CREATING, TESTING AND APPLYING A GIS ROAD TRAVEL COST MODEL FOR ROMANIA

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ABSTRACT:
Simulating road network functionalities has a critical importance nowadays: it gives the opportunity to understand network architecture and places' accessibility in a fast and effective manner. Our method integrates different factors of travel impedance – such as legal speed limitations, morphology, quality and hierarchy of network infrastructure. The tests show similar features to those of the professional route planner platforms, which enable us to use this model in further applications and to propose it as a method for other networks. Our application in the field of tourism accessibility has shown interesting results. Average speed of reaching business tourism destinations plays a certain role in destination development, though it is still hard to be estimated. Certainly, applying the model to more contrasting road networks would show critical spatial differentiations.

Keywords: *road network functionalities, factors of travel impedance, route planner.*

1. INTRODUCTION

Difficulties in collecting different territorial statistic data constrain geographer to imagine theoretical models which are able to reflect reality as accurate as possible. Romanian researcher assists to a lack of various statistical indicators and often to partial, inadequate or irrelevant data provided by the INSSE (National Institute of Statistics and Economic Studies).

Data on travel and access to places and locations is still scarce or unorganized. Regional and national road administrators (DRDP or CNADNR) have little interest in creating a nationwide database describing travel cost between places. When contacting a regional office (DRDP Iasi – Regional Road and Bridges Department in Iasi, North-East Romania), geographer has the surprise to find out that the company does not use an integrated GIS platform in order to easily manage its road networks. No vector data can be provided and management is based on personal knowledge of the field. Only for Iasi Regional Department (1/5 of national networks), it is possible to have access to a few thousand pages register, with data on each road segment. Attributes of roads include functional category, technical class, viability, width of lane, date of last rehabilitation, rehabilitation state etc. Thus, creating a precise nationwide database would be possible only in a large research team and with time-consuming resources.

Travel cost between places has become very important in a growingly consumer society as people tend to consume more space as transport cost decreases. Cost is a wider concept, including derived indicators such as time, kilometric distance, expenses, mental distance etc. At worldwide scale, the cost and time of moving commodities, services and people have reduced in recent years and changes in transport infrastructure and means have induces relative changes in time, distance and trips (*Duval, 2007*). All features and concepts orbiting around the cost and ease of access are gathered in the concept of accessibility. Though claimed mostly by geographic and economic sciences, accessibility has gained all sciences interested in network. Networks are the expression of the changes that occur

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between places. Without networks, places would be isolated and there would be impossibility of access to them (at least, in modern society).

Xie and Levinson *(2007)* argue that the study of transport networks has shifted in recent years from topologic and geometric properties to large scale statistical properties of complex networks, often with empirical studies or with travel demand models. In order to apply different models which evaluate accessibility as access to places (shortest path or time) or as structure of network that assure access (morphometry, connectivity, connexity etc.), a cost model is needed. A GIS cost model needs a complex database with attributes that influence various features of cost of access.

2. METHOD OF CREATING A TRAVEL COST MODEL

Physical distance (with its derived travel expenses) has been until 18th century the unique measure of travel cost. Nowadays, one of the central indicators of cost is time of access. Nowadays travelers give a growing importance (sometimes capital) to travel time budget. The physical distance and the travel time are very important as they shape intensity of changes between places such as freight transport, people commuting, tourism etc. Storing and arranging such data on travel cost in a GIS environment (in a geodatabase) provides an excellent geographic tool which can be used in different geographic models. There are certain advantages of databases: they can simulate the behavior of geographic entities, they can be assigned rules and there is an efficient and consistent management of relations between internal datasets. (*Nicoara, Haidu 2011*).

Geographic Information Systems are powerful tools to calculate different aspects of territory, especially at a quantitative level. They tend to be used more as modeling tools, which is representation and analysis of potential phenomena between geographic places, especially when there is no statistical data or they lack accuracy.

In order to obtain a functional travel cost model, a few steps have been followed.

First step consisted in digitizing a polyline vector in ArcMap, representing the road network, using some starting opensource vector data (from openstreetmap.org) and then adjusted by using georeferenced Romanian topographic maps 1:50.000. The road hierarchy followed Road maps 1:700.000 from 2005 and 2008 and confronted to data offered by CNADNR, DRDP and MTI. As it is about a nationwide road network, we did not take into consideration communal and local roads. The hierarchy followed the Order of Ministry of Transport OMT 43/1998 but also integrated other classifications (as of above mentioned Road Maps) as follows:

- departmental (county) roads (regular county roads – ”DJ” or with regional importance – ”DR”)
- National roads (main – ”DN” or secondary – ”NS”) with its special cases – European roads (regular – ”E” or >12m ”E4”) and divided highways (”A”).

No infrastructural changes after 2009 were taken into consideration as they mostly represent unfinished or partial projects.

In order to have a complete network dataset, the following attributes were introduced (*Nicoara, Haidu 2011*):

- Meters (length of road section in meters, calculated automatically by the GIS geodatabase)
- Speed (estimated travel speed)
- FT_Minutes (time duration needed to travel the road section from the start node to the end node, measured in minutes)
- TF_Minutes (time to travel vice-versa, identical to the previous)

- Oneway, the possible directions to travel an arc
- Hierarchy (a classification of road importance in 3 classes, by administrative hierarchical rank).

The validation of the network geometry was crucial in order to eliminate editing errors by *topology validation* which is about verifying the position of nodes and arcs using a series of rules:

- No terminal nodes except the 1st degree nodes
- No line superposition
- Lines will not intersect in more than one point.

Once we had full configuration of lines, it was important to define *impedance*, which is a group of factors that impede the ideal travel on the road network. The speed of travel, one of the basic indicators of impedance, is subject to a series of factors, such as (*Bolog & Karnyanszky, 2008*):

- Type of vehicle;
- Legal speed limitations;
- Type of road and its features (width, viability);
- Linearity (sinuosity) and declivity of roads;
- Number of localities on the road, their length;
- Volume of traffic;
- Weather conditions.

As it is about general model, subject to independent travel, we will consider regular passenger car as the most frequent and efficient mean to travel between places, especially when it is about commuting or leisure/business traveling. Our model can be then reshaped for public passenger transport. As for freight transport, there is a more complex variety of means and traffic limitations, which will be considered in a future study.

The maximum legal speed on public roads is an absolute limiting factor (we will consider that by no means it could be exceeded) but also an ideal desideratum, as there are a few factors that impede reaching it. Unfortunately, there are no official documents that describe road properties that impede reaching maximum legal speed. Iași Regional Road Department, for example, can offer thick registers that classify road sections into classes of viability (a 3-class qualitative estimation) but identifying each vectorial road section and updating its viability attribute in attribute table requires a huge amount of time.

The document OMT 45/1998 (”Technical norms for design, build and modernize roads”) proposes a table that makes correlations between an independent variable – ”functional road category” and two dependent variables – ”road technical class” and ”designed speed” (depending on geographic environment).

This frame is only a guide. We notice a gradual decrease of designed speed as geographic morphology becomes more complex and as roads have an inferior rank. We may notice as well that few roads are designed to reach maximum legal speed (as mentioned in the following table). In order to establish a generic impedance class, we have calculated an average designed speed for each road section (**Table 2**). Then, we approximated a coefficient of impedance of designed speed to maximum legal speed as it follows:

Table 1. ***Correlations between road types and technical classes with designed speed.***

Functional Category	Correlations btw. functional category and technical class	Technical Class	No of lanes	Lane width	Designed speed		
					Plain	Hill	Mountain
Divided Highways	I	I	2 x 2	3,75	120	100	80
Express roads	I, II, III						
		II	4	3,5	100	80	60
European Roads	I, II, III						
		III	2	3,5	80	50	40
Main national roads	II, III, IV						
Secondary rd.	III, IV	IV	2	3,5	60	40	30
Departmental rd.	III, IV, V						
Communal rd.	IV, V	V	1/2	3,5	50	40	25
Vicinal rd.	V						

Table 2. ***Impedance calculus according to hierarchy and quality road class***

Functional category	Type	Abb-rev.	Max. Legal speed (kmph)	Designed speed and impedance			
				Designed speed range	Approx. imped.	Coeff. From max. speed	Estim. Max. speed
Highway	Divided highway	A	130	120	5%	0,95	123,5
European road	3-4 lanes/Express	E4	100	80-120	0%	1	100,0
	2 lanes (<7m)	E	100	80-100	10%	0,90	90,0
National road	Main	DN	90	60-100	5%	0,95	85,5
	Secondary	NS	90	60-80	15%	0,85	76,5
Department road	Regional	DR	90	50-80	25%	0,75	67,5
	Other	DJ	90	50-80	25%	0,75	67,5
Road in localities	European	LE	50	-	5%	0,95	47,5
	National	LN	50	-	15%	0,85	42,5
	Departmental	LR	50	-	25%	0,75	37,5
Ferryboat	Ferry (Danube)	BC	Est time: 40’	-	-	-	-

For example, in the case of Main National Roads (DN) which have a designed speed range from 60 to 100 km (average of 80), we have chosen a threshold of 5% impedance (5% less) from the ideal maximum speed of constant 90km/h. For Secondary National Roads as they are projected for 60 to 80 km/h (average of 70), we have chosen a general impedance of 15%; for Departmental roads (65 average) we have chosen an impedance of 25%.

When roads cross or pass by localities and inhabited spaces, there is a change in maximum legal speed. Up to 2009, most of roads inside localities had a maximum speed of 50 kmph (there are further specific changes up to 70 km/h in certain localities but they will not be considered here). The same impedance range was kept for roads inside localities. In order to identify them easily, we have used data from Corine Land Cover 2006 project that offer land use vector layers. We have extracted the build areas vector (continuous and discontinuous urban fabric – code 112) but also other types of territories that count for urban fabric (industrial areas, leisure parks etc.)

By superposing spatial data – polygonal urban fabric and linear road network – and by using spatial analysis module (*identify* command in ArcGis), roads were cut at ends of localities (**Fig. 1**).

Once the different road sections were discretized, maximum legal speed was assigned to different categories in attribute table (a new field called MAX_SPEED), as an ideal desideratum. Next to it, we defined the first impedance field – the quality of roads as derived of the "designed speed" – called QUALIT_IMPED which express the limitations prescribed by the constructor.

When ticking out the other impedance factors defined by Bolog & Karnyanszky (2008), we noticed that some of them are almost impossible to be taken into consideration. For example, volume of traffic and weather conditions are random and dynamic factors. Volume of traffic defines the functioning of the whole transport system which goes beyond the study of networks.

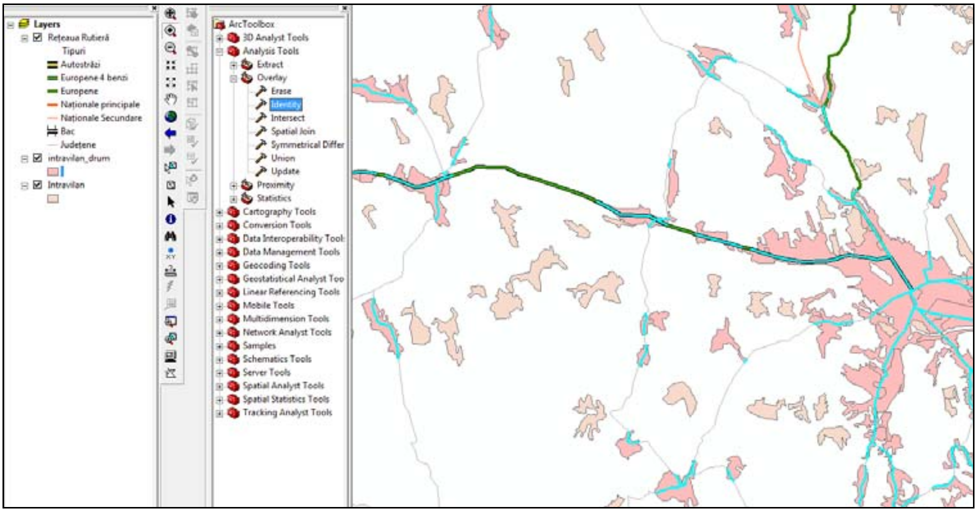

Fig. 1 Method of identifying and extracting roads inside localities

Linearity and declivity of roads play a static constant limiting role in reaching the ideal speed. Linearity is often expressed by it opposite – the sinuosity. This term comes from hydrology and it shows the degree of meandering or sneaking of a river, which is calculated by dividing real length of river between two points and direct ideal distance between those points. Thus, SI(i,j) = Dr / Dd , where SI(i,j) is the sinuosity index, Dr is real distance and Dd is direct distance between the points i and j. GIS can perform automatically this calculus, as points (ends of lines) and lines have geographic reference. In order to obtain unitary results, the road sections have been reduced to values between 0,5 and 5 km, as sinuosity may tend to decrease when considering smaller sections (a vector line section between two vertexes has no sinuosity). The module Sextante of the software gvSIG automatically calculated sinuosity in a field called SIN_INDEX. The obtained index goes from 1 (straight road, real and ideal straight road have same length) to a maximum length of 4,71. Only 5 road sections really go beyond an index of 3, usually high altitude roads (Transfagarasan, Transalpina, Mestecanis pass etc.)

Transforming sinuosity index into impedance coefficient has proven to be a more difficult task as the distribution of sinuosity index does not follow a linear distribution. Thus, we have conducted empirical measurements with own personal car to measure the way sinuosity of road sections affect reaching maximum legal speed, in normal road conditions. The recent modernized European road E576 between Gura Humorului and Vatra Dornei was used for measurements, as it provides excellent quality road and different values of sinuosity index.

Table 3. ***Correlations between sinuosity index of road section and real speed***

1. Sinuosity index by section	2. 1,02	3. 1,1	4. 1,4	5. 1,7	6. 2	7. 3
8. Average speed on E576 (km/h)	9. 100	10. 95	11. 85	12. 75	13. 70	14. 60
15. Impedance (% from maximum)	16. 0%	17. 5%	18. 15%	19. 25%	20. 30%	21. 40%
22. Coefficient sinuosity impedance	23. 1	24. 0,95	25. 0,85	26. 0,75	27. 0,70	28. 0,60

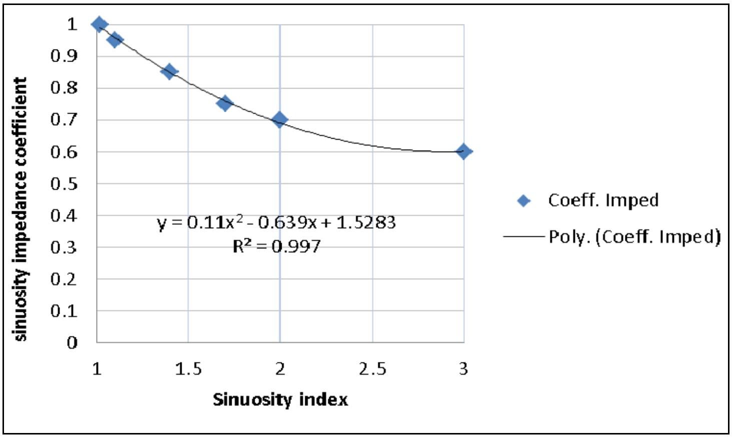

Fig. 2 Correlation between sinuosity index (x) and coefficient of impedance

There is a superior threshold (SI >3) above which the speed did not decrease less than 45% of the maximum speed. In the same time, under the value of 1,02 sinuosity did not prove to be a limiting factor, roads being considered straight, as in table 3 Bagheri, Benwell and Holt *(2006)* state this observation in their study, hypothesis confirmed by our empirical study, as well. In order to extrapolate to intermediary values, the field observations have been introduced in a dot diagram, in a coordinate system *x, y* in Microsoft Excel. This allows the calculus of the dependent variable *y* (Coefficient sinuosity impedance) in respect to the independent variable *x* (sinuosity index of road section) through a polynomial equation of second degree which expresses the intermediary estimated values. Thus, in the attribute table of road lines, the impedance operated by sinuosity was calculated as follows:

$$\text{SIN\_IMPED} = 0{,}11*(\text{SIN\_INDEX})^2 - 0{,}639*\ \text{SIN\_INDEX} + 1{,}5283.$$

Declivity (or slope) plays also an important role but it is often correlated with sinuosity. The origin of the road meandering relies in the morphology of the traversed road, intimately connected to declivity. There is no integrated available data on road section slope. GIS software offers the possibility of calculating slope in raster environment but its method takes into consideration the level differences between each pixel and the other 8 neighboring pixels which can be used for polygonal vector objects but not for linear ones. Anyway, we will consider that declivity is mostly included in sinuosity.

From our data, we can calculate the average estimated travel speed on each road section, depending on its geometrical and qualitative properties. EST_SPEED = MAX_SPEED * QUALIT_IMPED * SIN_IMPED. As we have real length of each road section and the estimated speed of travel, we can find out the average time of travel on each section, where $t = d/s$ (t = time, d = distance, s = speed).

Thus, we have obtained two quantitative characteristics of the travel cost on roads – distance and time of travel. Travel expenses are dependent on the first two, but also they vary a lot according to type of passenger car and number of passengers. Anyway, the expenses are usually a function of distance.

Thus our fully configured and validated network dataset has the necessary cost attributes and it is usable in different nodal and linear characteristics of Romanian road network.

3. TESTING THE TRAVEL COST MODEL

In order to test the accuracy of the model, we have chosen two important nodal points on the Romanian road network, created a routing cost (distance and time) between them and then compared our results to web platforms that do route calculations. It was the most simple way to test our model as further empirical observations can be very subjective and time consuming.

We have chosen Iasi and Timisoara, two extreme nodal points in Romania. The route command in Network Analyst (ArcGis) performs shortest travel time calculation between points, considering road hierarchy as priority. Fig. 3 presents the hierarchized road network as of 2009 and the shortest time-path between the two nodes. The shortest travel time is 10h 42’ (642’) for a distance of 726 km, considering maximum legal speeds, sinuosity limitations, road quality and road hierarchy.

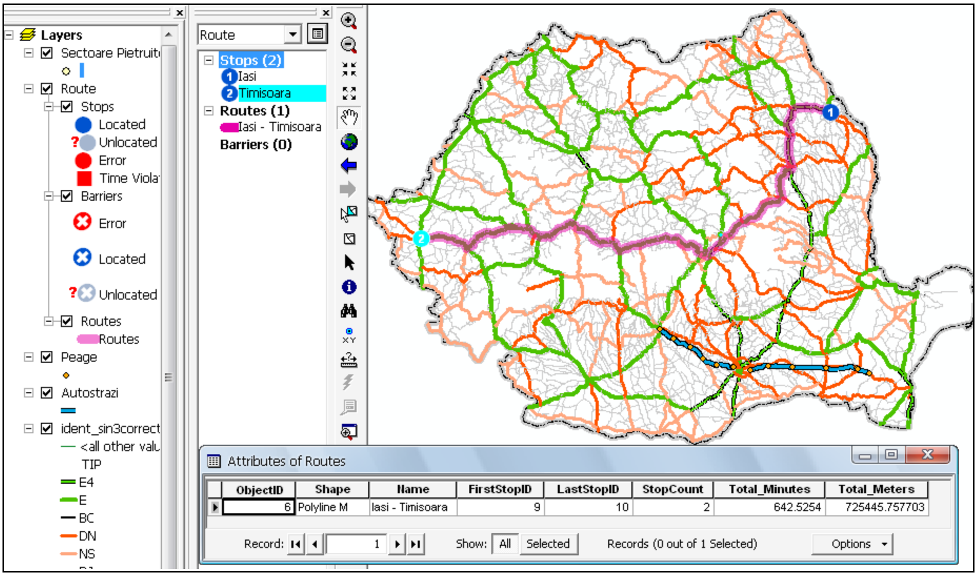

Fig. 3 Calculus of distance and time using own travel cost model in Network Analyst module

For the comparison, we have chosen Navteq Map24 and ViaMichelin, two professional web platforms that perform route calculations. Via Michelin offers the possibility to select the path between two points in terms of quickest (time), shortest (distance), sightseeing (landscape) and economical (average personal car fuel consumption) road. NavteqMap24 offers the possibility to select the fastest path (time), the shortest (distance) and the type of vehicle (car, motorcycle, truck). When selecting quickest travel time, we notice that Navteq Map24 offers 14h31' (2h50' more than our calculus) but calculated the exact same distance and route.

When analysing their routing method, we notice that the calculus is more precise, taking into consideration each turning point or road change (adding up a 20 to 30 seconds for each turn) and has a higher impedance in big cities (25 to 32 km/h speed comparing to our 35 to 45 km/h speed, as there is more yielding and stopping at traffic lights).

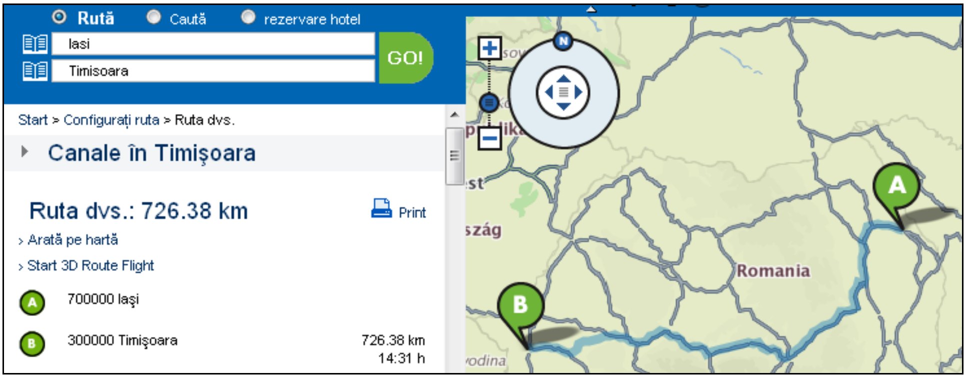

Fig. 4 Quickest route between Iasi and Timisoara as of NAVTEQ Map24 *http://star.map24.com/*

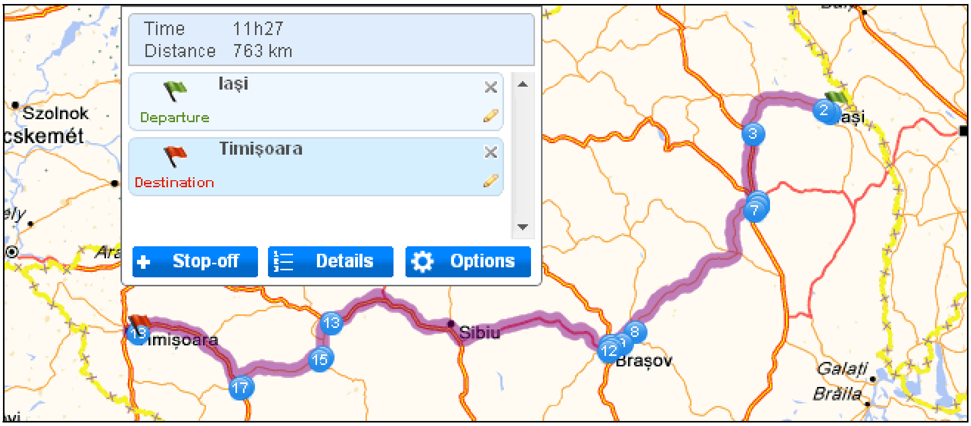

Fig. 5 Quickest route between Iasi and Timisoara as of Via Michelin *http://www.viamichelin.com*

As for Via Michelin, it calculates that the quickest route is a bit different (passing by Caransebes town) which makes the path 37 km longer, but offers a similar travel time (11h27', almost identical to ours if considering that it is about a longer path).

4. APPLICATION OF THE TRAVEL COST MODEL TO THE TOURISM ACCESSIBILITY

Travel cost model has great importance in different calculus of accessibility. Accessibility is defined as the ease or the difficulty by which a place can be reached, departing from other places. (*Bavoux et ai, 2005*) It is a quite ambiguous concept but includes a series of precise indicators. These indicators can reveal the properties of places' position in a territory (the *centrality* of places, *average speed* of reaching places departing from other places, degree of *sinuosity* of roads that lead to places) or from the properties of networks that lead to places (*length* of networks in a given territory, density, *connexity, connectivity, optimal itineraries* etc.) (*Chapelon, 1997*).

As we see, the palette of indicators is very large and the choice for a case study is very difficult. As we have shown above, travel cost related issues are of a great interest for tourists. Travel time to a destination, for example, is very important when choosing a leisure destination. Leisure tourists have a variety of destinations and the travel time can be one of the crucial factors in decision making. On the other side, business tourists tend to do more travels to a destination that is well connected, with efficient networks. Thus, higher speed access can play a certain role in business destination development.

We will chose the *average speed* of access as an indicator of accessibility that plays a role in reaching urban regional centers by business travelers. In order to calculate average speed accessibility, we need to define destinations and origins. We will reduce the territory containing destinations to the region of Moldavia. Previous research experience of Alexandru Ioan Cuza University of Iasi in regional studies with emphasis on the historical region of Moldavia recommends this region as best suited for the study case.

We will take the case of business travelers from all over Romania that visit destinations in Moldavia. In this case there is a need of reducing the number of possibilities by certain criteria.

As for the origins, we know that urban or at least more populated areas are more susceptible to have business opportunities. GIS environment allows making queries in the attribute table of spatial objects. Thus, only localities with more than 15.000 inhabitants from all over Romania were selected as origins (which cumulate almost half of Romania's population).

Business destinations from Moldavia are more difficult to identify. A multi-criterial query has been applied to data offered by the INSSE:

a. Tourism criteria (a minimum of 300 places of accommodation, minimum 10.000 tourist arrivals or at least 20.000 overnights in 2009)
b. Administrative or demographic criteria (the role of Municipium, county seat nowadays or in the past).
c. Accessibility criteria (central, accessible or hub position in its hinterland, access to higher rank networks).
d. Economy criteria (a higher business turnover per locality – minimum 10 billion RON/year)

A number of 25 localities meet at least two of these conditions and are susceptible to have an attraction for business tourists (as of **Fig. 6**).

Chapelon *(1997)* defines Multipolar Average Speed Accessibility as the mean speed towards a node a, departing from all other nodes, proposing the following formula, where *b* is the generic symbol for all origins, *a* is the destination, e_{km} is the "ecart" or the physical distance between the sum of origins *b* and the destination *a,* t_{min} is the time needed to reach the destination from each origin and *n* is the total number of origins (1).

$$\frac{\sum_{b=1}^{n}\left(\frac{e_{km}(b,a)}{t_{\min}(e_{km}(b,a))}\right)}{n-1} \quad (1)$$

As our travel cost model is ready to use, the physical distance will be assigned as real road distance between origins and destinations, the time represents the minimum temporal cost to reach destinations. There are a total of 126 localities over 15.000 inhabitants that might be origins for business travelers.

The Network Analyst module of ArcGis performs automatic sum between the above mentioned origins and destinations. The sum of distances and periods of time between each destination and the possible origins is done by exporting the attribute table of the Network dataset into Microsoft excel worksheets and then by calculating each total time and total distance to reach each destination. After that, a mean speed (*t/e*) is calculated for each destination, and represented by diagrams, as in next figure.

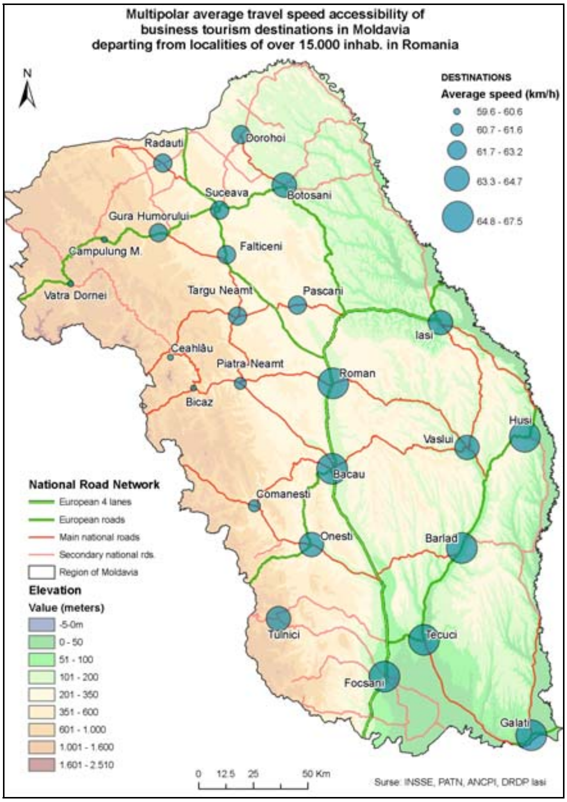

Fig. 6 Average travel speed to Moldavian destinations

Our findings are evocative. The Average Travel Speed has very low values in north-western part of the territory although this is a very attractive for leisure tourists. Less quality roads, great sinuosity and general high impedance to these destinations is a limiting factor for their business attractiveness. Indeed, the localities from north-west have a limited demographic development (they do not exceed 20.000 inhab. except Piatra Neamt) due to a series of factors, lower accessibility included. On the other hand, less attractive leisure destinations in the rest of the territory are better connected through higher hierarchical roads and there are less travel limiting factors. We might note the great potential of mid-Moldavia destinations such as Roman, Bacau or Focsani as they are well connected with the rest of the country. Though marginal, the biggest cities – Iasi and Galati – have a relatively high average speed connection which also proves that they enjoy a good infrastructural position. Galati enjoys even a higher average speed connection as its position is of great natural accessibility (hydrological convergence), it is connected to more linear networks and closer to the southern highways A1 and A2. Thus, Galati has the highest business turnover in the whole region.

The amplitude between the highest and lowest mean speed is not more than 10km/h, which is not critical. Applying it to a public transport system, for example, with real-time scheduled connections with contrasting covered areas, different transport type and/or multimodal transportation would show bigger differences and more evocative results.

It would have been interesting to be able to compare business arrivals by destinations (or by entire hinterland area) with average speed connection. Unfortunately the existent tourist arrival statistics do not classify arrivals by motivation.

5. CONCLUSIONS

Creating a travel cost model in terms of distance and time of travel for the national Romanian road network is very useful in the calculus of different indicators of accessibility. GIS environment is nowadays able to offer automatic, semiautomatic or manual scripts and commands that help user calculate different travel inconveniences deriving from network morphology, structure, hierarchy, quality, traffic limitations etc. Territories have often different assets because of different architecture of transport networks. GIS offers the possibility to analyze actual state of networks but also to simulate future changes in places' importance, rank and benefits when do occur changes in networks.

Our goal is to adjust this model in the future (by adding more importance to slope, turns or inner city limitations) and use it in the calculus of other accessibility indicators.

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