Explain the representation by using a diagram.

5. Refer to Figure 17.4*d*. Explain how the cell value of 5.5 (row 2, column 2) is derived. Is it the least accumulative cost possible?
6. Refer to Figure 17.4*d*. Show the least accumulative cost path for the cell at row 2, column 3.
7. Refer to Figure 17.5*b*. The cell at row 4, column 4 can be assigned to either one of the two source cells. Show the least cost path from the cell to each source cell.
8. What is an allocation raster?
9. How does the surface distance differ from the regular (planimetric) cost distance?
10. Explain the difference between a network and a line shapefile.
11. What is link impedance?
12. What is turn impedance?
13. What kinds of topological relationships are important for shortest path analysis?
14. What fields are normally included in a turn table?
15. Suppose the impedance value between nodes 1 and 4 is changed from 58 to 40 (e.g., because of lane widening) in Figure 17.11. Will it change the result in Table 17.2?
16. Define location–allocation analysis.
17. Explain the difference between the minimum distance model and the maximum covering model in location–allocation analysis.

APPLICATIONS: PATH ANALYSIS AND NETWORK APPLICATIONS

This applications section has six tasks. Tasks 1 and 2 cover path analysis. You will work with the least accumulative cost distance in Task 1 and the path distance in Task 2. Tasks 3 to 6 require the use of the Network Analyst extension. Task 3 runs a shortest path analysis. Task 4 lets you build a geodatabase network dataset. Task 5 runs a closest facility analysis. And Task 6 runs an allocation analysis.

Task 1: Compute the Least Accumulative Cost Distance

What you need: *sourcegrid* and *costgrid,* the same rasters as in Figure 17.4; and *pathgrid,* a raster to be used with the shortest path function. All three rasters are sample rasters and do not have the projection file.

In Task 1, you will use the same inputs as in Figures 17.4*a* and 17.4*b* to create the same outputs as in Figures 17.4*d,* 17.5*a,* and 17.5*b.*

1. Connect to the Chapter 17 database in ArcCatalog. Launch ArcMap. Rename the data frame Task 1, and add *sourcegrid, costgrid,* and *pathgrid* to Task 1.
2. Make sure that the Spatial Analyst toolbar is available. Click the Spatial Analyst downward arrow, point to Distance, and select Cost Weighted. In the Cost Weighted dialog, do the following: select *sourcegrid* for distance to, select *costgrid* for the cost raster, check to create direction, check to create allocation, and opt for temporary rasters including the output raster. Click OK to run the commands.
3. *CostDistance to sourcegrid* shows the least accumulative cost distance from each cell to a source cell. You can use the Identify tool to click a cell and find its accumulative cost.

Q1. Are the cell values in *CostDistance to sourcegrid* the same as those in Figure 17.4*d*?

4. *CostDirection to sourcegrid* shows the least cost path from each cell to a source cell. The cell value in the raster indicates which neighboring cell to traverse to reach a source cell. The directions are coded 1 to 8, with 0 representing the cell itself (Figure 17.19).

6	7	8
5	0	1
4	3	2

Figure 17.19
Direction measures in a direction raster are numerically coded. The focal cell has a code of 0. The numeric codes 1 to 8 represent the direction measures of 90°, 135°, 180°, 225°, 315°, 360°, and 45° in a clockwise direction.

5. *CostAllocation to sourcegrid* shows the allocation of cells to each source cell. The output raster is the same as Figure 17.5*b*.
6. Click the Spatial Analyst downward arrow, point to Distance, and select Shortest Path. In the Shortest Path dialog, select *pathgrid* for path to, *costgrid* for the cost distance raster, *CostDirection to sourcegrid* for the cost direction raster, and specify the path type for each cell. Specify *Path.shp* for the output features. Click OK to run the command. *Path* shows the path from each cell in *pathgrid* to its closest source. *Path* is the same as Figure 17.5*a*.

Task 2: Compute the Path Distance

What you need: *emidasub,* an elevation raster; *peakgrid,* a source raster with one source cell; and *emidapathgd,* a path raster that contains two cell values. All three rasters are projected onto UTM coordinates in meters.

In Task 2, you will find the least cost path from each of the two cells in *emidapathgd* to the source cell in *peakgrid.* The least cost path is based on the path distance. Calculated from an elevation raster, the path distance measures the ground or actual distance that must be covered between cells. The source cell is at a higher elevation than the two cells in *emidapathgd.* Therefore, you can imagine the objective of Task 2 is to find the least cost hiking path from each of the two cells in *emidapathgd* to the source cell in *peakgrid.*

1. Insert a new data frame in ArcMap, and rename it Task 2. Add *emidasub, peakgrid,* and *emidapathgd* to Task 2. Select Properties from the context menu of *emidasub.* On the Symbology tab, right-click the Color Ramp box to uncheck Graphic View. Then select Elevation #1. As shown in the map, the source cell in *peakgrid* is located near the summit of the elevation surface and the two cells in *emidapathgd* are located in low elevation areas.
2. Open ArcToolbox in ArcMap. Select the Chapter 17 database for the current workspace. Double-click the Path Distance tool in the Spatial Analyst Tools/Distance toolset. Select *peakgrid* for the input raster, specify *pathdist1* for the output distance raster, select *emidasub* for the input surface raster, specify *backlink1* for the output backlink raster, and click OK to run the command.

Q2. What is the range of cell values in *pathdist1*?

Q3. If a cell value in *pathdist1* is 900, what does the value mean?

3. Double-click Cost Path in the Spatial Analyst Tools/Distance toolset. Select *emidapathgd* for the input raster, select *pathdist1* for the input cost distance raster, select *backlink1* for the input cost backlink raster, specify *path1* for the output raster, and click OK.
4. Open the attribute table of *path1.* Click the left cell of the first record. As shown in the map, the first record is the cell in *peakgrid.* Click the second record, which is the least cost path from the first cell in *emidapathgd* (in the upper-right corner) to the cell in *peakgrid.*

Q4. What does the third record in the *path1* attribute table represent?

Task 3: Run Shortest Path Analysis

What you need: *uscities.shp,* a point shapefile containing cities in the conterminous United States; and *interstates.shp,* a line shapefile containing interstate highways in the conterminous United States. Both shapefiles are based on the Albers Conic Equal Area projection in meters.

The objective of Task 3 is to find the shortest route between two cities in *uscities.shp* on the interstate network. The shortest route is defined by the link impedance of travel time. The speed limit for calculating the travel time is 65 miles/hour. Helena, Montana, and Raleigh, North Carolina, are two cities for this task.

1. First preview the table of *interstates.shp* in the Catalog tree. *interstates.shp* has several attributes that are important for network analysis. The field MINUTES shows the travel time in minutes for each line segment. The field NAME lists the interstate number. And the field METERS shows the physical length in meters for each line segment.
2. Select Extensions from the Tools menu. Make sure that Network Analyst is checked.
3. This step uses *interstates.shp* in the Catalog tree to set up a network dataset. Right-click *interstates.shp* and select New Network Dataset. The New Network Dataset dialog allows you to set up various parameters for the network dataset. Accept the default name *interstates_ND* for the name of the network dataset. Click on the Connectivity button in the next dialog. The Connectivity dialog shows interstates as the source, end point for connectivity, and 1 connectivity group. Click OK to exit the Connectivity dialog. In the New Network Dataset dialog, opt not to modify the connectivity with elevation field data and opt not to model turns. The next window shows Meters and Minutes as attributes for the network dataset. Click Next. Select yes to establish driving directions settings, and click the Directions button. The Network Directions Properties dialog shows that the display length units will be in miles and the length attribute is in meters. NAME in *interstates.shp* will be the street (interstate in this case) name field. You can click the cell below Suffix T . . . and choose None. Click OK to exit the Network Directions Properties dialog, and click Next in the New Network Dataset dialog. A summary of the network dataset settings is displayed in the next window. Click Finish. Click Yes to build the network. Notice that *interstates_ND.nd,* a network dataset, and *interstates_ND_Junctions.shp,* a junction feature class, have been added to the Catalog tree. To make sure that the network dataset is complete, preview the table of *interstates_ND_Junctions.shp.* The table should have hundreds of records for junctions.
4. Launch ArcMap if necessary. Insert a data frame and rename it Task 3. Add *interstates_ND.nd* to Task 3. Click yes to add all feature classes that participate in *interstates_ND* to map. Add *uscities.shp* to Task 3. Choose Select By Attributes from the Selection menu. In the next dialog, enter the following expression to select Helena, MT, and Charlotte, NC: "City_Name" = 'Helena' Or "City-Name" = 'Charlotte'.
5. Select Extensions from the Tools menu, and make sure that the Network Analyst extension box is checked. Click View, point to Toolbars, and check Network Analyst. The Network Analyst toolbar should now appear with *interstates_ND* in the Network Dataset box. Click the Show/Hide Network Analyst Window button on the toolbar to open the window. Select New Route from the Network Analyst's dropdown menu. The Network Analyst window opens with three empty lists of Stops, Routes, and Barriers. A new Route analysis layer is also added to the table of contents.
6. This step is to add Helena and Charlotte as stops for the shortest path analysis. Because the stops must be located on the network, you can use some help in locating them. Click the Route Properties button at the upper right of the Network Analyst window. On the Network Locations tab, change the Search Tolerance to 1000 (meters). Click OK to exit the Layer Properties dialog. Zoom in on

Helena, Montana. Now click Stops (0) in the Network Analyst window, and then use the Create Network Location tool on the Network Analyst toolbar to click a point on the interstate near Helena. The clicked point displays a symbol with 1. If the clicked point is not on the network, a question mark will be next to the symbol. In that case, you can use the Select/Move Network Locations tool to move the point to be on the network. After Helena is located, repeat the same procedure to locate Charlotte on the network. Click the Solve button on the Network Analyst toolbar to find the shortest path between the two stops.

7. The shortest route now appears in the map. The route is also added to the Network Analyst window. Click the plus sign next to Routes (1) in the Network Analyst window to open the route called *Graphic Pick 1 – Graphic Pick 2.* (The numbers may be different from 1 and 2.) Right-click *Graphic Pick 1 – Graphic Pick 2* and select Directions Window. The window shows the travel distance in miles, the travel time, and detailed driving directions from Helena to Charlotte.

Q5. What is the total travel distance in miles?

Q6. Approximately how many hours will it take to drive from Helena to Charlotte using the interstates?

Task 4: Build a Geodatabase Network Dataset

What you need: *moscowst.shp,* a line shapefile containing a street network in Moscow, Idaho; and *select_turns.dbf,* a dBASE file that lists selected turns in *moscowst.shp.*

moscowst.shp was compiled from the 2000 TIGER/Line files. *moscowst.shp* is projected onto a transverse Mercator coordinate system in meters. For Task 4, you will first examine the input data sets. Then build a personal geodatabase and a feature dataset. And then import *moscowst.shp* and *select_turns.dbf* as feature classes into the feature dataset. You will use the network dataset built in this task to run a closest facility analysis in Task 5.

1. Preview the table of *moscowst.shp* in the Catalog tree. *moscowst.shp* has the following attributes important for this task: MINUTES shows the travel time in minutes, ONEWAY identifies one-way streets as T, NAME shows the street name, and METERS shows the physical length in meters for each street segment.

Q7. How many one-way street segments (records) are in *moscowst.shp*?

2. Preview the table of *select_turns.dbf. select_turns.dbf* is a turn table originally created in ArcInfo Workstation. The table has the following attributes important for this task: ANGLE lists the turn angle, ARC1_ID shows the first arc for the turn, ARC2_ID shows the second arc for the turn, and MINUTES lists the turn impedance in minutes.
3. Now create a personal geodatabase. Right-click the Chapter 17 database in the Catalog tree, point to New, and select Personal Geodatabase. Rename the geodatabase *Network.mdb.*
4. Create a feature dataset. Right-click *Network.mdb,* point to New, and select Feature Dataset. In the next dialog, enter *MoscowNet* for the name. Then click Projected Coordinate Systems and Import to import the coordinate system of *moscowst.shp* to be *MoscowNet*'s coordinate system. Select None for Z coordinate. Take the default values for the tolerances. Then click finish.
5. This step imports *moscowst.shp* to *MoscowNet.* Right-click *MoscowNet,* point to Import, and select Feature Class (single). In the next dialog, select *moscowst.shp* for the input features, check that the output location is *MoscowNet,* enter *MoscowSt* for the output feature class name, and click OK.
6. To add *select_turns.dbf* to *MoscowNet,* you need to use ArcToolbox. If necessary, click the Show/Hide ArcToolbox Window button to open the ArcToolbox window. Double-click the Turn Table to Turn Feature Class tool in the Network Analyst Tools/Turn

Feature Class toolset to open its dialog. Specify *select_turns.dbf* for the input turn table, specify *MoscowSt* in the *MoscowNet* feature dataset for the reference line features, enter *Select_Turns* for the output turn feature class name, and click OK.

7. Click the plus sign next to *MoscowNet* in the Catalog tree. *MoscowSt* and *Select_Turns* should be in the dataset. Preview the table of *Select_Turns*. Although the table contains the same information as *select_turns.dbf*, it has different fields. Each turn in *Select_Turns* is set up to have a maximum of five edges. For Task 4, only two edges are involved in each turn. The field Edge1FID is the same as ARC1_ID in *select_turns.dbf*, and the field Edge2FID is the same as ARC2_ID.
8. With the input data ready, you can now build a network dataset. Right-click *MoscowNet*, point to New, and select Network Dataset. Do the following in the next four windows: take the default name (*MoscowNet_ND*) for the network dataset, select *MoscowSt* to participate in the network dataset, take the default connectivity settings, and do not modify the connectivity with elevation fields. In the next dialog, click yes to model turns, check the box next to *Select_Turns*, and click Next. Notice that Minutes and Oneway are the default attributes for the network dataset. Opt to establish driving directions. After reviewing the summary, click Finish. Click Yes to build the network. Notice that *MoscowNet_ND*, a network dataset, and *MoscowNet_ND_Junctions*, a junction feature class, have been added to the Catalog tree.

Task 5: Find Closest Facility

What you need: *MoscowNet*, a network dataset from Task 4; and *firestat.shp*, a point shapefile with two fire stations in Moscow, Idaho.

1. Insert a new data frame and rename it Task 5. Add the *MoscowNet* feature dataset and *firestat.shp* to Task 5. Turn off the *MoscowNet_ND_Junctions* layer so that the map does not look too cluttered.
2. Make sure that the Network Analyst toolbar is available and the Network Analyst window is open. Select New Closest Facility from the Network Analyst dropdown menu. The Network Analyst window opens with four empty lists of Facilities, Incidents, Routes, and Barriers. A new Closest Facility layer is also added to the table of contents.
3. Right-click Facilities in the Network Analyst window, and select Load Locations. In the next dialog, make sure that the locations will be loaded from *firestat*, before clicking OK.
4. Click the Closest Facility Properties button in the Network Analyst window. On the Analysis Settings tab, opt to find 1 facility and to travel from Facility to Incident. (Uncheck the box for Oneway for emergency services.) Click OK to dismiss the dialog. Click Incidents (0) in the Network Analyst window. Then use the Create Network Location tool on the Network Analyst toolbar to click an incident point on the network. Click the Solve button. The map should show the route connecting the closest facility to the incident. Click the Directions Window button on the Network Analyst toolbar. The window lists the route's distance and travel time and details the driving directions.

Q8. Suppose an incident occurs at the intersection of Orchard and F. How long will the ambulance from the closest fire station take to reach the incident?

Task 6: Find Service Area

What you need: *MoscowNet* and *firestat.shp*, same as Task 5.

1. Insert a new data frame and rename it Task 6. Add the *MoscowNet* feature dataset and *firestat.shp* to Task 6. Turn off the *MoscowNet_ND_Junctions* layer. Select New

Service Area from the Network Analyst's dropdown menu. The Network Analyst window opens with four empty lists of Facilities, Barriers, Polygons, and Lines. A new Service Area analysis layer is also added to the table of contents.

2. Next add the fire stations as facilities. Right-click Facilities (0) in the Network Analyst window and select Load Locations. In the next dialog, make sure that the facilities are loaded from *firestat* and click OK. Location 1 and Location 2 should now be added as facilities in the Network Analyst window.
3. This step sets up the parameters for the service area analysis. Click the Service Area Properties button in the Network Analyst window to open the dialog box. On the Analysis Settings tab, select Minutes for the impedance, enter "2 5" for default breaks of 2 and 5 minutes, and check direction to be away from Facility, and uncheck Oneway restrictions. On the Polygon Generation tab, check the box to generate polygons, opt for generalized polygon type and trim polygons, select not overlapping polygons per facility, and choose rings for the overlay type. Click OK to dismiss the Layer Properties dialog.
4. Click the Solve button on the Network Analyst toolbar to calculate the fire station service areas. The service area polygons now appear in the map as well as in the Network Analyst window. Each fire station is associated with two service areas, one for 2 minutes and the other for 5 minutes. To see the boundary of a service area (e.g., 2 to 5 minutes from Location 1), you can click the plus sign to expand Polygons (4) and then click a service area.
5. This step shows how to save a service area as a feature class. Exit ArcCatalog before proceeding with the operation. First select the service area (polygon) in the Network Analyst window. Then right-click the Polygon layer in the table of contents, point to Data, and select Export Data. Save the data as a feature class in *MoscowNet*. The feature class attribute table contains the default fields of area and length.

Q9. What is the size of the 2-minute service area of Location 1 (fire station 1)?

Q10. What is the size of the 2-minute service area of Location 2 (fire station 2)?

Challenge Task

What you need: *uscities.shp* and *interstates.shp*, same as Task 3.

This challenge task asks you to find the shortest route by travel time from Grand Forks, North Dakota, to Houston, Texas.

Q1. What is the total travel distance in miles?

Q2. Approximately how many hours will it take to drive from Grand Forks to Houston using the interstates?

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