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The Evolution of Connectivity in Sig-T Modeling. The Case of the Spatial Data Infrastructure of Andalusia

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Abstract

Connectivity is considered a crucial condition in vector network modeling, since route optimization analysis or geomarketing analyses could not be performed without it, when accessibility is among their parameters. Andalusia's spatial data infrastructure got its start in 1990, with the creation of the Andalusian Institute of Cartography. The first public product of a vector cartography was the 1:400,000 digital map of Andalusia. Several series have been released at a scale of 1: 100,000 ever since, with different connectivity conditions that have required subsequent adjustments by transport networks researchers. The development of digital cartographic sources should not only result in an improvement in precision, but also in their operational capacity. This article analyzes the quality of these products based on their connectivity capacity with the intention of creating rules for modeling that ensure the ability to perform network analysis tasks using public and affordable spatial data infrastructures.

Keywords: GIS-T, Network Analysis Spatial Data Infrastructure, Connectivity, Topology

1. Introduction.

Despite the existence of popular tools and commercial sources focused on route choice and geomarketing, spatial data infrastructures are fundamental sources for the development of territories, European Parlament (2007). One of its main sources for spatial analysis is the data that allow the elaboration of a GIS-T, Miller, H. J. (1999). The spatial data Infrastructure of Andalusia was promoted by the Institute of Statistics and Cartography and has produced new versions of vector and raster cartography since its creation in 1990. Since then, there has been an important scientific production such as doctoral theses and articles in scientific journals: Moreno-Navarro, JG (2003), Garrido-Cumbrera (2005), Zamorano et al (2009), Latorre, F. et al (2010), M. Narvaez, AG, (2011) Díaz, VR (2011), Calvo-Poyo, et al (2019)

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etc. The sources contained in the public SDIs have therefore been the most used for GIS-T research in Spain, Escolano, (2018), Gutiérrez Gallego, et al (2015) in the case of documents that allow dynamic modeling, facilitating the elaboration and demonstration of hypotheses on ex-ante/ex-post bases. and ex-post. Calkins, H.W. (1990).

The lack of connectivity in the GIS models of Andalusian transport networks arose in the first series of the 1: 100,000 map of Andalusia in 1998. Until then, network analysis works on a scale smaller than the municipal scale had been carried out on the map 1:400,000 (1996), and the Digital Chart Of the world (1: 1000,000). The lack of connectivity in this first series forced the use of older sources such as DCW (1993) or the digital map of Andalusía (1996) A.G, Díaz, V.R (2011). In other cases, they were solved using topological correction techniques that had already fallen into disuse, but with acceptable results. However, the appearance in 2019 of a new extraordinarily detailed series about Andalusian roads, put in doubt the convenience of applying these techniques. In this new series, there were not only connectivity problems, but the details in the road junctions made it necessary to model directions in a complex way

A trend towards geometric and geographical accuracy has been noted, ignoring the primary role that these sources play in conducting network analysis on a regional or even continental scale, should the INSPIRE initiative succeed to the latter extent.

2. GIS-T connectivity.

Network analysis with GIS is one of the most complex tasks that we can perform with vector GIS tools, Fischer, M.M (2006), but also one of the most effective due to their capacity to generate strategic information in terms of logistics , geomarketing and even the design of transport infrastructure. In this sense, a network must have the attribute of allowing transit between the elements that compose it by establishing rules. To achieve this, the design of the network in its simplest state must enable flows to go between points of the network following the shortest path. The complexity of the rules and the risks of disruption increase as the network becomes more accurate. Networks modeled with GIS are analyzable as such because they have their operational foundations based on graph theory, Euler, L. (1736). In the language of GIS, vertices and edges in graph theory are called arcs and nodes; there can only be connectivity between two adjacent arcs if they share a node. And this is the circumstance that must be established from the very precise moment the network is being designed.

3. Cartographic sources and methodology.

To detect the lack of connectivity, it is enough to operate the GIS-T and observe if it yields illogical routes or isochronous areas appear with irregularities. Fig 1. After verifying the optimal route layouts, the network has been tested to quantify the number and types of errors that occur in each of the layers.

3.1 The cartographic source series.

Table 1. Cartographic series.

Year	Junctions	Polylines
1996	3248	4656
1998	6179	7721
2009	15403	14619
2013	14688	13592
2015	15771	13444
2017	20402	18068
2019	138670	217836
2019 (Only Seville)	120574	47459

Source: prepared by the authors on the basis of IECA data.

3.2 Verification of optimal routes and isochronous areas.

The software used for network analysis and topological settings is ArcGis 10.4 with Network Analyst module. The response of illogical routes between two points has allowed us to fence in errors in order to identify and classify them.

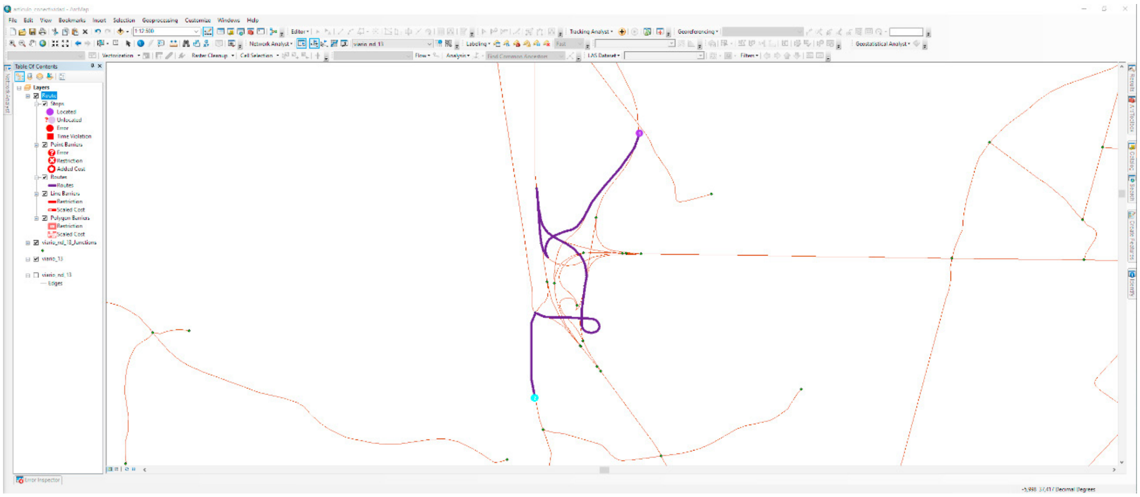


Fig. 1. Route traveled between two points following an illogical path.

Source: prepared by the authors on the basis of IECA data.

The offset of one of the two points to check another route solution enable us to encircle the disconnection points. In this way we can identify the existence of errors and classify them. Connectivity is fundamentally lost by two types of common errors: false nodes and dangling nodes. Once the lack of connectivity has been verified, a topological study is carried out using a tool just set to find out the number of errors, which is usually too large to be searched manually. The application of the tool will be resolved in point 5. The causes of connectivity loss in the design of the layers will be exposed too.

4. Statement of the problem.

Loss of connectivity occurs for a variety of reasons and can be corrected with tools that generate or correct the layer topology. However, these corrections can also generate nodes where turns are not possible. Elements and bases are set out below to describe the problem.

4.1 Why do we lose connectivity?

The layers on transport issues have been losing rigour in the elaboration of the connections, possibly due to the abandonment of the topological condition required as essential in the 90s; every intersection of two arcs generated a node. Only with the need to use network analysis tools, we get again the requirement to consider nodes, in some cases referred to as “junctions” in those layers that already have a network geometry. The connectivity deficiencies require so laborious preparatory operations, that they even lead to discard more recent sources in favor of older but more reliable ones, Díaz, V. R. (2011). Topological requirements forced the generation of nodes at all intersections in older series, such as the Digital Chart of the World, the digital map of Andalusia 1:400,000 and even the first Andalusian models at a scale of 1:100,000. These were small scales that did not require details in road junctions, interchange, flyover, underpass, etc. Figures 1 to 3 have been taken on the same road junction with the different sources evaluated. It should be noted that the enormous difference in scales offers a very different cartography about the same link. As can be seen in figure 1, the small scales (a) Digital Chart of the World (1992) and Digital Map of Andalusia 1: 400,000 have a low density of arches and nodes, thus the crossings and accesses are not detailed and are never dual carriageways are never considered.

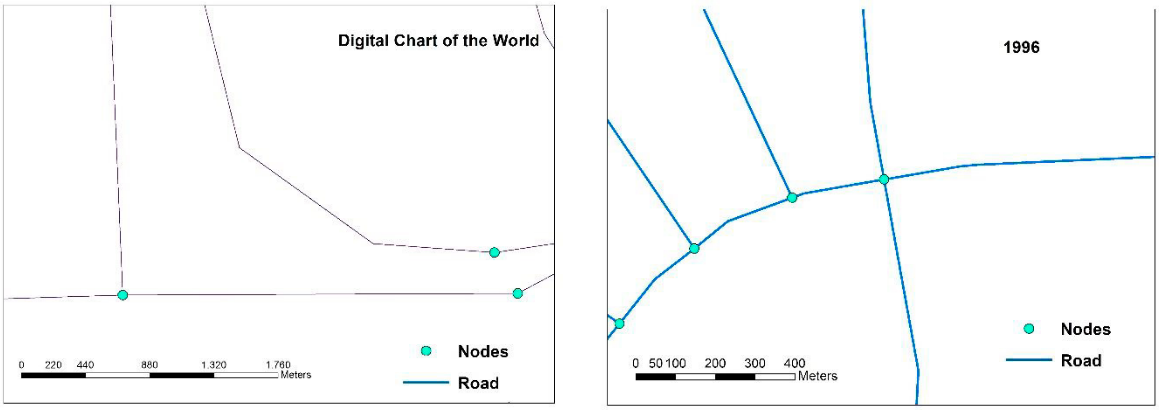


Fig. 2 (a) Digital Chart of the World (1992) 1:1000.000; (B) Mapa digital de Andalucía 1:400.000

In these cartographic series, connectivity errors are few and not very laborious to solve. On the other hand, in the following figure 2 (a) we can see the existence of intersections that allow impossible turns. This has been fixed up in figure 2 (b) series from 2013

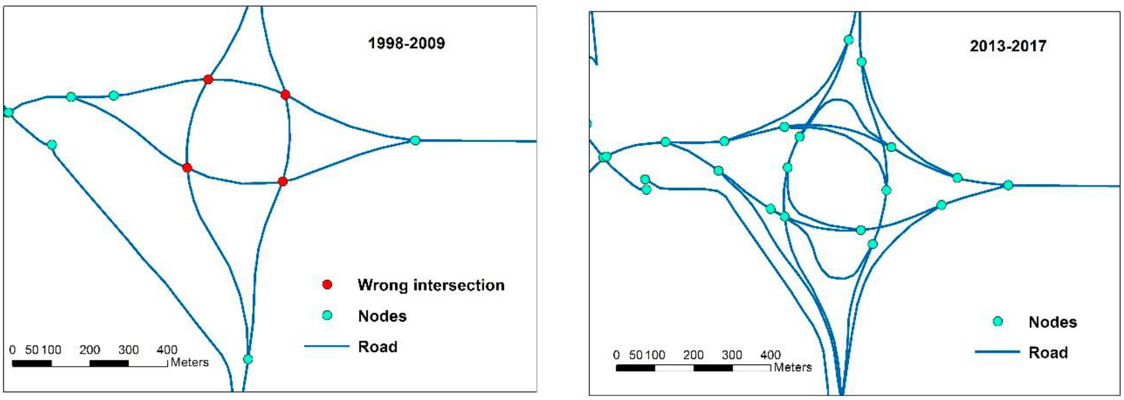


Fig. 2. Spatial reference Data of Andalusía (DERA) 1:100.000. (a) 1998-2009 y (b) 2013-2017

Finally, in the 2019 series, as can be seen in Fig 3 (a), the network has been updated, increasing the precision of the accesses, but as we will see in the next point, many topological errors have been made, besides redundant nodes that multiply the number of elements in the layer have been added. This last circumstance is a serious handicap for the operation of the layer in the case of being part of a SIG-T. The topological correction of these errors in Fig 2 (b) in the Digital Street map of Andalusia has once again created false nodes y flyovers and underpasses.

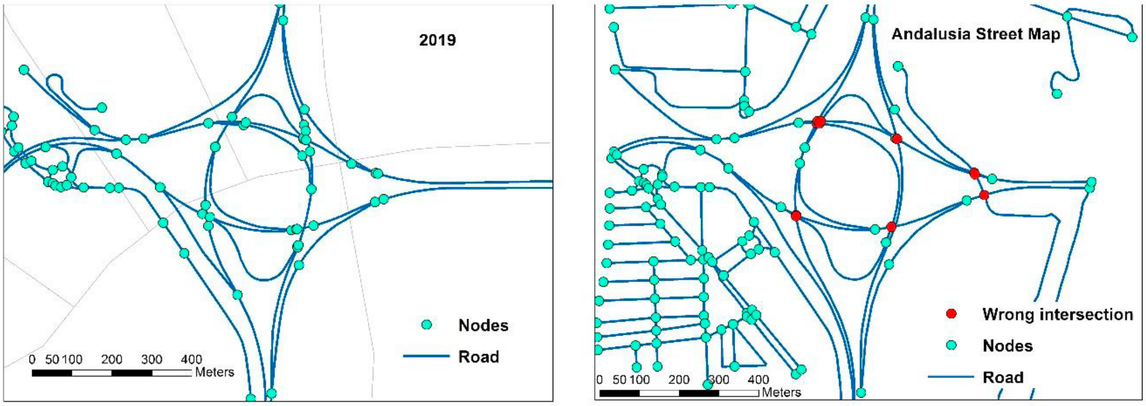


Fig. 3 (a) Spatial reference Data of Andalucía (DERA)1:25,000 (b) Street Map of Andalusía. (1:10,000)

Source: Prepared by the authors

The topological correction creates a node at each intersection no matter if it is a flyover or an underpass, which would be an operational inconvenience. In the case of the latest DERA series, there are numerous topological errors that, when correcting them, can create false nodes at these intersections enabling impossible turns in the model. The real errors that really need to be corrected are those that are represented in Fig 4 below

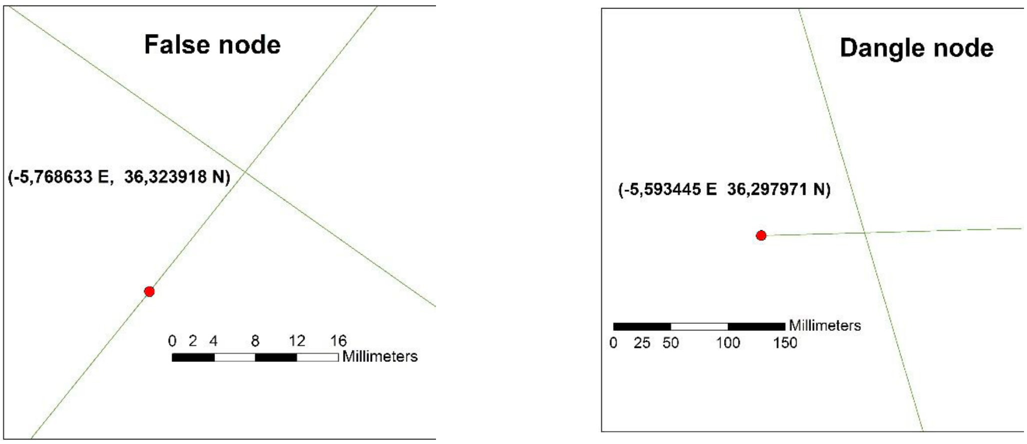


Fig. 4 Frequent connectivity errors in the DERA layers and location of two examples very close to each other.

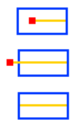
Source: prepared by the authors

The connectivity deficiencies are not only due to interruptions, but to distortions due to intersections that should not lead to a connection between arches, either because they are two lines representing two different modes of transport in an intermodal GIS-T Moreno-Navarro, JG (2006) and Moreno-Navarro, JG et al (2015) or simply because it is a false node that would allow a turn where in reality it is not possible. But in this case we are referring only to unimodal networks.

5. The topological analysis.

An analysis based on the geometry of the layers was carried out, that is, using the topology tool. Spatial rules are applied relating the geometry of the elements of a layer between them or between layers. This is a task to verify the connectivity of the layers prior to the establishment of a network and only the DERA layers of 2017 (arch), 2019 (Roads) and Seville streets (section) were used in this example. The topological rules that were applied to these line features are explained graphically and descriptively below.

Table 2. Topological operations

Topological rules	Description	Graphic basis
Must not overlap	The system displays an error if there are overlaps between the entities, that is, if there are duplicates	
Must not intersect	One line must not intersect or overlap another without a cut at the intersection	
Must not have dangles	Also known as voids. The initial or final vertex of a line must touch or intersect another line or polygon at one of these vertex. Any final vertex that does not meet another entity will be seen as an error. Caution must be exercised when reviewing this error because it is usually seen as exceptions, depending on whether the topology with bordering layers or with others was analyzed in an integral way.	
Must not have pseudo nodes	It must not have false nodes or pseudo nodes, that is, if a line is continuous but is cut without intersection of another line of the same layer, this will be marked as an error	
Must not self-overlap	A line of a feature must not overlap or overlap itself, that is, it cannot have a final vertex before an intermediate vertex, this is a digitization error	
Must not self-intersect	A line in a layer must not intersect itself without a cut that divides the element in two parts.	
Must be a single part	A line of an entity must not have more than one part, that is, if there is a gap, it is two lines, not one continuous	

Source:prepared by the authors with ArcGis software.

These rules were applied to each of the aforementioned layers, working separately with each one and validating the process through the software; and, thus, an overview of the formation of the layers, their spatial relationships and possible digitization errors was obtained.

Below is a table that synthesizes the number of “errors” found in the layers, including the exceptions that can be derived from rule 3 “must not have dangles”.

Table 3. Outcome from topological operations.

Topological rules	DERA_2017	DERA_2019	Street Map
Must not overlap	168	70.181	0
Must not intersect	4.104	77.851	76
Must not have dangles	8.191	994	872
Must not have pseudo nodes	5.168	74.821	210
Must not self-overlap	1	3	0
Must not self-intersect	3	3	0
Must be a single part	147	0	0
Total errores (incluye excepciones)	17.782	223.853	1.158
Total elementos (líneas) analizados	18.068	217.836	17.702

Source:prepared by the authors with ArcGis software.

These errors in turn represent cuts, gaps or even the absence of sections that directly affect connectivity in a network, affecting travel time, the design of optimal routes and the distance effectively traveled.

As can be seen in the summary table of topological errors, the increase in the number of linear elements analyzed for the year 2019 in relation to the year 2017 is striking. Despite having passed only two years, the number of registrations, which means an exorbitant increase in sections, by one thousand percent (18,068 in 2017 and 217,836 in 2019), allow us to infer a possible duplication in the records, that is, overlaps or duplicate sections. In addition, it is reflected in the number of errors of this type (overlap). This is directly related to the connectivity of a network from the perspective that in a modeling, if the section is twice the arc length, it also doubles, increasing travel time. Then a geometric correction is needed too.

As can be seen in the table that summarizes the presence of topological errors, the Seville Street Map has fewer errors in relation to the number of objects analyzed, and most of them are dangles, that is, vertices that do not connect with another element , which in this case refer to the cut that the layer has in the border area. This layer is the one with the best connectivity in the direction of movement flow through the network. This circumstance is most likely due to the topological correction action on the layer. But as previously commented and it also could be verified in figure 3 (b), these corrections generate nodes where in reality there are flyovers and underpasses, generating in the model impossible or prohibited turns in the real infrastructure.

6. Conclusions.

It is urgent to consider a special dedication to networks for their functional analysis as flow carriers and not only as elements of the terrain involved in mere spatial analysis or maps. The accuracy of digitization will increase, but this must not make us lose our operational capacity, so we must establish a new methodology for digitization and updating of transport networks.

The lack of connectivity in the evolution of the DERA layers has been noticed and corrected in the preparation of the Andalusian Digital Street Map, but it is necessary to once again eliminate the nodes which have been generated at intersections which should not be connections on the real road.

It is suggested to identify all the intersections at different levels in order to differentiate them from topographical errors and add them to the network as a last step, once connectivity in the rest of the layer has been guaranteed.

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