Geospatial Problem Solving

Network Analysis

Image from NASA:
https://commons.wikimedia.org/wiki/File:Earth_Western_Hemisphere_transparent_background.png#filelinks

In this module, I expand upon the last module focused on vector-based spatial analysis by now exploring network analysis.

Module Topics

1. Geocoding
2. Linear referencing
3. Network datasets and topology
4. Routes
5. Service areas
6. Closet facility
7. Location-allocation

2

These are the topics covered in this module.

Network Analysis

Types of Networks

- Roads
- Streams
- Railroads
- Pipelines
- Electrical distribution

4

There are many examples of networks in geographic space such as the examples provided on this slide. Solving problems along networks are thus common in our discipline.

In this section, we will discuss methods used to model geographic networks and answer questions that involve networks.

Geocoding

- Process of converting addresses in a table to coordinates on a map
- What is needed:
- Table of addresses
- Reference database
  - Street names
  - Address ranges
  - ZIP codes

Parsing = breaking an address up into its component parts

Address Standardization = setting up the components of an address in a regular format

Example: AVE vs. AV vs. Av vs Ave

98 Beechurst Avenue,	Morgantown,	WV	26506

5

Geocoding is the process of creating coordinates or point features from addresses. If you want to obtain driving directions between two addresses, you need to know where these addresses occur and specifically where they occur along the road network. So, geocoding is often a prerequisite process for network analysis along road networks.

In perform geocoding, you need a table of addresses and a reference database to compare the addresses to. It is best if the address information is complete. For example, you should have the street address, town, state, and zip code available in the table. If the provided information is incomplete or inaccurate, it will be more difficult to obtain quality results.

I have found that it is best to store each component of the address in separate columns in the table. If the entire address is provided as a single column, then it will need to be parsed. Parsing is the process of breaking an address up into its component parts.

It is also necessary to perform address standardization, since addresses can be written in multiple ways. For example, the software must be able to recognize all the different ways to abbreviate or write “avenue” represent the same thing.

Linear Referencing

- Placing the address along a line segment based on where the address fits within the range of available addresses

- Example: If the address is 620 and the address range associated with the line segment is 600 to 700, the address will be located one-fifth of the street segment from 600 (Chang, 2012)
- You can also place addresses on the appropriate side of the line if you have the required information to do so

6

Linear referencing is one means to perform geocoding.

This process works by placing a coordinate along a line segment representing sections of roads or streets.

Each line segment will be attributed with the range of addresses that occur along it. For example, if the address is 620 and the address range associated with the line segment is 600 to 700, the address will be located one-fifth of the street segment from 600.

You can also place addresses on the appropriate side of the line if you have the required information to do so. In this case, you would have to know which addresses occur on each side of the road (for example, evens on right, odds on left).

This is not the only way to perform georeferencing. It is just an example.

Address Locator

- Algorithm used to geocode addresses
- ESRI offers geocoding services

https://geocode.arcgis.com/arcgis/

7

An address locator is an algorithm used to perform georeferencing.

You can make use of available address locators, or you can create your own.

ESRI offers an online geocoding service that can be used in ArcGIS Pro and ArcGIS Online. However, it requires credits to use the service.

West Virginia Geocoding

Address Geocoding

Name	Description	Projection	Date	Information	REST Services
Composite Geocoder	WV Street & Site Geocoder from Statewide Addressing & Mapping System (SAMS)	UTM 17N	2017	Link	Link
Site Geocoder	WV SAMS Site Locator Service	UTM 17N	2017	Link	Link
Street Geocoder	WV SAMS Street Locator Service	UTM 17	2017	Link	Link

https://www.mapwv.gov/gis_services.html

ESRI is not the only producer of address locators. For example, in the state of West Virginia our Statewide Addressing and Mapping Board offers address locators for addresses occurring within the state. These services can be accessed via the West Virginia GIS Technical Center at the link provided on this slide.

Components of a Network Dataset

- ❖Network = system of linear features that has the appropriate attributes for the flow of objects
- ❖Topology = lines meet at intersections, lines cannot have gaps, lines have directions
- ❖Junctions = where lines meet
- ❖Edges = lines that connect the junctions

9

In order to perform network analysis, you will need a digital representation of the network. A network is defined as a system of linear features that has the appropriate attributes for the flow of objects, such as motor vehicles. In order to accurately model movement along networks, it is important to understand how linear features are connected. So, it is important to model topology.

When modeling road networks, roads should meet at intersections (there are not generally gaps between road segments), and direction of motion should be defined (for example, one-way streets and divided highways). These are examples of topological rules that must be modeled.

In ArcGIS Pro, networks are commonly stored as network datasets within geodatabases. Within the geodatabase, they are commonly stored inside of a feature dataset.

Networks are modeled as junctions and edges. Junctions represent the point locations or intersections where line segments meet. Edges define the line segments. For example, for a road network, junctions would represent road intersections while edges would represent the roads.

Impedance

- Cost of traveling between junctions on edges
- Can be defined based on travel distance or travel time
- If you now speed limit and distance, you can estimate travel time

10

Impedance measures resistance to motion or cost of motion along networks.

For example, when trying to find the optimal route along a road network, you could choose to optimize based on travel time or travel distance. So, both travel time and travel distance are measures of impedance.

When solving a routing problem, the goal is generally to find the route that minimizes impedance. So, you could minimize travel time or travel distance. In a network dataset, the optimal route would be the one that has the minimal total travel time or total travel distance when adding this measure of impedance with travel between junctions along edges.

Complexities of Networks

- Incomplete data
- Outdated data
- Detours and road closures
- Changing traffic patterns
- Overpass and underpasses
- One-way streets
- Turning rules
- Barriers to movement

11

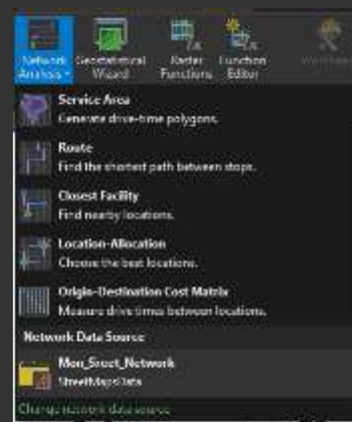
In the real world, road networks can be very complex. This slide provides a list of example complexities.

How can the software know that a road is a one-way street or that no right turns are allowed at red lights?

This additional information can be provided as attributes associated with the network data. These additional measures can then be incorporated into the problem to provide a more realistic solution.

Types of Problems

- ❖Shortest route between stops based on time
- ❖Shortest route between stops based on distance
- ❖Defining service areas based on travel time
- ❖Defining service areas based on travel distance
- ❖Find the closest facility to other locations
- ❖Finding the best location at which to site a facility
- ❖Travel costs between origins and destinations

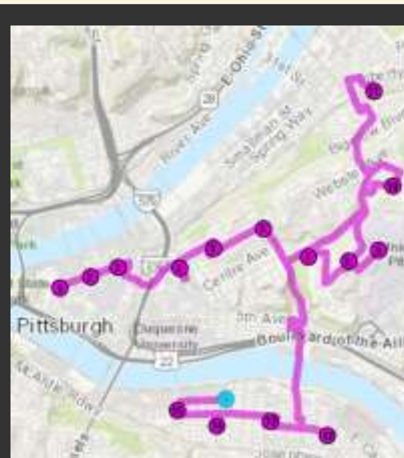


12

This slide provides some examples of different types of network problems that can be solved using network analysis. In the remaining slides, I provide some examples.

Routes

- ❖Must input stops
- ❖Find the best (shortest) route based on time or distance
- ❖Take into account the network rules and the impedance
- ❖Can take into account: order of stops, type of impedance, and barriers



13

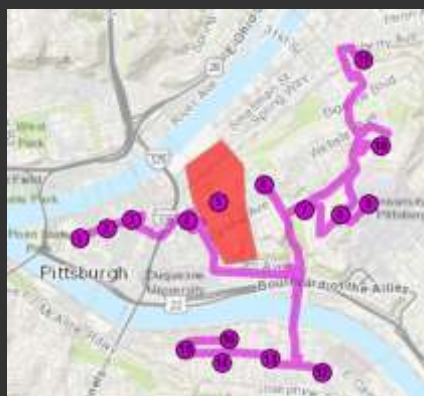
Routing problems involve finding the optimal travel path along the network between two stops or multiple stops.

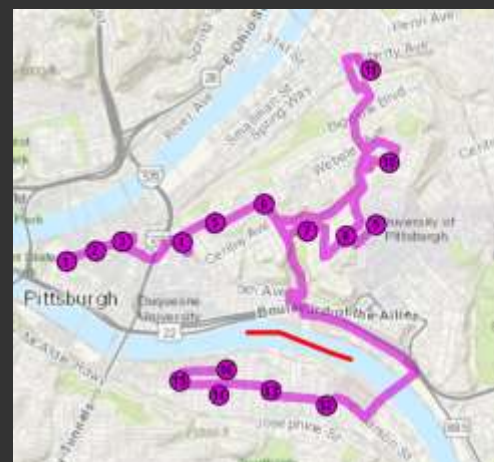
The optimal route will be the one that provides the lowest impendence (for example, total travel time or total travel distance).

You can also incorporate network rules, such as no U-turns. You can take into account the required order of the stops, the type of impedance, and barriers.

Barriers

- Barriers can be defined as point, lines, or polygons





14

Barriers can be represented as points, lines, or polygons.

In a network analysis problem, barriers cannot be crossed and a route must be defined that takes this into account.

As an example, barriers could be used to define detours or closed roads.

Service Areas

- ❖Must input facilities
- ❖Find areas that are within a certain distance or travel time from facilities
- ❖Can specify direction of travel (to or from)
- ❖Can solve for travel time or travel distance
- ❖Can solve for multiple travel distances or times
- ❖Can incorporate barriers

Service area problems involve finding the area that is within a certain travel time or travel distance from one or multiple input facilities.

When solving these problems, you can specify whether you are traveling to or from the facilities. You can solve for travel time or travel distance, and you can incorporate multiple distances or times.

You can also include barriers.

Closest Facility

- ❖Must input facilities and incidents
- ❖Find what facilities are closest to each incident based on travel time or travel distance
- ❖Can incorporate barriers
- ❖Can specify direction (to or from)

16

Closest facility problems involve finding what facilities are closest to incident locations along the road network based on travel time or travel distance.

For example, you could use these methods to find which fire station is closest to each house.

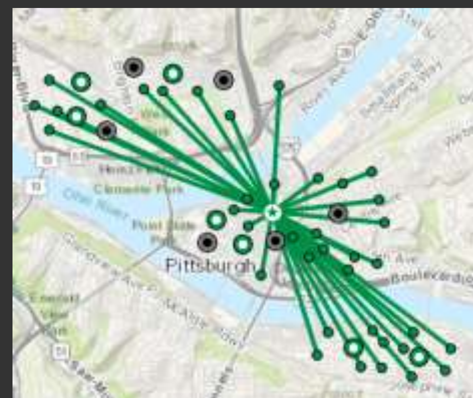
In order to perform a closest facility analysis, you will need to provide input facility locations and incident locations.

You will also need to specify a measure of impedance.

You can specify the direction of travel (to or from the facilities) and incorporate barriers.

Location-Allocation

- ❖Must provide potential facilities and demand points
- ❖Find location that services the demand points most efficiently
- ❖Can provide location of competitors
- ❖Can solve for time or distance
- ❖Can specify direction (to or from)
- ❖Can incorporate barriers
- ❖Many different methods to solve



Location allocation problems are a wide variety of techniques to solve a variety of problems.

The goal is to find facilities that service demand locations most efficiently.

You must provide facility locations and demand points. You can solve the problem based on travel time or travel distance. You can also specify a direction of travel (to or from the facilities). You can incorporate barriers. Some methods allow you to include competitor locations.

An example of a location allocation problem would be finding the optimal location to place a new distribution center from a set of potential new locations. To solve this problem, you would need to provide the potential locations and the demand locations. The demand locations could represent stores that the distribution center will service. Since the location of competitors could impact the demand, you may also want to include this information.

The next two slides provide some examples of location-allocation problem types. Take some time to read through the examples.

Location-Allocation Problem Types

- Minimize Impedance = Best location is the one that provides the lowest cumulative impedance between demand locations
- Maximize Coverage = Facilities are located such that as many demand points as possible are allocated to solution facilities within the impedance cutoff
- Maximize Capacity Coverage = Facilities are located such that as many demand points as possible are allocated to solution facilities within the impedance cutoff; additionally, the weighted demand allocated to a facility can't exceed the facility's capacity
- Minimize Facilities = Facilities are located such that as many demand points as possible are allocated to solution facilities within the impedance cutoff; additionally, the number of facilities required to cover demand points is minimized

http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/location-allocation.htm#ESRI_SECTION3_F8EBCD830EDA464384FEC1E54DBA2707

Location-Allocation Problem Types

- Minimize Attendance = Facilities are chosen such that as much demand weight as possible is allocated to facilities while assuming the demand weight decreases in relation to the distance between the facility and the demand point
- Maximize Market Share = A specific number of facilities are chosen such that the allocated demand is maximized in the presence of competitors. The goal is to capture as much of the total market share as possible with a given number of facilities, which you specify. The total market share is the sum of all demand weight for valid demand points
- Target Market Share = Chooses the minimum number of facilities necessary to capture a specific percentage of the total market share in the presence of competitors. The total market share is the sum of all demand weight for valid demand points. You set the percent of the market share you want to reach and let the solver choose the fewest number of facilities necessary to meet that threshold

http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/location-allocation.htm#ESRI_SECTION3_F8EBCD830EDA464384FEC1E54DBA2707

Destination Cost Matrix

- Requires input destinations and origins
- Computes a matrix of cost of travel distance/time between all origins and destinations
- Can incorporate barriers

DestinationID	DestinationRank	Shape_Length	Total_Minutes	Total_TravelTime	Total_Miles	Total_Kilometers
8	1	1445.742157	<Null>	3.360779	<Null>	1.557115
1	2	1141.222499	<Null>	4.449583	<Null>	0.912656
2	3	796.808437	<Null>	4.624071	<Null>	0.957
7	4	1900.339831	<Null>	4.790759	<Null>	1.962379
3	5	903.373911	<Null>	4.840983	<Null>	1.109768
4	6	2532.706364	<Null>	8.929359	<Null>	2.322573
6	7	4009.961299	<Null>	9.403627	<Null>	4.214151
5	8	3505.266603	<Null>	10.930741	<Null>	4.723239
3	1	1073.110306	<Null>	4.751589	<Null>	1.426032
2	2	1361.303939	<Null>	5.290183	<Null>	1.466294
[illegible]	[illegible]	[illegible]	<Null>	6.658199	<Null>	1.713605
[illegible]	[illegible]	[illegible]	<Null>	7.126863	<Null>	2.711584
[illegible]	[illegible]	[illegible]	<Null>	8.556843	<Null>	3.116644
[illegible]	[illegible]	[illegible]	<Null>	9.141442	<Null>	2.733663
[illegible]	[illegible]	[illegible]	<Null>	11.623727	<Null>	4.944844

20

Lastly, it is possible to generate a cost matrix between origins and destinations. The travel time or travel distance along the network will be calculated for every origin-destination combination.

Network Analysis In ArcGIS Pro

21

The following exercises ask you to perform different vector-based spatial analysis operations in ArcGIS Pro.

Network Analyst

- Analysis Tab → Network Analysis

22

Network analyses can be performed using the options available under Network Analysis within the Analysis tab.

Geocoding

- Geocoding Tools
- Can add table to map and geocode table

23

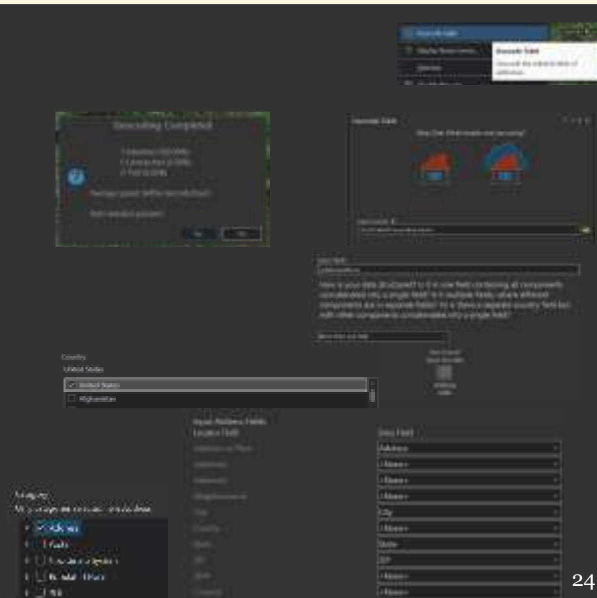
Geocoding tools are made available in the Geocoding Tools toolbox. If you add a table to a map, you can right-click on it to geocode the data if adequate information, such as a complete address, is provided in the table.

The following slides ask you to perform different geocoding or network analysis tasks.

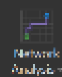
Geocode Addresses

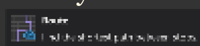
1. Use the NetworkAnalysis map.
2. Right-click on the addressesM.csv file in the Contents Pane.
3. Select Geocode Table. This will open the Geocode Table Wizard.
4. Click Start on the first window.
5. Use the *ArcGIS World Geocoding Service* in the second window. Click Next.
6. Make sure *More than one field* is set in the next window. Click Next.
7. The fields should automatically be correctly matched in the next window. Click Next.
8. You can use the default **Output** name. Click Next.
9. Set the **Country** to *United States*. Click Next.
10. Set the **Category** to *Address*. Click Next.
11. Click Finish than Run to execute the process.

A new point layer should be added to the map. All five locations should be matched.

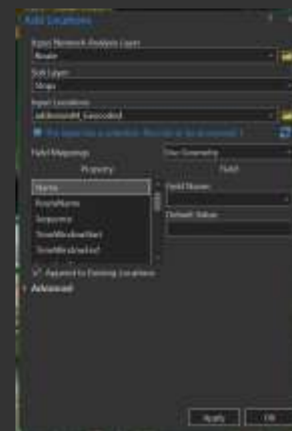


Route Calculation

1. Use the NetworkAnalysis map.
2. In the Analysis Tab, click on the Network Analysis icon followed by the Route option. This will add a new set of layers to the Contents Pane.




3. Navigate to the Route Layer Tab.
4. Click Import Stops and import the point features that were geocoded above.
5. In the Route Layer Tab, make sure the **Mode** is set to *Drive Time* and the **Sequence** is set to *Find Best*.
6. Click Run in the Route Layer Tab to execute the tool.


Service Area Calculation

1. Use the NetworkAnalysis map.
2. In the Analysis Tab, click on the <u>Network Analysis</u> icon followed by the <u>Service Area</u> option. This will add a new set of layers to the Contents Pane.

3. Navigate to the Service Area Layer Tab.
4. Click <u>Import Facilities</u> and import the motownEM layer (emergency medicine).
5. In the Service Area Layer Tab, make sure the **Mode** is set to *Drive Time*, **Direction** is set to *Away from facilities*, and **Cutoffs** is set to *2* (2 minutes).
6. Click <u>Run</u> in the Service Area Layer Tab to execute the tool.

Is Brooks Hall within one of these 2-minute service areas?

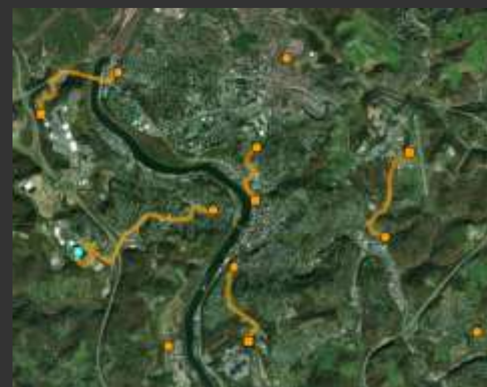
26

Closest Facilities

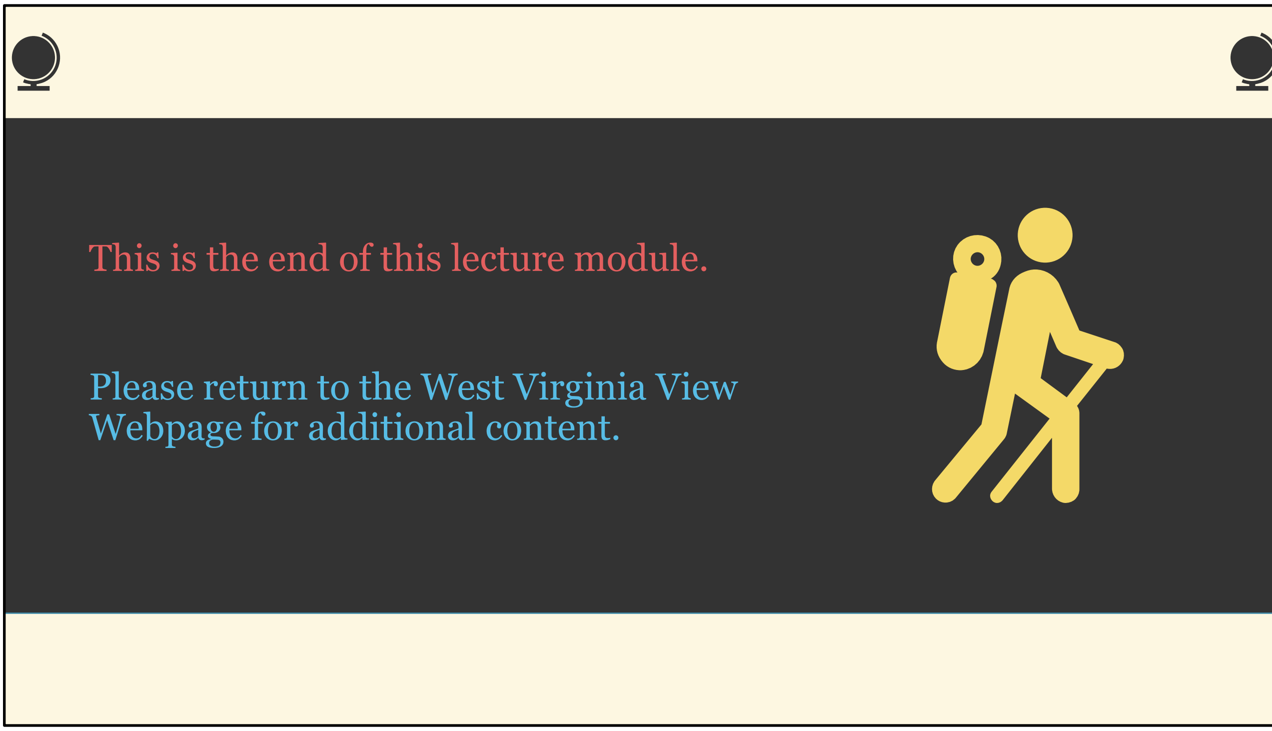
1. Use the NetworkAnalysis map.
2. In the Analysis Tab, click on the Network Analysis icon followed by the Closest Facility option. This will add a new set of layers to the Contents Pane.

3. Navigate to the Closest Facility Layer Tab.
4. Click Import Facilities and import the motownEM layer (emergency medicine).
5. Click Import Incidents and import the point layer created using georeferencing.
6. In the Closest Facility Layer Tab, make sure the **Mode** is set to *Drive Time*, **Direction** is set to *Away from facilities*, and **Facilities** is set to *1*.
7. Click Run in the Closest Facility Layer Tab to execute the tool.

Which facility is closest to Brooks Hall?



27



Thanks! Hope you found this useful.