

Slopes, Sharp Turns, and Speed

Refining Emergency Response Networks to Accommodate Steep Slopes and Turn Rules

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Exercises in previous *ArcUser* issues demonstrated how the ArcGIS Network Analyst 9.2 extension can be used to model essential services provided by existing and proposed fire stations in King County, Washington. In this issue, the area modeled is farther north—the city of Burnaby, British Columbia, Canada. This exercise will model optimized response areas for a fire department that have been optimized to include time-based travel penalties for steep slopes and sharp turns.

The Slope/Turns Exercise

The challenge in this exercise is to build the street dataset to display slope in percent for the Burnaby Fire Department's service area. The department is building a new fire hall. Fire Hall 7 will serve a large area in central and western Burnaby. Burnaby's irregular terrain includes slopes of more than 15 percent. To properly model time-based travel, a slope correction factor for steep streets was developed

and field-tested. The slope adjustment, together with global turn rules, was applied to posted speed limits to calculate valid travel times and define optimal response areas.

Getting Started

Download the zipped sample dataset for this exercise from *ArcUser Online* (www.esri.com/arcuser) and place it near the root of the drive that houses the project. Unzip the data and explore it in ArcGIS ArcCatalog. Note that the sample data is contained in a file geodatabase. The geodatabase includes a special feature dataset named Transportation_Model that contains a single feature class named Highways_Streets. This feature class will support time-based modeling. Study the geodatabase layer files for symbolizing municipal boundaries, fire stations, hydrants, and historic incidents and the registered JPEG and its layer file.

This exercise will model detailed slope derived from a large triangulated irregular network (TIN) model. Because the actual background TIN is too large to easily download, a picture of hillshaded slope (Slpp_300.jpg) will be used instead to emphasize steep areas.

Start ArcMap, open a new, blank map document, and save it as Burnaby1.mxd. Load the City Boundary.lyr from \Burnaby\GDBFiles\UTM83Z10\ . Check the layer's coordinate system and load Analysis Area.lyr, Streets - Slope.lyr, and Fire Halls.lyr from this same folder. Note that Streets - Slope has been thematically symbolized. From \Burnaby\JPFiles\UTM83Z10\, load Slope, Percent, Hillshade JPEG.lyr and move it to the bottom of the table of contents (TOC). Ignore the warning box about the spatial reference.

Preparing the Street Data

Open and inspect the attribute table for Streets - Slope. Eight fields in this table contain zero (0) values. Before the slope can be depicted, values for the LENGTH_KM, MINUTES_R, SLOPE_ABS, SLOPE_ADJ_1, MINUTES_S, and SPEED_ADJ1 fields will be calculated.

The values for these fields will be calculated

outside an editing session. If a field requires recalculating, simply zero out the field. Right-click on the field header, choose the Field Calculator, select the field name to zero out, input "0" into the text field, and click OK.

1. Locate LENGTH_KM field and right-click on its header. Select Calculate Geometry to calculate length of all street segments in kilometers. In the Calculate Geometry dialog box, set the Property as Length, the Coordinate System to Use Coordinate System of the Data Frame, and Units as Kilometers and click OK.
2. To calculate the unadjusted travel time, right-click on MINUTES_R and choose the Field Calculator. In the Field Calculator text field, input the following equation and click OK.

$$[\text{Length_Km}] * (60 / [\text{SpeedZone}])$$

3. Next use the Field Calculator to determine the absolute slope and place that value in the SLOPE_ABS field. Remove the previous formula from the text field. Choose the Abs function from the list of functions and select the SLOPE1 field. Abs ([Slope1]) should display in the text field. Click OK.
4. Move the table if necessary to look at the changes these calculations have made to the thematic display of the Streets - Slope layer. Keep the Streets - Slope table open and save the map document.

Calculating Slope Adjustment

1. In the Streets - Slope table, calculate slope adjustment factor by right-clicking on the Slope_Adj1 field header, choosing Field Calculator, and removing the previous formula from the text field. Input the following equation and click OK.

$$1 + ([\text{Slope1}] / 10)^2$$

Slope_Adj1 is a multiplication factor that increases travel time for steep slopes.

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Introducing Burnaby

Originally a rural agricultural area, Burnaby, British Columbia, received city status in 1992 and has developed into a major business, residential, and transportation corridor between Vancouver and British Columbia's Lower Mainland. With a population of 202,799 (in 2006) and an areal extent of nearly 100 kilometers, Burnaby is the third largest urban center in the province. It is bordered by the Burrard Inlet on the north and the Fraser River to the south. Burnaby's landscape is characterized by hills, ridges, valleys, and an alluvial plain. Elevation ranges from mean sea level to 375 meters. Land features have controlled and constrained development throughout this community.

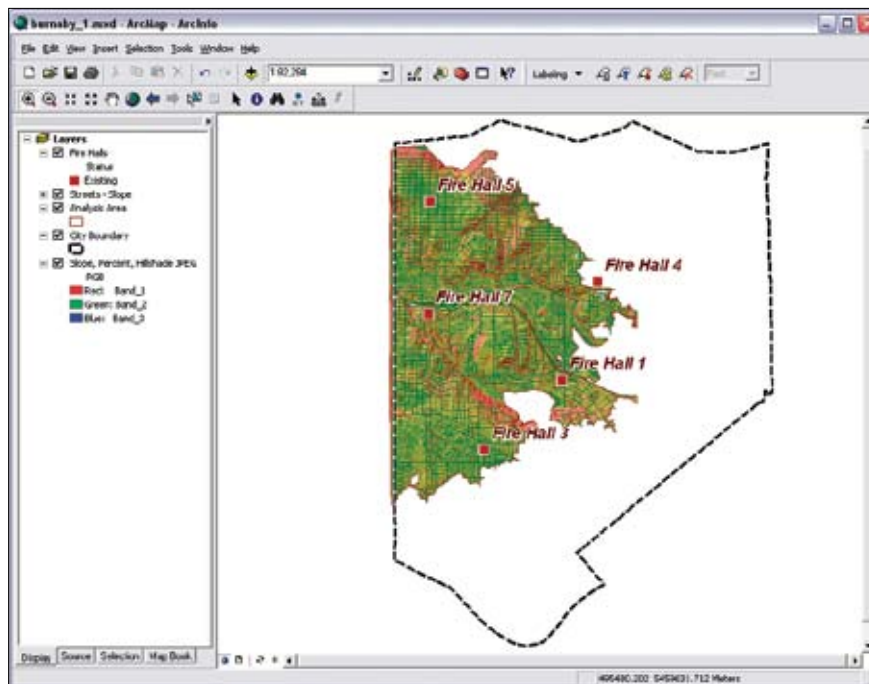
The Burnaby Fire Department serves the entire municipal area and provides aid response into neighboring jurisdictions. The department staffs six fire halls, and a new station will open soon. The first line of response includes six first line engines, four ladders, a command unit, rescue truck, an equipment truck, and other specialized equipment. The agency's fire suppression and administrative staff numbers 286. In 2006, the department responded to 13,400 calls. The Burnaby Fire Department works closely with the city's excellent Engineering Department to plan and optimize service throughout the area. Burnaby Engineering uses ArcGIS Network Analyst to optimize response areas.

What You Will Need

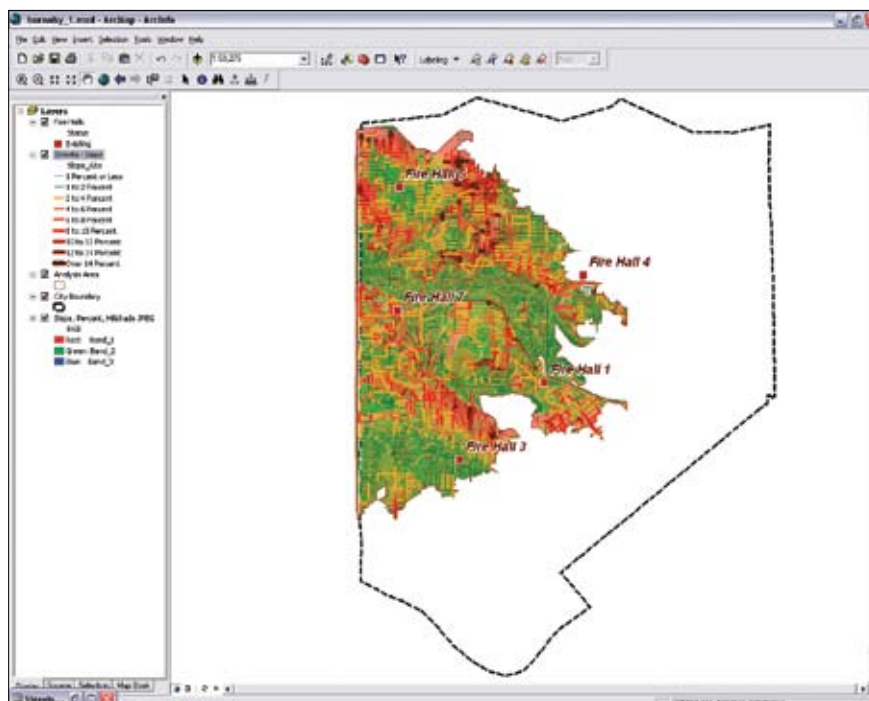
- ArcGIS Desktop 9.2 (ArcInfo, ArcEditor, or ArcView license level)
- ArcGIS Network Analyst 9.2 extension
- Sample data from [ArcUser Online](#)

Slope (in percent)	Travel Time Multiplier	Comments
0	1.00	Base time
1	1.01	
2	1.04	
3	1.09	
4	1.16	
5	1.25	1.25 times as long
6	1.36	
7	1.49	
8	1.64	
9	1.81	
10	2.00	Twice as long
11	2.21	
12	2.44	
13	2.69	
14	2.96	
15	3.25	
16	3.56	
17	3.89	
18	4.24	
19	4.61	
20	5.00	5 times as long
21	5.41	
22	5.84	
23	6.29	
24	6.76	
25	7.25	
26	7.76	
27	8.29	
28	8.84	
29	9.41	
30	10.00	10 times as long
35	13.25	
40	17.00	Very steep

Table 1: Slope Adjustment Factors



After downloading and unzipping the sample dataset, load City Boundary.lyr, Analysis Area.lyr, Streets – Slope.lyr, and Fire Halls.lyr, and the JPEG image of a hillshade.



Note the effects the field calculations have made on the symbolization of the Streets – Slope layer.

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Table 1 shows the empirical slope factors in 1 percent intervals. Notice that it takes twice as long to climb or descend a 10 percent slope than it does to travel on flat street segments.

- Now, calculate the slope-adjusted travel time in minutes. Right-click on the MINUTES_S field header, choose Field Calculator, remove the previous formula from the text field, and input the following formula:

$$[\text{Minutes}_R] * [\text{Slope}_Adj1]$$

- Calculate slope adjusted travel speed in minutes. This calculation incorporates the slope adjustments in Table 1 and generates the equivalent speed for travel on each street segment. Right-click on the [Speed_Adj1] field header, choose Field Calculator, remove the previous formula from the text field, and input the following equation:

$$([\text{Length}_Km]/[\text{Minutes}_S])*60$$

- Save the map document.

Building the Street Network Dataset

Close ArcMap and open ArcCatalog. In the Burnaby_Fire geodatabase, navigate to the Transport_Model feature dataset and refresh ArcCatalog. Select the Highways_Streets feature geodatabase class, click on the Preview tab, and choose Table from the drop-down. Look at the ONE_WAY, F_ELEV, and T_ELEV fields.

- In ArcCatalog, choose Tools > Extensions and check the box next to Network Analyst.
- Right-click on Transport_Model, choose New > Network Dataset, name the new dataset Transport_Model_ND, and click Next.
- Check the box next to the Highways_Streets feature class and click Next.
- Click the Connectivity button and note that End Point connectivity is checked. Click Next.
- Click to modify connectivity with the elevation fields F_ELEV and T_ELEV. Click Next.
- Accept Global Turns and click Next.

Defining Network Attributes and Turn Rules

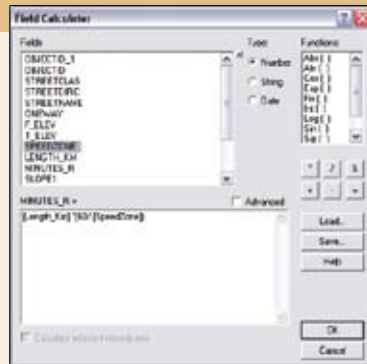
Network attributes for time and distance travel must now be specified.

- Click the Add button. In the wizard pane to specify the attributes for the network dataset, add the Length_KM, Minutes_R, and Minutes_S fields and set the values as shown in Table 2.
- If Oneway is not already set as a default, right-click on it and set it as a default.
- In the same wizard pane, highlight Minutes_S and click the Evaluators button.
- Click the Default Values tab. Right-click the element named Turn, choose Type, and click VBScript.
- With the Turn element still highlighted, look for the Evaluator Properties button on the right side of the wizard pane. Click on it.
- In the Script Evaluators dialog box, make sure Turn is set as type, and click the Load button. Navigate to the \Burnaby\Utility folder. Locate and load TurnTime.sev. Click OK.

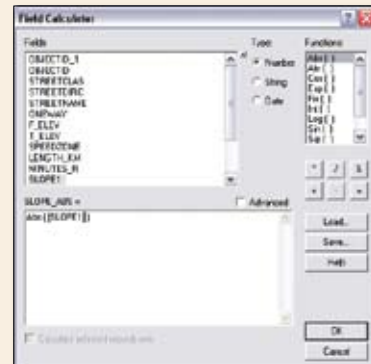
Preparing Street Data



Use Calculate Geometry to calculate all the street segments in kilometers.



Use the Field Calculator to generate unadjusted travel time values for the MINUTES_R field.

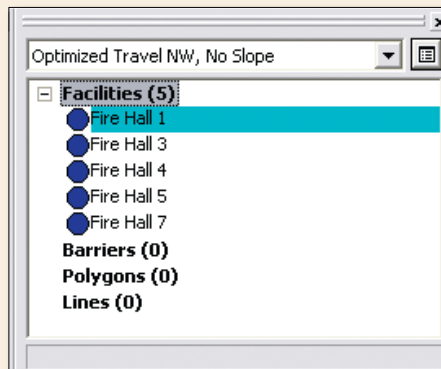


Use the absolute value function on SLOPE to obtain absolute slope values.

Loading Fire Hall Locations



Load the fire hall locations into the network and set the sort field as INDEX and the search tolerance at 200 meters.



Once the fire hall locations have been loaded, check that halls 1, 3, 4, 5, and 7 are listed in the Network Analyst window.

Name	Usage Type	Units	Data Type	Set as Default
Length_KM	Cost	Kilometers	Double	No
Minutes_R	Cost	Minutes	Double	No
Minutes_S	Cost	Minutes	Double	Yes

Table 2: Values for new network dataset

- Back in the previous dialog box, select Minutes_R from the Attribute drop-down box. Right-click the element named Turn, choose Type, then click VBScript.
- With the Turn element still highlighted, look for the Evaluator Properties button on the right side of the wizard pane. Click on it.
- In the Script Evaluators dialog box, make sure Turn is set as type and click the Load button. Navigate to the \Burnaby\Utility folder. Locate and load TurnTime.sev. Click OK. Click Apply. Click OK.
- Back in the New Network Dataset wizard pane, click Next. These 10 steps have established the turn rules for the streets corrected for slope

- and streets not corrected for slope. The default turn rules in TurnTime.sev specify a 10-second delay for left turns, a 5-second delay for right turns, and a 2-second delay for straight travel from one segment to the next. A 30-second penalty is imposed on U-turns. Table 3 lists the turn rules applied for municipal areas.
- In the next wizard pane, click Yes to establish driving directions.
- Review the summary page for the New Network Dataset, select the text, copy it to the Windows clipboard, and paste it into a WordPad document. Save it as NW_YYMMDD.rtf (i.e., year, month, day) in the \Utility folder.

- Click Finish and click Yes to build dataset. Wait while the network dataset builds.

Adding the Network Dataset

The next steps add the network dataset to the map document so travel can be modeled.

- Close ArcCatalog and restart ArcMap and open Burnaby1.mxd.
- Add Transport_Model_ND from the Transport_Model feature dataset in the GDBFiles folder. Do not add other participating feature classes. Move the network dataset below Highways, Streets and turn it off.
- Right-click on the Streets - Slope layer and choose Zoom to Layer.
- Enable the Network Analyst extension. Choose Tools > Extensions and check Network Analyst. Add the Network Analyst toolbar and dock it at the top of the map.
- Make the Network Analyst Window visible by clicking the Show/Hide Network Analyst Window button on the Network Analyst toolbar.

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Defining Attributes and Turn Rules



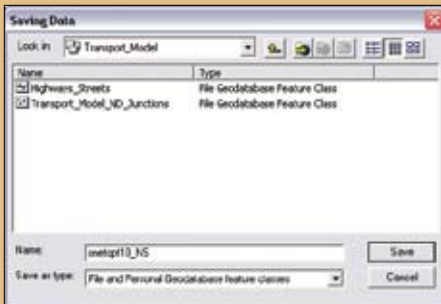
In ArcCatalog, set the network attributes for time and distance travel using the New Network Dataset wizard.



Under the default values for the Turn element for the MINUTES_S Evaluator, attach a VBScript.



Apply TurnTime.sev to the Evaluator for MINUTES_S.



After joining the fire hall attributes to the network analysis layers, save these layers as feature classes so they are permanent and can be shared. Store these feature classes in the Transportation Model in the Burnaby geodatabase.



Use an expression to label the service areas with the area of each in square kilometers.



In the Optimized Travel Network, Slope attribute table, summarize on the LABEL field using the Shape_Length statistics.

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Setting Up Service Areas

The steps in this section create the service areas and load fire hall locations.

1. On the Network Analyst toolbar, click the Network Analyst drop-down and select New Service Area. Click the Properties button on the top of the Network Analyst Window and name this service area Optimized Travel NW, Slope.
2. Repeat this process to build a second service area called Optimized Travel NW, No Slope.
3. Create a new layer group, name it Optimized Travel NW Group, and drag and drop both service areas to add them to the group. Move Optimized Travel NW Group to the bottom of the TOC, above Slope, Percent, Hillshade JPEG.

Loading Fire Hall Locations into the Network

The following steps will be applied to both the no slope and slope network datasets to load the fire hall locations.

1. Change the network dataset in the Network Analyst Window drop-down to Optimized Travel NW, No Slope. Right-click on Facilities (0) and choose Load Locations. In the Load Locations dialog box, add the parameters shown in Table 4. Click OK. Facilities now shows (5) items. Expand the entry to see that fire halls 1, 3, 4, 5, and 7 have loaded.
2. Change the Network Analyst Window drop-down to Optimized Travel NW, Slope. Using the same procedure and parameters, load fire hall locations into this dataset.
3. Save the map document.

Field	Value
Load From	Fire Halls
Sort Field	Index
Name	LABEL
Search Tolerance	200 Meters

Table 4: Fire hall location parameters

Defining Travel Area Parameters for No Slope and Slope

1. Right-click on the Optimized Travel NW, No Slope layer in the TOC and choose Properties.
2. Click on each tab listed in Table 5 and change the settings as indicated. On the Analysis Settings tab, make sure the Impedance is set to Minutes_S (Minutes). This is an important parameter and it is not a default. Double-check these parameters and click Apply and OK.
3. Save the project.
4. Repeat these analysis selections for Optimized Travel NW, Slope service area.
5. Save the map document.

Turn Rule	Right-Turn Penalty (in seconds)	Left-Turn Penalty (in seconds)	U-Turn Penalty (in seconds)	Straight Line Travel Penalty (in seconds)
No Penalty	0	0	0	0
Slight Penalty	1	2	10	0
Moderate Penalty	2	4	20	0.5
High Penalty	3	5	30	1
Very High Penalty	5	10	30	2
Turn Angle, Minimum	30	210	150	330
Turn Angle, Maximum	150	330	210	30
Turn Angle, Range	120	120	60	60

Table 3: Turn rule options

Tab and Parameters	Setting
Analysis Settings Tab	
Impedance	Important: Use Minutes_S (Minutes) for Slope. Use Minutes_R (Minutes) for No Slope.
Default Breaks	10
Oneway	check Restrictions
Polygon Generation Tab	
Generate Polygons	Check
Detailed	Select
Trim Polygons	Check and Set Trim to 200 Meters
Multiple Facilities Options	Not Overlapping
Overlap Type	Disks (Not essential but a good habit)
Line Generation Tab	
Generate Lines	Check
Include Network Source Fields	Check
Overlap Options	Not Overlapping
Accumulation Tab	
Minutes_S, Minutes_R, Length_Km	Check

Table 5: Travel area parameters

Solving

With all the parameters established for the network datasets, the network solver can be applied.

1. With the Optimized Travel NW, No Slope selected in the Network Analyst Window drop-down, click the Solve button on the Network Analyst toolbar. When the process is complete, five polygons will be added to the Network Analyst Window. Save the map document.
2. Change the drop-down to Optimized Travel NW, Slope and use the same process as in the previous step. Save the document again.
3. Turn off the Streets - Slope and Slope, Percent, Hillshade JPEG layers and turn the

Optimized Travel NW, Slope and Optimized Travel NW, No Slope layers on. Inspect both network solutions to discern the differences between them.

4. Save the map document.

Joining Attribute Tables

Right-click on Polygons in the Network Analyst Window for either service area and open the attribute table. Notice the table contains a NAME field that lists the responding station and the 10-minute maximum time. Open and inspect the Line attributes table for one of the service areas. Lines contain only a Facility ID for the related fire hall but no fire hall name. These network output file attribute tables will

require tabular joins back to the Fire Halls layer attribute table.

1. Join the Fire Halls table with the polygon and line attribute tables to incorporate this data. Right-click on Polygons in the Optimized Travel NW, Slope layer in the TOC and choose Joins > Joins and Relates. Fill in values for the Join Data dialog box using the parameters in Table 5. Click OK.
2. Repeat this process for the lines in Optimized Travel NW, Slope and for polygons and lines in Optimized Travel NW, No Slope. It is clear now why the Fire Halls were indexed. Open the attribute tables to ensure the joins were made correctly. If not, right-click on the layer and choose Joins and Relates > Remove Joins.
3. Save the project.

Join Parameter	Value
Field in this layer that the join will be based on	FacilityID
Table to join to this layer	Fire Halls
Field in the table to base the join on	INDEX

Table 6: Join parameters

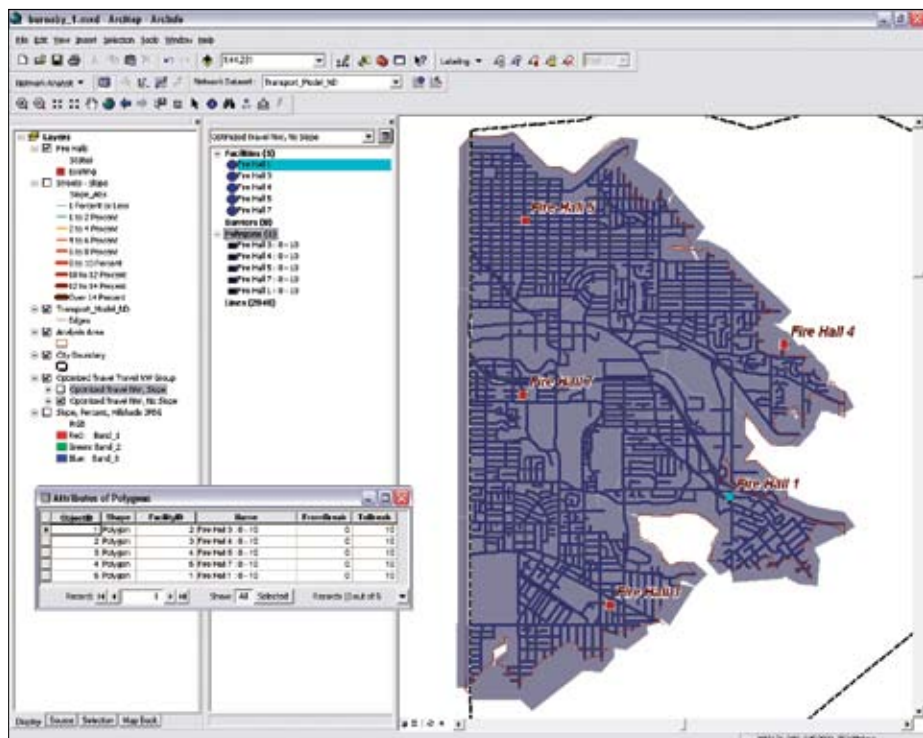
Exporting Travel Areas and Travel Networks to New Feature Classes

The results of a service area solver are stored in the ArcMap document. To share these results with others, network solutions can be saved as geodatabase feature classes or shapefiles.

1. Make sure ArcCatalog is closed. In the ArcMap TOC, right-click on Lines in the Optimized Travel NW, No Slope layer and choose Data > Export Data.
2. Export All features using the layer's coordinate system. Click the folder icon button to browse to Burnaby_Fire.gdb\Transport_Model. Set Save as type to Personal and File Geodatabase feature classes. Name the file snetopt10_NS. Add the feature class to the map document.
3. Save the map document.

Network Analysis Layer	Feature Class Name
Optimized Travel NW, No Slope, Lines	snetopt10_NS
Optimized Travel NW, No Slope, Polygons	sareaopt10_NS
Optimized Travel NW, Slope, Lines	snetopt10_SL
Optimized Travel NW, Slope, Polygons	sareaopt10_SL

Table 7: Names for exported feature classes
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After setting the travel area properties, click the Solve button to generate the service area polygons.

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Organizing and Symbolizing Travel Areas and Networks

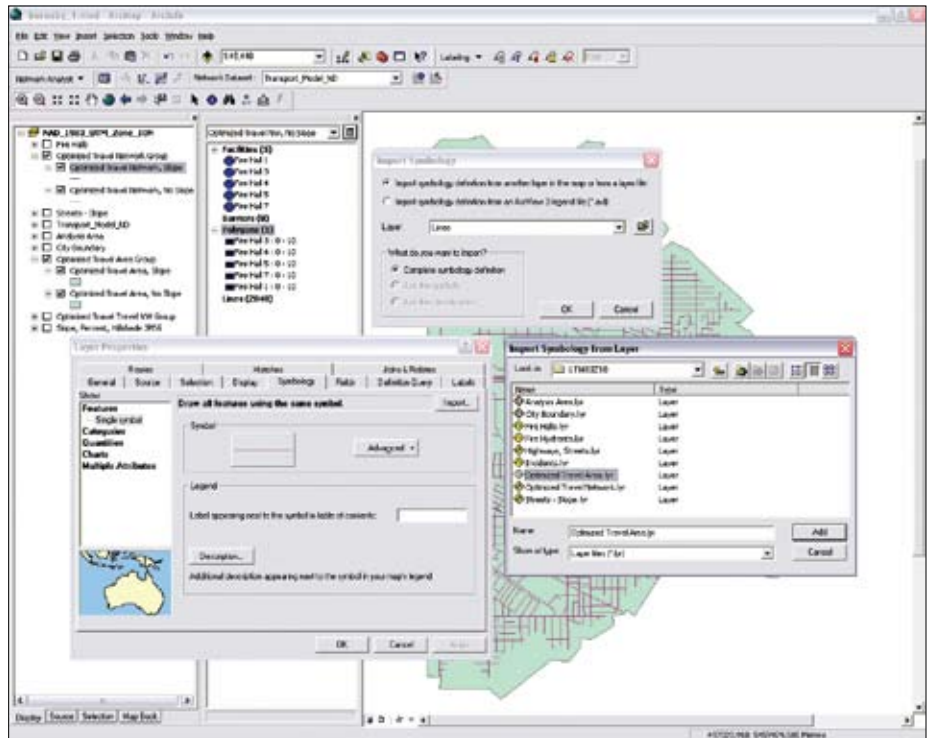
After creating feature classes for the networks and areas, grouping and symbolizing them will make comparing them easier.

1. Minimize all layers and groups in the TOC. Create a new group and name it Optimized Travel Network Group. Place this group below Fire Halls.
2. Rename snetopt10_SL to Optimized Travel Network, Slope and drag it to the Optimized Travel Network Group.
3. Rename snetopt10_NS to Optimized Travel Network, No Slope and drag it to the Optimized Travel Network Group.
4. Create another new group, call it Optimized Travel Area Group, and place this group above the Travel NW Group.
5. Rename sareaopt10_SL to Optimized Travel Area, Slope and place it in the Optimized Travel Area Group.
6. Rename sareaopt10_NS to Optimized Travel Area, No Slope and place it in the Optimized Travel Area Group.
7. Double-click on the Optimized Travel Area, Slope layer. Click the Symbology tab and click the Import button. Navigate to Optimized Travel Area.lyr in E:\02_TESTDRIVE\Burnaby_1\GDBFiles\UTM83Z10 to import its thematic symbology. Repeat this process for Optimized Travel Area, No Slope.
8. Use the same procedure to import the Optimized Travel Network.lyr symbology for Optimized Travel Network, Slope and Optimized Travel Network, No Slope.

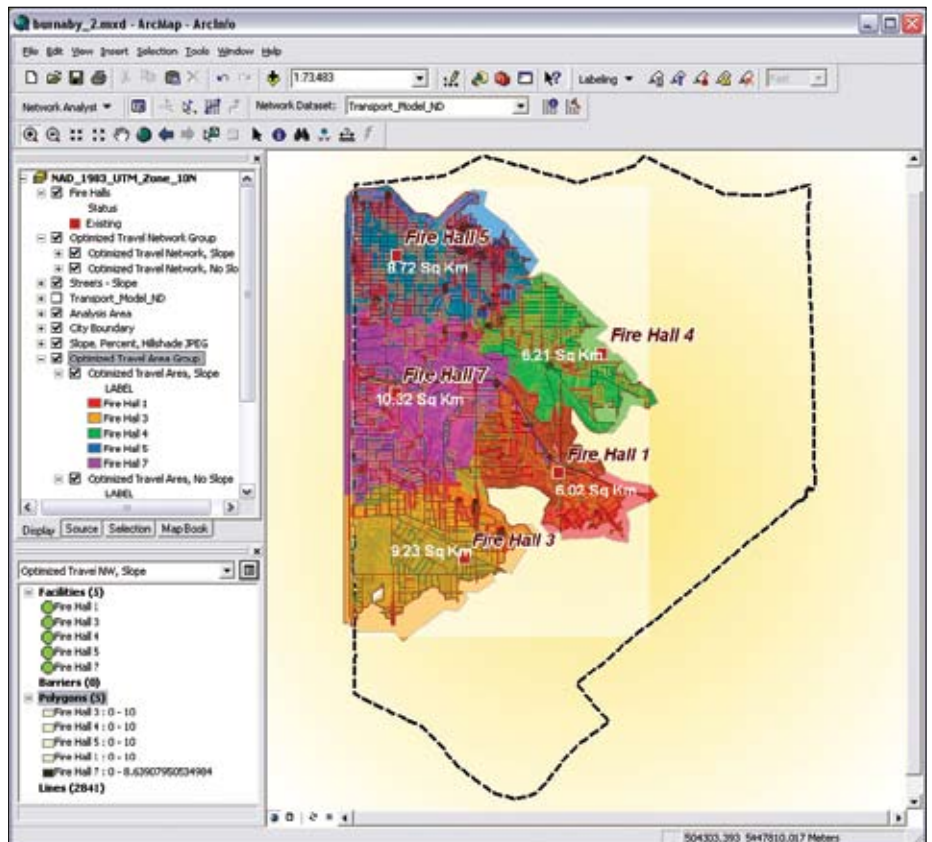
Calculating Optimized Area for Each Fire Hall

Now summarize the characteristics of the optimized travel areas.

1. Open the attribute table for Optimized Travel Area, Slope and notice that each fire station has only one footprint polygon. The area is calculated in square meters. To label each polygon with the area in square kilometers requires only applying a simple math function and rounding.
2. Right-click on the Optimized Travel Area, Slope layer name in the TOC and click Label Features. Right-click on this layer again and select Properties. Click on the Label tab. Change the text symbol color to white, bold, and 12 points. Do not close this dialog box.
3. Click the Expression button. Type `ROUND([Shape_Area]/1000000,2) & " Sq Km"` into the formula window. Click the Verify button to check the calculation and see a sample label. Click OK.
4. Looking at the service areas, new Fire Hall 7 has the largest area (10.32 sq



After generating the service areas and networks, use the layer files in the sample dataset to quickly symbolize these layers.



When complete, the map allows the service areas and fire hall locations to be easily compared visually.

km) and Fire Hall 4 has the smallest (6.21 sq km). To effectively model response areas for all Burnaby fire halls would require building a complete three-dimensional street network and adding the other stations located outside of the study area.

Calculating Total Street Length Traversed by Each Fire Hall

Open the Optimized Travel Network, Slope attribute table. Note that each fire hall has multiple street segments. The Label field

identifies which segments correspond with each station. The next step will be to summarize this data to assign total kilometers to each station.

1. Open the attribute table for Optimized Travel Network, Slope.
2. Right-click on the Label field and choose Summarize.
3. Summarize on LABEL. Under statistic to summarize on, scroll to the bottom of the list, expand Shape _Length, and check Sum.

4. Name the table snetopt10_SL_Sum1, specify that it is a File and Personal Database Table, and store it inside Burnaby_Fire.gdb.
5. Add the summary table into the map and open it. Notice that Fire Hall 5 protects nearly 98 km of streets while Fire Hall 4 protects only a little more than 50 km. (Note that the dataset was clipped for training purposes.) The new Fire Hall 7 protects nearly 84 km of streets including a significant portion of Highway 1.

Conclusion

In this exercise, slope- and turn-adjusted time-based optimum response areas were used for carefully defining primary response areas for each fire hall and its neighboring stations. Modeling coverage for existing and proposed stations often requires running multiple models and summarizing value, hazard, risk, and protection within all station footprints for multiple scenarios. This requires a bit of work, but the results are very convincing.

Acknowledgment

The author thanks the City of Burnaby Fire Department, the Burnaby Engineering Department, and ESRI Canada Limited for the opportunity to define and test this complex time-based solution and for the opportunity to use it in a training mode.

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