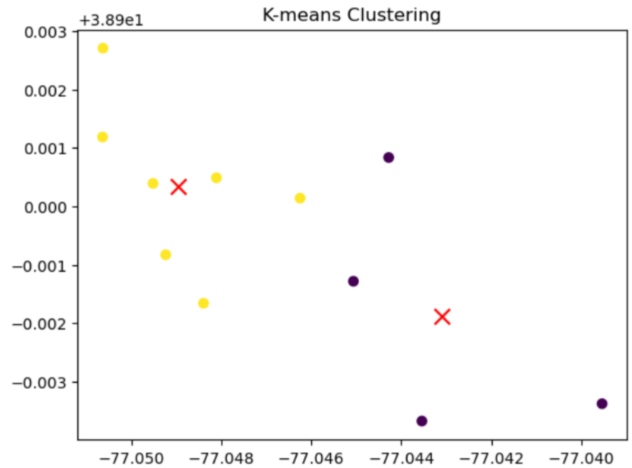


Figure 7. Visualization of K-mean

(5) Based on the results of the K-median model, we can conclude that the latitude and longitude of the central point are [-77.04403504, 38.89802389], [-77.04937342, 38.89978107], and [-77.04937342, 38.89978107]. The left-hand centroid in the K-meidan model is located at Duques Hall School of Business, while the right-hand centroid is also located near Thurston Hall.

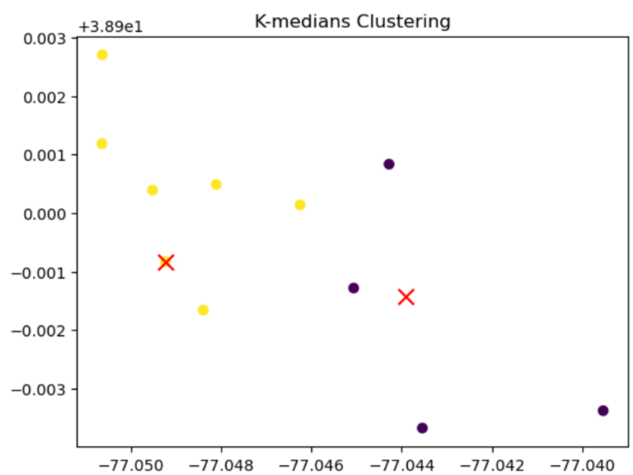


Figure 8. Visualization of K-median

**Result**

Combining the K-mean and K-median model typologies, we believe that the K-median model is better. We also find that the center point on the right is located just near our existing canteen, Thurston Hall, while the center point on the left is located near Duques Hall due to the fact that we cannot open a canteen in Duques Hall, so we can choose to open one near Duques Hall, so Shenkman Hall, which is located near Duques Hall is a good choice.

**Limitation**

(1) The relatively small amount of data, as there are only 11 colleges, can affect the accuracy of the analysis.

(2) There is a certain amount of error in the latitude and longitude because the overall area of the school is not very large, so our analysis is focused on a relatively small area, where the latitude and longitude are calculated by taking the center point of a building, and because there is a certain amount of volume in the building itself, although the size of the building itself is negligible in large scale statistics, in this model the size of the building itself will affect the statistical results.

**Report Conclusion**

To meet the requirements of food distribution at GW's Commencement, we have designed two scenarios, food delivery starting from the canteen(s) and pick-up station location, gaining some unexpected results.

In scenario 1, we have found that if we set the source node at the Shenkman Hall via one van, the total distance would be less than that of the route starting from the Thurston Hall. And while comparing this optimal objective with the sample solution gained by the vehicle Routing Problem, delivering via two vans, we have found that it was not always more efficient to deliver via two vans than via only one van.

In scenario 2, we have used two models to locate the optimal pick-up stations, and found that after we set an accessible coverage distance, there would be 2 pick-up stations, and they were coincidentally Shenkman Hall and Thurston Hall. Even when we used the machine learning skills to figure out the pick-up stations' locations via K median, we have gained the results of 2 stations (K=2), Thurston Hall and somewhere near the Shenkman Hall, proving that the existing canteens were planned to locate reasonably.