GEO/EVS 423 / EVS 523
Exercise 11: Network Analysis I

Networks typically involve systems of linearly-oriented routes that present alternative mechanisms to get from one place to another. Possibly the most familiar form of network analysis is a car-mounted GPS, which you can ask how to get from where you are to where you want to be.

When translated to a GIS, they typically comprise an arc feature class. To deal with network analysis, one must identify junctions, edges, and weights. A *junction* is a node where a route begins or ends. An *edge* is the arc, or route along which transit can take place. A *weight* is the impedance to transit; at its basic it is the distance of transit (i.e. arc length), although different arcs can be assigned different sorts of weights.

In this exercise, we will look at some of the basic aspects of network analysis using road and utility networks from Rapid City, South Dakota. In the case of the road network, we can consider a beginning node-of-travel, or *source* and an ending node-of-travel, or *sink*. There are few limitations on where a driver can go, so that drivers can go from the source node to the sink node on any number of arcs, passing through numerous nodes. In the case of the utility network, there are limits to the feasible paths for – in this case – the flow of water. In either case, network analysis can inform us as to the quickest way to get between two points or the shortest point between the same two points (not always the same things!), or the likely service area of a particular shopping center.

To analyze a network, one first establishes the parameters of the analysis (e.g., what are the sources and sinks, what are the barriers to movement through the network, and what arcs are available for movement) and then one solves the system.

Network Analysis of a Road System

In this exercise, the available arcs of the network are set – they are the road system in Rapid City. You will establish the sources, sinks, and barriers and then solve. Before you do anything else, insure that you have turned on the Network Analyst extension!

Copy the RapidCity folder from the P: drive to your X: drive. In ArcCatalog, navigate to that directory and expand the rapidnets geodatabase. This geodatabase contains two feature datasets, one of which is Transportation. Expand the feature dataset. You will notice that one of the things in this dataset is the Road_Net network, which comprises the other two feature classes in this geodatabase; these feature classes have been combined into a single feature dataset as a network. Right-click on the Road_Net network, and choose Properties. Have weights been established that would define different impedences for different classes of roads in the network? Close the Transportation Properties.

Open ArcMap and add the Road_Net network to the layout. Also add the Schools and Restaurants layers to your layout. You will notice that the Schools and Restaurants layers behave as you would expect. However, the Road Network that you added to the layout does not appear in the table of contents; rather the two datasets comprising it appear! Open the Utility Network Analyst toolbar, and make sure that the Network window in the toolbar is set to Road_Net. You will notice that this toolbar has several fields:

Network: the name of the network you are dealing with
Flow: allows you to place arrows on the dataset showing direction of flow
Analysis: allows you to set certain options for your analysis
Flag icon: allows you to place sources, sinks, and barriers on the network
Trace task: allows you to specify the specific task to be solved.

You can vary information in all of these fields, but you may not need to if the default is valid. You will always need to insure that the proper network is being analyzed, you will always need to set your sources, sinks, and barriers, and you will always need to insure that the correct trace task is being performed. You may or may not need arrows, and you may or may not need to vary the options in the Analysis field.

Click on the Flag icon to show the Junction Flag tool. This is the tool that looks like a flag with an X at the bottom. It will define sources, sinks, and waypoints at nodes in the network. It is different from the Edge Flag tool, which looks like a flag with a line at the bottom; it defines sources, sinks, and waypoints as individual arcs rather than nodes. Using the Junction Flag tool, click on two nodes on opposite sides of the city. Make sure that the trace task is set to Find Path. Now click on the Solve icon. The path from one to the other should appear. Also, on the lower left-hand side of the screen, the “Total Cost” of the transit will appear. The nature of this basic cost isn’t really very meaningful in this instance; it is the number of edges (arcs) traversed in going from the first junction to the second.

To clear the network, click on Analysis -> Clear Results and Analysis -> Clear Flags. You should try joining several pairs of junctions to be sure what you are doing. Next, you should add some additional flags to your network. What is the relationship between the order in which you place the flags and the resulting pathway? You should also experiment with other trace tasks. Some have null results – they won’t do anything that you can see. Others will have an undefined result – the computer will beep at you and act sullen.

Try the same thing with Edge Flags instead of Junction Flags. Do you see the difference? Note that you can’t mix the two kinds of flags and expect to solve a network (try it).

Now using both the Junction Barrier tool (the barrier over the X) with the Junction Flag tool and the Edge Barrier tool (the barrier over the arc) with the Edge Flag tool, evaluate the most reasonable path between two points with barriers in the way. Try adding barriers in the middle of a path defined by a solution of your network and solve it again. What happens? Can you add enough barriers to make a path impossible?

Now let’s calculate a specific path. Imagine that you live at 1250 East North Street and that you wish to attend a basketball game at Stevens High School. Your own son goes to Central High, and you don’t really know how to get to Stevens, so you go to your trusty computer. Using the “Find” icon on the icon bar (it looks like binoculars), enter “E North” in the “Find” field and insure that the “roads” layer is in the “In” field. When you click on the Find button, there will be a lot of E North entries. Right-click on several and then click on Identify. The From Address (FRADD) and To Address (TOADD) fields show the addresses represented in each section of the street. Find the section of East North Street that includes 1250. Right-click on that edge in the Find window (not the Identify window) and choose Add as Stop to Find Route. It won’t add a flag, but it will add a blotch indicating the right part of the street. Next find “Stevens” in the “schools” layer and Add it as a Stop to Find Route. Now go back to the layout and add edge flags to the appropriate section of East North Street and a likely entrance to Stevens High School. Solve the path from one to the other. Are you surprised by the result? Bear in mind that the default solution to a path is to minimize the number of edges traversed along the network between two points. What is the Total Cost of this traverse?

It might be more meaningful to know the distance of the traverse – and to take the shortest route instead of the route that traverses the fewest junctions. Click on Analysis -> Options -> Weights. You can choose predefined values of Junction Weights and Edge Weights. Choose to change both instances (i.e. From-To and To-From) of the edge weights from <none> to Distance. Solve the network again. Now you have the route with the minimum distance from your house to Stevens High School, and the Total Cost is the number of meters you have to travel. Print at least two scenarios of getting from your home at 1250 East North Street to Stevens High School, with a text explanation of the source of the difference in the two scenarios.

Now let’s make it more interesting. The City is putting in a new sewer, and they have closed West Main Street between Dakota Drive and Mountain View Drive, as well as West Chicago Street, West Omaha Street, Canyon Lake Drive, and Jackson Street to the north and south. You will never make it to the basketball game if you can't get around the construction. You are new in Rapid City, so you aren't sure where these streets are, so again, you go to your trusty ArcGIS. Right-click on the Roads layer and choose Properties. Click on the Display tab; then check the Show Map Tips box and make sure that ROADNAME is the primary display field. Your original route from home to Stevens High went along West Main Street. If you point your cursor along your route, you will now easily find which street is West Main. As you point at the cross-streets, you will easily find Dakota and Mountain View. Place a barrier. Now find the other 3 streets (they are close to West Main and parallel it), and place barriers where the sewer goes. Now when you solve the network, where are you directed?

You now want a list of the streets you traverse. Click on Selection -> Interactive Selection Method -> Create New Selection from the main menu bar. In the Table of Contents window, click on the "Selectable layers" icon and insure that all layers are selectable. In the Utility Network Analyst toolbar, click on Analysis -> Options -> Results. Change the results format to Selection, and uncheck the box for returning junctions. Click OK. Solve the network again. Now if you open the attribute table for the roads layer – and choose to look at the selected records – you will find the names of the roads comprising each leg of the traverse from home to Stevens High.

Another thing to make it interesting. Change your results back to Drawing (instead of Selection). Imagine that you are an absolute foodaholic and that you can't pass a restaurant without wanting to stop in. You have totally grossed out your children, and they have given you an ultimatum that if you choose a route from home to Stevens High that passes within 100 m of a restaurant they will not allow you to have any chocolate for a year. Click on Selection -> Select by Location from the main menu bar. Select roads that are within 100 meters of a restaurant, and close the selection window. Choose Analysis -> Options -> General, and choose to trace only on Unselected Features. Solve for the new path. Oh, what we do to please our children! Now imagine that McDonald's has just opened a new "restaurant" on Catron Boulevard, just off State Highway 16 near the southernmost point of your trip. It isn't in the database, so you have to add the barrier by hand. Place a barrier on Catron Blvd just west of SR 16. Solve again for the route to Stevens High. Print at least two scenarios of getting from your home to Stevens High. At least one of these scenarios should involve an intrusive sewer, and at least one should involve your family's aversion to your going near a restaurant.

Networks often aren't perfectly digitized. Clear your image (i.e. remove flags, barriers, selections, and results), and put a flag somewhere in the network. Set the trace task to Find Disconnected and click Solve. You probably won't see the problem immediately. But zoom in to the area around 641575 / 4883370. You will see a small sliver crossing the exit from the interstate highway that does not have a node that would connect with the exit ramp. It is probably a digitizing error. Open the editor toolbar and click on Editor -> Start Editing. Click on Roads in the Create Features window and then the Edit Tool icon. Select the road sliver you wish to delete, and then hit the Delete button. You should also delete the nodes at the ends of the arc. Click Save Edits and Stop Editing.

Zoom back to the full extent of the road network and change the trace task to Find Loops. Click the Solve icon. What happens? What does this image tell you? What are the roads that do not appear in red in this image?

Network Analysis of a Water System

The previous exercise dealt with network analysis in a context where one has some freedom of movement in all directions. Utility networks are a bit different. Let's look at a network comprising the water system for Rapid City. Return to the RapidCity geodatabase. Now use Add Data to add the Utilities network to a new layout. It comprises 5 layers: The first 4 are point features; these are Galleries, Endcaps, Tvalves, and Water_Net_Junctions. The fifth is a line feature, Waterlines. Make sure that the Utility Network Analyst toolbar is open and that the network listed is Water_Net. Take a look at the attribute tables for each of the layers in the feature database. Turn layers on and off so that you can see how the waterlines as line features relate to the point features.

As you look at the Galleries, note that the attribute table shows that they are functioning (i.e. the Enabled field is labeled True). They are the Source of water. Indeed a gallery is precisely the pumping station that takes water from the local water source and pumps it into the system of water mains. You should probably increase the size of the dots representing the galleries to around 10.

Now click on Flow -> Display Arrows in the Utility Network Analyst toolbar. This is something you didn't do with the roads network, as people can typically drive in either direction along a road, so that the source of a travel at one point will be the sink for the return trip. Water in a water system typically flows *from* the source *to* the sink and not vice versa. To edit the symbols (which you should do) you should click on Flow -> Properties. There are 3 types of flow. Adjust the size, color, and shape of the symbols to something that looks better and communicates more effectively. Click the Scale tab in the Flow Display Properties and change the settings so that they do not display arrows unless the map is zoomed in closer than 1:30,000. Click OK. Verify that the arrows appear and disappear as you zoom in and out.

Place a Junction Flag on the Civic Center Gallery. Change the trace task to Find Connected and click the Solve icon. Clear the flags, and place a Junction Flag on the East Rapid Gallery. Click again on Solve to find what is connected to that gallery. What does this tell you about the structure of the Rapid City water system? Try the same things with the trace task set to Find Disconnected.

Are there loops in the system? Set the trace task to Find Loops and see. Note that only one gallery has a loop!

We can use the network to find out if construction (for example) will result in service disruptions. Load the transportation network into the layout. The City is planning to repair a water main on St. Patrick Street between 4th and 5th Streets. They need to shut down the water main running along St. Patrick Street at 5th Street, and they need to notify the affected customers that they will not be able to flush their toilets. Use Find to locate St. Patrick Street. There is a T-Valve at 5th and St. Patrick, and that is the valve that will be cut off. First, you have to figure out what direction the water is flowing in the St. Patrick water main. Where does it go after it hits the T-Valve at 5th Street? Where are the downstream areas? How do you determine that? Find the water main that brings water to the T-Valve that is to be turned off. How far is it from the Civic Center Gallery to the T-Valve at 5th Street and St. Patrick? Print some maps showing the connections of each water line to the two pumping stations, both with and without the T-valve at 5th Street and St. Patrick Avenue turned off.

You might wonder how many kilometers of water main are served by each of the galleries. To find that, clear the flags and results, and place a flag on one of the galleries. Use Analysis -> Options -> Results to change the results format to selection, and hit OK. Set the trace task to Find Downstream and solve. The area served by the gallery is selected. Go to the attribute table for the waterlines, right-click on the Shape_Length field, and choose Statistics. The total length of all selected waterlines is shown in the Sum field of the table that results.

Portfolio

11-1 At least two scenarios of the route from 1250 East North Street to Stevens High School showing different options to the calculation

11-2 At least two scenarios of the route from 1250 East North Street to Stevens High School showing different options of sewer-related street closures and restaurant avoidance

11-3 Maps showing connections of water lines to pumping stations, with and without the T-valve at 5th Street and St. Patrick Avenue turned off