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Solving the transportation network problems using G.I.S. analysis

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Abstract. Many applications in GIS are characterized by data network representing and analysis. Network analysis is based on linear structures. The fields where these types of analysis are used are different, such as: roads network, electric networks, hydrographic network and so on. The subject of this paper involves the identification of the minimum cost of a route between 2 localities by using the landuse between them. In order to solve these problems we used GIS software which allows such an analysis, specifically ArcGIS v10. For finding the easiest way to get from a source point (locality) to a destination point (locality) by using the characteristics of the land we will consider landuse meaning how difficult is moving on it depending on what is on the surface and the slope. The steeper the slope, the harder the movement will be.

Keywords: GIS, Network, transportation, minimum route

1. INTRODUCTION

A network can be defined as a multitude of interlinked arcs. Each arc contains a start node and an end node. The route of an arc is directed by points. The connectivity of the network is determined by topological relations defined by nodes, the network analysis is closely related to the graph theory.

A **graph** represents any X class, finite or not (but countable) implying a internal binary relation Γ. A graph is represented as follows:

$$G = (X, \Gamma)$$
$$X = \{x_1, x_2, ..., x_n\} \quad (1)$$

A graph is represented by x_i points, named top of that graph and by arrows which represent the graph transitions Γ called graph arcs. The arrows are oriented in the direction of the Γ transitions. The arcs are represented by u_i and their multitude is represented by U, the direction of the arc is shown by the notation $x_i \rightarrow x_j$ or u_i^j. An oriented graph is represented by a graph where a direction of transition is defined.

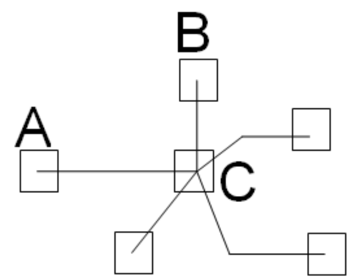

Fig. 1 Example of a network

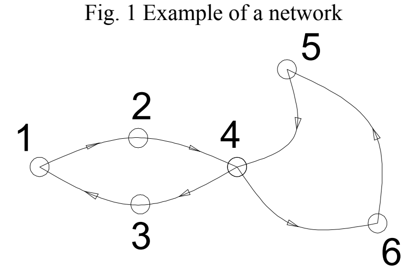

Fig. 2 Example of an oriented graph

Example: The A_1 locality must be connected with the localities: A_2, A_3, A_4, A_5, thus $X = \{A_1, A_2, A_3, A_4, A_5\}$.

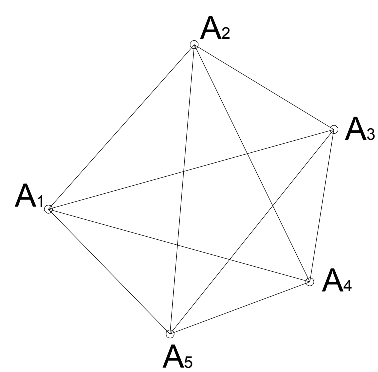

Fig. 3 Connection of a locality with the others

The multitude of all possible solutions imply: $R = \{X \times X\} \setminus \{(A_i, A_j), i = \overline{1,5}\}$. The optimum solution regarding the cost is proportional to the distance between the localities.

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2. ARRAYS ASSOCIATED TO GRAPHS

To any graph $G = (X, \Gamma)$ can be associated a square array of transitions $M = \left\| a_j^i \right\| (i, j = 1, 2, \ldots)$ which compose the Γ relation adding:

$$\begin{cases} a_j^i = 1 & IF \quad (x_i, x_j) \in \Gamma \\ a_j^i = 0 & IF \quad (x_i, x_j) \notin \Gamma \end{cases} \quad (2)$$

On i line there are marked the incident arcs towards the exterior with 1, and on the j line there are marked the incident arcs towards the interior with 1. The $M = \left\| a_j^i \right\|$ array is the array of the length roads 1 existing in graph G and is called the **adjacency array**.

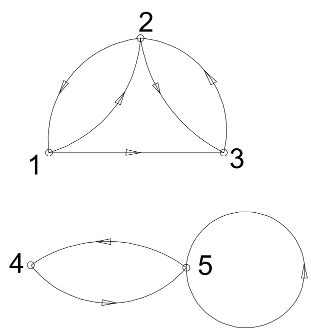


Fig. 4 Oriented graph

The adjacency array of the upper graph is the following:

$$\begin{array}{cccccccc} & 1 & 2 & 3 & 4 & 5 & & \sum \\ & 0 & 1 & 1 & 0 & 0 & 1 & 2 \\ & 1 & 0 & 1 & 0 & 0 & 2 & 2 \\ M = & 0 & 1 & 0 & 0 & 0 & 3 & 1 \\ & 0 & 0 & 0 & 0 & 1 & 4 & 1 \\ & 0 & 0 & 0 & 1 & 1 & 5 & 2 \\ & & & & & & & 8 \end{array}$$

3. EVALUETING THE STRUCTURE OF A NETWORK

Evaluating the structure of a network is done based on certain indicators:

- □ **indicator** :

$$\gamma = \frac{l}{l_{\max}} \quad (3)$$

Where l represents the number of links and l_{max} represents the maximum number of links calculated with the following formula:

$$l_{\max} = 3(n-2) \quad (4)$$

Where n represents the total number of nodes.

- **α indicator**:

$$\alpha = \frac{c}{c_{\max}} \quad (5)$$

Where c represents the number of existing circuits and c_{max} represents the maximum number of possible circuits calculate with the following formula:

$$c_{\max} = 2n - 5 \quad (6)$$

Network diameter represents the maximum number of steps necessary for crossing from one node to another going on the shortest way.

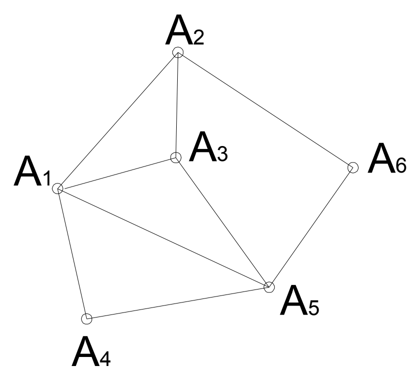


Fig. 5 Graph of 2 diameter

4. NETWORK ACCESSIBILITY

The accessibility of any network is determined by an accessibility array which can be calculated with the following formula:

$$T = A^1 + A^2 + A^3 + \ldots + A^d \quad (7)$$

Where d represents the network diameter.

For the graph in fig. 5 we have the following **adjacency array A**:

ARRAY A	1	2	3	4	5	6	SUM
1	0	1	1	1	1	0	4
2	1	0	1	0	0	1	3
3	1	1	0	0	1	0	3
4	1	0	0	0	1	0	2
5	1	0	1	1	0	1	4
6	0	1	0	0	1	0	2
							18

All the non-zero elements of array A represent the length roads 1, and all the null elements represent the nonexistence of the arc from i to j. If we square array A we obtain the following array:

ARRAY AxA	1	2	3	4	5	6	SUM
1	4	1	2	1	2	2	12
2	1	3	1	1	3	0	9
3	2	1	3	2	1	2	11
4	1	1	2	2	1	1	8
5	2	3	1	1	4	0	11
6	2	0	2	1	0	2	7
							58

Array A^2 has the following meaning: the unique number of roads which allow the crossing from one node to another through exactly 2 links is given by the elements of array A^2 meaning the elements a^2_{ij}. For example, on line 2 column 5 we have the element $a^2_{25}=3$ which means that we can get from node 2 to node 5 using exactly 2 different arcs by 3 possibilities.

If we calculated also array A^3 then the elements a^3_{ij} would represent the unique number of ways which allow crossing from one node to another going through exactly 3 links.

In this case **the accessibility array T** is the following:

ARRAY T

	1	2	3	4	5	6	SUM
1	4	2	3	2	3	2	16
2	2	3	2	1	3	1	12
3	3	2	3	2	2	2	14
4	2	1	2	2	2	1	10
5	3	3	2	2	4	1	15
6	2	1	2	1	1	2	9
							76

The elements of array T represent the total number of ways which allow crossing from one node to another directly or indirectly. The SUM column represents the total number of ways which allow crossing from one node to all the other nodes from the entire network. In this case the highest amount from SUM column is corresponding to node 1, so this node has maximum accessibility. The accessibility in a network indicates the crossing possibilities through to the respective network.

5. APLICATIONS OF THE GRAPH THEORIES USED IN NETWORK ANALYSIS

➢ **Minimum cost route**

Defining a transport network implies: the existence of a node which does not allow any edge to enter (called network entering node), the existence of a node from which no node goes out (network exit node), the representing graph has no isolated nodes and to each edge is associated a positive number called the edge capacity.

The inlet data in order to make this application were as follows: The field use categories - Landuse (Corine Land Cover 2000, CLC) that covers the studied area. The source and destination points, which in case of this application are made from towns: Reca□ and Lugoj from Timis County, DEM – the digital elevation model generated for the studied area by using the software Global Mapper [2],[3]. The methodology is as follows:

- *Conversion of clc layers into raster and reclassification of it*

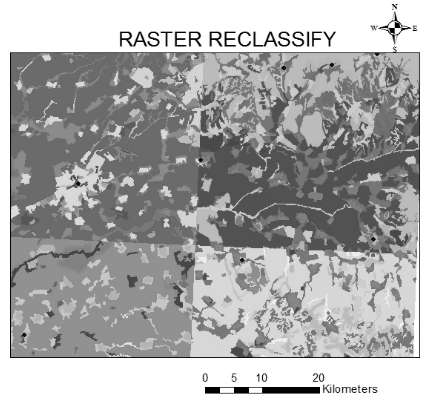


Fig. 6 Raster map of the studied area and Raster map of the reclassified studied area

- *The generation of the slopes map for the studied area by using the DEM model*

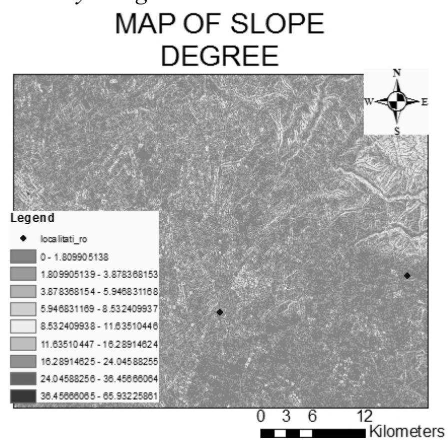


Fig. 7 Slopes map (degrees)

- *Creating a cost raster*

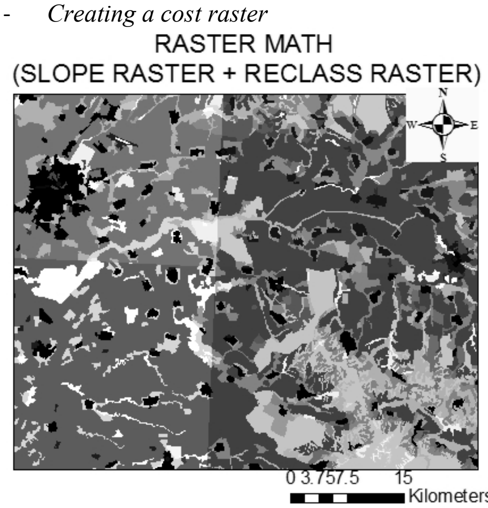


Fig. 8 COST Raster

- *Obtaining a raster with cost of move from the source point (town) to any other destination point (town)*

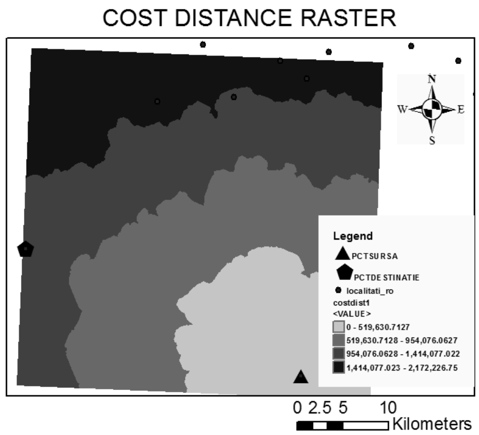
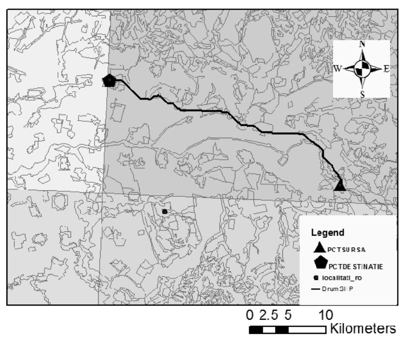


Fig. 9 COST Distance Raster

- *Determining the minimum road from the source to the destination*



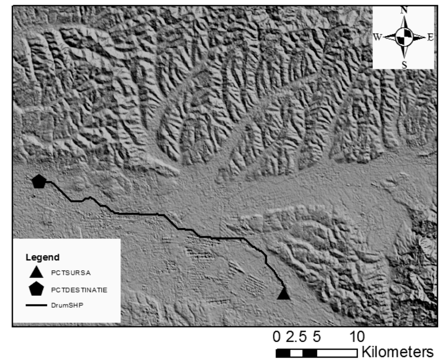


Fig. 10 The minimum road between 2 towns overlapped to CLC and DEM

- **Traveling salesman**

The problem of the salesman is finding the shortest way between 2 nodes, but having mandatory stops in other nodes. This implies only one starting point and many destinations. The nodes are connected through arcs which have certain statistical weight representing the distance between the nodes. The scope of this problem is to find the optimum route from crossing the mandatory nodes. A well known application of this problem is in the distribution field.

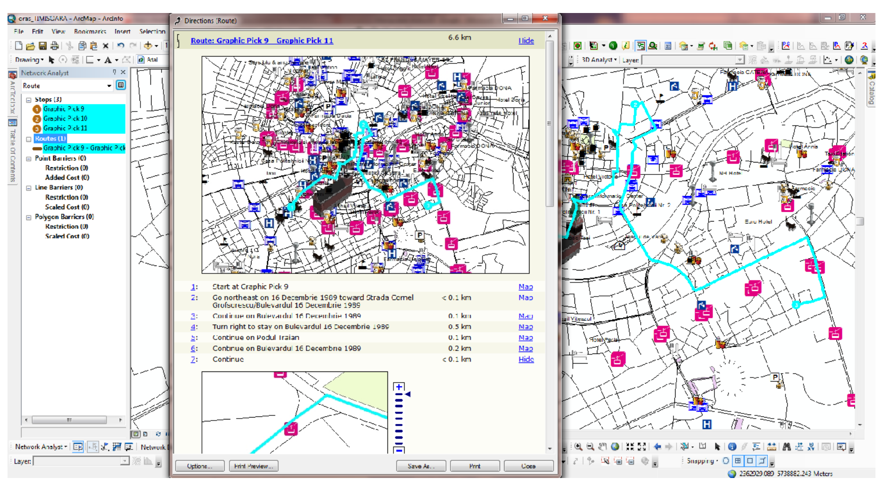


Fig. 11 Solving the salesman problem and viewing the salesman route using ArcGIS

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