Managing Volunteer Firefighter Response

Using the OD cost matrix to model personnel availability

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Emergency responders try to arrive on the scene of a fire or other emergency as quickly and safely as possible. Career firefighters respond on a 24/7 basis from fire stations or apparatus in the field. Volunteer responders, who include firefighters and emergency medical technicians, typically respond from homes, workplaces, or random locations.

Depending on department policy and response parameters, volunteers may respond to incidents in privately owned vehicles (POVs) or drive in a POV to a nearby fire station and respond in emergency apparatus. The additional time required for a volunteer responder to travel to a station to pick up emergency apparatus must be factored into a response model. Volunteers are not always available on a consistent schedule, and this must be considered when mapping an effective firefighting force.

The ArcGIS Network Analyst extension has an Origin-Destination (OD) cost matrix function that allows public safety GIS personnel to accurately determine and map travel times and distances from volunteer locations to a fire station. The OD cost matrix also determines optimal apparatus travel time to historic incidents and to hypothetical or staged scenarios, thereby validating historic data and supporting the design of response alternatives.

The Moab Valley Fire Protection District (MVFPD) protects lives and property from fire, flood, man-made, and natural disasters in an approximately 30-square-mile district. The district encompasses the entire resort destination city of Moab, Utah, and adjacent lands in Grand County outside the city limits. According to 2000 census figures, the district's permanent population is 7,723 people and another 209 people live in the district's contract response areas. The Fire Department roster averages 40 volunteer firefighters, based in two fire stations. The department maintains three full-time employees and operates a fleet of 16 vehicles, and the district maintains three full-time employees.

The exercise presented here uses modified firefighter residence locations and actual fire station sites in Moab to map and model volunteer response parameters. Although personnel data has been masked to ensure privacy, its composition and geographic distribution are realistic.

Network Analyst and the OD Cost Matrix

Functionality in the ArcGIS Network Analyst extension for calculating travel times and/or distances between families of origin and destination points was available at ArcGIS 9.1 and updated in ArcGIS 9.2. This group function, the OD cost matrix, quickly provides emergency service providers with measures of staff availability and response effectiveness. The procedure employs the same high-quality network dataset that emergency managers use for determining service areas, optimal routing, and other tasks. The OD

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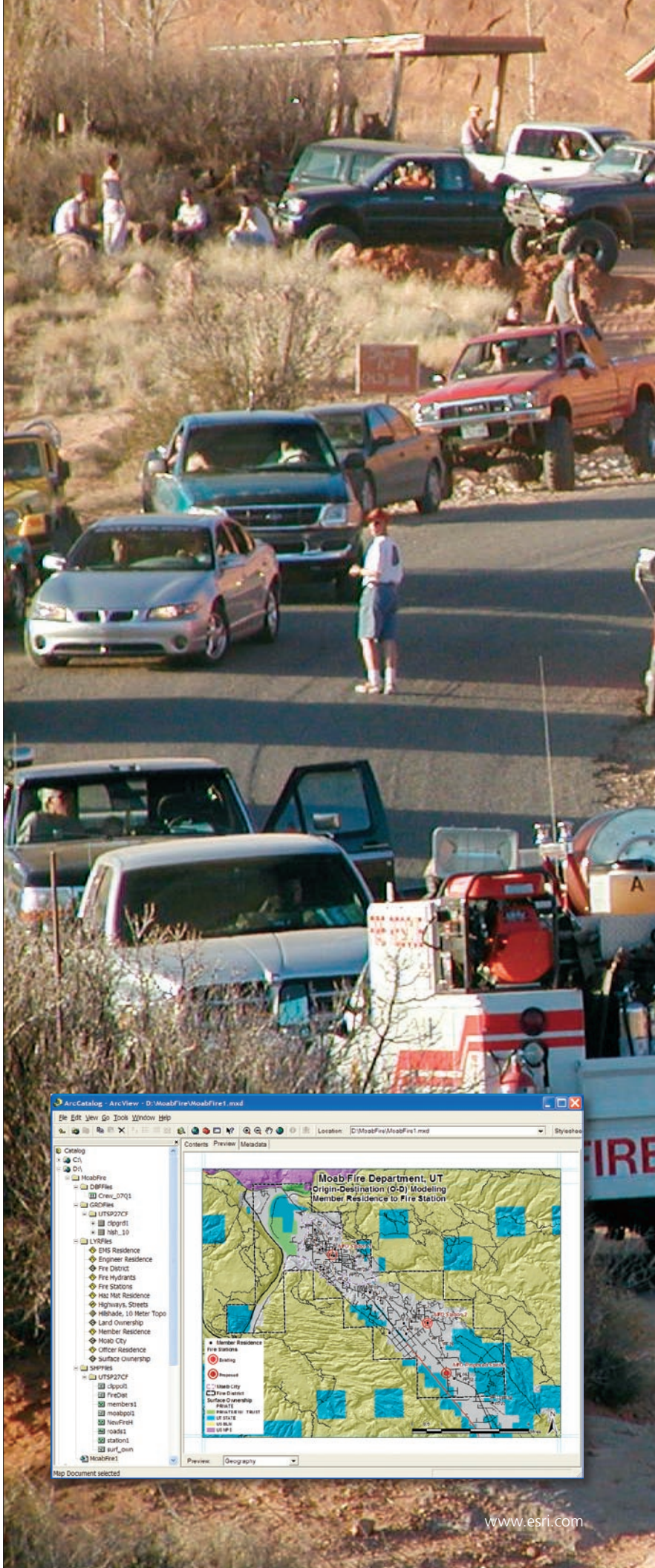


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Managing Volunteer Firefighter Response

Continued from page 44

cost matrix requires careful mapping of origin and destination point locations. The matrix records time and distance data for each pair of points and maps a two-node polyline connecting the endpoints.

Two primary uses for the OD cost matrix in public safety involve managing personnel and fire response preplanning. Emergency managers continually track availability of resources including volunteer responders. The OD cost matrix calculates travel times and distances for volunteer personnel traveling in personal vehicles from homes and offices to a station.

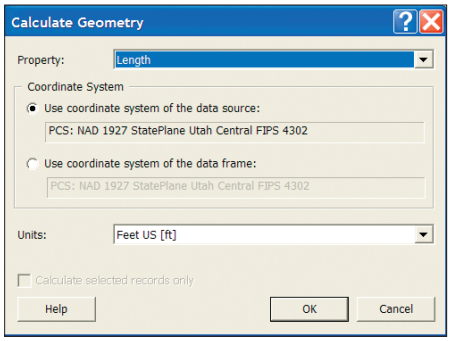
The OD cost matrix also calculates optimal travel times along shortest routes for historic incident responses; it provides a framework to confirm whether incident time tracking is accurate and determines where performance might be improved. This exercise shows how the OD cost matrix maps and assesses volunteer firefighter availability in a rural community that has 40 firefighters who will respond to any of three fire stations from their homes.

To add a bit of sophistication, this exercise will also use joined tabular data for determining travel parameters for a rotating Officer in Charge and available responders from a weekend roster. In practice, this model should be expanded to include work addresses and other predictable time-based locations for responders.

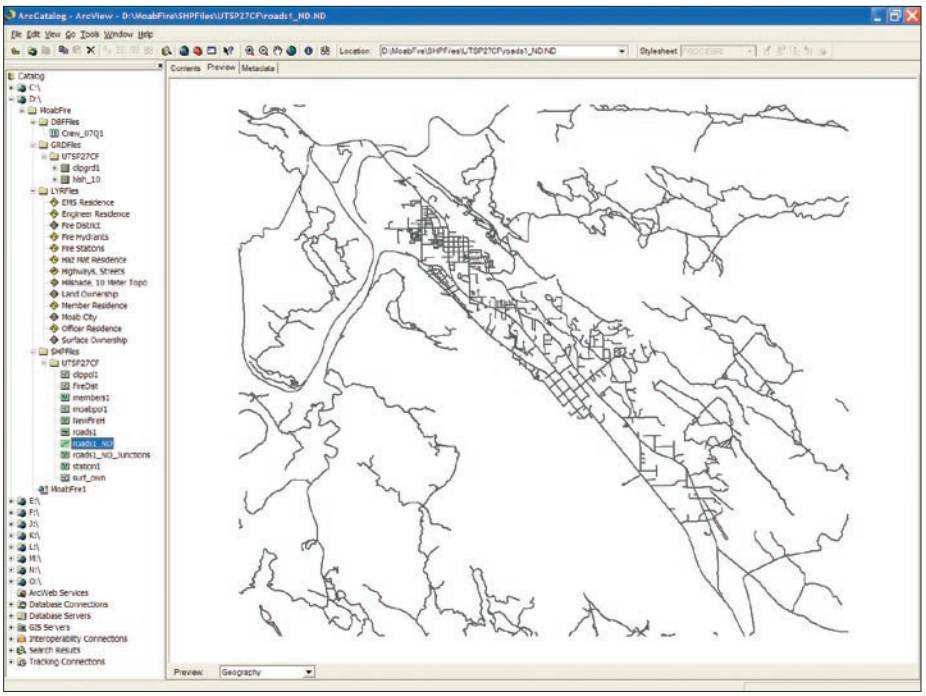
Getting Starting

1. Download the sample data for this exercise from *ArcUser Online* at www.esri.com/arcuser. Unzip the archive file in the root directory. Open ArcCatalog and inspect the files. The sample dataset contains one dBASE file, a topography hillshade grid, many Layer files, several shapefiles, and a startup ArcMap document. All data is registered in Utah State Plane Central Zone. The datum is North American Datum 1927, and units of measure are U.S. Feet.

2. Using ArcCatalog, inspect the data attributes to verify they will support time-based networking. Navigate to \MoabFire\LYRFiles\ and locate the Highways, Streets Layer file and preview its attribute table.



In the Highways, Streets attribute table, use Calculate Geometry to calculate the contents of the LENGTH_FT field.



Inspect the roads1_ND in ArcCatalog.

3. Scroll right and notice that this table contains fields for geocoding addresses. These streets are a subset of streets mapped by Grand County's Road Department as part of a U.S. Geological Survey rural transportation prototype program. This data is used by Grand County Emergency Management for geocoding incidents. The Speed_MPH column will be used to calculate travel time along segments. The three rightmost columns—Length_FT, Length_MI, and MINUTES—contain zeroes and will be used to record impedance data: segment length in U.S. feet and miles and travel time in minutes.

4. Preview the table for the Fire Stations layer. The Moab Valley has two existing stations and one proposed station, now occupied by a temporary apparatus facility. The Index and Label fields are very helpful for loading locations for network analysis.

5. Inspect the Members Residence table. It contains the same Index and Label fields. This exercise includes data for 40 firefighters including a chief, an assistant chief, two battalion chiefs, four captains, four lieutenants, and 28 firefighters. Fields on the right track training status including engineering, emergency medical, and hazardous material certifications. These fields will help verify that sufficient officers, engineers, and other specially trained personnel will be available during an emergency.

6. Finally, navigate to \MoabFire\DBFFiles\ and preview Crew_07Q1.dbf. This table lists scheduled availability of firefighters on weekends during the first three months of 2007. The number 1 indicates that a firefighter will be available through the weekend, and a 2 identifies the Officer in Charge for that weekend.

7. Click on several headers for these columns and choose Statistics from the context menu. More than 24 firefighters are available for weekend response on all but two holiday weekends, when availability drops to less than 20. (Hint: Subtract 1 from the sum to account for the Officer in Charge. The sum generated by Statistics represents 23 firefighters and one officer.)

Calculating Distances and Travel Times

Before using ArcCatalog to create the Roads_1 Network Dataset, distances and travel times must be calculated in ArcMap.

1. Start an ArcMap session and open \MoabFire\MoabFire1.mxd.

2. Open the Highways, Streets attribute table and move to the LENGTH_FT field. Right-click on this field and select Calculate Geometry, a new ArcGIS 9.2 function.

3. Set Property as Length, click on the radio button next to Use Coordinate System of the Data Source. Make sure the units are Feet US [ft] and click OK.

4. Right-click on the LENGTH_MI field header and select Field Calculator. Enter [LENGTH_FT]/5280 in the formula box, click OK, and check these calculations.

5. Calculate the travel time in minutes for each segment by opening a Field Calculator for the MINUTES column and entering [LENGTH_MI]*(60/[SPEED_MPH]) in the formula box. Click OK, check the final calculations, and return to ArcCatalog.

Creating a Network Dataset

In the ArcCatalog Catalog tree, move to /SHPFiles/UTSP27CF/, open roads1 and preview its table, particularly the rightmost fields.

1. Right-click on roads1 and select New Network Dataset. Accept default parameters for Connectivity, Connectivity Elevation, and Turns.

2. On the Attributes Setting pane, Minutes is a Network Analyst keyword. This field will be included in the dataset. Specify the distance parameter by clicking the Add button and typing Length_Mi in the Name box. Set the Units to Miles, accept other default parameters, click OK, and click Next.

3. Specify driving instructions and capture the text in the Summary screen into a WordPad document for future reference. Click Finish and build the new Network Dataset.

4. Inspect the new Network Dataset. For more information about creating network datasets, read "Got It Covered—Modeling Standard of Cover with ArcGIS Network Analyst 9.2" in the October–December 2006 issue of *ArcUser*, available online at www.esri.com/news/arcuser/1006/files/covered.pdf.

People and Places—Mapping Response Resources

Return to the ArcMap document, MoabFire1. Check that a license for an ArcGIS Network Analyst extension is available, display the Network Analyst toolbar, and open the Network Analyst window by clicking the Network Analyst window.

Parameter	Value
Load From	Fire Stations
Only Show Point Layers	Checked
Location Analysis Properties	Curb/Approach (Default) Name (LABEL)
Location Position	Use Geometry
Search Tolerance	500 Feet

Table 1: Values for loading Destination Fire Stations.

Parameter	Value
Impedance	Minutes(Minutes)
Default Cutoff Value	<None>
Destinations to Find	<All>
Allow U-Turns	Everywhere
Output Shape Type	Straight Line

Table 2: Analysis Settings tab.

1. Click the Add Data button and locate the /roads1_ND.ND in /SHPFiles/UTSP27CF and add it to the project. Because this project already includes the source roads and won't use intersection nodes, do not add other feature classes. Verify that the Network Dataset has successfully loaded.

2. Click the Network Analyst drop-down menu and select New OD cost matrix. Right-click on Origins in the Network Analyst window and select Load Locations. Select Member Residences as the Origin set, specify INDEX as the Sort Field and LABEL as the Name field, and set Search Tolerance as 500 Feet. Verify that 40 member origins load successfully.

3. Load the Destination Fire Stations using parameters in Table 1. Verify that three stations are properly mapped.

4. Now move the OD Matrix group below the Member Residences and Fire Stations layers in the table of contents. Save the map document.

5. Return to the table of contents and right-click on the OD cost matrix group name. Under the

Continued on page 48

Managing Volunteer Firefighter Response

Continued from page 47

General tab, rename it Firefighter Residence OD cost matrix. Accept defaults for the Layers and Source tabs and open the Analysis Settings tab and set them as shown in Table 2. Click the Accumulation Attributes tab and check both Length_Mi and Minutes, inspect Network Locations, and click OK to set all parameters.

6. Solve the OD cost matrix by right-clicking on its name and selecting Solve or by clicking the Solve button on the Network Analyst toolbar. Save the map document.

Mapping Responders

1. Open the attribute table for the Lines layer of the Firefighter Residence OD Matrix group. Inspect fields and observe that there are a number of informative fields including the Name of the firefighter and the modeled station, each firefighter's OriginID (i.e., the firefighter residence index), a DestinationID (the fire station index), a DestinationRank, TotalMinutes, and Total_Length_Mi.

2. Tidy up the OD vectors to highlight each station set with a different color. Minimize the table and open Lines Properties. Select the Symbology tab and change to a Unique Values legend. Specify DestinationID as the Value Field and specify 2 point lines for values 1, 2, and 3 (Stations 1, 2, and 3, via indexing). Select a bright red for 1, green for 2, and blue for 3 to show the connection between each firefighter's home and all stations.

3. Return to the Lines table and experiment with this data. Try to find the closest firefighter to each of the three stations. Who lives the farthest in time and distance from Station 1? Which station is closest to each firefighter's home? (Hint: Query for DestinationRank = 1; do you think that this time-based response information might help resolve a few arguments?)

Enhancing Response Data with Tabular Joins

The next step is to model each firefighter's weekend availability.

1. Load a table listing each volunteer's status on weekends by clicking the Add Data button and selecting Crew_07Q1.dbf from \MoabFire\DBFFiles\.

2. Open this table and inspect it. It includes fields for Label, Rank, and the helpful Index. Fields to the right of Rank contain flags listing the weekend Officer in Charge (coded with 2) and available firefighters (coded with 1).

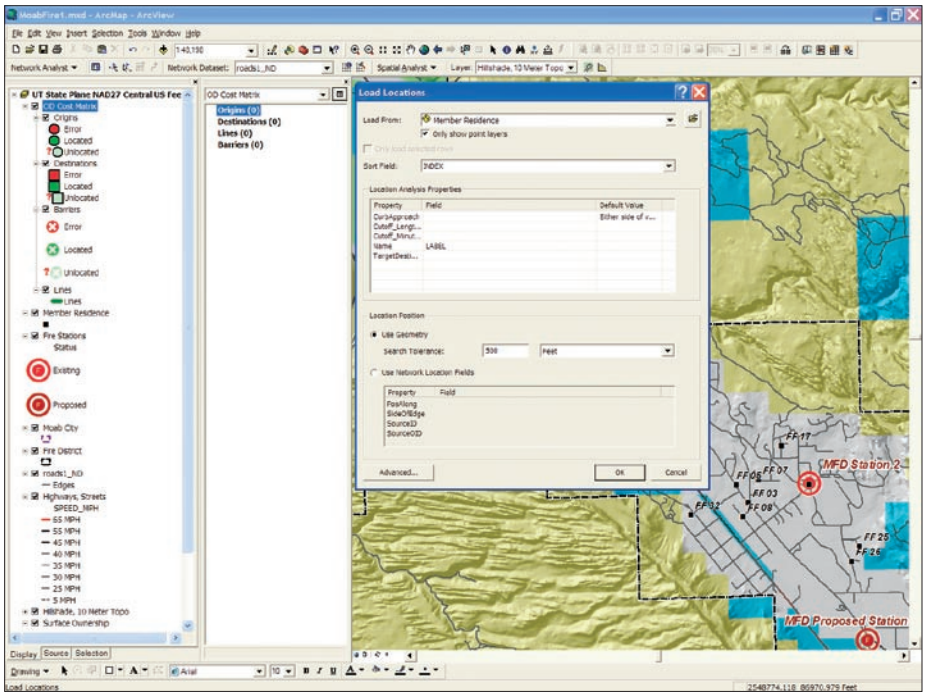
3. In the table of contents, right-click on the Member Residences and choose Joins and Relates > then Join. Select INDEX as the field that the Join will be based on, specify Crew_07Q1 as the table to join, and select INDEX as the key field in the joined table. Click OK and verify the join by opening the attribute table.

4. Repeat this process with the OD Matrix Lines. Select OriginID as the field that the Join will be based on, specify Crew_07Q1 as the table to join, and select INDEX as the key field in the joined table. Click OK and verify the join.

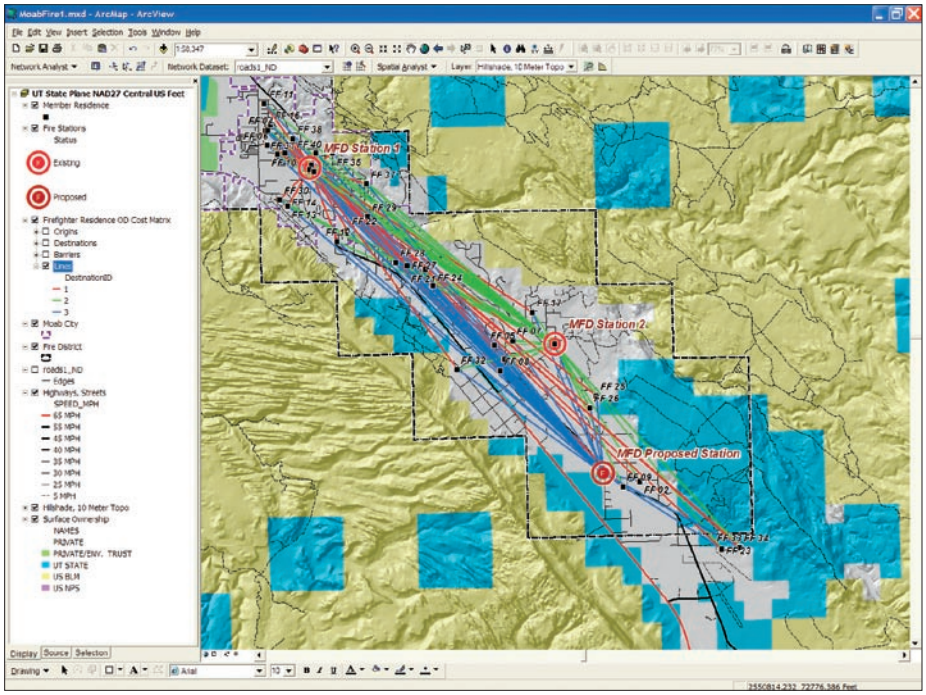
Finding Firefighters—Definition Queries Using Tabular Joins

With the weekend availability data joined to Member Residence points and OD Matrix Lines, definition queries can be applied that will show staff availability. Let's start with the first weekend in January.

1. Double-click on Member Residences, click the Definition Query tab. Click the Query Builder button and use the interface to create



After creating the roads1_ND, click the Network Analyst drop-down menu and select New OD cost matrix, right-click on Origins in the Network Analyst window, and select Load Locations to load the firefighter residence locations.



Symbolize the Lines in Firefighter Residence OD Cost Matrix layer to show the connection between each firefighter's home and all stations.

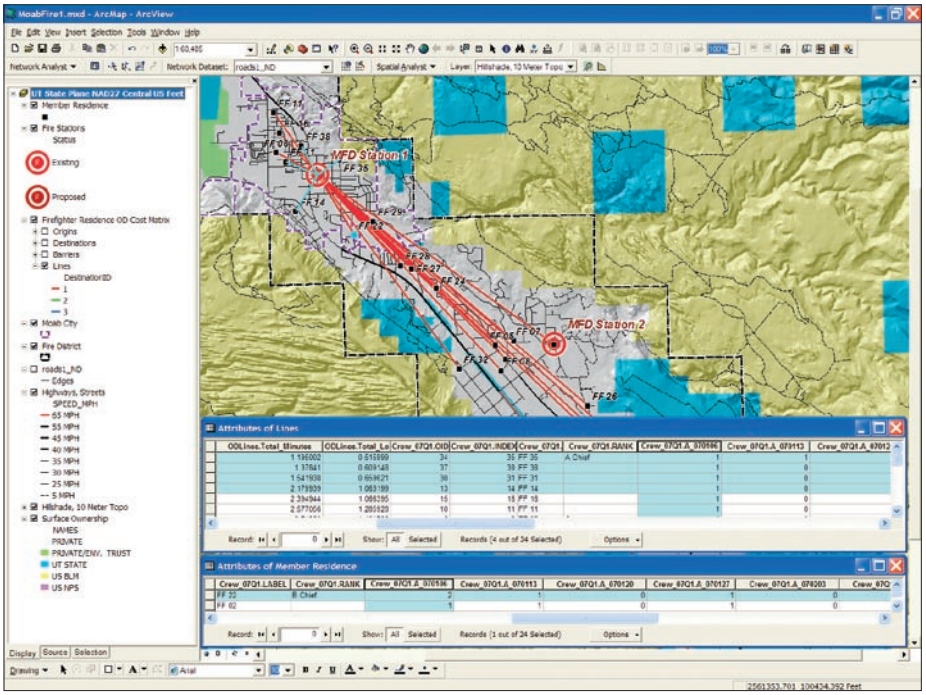
the query "Crew_07Q1.A_070106" >0 that will display all firefighters available for the weekend. Click OK.

2. Review the selection. Can you find the Officer in Charge this weekend? What is his/her rank and Engineer/Driver status? How far is the officer's home from Station 1, in terms of time and distance? This query locates the officer's home, rank (e.g., battalion chief), and engineer training but cannot display travel time to Station 1.

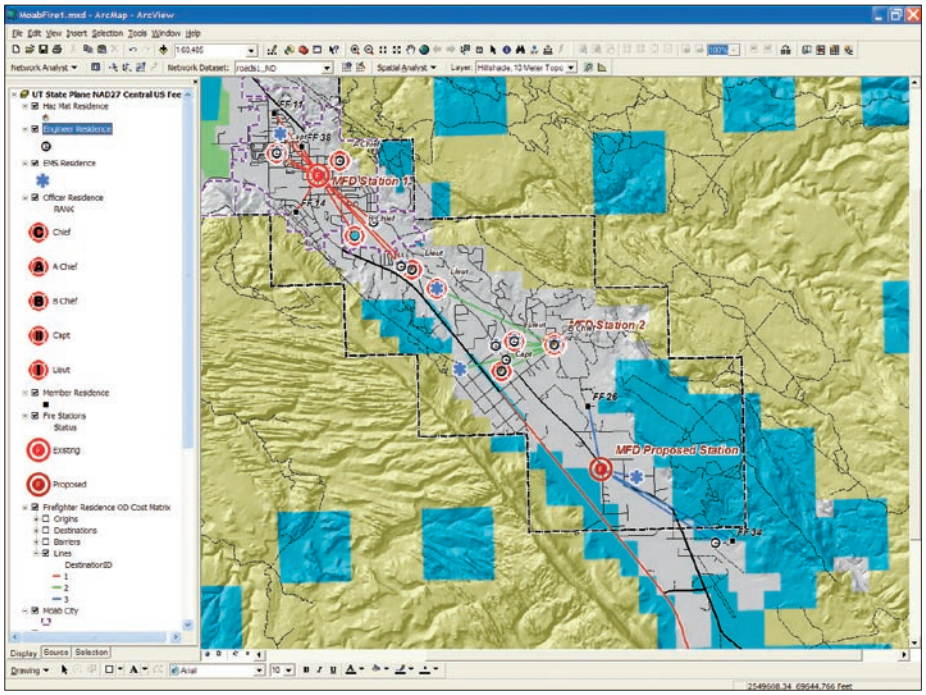
3. To map drive times for POVs requires building a second definition query for the OD Matrix Lines. Create this definition query by using the initial query to produce the expression "Crew_07Q1.A_070106" >0 AND ODLines.DestinationID=1

4. Inspect the results and locate FF 22. This officer's drive time is 2.27 minutes over a distance of 1.66 miles. Other responders should arrive at the station ahead of the weekend officer.

5. To map fastest responders, locate the ODLines.Total_Minutes field in the Lines table and sort it in ascending order. Assuming that four firefighters should be on an engine before it responds, manually select the top four records and look at them on the map. The travel time for the fourth arriving firefighter is 2 minutes; 11 seconds is the lag time between the time all firefighters leave their homes and the arrival time of the fourth crew member. This makes a basic assumption that all firefighters take the same time to react to the call and begin driving their POVs.



This map identifies the first four firefighters arriving at Station 1 and the residence location of the weekend officer.



This map shows routes to the closest station for all January 6 firefighters. It also shows firefighter status including engineers, EMTs, and hazmat technicians.

Making a Pretty Map and Experimenting with Availability Data

Included in the sample dataset are Layer files to map available fire officers, engineers, firefighters/emergency medical technicians, and hazmat technicians. Load these Layer files, then relink these layers to the members1.shp. Create your own staffing questions and remap the data.

As a challenge exercise, create tabular joins to Crew_07Q1.dbf and create definition queries for other weekends. Experiment with responses to other stations on different weekends. Pay special attention to the holiday weekends, January 13 and February 17, when a minimum number of staff members are in town and decide if staffing is adequate to handle the wide variety of emergency situations that confront Moab firefighters.

Summary

Moab's Fire Department provides exceptional service to Valley residents, relying largely upon volunteer staff. Dedicated personnel, a high level of training, and careful planning make it all possible. This article demonstrates one use of the Network Analyst OD cost matrix to answer real-world questions. The OD cost matrix has other uses in emergency management that may be the subject of future articles.

Acknowledgments

The author thanks the Moab Valley Fire Protection District and Grand County Emergency Management for providing representative data for this activity. All personnel data has been synthesized for training purposes and any resemblance to actual conditions is accidental.