Lecture 6: Network Analysis

GEOG413/613
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Network Analysis

- Spatial Networks
  - Vector data model

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Network Analysis

- A Spatial Network
  - is “a set of geographic locations interconnected in a system by a number of routes”
  - is a system of linear features that has appropriate attribute for the flow of objects
- A spatial network may be reduced to a topological graph.
- A connectivity matrix represents the interconnections between the **nodes** and **edges**

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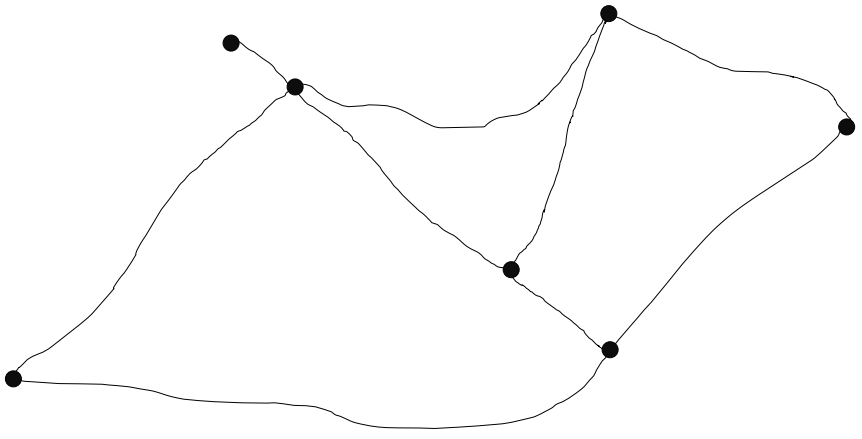
Network Analysis



Spatial Network

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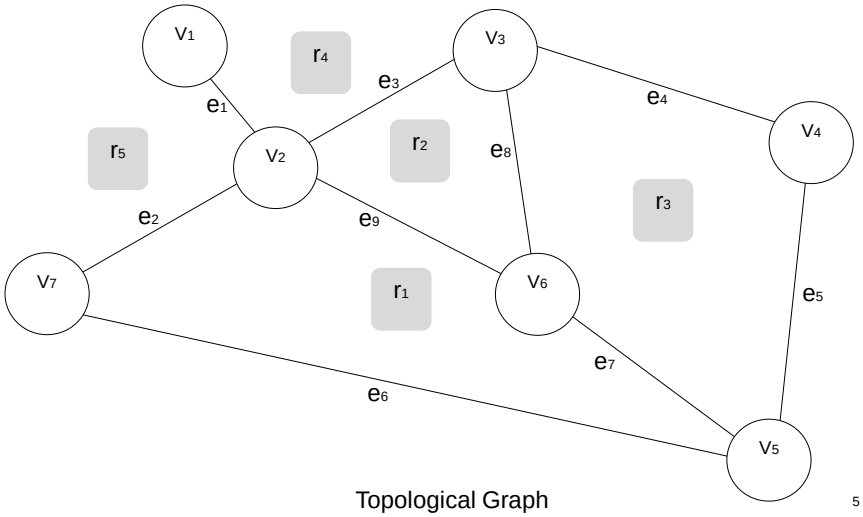
Network Analysis



Topological Graph

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Network Analysis

	Vertices(v)								Regions(r)						Edges(e)								
	1	2	3	4	5	6	7		1	2	3	4	5		1	2	3	4	5	6	7	8	9
1	0	1	0	0	0	0	0	1	0	1	1	0	1	1	0	1	1	0	0	0	0	0	1
2	1	0	1	0	0	1	1	2	1	0	1	1	0	2	1	0	1	0	0	1	0	0	1
3	0	1	0	1	0	1	0	3	1	1	0	0	0	3	1	1	0	1	0	0	0	1	1
4	0	0	1	0	1	0	0	4	0	1	0	0	1	4	0	0	1	0	1	0	0	1	0
5	0	0	0	1	0	1	1	5	1	0	0	1	0	5	0	0	0	1	0	1	1	0	0
6	0	1	1	0	1	0	0							6	0	1	0	0	0	0	1	0	0
7	0	1	0	0	1	0	0							7	0	0	0	0	1	1	0	1	1
														8	0	0	1	1	0	0	1	0	1
														9	1	1	1	0	0	0	1	1	0

0 = Not connected; 1 = Connected

Connectivity Matrices

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Network Analysis

- A network is topology-based
  - Lines meet at intersections
  - Lines cannot have gaps
  - Lines have directions
- Some topological measures of planar network graphs
  - Cyclomatic number, Alpha index, Beta index, Gamma index
  - Useful in transportation geography

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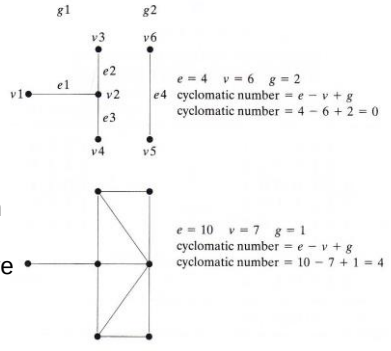
Network Analysis

Number of edges, ***e***
Number of vertices, ***v***
Number of non-connecting graphs, ***g***

Cyclomatic number (μ) = e – v + g
Measures spatial structure by providing an indication on the number of closed circuits in the graph. Highly connected graphs have high cyclomatic numbers. Can be used to identify route redundancy



Adapted from: Lo and Yeung, 2007

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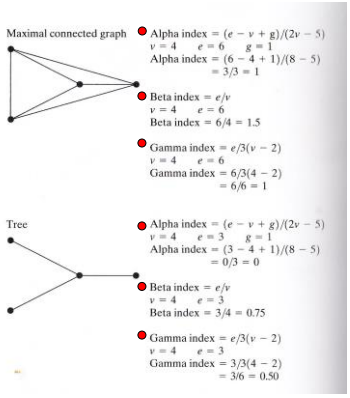
Network Analysis

Alpha index (α) = (e – v + g)/(2v - 5)
Ratio between observed number of circuits and maximum number of circuits. Index varies from 0-1. Completely interconnect network alpha index = 1

Beta index (β) = e/v
Shows the relation between the edges and the nodes in the network. A more complicated network exhibits a higher beta index



Adapted from: Lo and Yeung, 2007

Gamma Index (γ) = e/3(v-2)
Like the cyclomatic number measures the degree of connectivity in a network. It is a measure of the ratio of the number of edges in a network to the maximum number possible in a planar network. The index varies from 0-1

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Network Analysis

- A GIS can find the shortest route between two nodes on a network
  - A user can control the route by selecting specific nodes the route must pass through
- Attributes of the edges represent **impedance**
  - Impendence is the amount of resistance (or cost) when traversing along the network
  - Examples of Impedance
    - Length of the edge (distance or travel time)
    - Turn Impedance
      - A turn is a transition from one edge to another
      - Turn impedance is directional

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Network Analysis

- In ArcGIS network analysis, there are four types of operations that can be performed using route finding algorithms
  - Finding a shortest route between point locations
  - Determining the service area for a facility
  - Finding the closest facility across the network
  - Creating an origin–destination matrix

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Network Analysis

- Shortest route
  - Starts with impendence matrix
  - Shortest route may be represented by distance or travel time
  - Commonly uses the Dijkstra algorithm
    - Problems
      - Traveling salesman problem
        - Visits each stop, can start anywhere, must return to origin
      - Vehicle routing problem
        - Given a fleet of vehicles and customers, minimise travel time for each vehicle

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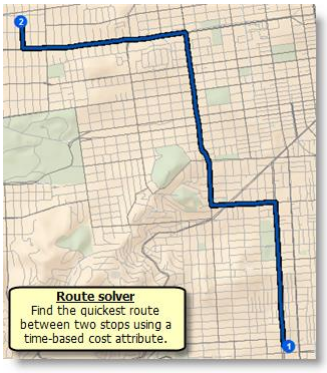
Network Analysis



Source: ESRI

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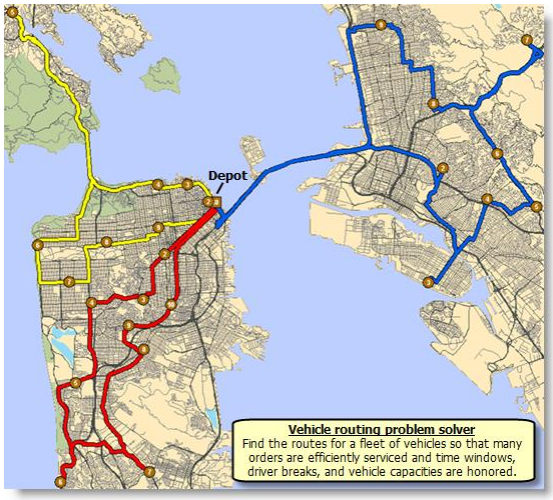
Network Analysis



Source: ESRI

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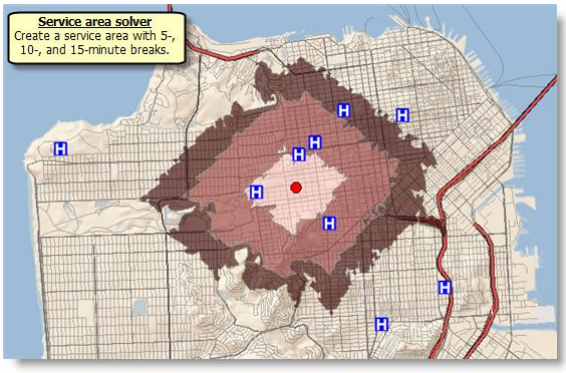
Network Analysis

- A service area for a facility
  - A region that encompasses all accessible locations with a specified impedance (isochrones). E.g. 5min service area



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Source: ESRI

Network Analysis

- Location-allocation
  - find the shortest path from the facility to demand points on the network
  - allocating demand points to their nearest facility
  - Some ESRI application examples:
    - Given a set of existing fire stations, which site for a new fire station would provide the best response times for the community?
    - If a retail company has to downsize, which stores should it close to maintain the most overall demand?
    - Where should a factory be built to minimize the distance to distribution centers?

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Network Analysis

Source: ESRI

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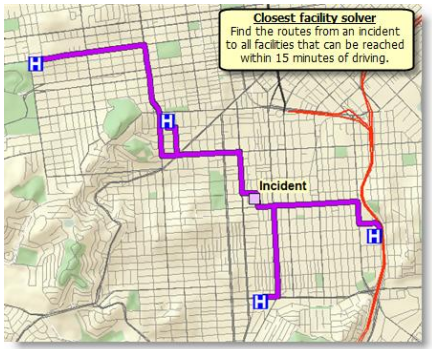
Network Analysis

- The closest facility for a location
  - find the shortest path from the location to each possible (candidate) facility
  - choose the shortest of these solutions.



Source: ESRI

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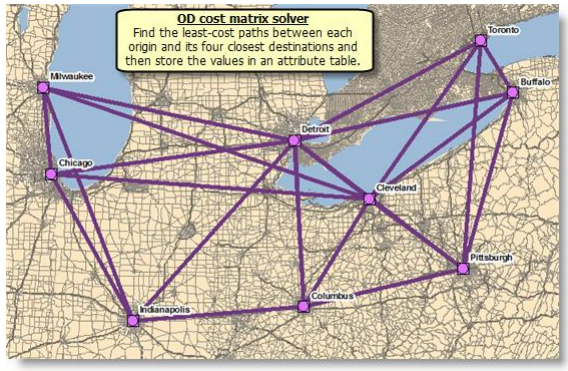
Network Analysis

- An origin–destination matrix is table of shortest paths between all origins and destinations



Source: ESRI

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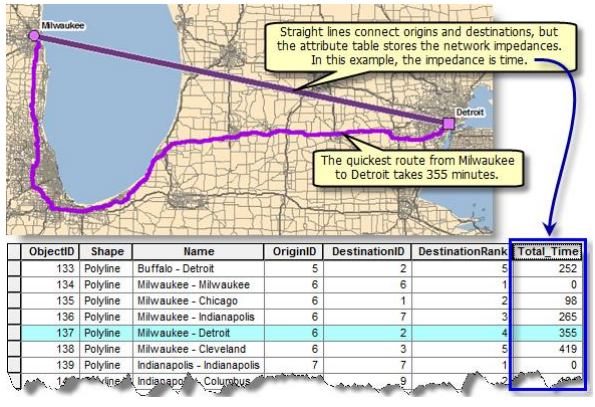
Network Analysis

- An origin–destination matrix is table of shortest paths between all origins and destinations



ObjectID	Shape	Name	OriginID	DestinationID	DestinationRank	Total_Time
133	Polyline	Buffalo - Detroit	5	2	5	252
134	Polyline	Milwaukee - Milwaukee	6	6	1	0
135	Polyline	Milwaukee - Chicago	6	1	2	98
136	Polyline	Milwaukee - Indianapolis	6	7	3	265
137	Polyline	Milwaukee - Detroit	6	2	4	355
138	Polyline	Milwaukee - Cleveland	6	3	5	419
139	Polyline	Indianapolis - Indianapolis	7	7	1	0
14	Polyline	Indianapolis - Columbus		9		

Source: ESRI

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Network Analysis

- Utility Networks
  - Referred to as Geometric Networks in ArcGIS
  - Examples: water distribution, electrical lines, gas pipelines, telephone services, and water flow in a stream
  - Junctions can act as **sources** or **sinks** and determine flow direction in a network
    - Flow is away from sources
    - Flow is toward sinks

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Network Analysis

- Utility Networks
  - A common type of analysis in geometric networks is **network tracing**.
    - involves placing a marker on the network and tracing either upstream, or downstream, or both.

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References

- Further Reading
  - ESRI ArcGIS Network Tutorial (e.g. link below)
    - http://pro.arcgis.com/en/pro-app/help/analysis/networks/what-is-network-analyst-.htm
  - Curtin, Kevin M. (2007). Network analysis in geographic information science: Review, assessment, and projections. Cartography and Geographic Information Science 34.2 (2007): 103-111.
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  - Fischer, M.M. 2006. GIS and network analysis. Spatial Analysis and GeoComputation: Selected Essays (2006): 43-60.
  - Ducruet, C and Rodrigue, J Graph (2017) Theory: Measures and Indices. https://people.hofstra.edu/geotrans/eng/methods/ch1m3en.html

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