



Network analysis

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The importance of networks

- Networks are all around us.



- The techniques have been developed to analyse these most geographical phenomena.



Data requirements for network analysis

Data requirements (Clausen 1991, road analysis):

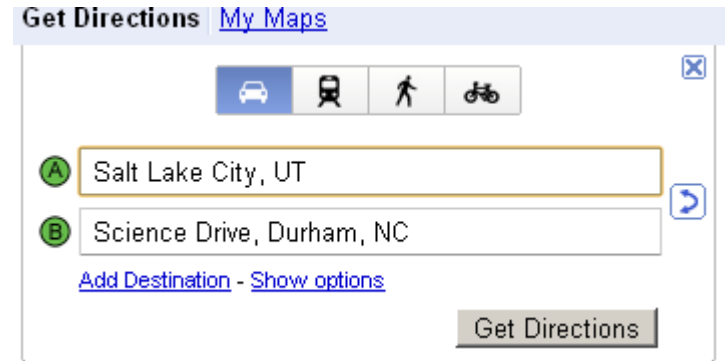
- Accurate
- Up to date
- Topologically correct
- Attributes:
 - road conditions
 - classification
 - speed restrictions
 - one way streets
 - turning restrictions
 - width and height restrictions
 - junctions
 - roundabouts
 - reference landmarks



Networks and GIS

Cost:

- What is the impact of an object flowing through the network?
- Types
 - Time
 - Distance
- Based on connectivity, flow, and rules



Directions to Science Dr, Durham, NC
2,121 mi – about 1 day 10 hours





Network characteristics – formal description

- A network can be defined as a set of linear features through which resources flow.
- A network is referred to as a ***pure network*** if only its **topology and connectivity** are considered.
- If a network is characterised by its **topology and flow characteristics** (such as capacity constraints, path choice and link cost functions) it is referred to as a ***flow network***.
- A *transportation network* is a flow network representing the movement of people, vehicles or goods (Bell and Iida, 1997).

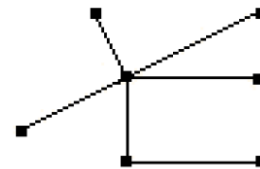
Nodes and links

Building stones - **nodes** (the end points of lines) are used as origins and destinations, and **links** (lines) travers from one node to the other.

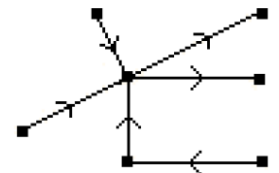
A classification of networks (adapted from Laurini & Thompson, 1992).

Directed links are referred to as *arcs* while undirected links as *edges*.

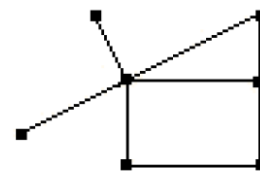
Which one fits for the river network?



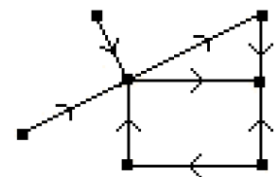
unoriented



oriented



unoriented with loops



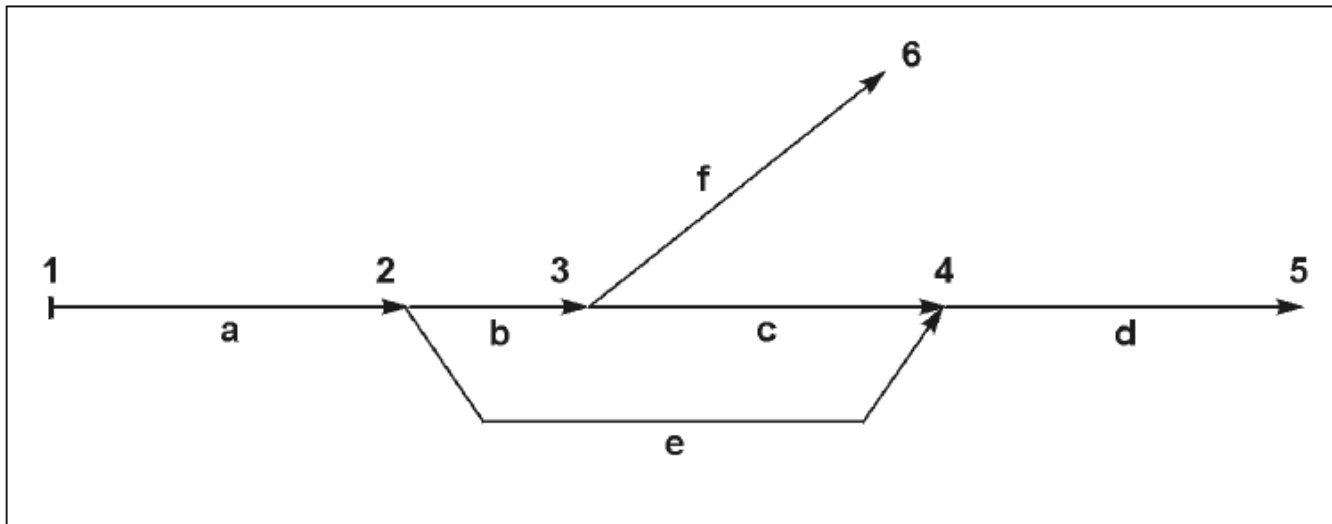
oriented with loops

Network data model - conceptual

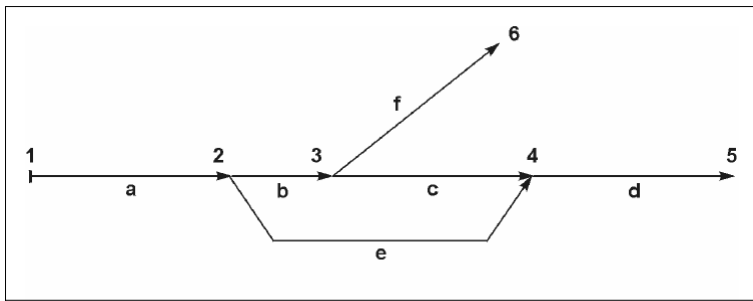
- **A data model is an abstract representation of some real-world situation used to organise data in a database.**
- **three different levels of abstraction: conceptual, logical and physical levels.**
- The *entity-relationship* and the *extended entity-relationship* models are the most widely used conceptual data models.
- The network data model (vector) is built around two core entities: the *Node* (a zero-dimensional entity) and the *Arc* (a one dimensional entity).

Network data model - logical

- logical data model that supports the node-arc representation of networks is the georelational model.
- separates **spatial (geometry)** and **attribute** data into different data models.



(a) Example network for the relational model example



(a) Example network for the relational model example

Arc – node data model

Arc ID	Street Name	Lanes	Other Attributes
a	High Street	2	
b	High Street	4	
c	High Street	4	
d	High Street	2	
e	River Way	2	
f	Hill Street	2	

(b) A simple arc table

Arc ID	Stop Light	Other Attributes
1	n	
2	y	
3	n	
4	y	
5	n	
6	n	

(c) A simple node table

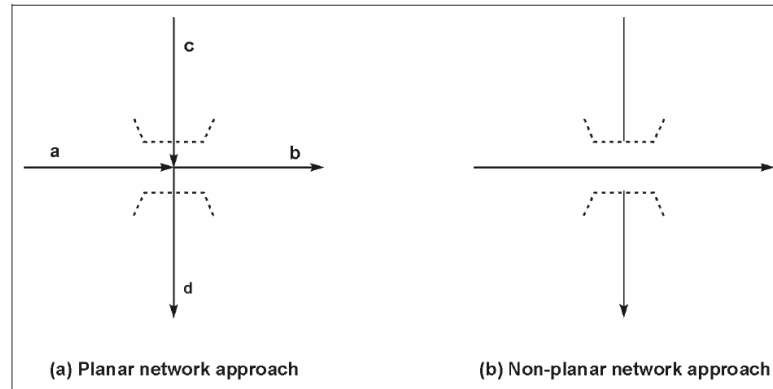
Arc ID	Street Name	Lanes	From Node	To Node
a	High Street	2	1	2
b	High Street	4	2	3
c	High Street	4	3	4
d	High Street	2	4	5
e	River Way	2	2	4
f	Hill Street	2	3	6

Node ID	Stop Light?	Arc Links
1	n	a
2	y	a, b
3	n	b, c, f
4	y	c, d, e
5	n	d
6	n	f

(d) Pointers added to the arc and node tables to represent connectivity

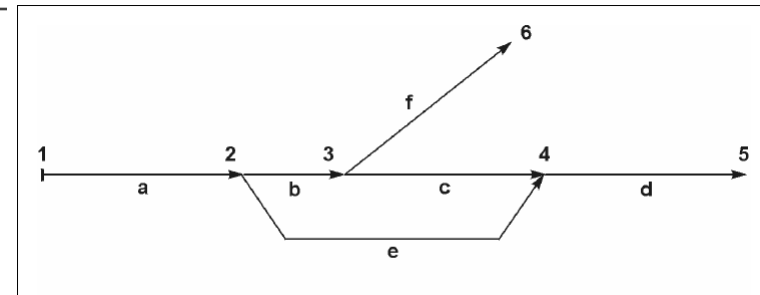


Connectivity and planar networks



- standard fully intersected planar network data model has been extended by adding a new structure, called the *turn-table* – **node rules**.

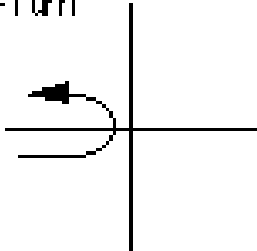
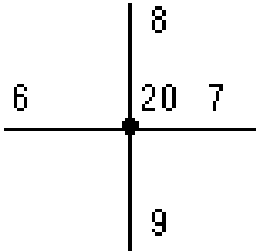

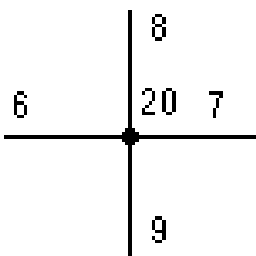

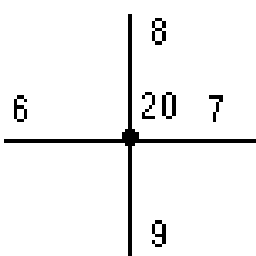
From Arc	To Arc	Turn ?
a	c	n
a	b	y
a	d	n
b	a	y
b	c	n



(a) Example network for the relational model example

Turn table examples

0 = No Impedance
-1 = No Turn

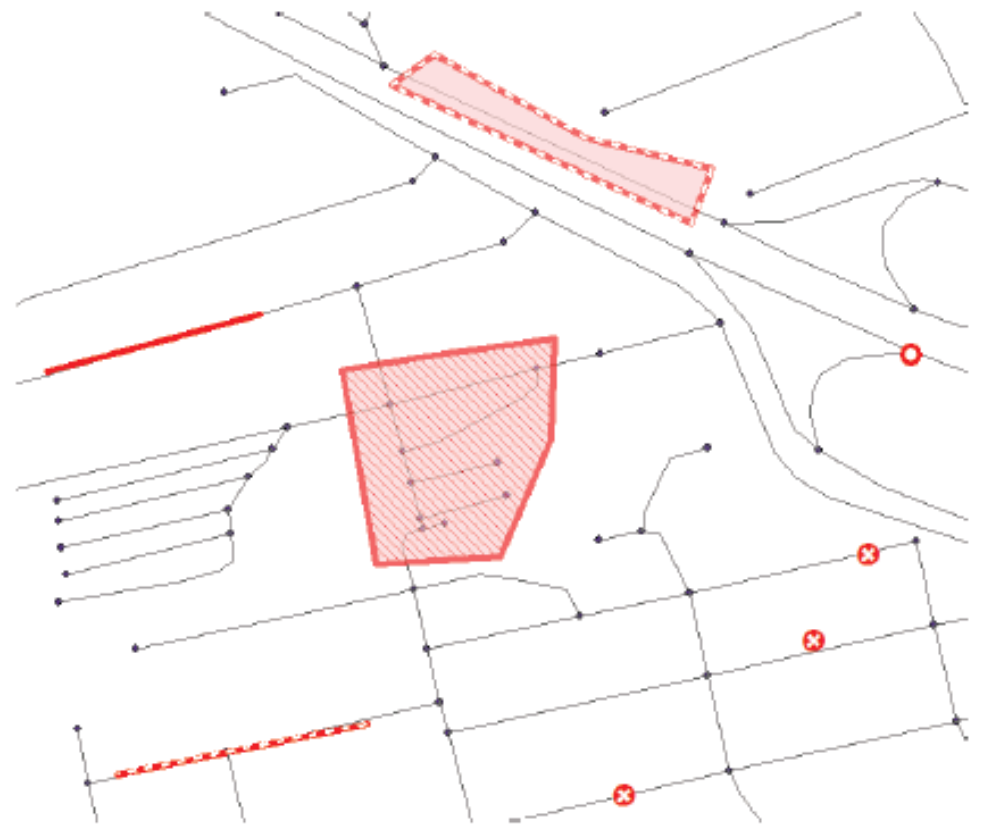
Situation	Representation	Turntable																				
U-Turn 		<table border="1"> <thead> <tr> <th>NODE#</th> <th>FROM ARC#</th> <th>TO ARC#</th> <th>ANGLE</th> <th>TIME IMPEDANCE (seconds)</th> </tr> </thead> <tbody> <tr> <td>20</td> <td>6</td> <td>6</td> <td>180</td> <td>20</td> </tr> </tbody> </table>	NODE#	FROM ARC#	TO ARC#	ANGLE	TIME IMPEDANCE (seconds)	20	6	6	180	20										
NODE#	FROM ARC#	TO ARC#	ANGLE	TIME IMPEDANCE (seconds)																		
20	6	6	180	20																		
Stop sign 		<table border="1"> <thead> <tr> <th>NODE#</th> <th>FROM ARC#</th> <th>TO ARC#</th> <th>ANGLE</th> <th>TIME IMPEDANCE (seconds)</th> </tr> </thead> <tbody> <tr> <td>20</td> <td>6</td> <td>7</td> <td>0</td> <td>15</td> </tr> <tr> <td>20</td> <td>6</td> <td>8</td> <td>90</td> <td>20</td> </tr> <tr> <td>20</td> <td>6</td> <td>9</td> <td>-90</td> <td>10</td> </tr> </tbody> </table>	NODE#	FROM ARC#	TO ARC#	ANGLE	TIME IMPEDANCE (seconds)	20	6	7	0	15	20	6	8	90	20	20	6	9	-90	10
NODE#	FROM ARC#	TO ARC#	ANGLE	TIME IMPEDANCE (seconds)																		
20	6	7	0	15																		
20	6	8	90	20																		
20	6	9	-90	10																		
No Right Turn 		<table border="1"> <thead> <tr> <th>NODE#</th> <th>FROM ARC#</th> <th>TO ARC#</th> <th>ANGLE</th> <th>TIME IMPEDANCE (seconds)</th> </tr> </thead> <tbody> <tr> <td>20</td> <td>6</td> <td>9</td> <td>-90</td> <td>-1</td> </tr> <tr> <td>20</td> <td>6</td> <td>7</td> <td>0</td> <td>5</td> </tr> <tr> <td>20</td> <td>6</td> <td>8</td> <td>90</td> <td>10</td> </tr> </tbody> </table>	NODE#	FROM ARC#	TO ARC#	ANGLE	TIME IMPEDANCE (seconds)	20	6	9	-90	-1	20	6	7	0	5	20	6	8	90	10
NODE#	FROM ARC#	TO ARC#	ANGLE	TIME IMPEDANCE (seconds)																		
20	6	9	-90	-1																		
20	6	7	0	5																		
20	6	8	90	10																		



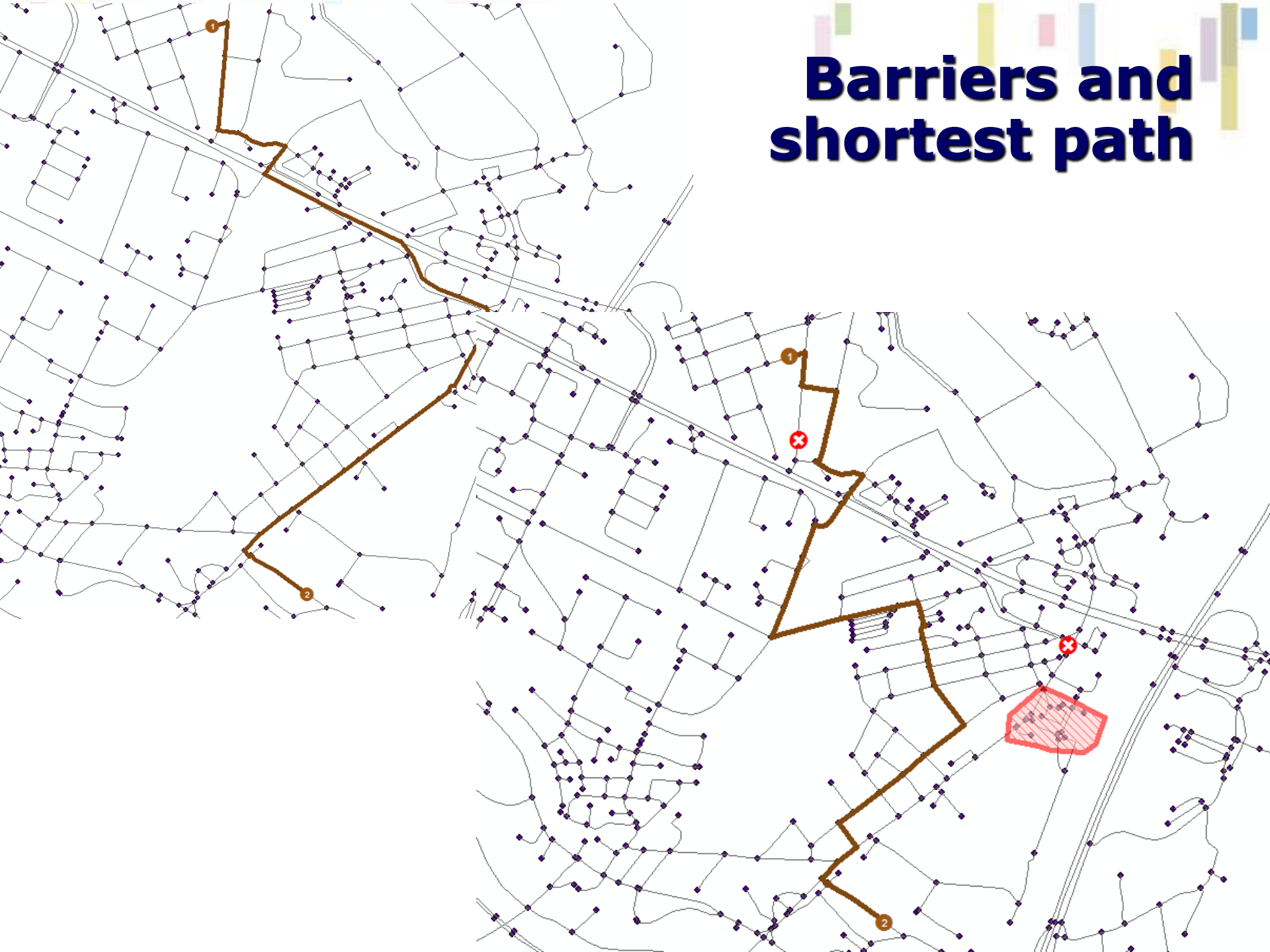
Barriers

Barrier represents certain limitations within the network. Different geometry types – point, line, polygon

- **Restrictions** (complete closures of the street/road segment),
- **Scaled cost** (traffic lights, one way closure, traffic accident, traffic signs).



Barriers and shortest path



Data for network analysis

- **ZABAGED, OpenStreetNet, JSDI**
- **StreetNet (CEDA) – updated 2x year; seamless and fully routable road network supplemented by additional topographic layers and layers of administrative boundaries.**
- **Road DB – its descriptive information (number, international number and class of the road, street name etc.), attributes describing technical and functional state of individual segments and basic attributes for movement on the network.**



Street Net sample





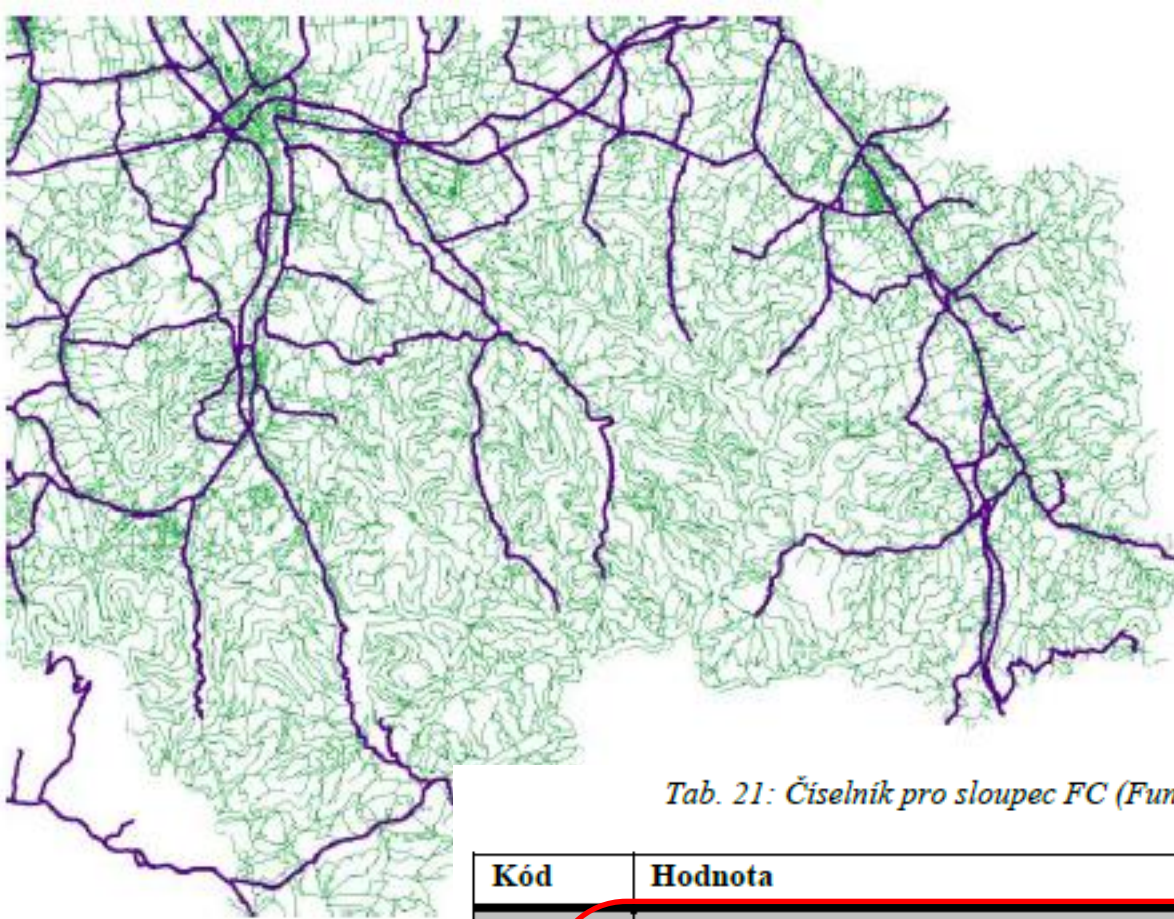
Streetnet

Horák a kol. 2015



ZABAGED

Street Net selection of roads



Tab. 21: Číselník pro sloupec FC (Funkční kategorizace) (CEDA, 2014a)

Kód	Hodnota
0	dálnice
1	hlavní silnice (zejm. mezinárodně významné silnice evropské tahy E)
2	ostatní významné silnice
3	silnice regionálního významu
4	spojovací silnice lokálního významu
5	významné spojnice v rámci sídel
6	ostatní významné komunikace v rámci sídel
7	místní komunikace
8	účelové komunikace (lesní a polní cesty, chodníky pro pěší, stezky pro cyklisty, ...)

Obr. 155: Porovnání vrstvy



Real Time data for network analysis

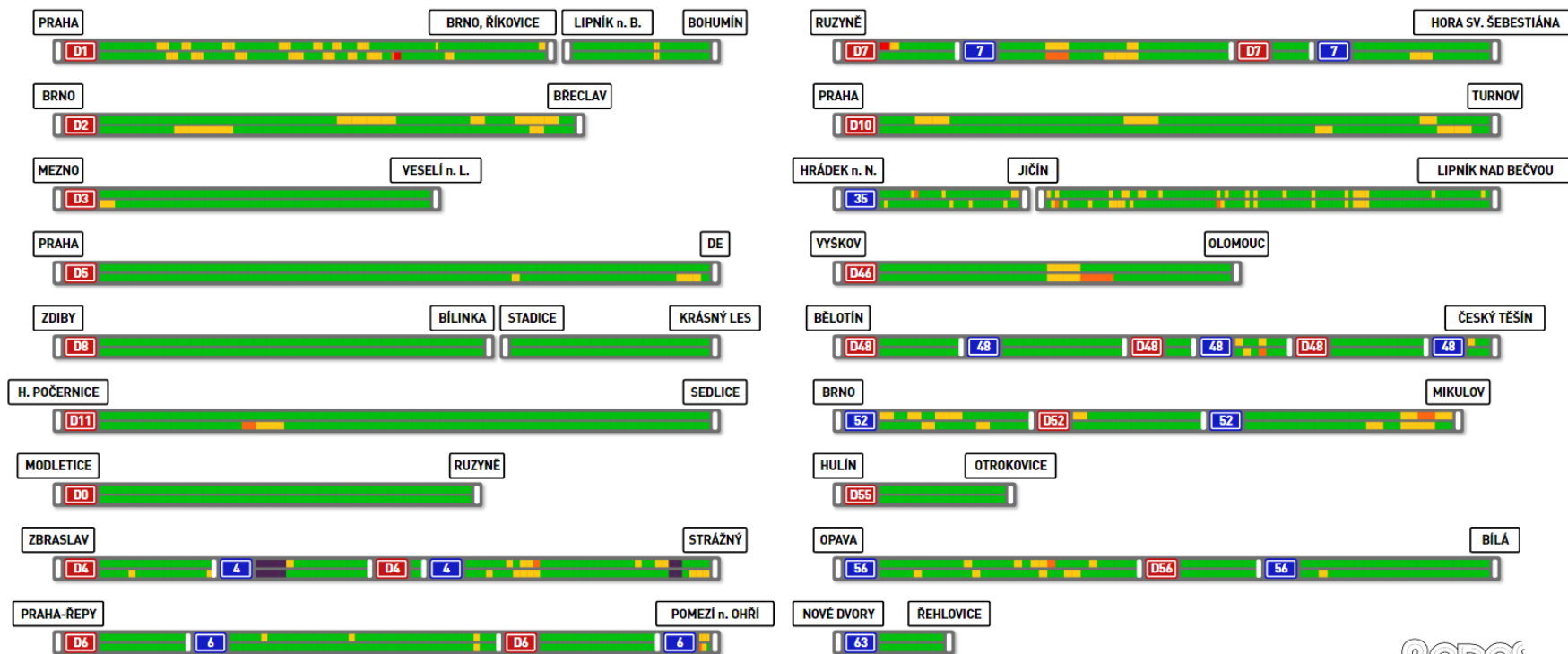
- **Rodos** <http://rodos.vsb.cz/>
- Dynamic Mobility Model (DMM) integrating the movement of persons, vehicles, and goods.

Česká Republika
Dálnice a rychlostní silnice

EN | CS | Průvodce aplikací | Kontakt

Automatická aktualizace za 22s

Dálnice a rychlostní silnice | Rozcestník | Česká Republika | Praha | Brno | Ostrava | Kongesce | Analýza uzávěrek | Modernizace D1 | Meteoradar





Detail view on Brno with traffic delays

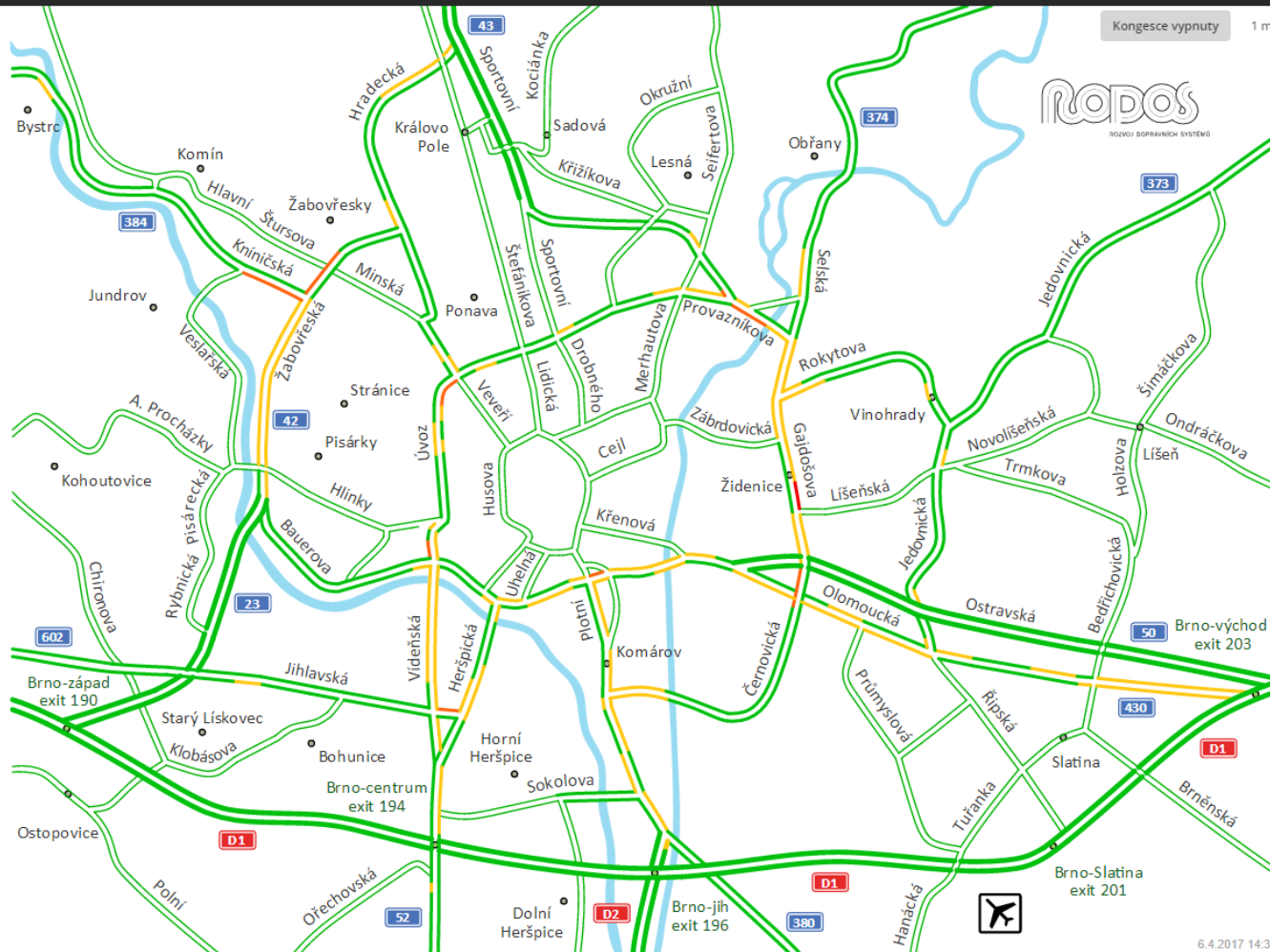
EN | CS | Průvodce aplikací | Kontakty

Brno
Náhled

Automatická aktualizace za 2s

Dálnice a rychlostní silnice | Rozcestník | Česká Republika | Praha | Brno | Ostrava | Kongesce | Analýza uzavírek | Modernizace D1 | Meteora

Kongesce vypnuty 1 min 2 min 3 min 4 min 5 min



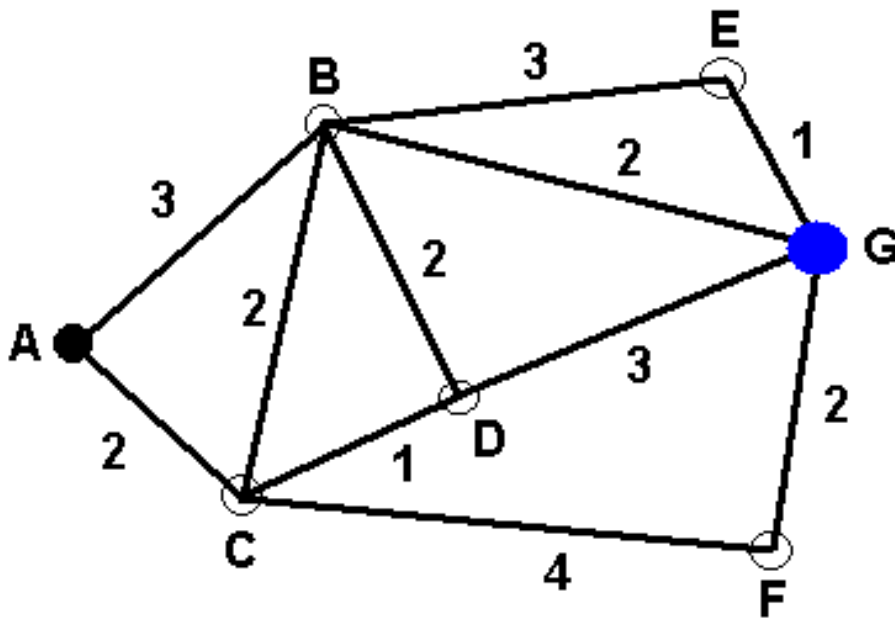
Algorithms for network operations

- **Search procedure – alternations - no turning back, fewest number of nodes, minimum cost.**
- A common question is "what is the shortest path?," - **Dijkstra algorithm**, mathematically designed to find the lowest cost route between two locations when a measure of cost is attached to each link.
- Simplification - one way, no loops.

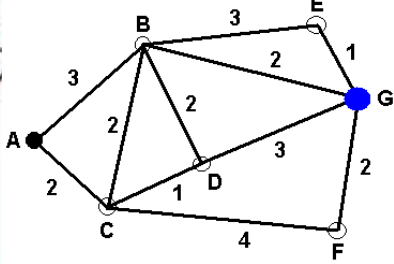


Dijkstra algorithm I

Task: find the shortest path between an origin (A) and a destination (G). Trial and error method 😊

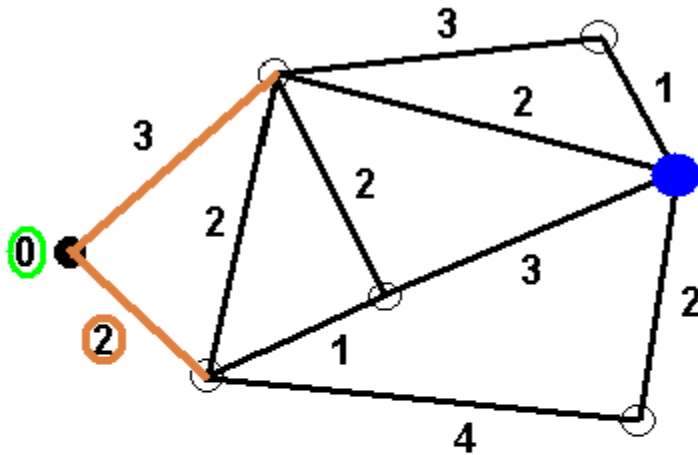


	Dist.	Parent	Incl.
A	0	-	No
B		-	No
C		-	No
D		-	No
E		-	No
F		-	No
G		-	No

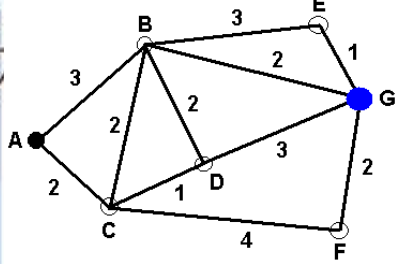


Dijkstra algorithm II

- List all the nodes of the graph that link directly to the starting node and label each link with its cost value.

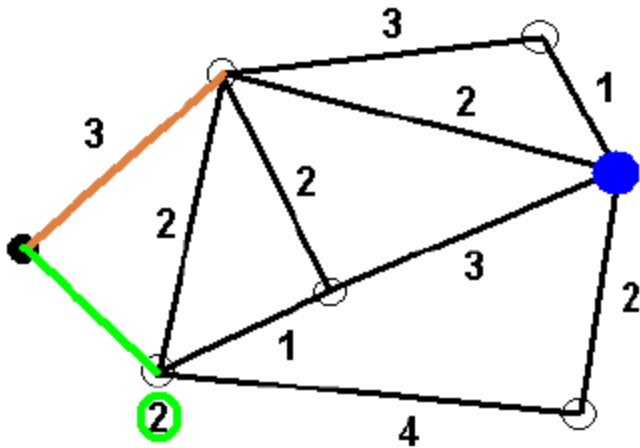


	Dist.	Parent	Incl.
A	0	-	Yes
B	3	A	No
C	2	A	No
D		-	No
E		-	No
F		-	No
G		-	No

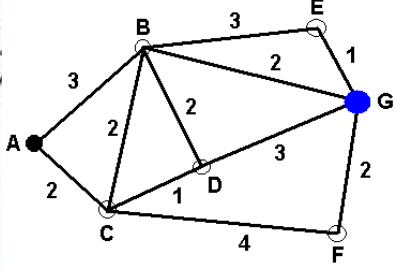


Dijkstra algorithm III

Find the node with the lowest link value and label the node with this value. This is the lowest cost path between the origin and this node.

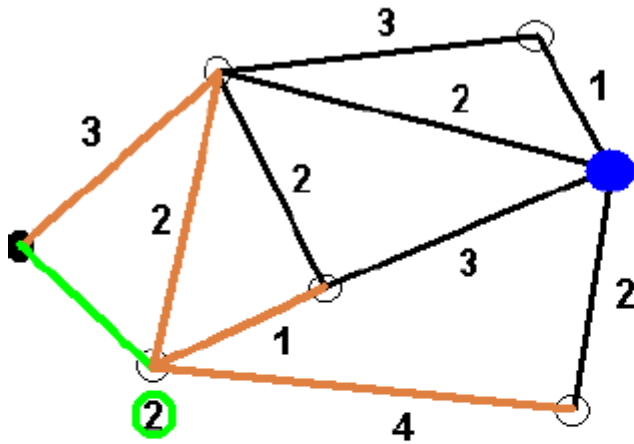


	Dist.	Parent	Incl.
A	0	-	Yes
B	3	A	No
C	2	A	Yes
D		-	No
E		-	No
F		-	No
G		-	No

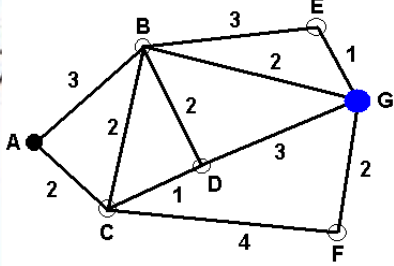


Dijkstra algorithm IV

Extend the search from this node. Brown and green lines.

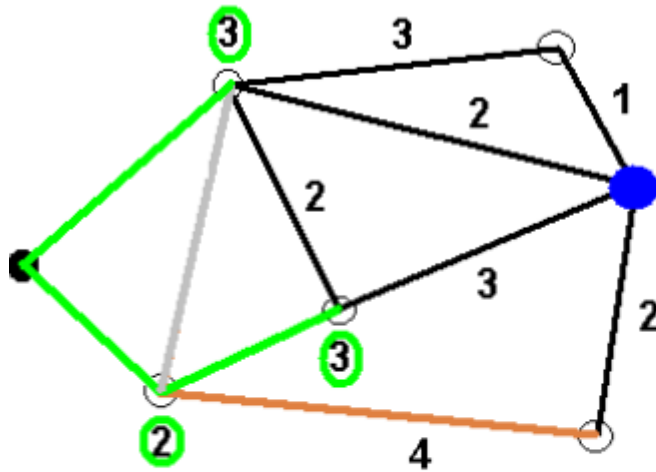


	Dist.	Parent	Incl.
A	0	-	Yes
B	3 or 4	A or C	No
C	2	A	Yes
D	3	C	No
E		-	No
F	6	C	No
G		-	No

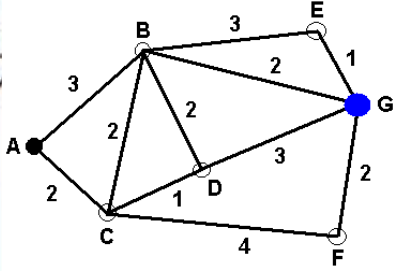


Dijkstra algorithm V

- Find the node with the lowest cumulative cost and label the node with this value.
- If there is more than one node that has been reached in the same cumulative cost so we label them both

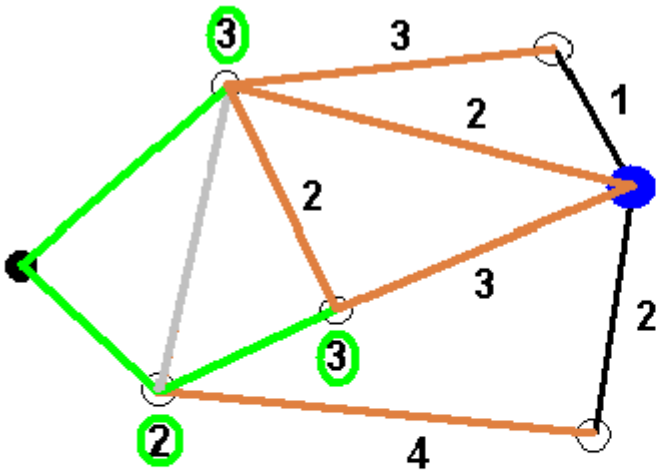


	Dist.	Parent	Incl.
A	0	-	Yes
B	3	A	Yes
C	2	A	Yes
D	3	C	Yes
E		-	No
F	6	C	No
G		-	No

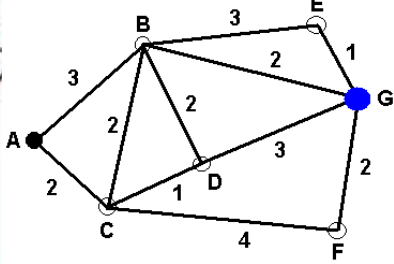


Dijkstra algorithm VI

- Extend the search again. Add new linked nodes to the list of nodes and calculate the cumulative cost to each.

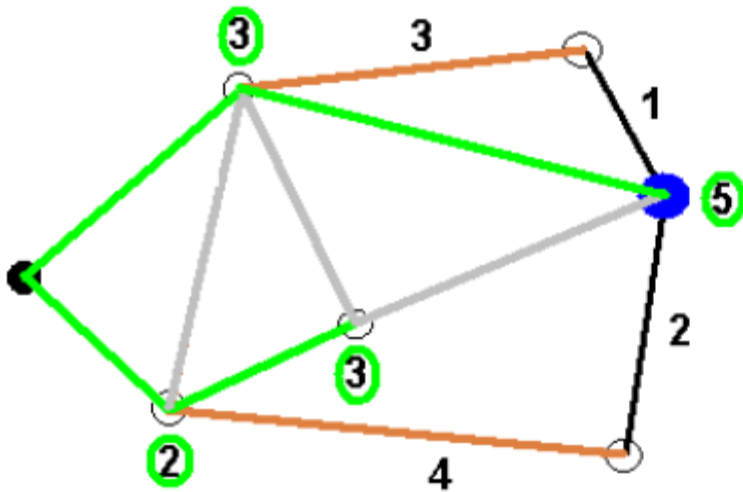


	Dist.	Parent	Incl.
A	0	-	Yes
B	3	A	Yes
C	2	A	Yes
D	3	C	Yes
E	6	B	No
F	6	C	No
G	5 or 6	B or C	No



Dijkstra algorithm VII

the node with the lowest cumulative cost



	Dist.	Parent	Incl.
A	0	-	Yes
B	3	A	Yes
C	2	A	Yes
D	3	C	Yes
E	6	B	No
F	6	C	No
G	5	B	Yes

Node **G** is reached from B which is reached from A
i.e. shortest path = **A B G**.



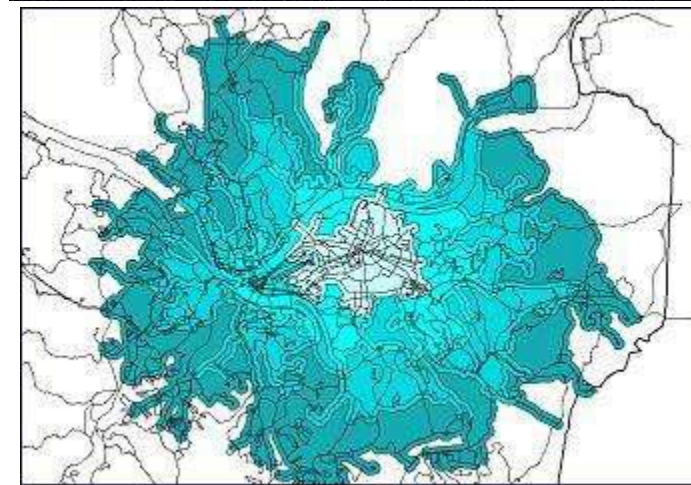
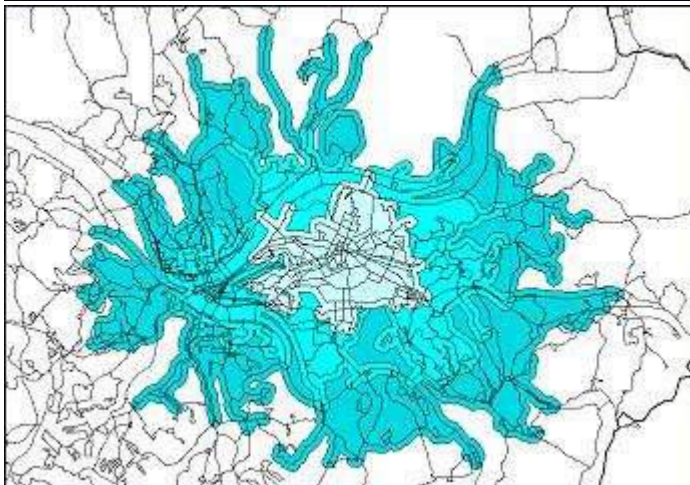
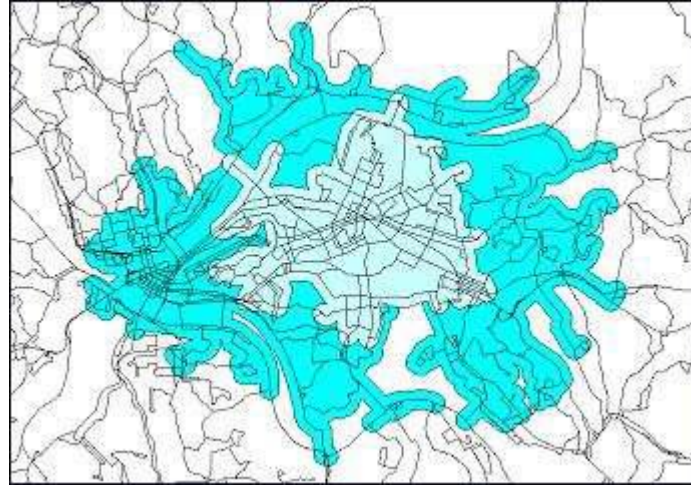
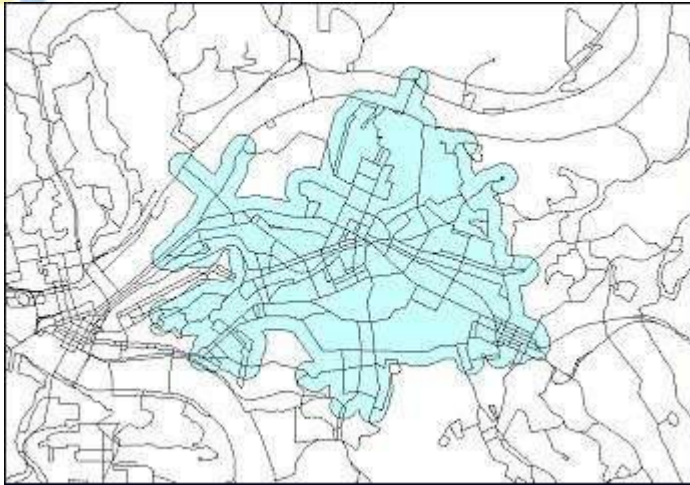
Applications of network analysis

- **Routing** - Finding shortest routes is probably the commonest routing problem to occupy GIS users. Finding the shortest route from A to B through a road network is crucial for emergency services, business journeys, or simply planning routes for holiday makers touring a region.
- **Service area** - The objective is to create service areas around a centre and optimise the distribution of the resources based on the capacity of each facility.



Isochrones

- 15 – 60 min



The logo for IGC (International Geographical Centre) is located in the top left corner. It features a stylized globe with blue and white lines, and the letters 'IGC' in blue below it. The background of the slide is decorated with vertical bars of various colors (blue, green, yellow, orange, pink, purple) and small squares of the same colors scattered across the top.

Finding Service Areas Using ArcGIS Network Analyst

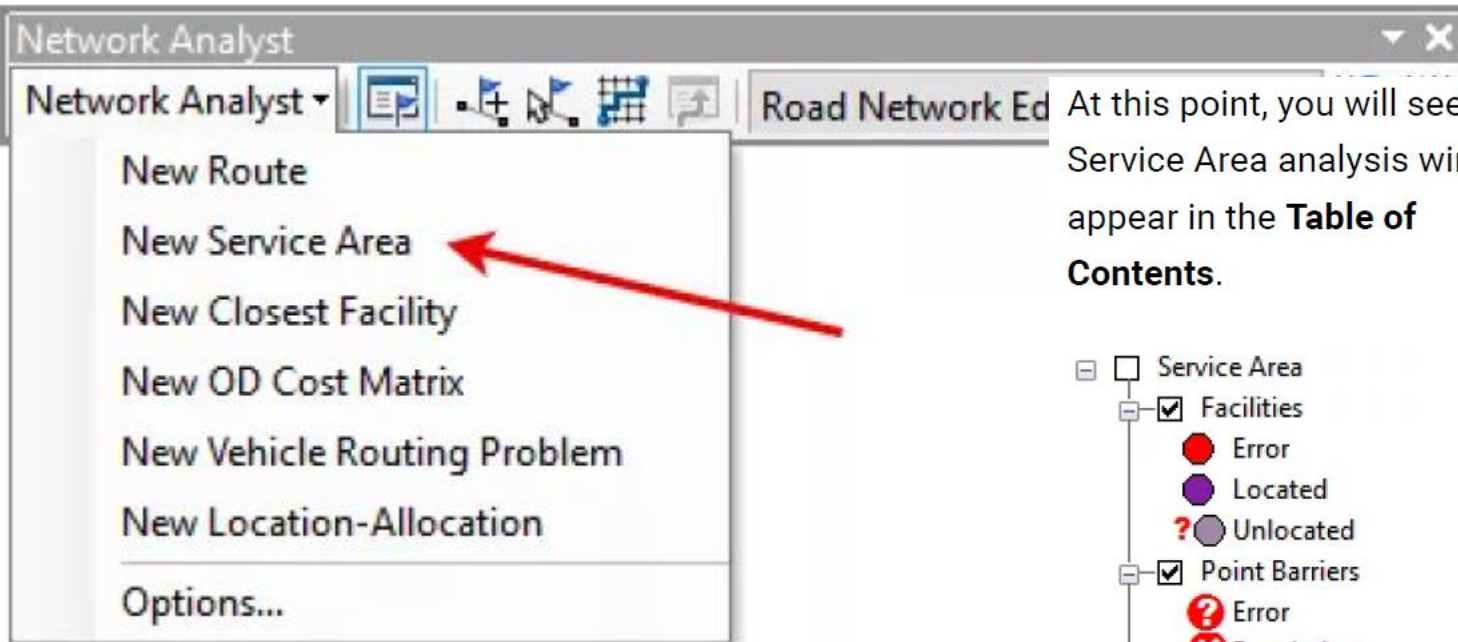
- Create Isochrone Maps – How Far Can Firefighters Service?
- that each facility will have it's own service area – or extent for how far firefighters can reach in a given amount of time (isochrone).
- different scenarios – including setting up **lengths** and **time**.

What You Will Need

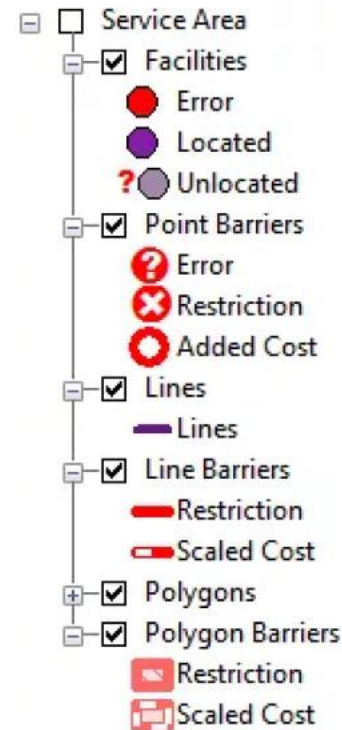
- Network Analyst Extension
- Road Network – topologically correct.
- Facilities Layer (Fire stations, police stations, hospitals, etc)



Start new Service area

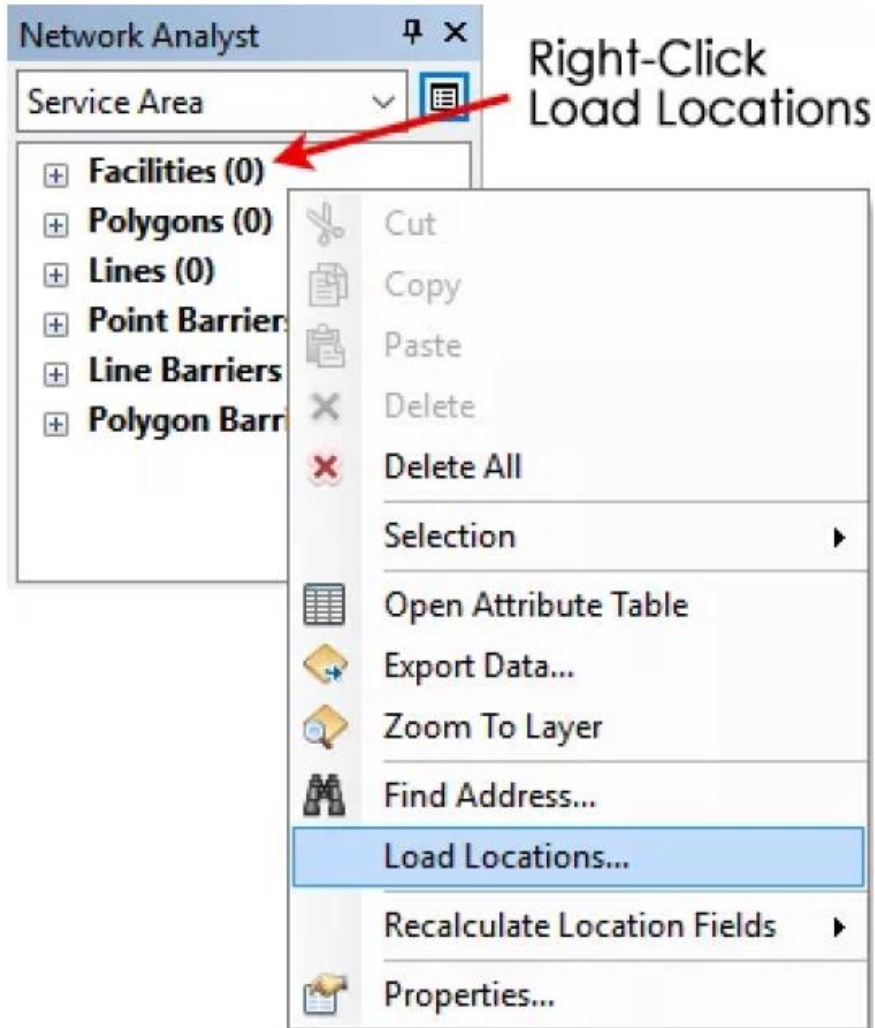


At this point, you will see the Service Area analysis window appear in the **Table of Contents**.





Adding facilities



- **Load facilities point data**
- **Visualize and check for errors**





Service area problem set up

Network Analyst

Service Area

- Facilities (30)
- Polygons (0)
- Lines (0)
- Point Barriers (0)
- Line Barriers (0)
- Polygon Barriers (0)

Service
Prop

Layer Properties

Line Generation		Accumulation		Network Locations	
General	Layers	Source	Analysis Settings	Polygon Generation	
Settings					
Impedance:	Length (Meters)				
Default Breaks:	1000, 2500, 5000				
<input type="checkbox"/> Use Time:	Time of Day: 8 AM				
	<input checked="" type="radio"/> Day of Week: Today				
	<input type="radio"/> Specific Date: 2015-11-22				
Direction:					
	<input checked="" type="radio"/> Away From Facility				
	<input type="radio"/> Towards Facility				
U-Turns at Junctions:	Allowed				
<input type="checkbox"/> Use Hierarchy					
<input checked="" type="checkbox"/> Ignore Invalid Locations					
Restrictions					
[Empty Box]					

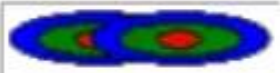
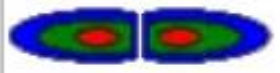
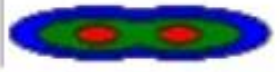


[About the service area analysis layer](#)

Variables:

- Impedance
- Breaks (m, min)
- Direction



Polygon generation table option

Line Generation		Accumulation		Network Locations
General	Layers	Source	Analysis Settings	Polygon Generation
<input checked="" type="checkbox"/> Generate Polygons				
Polygon Type				
<input checked="" type="radio"/> Generalized				
<input type="radio"/> Detailed				
<input checked="" type="checkbox"/> Trim Polygons:				
<input type="text" value="100"/>				
<input type="text" value="Meters"/>				
Multiple Facilities Options				
<input checked="" type="radio"/> Overlapping				
Create polygons for each facility. These polygons may overlap.				
<input type="radio"/> Not Overlapping				
Allocate polygons to the closest facility.				
<input type="radio"/> Merge by break value				
Join polygons of multiple facilities having the same break values.				
				
				
				
Excluded Sources				
<input type="checkbox"/> TER_CANMAP_ROAD				
Overlap Type				
<input checked="" type="radio"/> Rings				
Do not include the area of the smaller breaks. Create the polygons going between consecutive breaks.				
<input type="radio"/> Disks				
Create the polygons going from the facility to the break.				
				
				

Line generation options – the use of linear referencign system.



General Layers Source Analysis Settings Polygon Generation

Line Generation Accumulation Network Locations

Generate Lines

Generate Measures

Split Lines At Breaks

Include Network Source Fields

Overlap Options

Overlapping
Include a separate line feature for each facility within break impedance units of the line.

Not Overlapping
Include each line at most once and associate it with its closest (least impedance) facility.

The diagram illustrates two scenarios for line generation. The top scenario, labeled 'Overlapping', shows two parallel horizontal lines, one blue and one red, with green circles at their ends. The bottom scenario, labeled 'Not Overlapping', shows a blue line and a red line that do not overlap, with green circles at their ends. The lines are represented by black dots at their endpoints and midpoints.








Generate the service area polygons and lines/road segments

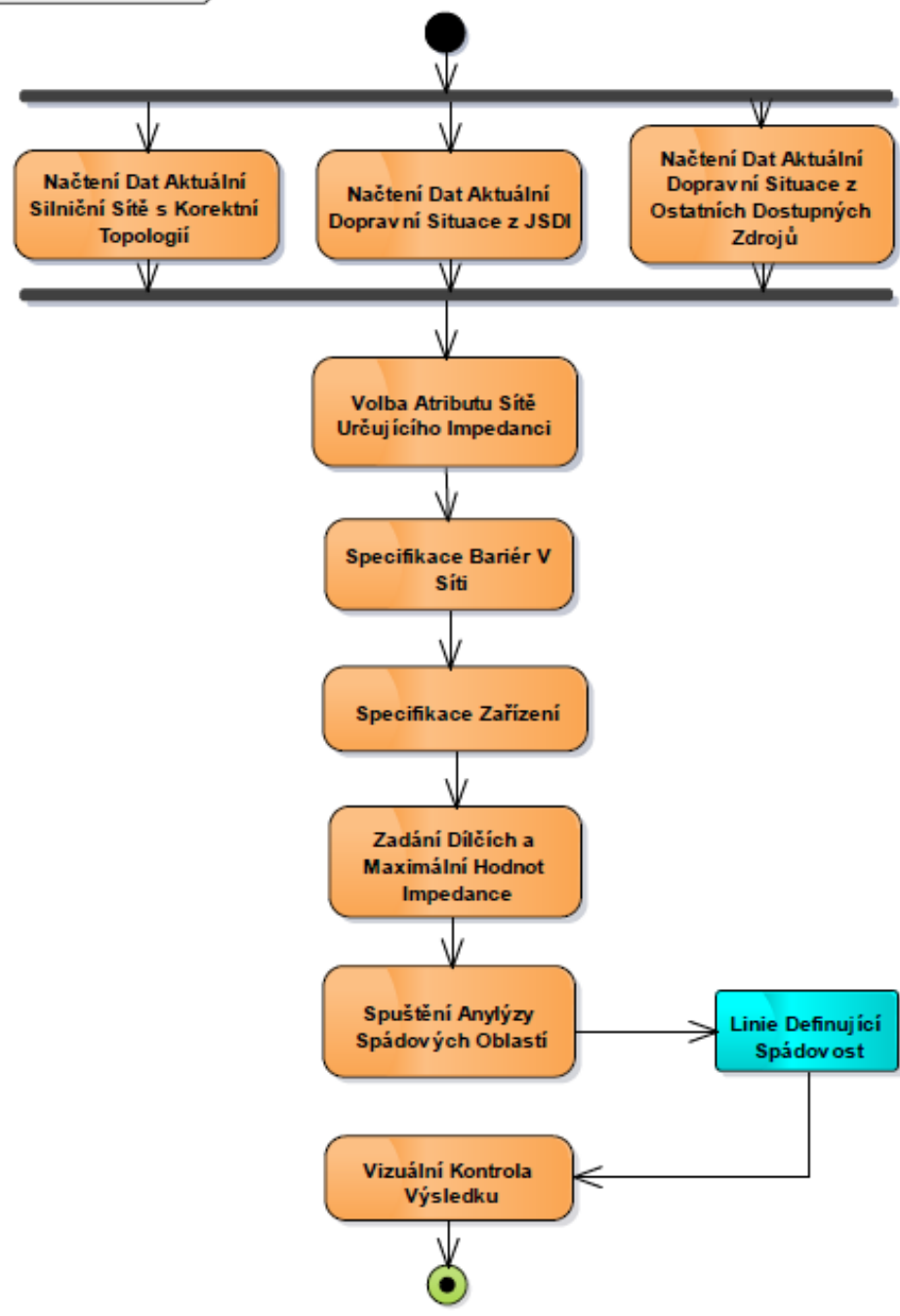


Solve



Using barriers

- Service Area
 - Point Barriers
 -  Error
 -  Restriction
 -  Added Cost
 - Line Barriers
 -  Restriction
 -  Scaled Cost
 - Polygon Barriers
 -  Restriction
 -  Scaled Cost



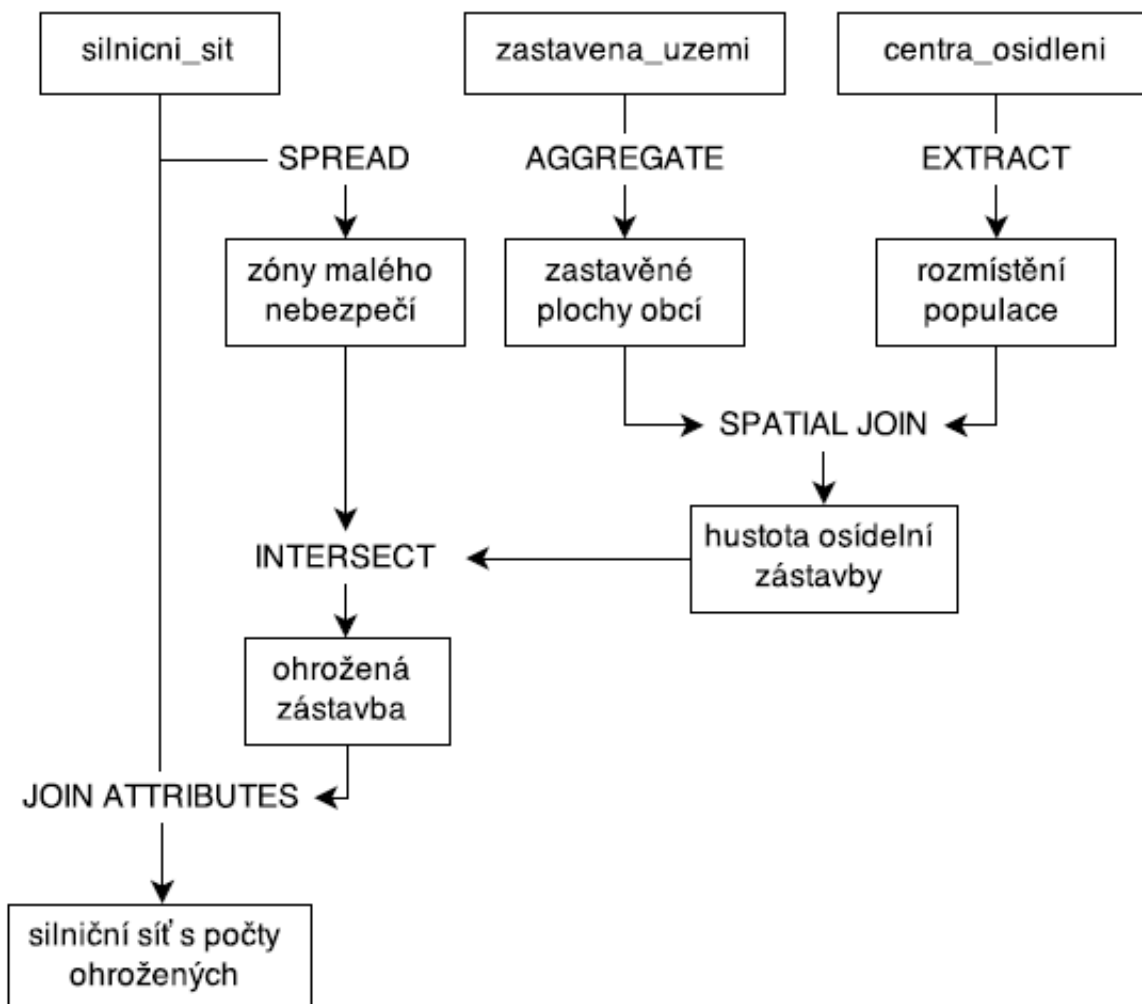


Transportation of dangerous goods – case study (Leitgeb 2015)

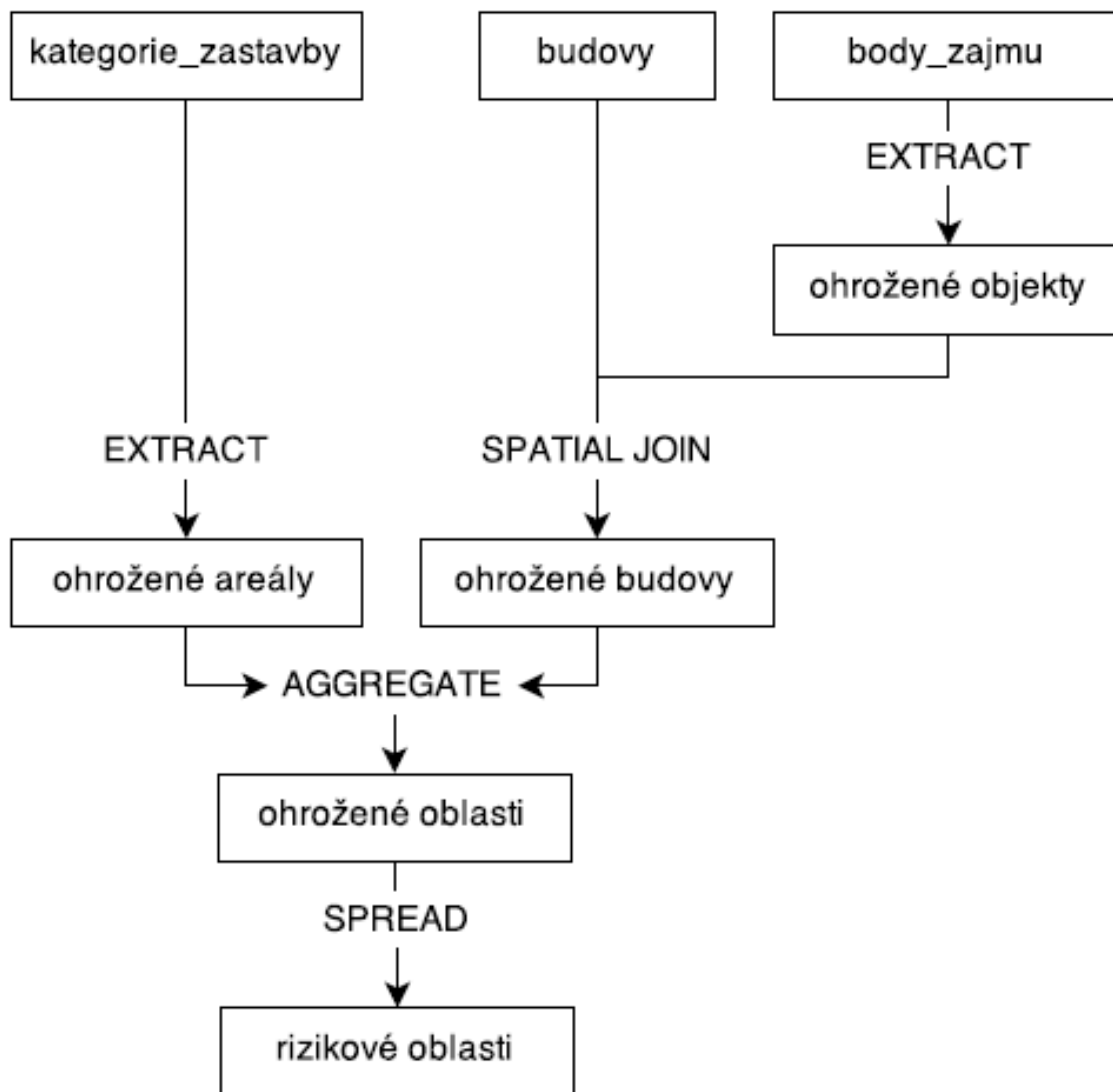
- **Goal: Minimise the potential impact on inhabitants during the transportation of dangerous substances (flammable, explosive...).**
- **ADR classification, Police and army internal legislation.**
- **Alternative criterion:**
 - Population concentration based on street/road segments;
 - Buildings (POIs) with high concentration of inhabitants and sensitive objects.



Criterion 1 – street segments



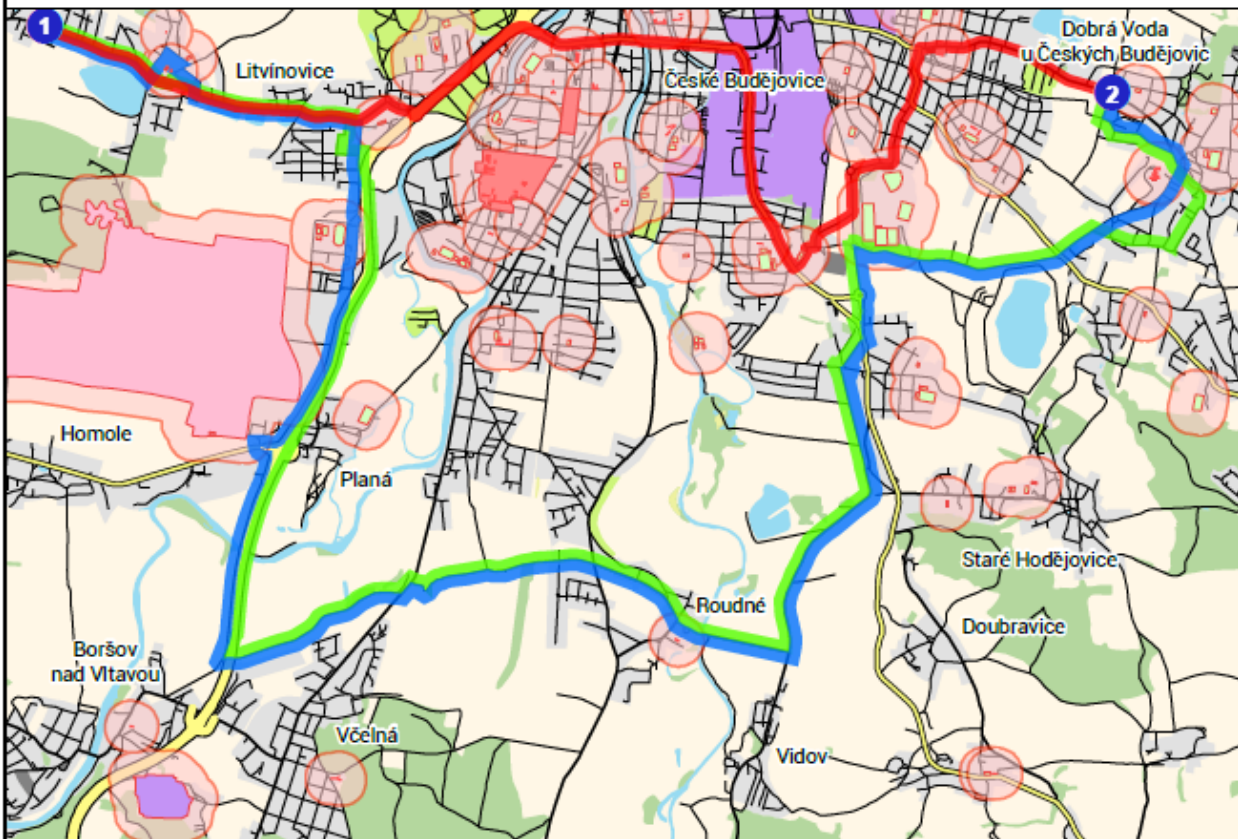
Criterion 2 – sensitive objects and PoI



OPTIMALIZACE TRASY PŘEVOZU VÝBUŠNIN NA MODELOVÉM ÚZEMÍ ČESKOBUDĚJOVICKA

0 500 1 000 2 000 m

TRASA Č. 1



Pokryv povrchu a půdy

Park	Včelná
Bažina	Zastavěné oblasti
Lesy	Vodní plochy a toky
Hřbitov	Pole a louky

Zájmové areály

Ohrožená a neohrožená letiště
Ohrožená a neohrožená průmyslová zóna
Ohrožená a neohrožená nemocnice
Ohrožená a neohrožená hřiště/stadion

Prvky trasy

Krajní bod trasy
Trasa A
Trasa B
Trasa C

Bariéra zvýšené ceny, citlivá budova, hřiště
--

Pozemní komunikace

Silnice 1., 2. a 3. třídy
ostatní komunikace

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Použitý software: ArcGIS 10.3,
Arc/Info, © ESRI

Souřadnicový systém: S-JTSK

Zdroje dat: Street Net NAV, Global
Network, © CEDA
© Příspěvatelé OpenStreetMaps

Brno 2015, GÚ PŘF MUNI

- **A**- shortest path
- **B** – criterion 1
- **C** – criterion 2