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THE GIS-BASED ROAD DISTANCE AND TIME CONNECTIVITY INDEX OF THE SETTLEMENTS WITHIN THE WEST REGION OF ROMANIA

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ABSTRACT. – The GIS-Based Road Distance and Time Connectivity Index of the Settlements within the West Region of Romania. This study is based on previous approaches to the subject of connectivity index (R. Rusu, 2007; R. Rusu, 2008) and is organically linked to the work of R. Rusu, T. Man and C. Moldovan (2013) which introduced the road distance connectivity index for the settlements of Banat. While preserving the above-mentioned index and the methodology to calculate it, this study extends the research to the whole West Region of Romania and sets the methodological framework for calculating a road time connectivity index, based on driving times from each settlement to the nearest central places of every rank. Although the values of the road time connectivity index would in fact depend more on various factors that have an impact on driving speed, it is a more reliable instrument to calculate connectivity. Settlements close to motorway entries/exits or located along or near national roads will have a better value of the time-based connectivity index than of the distance-based connectivity index. Both distance-based and time-based road connectivity indexes may represent useful tools in the planning and management of infrastructure projects, in development strategies meant to reduce territorial disparities, as well as in regional and local planning.

Keywords: *West Region of Romania, road distance connectivity index (RD), road time connectivity index (RT), accessibility, isolation, settlements, GIS.*

1. INTRODUCTION

Communication and accessibility are very important issues for every settlement. The location of a town or village along the main road may provide an important competitive advantage in comparison to other similar settlements, lying far from the main communication lines. The benefits of such a location may eventually convert the settlement into a "central place" (W, Christaller, 1933). More than that, central places tend to organize their own transport and communication network within their area of influence. Therefore, roads and other transport networks tend to converge towards central places and this is more visible in the case of larger cities. In contrast, villages located at distance from the main roads may undergo severe drawbacks in terms of social and economic development. Isolation may lead to lack of investments, resulting in the absence of facilities, low living standards, lack of labour opportunities, which in their turn determine outmigration, demographic ageing and eventually the negative circle closes when the village has (almost) disappeared.

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However, accessibility is just one aspect to be taken into account. In fact, as stated above, the role of the communication lines is to give access to higher-grade central places, like towns or cities, which provide goods or services that one cannot find at home. Centrality is therefore crucial for the understanding of accessibility (R. Rusu, T. Man, C. Moldovan, 2013). Then, connectivity would not mean just the mere connection to the main transport network, but the degree in which this network would provide the means to get to higher-ranked central places.

The approach would be then to consider the position of specific groups of people in specific locations (either rural or urban communities) and postulate the means by which they might access a set of services or facilities deemed socially necessary. The welfare of the communities depends to a large extent on standards of connectivity and accessibility to such services or facilities. The most valid measure would be the assessment of the space (distance) and time budgets needed for the population of every settlement to reach specific destinations (S.D. Nutley, 1980; R. Rusu, T. Man, C. Moldovan, 2013).

This paper is indeed a sequel of our previous analysis on road connectivity index (R. Rusu, T. Man, C. Moldovan, 2013), based in its turn on former assessments of connectivity and accessibility in Banat (R. Rusu, 2007; R. Rusu, 2008). There are two notable differences between this study and the previous ones. First, the area of analysis has been enlarged, to include the whole West Region of Romania, therefore adding Hunedoara County to the already studied Arad, Timiș and Caraș-Severin counties. Second, and more important, a significant step forward has been made by introducing the road time connectivity index as a new manner of calculating connectivity, starting from the road distance connectivity index, presented in a recent paper (R. Rusu, T. Man, C. Moldovan, 2013).

2. METHODOLOGY

The methodology which fundamented the calculation and assessment of the road distance connectivity index has been drawn up in detail in our most recent work (R. Rusu, T. Man, C. Moldovan, 2013). However, since there is a strong link between the road distance connectivity index and the road time connectivity index, it is necessary to write a summarized version of the methodology for calculating the road distance connectivity index before focusing on the road time connectivity index. More than that, results for both road distance and time connectivity indexes in the West Region of Romania will be presented.

The above-mentioned paper comprised a short description of the recent Romanian contributions on the topics related to connectivity and accessibility (Alina-Gabriela Mureșan, 2008, I. Muntele *et al*, 2010, M.G. Oprea, 2011, Cs. Máthé, 2011) and assessed their strengths and flaws. All these works made reference to more or less recent foreign geographical literature (Haggett and Chorley, 1969; Taaffe and Gauthier, 1973; Chorley and Haggett, 1976; Weibull, 1980; White and Senior, 1983; Spiekermann and Wegener, 1996; Cairncross, 1997; Schürmann, Spiekermann and Wegener, 1997; Miller, 1999; Spiekermann and Neubauer, 2002; Lumsdon and Page, 2004; Duval, 2007; Olsson, 2009; Rodrigue *et al*, 2009, to point out just a few) but made little or no reference to each other or to other relevant Romanian works on the topic of connectivity, accessibility or isolation.

The methodology for calculating the road distance connectivity index was largely based on previous works (Rusu, 2007; Rusu, 2008) on the same subject. Nevertheless, while then a general connectivity index was sought for, this time the focus was on the road connectivity index, using a slightly different approach and GIS techniques. We relied only on the distance to the nearest central places (RD).

Ranking of central places considered for the West Region of Romania

Table 1.

Rank	Short description	Cities, towns and commune centres in the West Region	Settlements outside the West Region
0	National capital city		Bucharest
1	Regional centre	Timişoara	Cluj-Napoca, Craiova
2	Sub-regional centre	Arad	Oradea, Sibiu
3	County seat	Reşiţa, Deva	Drobeta T. Severin, Târgu Jiu
4	Important middle-sized city	Lugoj, Caransebeş, Hunedoara, Petroşani	
5	Small city or town with large area of influence	Lipova, Ineu, Sebiş, Chişineu Criş, Sânnicolau Mare, Deta, Făget, Oraviţa, Moldova Nouă, Bocşa, Oţelu Roşu, Brad, Haţeg, Orăştie, Lupeni, Vulcan, Petrila	Salonta, Ştei, Orşova, Câmpeni, Cugir
6	Small town with minor area of influence or urban-like commune centre	Pecica, Nădlac, Sântana, Curtici, Pâncota, Gurahonţ, Recaş, Gătaia, Ciacova, Jimbolia, Buziaş, Băile Herculane, Bozovici, Anina, Călan, Simeria, Uricani, Aninoasa, Geoagiu	Vaşcău, Baia de Aramă, Abrud, Zlatna, Bumbeşti-Jiu
7	High-grade commune centre	Vinga, Vladimirescu, Şiria, Săvârşin, Beliu, Cermei, Ghioroc, Şimand, Vârfurile, Hălmagiu, Biled, Orţişoara, Giroc, Jebel, Cărpiniş, Lovrin, Nădrag, Peciu Nou, Periam, Dudeştii Vechi, Mehadia, Berzasca, Topleţ, Caraşova, Teregova, Crişcior, Ilia, Certeju de Sus, Ghelari, Baia de Criş	
8	Commune centre	All the other commune centres	

Therefore, in order to assess the connectivity of settlements, we have first taken into consideration all classified roads within the territory of the analyzed region, and all the settlements. Distances by road were calculated (using GIS) from each settlement to the nearest central place of every rank (except for rank 3, where distance to the county seat was compulsorily considered). For this, a preliminary study was needed to determine the ranks of the settlements within the analyzed territory, and even in the neighboring areas. We relied our assessment on such a hierarchy, based on a previous analysis (Rusu, 2007), which classified the settlements into 12 ranks or levels, starting from the national capital, Bucharest (rank 0) down to the most underdeveloped villages or hamlets, with almost no inhabitants and no elementary services (rank 11). However, for the purpose of this study, we have only taken into account the first nine levels (rank 0 to rank 8, commune centre), considering that smaller villages (ranked 9 to 11)

are irrelevant as central places. Central places belonging to any rank are also included as central places for all the ranks below. For instance, Timişoara, ranked 1, is also considered as ranked 2, 3… down to the lowest rank, as it provides not only high services, specific for regional centres, but also basic goods, available in any low-grade settlement.

The values of distance were then aggregated for every settlement into a connectivity index using the following formula (R. Rusu, 2008; R. Rusu, T. Man, C. Moldovan, 2013):

$$RD = (3 - \frac{Dr0}{150}) + (3 - \frac{Dr1}{75}) + (3 - \frac{Dr2}{40}) + (3 - \frac{Dr3}{20}) + (3 - \frac{Dr4}{12}) + (3 - \frac{Dr5}{8}) + (3 - \frac{Dr6}{5}) + (3 - \frac{Dr7}{3}) + (3 - \frac{Dr8}{2})$$

where

RD – road distance-based connectivity index;
Dr0 – distance from the settlement ranked 0;
Dr1 – distance from the settlement ranked 1…
Dr8 – distance from the settlement ranked 8.

The maximal value for each component of the formula is 3, at zero distance, meaning that the settlement belongs to a rank above or equal to the one considered. Therefore, the formula takes into account a highest possible value of 27 in the case of the capital city of Bucharest. All the other settlements nation-wide have smaller values of the connectivity index. Although most settlements have positive scores, values may be negative for each component and overall.

Distances considered for a score of zero in every component of the formula

Table 2.

Rank	Distance (in km)
0	450
1	225
2	120
3	60
4	36
5	24
6	15
7	9
8	6

As distances were calculated from every settlement using classified roads, one may face the issue that not all the settlements are actually located on roads, or at least the point representing the settlement is not on any road. Therefore, a range of 4 kilometres to the nearest road has been taken into consideration for the West Region settlements, as for instance 32 villages of Banat are not reached by any public classified road (Rusu, 2007).

To calculate distances a networks dataset was generated using ArcGIS Network Analyst Extension. This dataset included all the roads categorized by types and all the nodes (access points to the network). Based on these the shortest route from each localities to the nearest attraction point was calculated. The final step was to calculate the RD index. The RD value for each settlement was used as input point in interpolation process using ArcGIS Spatial Analyst resulting a raster dataset representing the spatial variability of RD. The overall values for each settlement have been interpolated to produce a map of the road connectivity index in the West Region of Romania (fig. 1).

For the road time connectivity index, we transformed the distances into driving times needed for a motor vehicle to get to certain locations. While distances are important to assess the connectivity of a certain settlement, journey times to central places provide a better and more realistic picture on accessibility and the real connection each settlement has to the nearest central places. For each type of road, we considered a

certain average speed (table 3). Distances may be perfectly calculated and are always the same (except when new infrastructure is built). Journey times represent however just a mere approximation, because the speed also depends on many factors – the quality of the road, the weather conditions, the density of traffic, the number of settlements and stops on the road. On the same road, the same journey will take longer at peak hours or in heavy weather.

Average speeds for motor vehicles according to the type of road

Table 3.

Type of road	Average speed
Motorway	110 km/h
National road	70 km/h
County road	50 km/h
Local (commune) road	30 km/h

More than that, roads are quite different, even if they belong to the same category. An average speed of 70 km/h is not possible on all national roads. Different road sectors allow for different speeds. Vehicles slow down while passing through towns or villages.

Temporary works on certain roads may also determine a high variability of the average speed. In winter or in heavy conditions, speed must also be adjusted. Differences between roads increase as one refers to lower grade roads. Few county roads are perhaps better than some national roads, while other county roads are unmodernized and even unreliable for driving. The local roads are the most diverse in terms of modernization. While many are still not fit for motor vehicle traffic, important works are in progress in many villages, as a result of the implementation of rural infrastructure rehabilitation programmes.

Accepting the fact that time needed to get to a destination is more relative than the distance to that destination, we transformed all distances into driving times. In few cases, it came out that the shortest route (in terms of distance) is not necessarily the fastest one (in terms of time), as for example between Timişoara and Reşiţa. Lower classified roads may cut distances, nevertheless they might increase journey times.

Using the same technique as in the case of distance, we assessed the time needed to get from each settlement to nearest central place of every rank (except for rank 3, where the county seat was compulsorily considered). Then we used a similar formula as for the road distance connectivity index, assuming that 1 kilometer = 1 minute, which means that an average speed of 60 km/h is to be considered to achieve a perfect similarity:

$$RT = (3 - \frac{Tr0}{150}) + (3 - \frac{Tr1}{75}) + (3 - \frac{Tr2}{40}) + (3 - \frac{Tr3}{20}) + (3 - \frac{Tr4}{12}) + (3 - \frac{Tr5}{8}) + (3 - \frac{Tr6}{5}) + (3 - \frac{Tr7}{3}) + (3 - \frac{Tr8}{2})$$

where

RT – road time-based connectivity index;
Tr0 – journey time to the settlement ranked 0;
Tr1 – journey time to the settlement ranked 1…
Tr8 – journey time to the settlement ranked 8.

Results would be different from those of the distance-based connectivity index. Although the values of the road time connectivity index would in fact depend more on various factors that have an impact on driving speed, it is a more reliable instrument to calculate connectivity. Settlements close to motorway entries/exits or located along or

near national roads will have a better value of the time-based connectivity index than of the distance-based connectivity index. On the contrary, isolated settlements, situated far from the main roads, sometimes at the end of a minor local road, would have worse values of the time-based connectivity index than of the distance-based connectivity index (fig. 2).

3. RESULTS

3. 1. The distance-based connectivity index

The results have been already presented for Banat in our previous work (R. Rusu, T. Man, C. Moldovan, 2013). In this paper, Hunedoara County is added to have an overview of the distance-based connectivity index of the whole West Region of Romania (fig. 1).

The overall score of the connectivity index for the 1405 settlements comprised in Arad, Caraş-Severin, Hunedoara and Timiş counties varies between 23.38 (Timişoara, also the largest urban centre) and – 31.91 (Bigăr). More than half of the settlements (804) have positive values of the connectivity index, while the other 601 have negative values and are rather isolated. However, most settlements (1061, or more than 75%) have rather average scores, between 10 and – 10.

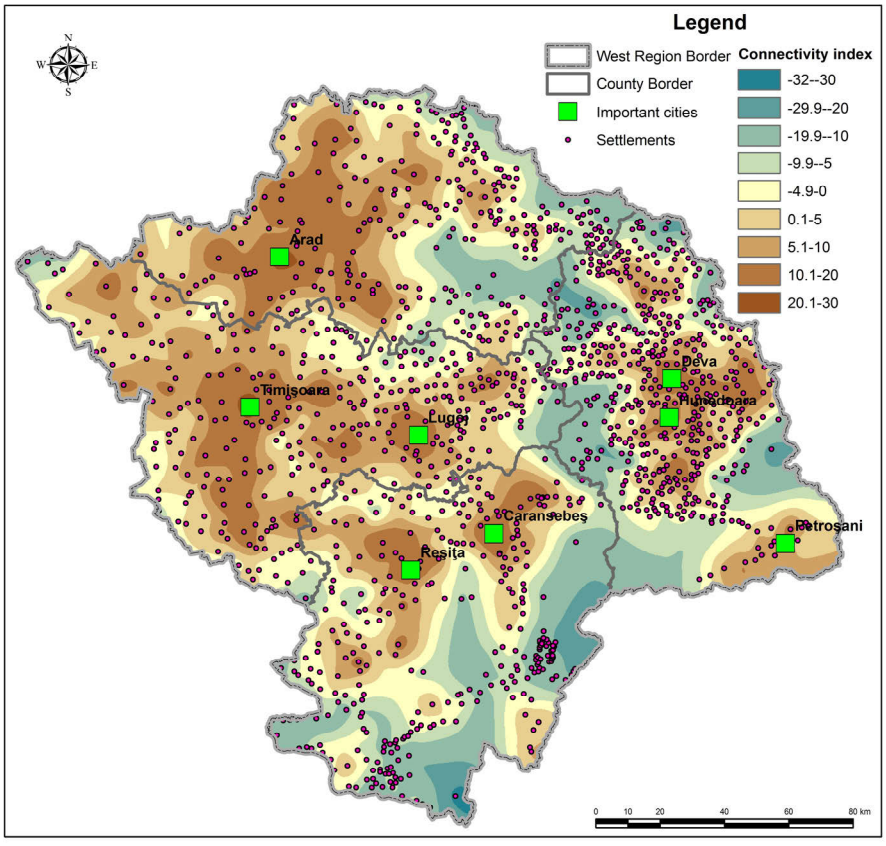

Fig. 1. The distance-based road connectivity index in the West Region of Romania.

Timişoara (23.88), Arad (22.69) and Reşiţa (20.10) dominate the classification. Large areas with positive values of the connectivity index are surrounding these cities. In Arad County, the area with best connectivity lies between the city of Arad and Chişineu-Criş (to the North), Pecica (to the West), Lipova (to the East). To the South, it is connected to the area centered on Timişoara, which also extends a great deal to the East (to Lugoj and even farther) and to the South (to Deta and Gătaia). In Caraş-Severin County, large areas with high values are situated around Reşiţa and Caransebeş. In Hunedoara County, although maximal values are a bit lower compared to the other three counties, there is still a compact area with values above 10 along the Mureş (Orăştie) Corridor and to its South, centered on the quadrangle formed by Deva – Hunedoara – Călan – Simeria. High values are also characteristic for the northern part of Haţeg Basin, for Petroşani Basin, for the centre of Brad Basin, and for towns like Sânnicolau Mare, Ineu, Sebiş, Oraviţa, Anina, Buziaş, Jimbolia, not too far away from the main cities.

The lowest values correspond to the least accessible areas, usually in the mountains, where road connections are weak. Therefore, the lowest score was registered for Bigăr, an isolated village in Almăj Mountains. Similarly low values are recorded for settlements in Metaliferi, Cerna, Ţarcu, Şureanu, Găina and Codru Moma Mountains, as well as in Lipova Hills, eastern Zărand Mountains, Almăj Basin.

It is interesting to note that low values also characterize the settlements situated along the borders, like those along the Danube or Nera. Even lowland settlements like Iam, Lăţunaş, Grănicerii, Beba Veche (the westernmost village in Romania) and their surroundings, located near the border with Serbia, have low connectivity. This is due to the poor infrastructure close to the borders, on the one hand, and the large distances to the main cities. In these cases, the political factor (the border) acts as a restriction, not the morphology, as in the mountains (R. Rusu, T. Man, C. Moldovan, 2013).

3. 2. The time-based connectivity index

Values of the road time-based connectivity index are significantly different than those of the distance-based connectivity index. While settlements in the upper part of the classification slightly improved their score, due to their good connections to high-grade roads and even motorways, the values decreased a lot for the lower-end settlements, which are not just very far away from central places, but also connected to them by poor infrastructure.

The values of the time-based connectivity index range between 24.08 (Timişoara) and – 64.87 (Meria, in Poiana Ruscă Mountains, Hunedoara County). Less than half of the settlements (666 out of 1405) have positive values of the index; therefore the majority of the settlements have negative values, which points out the low quality infrastructure in many parts of the West Region. About 13% of the settlements have an index above 10, but more than 20% have an index below – 10 and more than 5% register values below – 20.

Once again, the major cities and the county seats are best classified: Timişoara, Arad (23.52), Reşiţa (20.97), Deva (20.66 – this score does not take into account the recent opening of the motorway sector between Deva and Orăştie). Most of the other cities and towns (Lugoj, Bocşa, Caransebeş, Hunedoara, Simeria, Lipova, Orăştie, Pecica and so on) have scores above 10. Similar high scores characterize the rural areas located in the immediate neighbourhood of cities (Dumbrăviţa, Giroc, Săcălaz, Chişoda, near Timişoara; Vladimirescu, Fântânele, Şagu, near Arad, to point out just a few).

The main axes where positive values are registered are generally superimposed on the route of the motorway sectors and the national roads. One large North-South axis crosses the region from Zerind, at the border with Bihor County, to Moravița, in southern Timiș County. Timișoara and Arad lie in its centre. Other areas with positive values are around the large cities, as mentioned before, but they also extend to the West and to the East, along Mureș Corridor (from Arad) or Bega and Timiș valleys (from Timișoara). In Hunedoara County, one should mention the high values of the area between Deva, Hunedoara, Hațeg and Orăștie, as well as most of Petroșani, Hațeg and Brad basins.

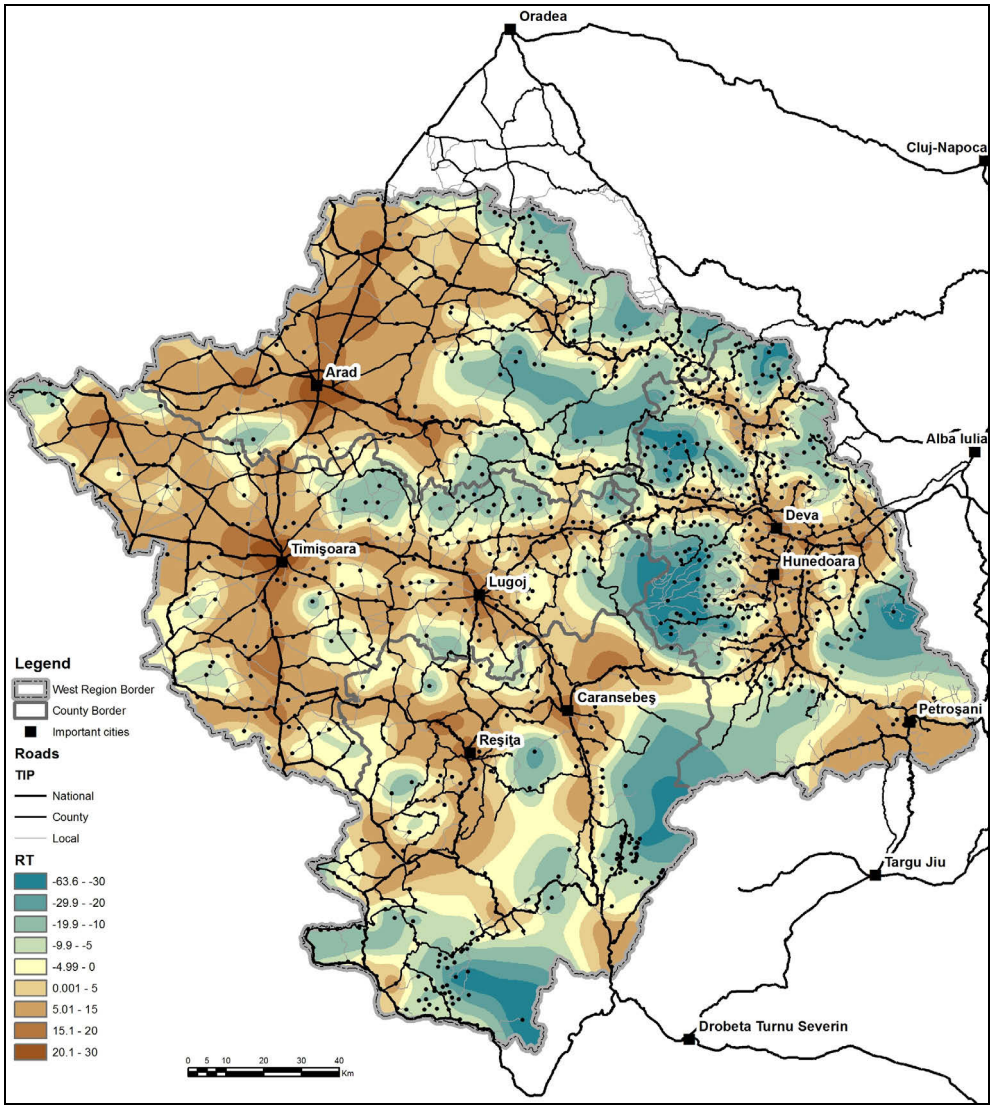

Fig. 2. The time-based road connectivity index in the West Region of Romania.

As in the case of the distance-based connectivity index, the poorest values correspond to isolated settlements, most of them located in the mountains. Meria and Dănulești (in Metaliferi Mountains, - 59.01) register the lowest values. Areas with very low values are Poiana Ruscă, Metaliferi, Găina, Almăj, Șureanu and Cernei Mountains, where certain settlements are grouped either on watersheds (Poiana Ruscă Mountains) or on slopes and dead ends of the valleys.

Low scores are also registered in lower mountains and hilly areas, where topography is not so much to be blamed. Areas in the "shadow" of investments, usually between counties, like Lipova Hills, Buziaș Hills, eastern Zărand Mountains, Codru Moma Mountains and Codru Hills. Also, settlements near the border, but not close to a border crossing point, are in the same situation, as infrastructure is generally poor.

The average value of the road time connectivity index (RT) for the West Region was – 1.87 compared to a positive value of 0.65 of the road distance connectivity index (RD) for the same region. However, while distances are unlikely to change, journey times might improve with the construction of new high speed roads, especially motorways. In the West Region of Romania, works are in progress on the basically West – East A 1 motorway passing near Nădlac, Arad, Timișoara, Lugoj, Făget, Ilia, Deva, Simeria and Orăștie. For the moment, only Arad – Timișoara and Deva – Orăștie sectors are functional, but the whole sector within the West Region and down to Sibiu is supposed to be ready in the near future. The motorway will definitely improve journey times and have a positive impact on RT values for the West Region settlements, especially those located near motorway exits.

4. CONCLUSIONS

This study is based on previous approaches to the subject of connectivity index (R. Rusu, 2007; R. Rusu, 2008) and is organically linked to the work of R. Rusu, T. Man and C. Moldovan (2013) which introduced the road distance connectivity index for the settlements of Banat. While preserving the above-mentioned index and the methodology to calculate it, this study extends the research to the whole West Region of Romania and sets the methodological framework for calculating a road time connectivity index, based on driving times from each settlement to the nearest central places of every rank. Therefore, the main point is that the welfare of the communities depends on the standards of connectivity and accessibility to services and facilities located in central places and that the most valid measure of connectivity would be the assessment of the space (distance) and time budgets needed for the population of every settlement to reach specific destinations (S.D. Nutley, 1980; R. Rusu, T. Man, C. Moldovan, 2013).

The road time connectivity index (RT) is a more reliable instrument to calculate connectivity, even if journey times might vary according to numerous factors that have an impact on driving speed. While distances are unlikely to change, journey times may improve with the construction of the motorways. In the West Region, the execution of the A 1 motorway will definitely have a positive impact on RT values of the settlements.

Both distance-based and time-based road connectivity indexes may represent useful tools in the planning and management of infrastructure projects, in development strategies meant to reduce territorial disparities, as well as in regional and local planning.

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