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Mapping Time-Varying Accessibility and Territorial Cohesion With Time-Distorted Maps

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ABSTRACT Human societies have radically changed from the second half of the 20th century. Urban areas are increasingly concentrating more people and economic activities. Connections between market economies in different regions have increased exponentially the flow of people and goods at a global level. These movements are spatially organized through a hierarchical transportation network that connects different areas. The quality and coverage of such network vary greatly across regions. Territorial cohesion and accessibility within a region could be roughly evaluated through the existing level of connectivity between urban nodes. This can be easily done by estimating travel times between different points in the territory, which would show relevant differences based on both the territory itself and the existing infrastructure. Unfortunately, this information is not typically shown in traditional maps. In this paper, we propose a novel methodology for assessing the degree of territorial accessibility within and across urban networks, by using time-distorted maps. To this end, we consider multiple scenarios related to different public transport modes and times of the day. The study area corresponds to a Spanish region, where we set up a relatively extended network by considering its most relevant cities and towns. Final maps can clearly illustrate the deficiencies in transport infrastructure and/or connections from a spatial perspective. These maps can be excellent tools for supporting technicians, politicians, public managers, and other stakeholders in the decision-making process.

INDEX TERMS (Time varying) accessibility, geographic information systems, territorial cohesion, time distorted maps, transport geography, travel-time maps.

I. INTRODUCTION

Global transport flows have rapidly increased in the last halfcentury, mostly due to the increased levels of urbanization and the democratization of private cars, among other factors. As a result, there is a real need for new strategies to address the challenges created by the exponential increase in mobility rates.

One of the main policy objectives of governmental authorities is the *sustainable development* of their regions. It not only refers to the balanced exploitation of resources but also to the well-adjusted progress across the different areas within a territory. In addition, this concept inherently includes principles such as spatial*convergence* and *cohesion*, both from a social and an economic perspective. For this reason, the development of any region must consider the evolution of the lowest administrative units, in addition to enhancing the relationship between them. Unfortunately, the perverse effects generated by developing societies can break down cohesion and increase the segregation, especially in the context of an economic crisis [1]. To address this, governmental authorities are proposing policies and initiatives to avoid, or at least reduce,the current social and territorial inequalities.

The process for the establishment of the *European Union* (EU) has been, for example, one of the most ambitious programsin the last decades on territorial cohesion [2]. Since its beginning, countries with vastly differing levels of wealth were merged in a single European market. To do so, EU authorities implemented different policies, initiatives, and mechanisms such as the ''European Territorial Strategy'' [3],

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and the successive "European Territorial Agenda(s)" [4], [5]. All of them considered the *territorial dimension*as one of the most relevant factors for their social policies [6].

Given that transportation infrastructure is the backbone of any territory, its spatial layout, design, development, and management can contribute to the spatial distribution of human settlements and the economic activities between them. Therefore, transportationinfrastructureshould not be designed and configured based exclusively on supply and demand factors. In the case of the EU, for example, Ramos Pérez [7] argues that its development should be part of a social and institutional project for reinforcing the economic and social cohesion between the different regions. In fact, the *Trans-European Transport Network* (TEN-T) was originally designed as a mechanism for reducing territorial imbalances between different regions [8]–[10].

There is a widespread perception that transportation infrastructure generates wealth [11], [12]. Experts argue that transportation infrastructure can increase the levels of productivity and competitiveness by enabling mobility andreducing transport costs, i.e. more accessibility is normally linked to higher levels of economic development [13]. In the short term, building new infrastructure can generate new jobs, while in the medium to long term this infrastructure can increase the levels of accessibility, competitiveness, and employment within a region [14], while further increasing the demand.

In particular, there is some literature assessing the regional impact of transportation infrastructure by relating *accessibility*and *territorial cohesion* [15], [16]. The degree of accessibility is a relevant parameter fordetermining equality in the access opportunities to the labor market according to where people live and/or work. In general, the *accessibility*concept refers to the ability to reach desired goods, services, activities and destinations, which is the ultimate goal of most transportation systems [17]. However, the*actual accessibility*is relatively difficult to measure, as it depends on multiple factors related to time, money, discomfort and risk, among others [18]. Thus, many studies use*activity-based travel models*and *integrated transportation/land use models*to estimate accessibility parameters and link them to transportation infrastructure [19]. Nevertheless, some researchers argue that theterm has been rarely translated into performance measures by which policies must be evaluated [20]. More recent studies have tried to develop some quantitative indicators for measuring existing levels of accessibility [21], [22] focusing on extensive areas, such as whole countries or even the whole EU [23]–[26].

Within the EU context specifically, some studies argue that the TEN-T has mainly favored the development in central regions, whereas it tends to perpetuate imbalances in peripheral regions [27], [13]. Fürst *et al.* [28] consider that investing on transportation infrastructure is not enough for overcoming the negative socio-economic dynamics that exist in some regions. Other studies argue that most of the EU transport policies are focused on spatial patterns that mainly connect the territory from center to periphery, while the connectivity between areas located in the periphery remains extremely low. In addition, the design of the TEN-T is mostly based on connections between urban nodes with high capacity corridors, neglecting the role of minor networks, and generating significant empty spaces in between [7].

This article proposesa new methodologyfor estimating the degree of territorial cohesion by evaluating the physical accessibility to different areas within a region. To this end, we analyze the minimum travel time between a relatively dense and spatially well-distributed *network*, which includes the most representative urban nodeswithin a region.

We will focus on a concrete case study of the public transport system at three different times of day (i.e.*time-varying accessibility*). In addition, and in contrast to previous studies that focus on very large regions, the spatial scale of the analysis is much more compact, allowing us to include a higher level of detail. We then present the results using*time distorted maps,*in which distances between nodes represent the actual travel times between them. In addition, levels of distortion of these maps are quantified, showing the magnitude of the inefficiencies across areas and time of day. This article is structured as follows. Section II introduces the study area, while the methodology is explained in section III. Results are shown in section IV. Analysis and discussion of resultsare compiled in section V. Section VI summarizes the most relevant insights.

II. STUDY AREA

The case study focuses on the region of Galicia, located in the northwest of Spain (Figure 1). This region covers an area of 29,574 km^2 and has 2,732,347 inhabitants [29]. Both, its surface and population represent about 5.8% of the total surface and population of Spain. Thus, its population density is similar to the national average, with around 92 inhabitants per km^2.

This general data hides large internal disparities. For example, the spatial pattern of human settlements in Galicia is characterized by high levels of dispersion and fragmentation [30]. In fact, there are 27,312 human settlements in the region, more than half of the Spanish total number of settlements [31].

The population spatial distribution stems from a polycentric system of seven main cities: Ferrol, A Coruña, Santiago, Pontevedra, Vigo, Lugo, and Ourense. Five of these cities are located on the *Atlantic Corridor*, which concentrates most of the economic and socio-demographic activities (Figures 2.a and 3.b). A Coruña and Vigo are the most populated cities, each with about 250,000 inhabitants. The population of the other main cities is between 75,000 and 100,000 inhabitants. Since the last quarter of the 20th century, a significant number of settlements surrounding these main cities have increased their population substantially. The rest of the region is organizedbased on a group of *head towns*, which behave as small cities that concentrate most of the economic activities of their respective areas. From a quantitative perspective,

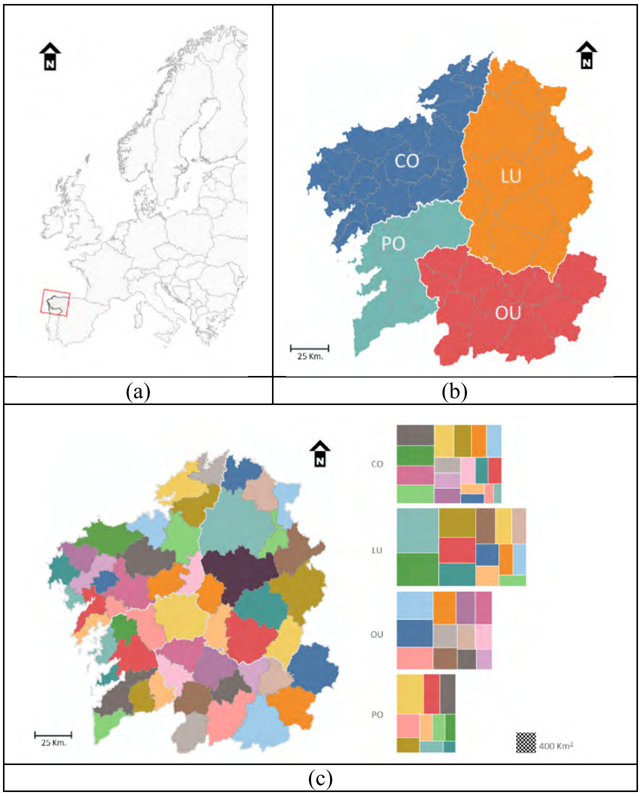

FIGURE 1. (a) Location of Galician region within Europe. (b; c) Its administrative structure comprises four provinces (A Coruña –CO–, Lugo –LU–, Ourense –OU– and Pontevedra –PO–)and 53 counties. (c) Mapping of these counties within the region and representation based on treemaps. Theseshow the county areas by means of rectangular polygons corresponding to their size. Color legend is the same for both maps shown in (c).

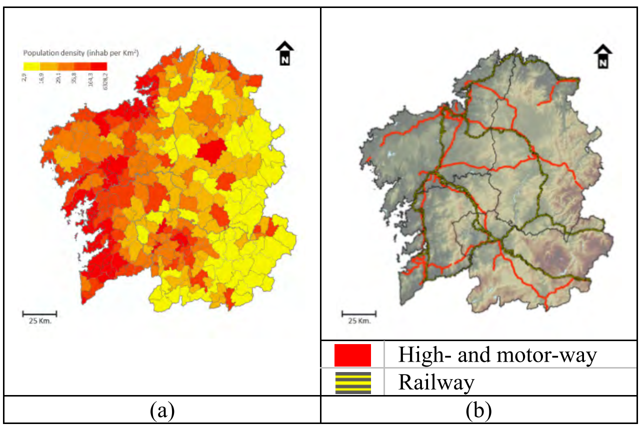

FIGURE 2. (a) Population density in Galicia. (b) Most important road and railway infrastructure overlaid on the topography.

the spatial pattern of population distribution is characterized by the quasi-generalized absence of urban nodes with population levels in the interval between 25,000 and 75,000 inhabitants.

Low population densities normally require high investments *per capita* for the development of a proper transportation infrastructure (Figure 2.b). In addition, there exist other constraints such as the hilly orography in the eastern-southeastern areas of the region, besides the fact that Galicia is in the periphery of Spain. Therefore, to reach an optimal level of regional development and to avoid social exclusion dynamics in some areas, extra efforts and investments must be made to ensure adequate levels of territorial accessibility across the whole region [32].

III. METHODOLOGY

Our proposed methodology consist of fivedifferent steps-geared towards the creation and design of a network, which is ultimately used to spatially deform the whole region based on travel times. The methodology is explained in detail below.

A. CREATION OF THE INITIAL NETWORK

A number of well distributed nodes across the whole region is required for setting up the initial network. To this end, we analyze the distribution of the most populated (and relevant) cities/towns by considering all the administrative and political sub-divisions within the region. Ultimately, we need to reach the best compromise between an optimal density and a well-spread distribution of nodes within this region. As [1] proposed, we select the *counties* as the best territorial unit for the study goals proposed here. In fact, and despite not having currently any significant political or administrative competences, this territorial entity is relevant because it is based on the aggregation of municipalities that show similarities both from a physical and socio-economic perspective.

The region of Galicia includes 53 counties that are distributed in four provinces (Figure 1.c). For each county, we select the most populated node. We then implement a network based on these nodes, taking into account the spatial distribution of population within the region.

Next, one of the nodes is arbitrarily assigned as the *reference*or *central node*. This node will act as a traffic source, while the other nodes will act as the destinations. In this study, the city of *Santiago de Compostela*is assigned the central node because of two main reasons: (a) its central location in relation to the other nodes, and (b) for being the political capital of this region.

The implemented networkcan connect each destination node to the source (central node) by means of direct links. This generates a theoretical network with 53 nodes and 52 links, shown in Figure 3.a. In practice, however, theactual traffic flows are hierarchically organizedwithin the region depending on the relevance of the nodes, with the most populated nodes often acting as intermediate destinations or transit nodes towards to smaller ones.

B. ESTIMATION OF TRAVEL TIMES AND DISTORTED DISTANCES BETWEEN NODES

To complete an *Origin-Destination vector*, we have to estimate travel times from the origin (central node) to the different destinations (rest of nodes). To do so, we used some API tools for retrieving travel data from web-based applications [33], [34]. Additionally, we double-checked the travel

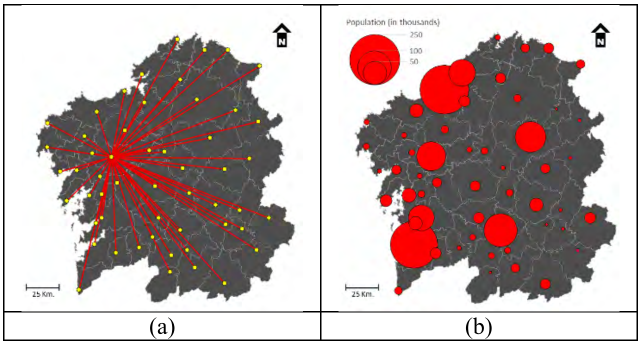

FIGURE 3. **(a) Point distribution and theoretical network. (b) Circle size refers to the total population in each node [34].**

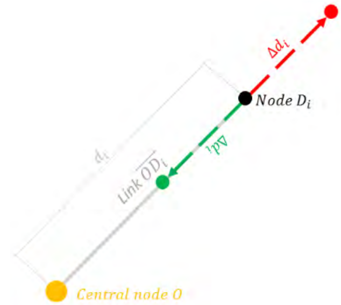

FIGURE 4. **Parameters for the estimation of distortion rate (R_i) based on the Euclidean distance (d_i) and the distortion of this distance ($\pm\Delta d_i$). Final node location will be closer/fartherto/from the central node depending on the relation between V_i and V_{ref}.**

times associated with different transportation alternatives for specific destinations withthe official timetables published by the public transport companies. If more than one route per origin-destination pair was available, the one with the lowest time was selected.

Travel times were only estimated for public transport systems, including buses and/or railways at three different times of day[1]: (a) 08:00 am, (b) 04:00 pm, (c) 00:00 am. Depending on whether transfer and/or waiting times were considered, travel times showed significant differences. Thus, we decided to establish two scenarios: (a) the *actual*, and (b) the *effective*. In the *actual scenario* (henceforth AS) we refer to the total time that it is required for displacing between two nodes. In the *effective scenario* (henceforth ES) we only consider the time that the user is properly moving, while transfer times are excluded.

To estimate the travel speed between the central node and each destination node $i(V_i)$, we use the actual travel time and the Euclidean distance between both nodes.We then assume the same reference speed(V_{ref}) for all the links, so most of the nodes get displaced from their current location. This displacement is realized along the vector ($\vec{OD_i}$) that links each node (D_i) with the fixed, central one (O). Depending on whether the estimated speed value is slower or faster than the reference speed, the destination node is shifted away from or towards to the central node, respectively. Thus, in the case $V_i > V_{ref}$, the node D_i tends to be closer to the central node O, whereas if $V_i < V_{ref}$ the node D_i will move away, creating a distorted network. In this study, we assume anarbitrary *reference speed* for each scenario: 25 and 50 km/h for AS and ES, respectively.

C. COMPUTATION OF DISTORTION RATIOS

After that, we estimate a parameter based on the speed value and Euclidean distance for each node. This parameter, which is called *distortion rate*(R_i), represents how much a link is distorted with respect to the distance traveled:

$$R_i = \Delta d_i / d_i \tag{1}$$

where Δd_i is the difference with regard to the original length of the link (d_i). Note that R_i can be positive or negative depending on the speed value (V_i). Thus, R_i is positive if $V_i < V_{ref}$ and is negative when $V_i > V_{ref}$. Notice that in all cases R_i is a function on d_i (Figure 4).

D. INTERPOLATION TO THE WHOLE REGION

Values from the individual nodescan be interpolated to the whole region with two different procedures. The first one is based on a planimetric deformation of the polygon that represents the whole region. For this, we use the software *Darcy 2.2* in addition to GIS software tools. *Darcy* allows the distortion of (polygonal) geometries based on input points by using different transformation models [35]. Our modelincludes an adjustment prior to the interpolation, which uses the *Euclidean bidimensional regression* [36]. The main equation for this transformation model is given by

$$\left(X^T Y^T\right) = \alpha + \beta \cdot (AB) \tag{2}$$

where A and B are the independent coordinates, while X and Y are the dependent ones. This model is based on a *least squares adjustment*, which uses input parameters α and β. These parameters describevariations on factors of translation and scale between the original system and the final solution. These adjustments can warp the territory by applying stretching and/or shrinkage modifications in some areas depending on the location of the input points. Results show distorted polygon geometries, which canbe downloaded in avectorial format.

The second procedure is based on the deformation of *Z-values*by applying an interpolation algorithm. This allows to estimate values for the whole region by adding node values and distances in between. For this, we apply a method based on the algorithm *Inverse Distance Weighting*(IDW)by using GIS tools. Input parameters for this algorithm are the values and size of cells within a raster model, in addition to the number of nodes that are usedfor computing those values. In our case, we assign a cell size of 100 meters. This cell size is sufficiently small for achieving high spatial resolution

[1] Travel times wereestimatedforthesameday:Tuesday, July 07^{th} 2018 (workingday).

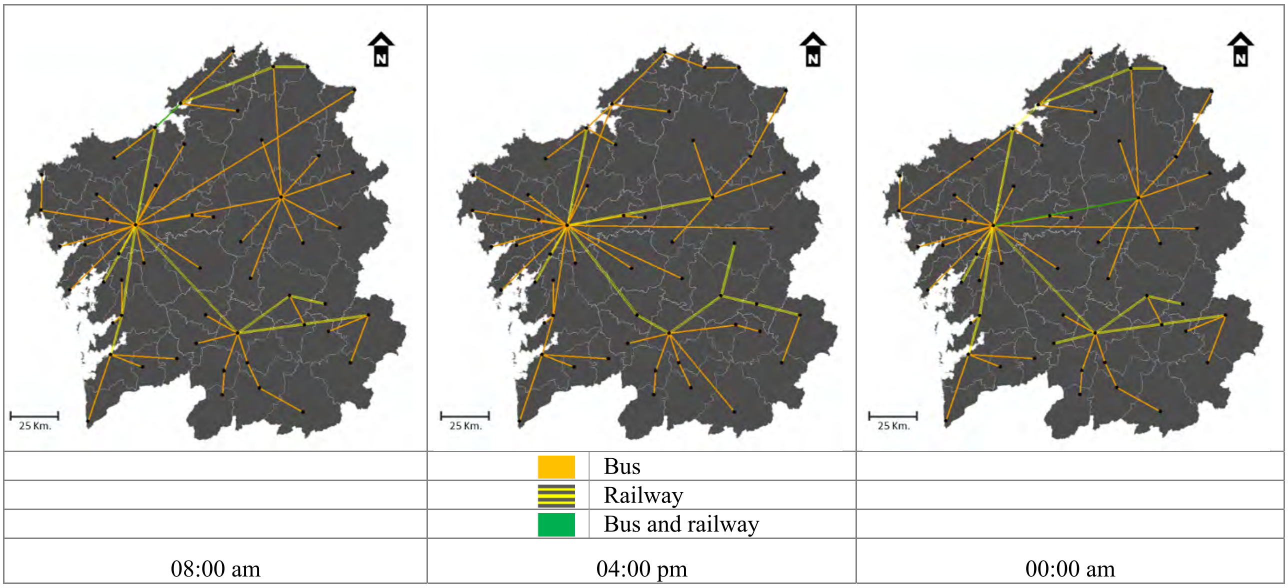

FIGURE 5. **Most efficient connections for traveling from the central node to the other ones at three different time periods: 08:00 am, 04:00 pm, and 00:00 am. The color of the links represents the most efficient transport modes for each route.**

within our study area, yet large enough to keep the problem computationally efficient. The number of nodes used for the interpolation algorithm is four. This number allows us to consider the influence of the nearest neighboring nodes located in any direction. In addition, since the method used is based on the IDW algorithm, the influence of these nodes largely depends on the distance betweenthem.Results are raster maps where a discrete valueis attached to each cell.

E. QUANTITATIVE ANALYSIS

Here we can evaluate how speed values relate to factors such as physical distance and population in each time periodand/or scenario. In addition, the distortion effect is quantified by means of *treemaps*. These charts allow us to compare distribution patterns for different scales.

In short, the methodology proposed here is more exhaustive than the ones shown in Balsa-Barreiro *et al.* [37]–[39], incorporating among other things an extended network, which is better distributed across the region, allowing us to study the time-varying accessibility and perform an exhaustive quantitative analysisof the current accessibility in this region.

IV. RESULTS

After collecting all the data, for each link we select the best connections and transportationalternatives in terms of travel time. These connections are traced in maps, showing different route configurations for each time period. We can observe in Figure 5 a polycentric system where nodes are organized on different levels depending on the number of connections with other nodes. Links between nodestend to be organizedalso hierarchically, originating from the most important urban nodes. Notice that these networks are different from the theoretical one shown in Figure 3.a. The color of the links represents the most efficient transport modes for each route at each time period.

Times required for traveling between nodes are shown in Figure 6. The size of each node[2] represents the actual travel time (scenario AS) required to reacheach node.

We now explore if there is any correlation between distance traveled and average speed. Figure 7 shows for different scenarios and time periodsthe level of correlation between Euclidean distances (X-axis) and travel times (Y-axis). The node size represents the total population while the node color refers to each province.[3] As we can observe, no correlation is apparent between distance traveled and average speed for any scenario, except for AS at 00:00 am. In this case, we observe that the most distant points tend to show higher average speeds.

Most populated cities, represented by the largest circles, are all located between 50 and 75 km apart from the central node. These cities tend to show the best connectivity across most scenarios and time periods, with it being more clearly visible for the ES scenario.

The graycolored area in the background shows the reference speed for each scenario, i.e. 25 km/h in AS and 50 km/h in ES. We can see how a large number of nodes have speeds lower than the reference values. In particular, we can see that all the connections from 0:00 h (AS), without exception, have lower speeds than the reference value. Also, we can observe that the speeds for most cities during the 04:00 pm and 00:00 am time periods are hardly higher than the threshold

[2]The size scale is the same for 08:00 am and 04:00 pm, butnot for 00:00 am.

[3]The colorforeachprovince in this chart and in followingonesisthesamethattheinitiallyshown in Figure 1.b.

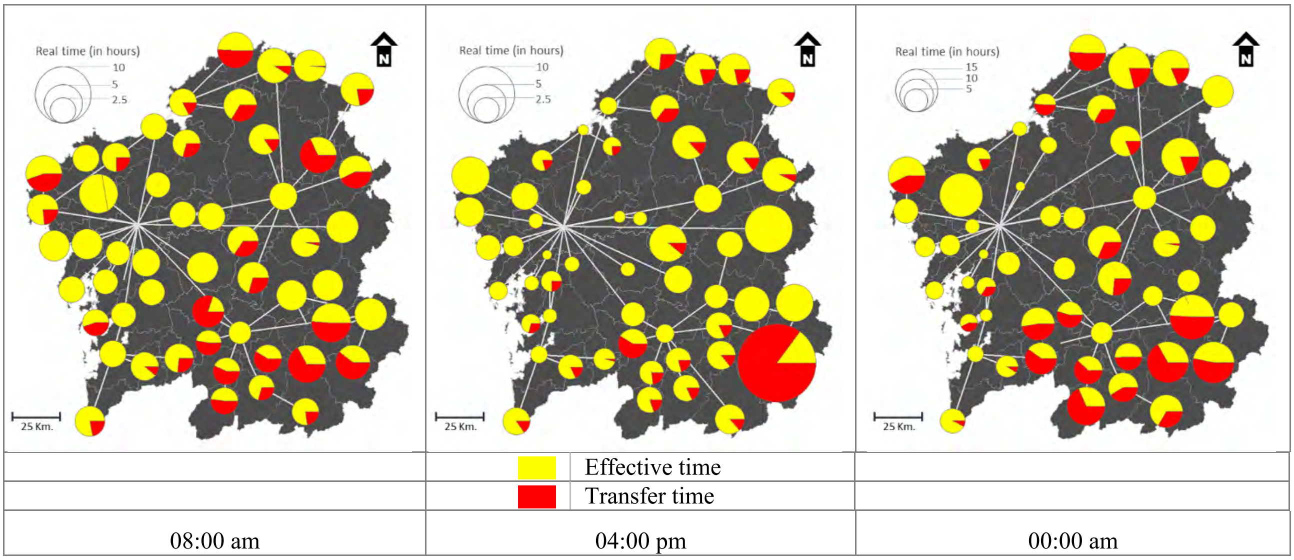

FIGURE 6. Time required for traveling from the central node to the other ones at different time periods. The circle size is related to the total travel time that is required (AS). The yellow color shows the effective travel time (ES), and red color shows the transfer time required between transport modeswhen appropriate.

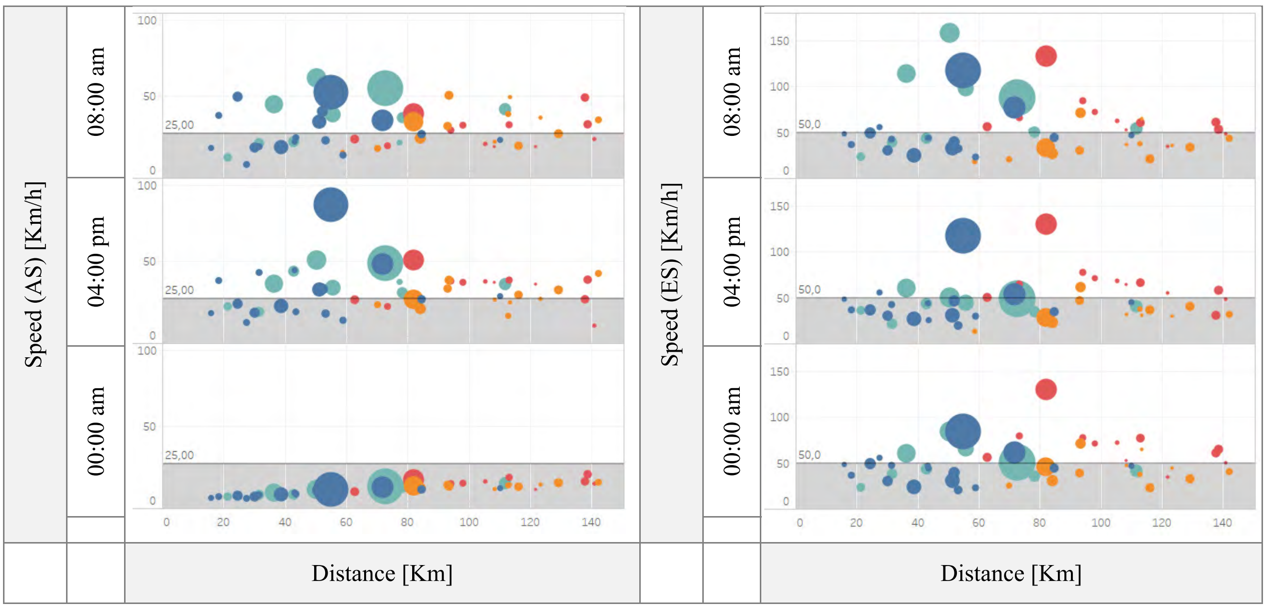

FIGURE 7. Correlation between distances and speed values for each scenario at different time periods.

(considering the ES scenario). This could partly be related to the choice of threshold values.

Figure 8 shows the degree of correlation between speed values for each scenario and time period. Here, the X-axis represents speed values for ES, while the Y-axis represents speed values for AS. The units of both axes are normalizedfor comparability. Trend lines show the degree of correlation by provinces, which are plotted in different colors. If no transfers were necessary, each node would be located on the diagonal of this chart. However, lines below and over the diagonal are apparent. At 08:00 am, we see a cluster with the main cities, showing relatively high-speed values in both scenarios. For the other two time periods(04:00 pm and 00:00 am), thispattern is not so clear. At 0:00 am, we observe that all the nodes are highly concentrated, showing poor ratios between effective and actual speed values due to the absence of transport connections during the night hours.

Travel times are estimatedfor the whole region by interpolating node values in a raster map. These mapsare shown in Figure 9 for each scenario and time period. The central nodeis representedby a black dot. Given this methodology, we can define areas that are closer or further away from

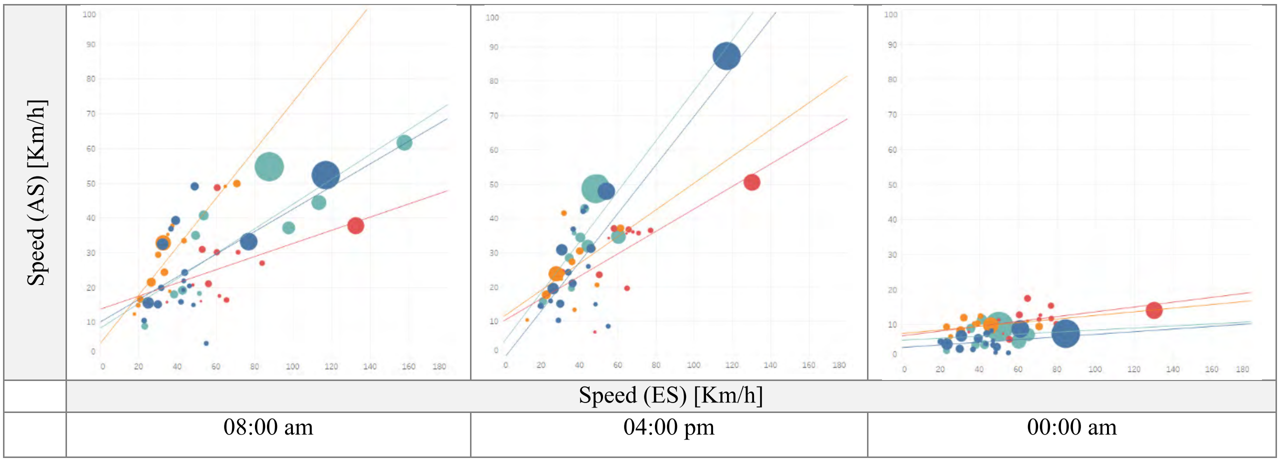

FIGURE 8. Ratio between speed values in both scenarios (AT and ET) at different time periods.

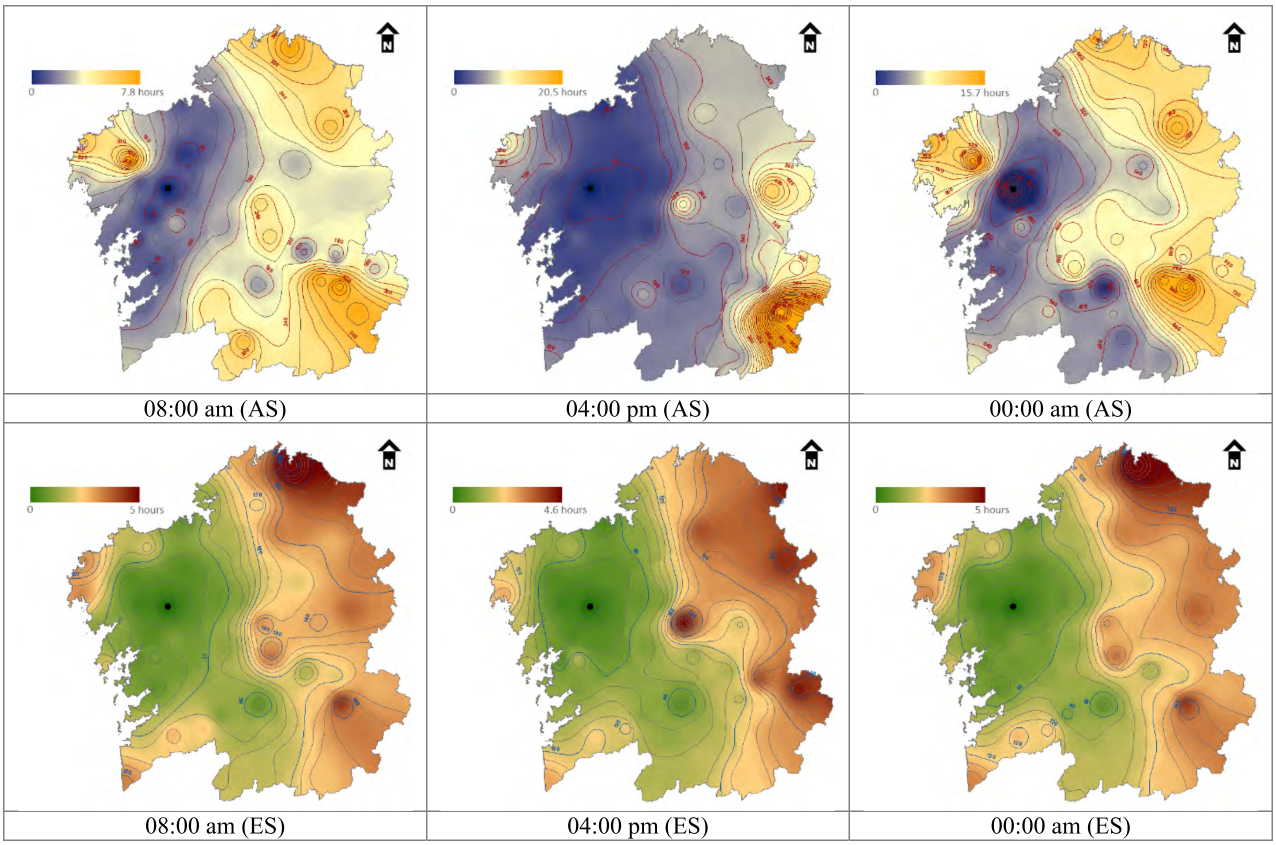

FIGURE 9. (AS and ES) for traveling to the whole region at different time periods. Isochrones are labelled in minutes.

the central node. In the first scenario (AS), orange tones represent areas farther away, whereas blue tones indicate areas that are closer to the central node. In the second scenario (ES), brown tones represent areas further away, whereas green tones represent the nearest ones. In addition, the most representative *isochrones*, which define areas with similar travel times, are drawn and superimposed onto all the maps.

The proposed methodology allows us to obtain a more exhaustive perspective on the accessibility within a region. For this, distortion values (R_i) for each node are estimated for both scenarios. Note that these distortion values depend not only on the average speed (Figure 8) but also on the length of each link (d_i). Figure 10 shows how the respective distortion rates (R_i) for each node i in both scenarios are correlated. X-axis shows R_i for the ES scenario, whereas

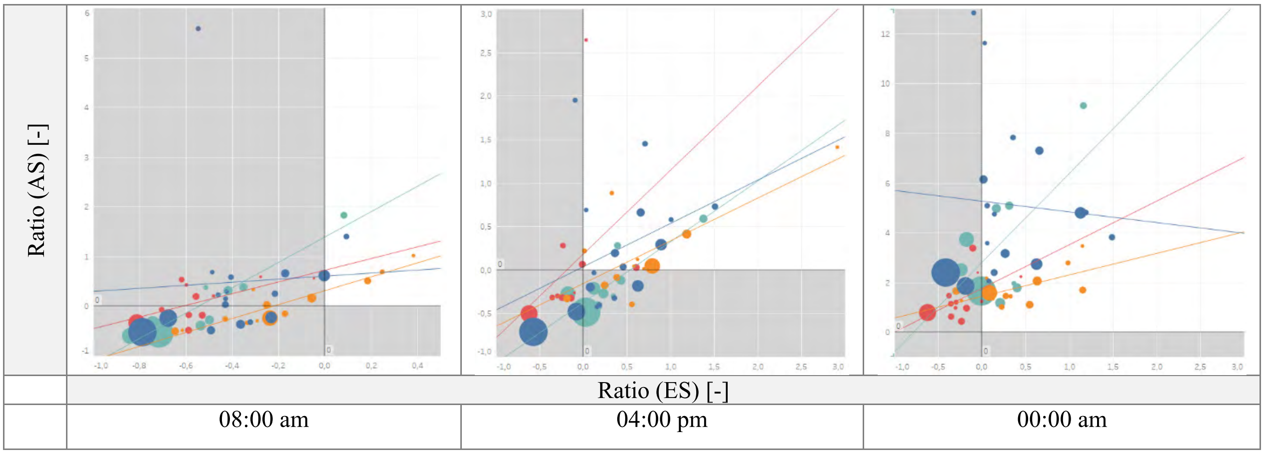

FIGURE 10. **Correlation between distortion rates(R_i) for both scenarios at different time periods.**

Y-axis does the same for the AS scenario. The grey shaded area encompasses nodes with negative distortion values, i.e. nodesthat are moving closer to the central node.

These charts show different patterns. At 08:00 am, most of the nodes (47 of 53) are located in the grey shaded area, although only half of them (25) are in the grey shaded area overlappingboth scenarios. However, this number is significantly lower for the other time periods: 13 nodes at 04:00 pm and no node at 00:00 am. Note that most of the nodes at 04:00 pm (8 of 13) are located in the province of Ourense. As a matter of fact, the most populated nodes tend to show lower distortion ratesfor each scenario. In addition, a linear correlation between distortion rates for both scenarios is apparent. Notice, however, that there are outliers in all the time periods.

If the distortion values (R_i) are interpolated to the whole region, we can estimate intermediate values for each cell. For this, we apply the same methodology that we use for the case of the travel times (Figure 9).The color legend shown in the next figures goes from green to red tones, referring to negative and positive values, respectively. This means thatgreen tones correspond to a shrinkage effect within the region ($R_i < 0$), whereas red tones correspond to a stretching effect of the surrounding areas ($R_i > 0$). The value scale goes from-1until $\geq$ 2 and it is distributed in seven intervals. Resulting maps for different scenarios and time periodsare shown in Figure 11.

These maps show different patterns of distortion in the region and there exists a clear variability over time. Moreover, it is noticeablethat red or green colors are quite dominant in some areas, showing the two extremes.

Distortion effectscan be quantified by using discrete values. For this, the distortion value for each cellis extracted and classified according to the same seven intervals we defined before, between -1 and $\geq$ 2. Each cell covers a regular area of 0.1 km^2 (raster format). The sum of the cell values within each county allows us to classify and quantify thecurrent distortion effect in each county. The internal fragmentation in Figures 12 and 13 split the counties within each province according to such classification. Bothfigures show the level of distortion for each scenario for the different time periods. On the left side, it is shown how fragmented each county[4] is, depending on the different intervals of distortion. On the right side,these fragmented pieces are colored based on the magnitude of the distortion. The color legend is the same as we used in previous maps (Figure 11).

Figure 12 represents the AS scenario. Treemaps on the right side show significant differences in color if we compare the two first time periodswith the last one. At 08:00 am, we observethat the most intense red tones are located in the province of A Coruña, while at 04:00 pm these ones are present in all provinces, although less clearly in Pontevedra. At 00:00 am there is a clear predominance of red tones in the whole region, although they appear to be less intense in the province of Ourense.

Figure 13 depicts the same analysis for the ES scenario. Treemaps on the right side clearly show how most of the counties are colored in green at 08:00 am. More similarities between provinces are shown in the other time periods, not only with a range of colors but also with the internal fragmentation of the counties. In some cases, the fragmentation is higher, but this can be explained by the more significant differences in travel times between nearby nodes. In general, we can state that the provinces of Lugo and A Coruña show the worst connections across time periods, which is confirmed by the stronger presence of yellow tones at 08:00 am, and red tones at both 04:00 pm and 00:00 am.

Both figures (12 and 13) show different patterns, depending on both space and time, which demonstrates the complexity of the distortion process.

The final step is to map the distortion effect by means of the so-called *distance cartograms* or *time-distorted maps*. These

[4]The original tree map of counties (Figure 1.c) may be used as reference. In total, this region counts 53 counties,which areshown in different colors.

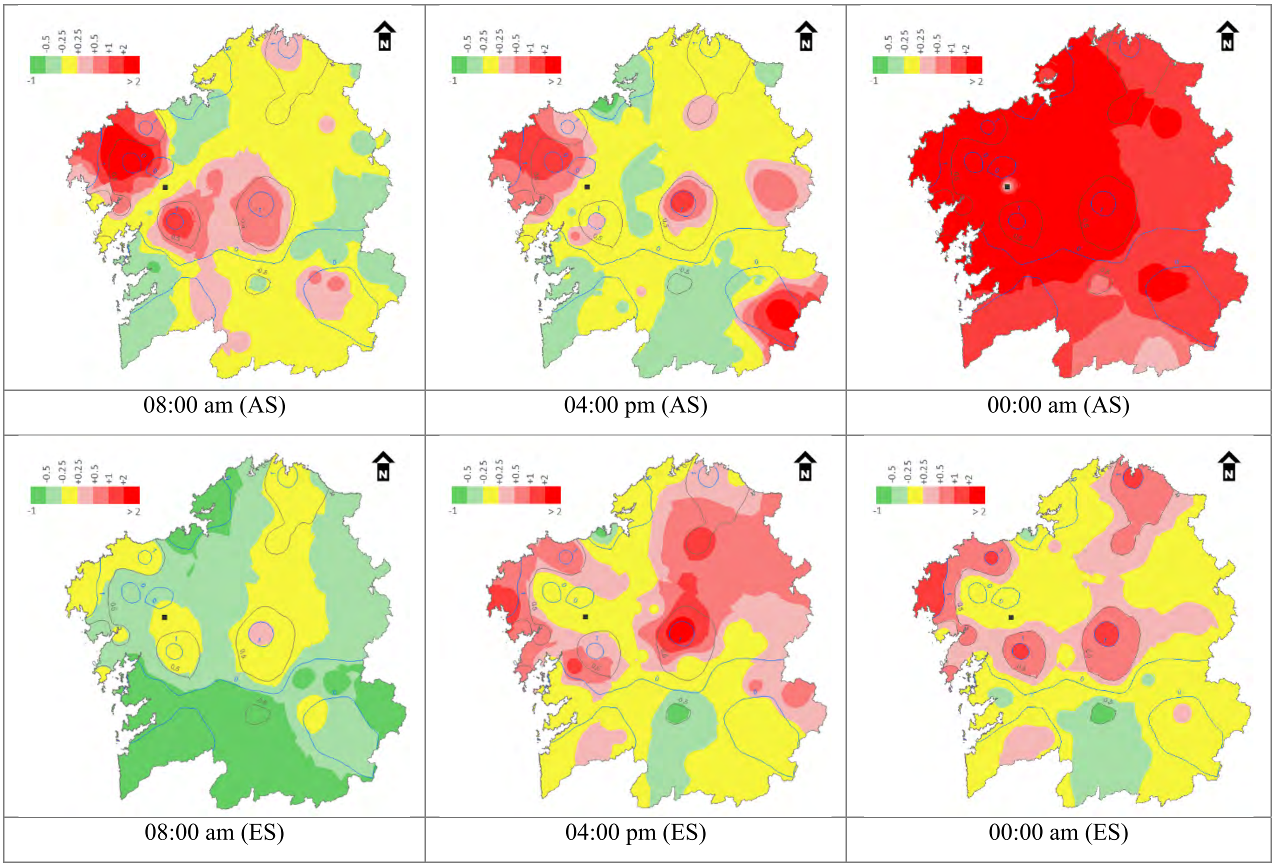

FIGURE 11. Distortion rate of the whole region with respect to the central node at different time periods. Results for both scenarios are represented. Contour lines represent distortion rates, whose time value (in minutes) is shown in labels.

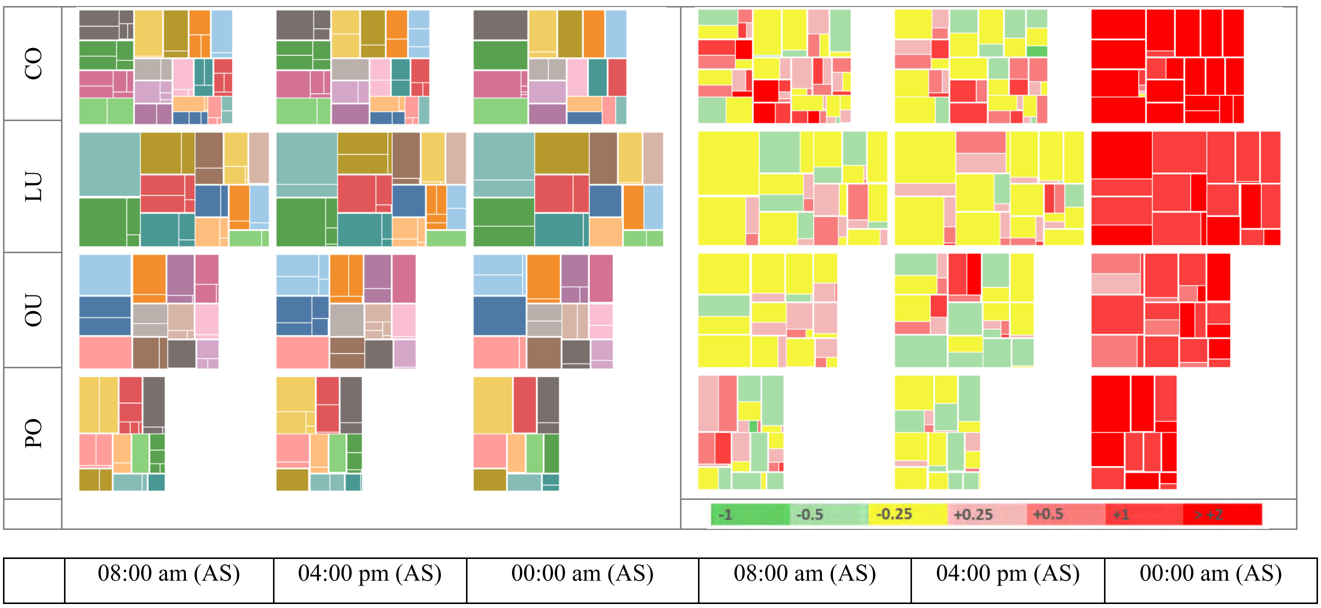

FIGURE 12. Distorted rate at different time periodsfor AS: (left) Area of each county and province. (Left and right) County divisions show the internal fragmentation due to different distortion rates. Eachcolor on the left represents one county. (Right) Level of distortion in each county and province.

maps apply an anamorphic effect to the traditional ones, which is related to travel times between nodes. The degree of distortion in each area of the map allows us to know the current time-varying accessibility within this or any region, starting from the center node. Final time-distorted maps for both scenarios are shown in Figure 14.

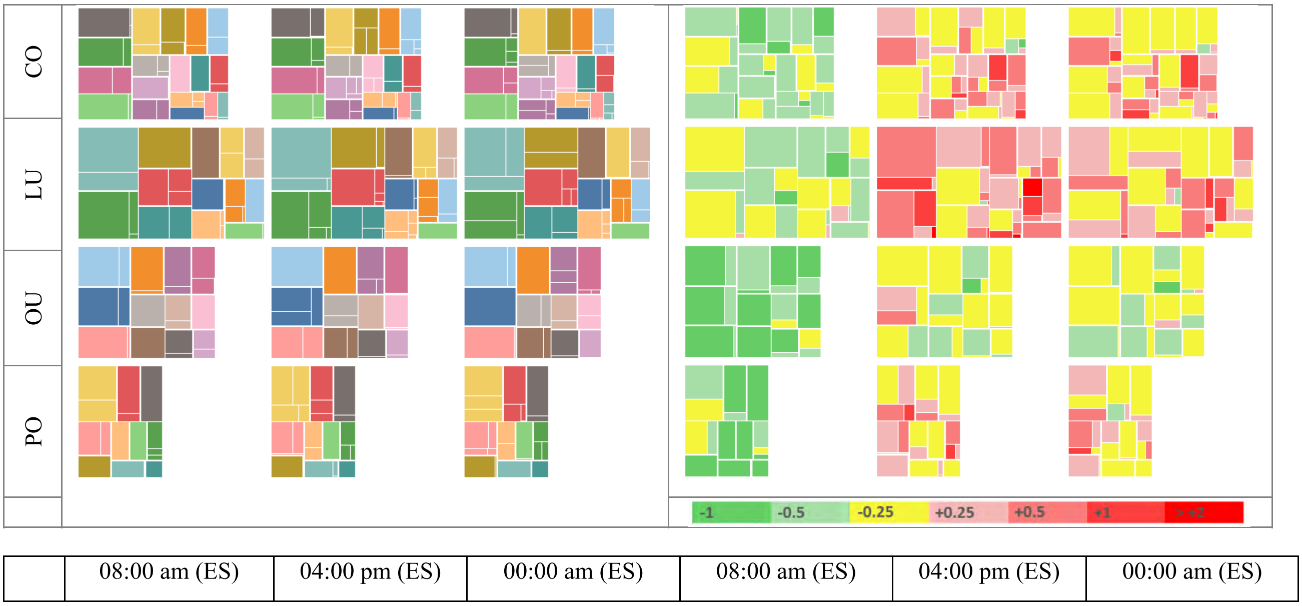

FIGURE 13. Distorted rate at different time periodsfor ES: (left) Area of each county and province. (Left and right) County divisions show the internal fragmentation due to different distortion rates. Each color on the left represents one county. (Right) Level of distortion in each county and province.

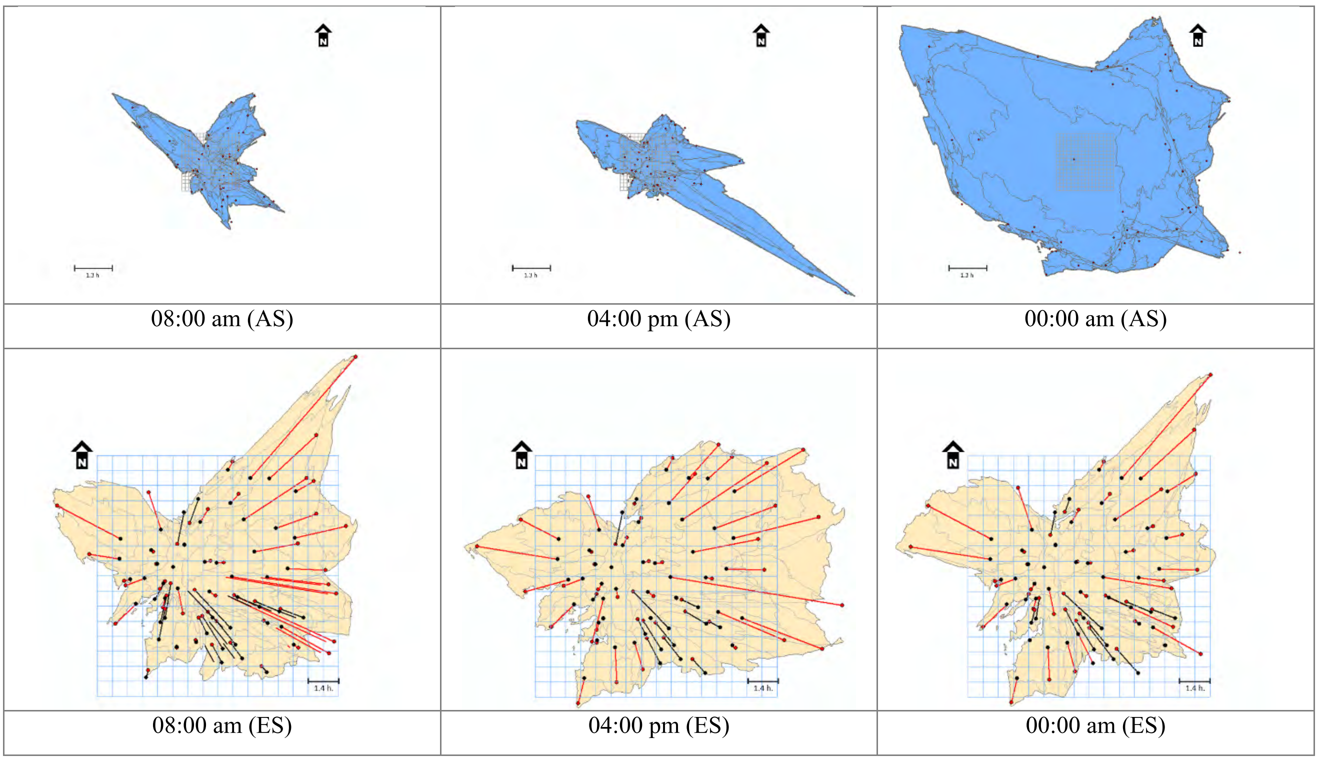

FIGURE 14. Time-distorted maps at different time periods. In the ET scenario, black vectors indicate shrinkage effect, while red ones indicate stretching effect.

V. ANALYSIS OF RESULTS AND DISCUSSION

Differences between *time distorted maps* and *traditional mapsallow* us to observe the existing levels of accessibility within any region. Resulting maps show how the inner areas of the province of Lugo and the southeastern Ourense, in addition to the northern/northwestern coast,have the poorest levels of accessibility. These areas cover amuch larger area in Figure 14 than in reality (see Figure 1b).

The northwestern coastal area is poorly accessible, despite its closeness to some of the most populated cities. This is because its public transport connections have very low frequencies. In the northern and eastern areas, most of the nodes are not directly connectedto each other, and the transfer times between different transport modes can vary substantially. The highest transfer times and worst connections are found in the east of the region and these can be explained bya sub-optimal schedule, limited supply of transport services, and time delayscaused by limited *intermodality* options,driven by poor connectivity between different transport systems.

By contrast, areas with the highest levels of accessibility are represented by means of a shrinkage effect (or less stretching than other areas). These areas coincide with the two main dynamic axes that shape this region: (a) the internal one, so-calledthe *Atlantic Corridor*, and (b) the external one, known as the *Spanish radial*connection. This last onelinks the Galician region with Madrid, the political capital of Spain. Both axes have high-speed trains, although the connection with Madrid is not totally finished yet.

From the perspective of the whole region, most of the maps show how the governmental authorities have prioritized radial connections with Madrid. This can be observed in the stretched area represented by the *Santiago-Ourense axis*, especially when compared to other ones located in the western, central, and northern areas. In those areas, railway infrastructure does not yet exist or is obsolete, e.g. the narrow-gauge railway, so-called *FEVE*, which runs along the North Corridor.

It can also be observedthat topography does not substantially predetermine the layout of the transportation infrastructure, but it restricts the current degree of accessibility. In fact, the resulting maps obtained for the ES scenario at different time periodsclearly show how the eastern area, where the topography is hilly, is significantly distorted.

Time distorted maps show how the relationship between territorial accessibility and economic development within a region is not a trivial matter. Given any increase in infrastructure spending, we would expect that the differences between the spatial and temporal maps disappear over time, i.e. the shape of the *time distorted maps* should become similar to the traditional maps. However, this does not happen so often. In fact, many times a *downward spiral*can be observed in some areas, where the levels of competitiveness and territorial accessibility are continuously decreasing. This results in furtherinvestment cuts for road infrastructure and transport services. Thus, these areas tend to be less connected and accessible, which, in turn,leads to regressive demographic and economic dynamics.Indeed, investments in road infrastructure should not only follow a demand-based approach, but should also promote the development of the most depressed areas. The inner area of the province of Lugo and the so-called *A Costa da Morte*, in the western coast of A Coruña, are clear examples thereof. A Coruñasuffers from a traditional isolation process, despite its proximity to the *Atlantic Corridor*. In fact, this area has lost around 16.6% of its inhabitants since 1960, while the total population in its province has increased by 10.7% [40,41]. As a result, its relative demographic weight with regard to its province has dropped more than 7% from the year 1920 [42].

Note that the *time distorted maps* shown in Figure 14 remain recognizable [43], [44], despite some topological inconsistencies. Our results are basedon a relatively dense network, which is well distributedacross this region, despite the relevant differences in the population across nodes. In fact, 11 urban nodes with less than 2,500 inhabitants were considered and compared with nodes that were hundred times more populated. Undoubtedly, this can explain some existing differences between levels of service both from a quantitative and aqualitative perspective. Future studies should consider alternative setups for analyzing and comparing how distortion effectsrelate to population and economic activity.

Furthermore, we should notice that some computational procedures could influence the results, e.g. the used interpolation algorithm and/or the presence of some extreme values (and/or outliers). For example, the AS scenario at 04:00 pm (Figure 14) shows a huge distortion effect in southeastern Galicia. This is attributed to the 20.5 hours required for arriving at a node located in the southeast: *Viana do Bolo*. In addition, we should note that the resultsobviously depend on the choice of the*central node*. Future studies should consider the differences of the distortion effect as a function of the central node, in addition to the use of actual distances instead of Euclidean ones.

All in all, these final maps are excellent tools for assessing the current degree of accessibility within a region. This methodology offers additional value in comparison to the traditional maps because it represents the time-varying accessibility by considering some additional factors such as different transport modes and time periods.

The spatial analysis shown is adapted to an intraregional scale. However, our methodology is transferable to other mapping scales, such as urban areas, where the main issues are usually related to congestion, and management of traffic flows, among others [45], [46].

This methodology shows a huge potential for adopting policies and/or strategic decisions by professionals whose field of knowledge is relatedto territorial planning, such as urban planners, transport planners, architects, geographers, etc.

VI. CONCLUSIONS

This article proposes to use*time-distorted maps*for assessing the time-varying accessibility and the resulting territorial-cohesiveness. Resulting maps allow us to visualize, in a clear way, the existing deficiencies in transport infrastructure and/or connecting services. In addition, results can be classified and quantifiedby using very intuitive charts.

Furthermore, the proposed method allows to simplify the analysis and interpretation of data and facilitates the interaction with multidisciplinary working teams. Thus, these maps can be usedto aid decision makers in topicsrelated to regional planning and transportation.

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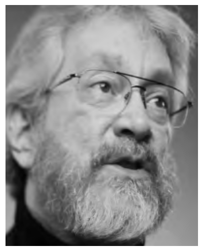

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