

## Chapter 9. Network Analysis

### Objectives

- Learning the function and terminology of networks
- Understanding the different properties of transportation and utility networks
- Performing tracing analysis on networks
- Understanding how networks are constructed

### Mastering the Concepts

#### GIS Concepts

##### *About networks*

A network consists of a system of paths traveled by a variety of things, such as traffic, water, sewage, or electricity. Common examples of networks include roads, utility lines, airline routes, and streams. Modeling the behavior of a “commodity” flowing through the network can help answer questions such as these: How long would it take a chemical spill in this watershed to reach the city water supply? If this transformer blows, which parts of the city will be out of power? If a problem develops with a sewer line, which shutoff valve can we use to halt flow during repairs while affecting the fewest possible people?

All feature classes participating in a network must take the role of either an **edge** or a **junction** (Fig. 9.1). An edge feature represents a path along the network. Examples of edges include roads, pipelines, and electric cables. Edges must come from a line feature class. A junction represents a point in a network where edges meet or where an object such as a valve exists. A street intersection, for example, is represented by a junction. T-valves or straight-line connectors would constitute junctions in a pipeline network. Junctions can come from two sources: they can be automatically constructed during network building wherever edges meet, or they can be specific objects that come from a point feature class, such as valves.

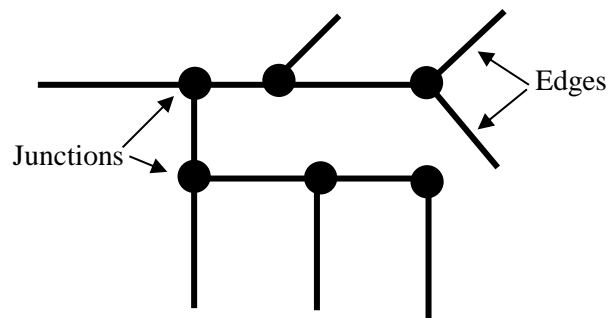


Fig. 9.1. A network is composed of edges and junctions.

Network features can take one of two states: enabled or disabled. An enabled edge or junction allows material to flow through it. A disabled edge or junction blocks travel, whether of water, electricity, or cars. The feature state is initially assigned during construction of the network; however, it may be temporarily modified during analysis, such as disabling a street edge to represent road construction that blocks travel. The states of the network features are stored in the attribute table of the feature class in a field named Enable.

Network storage in a data model has two aspects (Fig. 9.2). The **geometric network** consists of the actual points and lines in the feature classes that participate in the network. These features are stored as the familiar feature classes containing points and lines. Certain fields are added to the attribute tables of the feature classes to help track the participation of each feature in the network. The **logical network** includes a set of tables that store information about the construction and operation of the network elements. Users do not usually have direct access to the logical network. The files are created at the time the network is built from the feature classes. The geometric network and the logical network are interconnected, and changes in the geometric network require changes to the logical network. During editing, the relationships between the geometric and the logical networks are maintained automatically.

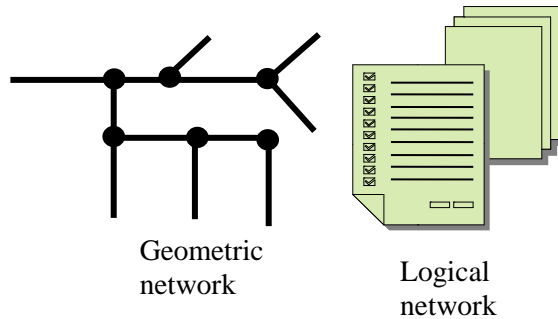


Fig. 9.2. The geometric network consists of features in a feature class. The logical network contains relationships, connections, and behavior as tabular data.

### Types of networks

Networks fall into one of two basic categories: transportation networks or utility networks. The material in a transportation network (cars) has few constraints on travel; the drivers go where they choose (Fig. 9.3). The vehicles can usually travel in either direction along an edge and through intersections, represented by junctions.

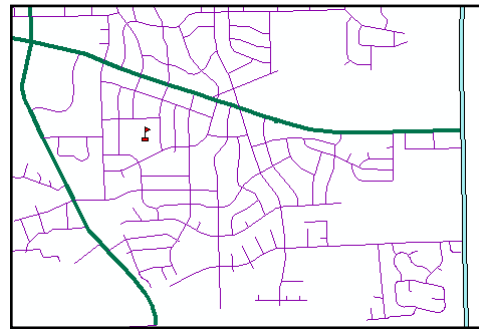


Fig. 9.3. In a transportation network, the drivers choose the way to travel.

Utility networks have established directions of flow determined by the topology of the connections and the location of sources or sinks (Fig. 9.4). A **source** point provides material to the network and “pushes” the material away from itself. A power plant is a source for an electric grid; a water treatment plant might act as a source for a water line network. A **sink** represents a location where material is used or leaves the network. Sinks draw the material toward themselves. Electric meters or water meters on a building might be considered sinks, as would a sewage treatment facility discharging to a lake.

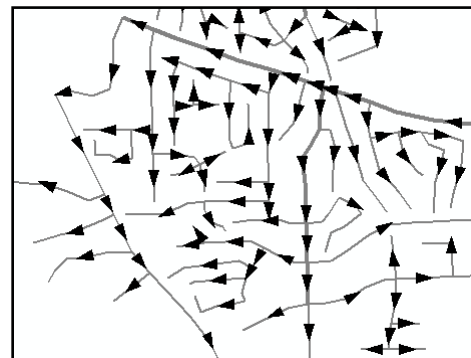


Fig. 9.4. In a utility network, the flow of the material is determined by the network configuration.

Transportation networks and utility networks have different types of analysis functions available for use in modeling flow. A transportation network could be used to solve problems such as the following:

- What is the best path to travel to 16 delivery locations?
- What is the likely service area of a fire station based on travel time?
- What is the shortest path from point A to point B?

Utility networks might be used to address other kinds of problems:

- If this valve fails, which customers will be affected?
- If I have to close this pipe for repairs, can I reroute water through another path to minimize service disruption?
- How will contamination at one location propagate through the network?
- Which sewer lines serve only residential customers?

Utility network flow must be established before the network can be analyzed. You establish flow by specifying the sources or the sinks in the network and solving for the flow direction. A utility network edge may have three possible states: it may be unassigned if network flow has not yet been established; it may have a determinate flow, meaning that a single flow direction was established; or it may have an indeterminate flow, meaning that the flow direction is ambiguous and cannot be uniquely determined. The third case generally results from a topological error in the network or from an error in specifying the sources and the sinks.

### Network analysis

Network analysis problems are tackled using a program called a **solver**. Many types of solvers are possible. Figure 9.5 shows the set of solvers that comes with ArcMap. Some general features of using solvers are discussed in this section.

A **flag** pinpoints a location of interest, such as the starting and the endpoints of a journey, the delivery stops on a route, or a location from which to trace up- or downstream. Flags may be placed along edges or at junctions (Fig. 9.6).

A **barrier** represents a temporary blockage or outage in the network, such as a damaged bridge, a closed valve, or a broken power line. As with flags, barriers may be placed on either edges or junctions (Fig. 9.6). When placed on a feature, barriers temporarily override the normal “Enabled” state of the feature, as stored in the layer’s attribute file.

**Network weights** can be stored for each edge or junction as attributes and specify the “cost” of traversing the network. Common edge weights include distance along the edge or travel time as dictated by the street length and speed limit. Common junction weights include a loss of pressure at a pipe T-junction or a waiting time imposed at a traffic light. Solvers can take these weights into account when finding solutions, such as finding the path with the least wait time at intersections rather than finding the shortest path between two points.

The output of a network tracer usually takes the form of a set of edges and junctions along the traced path. Network analysis offers several options concerning the form of this output. The path solution may be returned either as a graphic or as a set of selected features. If returning a selection, one may choose to return only edges, only junctions, or both.

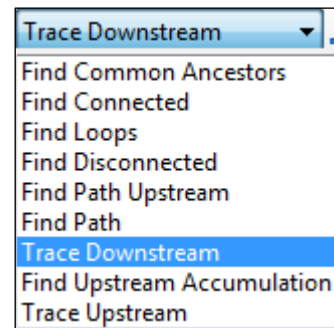


Fig. 9.5. Tracing solvers

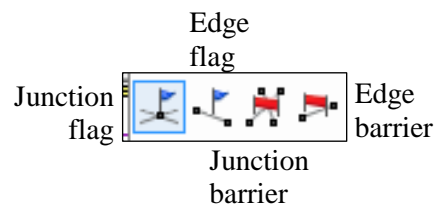


Fig. 9.6. Flags mark locations of interest. Barriers stop flow.

### Generic trace solvers

The solvers in this section may be applied to either utility or transportation networks. They carry out their work without regard to the direction of flow through the edges and junctions.

#### Finding paths

This solver traces the least-cost path between two or more flags placed on the network. It can find a way to travel from one location to another or to plan a path to most efficiently visit a series of locations such as delivery stops. When finding paths, the solver keeps track of the “cost” of traveling the path. By default the cost is the number of edges traversed. Figure 9.7a shows the lowest-cost path, in terms of the number of edges traversed, for driving from a student’s house to a school. The flags are shown as green boxes at the locations of interest; in this case, edge flags are used.

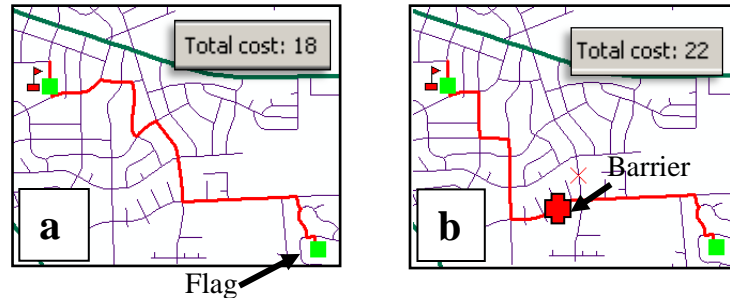
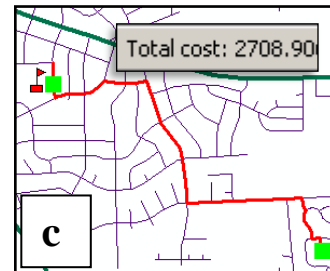


Fig. 9.7. Finding paths:  
 (a) finding the shortest path with cost in edges;  
 (b) finding the shortest path with a barrier;  
 (c) finding the shortest path using a distance weight (meters)



The user can modify solver behavior by specifying barriers to travel, such as road construction. Figure 9.7b shows the new path found when a barrier is placed along the original one. The cost has increased to 22 edges, but the new path is still the least-cost path, given the presence of the barrier.

Users can also specify a weight, such as distance or travel time. Without weights, the solver simply counts the number of edges traversed. However, the lowest number of edges does not always mean the shortest path; in some cases the shortest path could have more edges. Finding the shortest path requires a distance weight. In Figure 9.7c, the distance along the edges has been chosen as the weight. A slightly different path results than when simply counting edges. The cost shows up in the distance units—in this case, meters.

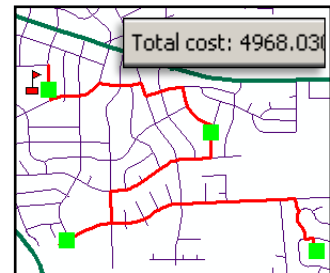


Fig. 9.8. Finding the best path to pick up a child’s friends on the way to school

Finally, the user can specify multiple flags in order to find the least-cost route for making several stops in sequence. Figure 9.8 shows a path to pick up a child’s friends and take them to school. The Find Path tracer simply visits the stops in the order given. Other solvers must be used to solve the classic “traveling salesman” problem: given a set of locations to visit, devise the most efficient sequence and path to follow.

### Find Connected/Find Disconnected

The Find Connected solver traces along the features and highlights those that are connected to the flag(s) placed on the network. Such a solver might be used to find all of the water lines that are supplied by a single water intake gallery along a river (Fig. 9.9). Such information might be useful in gauging the impact of a chemical spill near the intake and determining which customers must be warned to purchase drinking water until the contamination is removed.

Barriers placed at specific locations affect the results of this solver. Any feature with a barrier between it and the flag location will be considered disconnected from the network (Fig. 9.9).

Find Disconnected performs the opposite function of Find Connected; it locates portions of the network that can't be reached from the flagged locations. This solver is particularly useful for diagnosing problems when constructing networks. Sometimes a failure in snapping two line ends together or neglecting to split a line at an intersection will result in part of the network being disconnected. The solver finds these problem areas so that they can be fixed.

The Find Connected and Find Disconnected solvers are most useful for utility networks, but they can also be applied to transportation networks. A road network is designed to facilitate connecting all locations for easy travel. Thus, Find Connected usually results in the selection of the entire network (not a very useful result most of the time). However, one useful application might include finding which parts of the city might be seriously affected by construction placed at a critical location. Find Disconnected also helps locate network errors, as previously noted.

### Finding loops

A loop is a section of a network that forms a continuous loop, or ring. In a transportation network, loops are generally the rule, as most streets eventually connect to other streets and can be traversed in a circular fashion. This solver finds little utility in transportation networks. In utility networks, loops indicate a topological error rather than a legitimate situation. A water pipe that forms a loop would cause problems when the emerging flow reentered the loop. The Find Loops tracer, then, has its primary use as a tool for detecting and fixing loops. A flag must be specified as the place to begin tracing, and the solver finds all loops that lie downstream of the flag.

Figure 9.10 shows an example of a loop in a utility network. The flag has been placed at the upper right of the picture. The arrows indicate the direction of flow along the network. The loop found by the tracer is marked with small circles, which indicate that flow in the loop is indeterminate; because of the loop, the flow direction cannot be established from the two possible solutions. To fix the loop, one end must be disconnected from the circle, or an edge or a junction must be disabled.

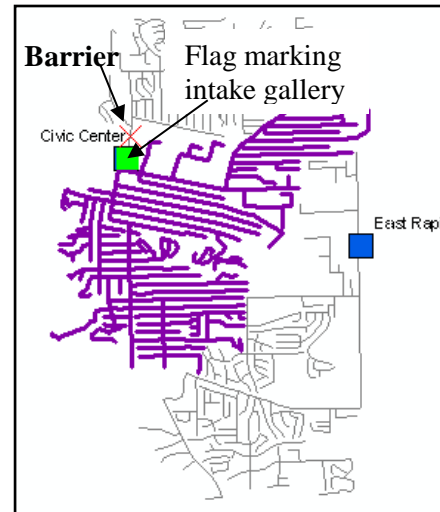


Fig. 9.9. Find Connected returns all parts of the network connected to one or more points of interest.

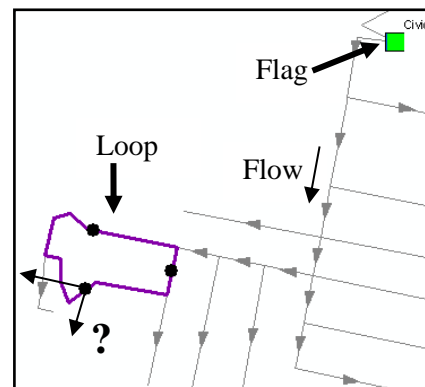


Fig. 9.10. A loop in a utility network cannot flow.

### Utility trace solvers

The solvers in this section are used only for utility networks. They rely on an established flow direction in order to carry out the analysis.

#### Find Path Upstream

This solver works similarly to the Find Path solver previously discussed, except that movement along the edges is always constrained to be in the upstream direction. The tool can locate a path between a single location and its source (Fig. 9.11). If more than one flag has been specified, the paths of each flag are traced upward.

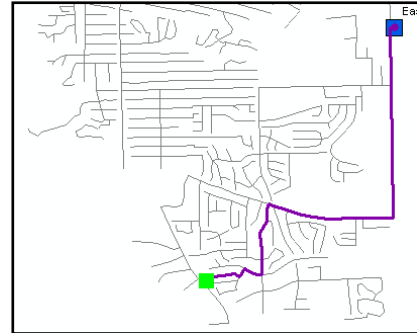


Fig. 9.11. Find Path Upstream traces the flow from a location to its source.

#### Find Upstream Accumulation

This solver is a variation of the Find Path Upstream tool, but it keeps track of the weights on each edge and junction and applies them to determine a total accumulation of resources along the path.

#### Trace Upstream/Downstream

Trace Upstream and Trace Downstream provide a way to follow the flow from a specified location. Trace Upstream is essentially the same solver as Find Path Upstream. The downstream trace finds all the edges that lie downstream of a flagged location or locations. Such a solver might be used to find the service areas that would be disrupted by a downed power line or a water line break (Fig. 9.12).



Fig. 9.12. Trace Downstream could find the service area disrupted by a broken pipe.

#### Find Common Ancestors

This solver takes a group of flags and finds any upstream edges and junctions that are shared by all the individuals in the group. The tool can be used by utility companies to help locate failures in the system based on reports by customers. Suppose that a utility company receives 50 calls in one evening from customers complaining about a loss of water pressure. By entering the locations of these reports as flags, the company can isolate possible locations of the suspected break by finding the set of pipes that is common to all the calls. The break will most likely be found near the lower end of the common ancestors (Fig. 9.13).

#### About ArcGIS

Geodatabases are used in ArcGIS to create and store networks. Networks are topological data structures that can be built from existing simple feature classes. A feature class containing roads, for example, can be used to create a transportation network. Multiple layers can be combined to form more complex networks. A water supply network might include feature classes representing pumping stations, pipes, valves, and meters.

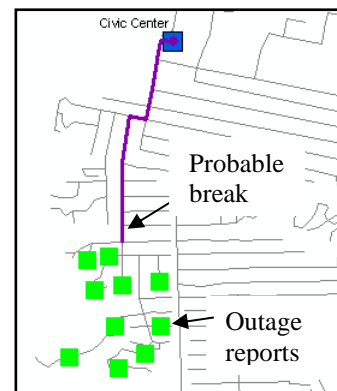


Fig. 9.13. The Find Common Ancestors solver can locate service failures.



Networks may only be created in feature datasets. All feature classes participating in a network must belong to the same feature dataset; however, the dataset can contain other feature classes that do not participate in the network. A Transportation feature dataset containing roads and rail lines could have a roads network that did not include the rails.

Figure 9.14 shows a geodatabase containing two networks. The Transportation feature dataset contains a single line feature class, roads, plus two feature classes that constitute the network, Road\_Net and Road\_Net\_Junctions. The Utilities feature dataset contains four feature classes plus the Water\_Net and Water\_Net\_Junctions. It is not obvious from looking at the geodatabase which feature classes in the feature dataset participate in the network; however, this information can be obtained by examining the properties of the network in ArcCatalog.

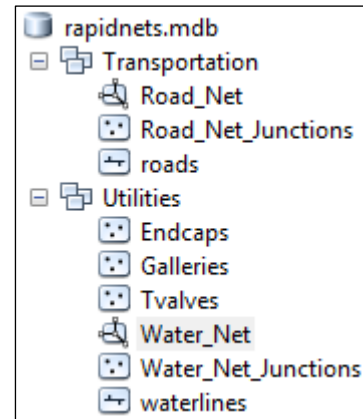


Fig. 9.14. Networks are built from feature classes in feature datasets.

### **The Utility Network Analyst toolbar**

A **trace** is an algorithm that solves network problems, and ArcMap comes with a set of simple traces that follow network connections (see Fig. 9.5). More advanced and complex network analysis tools are also available for users who purchase the Network Analyst extension. Knowledgeable users may employ the special customization languages provided with ArcGIS to write new solvers. ArcMap solvers require input in four forms: the network itself, the weights of elements along the network, the locations of interest, and any barriers to flow.

ArcMap contains a special toolbar used to direct and control the analysis of networks (Fig. 9.15). The main features of this toolbar are as follows:

- The Network drop-down list controls which network is being analyzed. One network may be analyzed at a time.
- The Flow menu controls the display of symbols representing flow directions in a utility network. The user can turn the symbols on and off and change the symbols being used.
- The Establish Flow button next to the Flow menu is used during editing to establish the initial flow direction in a network, and it requires an ArcGIS Standard or Advanced license. ArcGIS Basic can perform analysis on networks for which this task is already complete.
- The Analysis menu manages the analysis by placing flags or barriers, clearing both flags and barriers, or clearing previous results in preparation for a new analysis. The Trace Task menu specifies which kind of analysis will be performed.
- The drop-down flag tool controls which type of flag or barrier to add to the map.
- The Solve button must be clicked to perform the trace. All of the trace tasks require that at least one flag be added to the map before any analysis can occur. If no flags are present, the Solve button will be dimmed.

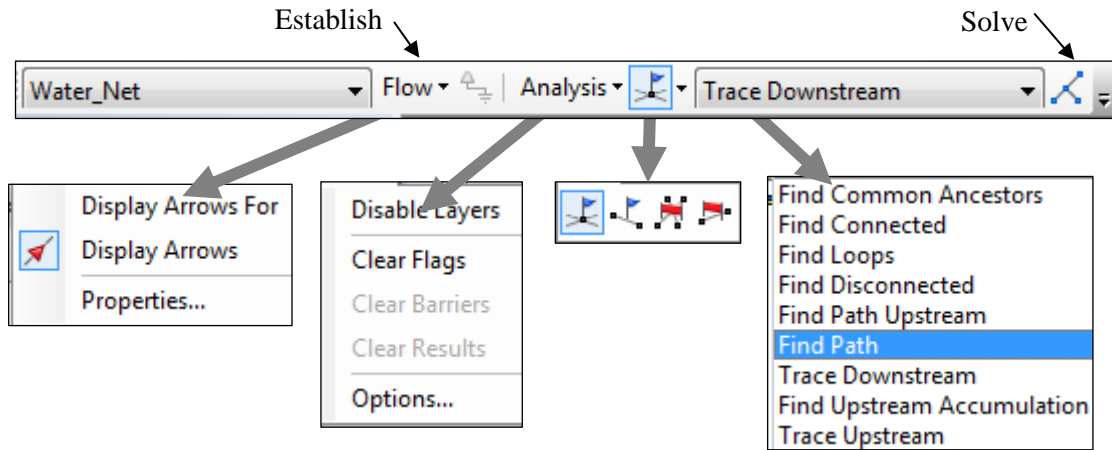


Fig. 9.15. The Utility Network Analyst toolbar contains all the functions needed to analyze networks in ArcMap.

The overall process of analyzing a network includes specifying the network to be used, choosing the tracing task, adding flags or barriers, and solving. Once a solution is obtained, it may be cleared before going on.

The Analysis > Options menu choice opens a window with four tabs. These options control the analysis by specifying which features will be traced, whether the features will be weighted, and the format of the results. The output of a trace may take the form of a drawing or a set of selected features (Fig. 9.16). The features returned can include all features matching the criteria of the trace task or simply those stopping the trace. The user can also choose whether to return edges or junctions or both.

**Building networks**

Building valid networks requires ingenuity and attention to detail, especially if the network is to be used for sophisticated modeling. The planning stage is important, and the builder must consider a number of issues in designing the network, including using simple or complex edges, assigning weights, using domains or subtypes, and establishing connectivity rules.

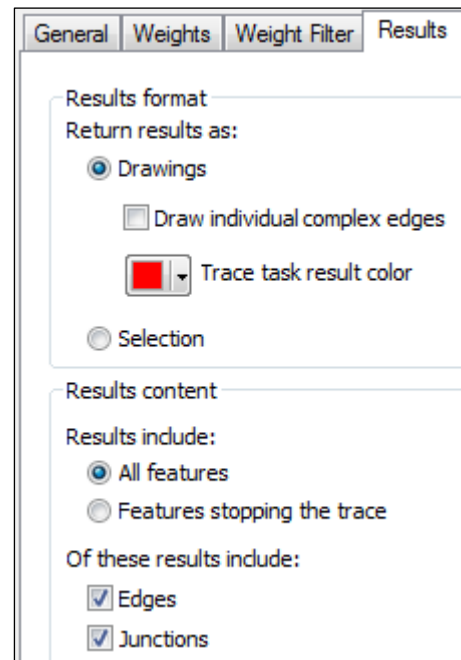


Fig. 9.16. Choosing the format of the output results

**SKILL TIP:** An ArcGIS Standard or Advanced license is required in order to create networks. If you have the license and want to try creating a network, learn how in the Skills Reference (Files and Geodatabases).



### Simple edges or complex edges?

Network edges occur in two different styles, simple edges and complex edges (Fig. 9.17). A simple edge can have junctions only at its endpoints. A complex edge can have one or more junctions in its middle.

Complex edges offer advantages when keeping track of long features. For example, a water main along a street has junctions composed of T-valves that branch off to laterals carrying water to each individual house. Using simple edges, the main would have to be broken into multiple pieces between each T-valve. However, for purposes of queries and maintenance, the water main is more logically and easily treated as a single feature. When clicking on the water main, it would be better to select the entire feature, not just one tiny segment between two laterals. By using a complex edge network, the water main can remain a single feature while allowing the junctions of the laterals to connect to it.

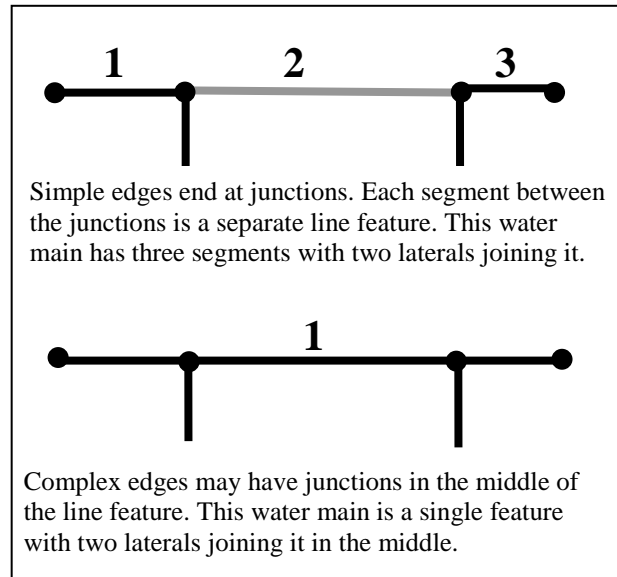


Fig. 9.17. Networks with simple edges versus networks with complex edges

Junctions also can be implemented as simple or complex features. A complex junction can be built from a set of simple junctions and simple edges. For example, a dam in a stream network might be represented as a complex junction, which itself is composed of edges and junctions representing flow gates, generators, turbines, and more. The geodatabase model comes equipped with simple junctions, simple edges, and complex edges. Complex junctions must be created using advanced modeling tools, and their construction is beyond the scope of this book.

### Network weights

When creating a network, the user can include certain attributes that establish weights for each edge and junction. Such weights allow for more realistic modeling of flow. For example, in analyzing possible routes from a fire station to a fire, the shortest route is not necessarily the fastest. A longer route with less traffic, fewer traffic lights, and a higher speed limit might serve better than the shortest route. A more realistic travel network could include a travel time attribute for the road features and point junctions representing traffic lights with different average delays.

When creating the network, these attributes would be specified as weights, to take into account costs associated with traversing the edges or passing through the junctions. Weights can only be established during network creation.

## Summary

- Networks are used to model the flow of objects or materials along an interconnected system of edges and junctions.
- Transportation networks are distinguished by the fact that the material can independently determine how it will flow. In a utility network, the direction of flow is determined by the network topology and the location of sources and sinks.
- Programs called solvers may be applied to analyzing flow through a network. Solvers typically use three types of input: the network itself, flags indicating points of interest such as delivery locations, and barriers that prevent flow.
- Network weights are stored as attributes of edges. Weights can be used during analysis to determine, for example, the shortest path or the shortest travel time. They can also be used to accumulate the costs of moving along the network.
- Networks are stored in feature datasets, and they may include some or all of the feature classes in the dataset.
- Network topology, connectivity, and relationships are stored in data tables and collectively represent the logical network. The actual line and point features represent the geometric network.
- Network topology is created in ArcCatalog. Once established, it is updated and maintained during editing. Building networks requires an ArcGIS Standard or Advanced license.
- Networks may be composed of simple edges, which always end at junctions, or complex edges, which can contain junctions in the middle of the feature.

**TIP:** Weights are set up at the time the network is created. If no weights are listed in the drop-down boxes, then the network contains no weights, and none can be used.

**TIP:** Some tracing tools will not work if the flags or the barriers are of different types. For an analysis, try to always use edge flags and edge barriers together or junction flags and junction barriers together.

## Important Terms

barrier	geometric network	network weights	source
edge	junction	sink	trace
flag	logical network	solver	

## Chapter Review Questions

You may need to consult the Skills Reference section to answer some of these questions.

1. What kinds of feature classes can be used to create networks?
2. Explain the difference between a geometric network and a logical network.
3. What characteristic distinguishes a transportation network from a utility network?
4. Networks are composed of what two spatial elements? What is the role of each?
5. What are sources and sinks? In what type of network are they found?
6. What purposes do flags and barriers serve?
7. What are loops? Are they desirable?
8. By default, does the Find Path solver always find the shortest path? Explain.
9. What is the purpose of using network weights?
10. How do simple edges and complex edges differ?

## Mastering the Skills

### Teaching Tutorial

The following examples provide step-by-step instructions for doing basic tasks and solving basic problems in ArcGIS. The steps you need to do are highlighted with an arrow →; follow them carefully. Click on the video number in the VideoIndex to view a demonstration of the steps.

- Start ArcMap with the ex\_9.mxd map document in mgisdata\MapDocuments.
- Use Save As to rename the document and remember to save frequently as you work.

- 1 → Open the Catalog tab and expand the Folder Connections, if necessary.
- 1 → Navigate to the mgisdata\Rapidcity folder.
- 1 → Expand the rapidnets geodatabase.
- 1 → Expand the Transportation feature dataset.
- 1 → Right-click the Road\_Net network and choose Properties.

1. What, if any, weights have been created for this network? \_\_\_\_\_

- 1 → Close the Transportation network properties.
- 1 → Click the ArcCatalog tab, expand the Utilities feature dataset, and open the properties for the Water\_Net network.

2. Which feature classes participate in the network, and what roles do they play?  
\_\_\_\_\_

3. What weights does the Utilities network have? \_\_\_\_\_

- 1 → Close the Utilities network properties.

### Finding paths

We will begin by finding some simple paths through this transportation network.

**TIP:** Be sure to use the *Utility Network Analyst* toolbar, not the *Network Analyst* toolbar. *Network Analyst* is an extension that must be purchased.

- 2 → Choose Customize > Toolbars from the main menu bar and select the Utility Network Analyst toolbar.
- 2 → Make sure that the Network is set to Road\_Net in the Utility Network Analyst toolbar.
- 2 → Set the trace task to Find Path.
- 2 → Click on the Junction Flag tool.
- 2 → Click on the ends of two roads on opposite ends of town, as shown in Figure 9.18.
- 2 → Click the Solve button.

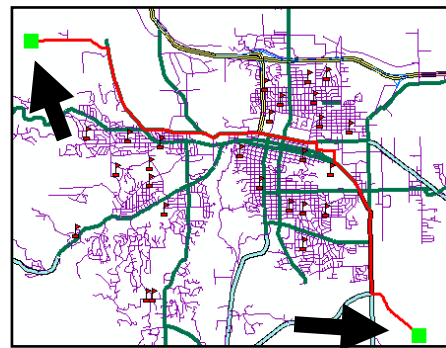


Fig. 9.18. Finding a path between two flags

**TIP:** Flags and barriers should match types. For best results, always use junction flags and junction barriers together or edge flags and edge barriers together.

The path solution appears as a bold red line connecting the flags. This path meets the criterion that it follows the minimum number of edges through the network. Since this is a transportation network, traffic can travel in either direction. Now let's try another one.

- 3→ Choose Analysis > Clear Flags from the Utility Network Analyst menu.
- 3→ Choose Analysis > Clear Results from the Utility Network Analyst menu.
- 3→ Click the Junction Flag tool and add two flags at any locations you choose.

**TIP:** If the flag does not snap to the right location, clear the flags and start again. Zooming in will make it easier to snap to the right spot.

- 3→ Click Solve.



- 4→ Clear the flags and the results again using the Analysis menu.
- 4→ Choose the Edge Flag tool, try adding a pair of edge flags, and then solve.
- 4→ Clear the flags and the results.

**TIP:** Flags and barriers will be snapped to the closest feature within the snap tolerance set from the General tab in the Analysis > Options menu on the Utility Network Analyst toolbar.

Now let's explore the use of barriers to help find the best way to take a child to school. Imagine that you live on Harney Dr and that your child goes to Southwest Middle School.



- 5→ Choose Bookmarks > School Trips 1 from the main menu bar.
- 5→ Click the Find tool on the Tools toolbar.
- 5→ Type **Harney** as the text for which to search, and set the layer to Roads. Click Find.
- 5→ Hold down the Ctrl-key and click on each Harney Dr entry in turn to select them all. Don't select Harney Pl or the others.
- 5→ Right-click on one of the entries and choose Select. Harney Dr will be selected.
- 5→ Use the Find tool to locate **Southwest** and select the school in the Schools layer.
- 5→ Close the Find window.
  
- 6→ Zoom in to the extent of Harney Dr to more easily mark the right spot with the flag.
- 6→ Click the Edge Flag tool.
- 6→ Place a flag near the middle of Harney Dr, and use the Zoom to Previous Extent button to return to the original extent.
  
- 7→ Place another edge flag on Park Dr next to the school, zooming as necessary.
- 7→ Zoom back to see both flags, and make sure the trace task is set to Find Path.
- 7→ Click Solve.

Well, that was probably the answer you expected. Perhaps you are wondering, however, how far it is from home to school.

- 8➔ Click the Solve button again without moving the mouse off it, and this time keep an eye on the lower-left corner of the map window to see the cost.

4. What is the cost of this trip and what are the units of the cost? \_\_\_\_\_

It would be more interesting to learn the distance. To find distances, you must use a weight.

- 8➔ Choose Analysis > Options from the Utility Network Analyst menu bar.
- 8➔ Click the Weights tab.
- 8➔ Set both the along and the against edge weights to Distance. Click OK.
- 8➔ Clear the results (but not the flags).
- 8➔ Click Solve again and watch for the cost.


5. What is the cost and what are the units? \_\_\_\_\_

**TIP:** When specifying weights in a Transportation network, it is critical to specify a weight both FOR and AGAINST the direction of travel. If only one weight is chosen, then cost will accumulate only when travel is in the same direction as the line, and the total will be too small.

On the first day of school, you discover that an enormous traffic jam builds up at the intersection south of the school. You wonder if there is an alternate route through the tangle of residential streets north of the school and what the street names are. First, though, let's turn on Map Tips.

- 9➔ Right-click the Roads layer and choose Properties.
- 9➔ Click the Display tab. Check the *Show MapTips* box.
- 9➔ Make sure that the Display Expression Field is set to ROADNAME. Click OK.

With Map Tips on, use the cursor to hover over a street to find out its name. (In addition, the layer is set to label the streets at scales greater than 1:20,000.)

- 10➔ Clear the results (but not the flags).
- 10➔ Zoom in to the middle school to see it better and to see the road labels appear.
-  10➔ Click the Edge Barrier tool and place a barrier on Corral Dr between Park Dr and Sheridan Lake Rd.
- 10➔ Zoom to the previous extent when done.
- 10➔ Click Solve.

6. What is the distance of this alternate route? \_\_\_\_\_

To make it easier to find the way tomorrow morning, make a list of the streets involved in this path. One way to get a list is to return the path as a selection instead of as a drawing.

- 11➔ Choose Selection > Interactive Selection Method from the main toolbar, and make sure that it is set to Create New Selection.



- 11 → Switch to the List by Selection view in the Table of Contents. Click the toggle switches to make all layers selectable.
- 11 → Set the Table of Contents view back to List By Drawing Order.
- 12 → Choose Analysis > Options from the Utility Network Analyst toolbar.
- 12 → Click the Results tab.
- 12 → Change the results format to Selection, and uncheck the box for returning junctions. The edges will contain the street names. Click OK.
- 12 → Clear the results (but not the flags or the barriers).
- 12 → Solve again.

**TIP:** If no features are selected when solving a trace, check that the selection method is set to Create New Selection and that the network is one of the selectable layers.

- 13 → Open the Roads attribute table.
- 13 → Click the button to show only the selected records.

7. How many (different) street names are included on this path? \_\_\_\_\_

- 13 → Set the results format back to Drawings in the Analysis > Options menu, and check the box to return junctions once more. Click OK to close the window.
- 13 → Close the attribute table.

Finally, your other child attends Meadowbrook Elementary School. Normally she walks to school, but you want to plan a route to take both children on rainy days. In addition, you have agreed to pick up her friend who lives on Player Dr. Find a new path including all of these elements. The Middle School starts earlier than the others, so you plan to stop there first, pick up the child on Player Dr next, and then arrive at Meadowbrook. You need to enter the flags in the order of your planned stops (Fig. 9.19).

- 14 → Use Clear Selected Features from the Selection menu on the main menu bar to clear the trace.
- 14 → Clear the barriers and the flags.
- 14 → Place an edge flag on Harney Dr.
- 14 → Place an edge flag next to Southwest Middle School.

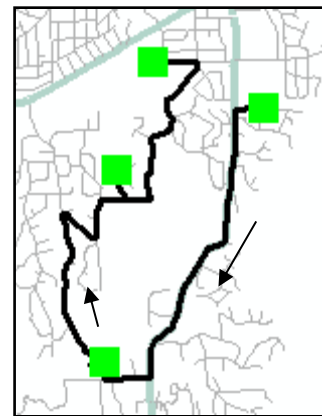


Fig. 9.19. Traveling a sequence of stops

- 15 → Locate Player Dr using the Find button or Map Tips, and place an edge flag on it.
- 15 → Place an edge flag next to Meadowbrook Elementary School (west and slightly north of Harney Dr).
- 15 → Solve for the path. When finished, clear the results and the flags.

### Advanced path problems

Combinations of selections, barriers, and other techniques can tackle more advanced path problems. To start, assume that you live on Red Dale Dr and work at the South Dakota School of Mines and Technology (SDSM&T). You decide to map a route to work.

- 16➔ Find Red Dale Dr and place an edge flag on the west end.
- 16➔ Zoom to the extent of the Roads layer.
- 16➔ Find SDSM&T (search for Mines), zoom in, and place an edge flag on E. St. Joseph St next to the school.
- 16➔ Zoom to the extent of the Roads layer again.
- 16➔ Solve for the path.

Now imagine that a doctor has placed you on a strict, low-cholesterol diet. Driving home from work in the evening, you find it nearly impossible to drive by a restaurant without stopping for something wonderfully greasy to eat. Try to find a route home that avoids all the restaurants in town. To begin, select all the road segments that are close to restaurants.

- 17➔ Choose Selection > Select by Location from the main menu bar.
- 17➔ Select roads that are within 100 meters of a restaurant.
- 17➔ Close the window after completing the selection.

Next, we will set the trace analysis options so that the selected roads act as barriers to travel.

- 18➔ Choose Analysis > Options from the Utility Network Analyst toolbar.
- 18➔ Click the General tab and fill in the button to *Trace on: Unselected features.*
- 18➔ Click OK.
- 18➔ Clear the previous trace results.
- 18➔ Solve for the path (Fig. 9.20).

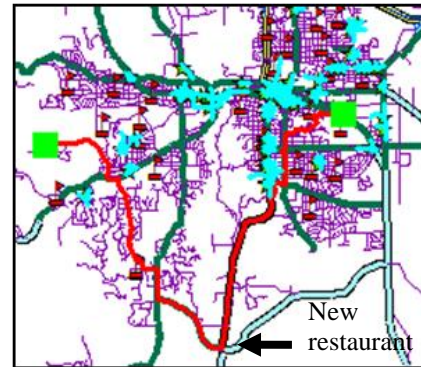


Fig. 9.20. Avoiding restaurants on the way home from work

Unfortunately, you discovered that last week a new restaurant with juicy burgers and crisp fries opened at the intersection of Catron Blvd and Highway 16. This new restaurant is not in the database, so enter barriers by hand.

- 19➔ Zoom in to the intersection of Catron Blvd and Highway 16 (Fig. 9.21).
- 19➔ Add two edge barriers to block off the intersection.
- 19➔ Zoom back to the previous extent.
- 19➔ Clear the previous result and solve for the path again.

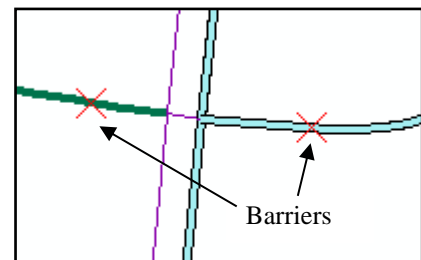


Fig. 9.21. Placing barriers on Catron Blvd

Looks like you can still get home, although the path is a little tortuous!

- 20➔ Clear the flags, the barriers, and the results.
- 20➔ Clear the selected set of roads.
- 20➔ Turn off the Restaurants and Schools layers.

### ***Finding transportation network errors***

Errors in topology are often created during the process of digitizing and creating networks. Once the network is built, the tracing tools can help you locate and fix these problems. One useful tool is the Find Disconnected solver. In a road network, it should be possible to get to any road. A disconnected road is usually the result of a failure to snap the end of a new road to the existing network or to split a road at a junction.

- 21➔ Zoom to the extent of the Road Network group layer.
- 21➔ Choose the Junction Flag tool and click to add a flag anywhere on the network.
- 21➔ Set the trace task to Find Disconnected and click the Solve button.

At first glance, no trace result appears. This network is in good shape. However, look closely at the north-south extension of the yellow interstate, I-190, for a small red glint.

- 22➔ Zoom in to this area for a closer look (Fig. 9.22).
- 22➔ Zoom in to the triangle with the two small red spots.
- 22➔ Zoom in to one of the spots until the red street fragment is clearly visible.

Here's the problem. A tiny sliver of road, which is probably a processing error, lies across the intersection. You could use editing (Chapter 12) to delete the slivers. For now, we will simply go on; these small extra segments will not affect the behavior of the network.

We can also use the Find Loops on transportation networks.

- 23➔ Zoom back to the extent of the Road Network group layer.
- 23➔ Change the trace task to Find Loops.
- 23➔ Click the Solve button.

This time nearly the entire network is returned as the result. We can expect this because typically road networks DO let people drive in loops. (How many times have you driven around the block?) However, the roads that are not part of the result do have a common feature—they are all “dead end” streets. Of course, some of them end merely because they go outside the city limits. Generally, finding connections and loops is not very useful with transportation networks.

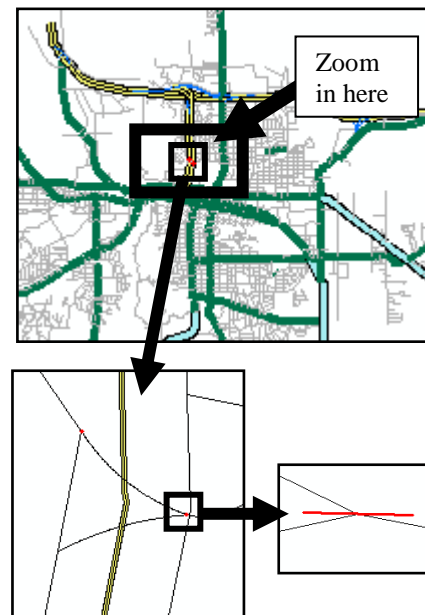


Fig. 9.22. Finding a disconnected road segment

### **Tracing on utility networks**

Although finding driving routes is amusing, utility networks also have interesting tracers. Now we will take a look at a portion of a hypothetical water utility system for east Rapid City.

- 24➔ Clear the flags and the results.
- 24➔ Turn off the Road Network group layer and collapse it using the minus box.
- 24➔ Turn on the Water Network group layer.
- 24➔ Zoom to the Water Network group layer.
- 24➔ Change the network to Water\_Net in the Utility Network Analyst toolbar.
- 24➔ Examine the network.

This network contains more elements than the roads network. The water mains themselves form the edges. In addition, there are galleries, end caps on the pipes, and T-valves at the pipe junctions. All of these features participate in the network.

- 25➔ Right-click the Galleries layer and choose Open Attribute Table.

The attribute table contains three fields. The Name field simply indicates the name of the gallery. The Enabled field is a part of the network setup. The value True indicates that the galleries are turned on and functioning as part of the network. The AncillaryRole field says Source, indicating that the galleries are water sources for the network. They are underground chambers that pull water in from Rapid Creek, filtering and treating it before it enters the water lines.

- 25➔ Close the attribute table.

- 26➔ Choose Bookmarks > Pipes from the main menu bar.
- 26➔ Choose Flow > Display Arrows from the Utility Network Analyst toolbar.

Arrows appear at the center of each edge, indicating the direction of flow. Here's how to edit the symbols used for portraying flow.

- 26➔ Choose Flow > Properties from the Utility Network Analyst toolbar.
- 26➔ Click the Arrow Symbol tab.

There are three different conditions of flow possible in the network. Uninitialized flow means that the flow direction has not yet been established for the network. Indeterminate flow means that flow has been initialized but cannot be determined for that section. Determinate flow indicates that flow has been established.

- 26➔ Click on each flow type to examine the symbol used to display it.

8. What is the symbol for Indeterminate flow? \_\_\_\_\_

- 27➔ Click the symbol for Determinate flow. The Symbol Selector appears.
- 27➔ Change the symbol color to blue. Click Apply. The map arrows change color.
- 27➔ Change the symbol for Indeterminate flow to a 12-point pink square. Click Apply.

Like other features in ArcMap, a display scale can be set so that the networks are not cluttered with arrows at small scales.

- 28→ Click the Scale tab (still in the Flow Display Properties).
- 28→ Fill the button for *Don't show arrows when zoomed out beyond* and enter 30,000. Click OK.
- 28→ Zoom to the extent of the Water Network group layer to check the scaling. The arrows should disappear.
- 28→ Return to the previous extent.

Notice that the arrows take a few moments to draw. Turn them off for now.

- 29→ Choose Flow > Display Arrows again to turn the symbols off.

Let's explore this network more by using some of the tracing tools. Let's start by seeing which parts of the network are connected to each gallery.

- 29→ Zoom to the extent of the Water Network group layer to show the entire network.
- 29→ Choose the Junction Flag tool and click to add a flag at the Civic Center gallery.
- 29→ Set the trace task to Find Connected. Click the Solve button.

Now it is easy to see which areas of town are served by the Civic Center gallery. We can use Find Disconnected to highlight the other pipes that are not connected to this gallery.

- 30→ Clear the results and change the trace task to Find Disconnected.
- 30→ Click the Solve button.

Next, let's use the Find Loops tracer to see if there are any loops in this network.

- 31→ Clear the results.
- 31→ Add another junction flag to the other gallery so that both subnets are examined for loops.
- 31→ Change the trace task to Find Loops and Solve.
- 31→ Zoom in to the single red loop result that appears (Fig. 9.23).
- 31→ Choose Flow > Display Arrows from the Utility Network Analyst toolbar.

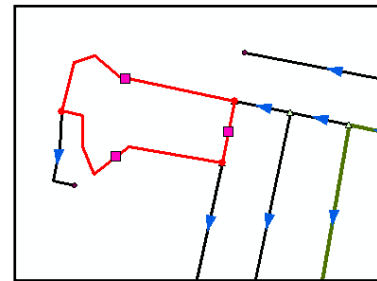


Fig. 9.23. Flow in a loop is indeterminate.

Note that all of the lines except the loop have blue determinate flow arrows. The loop has the pink square indeterminate flow symbols. The water could go around the loop in either direction. Fixing this would require editing the loop to break the connection at one point.

- 32→ Clear the flags and the results.
- 32→ Zoom to the extent of the Water Network group layer.

One useful benefit of using network models is the ability to predict what areas of town will experience service disruptions due to repairs and outages. The city has been planning to repair a leaking pipe on St. Patrick St between 6th and 7th Ave. They will need to turn off the flow to the pipe for several hours, and they want to notify the customers who will be affected.

- 33→ Turn on the Road Network group.

- 33➔ Use Select by Attributes to select the roads where [STREET] = 'ST PATRICK'. Click Apply rather than OK to keep the selection window open.
- 33➔ Change the Selection method to Add to Current Selection.
- 33➔ Select the roads where [STREET] = '6' OR [STREET] = '7'.
- 33➔ Close the Selection window.
  
- 34➔ Zoom in and add an edge flag to the segment of the water line that follows St. Patrick St between 6th and 7th. Then return to the previous extent.
- 34➔ Change the trace task to Trace Downstream.
- 34➔ Click the Solve button.

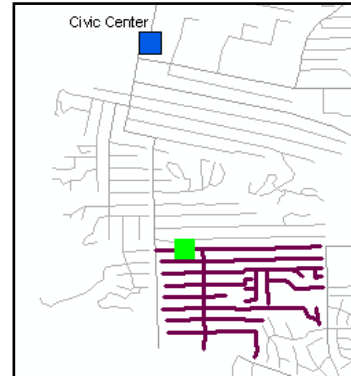


Fig. 9.24. Finding a service disruption due to repairs on St. Patrick St

Now you know where to notify customers (Fig. 9.24). If this network were complete down to the building connections for each parcel, then the utilities company would be able to automatically compile a mailing list to send to the affected customers.

The Trace Upstream tool performs the opposite task, finding the path that water has traveled to get to a particular location.

- 35➔ Clear the flags and the results.
- 35➔ Clear the selected features.
- 35➔ Use the Find tool to locate and select the streets N. and S. Grand Vista Ct. They are on the middle of the west side of the network (Fig. 9.25).

Tracing can also be done with accumulation, for example, to find the total distance water travels to get to a particular location.

- 36➔ Zoom in to the location of these two streets.
- 36➔ Place a junction flag on the end of the water main serving these streets, and return to the previous extent.
- 36➔ Change the task to Find Upstream Accumulation.
- 36➔ Click Solve and watch for the cost in the lower-left corner of the window.

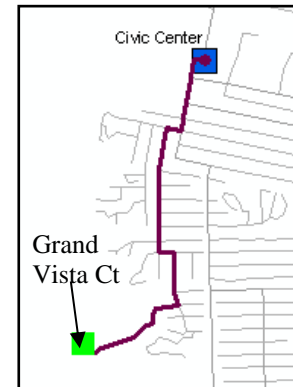


Fig. 9.25. How water gets to Grand Vista Ct

9. What is the cost in edges to get from the Civic Center to Grand Vista Ct? \_\_\_\_\_
  - 37➔ Choose Analysis > Options from the Utility Network Analyst toolbar.
  - 37➔ Click the Weights tab and set both the along and against weights to Distance. Click OK.
  - 37➔ Click the Solve button again.

10. How far does the water travel to get there? \_\_\_\_\_



There is no downstream equivalent to tracing with accumulation. However, we can use the selection result option to select the downstream features from a point and determine the total length of pipe beyond that point. First, we must make sure that Waterlines is a selectable layer.

- 38→ Switch to the List By Selection option on the Table of Contents.
- 38→ Check the selection toggle to make sure that Waterlines is selectable.
- 38→ Switch back to View By Drawing Order.
  
- 39→ Clear the flags and results.
- 39→ Place a junction flag at the East Rapid gallery.
- 39→ Choose Analysis > Options from the Utility Network Analyst menu.
- 39→ Click the Results tab and change the result format to Selection. Click OK.
- 39→ Change the trace task to Trace Downstream and Solve.

Now that the water lines are selected, it is easy to get their total length.

- 40→ Open the attribute table for the Waterlines layer.
- 40→ Right-click the Shape\_Length field and choose Statistics.

11. What is the total length in kilometers of pipe served by this gallery? \_\_\_\_\_

- 40→ Close the Statistics window and the attribute table.
- 40→ Clear the selected set.

This is the end of the tutorial.

- Close ArcMap. You do not need to save your changes.

**SKILL TIP:** Learn how to create a geometric network if you have an ArcGIS Standard or Advanced license (Files and Geodatabases).

## Exercises

1. Find the shortest path from Hidden Timbers Dr to Stevens High School. **Capture** a map showing the route.
2. What is the distance covered by the route in Exercise 1?
3. What is the shortest alternate route if you want to avoid the before-school congestion on Park Dr by Southwest Middle School? **Capture** the map. How long is the new route?
4. The cafeteria at Stevens High School makes daily lunches for several elementary schools in town. They are delivered in this order: Pinedale, South Canyon, Upper Rapid, Canyon Lake, Meadowbrook, and Cleghorn. Find the most efficient route to make the deliveries. **Capture** the map.
5. You are trucking a load of Canadian hemp from a distributorship on Olde Orchard Rd to a cowboy rope-making factory on Stacy St. Because of a bizarre technicality in the drug laws, you can be arrested if the truck is stopped within 250 meters of a school. Find a path to the destination that avoids this risk. **Capture** the map.
6. A construction worker accidentally breaks a water line at the intersection of E. St. Patrick St and Ivy Ave. Create a map showing the area of disrupted service. **Capture** the map.
7. Of the two water mains leaving the Civic Center gallery, which serves a greater length of pipes? What is the total pipe length for each main (north and south)?
8. What is the total length of water *mains* served by the East Rapid gallery versus the Civic Center gallery? (Do not include laterals or other water line types.)
9. The water main that ends at 5th St and Cathedral Dr/Fairmont Blvd passes through how many T-valves?
10. Joe did Exercise 9 with Selection as the result format and got 26 *selected* features. Mary did the same problem and got 51 *selected* features. Explain why they got different numbers. What is the cost in each case?

## Challenge Problem

Find a route that goes from Alta Vista Dr to the east end of E. Knollwood St and that travels **ONLY** on local streets. (**Hint:** You cannot ignore the role of junctions in this problem.) **Capture** your map.

## Skills Reference

### Examining network properties

1. In ArcCatalog, right-click a network in the catalog list and choose Properties.

The General tab reports which feature classes participate in the network (Fig. 180).

The Connectivity tab shows any rules that have been established regarding how the network elements can connect (e.g., a three-inch pipe can connect to a six-inch pipe only through a coupler junction feature). Connectivity rules are not required but are provided to help maintain network integrity.

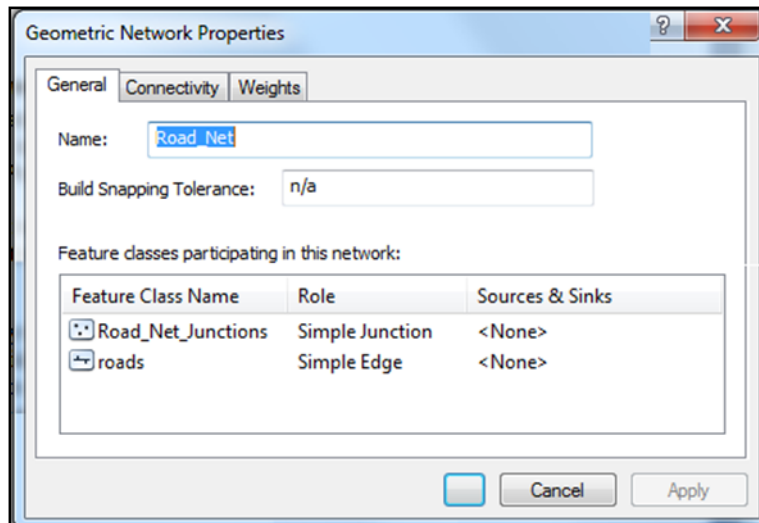


Fig. 180. General properties of a network

The Weights tab lists weights that have been set up for the network. Weights are created at the time the network is built, but they may be used during an analysis, if desired.

### Performing a trace

1. In ArcMap, click the Add Data button and choose a *Name\_Net* layer, such as Road\_Net, in the geodatabase containing the network. The network and its participating feature classes will be added to the map.
2. From the main menu, choose Customize > Toolbars > Utility Network Analyst.
3. Select the network to be analyzed, if more than one is available (Fig. 181).
4. Choose the Trace Task to be performed.
5. Click the Flag/Barrier tool and add desired flags and barriers at edges or junctions. For reliable results, do not mix edge and junction markers; use either but not both.
6. Click the Solve button to perform the trace.



Fig. 181. Performing a simple tracing task

### Setting general tracing options

1. Choose Analysis > Options from the Utility Network Analyst toolbar.
2. Click the General tab (Fig. 182).
3. Choose which features to trace. You can choose to trace only on selected features, only on unselected features, or on all features.
4. Choose whether to include edges with indeterminate or uninitialized flow when tracing.
5. Choose the snapping tolerance to be applied when adding flags and barriers. If the tool clicks a location within this distance from an edge or a junction feature, the flag or barrier will automatically snap to the feature.
6. Click OK to apply the options.

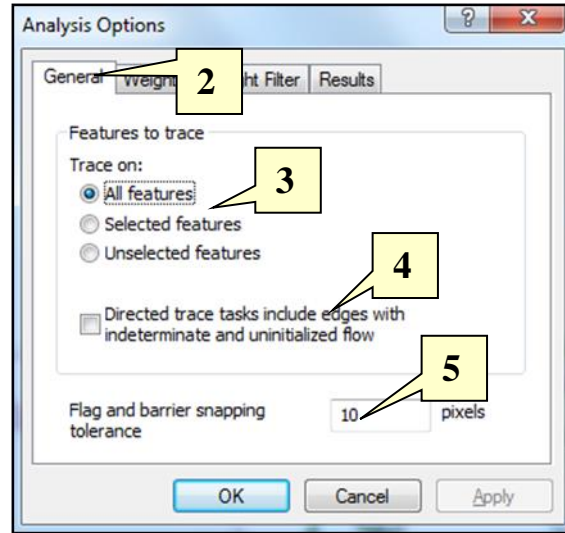


Fig. 182. Setting general options

### Changing the results format

1. Choose Analysis > Options from the Utility Network Analyst toolbar.
2. Click the Results tab (Fig. 183).
3. Choose whether the trace result will take the form of a drawing or a selected set of features.
4. If you choose to return a drawing, change the color of the trace, if desired.
5. Choose whether the result will include all features included in the trace or only the features that are stopping the trace.
6. Choose whether the trace result will include edges, junctions, or both. By default, both are returned.
7. Click OK to apply the changes.

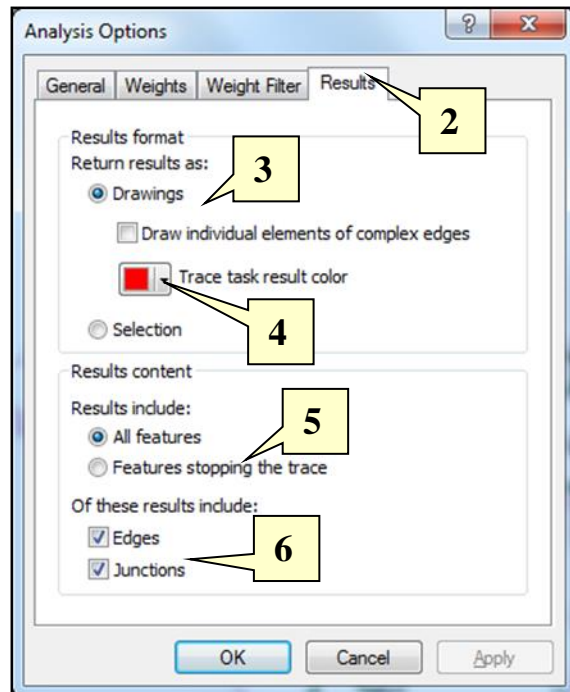


Fig. 183. Changing the results format

### Using weights when tracing

1. Choose Analysis > Options from the Utility Network Analyst toolbar.
2. Click the Weights tab (Fig. 184).
3. To use weights on junctions, specify the name of the weight desired.

For edge weights, you must specify a weight in both the *along* and *against* directions of the edge. Usually, they are the same weight, but they can be different (for example, if setting a weight for uphill travel versus downhill travel).

4. Specify the name of the weight to be applied in the same direction that the line was digitized.
5. Specify a weight to be applied against the digitized direction.
6. Click OK to apply the changes.

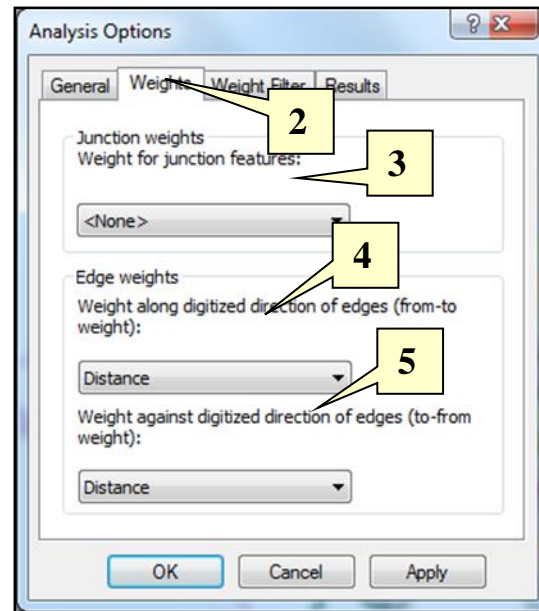


Fig. 184. Setting weights

**TIP:** Weights are set up at the time the network is created. If no weights are listed in the drop-down boxes, then the network contains no weights, and none can be used.

### Using weight filters

Filtering weights means to apply weights that fall within a specified range. For example, a junction weight called StopTime might specify an average waiting time at intersections. You might want to sum the total time spent at traffic lights and ignore the shorter weight at stop signs. A weight filter could screen out waits of less than 15 seconds.

1. Choose Analysis > Options from the Utility Network Analyst toolbar.
2. Click the Weight Filter tab (Fig. 185).
3. Choose the edge or junction weights.
4. Enter the weight range as min – max.
5. Click the Not button to use the weights NOT in the specified range.
6. Click Verify to check that the syntax is correct.
7. Click OK or Apply.

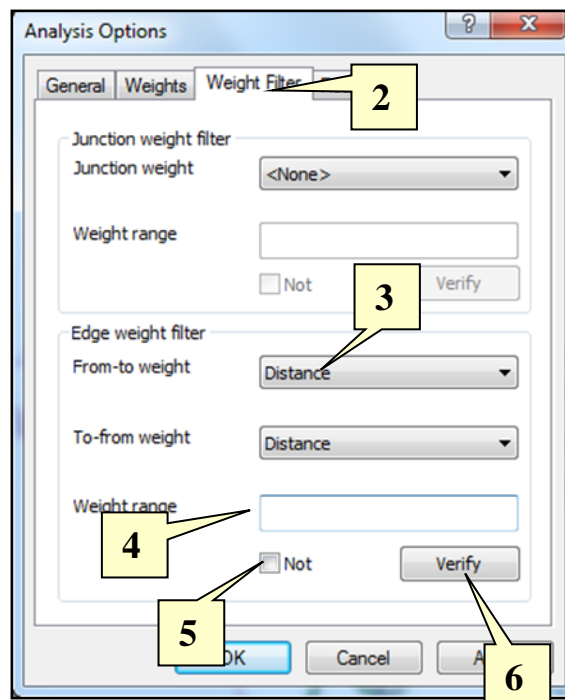


Fig. 185. Setting weight filters

### Viewing flow directions

1. Choose Flow > Display Arrows from the Utility Network Analyst toolbar.

### Changing flow symbols

2. Choose Flow > Properties from the Utility Network Analyst toolbar and click the Arrow Symbol tab (Fig. 186).
3. Select the flow category to see the symbol used for that category (Determinate, Indeterminate, or Uninitialized). The symbol for that category will be displayed to the right.
4. To change the symbol, click on it. The Symbol Selector appears. Choose the new symbol, set its size and color properties, and click OK.
5. Click OK or Apply.

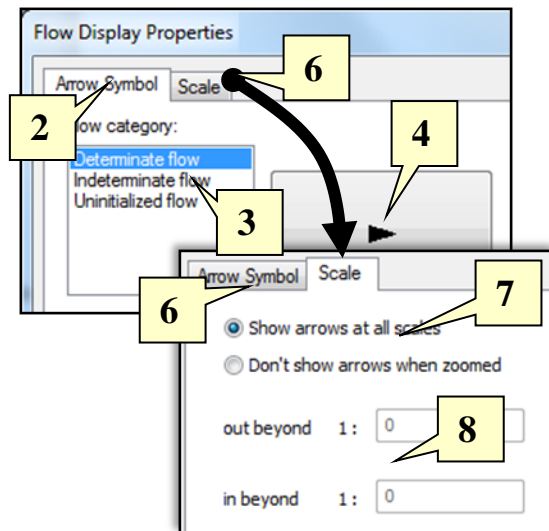


Fig. 186. Setting the flow symbols and display scale

### Setting the display scale

Use this feature to avoid clutter in the map by making symbols appear only at certain scales.

6. Click the Scale tab (Fig. 186).
7. Choose to *Show arrows at all scales*, or to *Don't show arrows when zoomed in* or *out beyond* a specified scale.
8. Enter the scale(s).
9. Click OK or Apply.

### Adding and clearing flags and barriers

Flags mark locations of interest in a network, and barriers temporarily stop flow.

1. Click the Flag tool drop-down button on the Utility Network Analyst toolbar (Fig. 187) and select the type of flag or barrier to add (edge or junction).
2. Click on a junction to add a junction flag or barrier. Click along an edge to add an edge flag or barrier.
3. To clear flags or barriers, choose Analysis > Clear Flags or Analysis > Clear Barriers from the Utility Network Analyst toolbar. All flags or barriers are cleared together.

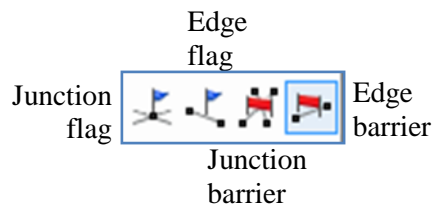


Fig. 187. Flags and barriers

**TIP:** Flags and barriers will be snapped to the closest feature within the snap tolerance set from the General tab in the Analysis > Options menu.

**TIP:** Some tracing tools will not work if the flags or the barriers are of different types. For an analysis, always use edge flags with edge barriers and junction flags with junction barriers.



### Finding a path

By default, the trace will return the path that traverses the fewest number of edges. This path will not necessarily be the shortest path.

1. Choose the network to trace on.
2. Set the trace task to Find Path.
3. Choose the Junction Flag or Edge Flag tool.
4. Click on the starting location to enter a flag.
5. Click on the end location to enter another flag.



6. Click the Solve button.

Total cost: 54

**TIP:** To see the cost (number of edges in the path), look in the lower-left corner of the ArcMap window before the mouse moves off the Solve button. The cost will vanish once the mouse is moved. Click Solve again to bring it back.

**TIP:** Enter more than two flags to visit a series of locations. The stops will be visited in the order in which they are entered.

### Finding the shortest path

To find the shortest path, the network must have a Distance weight based on the length of the edges. (It may be called something other than Distance.)

1. Choose the network on which to trace.
2. Set the trace task to Find Path.
3. Choose the Junction Flag tool or the Edge Flag tool. Enter the starting, end, and any intermediate flag locations.
4. Choose Analysis > Options from the Utility Network Analyst toolbar and click the Weights tab.
5. Set both the *along* and the *against* edge weights to Distance (or whatever the weight name is). Click OK.
6. Click the Solve button.

Total cost: 18097

**TIP:** The distance in map units along the path will be displayed in the lower-left corner of the ArcMap window. It will vanish when the mouse is moved. Click Solve again to make it reappear.

### ***Finding connections and loops***

These trace tools can be used to find features connected to a certain location, those features disconnected from a certain location, and those features that form loops.

1. Choose the network on which to trace.
2. Set the trace task to Find Connected, Find Disconnected, or Find Loops.
3. Click the Edge or Junction Flag tool and enter the location from which to start tracing. More than one location flag may be entered, in which case tracing will commence from each location separately.
4. Click the Solve button.

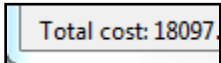
### ***Tracing upstream/downstream***

These tracers work only on utility networks.

1. Choose the network on which to trace.
2. Set the trace task to Trace Upstream or Trace Downstream.
3. Click the Edge or Junction Flag tool and enter a flag at the location to begin the trace. If more than one flag is entered, tracing will begin at each location separately.
4. Click the Solve button.

### ***Tracing with accumulation***

1. Choose the network to trace on.
2. Set the trace task to Find Upstream Accumulation.
3. Choose Analysis > Options and click the Weights tab to specify the weights to be accumulated during tracing.
4. Click the Edge or Junction Flag tool and enter a flag at the location to begin the trace. If more than one flag is entered, tracing will begin at each location separately.
5. Click the Solve button.
6. Read the accumulation value in the weights' units in the lower-right corner of the ArcMap window.

A small rectangular window with a light blue border and a white background. Inside the window, the text "Total cost: 18097" is displayed in a black, sans-serif font.

**TIP:** The accumulation value will vanish when the mouse is moved off the Solve button. To bring it back, click Solve again.