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A NETWORK ANALYSIS EXAMPLE: THE CLUJ-NAPOCA CITY ROAD NETWORK

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Abstract: The final aim of the authors of this paper is to provide a viable model of the Cluj-Napoca City road network by using the dedicated GIS capabilities. Once built, such a model can offer the basis for the projection and the simulation of real traffic situations which in turn can offer the foundation for a more efficient approach to some economical and urban activities. So far due to our recent steps in this endeavor the hereby paper is by no means intended to be an exhaustive one, but rather the prelude for a complex urban road network analysis which should cover all the aspects of network analysis. Thus we only present some key issues about our modeling as well as some preliminary results.

Key words: *road network analysis, GIS*

Introduction

Cluj-Napoca has a complex system of transportation, providing road, air and rail connections to major cities in Romania and Europe. It also enjoys a large internal transportation system, including bus, trolleybus and tram lines. Cluj-Napoca is an important node in the European road network, being on three different European routes (E60, E81 and E576). At a national level, Cluj-Napoca is located on three different main national roads: DN1, DN1C and DN1F. The Romanian Motorway A3, also known as *Transylvania Motorway* (*Autostrada Transilvania*), currently under construction, will link the city with Bucharest and Romania's western border. Section 2B between Câmpia Turzii and Cluj Vest (Gilău) is expected to be finalized during 2009. The Cluj-Napoca Coach Station (*Autogara*) is used by several private transport companies to provide coach connections from Cluj-Napoca to a large number of locations from all over the country. The number of automobiles licensed in Cluj-Napoca is estimated at 175,000. As of 2007, Cluj County ranks sixth nationwide according to the cars sold during that year, with 12,679 units, corresponding to a four percent share.

Such an increase in the number of cars can cause problems especially due to the fact that the road system is mostly based on the old medieval road network which crosses the city. According to the City Hall statistics the urban network of Cluj-Napoca has a total span of 662 km of which 443 km of modernized streets (street structure, public utilities etc). It covers a total surface

6900 hectare, and more than 300000 inhabitants, that is 45,2 % of the County population and 66,5 % of the urban one (the number of visitors, students, persons in passage has not be accounted for).

Whether the current network structure is still viable and efficient for such a heavy use or whether it still satisfies the needs of its users are questions that must be answered quickly for obvious reasons.

In order to answer the above questions we used the GIS environment for an analysis of the Cluj-Napoca network in terms of accessibility, connectivity and network density. For offering a more detailed answer we have chosen to compare the road network of Cluj-Napoca to that of Oradea

Theoretical aspects considered in modeling the topology of the Cluj-Napoca network

Network topology is the study of the *arrangement* or *mapping* of the elements (links, nodes, etc.) of a network, especially the physical (real) and logical (virtual) interconnections between nodes.

Topology is useful in GIS because many spatial modeling operations don't require coordinates, only topological information. For example, to find an optimal path between two points requires a list of the arcs that connect to each other and the cost to traverse each arc in each direction. Coordinates are only needed for drawing the path after it is calculated. It refers to the spatial relationships between connecting or adjacent features (e.g., arcs, nodes, polygons, and points). For example, the topology of an arc includes its from- and to-nodes, and its left and right polygons. Topological relationships are built from simple elements into complex elements: points (simplest elements), arcs (sets of connected points), areas (sets of connected arcs), and routes (sets of sections, which are arcs or portions of arcs). Redundant data (coordinates) are eliminated because an arc may represent a linear feature, part of the boundary of an area feature, or both.

Setting the network rules

Networks typically have rules about how objects move through them. For example, in any given street network, there may be prohibited turns, one-way streets, and speed limits. Some of the aspects that need to be considered when modeling networks are presented briefly below. No extended details are presented as they can be easily found in the ESRI documentation or any other documents concerning these issues.

The travel cost

The average time or distance required to travel along a street or to complete a turn. For example, it may take a minute to drive a kilometer in a high speed zone but two minutes to drive the same distance in a low speed zone. At a particular intersection, it could take five seconds to complete a right turn but 15 seconds to complete a left turn.

The conventions for stetting the cost attributes are presented in the table below.

seconds	FT_SECONDS and TF_SECONDS
minutes	FT_MINUTES and TF_MINUTES, or
	FT_DRIVETIME and TF_DRIVETIME, or
	FT_IMPEDANCE and TF_IMPEDANCE, or
	FT_TRAVELTIME and TF_TRAVELTIME
hours	FT_HOURS and TF_HOURS
meters	FT_METERS and TF_METERS

Table 1. *The attribute table conventions used for setting the travel cost*

The modeling of one-way streets (streets that can be traveled in one direction only)

In order to model the one –way streets the following values were used:

1. **FT, ft** → Travel is permitted from the start to the end of the line only, which is the same as the digitized direction.
2. **TF, tf** → Travel is permitted from the end of the line to the start of the line only, which is opposite the digitized direction.
3. **N, n** → Travel is permitted in neither direction, the line is closed to travel.
4. **No data** → Travel is permitted in both directions.

Prohibited turns or are turns that are not allowed. For example, it may be prohibited to make a U-turn at one intersection and to make a left turn at another.

Overpasses and underpasses

Are streets that pass over or under other streets. You cannot make a left or right turn when on an overpass or underpass.

Closed streets and other streets to avoid For example, you might want to avoid residential streets when routing a truck through a city or streets under construction or dedicated streets as bus lanes or industrial roads.

Attributes of drumuri_cluj

NUME	ID	TIP	SLENGTH	TLENGTH	RAPORT	ONE_WAY
Str. Mihail Kogalniceanu	1641	Strada	541,424069	544,291016	1,005295	B
Str. Hermann Oberth	1646	Strada	212,181662	212,206053	1,000115	Tf
Str. Emanuel de Martonne	1648	Strada	92,727217	92,727217	1	Tf
	1649	Strada	58,721284	58,721284	1	B
Str. Kovacs Dezso	1650	Strada	107,58191	107,58191	1	B
Str. Iuliu Maniu	1651	Strada	455,457723	455,982581	1,001152	Tf
Str. Bolyai Janos	1654	Strada	197,995701	198,010207	1,000073	Tf
Piata Unirii	1656	Piata	236,138904	312,592553	1,323766	B
Str. Matei Corvin	1660	Strada	198,562965	198,574555	1,000058	B
Str. Episcop Ioan Bob	1662	Strada	228,370773	228,765098	1,001727	B
Str. Napoca	1664	Strada	276,134791	276,432343	1,001078	Ft
Str. Ion Ratiu	1668	Strada	202,488271	202,5919	1,000512	B
Str. Samuil Micu	1670	Strada	255,926319	256,02319	1,000379	B
Str. Gheorghe Sincai	1673	Strada	323,180252	325,072828	1,005856	Ft
Str. Inocentiu Micu Klein	1675	Strada	226,938088	226,944125	1,000027	Tf
Str. Fortaretei	1678	Strada	221,427085	450,739536	2,035612	Ft
Str. Potaissa	1684	Strada	234,936089	235,052048	1,000494	B

Record: 0 Show: All Selected Records (0 out of 1391 Selected.) Options

Figure 1. *The attribute table of the streets that can be traveled in one direction only in Cluj-Napoca*

Selected Attributes of drumuri_cluj

NUME	TLENGTH	LINK_	ONE_WAY	F_ELEV	T_ELEV
Str. Locomotivei	125,862888	5	B	0	1
	163,304808	5	B	1	0
Str. Aurel Vlaicu	117,166663	4	B	0	1
Str. Aurel Vlaicu	70,076409	4	B	1	0
Calea Manastur	150,819908	6	B	0	1
Calea Floresti	556,853086	11	B	1	1
Calea Floresti	556,853086	11	B	1	0

Record: 0 Show: All Selected Records (7 out of 3009 Selected.) Options

Figure 2. *The modeling of the overpasses and underpasses – Cluj-Napoca*

In the case of Cluj-Napoca there are three important road passages that had to be modeled as they are essential for the traffic fluency. They are presented in Figure 2. In order to differentiate them from intersections two elevation fields were used in the line attribute table, an elevation field for the start of each line and an elevation field for the end of each line. Both fields must be present in order for overpasses and underpasses to be recognized by the

Network Analyst. There are three acceptable ways of naming these fields and they are presented below:

FNODE_ELEV and TNODE_ELEV, or
F_ELEV and T_ELEV, or
F_ZLEV and T_ZLEV

Results and discussion – the network analysis

The analysis of the Cluj-Napoca network was carried out using ESRI Network Analyst 3.1.

Our analysis can be divided from the point of view of the statistical tools used:

- Tools that describe the whole network (connectivity analysis)
- Tools that refer to the way in which each segment is accessed by its neighboring segments (accessibility analysis).
- Tools that describe the density of the network (density analysis)

Connectivity analysis

Connectivity is captured quantitatively and rendered in the form of the connectivity matrix, central element in the analysis of any (Taaffe, Gauthier and O'Kelly, 1996). A connectivity matrix (C1) expresses the connectivity of each node with its adjacent nodes. (Rodrigue J. P, 2006). The number of columns and rows in this matrix is equal to the number of nodes in the network and a value of 1 is given for each cell where this is a connected pair and a value of 0 for each cell where there is an unconnected pair. The summation of this matrix provides a very basic measure of accessibility, also known as the **degree of a node**:

$$C1 = \sum_{j}^{n} c_{ij}$$

- C1 = degree of a node.
- c_{ij} = connectivity between node i and node j (either 1 or 0).
- n = number of nodes.

The connectivity matrix does not take into account all the possible indirect paths between nodes. Under such circumstances, two nodes could have the same degree, but may have different accessibilities. To consider this attribute, the Total accessibility Matrix (T) is used to calculate the total number of paths in a network, which includes direct as well as indirect paths. Its calculation involves the following procedure:

$$T = \sum_{k=1}^{D} Ck$$

$$C1 = \sum_{j}^{n} c_{ij}$$

$$Ck = \sum_{i}^{n} \sum_{j}^{n} c_{ij}^{1} \times c_{ji}^{k-1} (\forall k \neq 1)$$

where D = the diameter of the network. Thus, total accessibility would be a more comprehensive accessibility measure than network connectivity.

The main focus of measuring accessibility does not necessarily involve measuring the total number of paths between locations, but rather what are the shortest paths between them. Even if several paths between two locations exist, the shortest one is likely to be selected (Rodrigue J. P, 2006). Consequently, the Shimbel (1954) index calculates the **minimum number of paths** necessary to connect one node with all the nodes in a defined network. The Shimbel accessibility matrix, also known as the **D-Matrix**, thus includes for each possible node pairs the shortest path.

The Shimbel index and its D-Matrix fail to consider that a topological link between two nodes may involve variable distances. It can thus be expanded to include the notion of distance, where a value is attributed to each link in the network. The valued graph matrix, or **L-Matrix**, represents such an attempt. It has a very strong similarity with the Shimbel accessibility matrix and the only difference lies that instead of showing the minimal path in each cell, it provides the **minimal distance** between each node of the network.

Accessibility analysis

Accessibility of a network considers that the accessibility of a location is the **summation of all distances** between other locations pondered by the number of locations. The lower its value, the more a location is accessible (Taaffe, Gauthier and O'Kelly, 1996).

$$A(G) = \sum_{i}^{n} \left(\sum_{j}^{n} d_{ij} \right) \Big/ n$$

$$d_{ij} = L$$

- A(G) = geographical accessibility matrix.
- d_{ij} = shortest path distance between location i and j.
- n = number of locations.

- L = valued graph matrix.

This measure (A(G)) is an adaptation of the Shimbel Index and the Valued Graph, where the most accessible place has the lowest summation of distances.

Although geographic accessibility can be solved using a spreadsheet (or manually for simpler problems), **Geographic Information Systems** have proven to be a very useful and flexible tool to measure accessibility, notably over a surface simplified as a matrix (raster representation). This can be done by generating a distance grid for each place and then summing all the grids to form the total summation of distances (Shimbel) grid. The cell having the lowest value is thus the most accessible place.

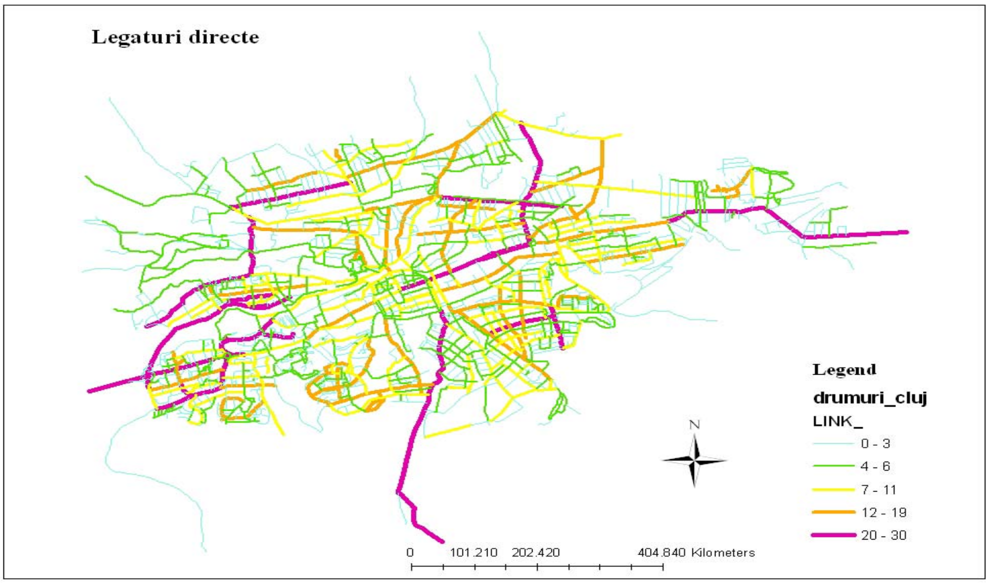

Figure 3. *The accessibility map in terms of direct links –Cluj-Napoca*

Potential accessibility is a more complex measure than geographic accessibility, since it includes simultaneously the **concept of distance weighted by the attributes of a location**. All locations are not equal and thus some are more important than others. Potential accessibility can be measured as follows:

$$A(P) = \sum_{i}^{n} P_i + \sum_{j}^{n} P_j / d_{ij}$$

- A(P) = potential accessibility matrix.
- d_{ij} = distance between place i and j (derived from valued graph matrix).

• P_j = attributes of place j, such as its population, retailing surface, parking space, etc.

• n = number of locations.

The potential accessibility matrix is not transposable since locations do not have the same attributes, which brings the underlying notions of emissiveness and attractiveness:

• **Emissiveness** is the capacity to leave a location, the sum of the values of a row in the A(P) matrix.

• **Attractiveness** is the capacity to reach a location, the sum of the values of a column in the A(P) matrix.

Connectivity indexes Cluj-Napoca	**Connectivity indexes Oradea**
α = 0,154439	α = 0,2
γ = 0, 230565	γ = 0, 200321
No. of nodes = 2013	No. of nodes = 1250
No. of links = 1391	No. of links = 750

Table 2. *The comparative connectivity indexes for Cluj-Napoca and Oradea*

No. of direct links Cluj-Napoca	**No. of direct links Oradea**
0-3	0-3
4-6	4-7
7-11	8-14
12-19	15-25
26-37	20-30

Table 3. *The number of direct links in Cluj –Napoca as compared to Oradea*

Based an all these theoretical considerations the following indexes were computed (Table 2):

1. ***the Beta Index (*** compares the number of links with the number of nodes in a network)
2. ***the Gamma Index (***Compares the actual number of links with the maximum number)
3. ***the Alpha Index: (***compares the number of actual (fundamental) "circuits" with the maximum number of all possible fundamental circuits)

Density analysis

Density analysis is an important parameter in analyzing a road network. For obtaining better computation accuracy this parameter was computed using the Line Density script provided by din ArcToolbox 9.1, although there are similar algorithms provided by ArcView 3.1.

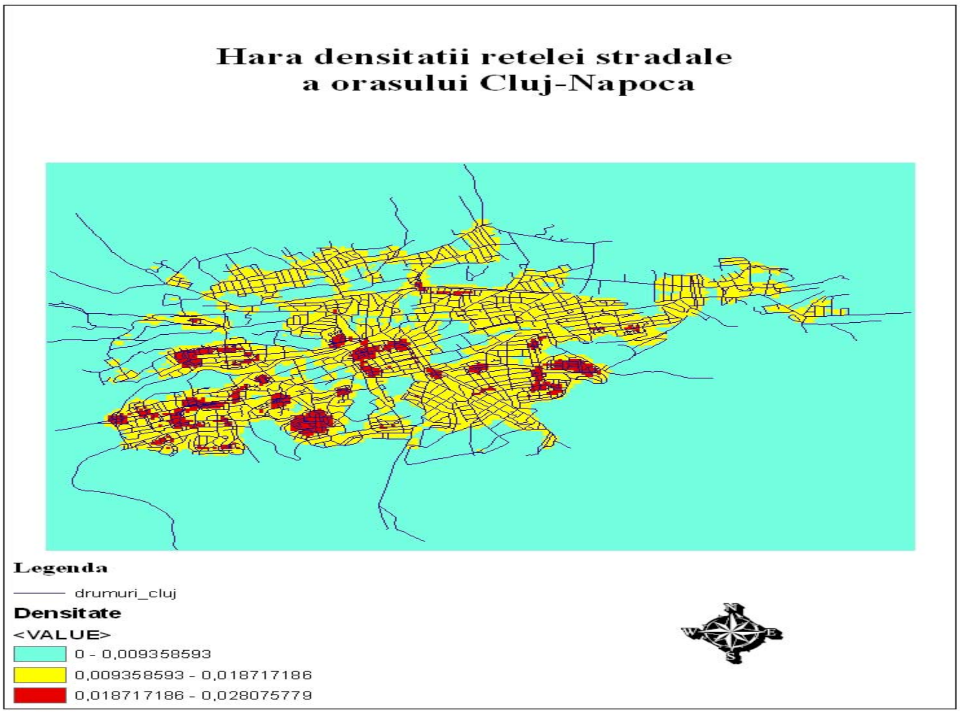

Figure 4. *The road density map of Cluj-Napoca*

The latter script helps calculating the line density from each neighboring cell of a raster. The computation takes place in the following manner: first the linear layer containing the road network is converted to raster; then a circle with a user predefined or computer defined radius is computed. In our case the radius equals the smallest length or width of a gridcell divided by 30. This is ideal for a 33m x 33m gridcell. The length of the radius contained by each cell is weighted against a default value or against a user defined weight and then divided by the search radius. . This is the ideal situation as obviously a boulevard is more important then an alley. As a weighting system is not yet defined by the authors the default value was used.

By comparing the Oradea indexes to the Cluj –Napoca indexes we could see the following:

a. Cluj-Napoca has a road network twice as the dense as compared to Oradea;

b. Cluj-Napoca as the alpha score shows can maintain a greater number of circuits as compared to Oradea;

c. considering the number direct links possible Oradea has a better overall connectivity than Cluj-Napoca as there are many roads in Oradea which have up to 37 direct links with the adjacent streets while in Cluj the maximum number of direct links for a major road is 30. (see Table 3)

Conclusions

At this point we would like to remember that the hereby article was never intended as an exhaustive study but rather the prelude of a more complex one. It merely presents some partial results and a topic of methodological discussion regarding road network modeling. With thus in mind we draw attention to some aspects:

- as the scale of Oradea and Cluj –Napoca is not similar the results need to be completed with an analysis of the partial connectivity of the both networks;
- considering the overall connectivity the Oradea road network is better equipped for handling heavy traffic;
- despite the fact that Cluj-Napoca road network can maintain a greater number of circuits than Oradea its high density patches superimposed on the crossing of vital traffic arteries can be the cause of great traffic jams unless a rethinking of the road network architecture is achieved as soon as possible;
- from a methodological point of view it is important to create realistic connectivity rules in order to create a realistic model of a road network. This can be achieved mainly with the aid of GIS which is far superior to any other solution.

References

Rodrigue, J-P, C. Comtois and B. Slack (2006) The Geography of Transport Systems, London: Routledge, 296 pages, ISBN: 0415354412.

SHIMBEL, A., (1954)- *Structure in communication nets,* Proceedings of the Symposium on Information Networks, Brooklyn Polytechnic Institute, New York, pages 119-203

Taaffe E.J, Gauthier H.L, O'Keely M.E (1996) - *Geography of Transportation,.* Ed.Prentice-Hall NJ.

West, Douglas B. (1996) - *Introduction to Graph Theory* - Second edition Prentice Hall. ISBN 0-13-014400-2.

xxx -Esri Help for ArcView 3x1 Ed. ESRI Press