EJTIR

Spatial Complex Network Analysis and Accessibility Indicators: the Case of Municipal Commuting in Sardinia, Italy

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In this paper a contribution is presented with respect to accessibility indicators modelling for commuters moving through the municipalities of Sardinia, in Italy. In this case, spatial complex network analysis is integrated into the construction of accessibility measures: one of the most relevant outcomes of the first tool –the detection of shortest road paths and distances- is adopted as an input for the second in modelling accessibility indicators. Instead of Euclidean distances often adopted in the literature, shortest road distances are chosen, as commuting implies movements that are usually repeated daily and very likely subjected, even unconsciously, to space and time minimization strategies.

In particular, two commuter accessibility indicators are constructed according to approaches based on a travel cost and a spatial interaction model with impedance function calibrated in exponential and in power form. The accessibility indicators are confronted each other and with relevant socio-economic and infrastructure characteristics of Sardinia.

In addition, they are described, with respect to their spatial distribution and their different implications, when adopted in decision-making and planning. The travel cost based accessibility indicator has a municipal spatial distribution strongly influenced by the main road infrastructure of the Island. By contrast, spatial interaction model based accessibility indicators are more reliable, with respect to their capacity to confirm a leading socio-economic role of the municipalities comprehended in the metropolitan area of the capital town Cagliari.

Keywords: Accessibility indicators, commuting, spatial planning, complex networks, distance, spatial interaction

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1. Introduction

In a number of research studies, accessibility is regarded and defined in a variety of ways. It is a multifaceted characteristic and implies a multidisciplinary approach. In a general unifying perspective for infrastructure planning, the accessibility for a city depends on the nature of the movements people adopt to reach it.

The studies on accessibility describe integrated systems on the user viewpoint rather than transport modes or service provision. A study by DHC and Transport Studies Group at the University of Westminster (2003) identified several different ways in which accessibility has been used for planning purposes ranging from distribution of transport impacts and new developments to access to opportunities and business travel planning. One of the lessons drawn from this study is that accessibility may become the permanent element of a planning methodology if a clear definition is given about how to define people and places, how to represent transport and communications, at what level of spatial/geographical detail this should be applied, and the ways in which current accessibility performance should be expressed.

Gould (1969) has described accessibility as a 'slippery' concept, which often becomes clear in front of the need to define performance indicators. Accessibility and its measurement have been the focus of many research studies (Litman, 2007; Martin and Reggiani, 2007; Weber and Kwan, 2003; Bruinsma and Rietveld, 1998; Reggiani, 1998; Handy and Niemeier, 1997; Jones, 1981; Black and Conroy, 1977; Weibull, 1976). According to Baradaran and Ramjerdi (2001), the performance of many accessibility indicators adopted for European systems is assessed. In this study the indicators are clustered according to their methodological principles in five approaches: travel cost, gravity or opportunity model, constraint-based, utility-based surplus, and composite approach. Geurs and van Wee (2004) reviewed accessibility approaches assessing their usability in evaluations of land-use and transport strategies and developments. They group accessibility measures according to the components that are of crucial relevance (land-use, transportation, temporal and individual) and to perspective on measuring accessibility (infrastructure-based, location-based, person-based and utility-based).

Recently, the availability of even larger data sets and the parallel explosion of computer processing power has made the systematic and intensive application of complex network analysis (CNA) to the study of very large networks possible. CNA is a methodology able to describe the collective behaviour and the emerging global and local properties of network systems starting from the inspection of a set of entities or agents (modelled as nodes or vertices) intertwined by a pattern of relations (modelled as links or edges). According to this approach, large systems can be approached by a statistical analysis of their simple elements and of their relations. A series of measures are calculated to describe the behaviour of complex networks, such as the degree -the level of connectivity of a node- and the clustering coefficient -the level of local connectedness. Besides, CNA is a methodology able to describe and model the evolution of network systems over space and time. One of the major findings in this field is the so called Barabási and Albert model (1999). According to this model, the hidden mechanism of construction of scale free networks –where the probability distribution of the degree of the nodes has a power form with a heavy tail- can be explained recalling a preferential attachment rule. In this rule, newcomer nodes tend to link to high degree nodes in order to receive the highest benefit possible in that system through the connection to a key (hub) node. According to Tobler (1970), the first law of geography states that: "Everything is related to everything else, but near things are more related than distant things". In the last decade this rule has been partially denied by studies about complex networks in spatial domains. The spread of virus as well as systems' collapses and failures have proven that for certain kinds of networks (such as small-world networks) the events are more related to the topology of the system than the distance between the nodes.

CNA has been applied to a number of real phenomena, providing with insights into a wide range of questions regarding food webs, human interactions, the Internet, the world wide web, the spread of diseases, population genetics, genomics and proteomics. For a review of theory and applications, see Albert and Barabási (2002) and Newman (2003).

Also in many fields grouped under the realm of regional and transport science, a number of scholars have begun applying the paradigm of complex network analysis for modeling urban, regional and socio-economic systems (Barrat et al., 2004; Schintler et al, 2005; Reggiani et al., 2008). A number of applications refer to the study of infrastructures and of commuters' complex behaviour (Strano et al, 2007; Porta et al, in press). These works are often developed on the assumption that the emergence of scale free properties is a signature of efficiency in the system general behaviour..

In the field of the analysis of commuters' behaviour, a weighted network analysis has been applied to the system of inter-municipal habitual movements of the inhabitants of the Italian region of Sardinia, the second largest island of the Mediterranean Sea (De Montis et al, 2007). In other investigations, similar analyses have been applied to the commuting system of Sicily (De Montis et al., 2008 and 2009). Thus, CNA has provided an interesting perspective for the characterization of infrastructure and transportation systems.

The aim of this paper is to contribute to the discussion on accessibility by integrating spatial CNA into the methodologies adopted for constructing accessibility indicators. In this case, a combined approach is proposed, by integrating CNA with two accessibility indicators belonging to the travel cost and the spatial interaction model-based approach. These indicators provide with a measurement of the level of accessibility to the towns for commuters moving in the island of Sardinia, Italy. Commuting in Sardinia develops mostly through the road system. Accessibility to towns in this paper is studied with reference to an inter-municipal commuter network, where the nodes stand for municipal towns and the edges for shortest distance road connections.

The argument is reported as follows. In section 2, an application of spatial CNA to the study of commuting on the road network of Sardinia is described. This study provides with a relevant spatial variable –i.e. the inter-municipal shortest road distance- that is adopted as input term for developing commuters' accessibility indicators. These indicators are introduced with respect to their methodological principles in section 3. In Section 4, the focus is on the presentation and discussion of the results. The spatial pattern of municipal accessibility levels measured according to the different indicators is commented and confronted with relevant socio-economic and infrastructure characteristics of Sardinia. Section 5 concludes this paper with some synthetic remarks which suggest further research work.

2. Spatial Complex networks analysis and commuting: the case of Sardinia

In this section, we report on a study about the spatial properties of commuter systems approached through CNA. In this research, the authors inspect the patterns of physical road connections among municipalities used by commuters. Inspired by the analyses of De Montis et al. (2007), Campagna et al (2007) and De Montis at al (2009a) investigate on the influence of geography on commuting by analyzing the spatial properties of the road network, the favourite infrastructure for commuters in Sardinia, Italy. In this study, Sardinia is regarded as a closed domain and its inter-municipal commuting system is represented as a weighted complex network. This network displays vertices corresponding to the Sardinian municipalities in 2001, and edges corresponding to a positive commuting relationship among them pair wise. This modelling was first adopted by De Montis et al. (2007) that referred to the origin-destination table (ODT) issued by the Italian National Institute of Statistics (Istat, 1991). The ODT is constructed on the output of a survey about commuting behaviours of Sardinian citizens. This survey refers to

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the daily movement from the habitual residence (the origin) to the most frequent place for work or study (destination). Regional commuters are clustered in two categories: workers and students. Data also comprise information on both private (car, motorbike, bike and walking) and public means of transportation (train, tram, metro and bus). A very important variable that measures the disutility of trips for commuters is the time used to cover the distance between an origin and a destination (i.e. travel time). The ODT provides information about the time usually spent by each commuter for the daily displacement: this variable is developed in four distinct ranges. Hence, the ODT dataset provides the analysts with all the information needed about the flows of commuters who regularly move among the Sardinian municipalities.

In order to inspect the influence of the space, Campagna et al (2007) and De Montis at al (2009a) introduce two spatial networks that are isomorphic to the commuting network above, as they display the same topology, i.e. the number of nodes and edges. By contrast, these spatial networks stand as different from that original network, when regarded as weighted networks, since they show two diverse attributes for the set of edges (the weights of the network). In the first case, they consider the segment ideally connecting two towns, whose length is equal to the Euclidean distance. In the second one, they take into account the road path between two towns that displays the shortest length.

Although in principle every town is connected with another through a certain path, in these spatial networks links are taken into account only if an actual commuting flow is present between the nodes (municipalities). The spatial road network was obtained by means of processing the spatial dataset of the Sardinian road network issued by the cartographic department of the Autonomous Region of Sardinia in 2003.
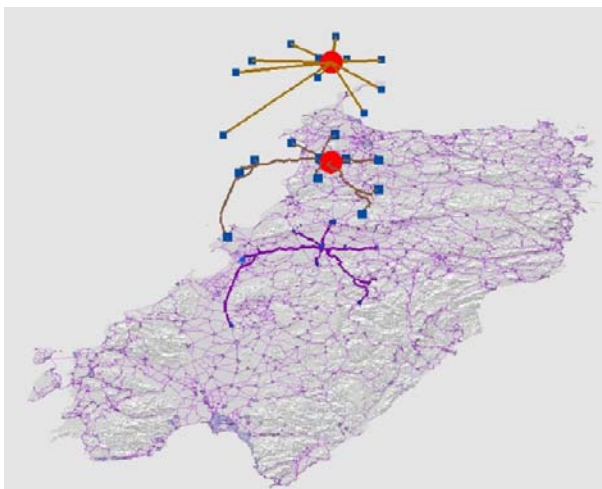

Figure 1. 3D visualisation of Sardinia. On the background the road-ways used by the commuters of the town of Soddì are highlighted, while the Euclidean distance is drawn on the top and the shortest road distance is floating in the middle (De Montis et al., 2009a).

As a general result, this study uncovers strong connections between the traffic properties of the system (commuters flows) and the geographical properties. As a special result, Campagna et al (2007) verify that the two spatial networks above display very similar statistical properties and show that Sardinian commuting flows are similarly correlated to both Euclidean distances and shortest road path distances between pairs of towns.

As far as this paper is concerned, the shortest road path between each pair of towns in Sardinia is assumed as starting input for constructing accessibility indicators.

In the next section, the integration between spatial CNA and accessibility indicators modelling is illustrated and referred to the municipal commuting system of Sardinia.

3. Integrating spatial CNA within the accessibility framework: travel cost- and spatial interaction model-based indicators

In this paper, accessibility is in general referred to as the capacity of a given municipal town to be reached with respect to other towns. In this particular case, the authors are interested to accessibility for commuters travelling daily mostly in a transport infrastructure –the road system- described as a network with certain spatial properties.

While in the literature it is possible to find a number of methodologies to set accessibility indicators (see Section 1), in this paper, the authors aim at measuring commuters' accessibility of each municipal town of Sardinia adopting two indicators designed according to a travel cost model and a spatial interaction model.

In this case, the authors propose an integration of the widely adopted indicators reported above by introducing a more reliable measure of the spatial impedance to commuting from a town to another. Spatial impedance to movement is estimated invoking the concept of shortest road path connecting couples of towns that exchange commuters. The measure of this length is obtained applying CNA to the study of the spatial properties of the inter-municipal commuting system of Sardinia, as reported in Section 2. The same measure has been performed through an advanced GIS-based analysis of the commuter network starting from the inspection of the spatial properties of the whole road infrastructure system of Sardinia. The choice of this proxy depends on the evidence that daily travellers -such as commuters- experience strategies to minimize costs and usually adopt shortest path connections to reach their habitual work or study place. In Table 1, the statistical properties of the shortest road distance are reported and confronted to the case of the Euclidean distance among municipalities. It is worth noting that on average the shortest path connection between two towns in Sardinia is much (around 1.4 times) higher than the corresponding Euclidean distance. This is a sign of an overall tortuousness of the Sardinian road network that still needs to be renovated and redesigned.

Table 1. Shortest road path versus Euclidean distance: statistical properties (measures in kilometers)

Distance measures	Min	Max	Mean	Standard deviation
Shortest road path length	0.95	318.5	53.8	40.8
Euclidean distance	0.7	237	38.5	29.9

In the reminder of this section, the accessibility indicators are described.

The first indicators belongs to the travel cost family of accessibility measures. It allows assessing the level of accessibility to places for commuters by considering the composite effect of the friction to movement caused by distance. Thus, the travel cost model based accessibility obeys to the following equation:

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$$A_i{}^{TC} = \sum_{j \in v(i)} \frac{1}{d_{ij}}$$

(1)

where A_i stands for the accessibility level of the municipal town i, TC for travel cost, $v(i)$ for the set of first neighbour towns of the municipality i and d_{ij} is the shortest road distance between the municipality i and its first neighbour municipalities j. It is worth recalling that this indicator provides the analyst with a measure of commuter accessibility at the level of local basin constituted by the topologically nearest towns to a given municipality i.

The second indicator belongs to the family of spatial interaction model based accessibility measures. According to this measure, accessibility assessment is referred to the behavioural aspects of travel, as in this spatial interaction model the number of trips between each pair of municipalities is estimated invoking the concept of potential of opportunities offered in the same towns. Similar definitions have been given by Stewart and Warntz (1958) about the traditional geographical systems measure of potential population, which is a central component in the definition of competition in spatial interaction models (Jiang et al, 1999).

This accessibility indicator may be interpreted as an evolution of the first presented above, as it is designed as well to take into account the effect of friction to movement caused by physical distance.

In this paper, spatial interaction model (SIM) based accessibility indicator obeys to the following rule:

$$A_i{}^{SIM} = \sum_j \frac{D_j}{f(d_{ij})} + \frac{D_i}{f(d_{ii})}$$

(2)

where $A_i{}^{SIM}$ stands for accessibility based on spatial interaction model to the municipality i, SIM for spatial interaction model, D_j for the total amount of commuters that travel from town i to town j (inter-municipal commuting), D_i for the total amount of commuters that travel within the same municipality i (intra-municipal commuting), and $f(d_{ij})$ or $f(d_{ii})$ for the impedance function.

In this formulation, the contribution of the intra municipal commuting is modelled by taking into account also the impedance function of the average distance of commuting trip within the urban area. The contribution of intra-municipal commuting to accessibility level has been obtained by hypothesizing the pattern of values of the average intra-municipal commuting distance within each town of the system. This variable has been studied and confronted with the evidence reported in the literature (Pocock, 1978; Mondschein, 2010). As Table 2 shows, the average commuting distance assumed in this study varies discontinuously with the demographic size of the town.

Table 2. Intra-municipal commuting distance versus population of Sardinian towns

Municipal population ranges	Average intra-municipal commuting distance [Km]
0 - 999	1
1,000 - 4,999	2
5,000 – 14,999	3
15,000 – 39,999	4
40,000 – 200,000	5

The impedance function is assessed by calibrating the model with respect to its fitness to a power and an exponential form.

In order to obtain the relevant coefficient of the model, the following expression has been calibrated:

$$T_{ij} = KO_iD_jf(d_{ij}) + K(O_i)^2 f(d_{ij}) \qquad (3)$$

where T_{ij} stands for the number of commuters between town i and town j, K for a spatial interaction constant, and O_i for the total amount of commuters leaving town i.

The impedance function is assessed in two forms indicated as follows:

$$f_p(d_{ij}) = d_{ij}^{\beta} \qquad (4)$$

$$f_e(d_{ij}) = e^{\beta d_{ij}} \qquad (5)$$

where $f_p(d_{ij})$ stands for the power law, and $f_e(d_{ij})$ for the exponential form, ß for the impedance to movement, i.e. an empirical constant representing the inhibiting effect of distance, and d_{ij} for the shortest road distance between towns i and j, like for the case of the travel cost based accessibility indicator.

While the first accessibility indicator A^{TC}_i is suitable to picture accessibility for commuters at the level of local clusters of first neighbour centres, the second accessibility indicator A^{SIM}_i is ideal to describe the level of accessibility of a single municipality taking to account the overall average behaviour of commuters travelling throughout the whole road infrastructure of Sardinia.

4. Results and interpretation

In this section, the results of the study are reported and commented.

In the case of the first accessibility indicator (A^{TC}_i), the availability of the input data on shortest road path length (Campagna et al, 2007) has enabled the authors to obtain directly the values described by of equation (1).

In the case of the second accessibility indicator (A^{SIM}_i), an unconstrained spatial interaction model has been considered and a calibration has been performed in order to appraise the parameters K and β in equations (3), (4), and (5). This process has been based on the resolution of an over determined linear system, where K and β are the unknown variables and O_i, D_j, d_{ij}, and d_{ii} are the known terms. In Table 2, the statistics of the calibration of the unconstrained spatial interaction models is reported for both the impedance function forms detailed in equation (4) and (5).

Table 3. Unconstrained SIM models: statistics of the calibration

Impedance function form	Parameter	Value	T-stat	Adjusted R²
Exponential	Log K	-6.42	-152,85	0.72
	ß	0.04	77,71	
Power law	Log K	1.44	-74,98	0.77
	ß	-3.55	98,250	

In Table 4, the top ten towns of Sardinia are reported according to the accessibility measures proposed and to their economic performance measured by means of the average household income (AHI). The AHI is available in a recent study (Regione Autonoma della Sardegna and Dipartimento di Ricerche Economiche e Sociali, 2009), where an analysis of the 2006 income-tax returns has been developed.

Table 4. Ranking of Sardinian municipalities by their commuters' accessibility and AHI

Rank	A^{TC}	A^{SIM}		AHI
		Exponential form	Power form	
1	Arzana	Cagliari	Monserrato	Sarroch
2	Elini	Monserrato	Selargius	Nuoro
3	Oristano	Elmas	Elmas	Elmas
4	Cagliari	Selargius	Cagliari	Capoterra
5	Ghilarza	Sestu	Sestu	Portoscuso
6	Selargius	Assemini	Sassari	Selargius
7	Ales	Settimo S. Pietro	Settimo S. Pietro	Cagliari
8	Abbasanta	Capoterra	Assemini	Sassari
9	Macomer	Sassari	Quartucciu	Decimomannu
10	Assemini	Quartu S. Elena	Oristano	Oristano

Cagliari, the capital town of Sardinia, is at the top, only according to the accessibility indicator A^{SIM} in its exponential form (now on A_e^{SIM}), while just at the fourth position, according to the accessibility indicator A^{TC} and to the accessibility indicator A^{SIM} in its power form (now on A_p^{SIM}), and at the seventh position of the "richest" (with highest AHI) centres in the Island. Sassari, the historically second most important town in Sardinia, is ninth, according to A_e^{SIM}, and sixth according to A_p^{SIM}, while being the eighth "richest" town. It is also interesting to note that nine towns, in the A_e^{SIM} ranking, and eight towns, in the A_p^{SIM} ranking, belong to the metropolitan area of Cagliari. By contrast, the same metropolitan area comprehends only five richest towns and only three top scorer towns in the A^{TC} ranking. This is confirmed also in general terms by the analysis of the interplay between economic performance and accessibility indicators described in Figure 5 and in Table 5. It is possible to see that municipalities with a higher accessibility – measured in whatever form- display a higher AHI. The scatter plots reported in Figure 5 give a clear idea of a higher dispersion in the case of AHI versus A^{TC}.

A positive correlation can be detected between accessibility indicators and AHI. In addition, A^{TC} correlates versus AHI with a much lower intensity that versus spatial interaction model based indicators (see Table 5).

In figure 2, a geographical analysis of both the accessibility models is reported. These pictures allow observing the pattern of the accessibility values in a synthetic and general view. In figure 3, the spatial distribution of the municipal AHI is reported.

Table 5. Coefficients of correlation between AHI and the different accessibility indicators .

	AHI
A^{TC}	0.15
A_e^{SIM}	0.50
A_p^{SIM}	0.49

The map of the accessibility indicator A^{TC} indicates that towns with a fairly high level of accessibility are located especially in the Campidano, which is a very important plain connecting Cagliari to Oristano, a provincial capital town located in the mid-western coast of the Island. In the Campidano, the main road infrastructure of Sardinia, the National Road n. 131, connects Cagliari to Sassari, beyond other major towns. Another important road infrastructure is National Road n. 130 that connects the metropolitan area of Cagliari and the Campidano to the Iglesiente in south-western Sardinia, one of the main industrial and productive areas of the Island (see Figure 4). The spatial pattern of the indicator A^{TC} describes a tendency of western towns to be slightly more accessible than eastern.

The maps of the second accessibility indicators A^{SIM} overall concord each other, while presenting some differences with respect to the picture conveyed by the travel cost indicator A^{TC}. As introduced above, both the indicators A_e^{SIM} and A_p^{SIM} show a spatial pattern where the two main towns of Cagliari and Sassari emerge as regional accessibility centres and the municipalities belonging to the metropolitan area of Cagliari constitute a community of highly accessible towns. According to the specific modelling details presented in Section 3, this general pattern is described in different way: in the case of A_p^{SIM}, two poles are eventually identified in the centre of Cagliari and Sassari displaying quite higher accessibility values with respect even to close municipalities; in the case of A_e^{SIM}, the leading position of those two towns is shared in a less polarized pattern with other first and often second neighbour centres belonging to highly accessible sub regional basins.

These partial dissimilarities are confirmed by the values of the coefficient of correlation reported in Table 6. As expected, the accessibility indicators A^{SIM} are strongly and positively correlated. By contrast, they display a weak positive correlation with respect to the accessibility indicator A^{TC}.

Table 6. Coefficient of correlation between the accessibility indicators.

	A^{TC}	A_e^{SIM}
A_e^{SIM}	0.46	
A_p^{SIM}	0.47	0.89

It is worthwhile confronting these results with relevant demographic elements reported in Figure 6 and described as follows.

The population of Sardinia is about 1.6 million (2.8% of the total Italian population). Cagliari, the capital town of Sardinia, has a resident population equal to 160000 inhabitants, while its metropolitan area hosts about 47% of the total population of the Island.
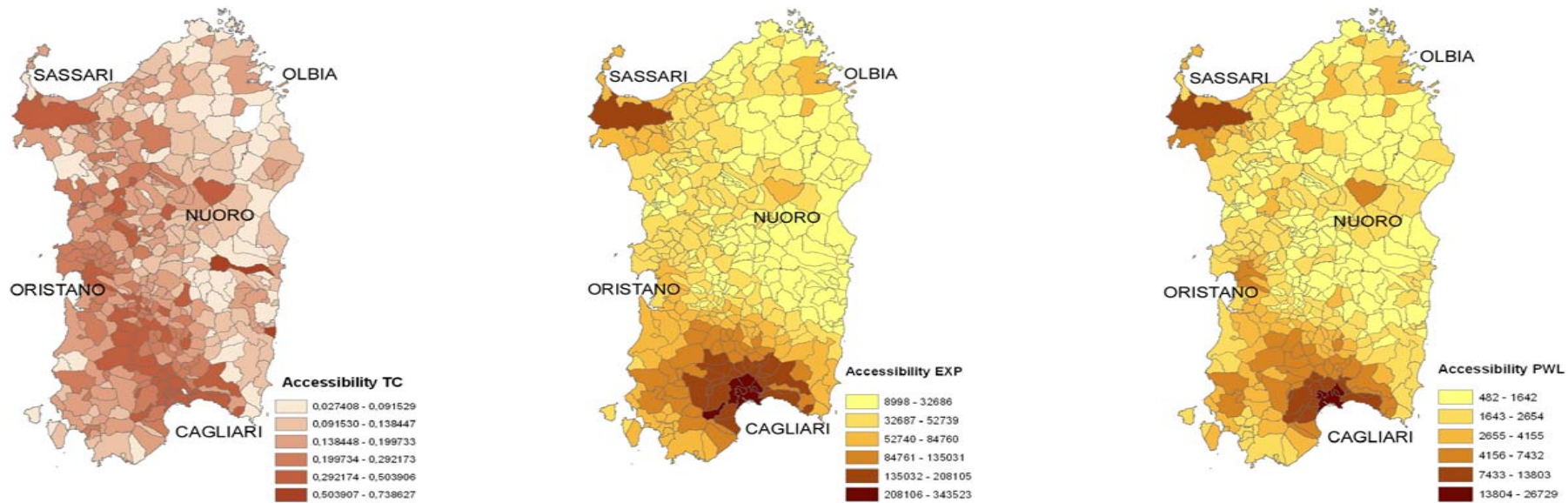
Figure 2. Maps of accessibility for commuters to municipalities of Sardinia, according to the travel cost approach (on the left), and to the spatial interaction model with impedance function in exponential (on the middle) and power (on the right) form.
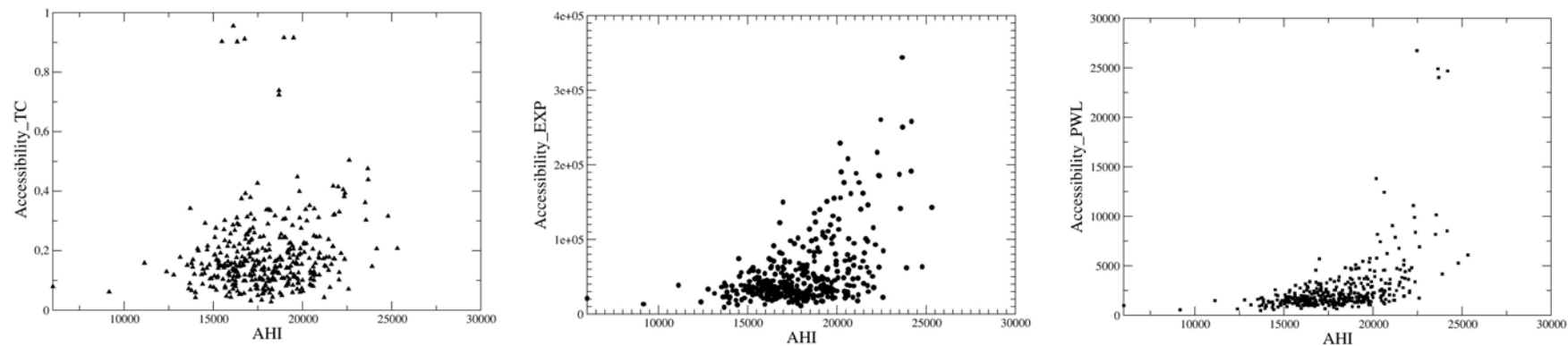

Figure 5. Scatter plot of accessibility indicators versus municipal AHI, in the case of approaches based on travel cost (on the left), and on spatial interaction models with impedance function in exponential (on the middle) and power (on the right) form.
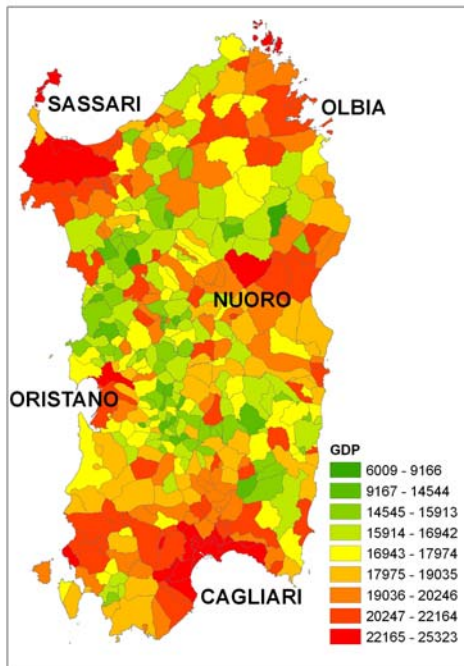
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Figure 3. Spatial distribution of municipal average household income (AHI).

Source: Regione Autonoma della Sardegna and Dipartimento di Ricerche Economiche e Sociali (2009).

Figure 4. 3D Visualization of the main road infrastructures of Sardinia over the regional Digital Elevation Model: National Road n. 131 (in red) and n. 130 (in violet).
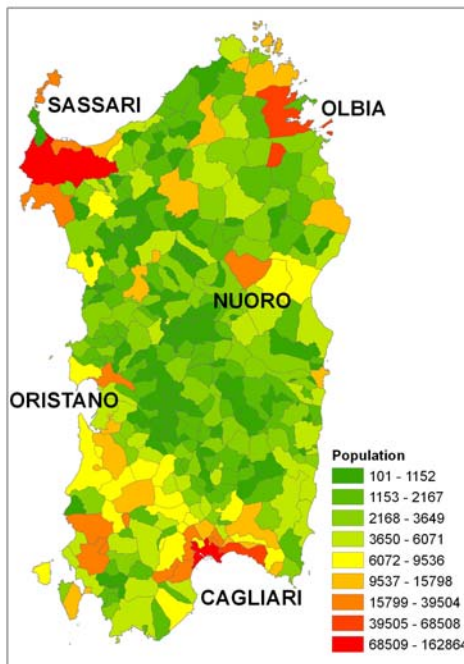
Source: Centro Interregionale (2007).

Figure 6. Spatial distribution of municipal resident population.

Source: Istat (2001).

The administration of Sardinia is organized in eight provinces, which correspond fairly to local systems of workforce: the richest municipalities are often provincial capital town, such as, beyond Cagliari and Sassari, Oristano, Olbia, and Nuoro. The distribution of municipal AHI reflects also the evidence that in Sardinia population and productive activities concentrate mostly on the coast line.

According to recent census analyses, Sardinian population polarizes into only 14 municipalities that have got more than 20000 inhabitants and totally host 42% of the whole resident population of Sardinia. About 43% of the same resident population lives in 239 medium-low size towns (1000-10000 inhabitants), while the remaining population lives in small villages sizing less than 1000 inhabitants.

5. Conclusions

In this paper, the authors integrate complex network analysis (CNA) with accessibility modelling by developing two indicators of accessibility for commuters moving on the road system of Sardinia, the second largest island of Italy.

The integration consists in the adoption of a measure obtained through spatial CNA – i.e. the variable describing shortest road distances between pairs of Sardinian municipalities exchanging commuters- as a relevant input for the construction of accessibility indicators expressed as functions of the same distance.

These indicators are referred to i) a simple travel cost model where the impedance to movement is described as a linear function of the shortest road distance (A^{TC}); ii) a spatial interaction model where impedance to movement is conceived as a function of the shortest road distance in exponential and power form (A^{SIM}).

In this research work, the accessibility indicators obtained offer interesting results on the hierarchy of Sardinian municipalities, with respect to the actual commuter flows. The indicators are also confronted each other and commented, with respect to the relevant road infrastructure and municipal socio-economic hierarchy.

A few final remarks are reported as follows.

In a first instance, in this paper the integration between CNA and accessibility analysis is performed in an approach, where an outcome of CNA over the road system of Sardinia –i.e. shortest road inter-municipal distances- is processed as input of accessibility modelling. In addition, in this case a spatial CNA has been performed through a GIS analysis of all the possible road paths connecting towns that exchange commuters. Commuting implies movements that are usually repeated daily and very likely subjected, even unconsciously, to space and time minimization strategies. This reason leads to choosing shortest road distances instead of just Euclidean distances often adopted in the literature. Hence, the impedance function -a very important element of the accessibility indicators studied in this paper- whatever the mathematical form adopted, is a reliable measure of the friction commuters perceive when moving through the actual road system of Sardinia.

Secondly, the accessibility indicators offer a hierarchy of municipalities that overall matches the pattern of spatial distribution of AHI in Sardinia. This evidence conveys a confirmation that an higher economic performance is sustained by a wider labour force and employment, which in turn leads to a higher number of commuters being involved. In particular, the correspondence accessibility versus economic performance is evident when spatial interaction model based indicators (A_e^{SIM} and A_p^{SIM}) are considered. In this perspective, the evidence of this research

suggest that these indicators are more reliable as better picturing the actual productive system of municipalities in Sardinia.

In third instance, the accessibility indicators studied in this paper do not supply the same information. Spatial interaction model based indicators (A_e^{SIM} and A_p^{SIM}) show a positive and strong correlation with each other, while they both are correlated positively but weakly with respect to the travel cost accessibility indicator (A^{TC}). According to this indicator, the municipalities located in the western part of the Island and in the neighbourhood of National Road 131 –i.e. the principal and backbone connection of Sardinia- are more accessible to commuters with respect to the other eastern municipalities. By contrast, spatial interaction model based indicators (A_e^{SIM} and A_p^{SIM}) emphasize, despite of the spatial details due to the different impedance function forms adopted, a leading role of the capital town Cagliari with its wide metropolitan area. The differences in modelling imply clearly different concepts and have a paramount relevance, which should always be taken into account when choosing these indicators to provide information supporting decision-making and planning over the infrastructure system of the whole Island of Sardinia.

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