Lab Exercise #9: Network Analysis **Due: Monday, Nov.6, 2023**

CRP 5080: Introduction to Geographic Information Systems
Fall 2023

Note: For this lab we will need to utilize a network dataset. A network dataset is an intelligent model of a road system. It contains not only the location and attributes of roads but also information about how roads relate to one another, such as which roads are connected, which turns between connected roads are allowed or prohibited, and other information that affects what travel paths are possible and how long travel takes. A networked dataset can be created from a georeferenced street network polyline file. To do this, click here. For the purposes of efficiency, we will provide the networked data set.

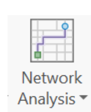
PART 1. IDENTIFY THE CLOSEST FACILITY The closest facility solver finds one or best more facilities that are closest to an incident based on travel time or travel distance and outputs the routes as driving directions between the incidents and the chosen facilities. **We are interested in finding the closest hospital (facility) to an accident site (incident).**

Open ArcGIS Pro. Create a new project for this lab

- Under Add data, navigate to and expand SanFrancisco.gdb. There are a number of feature datasets (Analysis, Basemap, Transportation), Recall that a feature dataset consists of collection of feature classes (shapefiles) that share the same spatial reference, are thematically organized, topologically related, and are part of a common network.
- Add the 'Transportation' feature dataset to Arc. You will see a number of feature classes that contain property information about the network: Junctions (points where edges meet), Signposts (line segments that define directionality for on and off ramps, access roads, etc.), restricted turns (line segments indicating one ways streets and turns, etc.), streets and SanFrancisco_ND .
- If you open the attributes table for Streets, you will notice a column title 'Minutes', which will allow us to calculate travel time.

  Using the on-the-fly method, set the 'Map' projection to match California State Plane. Not sure which zone to use for the San Francisco Bay area? Look it up.

- Now add the hospital layer. A point file with 8 hospitals is added. In addition, add the 'Incident' layer (a point file with a single point is added). This is the location of the accident. The closest facility solver finds one or more hospitals that are closest to the accident location.

1. On the **Analysis** tab, click **Network Analysis drop down** 

First note the Network Data source (in this case already set to SanFrancisco_ND. To change the network data source that will be used to create the network analysis layer, you can look under **Network Data Source**. Below that, there are a number of tools available.

Select **Closest Facility**. The **Closest Facility** layer is added to the **Contents** pane. It includes several sublayers that stores all the inputs, parameters, and results of a closest facility analysis.

If you click **Closest Facility** in the Contents pane, the **Closest Facility** tab appears in the **Network Analyst** group at the top of ArcGIS Pro. Click **Closest Facility** to see the tab's controls. You'll use these controls to define the closest facility results you want to generate.

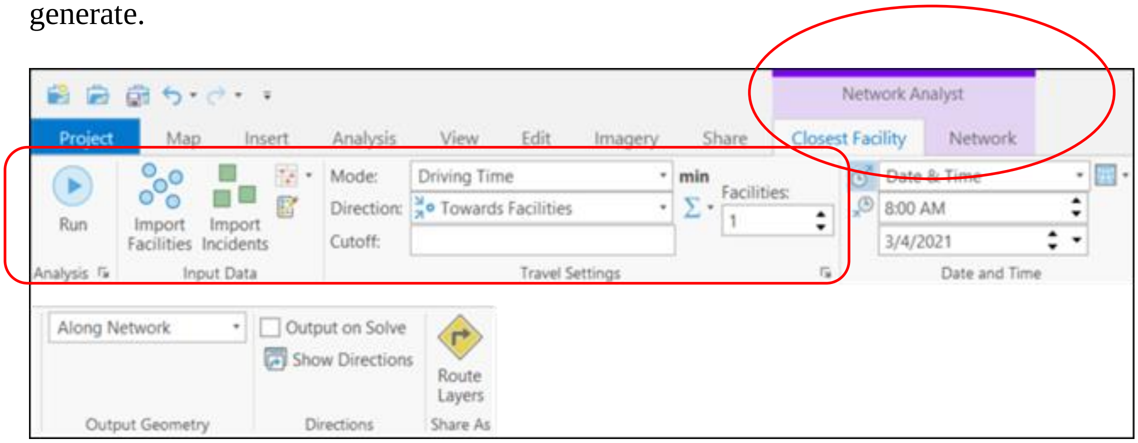


Figure 1: The Closest Facility function under Network Analyst group

1. We will now add our facilities (hospitals). On the **Closest Facility** tab, click **Import Facilities**. The **Add Locations** window appears.
2. Make sure **Input Network Analysis Layer** is set to **Closest Facility** and **Sub Layer** is set to **Facilities**.
3. Click the drop-down menu below **Input Locations** and choose **Hospitals**. This is the point feature class you previously added to the map.
4. Leave the default settings for the rest of the parameters and click the **Apply** button.

A total of 8 hospitals loads as facilities (take a look at the attribute table for 'Facilities')

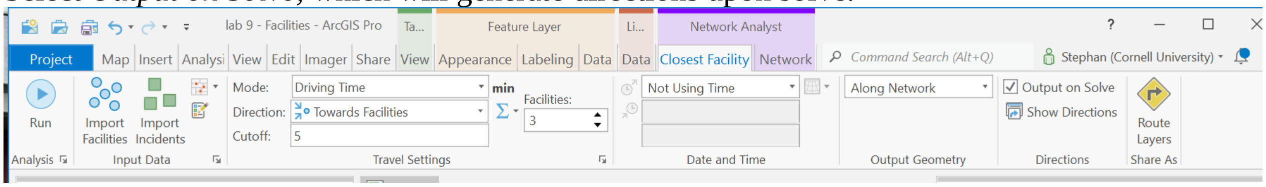
Add an incident: Consider an accident site as an incident. Under **Closest Facility,** click the Import Incidents button**,** set sub layer to Incidents and Input Locations to incident. Click Apply and OK. The address is added to the Incidents sublayer of the Closest Facility analysis layer.

Now let's set up travel settings for our closest facility analysis. Travel Settings allows us to specify properties for the analysis.

1. In the **Facilities** text box, increase the value to 3. The closest facility solver will search for a maximum of three hospitals from the accident site.

2. In the **Cutoff** text box, type 5. The closest facility solver will look for hospitals that can be reached within 5 minutes from the incident site. Hospitals outside the cutoff time are ignored. Since the current impedance is TravelTime, the units are in minutes.
3. From the **Direction** drop-down list, select **Towards Facilities**.

Select *Output on Solve*, which will generate directions upon solve.



Click **Run** .

When the solve process is complete, routes appear in the map display and in the **Routes** sublayer of the **Closest Facility** group layer (you may have to zoom in)

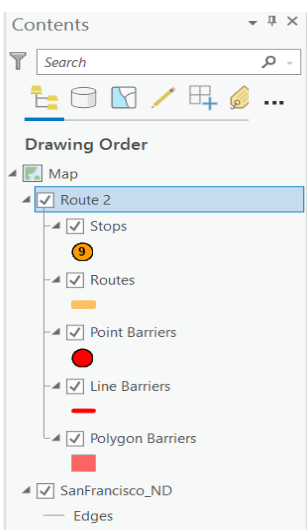
Click **Show Directions** . The **Directions** pane appears with the driving directions from the accident site to three hospitals that the closest facility solver has determined to be the closest.

Turn off the ‘Closest Facility’ layer (you can also minimize the layer to de-clutter your table of contents).

<u>PART 2. FINDING THE BEST ROUTE FOR THE GIVEN ORDER OF STOPS BASED ON TRAVEL TIME</u>

Creating the Route Analysis Layer

- Now go to the **Network Analysis drop down** and select **Route** . The Route layer is added to the **Contents** pane, which contains Stops, Routes and Barriers categories: point, line, and polygon (Figure 2).



Click the **Route** layer within the contents to see the control settings (Figure 3). You will use these controls to define the route you want to generate.

Figure 2: Best Route working layers

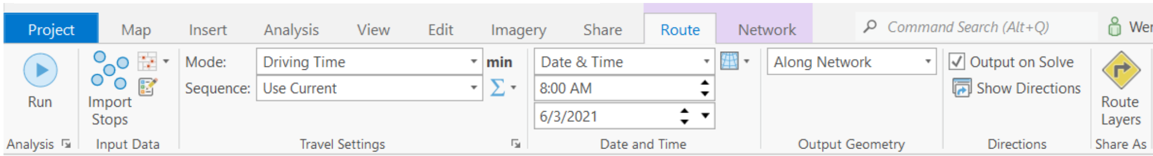


Figure 3: The Route tab under the Network Analyst group

Adding a Stop

Next, you will add the stops for which you will be creating the best route.

- In the Route tab, click **Create Features** button. The **Create Features** pane appears on the left, showing a list of layers that can be edited.

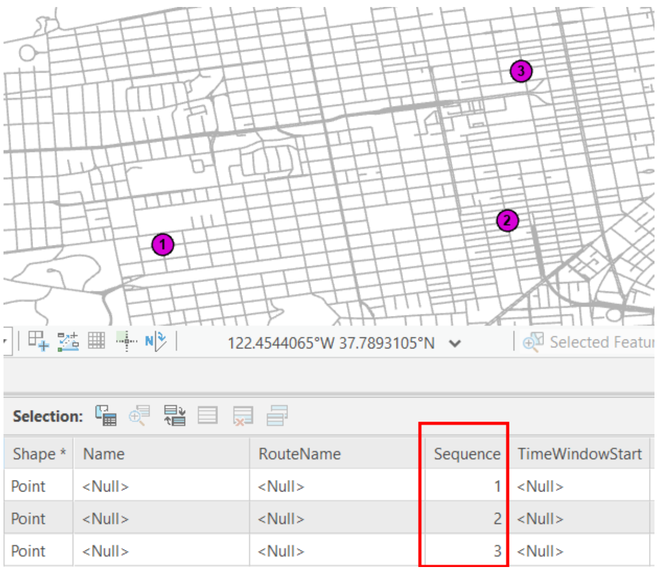


Figure 4: Setting Sequence of Stops

- Under **Route: Stops**, use the **Point** tool to create a stop on the map in the area covered by the network dataset. You will note that the snapping settings are on. If needed, zoom in and click anywhere on the street network to define a new stop location (be sure you don't select a hospital or other feature)..
- The program then calculates the nearest network location and symbolizes the stop with the located symbol. The stop will remain selected until another stop is placed or until it is unselected.
- Add two more stops on the map.
- On the **Edit** tab (at the top), click **Attributes** . Select any of the stops you created using the **Select** tool and edit their attributes, specifically **Sequence**. Sequence helps to change the order in which the stops will be visited. Specify a visiting order for the three stops (be sure to select Apply or Auto Apply once you input the sequence), and you will also find the numbers you assigned appears on each stop in the map.
- Back in the **Route** tab, click **Run** . The results show the fastest path through the network, connecting all the stops you created based on the sequence you specified.

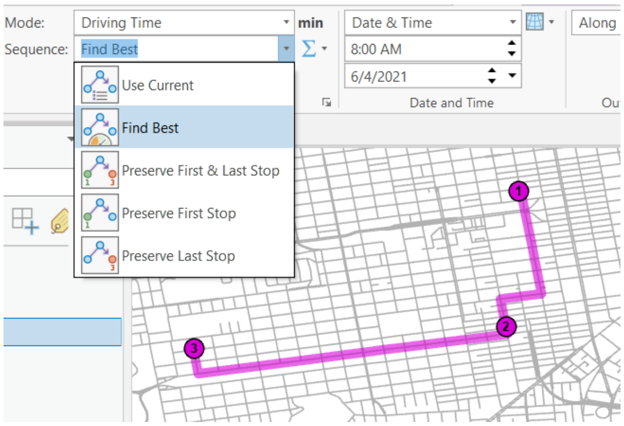


Figure 5: Routes based on the best option

- To create a route that finds the best way to visit all the stops (also known as the traveling salesperson problem) **regardless of the order**, from the **Sequence** drop-down menu select the **Find Best** option. Click **Run** . The resulting route will now show the best sequence to visit all the stops.

Adding a Barrier: We will now add a barrier on the route that represents a roadblock and will find an alternate route to the destination, avoiding the roadblock.

1. Under Create Feature button, select **Route: Polygon Barriers**, click **Polygon Barriers (or point)**
2. Use the **Polygon** tool to draw a polygon (or point) on the map. Make sure the point/polygon covers at least one street used by the route you already solved.
3. On the **Route** tab, click **Run** .

The map shows a different route that avoids the area covered by the barrier you created.

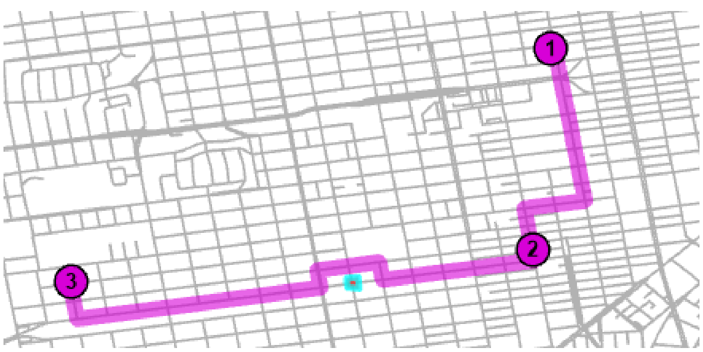


Figure 6: Best Route under a barrier

<u>Map 1:</u> Create a map layout of your route with stops and barriers. Symbolize appropriately. We were able to create this because we had travel times for each road segment. This may not always be the case. What else might we use for Mode?

Turn off the Route layer in the Table of Contents and minimize.

PART 3. CALCULATING SERVICE AREA

Next, we will create a series of service area polygons, which represent the distance that can be reached from a facility within a specified amount of time. We will calculate 3-minute and 5-minute service area polygons for hospitals in San Francisco.

- On the Network Analyst toolbar dropdown menu, click Service Area. The Network Analyst Window now contains an empty list of Facilities, Barriers, Lines, and Polygons categories.

Click **Service Area** to see the tab's controls. We'll use these controls to define the service area you want to generate:

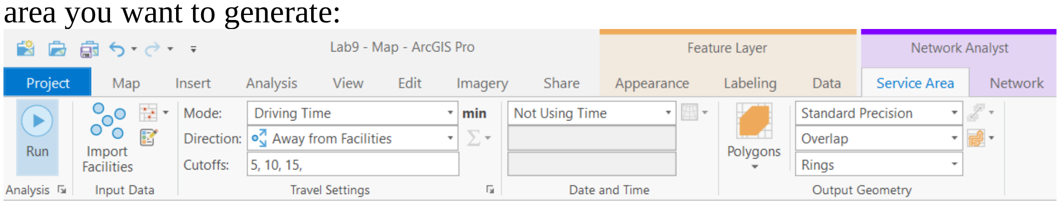


Figure 7: The Service Area tab of Network Analyst

Think of a facility as the starting location of a vehicle. The service area solver simulates all possible paths the vehicle can travel within an elapsed time when departing from the facility.
Since ambulances are typically parked at hospitals, we first load the hospitals into the Facilities sublayer.

- On the **Service Area** tab, click **Import Facilities** . The **Add Locations** window appears.
- Make sure **Input Network Analysis Layer** is set to **Service Area** and **Sub Layer** is set to **Facilities**.
- Make sure Hospital is set to input locations.
- Leave the default settings for the rest of the parameters and click the **OK** button.

Open the attribute table of Facilities, and we find there are 8 hospitals are added as facilities.

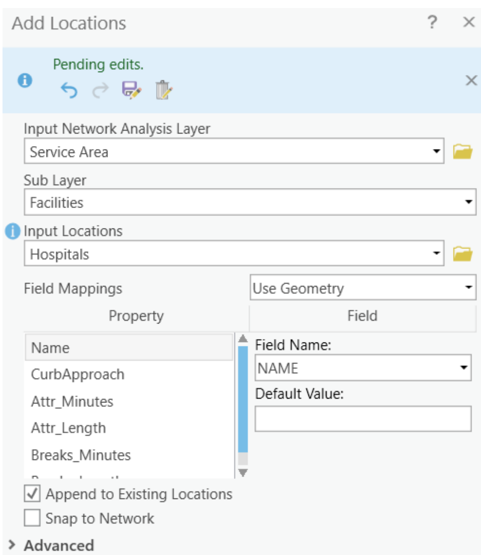


Figure 8：load the hospitals into the Facilities sublayer

Now we can establish the service areas. Change the Cuttoffs value to 3, 5 (Enter this as 3, 5 –the numbers are separated by a comma). This indicates 2 separate service areas.

- Under the Output Geometry group, make sure that “Polygons ” is checked. Select Standard Precision. This results in faster analysis. Detailed polygons are much more accurate but need more time to be generated.
- Under Multiple Facilities Options, select ‘Overlap.’ This creates individual polygons per facility that may or may not overlap.

- Click Rings for the Overlap type. This excludes areas of smaller breaks from the polygons of a bigger break.

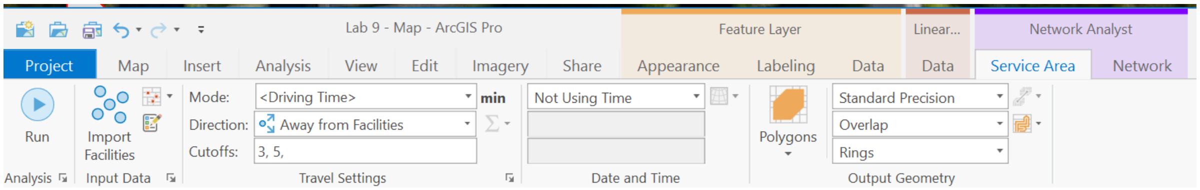


Figure 9: The Service Area toolbar

- Click the Run button on the Service Area tab. The service area polygons appear on the map.

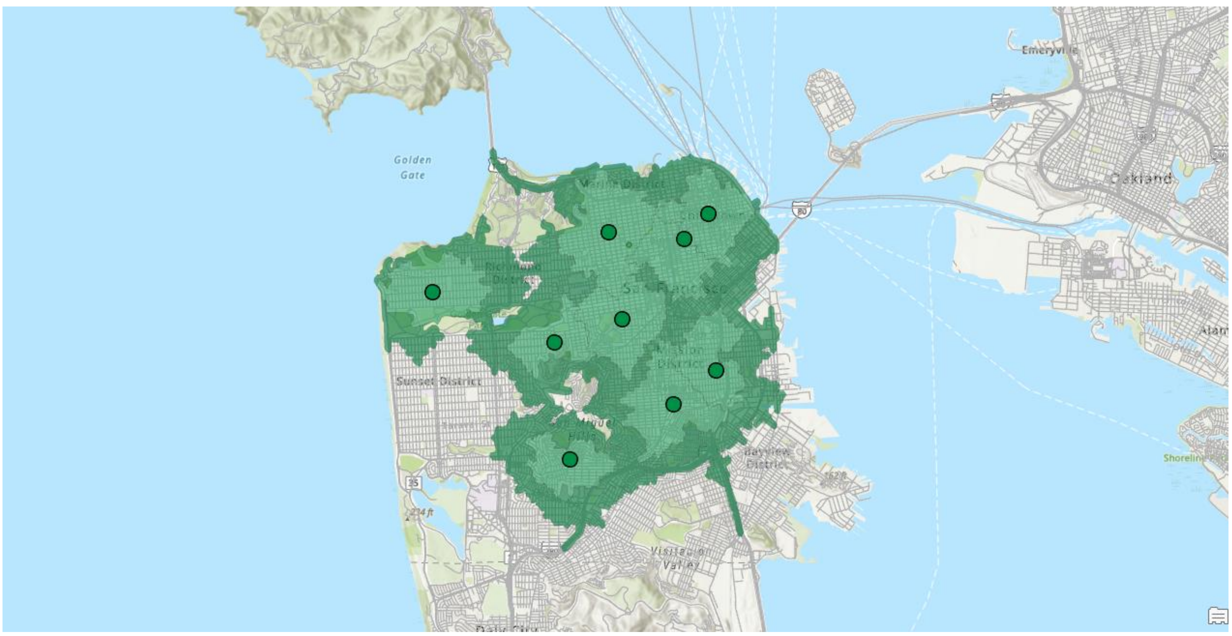


Figure 10: 3 minutes and 5 minutes Service Area

Map 2: Create a map layout depicting 3-minute and 5-minute service areas. Provide a short analysis of what you have just created – what are the benefits of creating service areas verses using the buffer tool?
Turn off the Service Area layer and minimize.

PART 4. CREATING AN OD COST MATRIX ANALYSIS LAYER

The origin-destination (OD) cost matrix solver finds and measures the least-cost paths along the network from multiple origins to multiple destinations. The best path on the street network is discovered for each origin-destination pair, and the travel times and travel distances are stored as attributes of the output lines.

Now let us create an origin-destination cost matrix for the driving time between libraries and hospitals (for emergency planning). The results of this matrix can be used to identify libraries that will be serviced by each hospital within a 10-minute drive time.

- Add the Library to your shapefile
- Under **Network Analyst**, select the **Origin-Destination Cost Matrix**

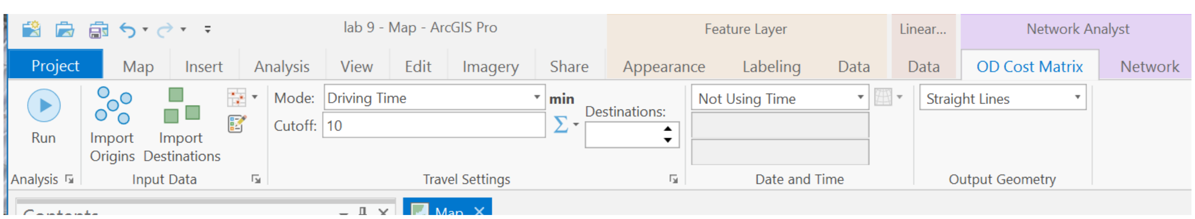
- The OD cost matrix analysis layer is added to the **Network Analyst** tab and the Contents pane. The network analysis classes (Origins, Destinations, Lines, Point Barriers, Line Barriers, and Polygon Barriers) are empty.

- Click Import Origins . Make sure **Input Network Analysis Layer** is set to **OD Cost Matrix** and **Sub Layer** is set to **Origins**. Choose Library as the **Input Locations**. Leave the default settings for the rest of the parameters and click the **OK**. The 31 new origins are displayed on the map. Check the attribute table of the Origin Layer.

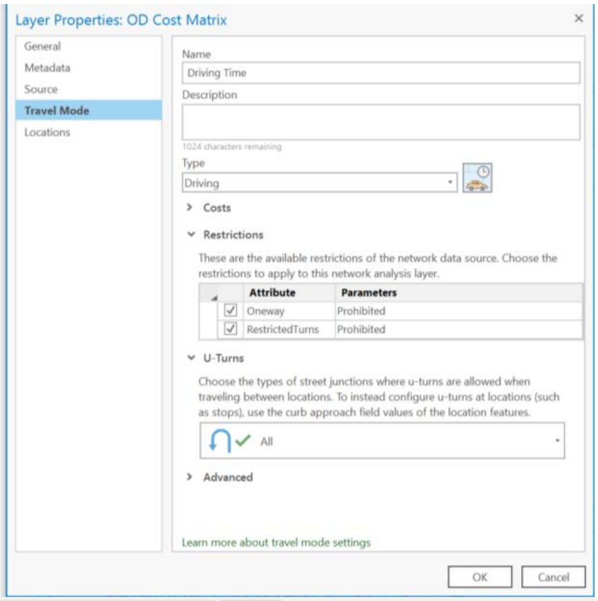
- In the OD Cost Matrix tab, click **Destinations** . Under the Input Locations drop-down list, select Hospital layer. Click Ok. The 8 new destinations are displayed on the map.

Next, you will specify that your OD cost matrix will be calculated based on drive time. You will set a default cutoff value of 10 minutes and ensure that all destinations are found within the specified cutoff.

1. On the **OD Cost Matrix** tab, ensure that **Driving Time** is selected for **Mode**.
2. In the **Cutoff** text box, type 10 (we are only interested in connections that are under 10 minutes).
3. Make sure the output is set to **Straight Lines**.



Lets check some of the properties of our network dataset before running. Open the layer properties dialog box by clicking the **Launch Travel Mode Properties** button on the right corner of the **Travel Settings** section. Allow for the U-Turns, but put restrictions on Oneway and RestrictedTurns.



Click the **Run** button. The OD lines appear on the map.

Open the attribute table of the Lines Layer. The Lines table represents the origin-destination cost matrix from each Library to the hospitals within a 10-minute drive time. The DestinationRank is a rank assigned to each destination that is served by a hospital based on the total drive time.

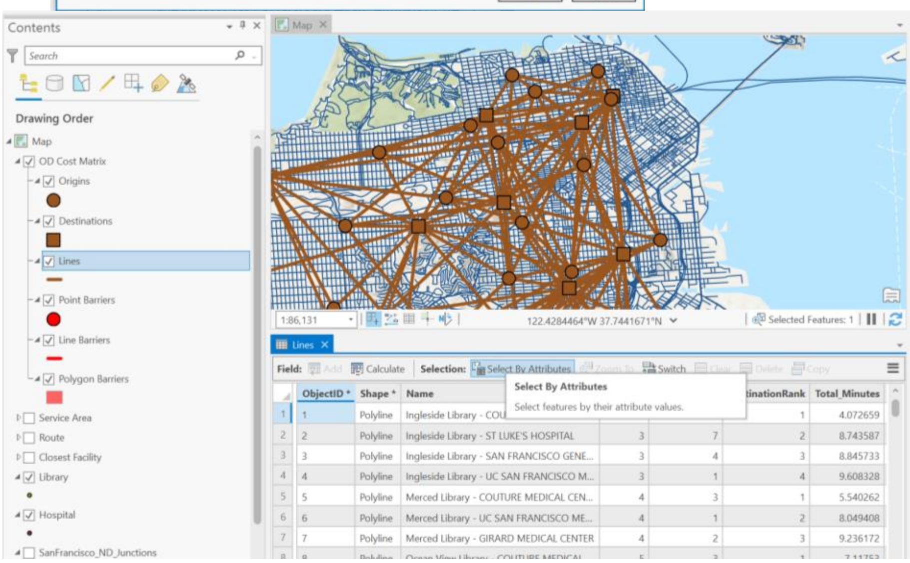


Figure 11: OD pairs within a 10-minute drive time.

The OD cost matrix displays the libraries serviced by each hospital along with the total drive time for each route. Some libraries are within the 10-minute accessibility zone of more than one hospital and can be served by anyone of them.

Map 3: Create an origin-destination map and accompanying table for the relationship between libraries and hospitals. What is the most accessible hospital? (10 points)

Turn off the OD Cost Matrix layer in the Table of Contents and minimize

PART 5: CHOOSING OPTIMAL STORE LOCATIONS THROUGH A LOCATION-ALLOCATION MODEL

In this part, you will choose the store locations that would generate the most business for a retail chain. The main objective is to locate stores close to population centers, which provide demand for the stores. This objective is based on the premise that people tend to shop more at nearby stores than at those that are farther away. You will perform the location-allocation analysis using three different problem types: **maximize attendance, maximize market share**, and **target market share.** The differences among these problem types will become apparent as you work through the exercise.

We will add several new shapefiles to our network map to conduct our analysis. From the Part 5 Data Folder, add:

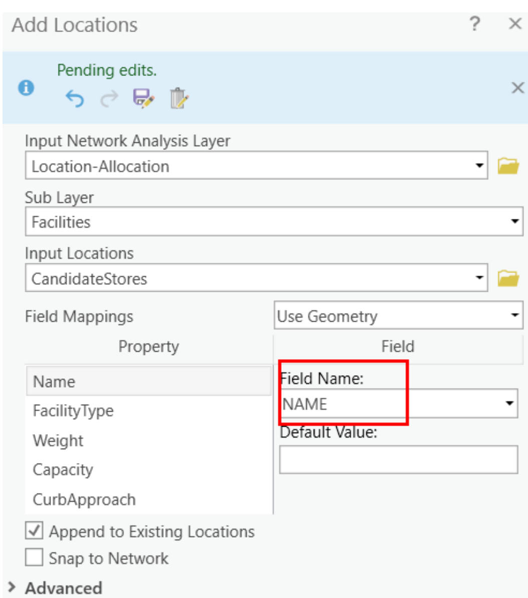
- Existing Store
- Candidate Store: The names of the stores are contained in the layer's attribute table. These are the potential places where you can open a store
- Competitor store
- Tract Centroids: These are the centroid of the census tract and contain census demographic variables.

Creating the location-allocation analysis layer

- Under the Network Analysis menu, go to Location-Allocation.
- The location-allocation analysis layer is added to the Contents pane. The network analysis classes (Facilities, Demand Points, Lines, Point Barriers, Line Barriers, and Polygon Barriers) are empty.

Adding candidate facilities

We will load the point features from Candidate Stores into the Facilities class of the location-allocation layer. The solution from the location-allocation process will include a subset of these stores.



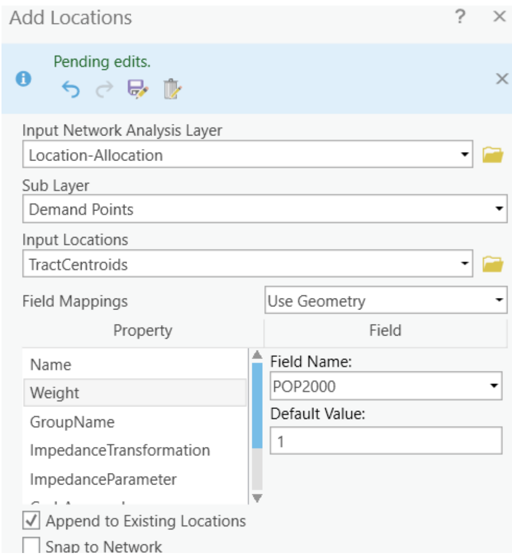
- On the Location-Allocation tab, in the Input Data group, click Import Facilities.
- Make sure **Input Network Analysis Layer** is set to **Location-Allocation** and **Sub Layer** is set to **Facilities**. Select **CandidateStores** from the **Input Locations** drop-down list.
- In the **Field Mapping**, make sure the **Field Name** is set to **NAME**.
- Leave the default settings for the rest of the parameters and click the **OK** button.

The 16 candidate stores load as facilities. These locations are drawn on the map with the candidate facility symbol.

Figure 12: Load Candidate Stores—
Supply side

Add demand points
The stores need to be located to best serve the existing populations. A point layer of census tract centroids is already added to ArcMap. Now you will load these centroids into the demand points network analysis class.

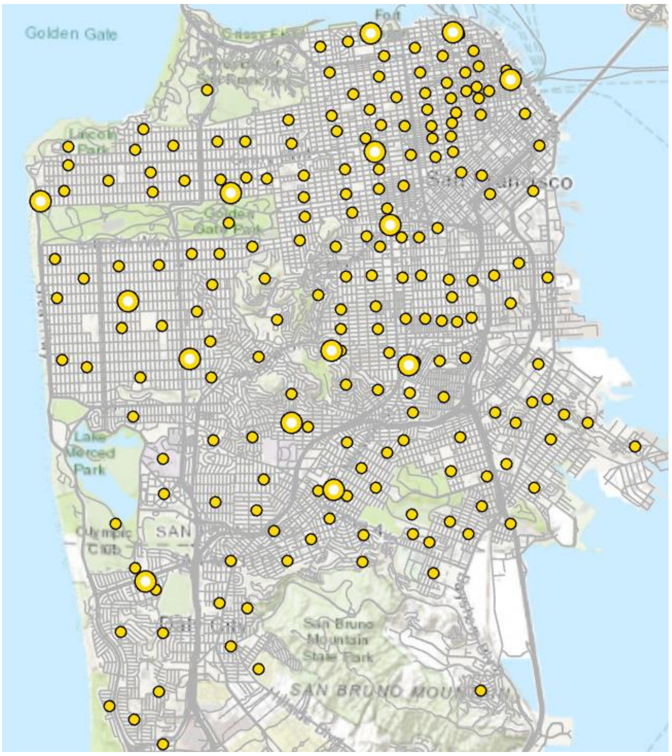
- On the **Location-Allocation** tab, click **Import Demand Points** .



- Select **TractCentroids** from the **Input Locations** drop-down list.
- From **Field Mappings > Property**, choose **Weight**. From the **Field Name** drop-down list, choose **POP2000**.
- click the **OK** button.

The 208 Tract Centroids load as demand and the population at each location is mapped to the weight property for the demand. These locations are drawn on the map with the demand symbol.

Figure 13: Load the census tract centroid—demand side



The **Location-Allocation** tab includes a **Problem Type** section, where you can specify properties for the locations.

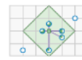
- In the **Problem Type** group of the Location-Allocation tab, click the **Type drop down**  and choose **Maximize Attendance**.  Maximize attendance is a good problem type for choosing retail store locations. It assumes that all stores are equally attractive, and that people are likely to shop at nearby stores.
- **Increase Facilities to Choose to 3** in the **Travel Settings** group. This will choose 3 out of the 16 candidate stores to optimally serve the 208 demand points.

Figure 14： Candidate Stores and the Census tract centroids

Increase Impedance Cutoff to 5: in the Cutoff text box, type 5. This setting implies that people are not willing to travel more than five minutes to shop at these stores.

Make sure that Cost Transformation Function is set to Linear. ArcGIS will use a linear decay in calculating people's propensity to visit a store. That is, with a five-minute impedance cutoff and a linear impedance transformation, the probability of visiting a store decay is 1/5, or 20 percent; therefore, a store one minute away from a demand point has an 80 percent probability of a visit compared to a store four minutes away, which only has a 20 percent probability.

Figure 15: Setting up the parameters for the Maximize Attendance problem

Click the **Run** button on the Location-Allocation tab. Once the solve process is completed, lines in the map display connect chosen stores to their associated demand points.

Now you will inspect the results in more detail. In the **Contents pane**, right-click the **Facilities** sublayer and choose open attribute table. Examine the attributes of the Facilities table. Three features have their FacilityType field values set to “Chosen” instead of the default status—“Candidate”.

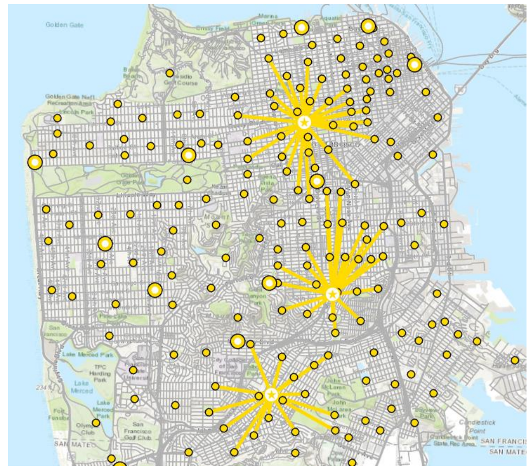


Figure 16: Results of for the Maximize Attendance problem: 3 stores are chosen

The DemandCount column lists the number of demand points assigned to each of the chosen facilities. Note that out of the 208 demand points, only 146 were allocated to the chosen facilities because some of the points were farther than the five-minute cutoff. The DemandWeight column lists the demand that is allocated to each facility. In this case, the value represents the number of people that are likely to shop at the store. Close the ***Facilities*** table.

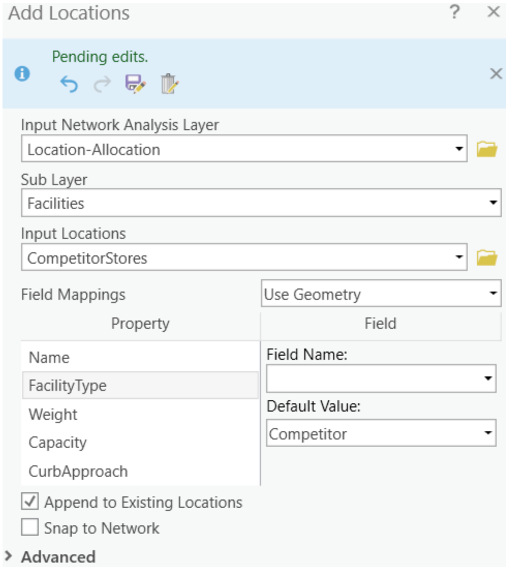
Open attribute table of the **Demand Points** sublayer. Examine the attributes of the Demand Points table. The Facility ID column has a value of <Null> if the demand point was outside the five-minute cutoff; but if a numeric value is presented, it represents the ID of the chosen facility the demand point was allocated to. The Weight column contains the population count that was loaded from the census tract feature class. The AllocatedWeight column contains the amount of demand that was apportioned to the associated facility. The amount of weight allocated is based on the linear distance decay and the five-minute cutoff parameters you set.

Open the attribute table of Lines sublayer. This table contains one record for each demand point allocated to a facility. It also lists the shortest path impedance between the two locations and the weight captured by the facility and includes travel time in minutes.

Map 4: Create the above Location –Allocation map. Now adjust one of the parameters (eg impedance cutoff, facilities to choose, impedance transformation etc.). Compare and contrast any differences.

Adding competing facilities

Location-allocation can locate new stores to maximize market share in light of competing stores. The market share is computed using a gravity model, which assumes that demand points have a probability of visiting stores based on some properties of the store as well as the distance away from that store.

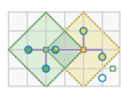


1. On the **Location-Allocation** tab click **Import Facilities**, and this time choose **CompetitorStores** as the **Input Locations**.
2. In the **Field Mappings** section, click **FacilityType**, and in the **Default Value**, choose **Competitor**.
3. Click **OK**.

Figure 17: Loading the competitor stores

Setting up the properties of the analysis (maximize market share)

You will change the properties of the location-allocation analysis layer so that it solves using the **maximize market share** problem type.

- Open the ***Location Allocation properties tab*** and in the ***Type*** choose **Maximize Market Share**. 
- choose **Power** for the **Cost Transformation Function**. ArcGIS will use a power distance decay in determining people's propensity to visit a store. Notice that **Impedance Parameter (*β*)** becomes available for you to edit.
- Change the **Impedance Parameter** value to **2**, which means the probability of visiting a store decay with the square of the distance between a demand point and a facility location.

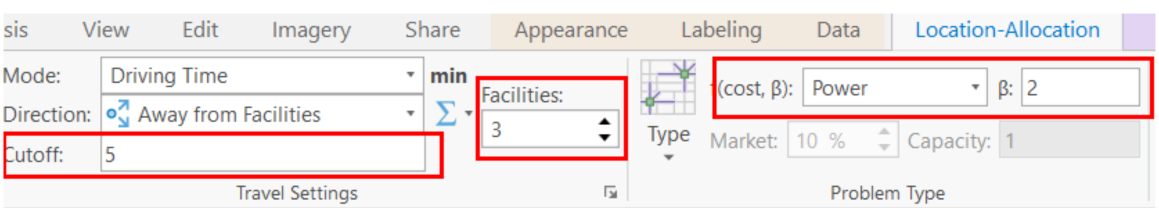


Figure 18: parameter settings for the maximize market share problem

Run the process to determine the best store locations (maximize market share)

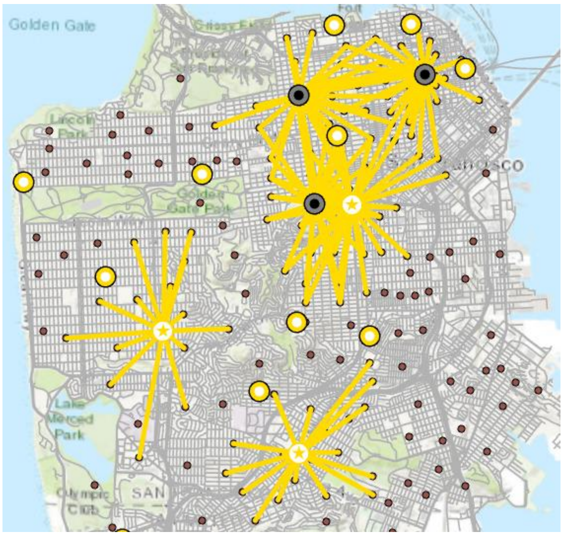
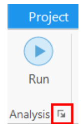


Figure 19: Results of the maximize market share problem

.

- Click the **Run** button. To look at the market share attained, click the "Solve history" icon  under the Run button 

. Note that we have attained 28% of market share.

Lines in the map connect demand points to chosen and competitor stores. Notice the chosen stores have changed to maximize the amount of demand given the presence of the three competitors.

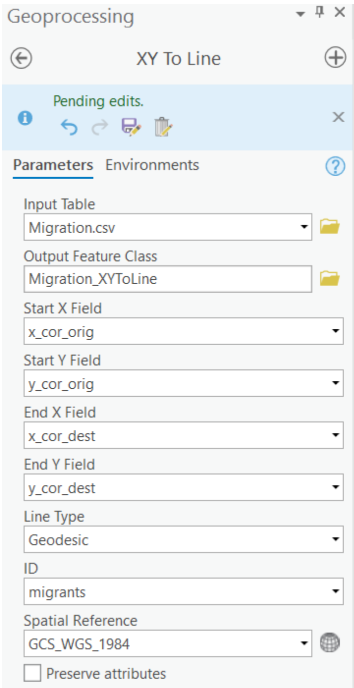
The lines overlap more than in the previous solutions, since each demand point in the maximize market share problem can interact with all the facilities that are within the impedance cutoff.

- In the ***Contents pane***, right click the **Facilities** sublayer and choose **Open Attribute Table**. Three facilities have a FacilityType value of Competitor, and three have a value of Chosen, which indicates the solver chose them as the best facilities to open.
- The DemandCount column lists the number of demand points assigned to each of the facilities. Note that some demand points were not assigned, since they were outside the five-minute cutoff.
- The DemandWeight column lists the sum of the demand weight assigned to each of the chosen facilities. The weight assigned to your stores versus that assigned to the competitor stores can be used to figure out the market share that was reported after the solve process finished.

Map 5 Achieving a target market share. In the last section, the three stores chosen accounted for only 28 percent of the market share. Say, however, you want to capture 70 percent of the market share. You need to know the minimum number of stores that would be needed, and where they should be located, to accomplish that goal. How many stores are chosen to achieve target market share? Use the target market share problem type to help you undertake this analysis.

PART 6: CREATE A FLOW MAP

We will now create a state to state migration flow map with both origin and destination coordinates.



Open ArcGIS Pro and add tl_2013_us_state.shp and migration.csv (in Part 6 Data).

- tl_2013_us_state is 2013 State shapefile downloaded from TIGER/line
- Open the attribute table for migration.csv.

Migration is the state-to-state migration data acquired from county-to-county migration dataset (2009-2013) aggregated at the state level. The data only include state to state migration over 1,000 people to reduce the processing time. Destination_state is the State Code for the destination. Origin_state is the State Code for origin. State code could be refereed to https://www.census.gov/geo/reference/ansi_statetables.html The respective latitude and longitude coordinates for each state are given as y_cor and x_cor (these reference the polygon centroids of each origin and destination state). These will provide the origin and destination directionality of our flow lines.

Figure 20: parameter settings for the flow map

1. Go to Geoprocessing toolboxes, and search for XY to Line (Data Management tool).
2. select the start field and end field as shown Above. Note: select migration as the ID, so the number of migrants will be shown in the attribute table of the Migration shapefile.
3. Click Run. A line shapefile will be created to show the migration from origins to destination.

Map 6: Create the map showing migration directions (use arrow). Also, use any classification method to classify the number migrants (use graduate symbol). You can exclude observations, such as observations with large number of migrants.

LAB 9 DELIVERABLES

Map 1: Create a map layout of your route with stops and barriers. Symbolize appropriately. We were able to create this because we had travel times for each road segment. This may not always be the case. What else might we use?
(10 points)

Map 2: Create a map layout depicting 3-minute and 5-minute service areas. Provide a short analysis of what you have just created – what are the benefits of creating service areas verses using the buffer tool? (10 points)
Map 3: Create an origin-destination map and accompanying table for the relationship between libraries and hospitals. What is the most accessible hospital? (10 points)

Map 4: Create the above Location –Allocation map. Now adjust one of the parameters (e.g. impedance cutoff, facilities to choose, impedance transformation etc.). Compare and contrast any differences. (15 points)

Map 5: Create a map layout achieving a target market share. Include discussion (15 points)

Map 6: Create a map layout show the number of migrants from origin state to destination states (10 points)