

CASPER for ArcGIS

User Manual

A Network Analyst Dynamic Evacuation Routing Extension



CASPER

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Introduction

This how-to document covers what the end user needs to know about “Evacuation Routing Analysis”. It is recommended that the user gets familiar with other built-in Network Analyst tools beforehand. Repetitive instructions that are common among other analysis like ‘Route’ and ‘Closest Facility’ will not be highlighted here. The Following link is a good online tutorial in this regard.

<http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//00470000005r000000.htm>

Installation

Download: <http://www.esri.com/arccasper>
Source code: <http://github.com/spatial-computing/CASPER>
Nightly Builds: <http://www.dropbox.com/sh/b01zkyb6ka56xiv/oOjJBINPlr>
Technical Article: <http://www.sciencedirect.com/science/article/pii/S0198971514000428>
Support: <http://www.facebook.com/casper4gis>

In order to install, first unzip the downloaded file. Next, install both versions of the [Visual C++ Redistributable packages](#). Then execute the "install.cmd" script. This script needs to run as administrator in Windows Vista and later operating systems. Make sure any previous installation is completely uninstalled. After installation, you should not move the content of the folder specially the DLL files. The script is going to install both 32bit and 64bit editions. You will need ArcGIS [64bit background geo-processing patch](#) in order to take advantage of the 64bit evacuation routing and simulation.

To uninstall the tool, simply execute the “uninstall.cmd” script and then remove the folder. Don’t forget to backup your data.

Requirements:

- [Visual C++ Redistributable Packages for Visual Studio 2013](#)
(Install both x86 and x64 versions)
- ArcGIS Desktop 10.3
- Network Analyst Extension
- (Optional) Background Geoprocessing (64-bit)
- (Optional) ArcGIS Desktop C++ SDK: only if you want to compile the program yourself

Caution: After upgrading your tool, your analysis layer may become unsolvable or unreadable due to incompatibilities. To avoid this, always export the evacuation data (evacuees, routes, etc.) before attempting to upgrade or downgrade. Note that ArcMap stores all network feature layers in the map document (.mxd) itself and not in the provided geodatabase.

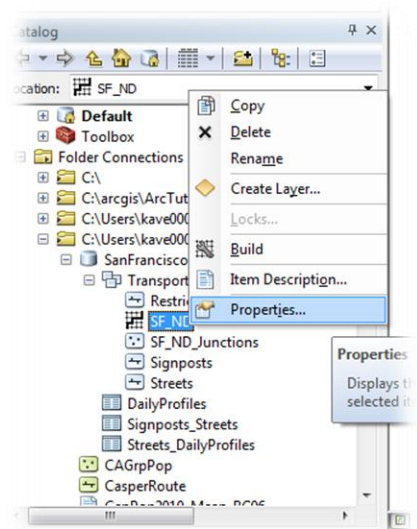


Figure 1: Network Dataset Properties

Section 1: Build a Network Dataset

In order to create and build a network dataset from your street data files please follow the link below:

http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/Exercise_1_Creating_a_network_dataset/00470000005t000000/

Once your network dataset is ready, you need to create one additional network attribute called “Capacity”.

Steps:

1. Start ArcMap by clicking Start > All Programs > ArcGIS > ArcMap.
2. Enable the Network Analyst extension if you haven’t done so already.
 - a. Click Customize > Extensions.
 - b. The Extensions dialog box opens.
 - c. Check Network Analyst.
 - d. Click Close.
3. Open the Catalog window. Click Window > Catalog.
4. Locate your network dataset, then right click on it and select “Properties” (Figure 1).
5. Navigate to the “Attributes” tab. Here you will see previously identified attributes.
6. Add “Capacity” attribute:
 - a. Click “Add”
 - b. Choose the name “Capacity”
 - c. Usage type “Descriptor”
 - d. Data Type “Double” or “Integer”. It depends on the related street shapefile field type.
 - e. Click OK when you are done.
7. Click “Apply”.
8. Now select “Capacity” from the list and click “Evaluators”.

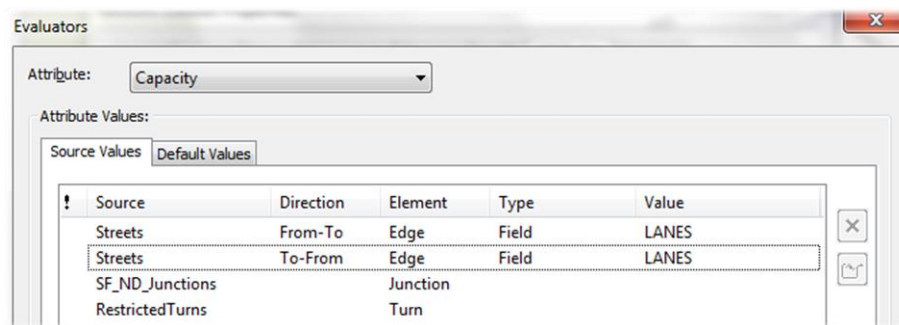


Figure 2: Capacity Network Attribute Evaluator

9. Now you have to specify which field of your street shapefile indicates road width or capacity. For example number of lanes could be one possibility. Set this only for the edges and leave the junction empty (Figure 2). If you do not see your desired field, go back to step 6.d and change the data type. When you are done click “OK”.
10. Click OK to exit network properties.
11. Build the network dataset.

Section 2: Identify Zones

In order to perform an evacuation routing, you need at least two sets of points: Safe Zone Points, and Evacuee Points. DynamicChanges zone is a polygon and it is an optional input. Safe zones are simply locations on the map where evacuees need to be routed to. Each safe zone has a capacity which limits the number of evacuees routed to each safe zone. If you want to have some safe zones with unlimited capacity, set their capacity to -1.

Evacuee points are locations of people who are in danger. Each evacuee point needs to have a name field and a VehicleCount field. The VehicleCount indicates the number of cars at that location that need to be evacuated. The tool does not care about the number of people in each car. For example, if you are using the US population data, you need to calculate the estimated number of cars per each location beforehand.

The DynamicChnage zone is a collection of polygons with start and end times. Each polygon identifies an area where part of the road network is altered for a specific period of time. You can think of this as a more advanced “Barriers” similar to what Closest Facility Analysis provides. With these polygons you can model an evacuation in a dynamically changing environment. For example, if you want to generate an evacuation plan after an earthquake where some part of the road network is damaged, or if you are working on flood evacuation and want to take into account the moving flood as the evacuation is happening, this would be for you. In order to correctly model these dynamic road changes, you need to have a polygon that encloses all road changes. For each polygon you have 5 attributes that will help you customize how these changes should be applied to the road network:

- **EdgeDirection:** Among all edges inside the polygon which ones should be affected? This is determined by the travel direction of the edge.
- **StartingCost:** This is the time that polygon changes will start to affect the evacuation. A value of 0 means it is in effect from the beginning. The unit of this value is the same as the selected network impedance.
- **EndingCost:** The end time for the changes. A value of -1 means the changes will stay forever. It’s worth mentioning that these changes are only local to this particular evacuation layer. The actual data in the network dataset are not altered.
- **CostChangeRatio:** This ratio indicates how much the costs of affected edges change. A value of 2 means that traffic on these edges are 2 times slower. A value of 10,000 means the affected edges are completely blocked.
- **CapacityChangeRatio:** This ratio indicates how much the capacities of affected edges change. For example a value of 0.5 means that these edges now have half the lanes they use to have. A value of 0.01 means the roads do not have any useable lanes/capacity.

Load Location Settings

Every time you load your data to a particular sublayer (Zones, Evacuees, or DynamicChanges) the Network Analyst Extension locates your data on the network dataset. Based on the results, it creates the necessary network analysis objects. After this process, each data point is tied either to a network junction or a network edge. For example after loading safe zone points, each safe point will be assigned to an edge and will reside along that edge. Additionally, 4 extra fields are populated on the sublayer: SourceID, SourceOID, PosAlong,

and SideofEdge. The user can control when to assign the data to junctions and when to assign them to edges. In order to change this behavior, open the layer properties, and go to the Network Locations tab (Figure 3). Set the checkboxes under the “Finding Network Locations” setting.

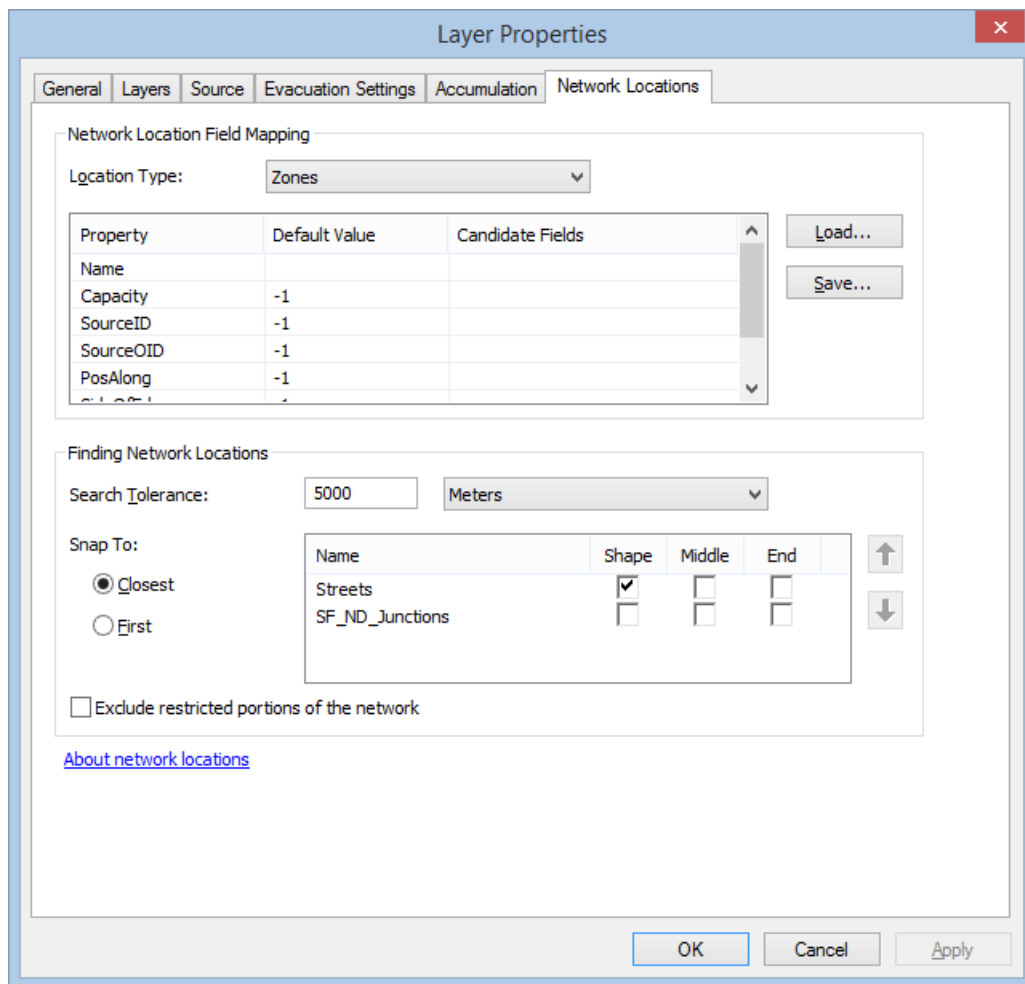


Figure 3: Load network locations options window

You have to select the correct “Finding Network Locations” checkbox BEFORE you load your locations. For example, if you want your safe zones to be assigned to junctions instead of edges, you have to uncheck the “Shape” box in front of the “Streets” and check the “Shape” box in front of the “SF_ND_Junctions”. Please note that naming could be different based on your network dataset. The drop menu at the top of the window does not play a role here. You have to set the right box before every load location step. It is generally advised to load safe zone points and assign them to junctions instead of edges because it would allow cars to reach the safe zone from multiple directions. As for DynamicChanges polygons, you HAVE TO assign them to edges, otherwise they will not have any effect on the evacuation result. To learn more about the load location process, read the following help page.

More Info: <http://resources.arcgis.com/en/help/main/10.1/index.html#//00470000003n000000>

Load Zones

Now that all evacuation inputs have been explained, let us have an example on how to load all the input data. Imagine a tsunami is coming toward San Francisco and we need to evacuate people who live close to the west side toward inland (Figure 6). We can use the Census block group population data for evacuees. We assume each person takes a car so we'll use the block group population directly for the VehicleCount field. A safe zone is simply a location with a good distance from the shoreline.

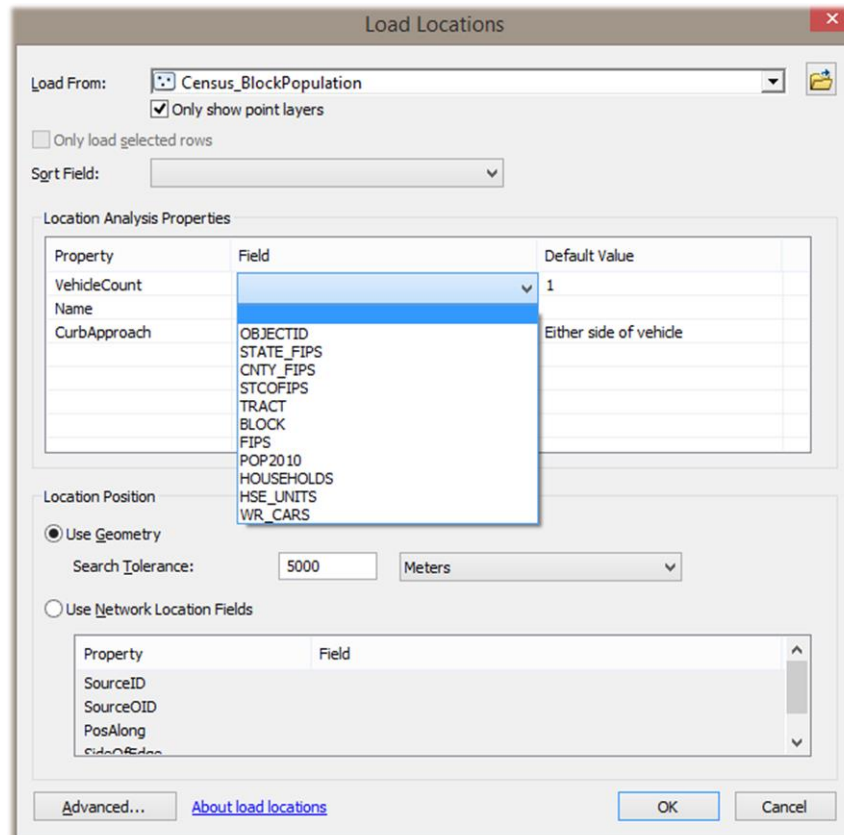


Figure 4: “Load Locations” window for Evacuees.

In this example we import California block group points as evacuees.

Steps:

1. Locate the Network Analyst toolbar in ArcMap. Click on “Network Analyst Window” so that you can see newly added layers.
2. From the toolbar, open the Network Analyst drop menu and select “New Evacuation Routing”. This will create a new empty layer and six sub-layers which you can see in the Network Analyst Window.
3. From the same drop menu, click on “Options” and change the “Messages shown after solve” to “All Messages”. You need to see all messages to understand the details of the evacuation result.
4. Right-click on the newly created evacuation routing layer and select “Properties”. Go to the “Network Locations” tab and make sure the “Streets” “Shape” is the only checked box (Figure 3).
5. If you want to import any dynamic change polygons, then right-click on “DynamicChnage” sublayer and select “Load Locations”. Select the right polygon feature class and set the right attributes.

6. Right-click on “Evacuees” sublayer from Network Analyst Window and select “load locations”. Select the point shapefile with population data. Select the appropriate fields for VehicleCount and name (Figure 4).
7. Before importing safe zones, you should change the network location setting. Right-click on the newly created evacuation routing layer and select “Properties”. Go to the “Network Locations” tab and make sure the “Junctions” “Shape” is the only checked box.
8. Right-click on “Zones” sublayer from Network Analyst Window and select “load locations”. Select the point shapefile with safe zone points. Select the appropriate fields for capacity and name.

Now you are ready to perform the evacuation routing.

Section 3: Evacuation Setting

If you right-click on the “Evacuation Routing” layer from the table of contents and select “Properties”, you will see the evacuation options (Figure 5). Below are short descriptions of the evacuation options:

Layer Properties

General Layers Source **Evacuation Settings** Accumulation Network Locations

CASPER for ArcGIS v10

Evacuation Options

Route Optimization Method: CASPER

Dynamic Mode (experimental): Smart

CARMA Sort Direction: BW Continuous

Init Delay Cost Per Evacuee: 0.0100

Cost per Safe Zone Density: 0.00

CARMA Ratio: 0.500

Selfish Routing Ratio: 0.000

Iterative Solver Ratio: 0.600

Routing Options

Capacity Network Attribute: Capacity

Cost Network Attribute: Minutes

UTurn Policy: Always Allowed

Traffic Options

Traffic Model: POWER

Critical Density per Unit Capacity: 20.00

Saturation Density per Unit Capacity: 500.00

Flocking Model Options

☐ Flocking enabled?

Flocking Profile: Car

Snapshot Interval: 0.1000

Simulation Interval: 0.0100

General Options

Population split or group: None

☐ Export Edge/Street Statistics

☒ Two way roads share capacity

☒ Run CARMA with DSPT

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OK Cancel Apply

Figure 5: Evacuation Options Window

- **Cost (Impedance) Network Attribute:** Select your impedance or cost attribute. Preferably pick something in “minutes”. Some of the settings’ default values are based on “minutes” as the unit of time.
- **Capacity Network Attribute:** Indicates the “Capacity” network attribute that we added in Section 1. Make sure it is set correctly. The program will read the roads widths/lanes/capacities through this attribute.
- **Route Optimization Method:** Indicates the routing algorithm. The interested reader can read the [technical article](#) which explains the mathematical details of these algorithms.
 - o **SP:** ShortestPath search for each evacuee. All the capacities will be ignored. This will technically make the program behave like the Closet Facility tool.
 - o **CCRP:** A known capacity-constrained technique which will fill up each path with evacuees from source to sink ([more](#)).
 - o **CASPER:** Capacity-Aware ShortestPath Evacuation Routing which will use the traffic model to determine realistic traversal speeds for each road segment based on the road capacity and the number of evacuees (population).
- **Dynamic Mode:** Indicates the algorithm for routing in a dynamically changing environment. The technical details of each choice is going to be published in a separate paper.
 - o **Smart (Recommended):** Every time the road network changes, it identifies the affected cars and reroutes them. It can predict the approximate location of cars based on dynamic change start and end times.
 - o **Full:** Every time the road network changes, it reroutes all cars again to safety based on new information and cars approximate locations.
 - o **Simple:** It ignores all start and end times of dynamic change polygons. It assumes all road network changes are in effect from the beginning to the end. This will greatly simplify the routing optimization but will generate unrealistic results.
 - o **Disable:** This option will completely ignore all road network changes. This option exists only for backward compatibility purposes.
- **CARMA Sort Direction:** Indicates how evacuees should be sorted before getting processed. It could either be furthest evacuee first or nearest evacuee first. The distance is based on evacuees predicted cost to nearest safe zone.
 - o **None:** Keep evacuees in the original order as loaded to the Evacuation Routing layer.
 - o **FW Once:** Process evacuees starting with the nearest one to safety first.
 - o **BW Once:** Process evacuees starting with the farthest one to safety first.
 - o **FW Continuous:** Process evacuees starting with the nearest one to safety first. Keep the list of evacuees that are nearest up-to-date and revise the order if necessary.
 - o **BW Continuous:** Process evacuees starting with the farthest one to safety first. Keep the list of evacuees that are farthest up-to-date and revise the order if necessary.
- **UTurn Policy:** Indicates the routing policy for U turns. Read more about *uturn_policy* at <http://resources.arcgis.com/en/help/main/10.1/index.html#//00480000001z000000>
- **Init Delay Cost Per Evacuee:** This number indicates the initial space between evacuees that are sharing their start locations. This translates to evacuee density on each road segment. For example, if you used *Minutes* for your *Cost Network Attribute* and set this parameter to one, each evacuee would leave their location in one minute intervals. This can reduce congestion and therefore overall

evacuation time, but depending on the size of the population at a certain threshold it could add significant time to the overall evacuation.

- **Cost per Safe Zone Density:** If safe zones have limited capacity, this parameter helps the program prioritize safe zones. For example, if a nearby safe zone is already full with 100 evacuees, how far should one evacuee be routed for the next safe zone? If the network impedance is in *minutes* and *Cost per Safe Zone Density* is 10, the evacuee is willing to travel an extra 0.1 minutes to find another safe zone. In general, a *cost per density* value of zero means we do not want to enforce the safe zone capacity. Higher *cost per density* values means we prefer to have a more balanced population density over the safe zones. With higher values, the total evacuation time may increase.
- **CARMA Ratio:** CARMA (Capacity Aware Reverse Map Analyzer) is a helper algorithm within CASPER which updates graph vertices based on some heuristic. The heuristic can guide the path finding during CASPER run. By keeping these vertices up-to-date, CASPER will run faster and might be able to find better routes as well. CARMA ratio should be a number from 0.0 to 1.0. Setting the ratio to 0.0 means vertices will be always up-to-date. Setting it to 1.0 means vertices will be updated only once at the beginning. It's recommended to leave this value at its default.
- **Iterative Solver Ratio:** A number between [0,1] that indicates how many of evacuees should be considered for re-evaluation at each iteration. A value of zero would disable iteration entirely and a value of 1 means that all evacuees can possibly be considered for re-evaluation. Originally CASPER was a greedy algorithm. It would have run only once for each evacuee. The new version is an iterative algorithm. After it processes each evacuee, it goes back and re-evaluates the ones that are congested or far away from a safe zone. It repeats this until it cannot improve itself.
- **Selfish Routing Ratio:** A number between [0,1] that determines how each evacuee should pick its evacuation route. This is an experimental feature. A value of 0 indicates a completely selfish routing behavior and a value of 1 indicates a completely selfless routing behavior. To turn it off, you can set the ratio to zero and it will behave like a normal CASPER. With a non-zero ratio, an evacuee may try and avoid some routes that overlaps with others.
- **Population split or group:** There are two main options: split and merge. The third option is a mix of both.
 - o **Split:** This option indicates if the program is allowed to separate the population at each location in order to optimize the routes. This will possibly take more time to compute but might lower the total evacuation time. This option may affect how safe zone density is processed.
 - o **Merge:** This option indicates if evacuees that share the same starting point can be merged. This can possibly improve the evacuation time and the program running time but you will lose all the tracking information for each evacuee.
- **Export Edge/Street Statistics:** If you select this, the tool will also output the edge reservations, which will be helpful in understanding the network bottlenecks.
- **Two-way roads share capacity:** It will tell the program that the capacity of the two-way road segments is shared between both directions as opposed to each direction having that much capacity. The reason we introduced this option in CASPER is because some road network data providers (e.g. NAVTEQ) report the total number of lanes for two-way roads instead of reporting the number of usable lanes per each direction of road. Turning this option on will allow CASPER algorithm to use each lane in any direction it likes. This usually leads to a better evacuation plan but it is not realistic.

Note: If you want to implement contraflow (allowing every lane to travel in the direction toward safety), this option would be no help. You have to directly modify your network dataset. For example you have to select some of your street segments and change their number of lanes. Re-build the network dataset afterwards.

- **Run CARMA with DSPT:** This enables a newer version of CARMA where heuristic values are updated using dynamic shortest path tree (DSPT) algorithm. This version of CARMA is experimental.
- **Traffic Model:** User can select different traffic modeling methods. These models help the program predict traffic delays on saturated road segments. Only CASPER optimization method can benefit from these models.
- **Critical Density per Unit Capacity:** This constant indicates the critical density of a road with one unit of capacity (e.g. one lane). It means the road can route up to this many evacuees without affecting the traversal speed. Here density refers to the number of evacuees (cars) per a unit of cost (impedance).
- **Saturation Density per Unit Capacity:** This constant indicates the saturation density of a road with one unit of capacity (e.g. one lane). It means if the road is routing this many evacuees, its traversal speed will reduce to half of the original traversal speed.
- **Flocking model:** This version of CASPER is equipped with a simulation model. The simulation is based on the work by [Craig Reynolds](#). If you enable this model, after the routing is done, the program will simulate each evacuee (car) second by second on the road network from source to destination. This enables you to compare final results, animate the evacuation scenario, verify the correctness of the traffic model, observe traffic congestions, and more. The simulation process is extremely slow and should not be attempted in large geographical areas.
- **Flocking Profile:** Indicates the type of evacuee's vehicle. This will directly affects the physics of the simulation like top speed, dimension, acceleration, safe distance from other vehicles, etc.
- **Simulation Interval:** Indicates the temporal resolution of the simulation. For example a value of 0.01 (assuming *minutes* for impedance value) means simulation will compute evacuee location every 0.6 seconds.
- **Snapshot Interval:** Indicates how often the simulation should store the evacuee locations. This will directly affect the length of the final animation. For example a value of 0.1 (assuming *minutes* for impedance value) means the simulation points are stored every 6 seconds. So the final animation will have a frame every 6 seconds.

Section 4: Output

In order to get the evacuation routes, from the toolbar, click on "Solve". Once it is finished, three output tables will be populated with results which we briefly explain in this section. Please note that ArcMap stores all these layers in the map document (.mxd file) and not in your default geodatabase. It is a good practice to always export output layers to your main data location after every "Solve".

Routes

Routes are polylines from each evacuee to the selected safe zone. If the 'Separable Evacuee' was ON, there would be many routes for each evacuee location. Figure 6 shows routes for our San Francisco tsunami scenario. Each route has the following attributes:

- **EvcCost:** Indicates total traversal cost on the route considering the congestions.
- **OrgCost:** Indicates the traversal cost without congestion considerations.
- **VehicleCount:** Shows how many evacuee cars will be on this route.
- **Name:** Name of the evacuee from the 'Evacuees' table. It can be used to join results with the origin points.
- **ObjectID:** This is an auto-generated unique number for each route. If you want to know in which order the algorithm assigned routes to evacuees, you can sort the 'Routes' table by 'ObjectID'. In another words, the 'ObjectID's are being generated as the routes being reserved on the network.
- **DestZoneName:** It has the safe zone name that is the route's destination. From here you can calculate how many reached which safe zone.

EdgeStats

This table lists all touched street segments with useful information about them. By visualizing this table the user can learn about the shortcomings of the network dataset in terms of capacity bottlenecks and safe zone availability. This table is populated only if the 'Export Edge Statistics' option is ON. Below you will find information about each 'EdgeStats' attribute.

- **EdgeID, Direction, SourceID, SourceOID:** The four of them uniquely identify one edge in the network dataset. The polyline shape, however, comes from the original 'streets' shapefile.
- **ReservVehicle:** Number of evacuee cars that are set to pass this edge during evacuation, not necessarily at the same time.
- **TravCost:** the traversal cost for this edge with congestion consideration.
- **OrgCost:** The original traversal cost of this edge according to the network dataset.
- **Congestion:** A number from 1 to 10,000 which indicates the congestion ratio on this edge. Equals 'TravCost' divided by 'OrgCost'.

Flocks

This table will be created if the simulation option is ON. It will have a point for every single evacuee at every time step. Each point has the following attribute:

- **Name:** Name of the evacuee point that this single evacuee belongs too.
- **ID:** Unique ID for every single evacuee.
- **Cost:** The traveled cost that this single evacuee had so far.
- **Velocity:** traversal speed as a vector in minutes per meter (assuming *minutes* for impedance value).
- **Speed:** Scalar current speed
- **Traveled:** distanced traveled in meters
- **MyTime:** Accurate time in current format. Can be used to create time-enabled layer.
- **PassedMin:** Exact minutes passed the start of the simulation as a floating-point number
- **Status:** The status of a single evacuee can be Moving, Stopped, Collided, and End.

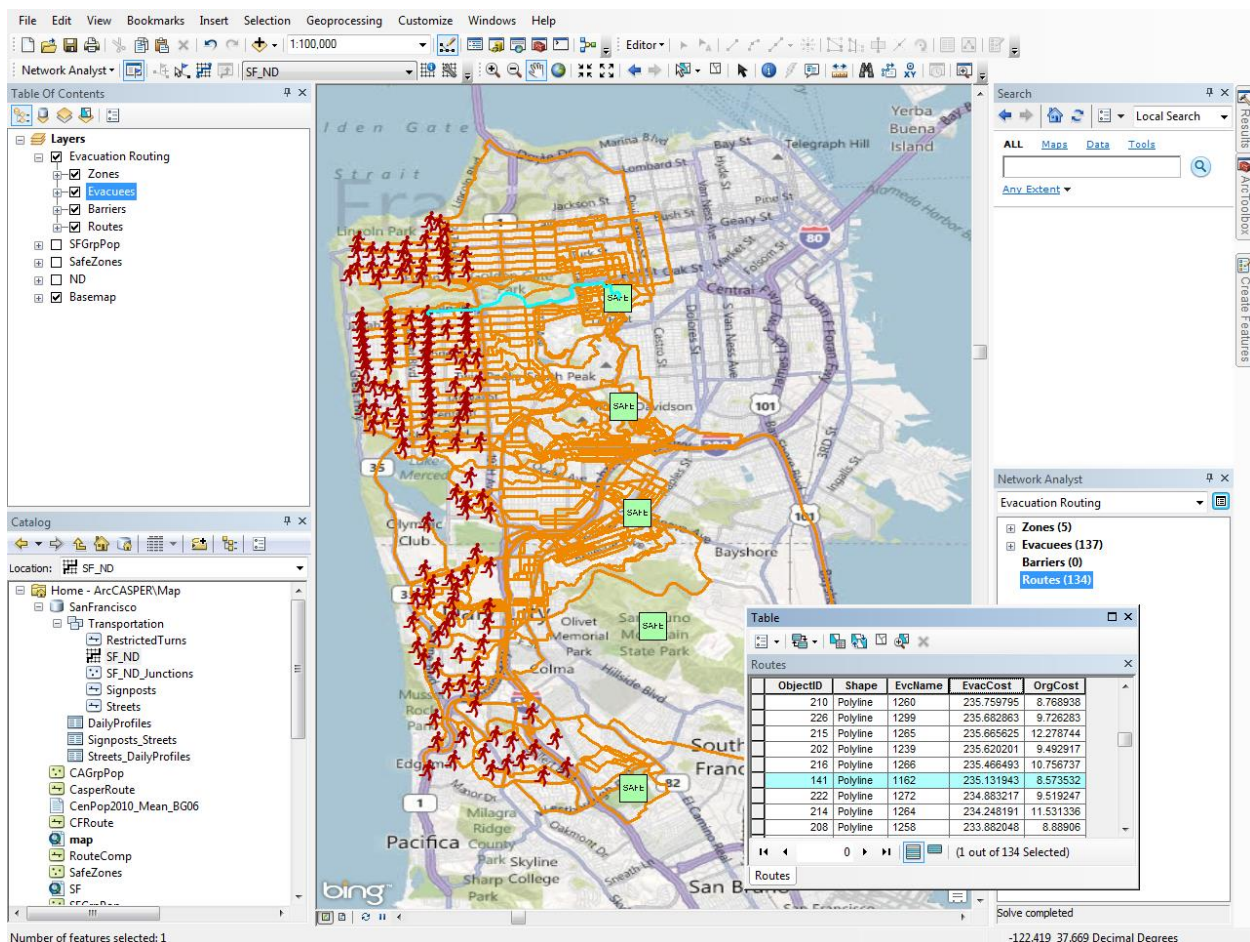


Figure 6: Calculated Evacuation Routes for Bay Area

Known Issues

- Multi-part turn restriction: The routing algorithm does not take into account complex (multi-part) turn restrictions that your network dataset may have. There are no workarounds at the moment.
- Sort by 'name' in route table: Sorting the 'Routes' table by name (which is the same as evacuee name) does not work. Also joining this table may result in unexpected behavior. The workaround is to export the routes as a separate shapefile and continue from there.

Acknowledgement

I would like to thank [Esri Application Prototype Lab \(APL\)](#), the Esri Network Analyst team, and USC [Spatial Sciences Institute \(SSI\)](#) for their support during the development of this tool. The programming of this tool started when I was a summer intern at Esri in 2011. I worked at APL during that summer and also received tremendous support from the Network Analyst team. After Esri, I continued as a PhD student and research assistant at USC SSI. Thanks to SSI support, I'm still actively developing the CASPER algorithm to improve the future of public safety.

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If you decided to use our tool in your work, we would ask that you cite it as:

K. Shahabi and J. P. Wilson, "CASPER: Intelligent capacity-aware evacuation routing," Computers, Environment and Urban Systems, vol. 46, pp. 12–24, Apr. 2014

Fibonacci Heap

For the heap data structure, the Fibonacci Heap implementation by [Tim Blechmann](#) from the [Boost libraries](#) has been utilized. The original source code is available under the [Boost License](#).

OpenSteer Library

This tool utilizes [OpenSteer](#) library to run evacuation simulations. The library is released under [MIT license](#).

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