Network analysis

Petr Kubíček

kubicek@geogr.muni.cz

Laboratory on Geoinformatics and Cartography (LGC)
Institute of Geography
Masaryk University
Czech Republic

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

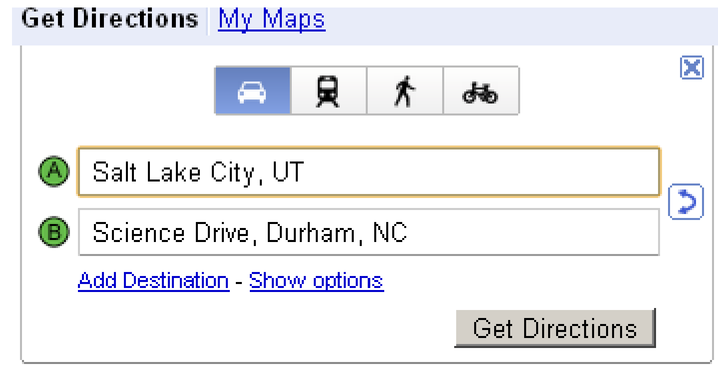
Data requirements (Clausen 1991, road analysis):

- 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**



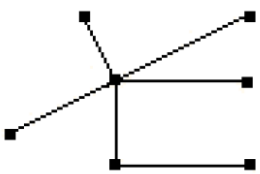
Directions to Science Dr, Durham, NC
2,121 mi – about 1 day 10 hours

Network characteristics – formal description

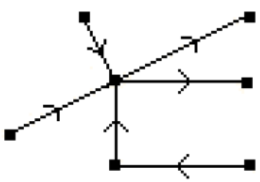
- A network can be defined as a set of linear features through which resources flow.
- A network is referred to as a ***pure network*** if only its **topology and connectivity** are considered.
- If a network is characterised by its **topology and flow characteristics** (such as capacity constraints, 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

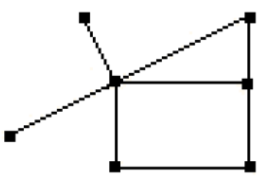
Building stones - n**odes** (the end points of lines) are used as origins and destinations, and **links** (lines) travers from one node to the other.
A classification of networks (adapted from Laurini & Thompson, 1992).
Directed links are referred to as *arcs* while undirected links as *edges*.
Which one fits for the river network?



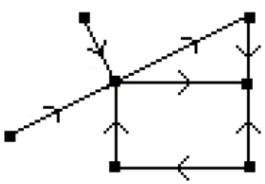
unoriented



oriented



unoriented with loops



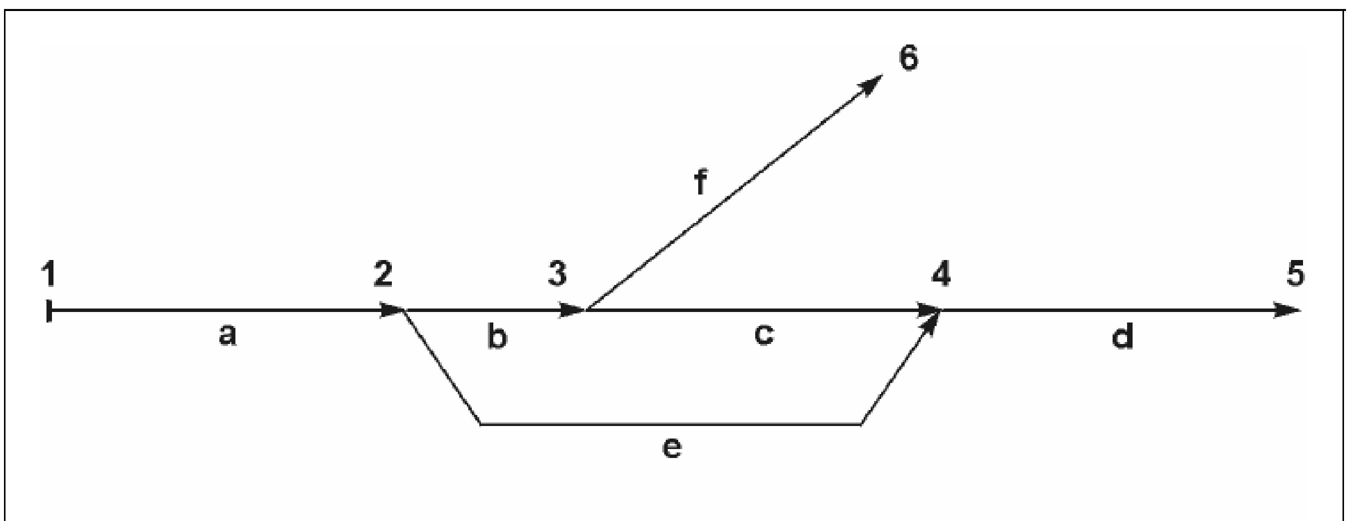
oriented with loops

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).

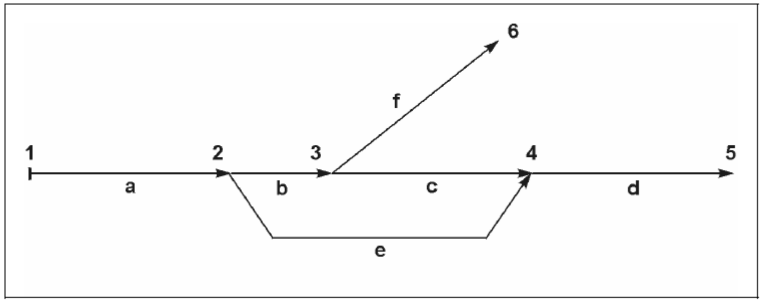
Network data model - logical

- 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

Arc – node data model



(a) Example network for the relational model example

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	

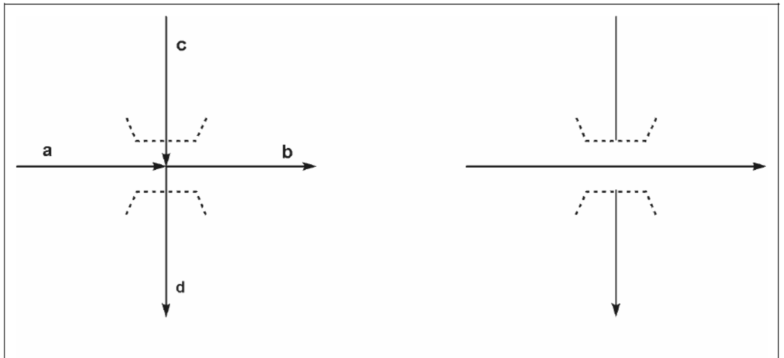
(c) A simple node table

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

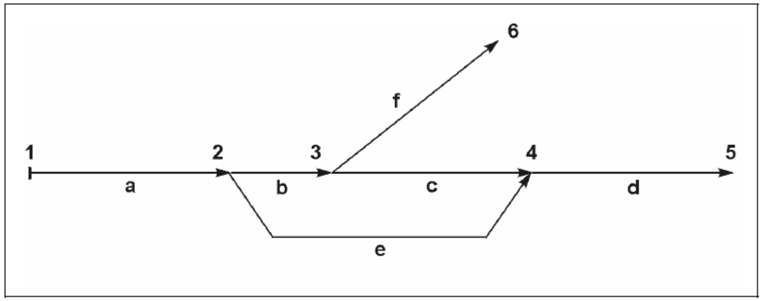
Connectivity and planar networks



(a) Planar network approach (b) Non-planar network approach

- 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



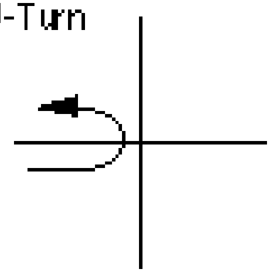
(a) Example network for the relational model example

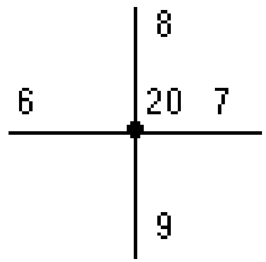
Turn table examples

0 = No Impedance
-1 = No Turn

Situation | **Representation** | **Turntable**

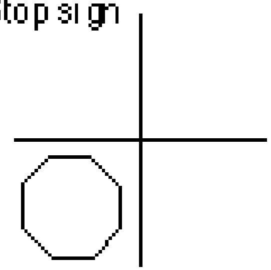
U-Turn

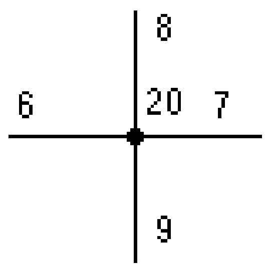




NODE#	FROM ARC#	TO ARC#	ANGLE	TIME IMPEDANCE (seconds)
20	6	6	180	20

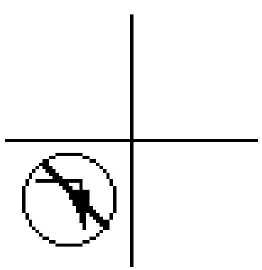
Stop sign

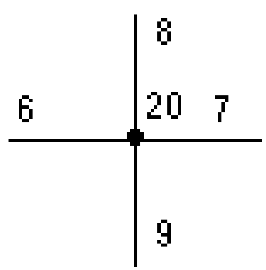




NODE#	FROM ARC#	TO ARC#	ANGLE	TIME IMPEDANCE (seconds)
20	6	7	0	15
20	6	8	90	20
20	6	9	-90	10

No Right Turn



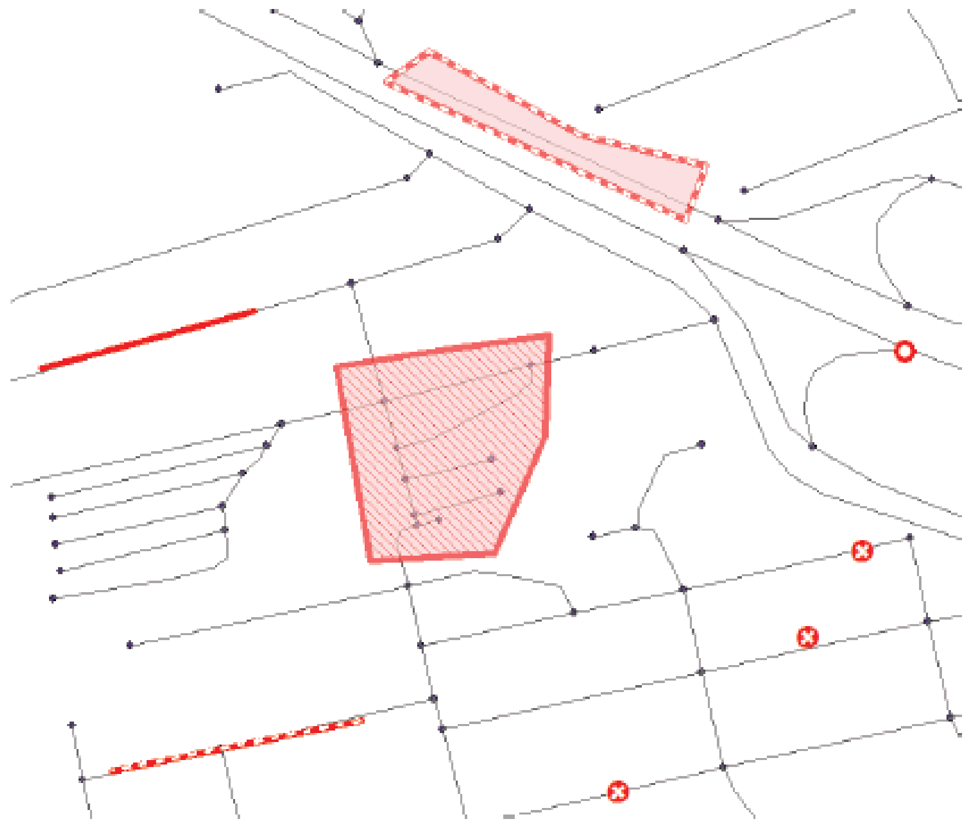


NODE#	FROM ARC#	TO ARC#	ANGLE	TIME IMPEDANCE (seconds)
20	6	9	-90	-1
20	6	7	0	5
20	6	8	90	10

Barriers

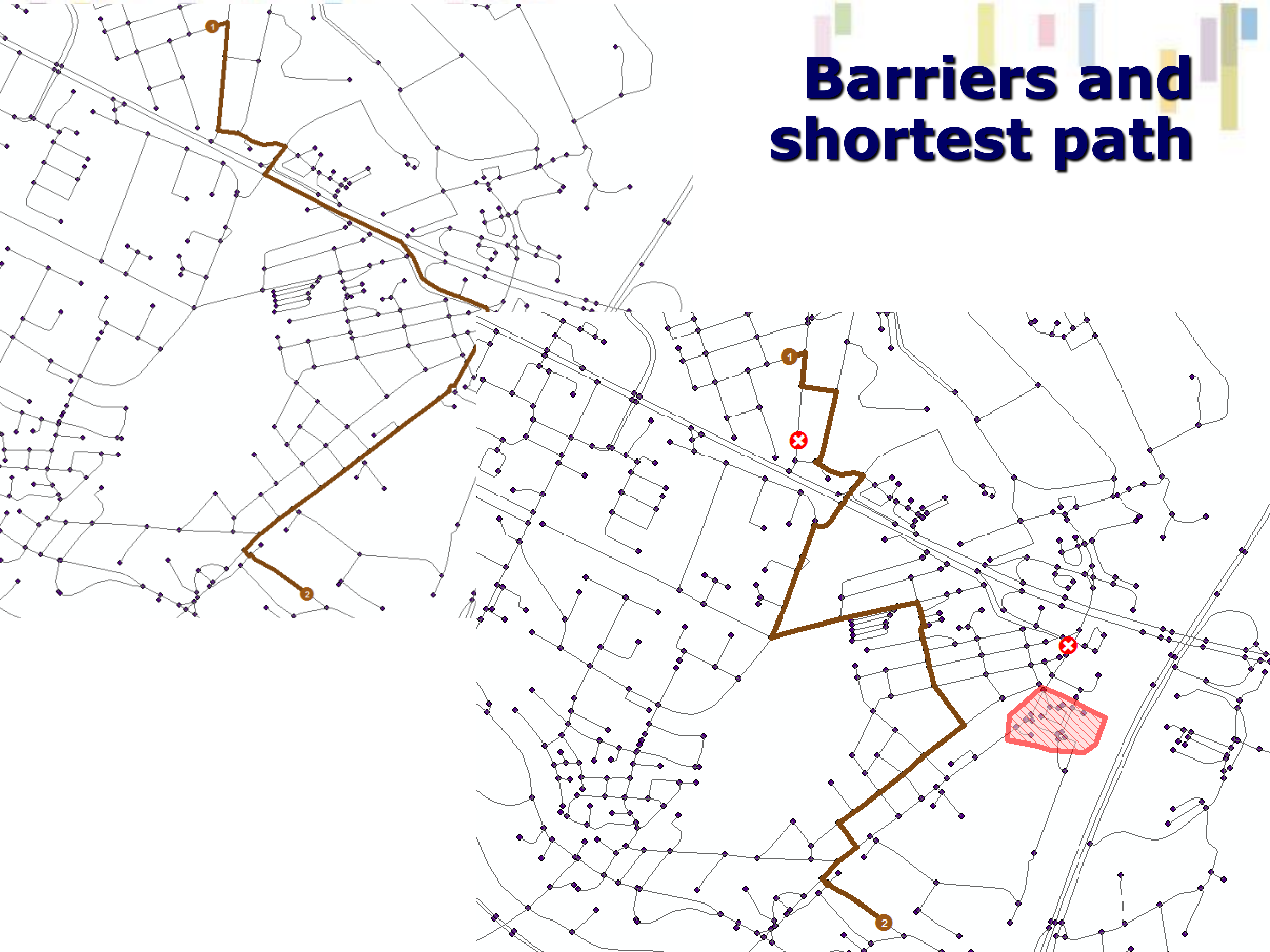
Barrier represents certain limitations within the network. Different geometry types – point, line, polygon

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



Horák a kol. 2015

Barriers and shortest path



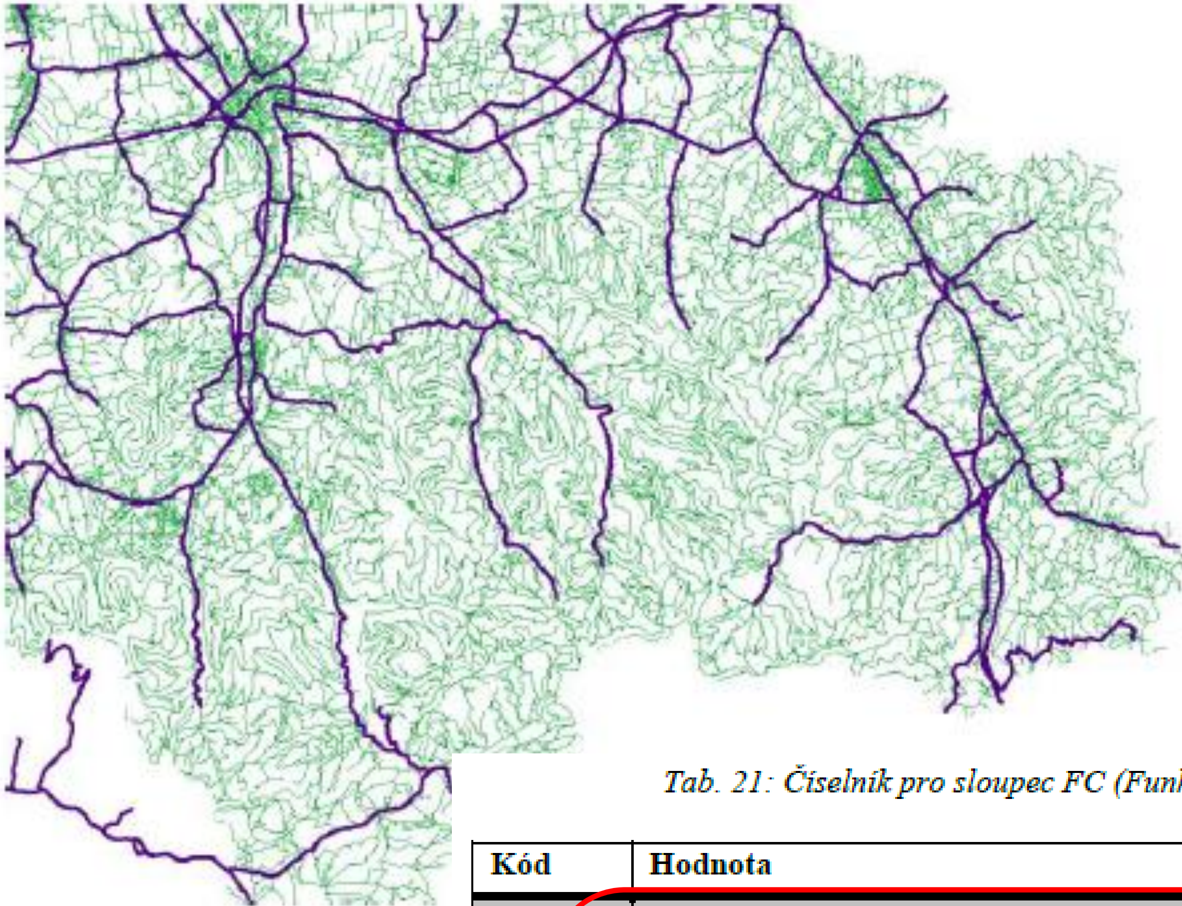
Data for network analysis

- 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

Horák a kol. 2015

Street Net selection of roads



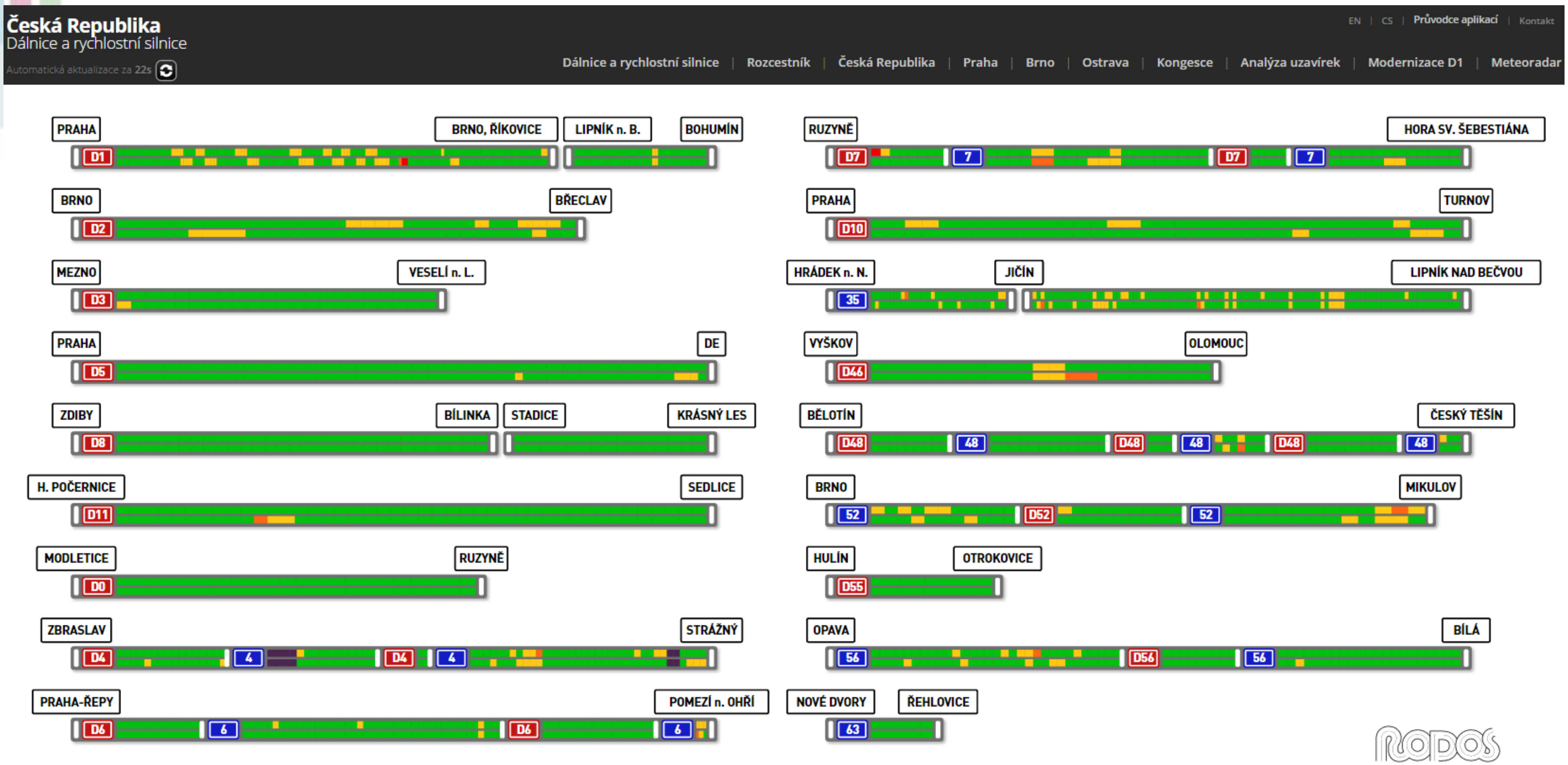
Obr. 155: Porovnání vrstvy

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

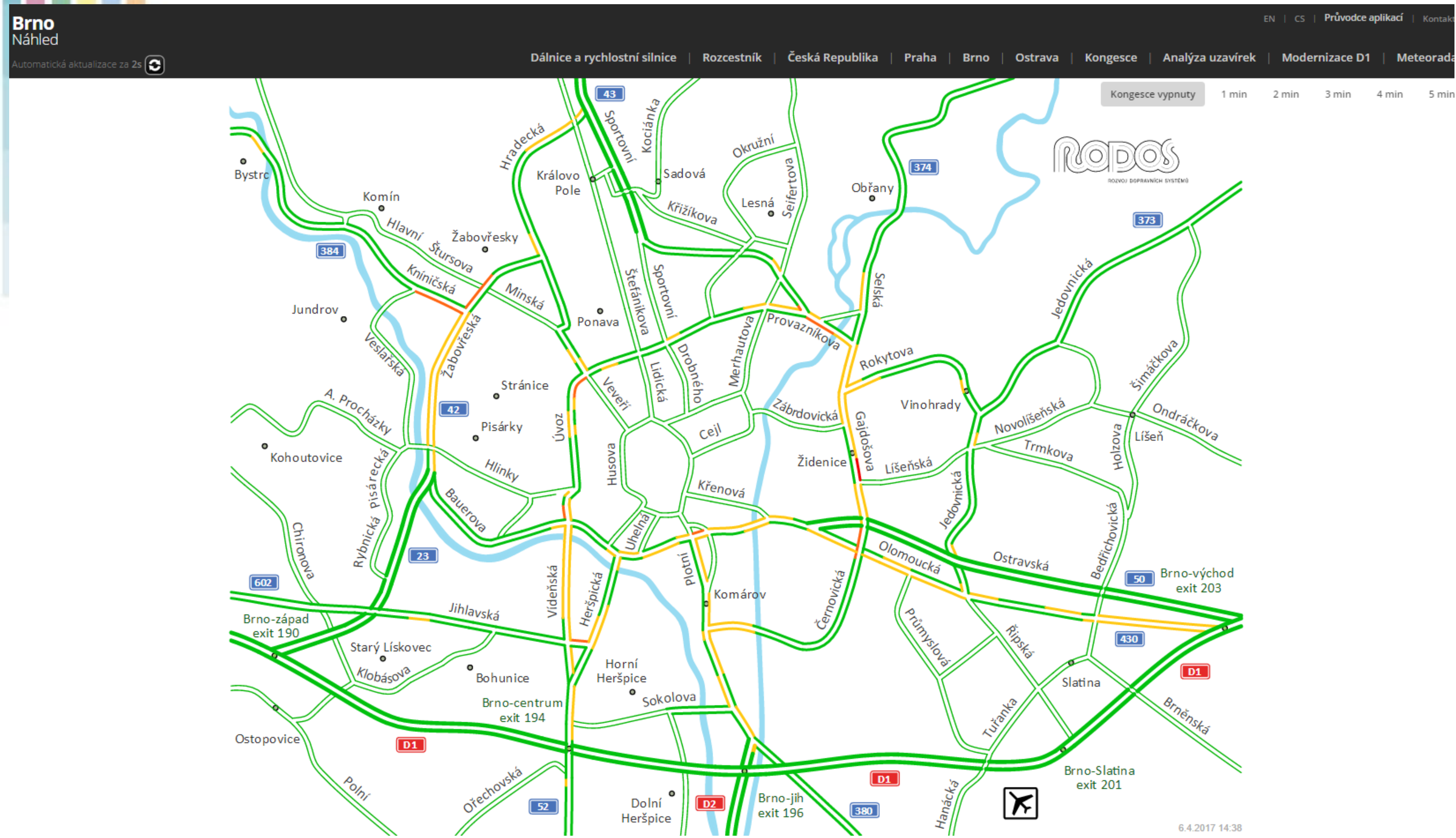
Kód	Hodnota
0	dálnice
1	hlavní silnice (zejm. mezinárodně významné silnice evropské tahy E)
2	ostatní významné silnice
3	silnice regionálního významu
4	spojovací silnice lokálního významu
5	významné spojnice v rámci sídel
6	ostatní významné komunikace v rámci sídel
7	místní komunikace
8	účelové komunikace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

Real Time data for network analysis

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



Detail view on Brno with traffic delays

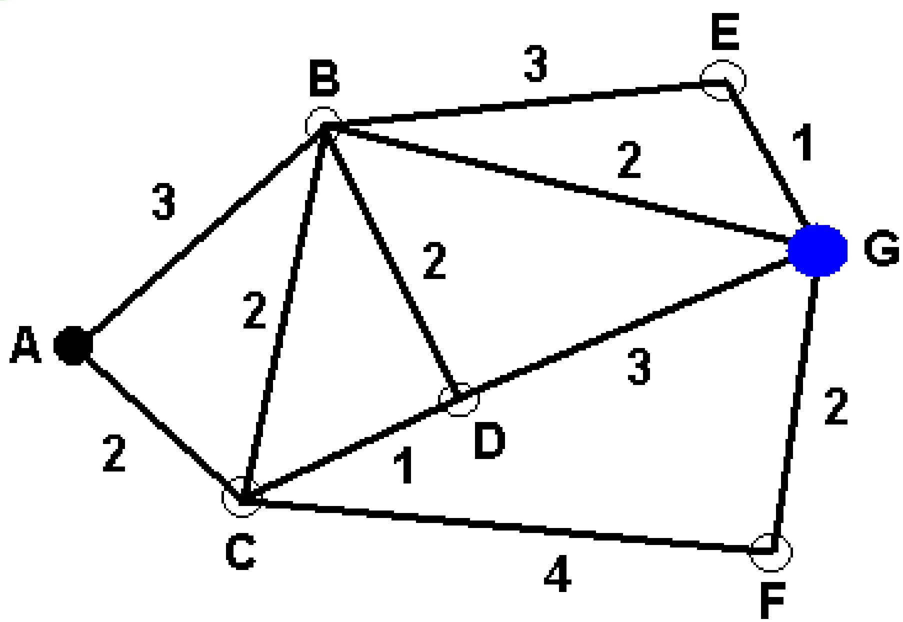


Algorithms for network operations

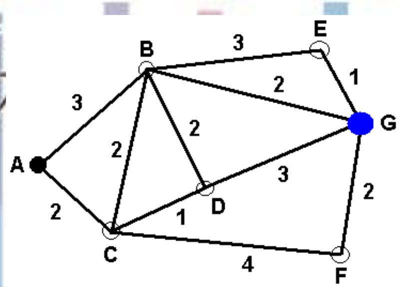
- **Search procedure – alternations - no turning back, fewest number of nodes, minimum cost.**
- A common question is "what is the shortest path?„ - **Dijkstra algorith**, mathematically designed to find the lowest cost route between two locations when a measure of cost is attached to each link.
- Simplification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

Dijkstra algorithm I

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

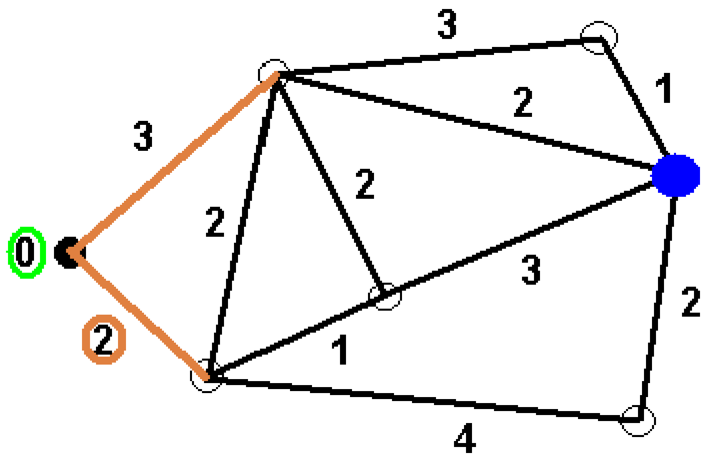


	Dist.	Parent	Incl.
A	0	-	No
B		-	No
C		-	No
D		-	No
E		-	No
F		-	No
G		-	No

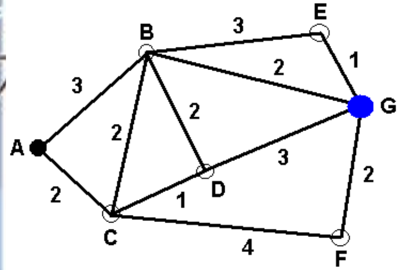


Dijkstra algorithm II

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

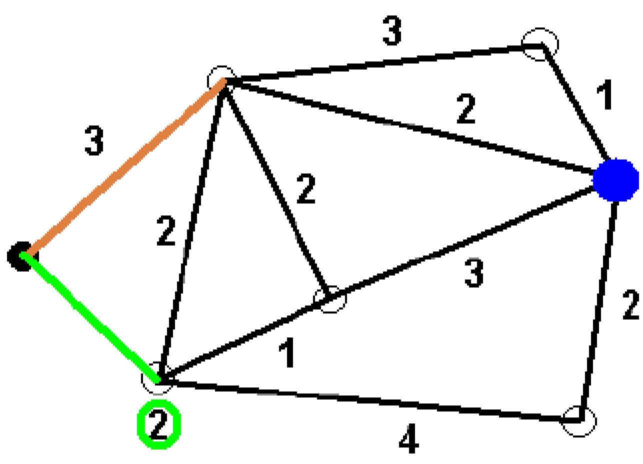


	Dist.	Parent	Incl.
A	**0**	**-**	**Yes**
B	3	A	No
C	2	A	No
D		-	No
E		-	No
F		-	No
G		-	No

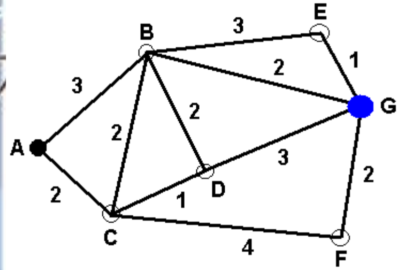


Dijkstra algorithm III

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.

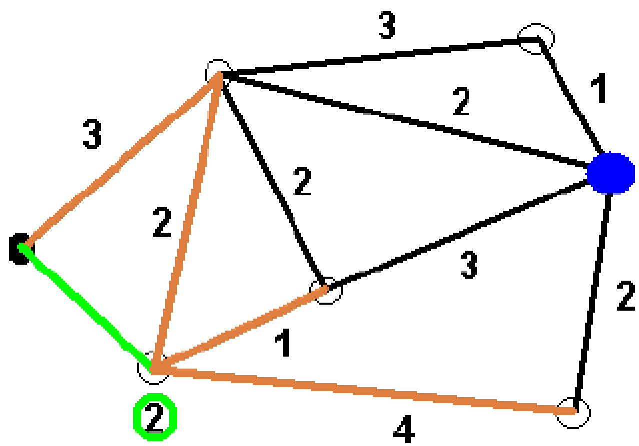


	Dist.	Parent	Incl.
A	**0**	**-**	**Yes**
B	3	A	No
C	**2**	**A**	**Yes**
D		-	No
E		-	No
F		-	No
G		-	No

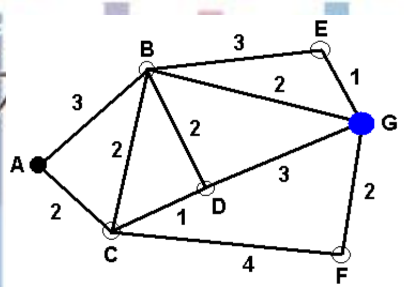


Dijkstra algorithm IV

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

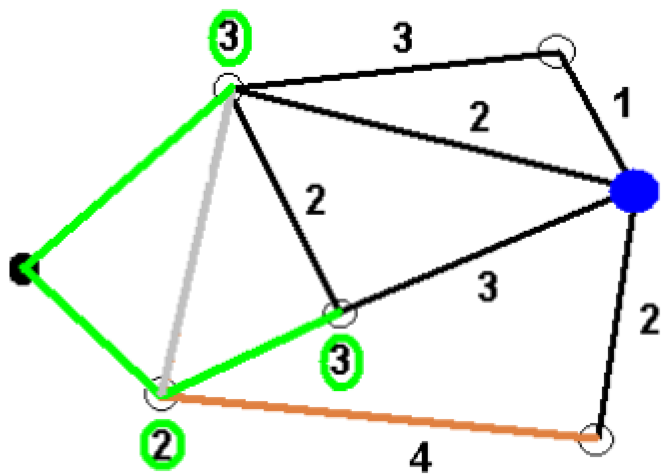


	Dist.	Parent	Incl.
A	**0**	**-**	**Yes**
B	3 or 4	A or C	No
C	**2**	**A**	**Yes**
D	3	C	No
E		-	No
F	6	C	No
G		-	No

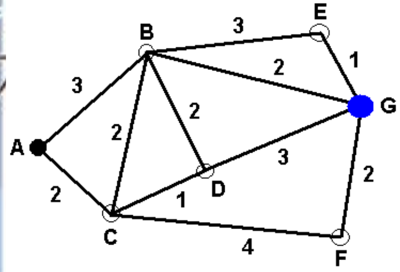


Dijkstra algorithm V

- **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**

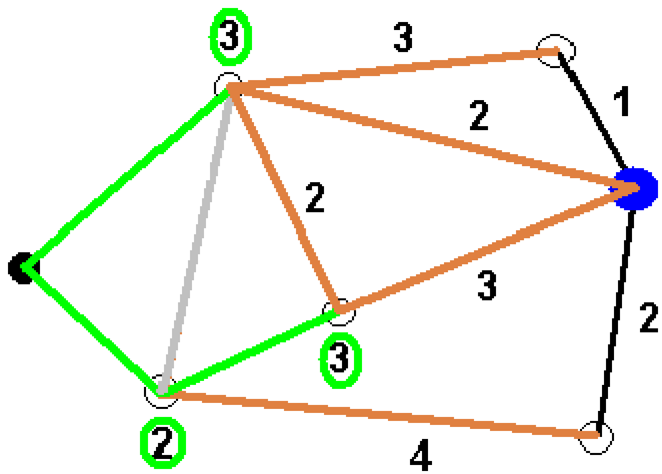


	Dist.	Parent	Incl.
A	**0**	**-**	**Yes**
B	**3**	**A**	**Yes**
C	**2**	**A**	**Yes**
D	**3**	**C**	**Yes**
E		-	No
F	6	C	No
G		-	No

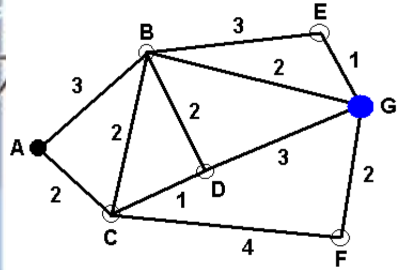


Dijkstra algorithm VI

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

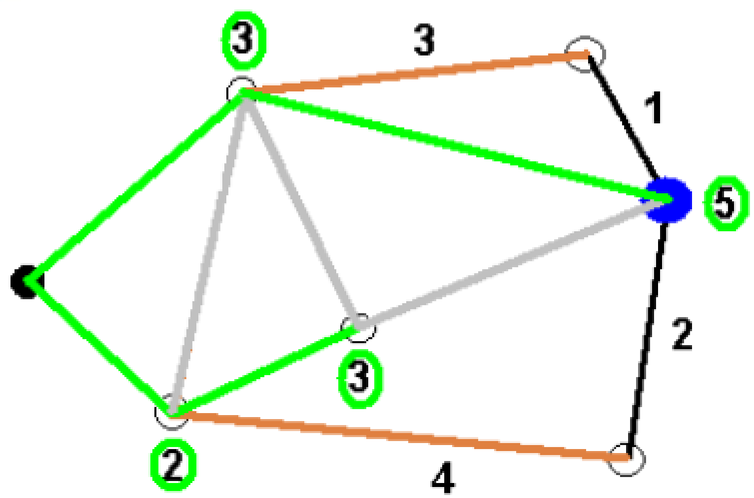


	Dist.	Parent	Incl.
A	**0**	**-**	**Yes**
B	**3**	**A**	**Yes**
C	**2**	**A**	**Yes**
D	**3**	**C**	**Yes**
E	6	B	No
F	6	C	No
G	5 or 6	B or C	No



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**

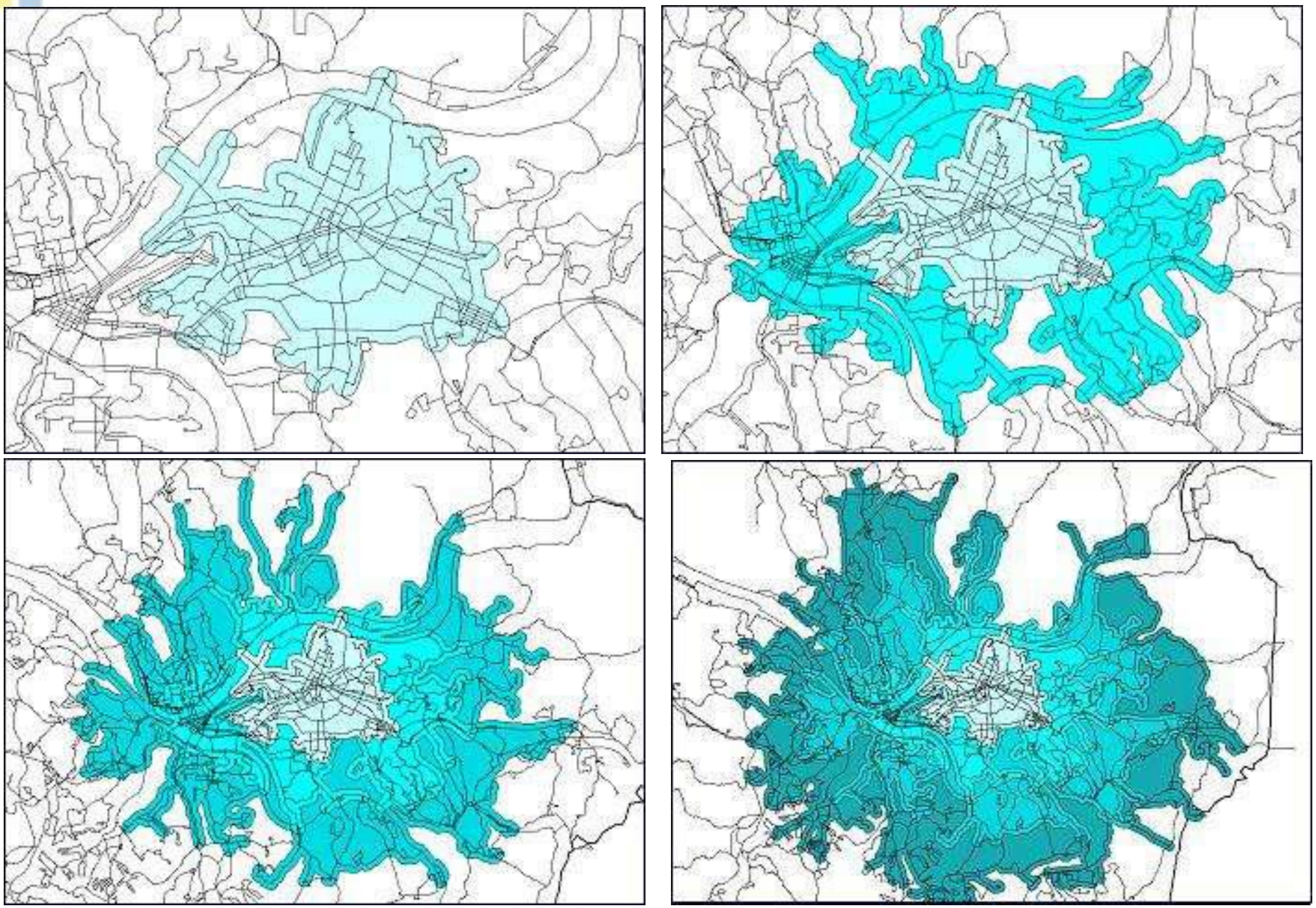
Node **G** is reached from B which is reached from A i.e. shortest path = **A B G**.

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**

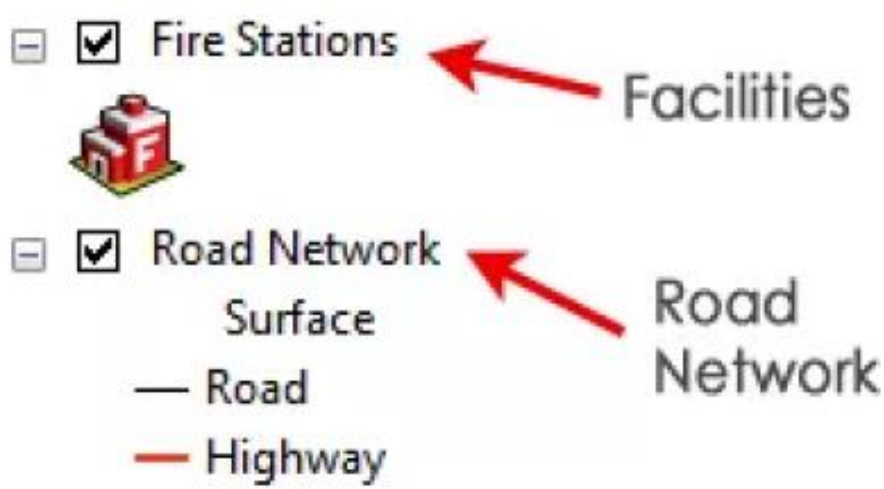


Finding Service Areas Using ArcGIS Network Analyst

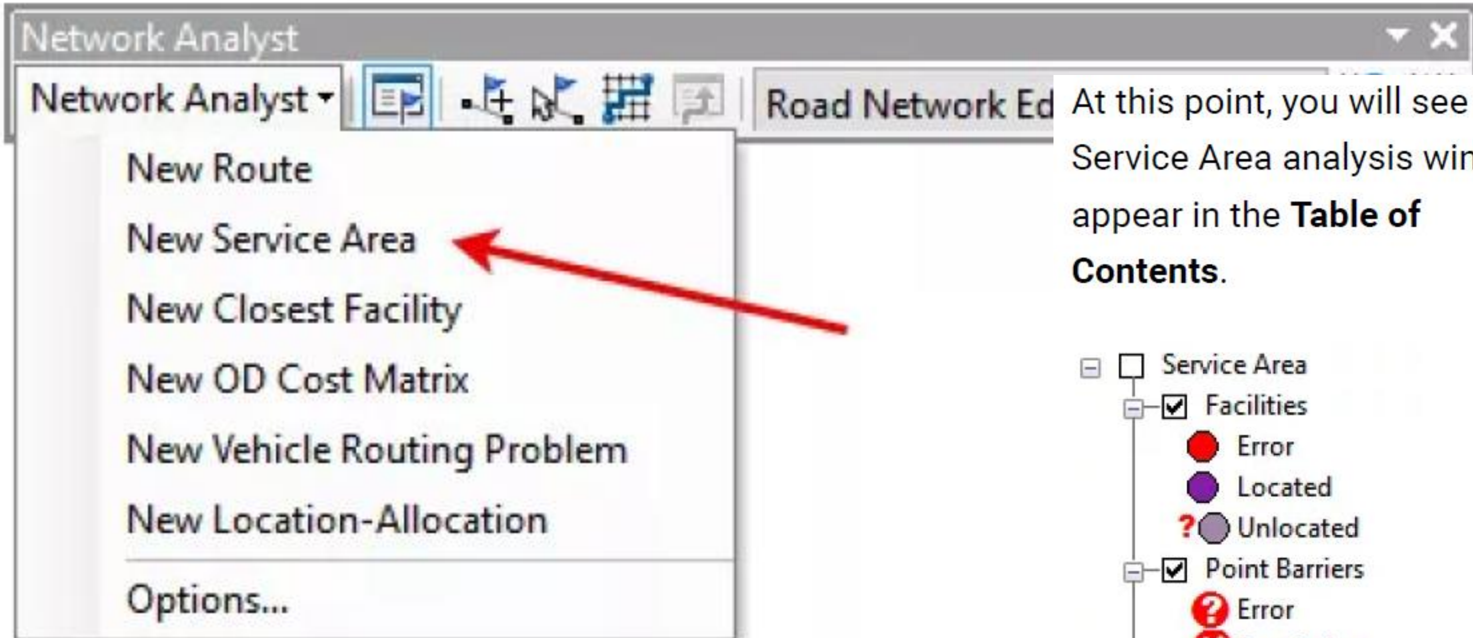
- Create Isochrone Maps – How Far Can Firefighters Service?
- that each facility will have it's own service area – or extent for how far firefighters can reach in a given amount of time (isochrone).
- different scenarios – including setting up **lengths** and **time**.

What You Will Need

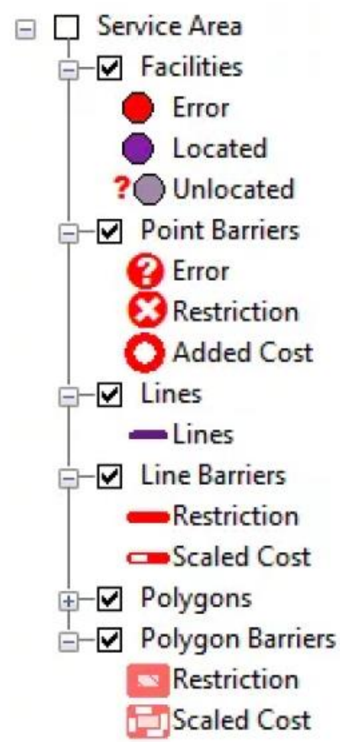
- Network Analyst Extension
- Road Network – topologically correct.
- Facilities Layer (Fire stations, police stations, hospitals, etc)



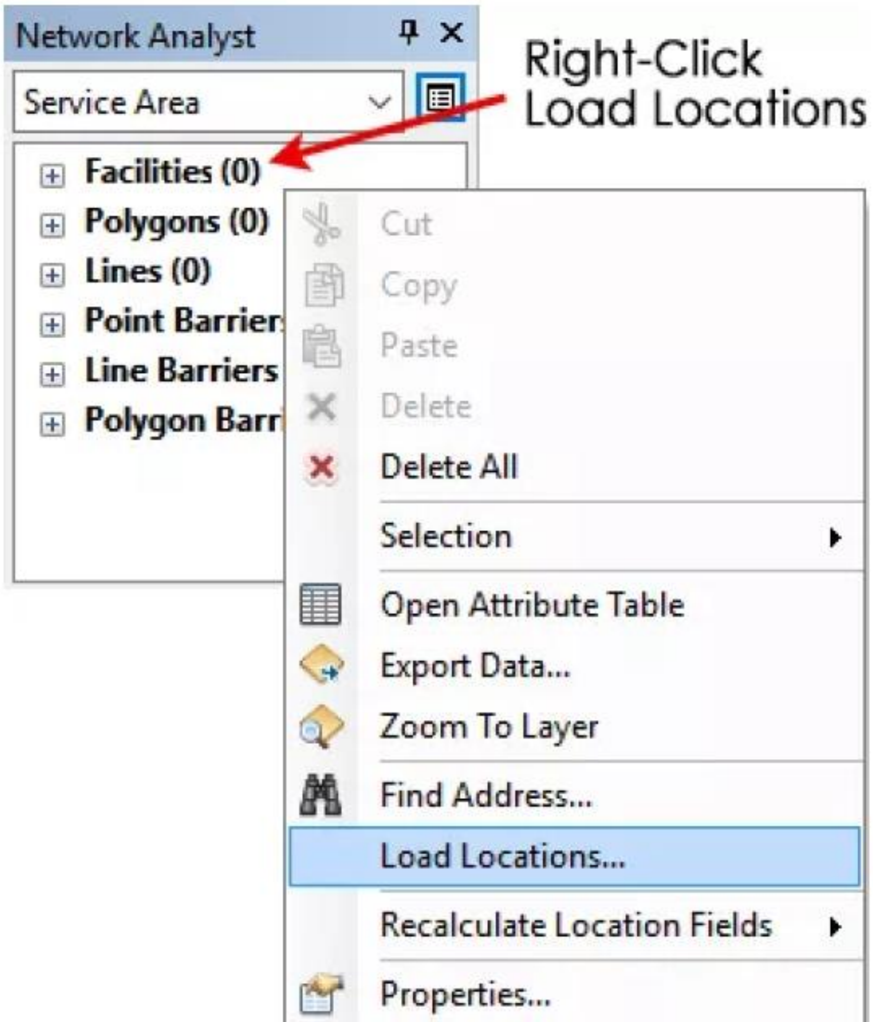
Start new Service area



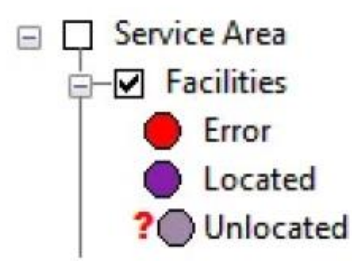
At this point, you will see the Service Area analysis window appear in the **Table of Contents**.



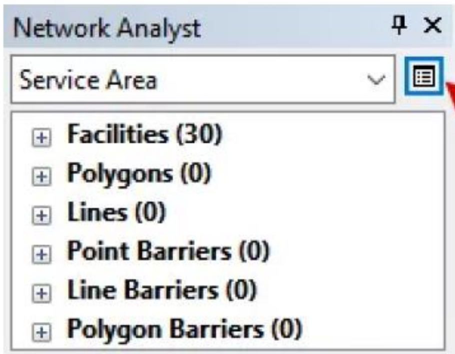
Adding facilities

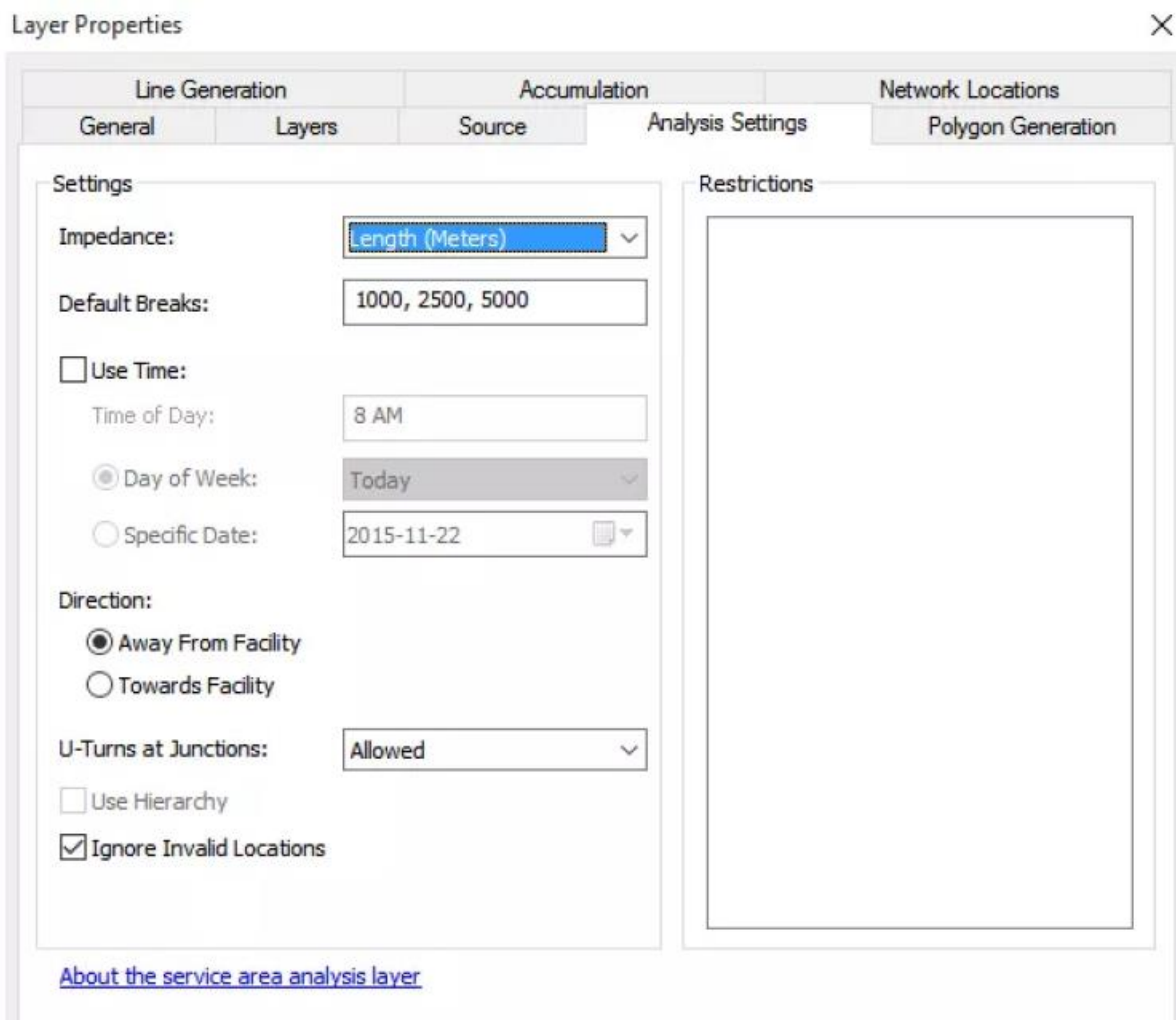


- Load facilities point data
- Visualize and check for errors



Service area problem set up

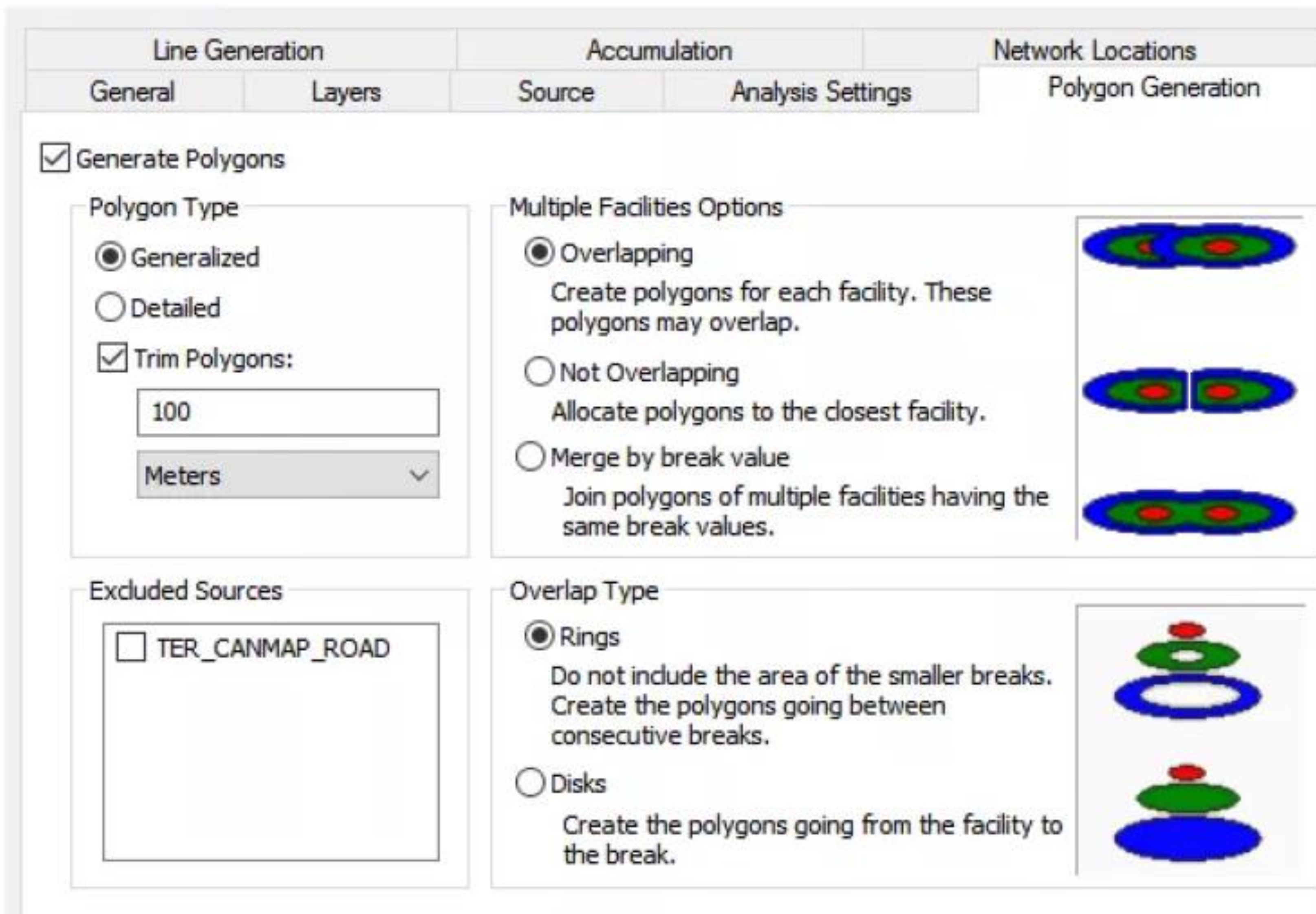




Variables:

- **Impedance**
- **Breaks (m, min)**
- **Direction**

Polygon generation table option



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

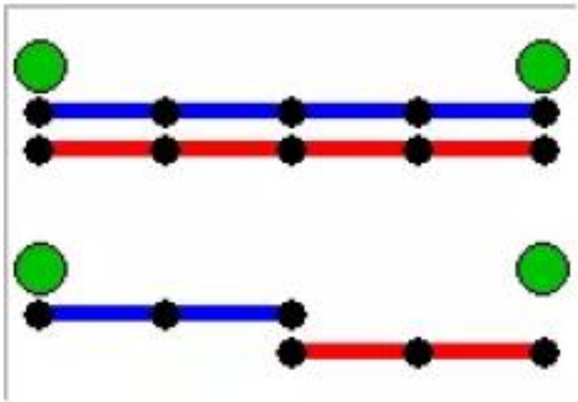
Overlap Options

◉ Overlapping

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

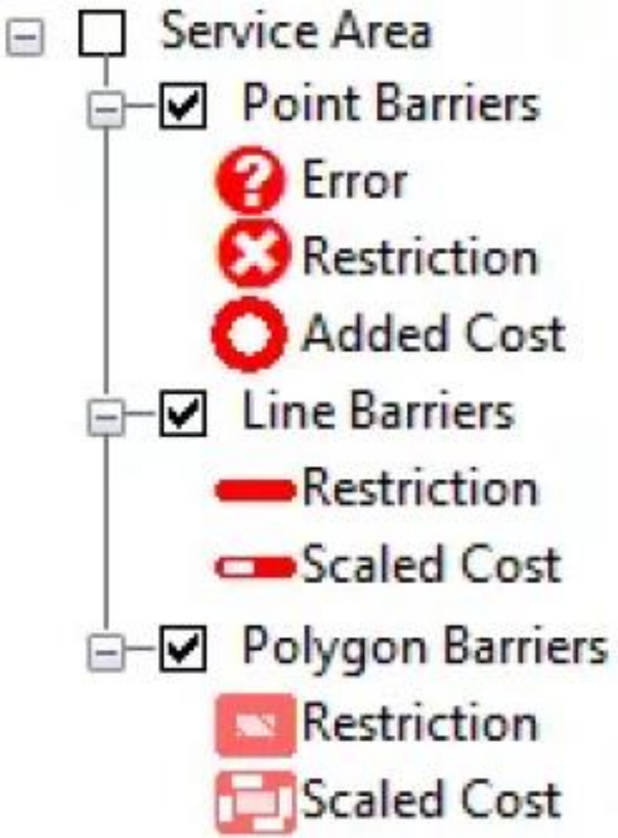
○ Not Overlapping

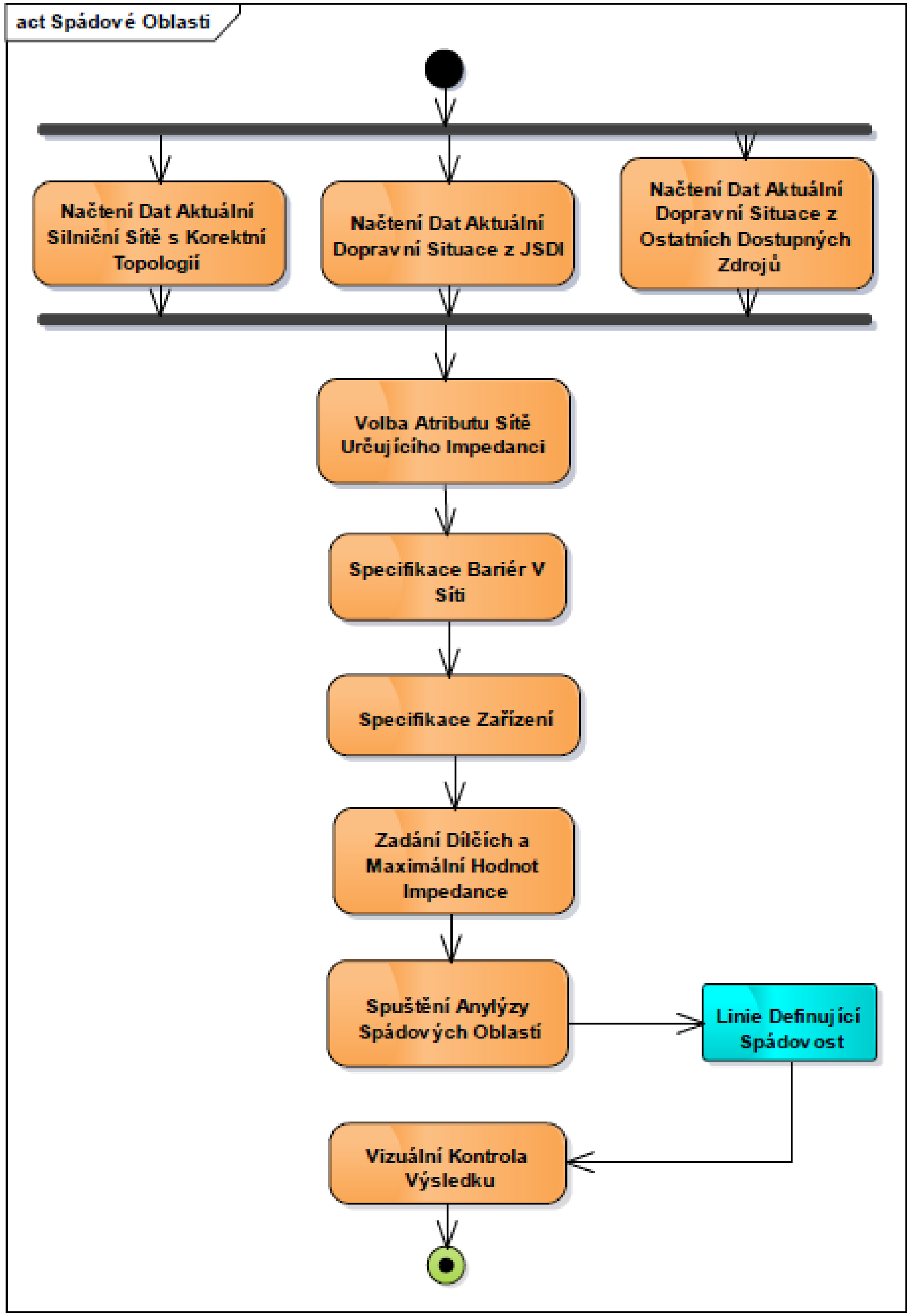
Include each line at most once and associate it with its closest (least impedance) facility.



Generate the service area polygons and lines/road segments

Using bariers

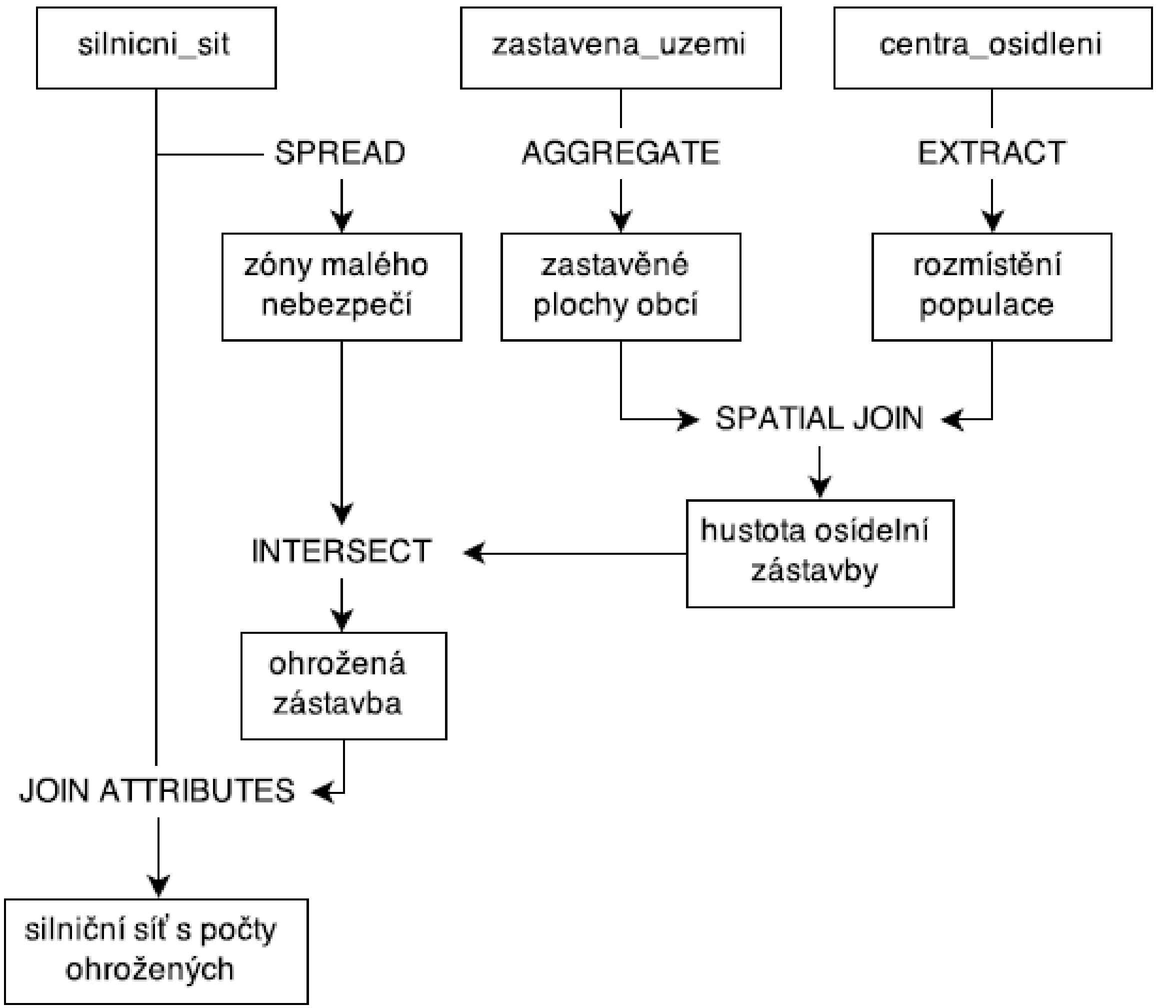



act Spádové Oblasti
Načtení Dat Aktuální Silniční Sítě s Korektní Topologií
Načtení Dat Aktuální Dopravní Situace z JSDI
Načtení Dat Aktuální Dopravní Situace z Ostatních Dostupných Zdrojů
Volba Atributu Sítě Určujícího Impedanci
Specifikace Bariér V Síti
Specifikace Zařízení
Zadání Dílčích a Maximální Hodnot Impedance
Spuštění Anylýzy Spádových Oblastí
Linie Definující Spádovost
Vizuální Kontrola Výsledku

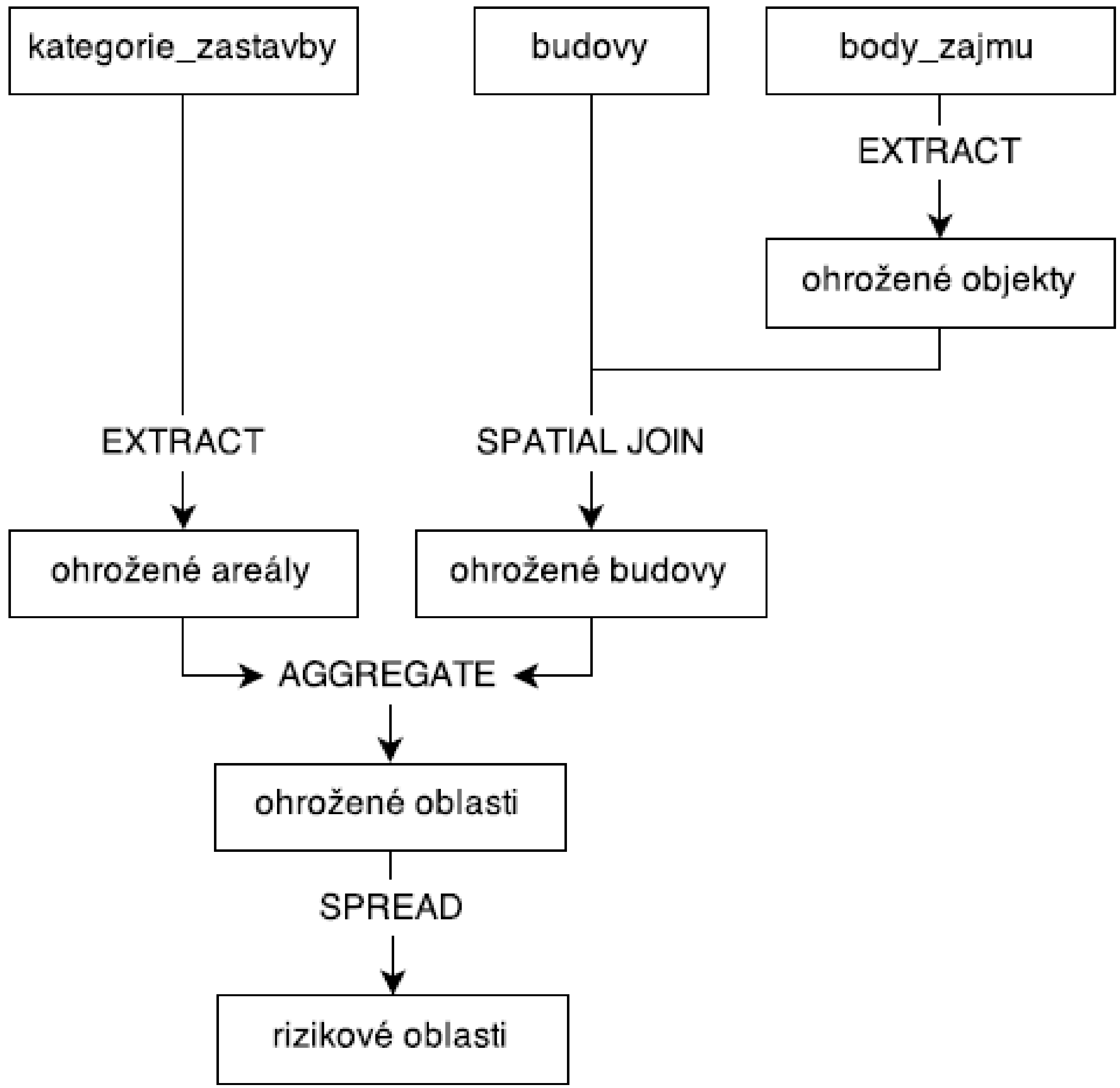
Transportation of dangerous goods – case study (Leitgeb 2015)

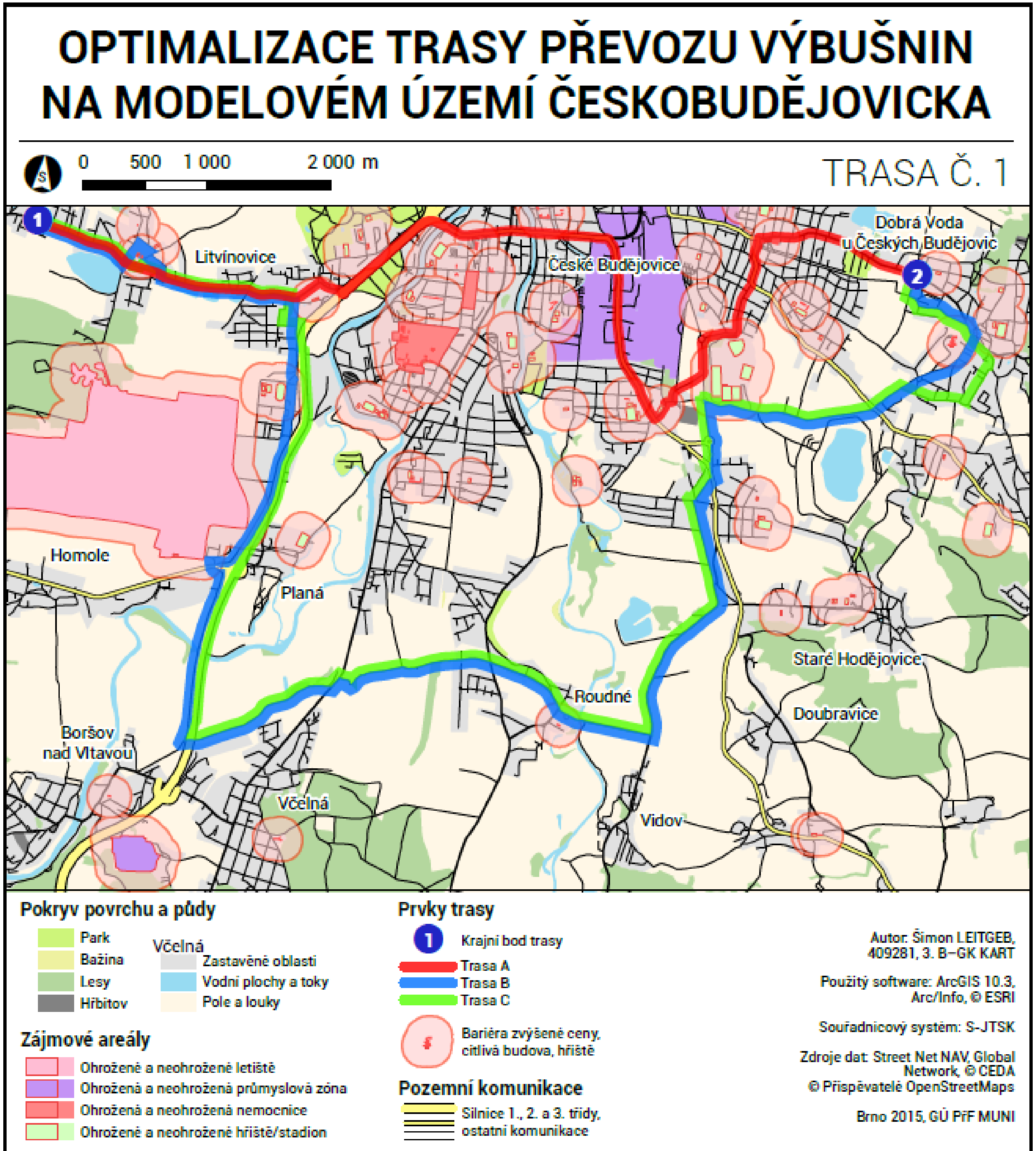
- **Goal: Minimise the potential impact on inhabitants during the transportation of dangerous substances (flammable, explosive…).**
- **ADR classification, Police and army internal legislation.**
- **Alternative criterion:**
  - Population concentration based on street/road segments;
  - Buildings (POIs)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

Criterion 1 – street segments



Criterion 2 – sensitive objects and PoI





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