Decoding Road Networks into Ancient Routes: The Case of the Aztec Empire in Mexico

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Abstract. Historical evidence in some regions of Latin America has suggested that the system of ancient routes between places could have determined the success or collapse of prehistoric societies. The identification of such routes provided essential information to understand initial conditions in the evolution of the actual road infrastructure. Looking into the increasing technology applied to generate and process geospatial information, we proposed a retrospective spatial analysis for discovering a large-scale network of ancient routes before the conquest of Aztecs by the Spanish around 1520 CE. Such a method consisted in analyzing existing road networks (highways) that connect a system of cities (continuously built-up areas) to deduce routes by using geoprocessing methods, network analysis, and historical evidence. The results of this research support the idea that the retrospective method may be applied to other cases to decipher and to understand initial conditions in the evolution of road infrastructures by combining different types of data and scientific fields.

Keywords: Road networks, ancient routes, Aztec Empire, geoprocessing methods, complex network measures, historical evidence.

1 Introduction

Through time, road networks have been one of the most important physical evidence of social organization and adaptation in heterogeneous landscapes. In particular, historical evidence in some regions of Latin America has suggested that the system of ancient routes between places could have determined the success or collapse of prehistoric societies affecting their evolutionary trajectory. Therefore, the identification of such routes can provide not only essential information to understand early levels of politic, ritual, and economic interactions, but also initial conditions in the evolution of the actual road infrastructure.

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To identify the network of ancient routes, formal and informal constructions, in a region is not trivial. Historical cartography, aerial photography, and remote sensing techniques have given important contributions to detect and analyze ancient roads [1], but they are limited by the scale and precision of geospatial data. Nowadays, looking into the increasing technology applied to generate and process geospatial information, we consider an alternative method for discovering a large-scale network of ancient routes. It consists in analyzing existing road networks (highways) that connects a system of cities (continuously built-up areas) to deduce such routes by using geoprocessing methods, network analysis, and historical evidence. We called this method a retrospective spatial analysis.

Based on the evidence of the relationship and stability of some cities and roads throughout time [1,2,3], the retrospective method provides us the bases for identifying ancient routes before the conquest of Aztecs by the Spanish around 1520 CE.

2 Data

The geospatial database consisted of vector layers related to highway lines and urban polygons at Mexico in the year of 2005 [4]. Historical evidence about the first layer corresponded to the most representative cartographic information and scientific analyses about ancient routes in the Aztec Empire. This data was divided into three types of scales: a) the city of Tenochtitlan [5,6,7], b) the Basing of Mexico [8], and c) large-scale network of routes [9]. On the other hand, ancient information about the second layer was related to the location of Aztecs settlements around 1520 [10,11].

3 Retrospective Spatial Analysis

Following the work of Burghardt [2] about the relation between road and city networks and the degeneration model proposed by Xie and Levinson [12,13], we defined the retrospective spatial analysis as the process for decoding existing road networks into ancient routes based on geospatial and historical information, where the actual geographic data of cities and roads was modeled by geoprocessing methods, analyzed by complex network measures, and compared to historical evidence (Fig. 1).

3.1 Geoprocessing Methods

Combining the large number of software and programming libraries to process and analyze spatial objects, for example the Geographic Information System (GIS) and third-party libraries of Python respectively, we integrated and modeled different types of spatial information. Urban polygons and road lines were mixed together in order to generate a planar graph, where the information of polygons was attached to superposed line segments by adding the polygon identification code to line segment points. The resulted graph was a modified version

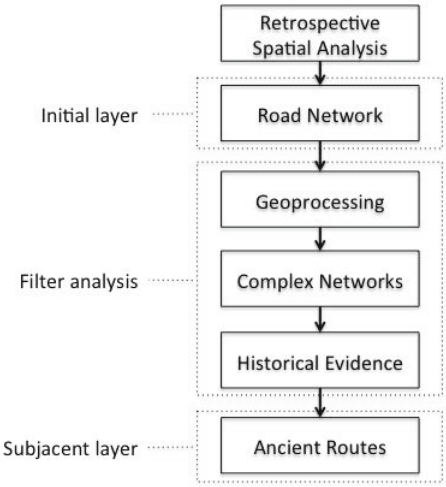

Fig. 1. Method

of the road network with identical topology and additional information in some lines segments. The process to create such a graph was divided into three steps: identifying lines inside polygons, transforming lines segments to individual lines, and defining nodes attributes.

3.2 Complex Network Measures

After modeling a planar spatial network, we used four types of complex network measures to approximate the identification of ancient routes. The first measure was the weighted average nearest-neighbors degree that identified a representative node into a set of nodes with similar polygon identification code. Such a node corresponded to the effective level of cohesiveness and affinity because it is connected with high- or low-degree neighbors [14]. The second was the shortest path defined as the minimum number of edges between a pair of nodes [15]. The third was the circuity measure, which is the ratio of network to Euclidian distance [15,16]. The fourth was the node accessibility that quantified different levels of road infrastructures suggesting efficient ways of how people traveling to their destination in a straight-line subject to other infrastructures and natural barriers.

3.3 Historical Evidence

The first scale of historical evidence concerned with the local organization in the city of Tenochtitlan. In particular, we analyzed two cartographic data: the Nuremberg map of 1524 and its artistic representation. The second scale was

a network analysis of the system of roads in the Basing of Mexico. The third scale corresponded to the study of long-distance trade routes in eastern Mexico before the Spanish conquest. In addition, we inspected the cartographic data of the ranking of Aztecs settlements in 1520 to identity their location.

4 Ancient Routes in the Aztec Empire

After applied the retrospective method, results suggested that some highway sections are good approximations to the network of ancient routes in the Aztec Empire (Fig. 2).

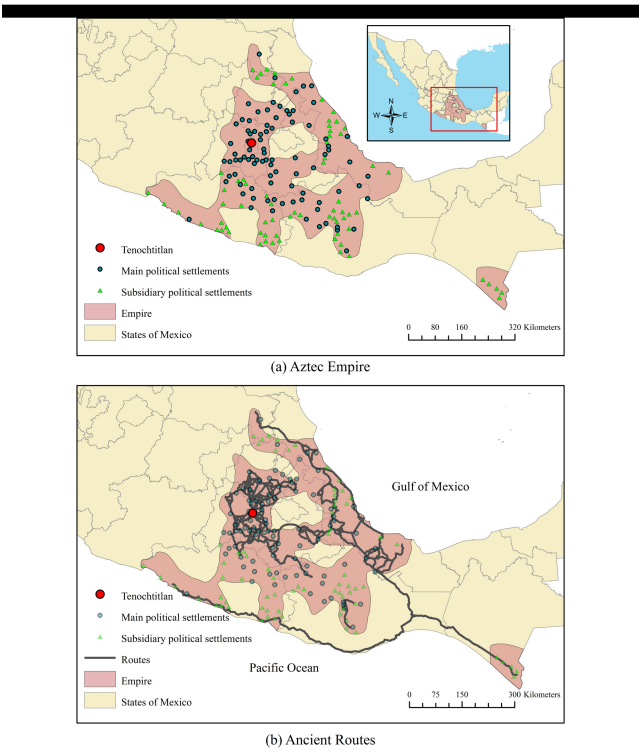

Fig. 2. The Aztec Empire and its Ancient Routes in 1520. Following the work of Solanes and Vela [10] and the Instituto de Geografía-UNAM [11], we generated the area of the empire based on two geographic criteria: altitude and water delimitations; and we located Aztec settlements georeferencing the cartographic data, respectively. Routes in Figure (b) correspond to low (< 70 km) and high ($> 1,100$ km) weighted shortest paths selected from the total number of highway sections possibly associated with ancient routes.

Figure 2(a) displays hierarchical settlements in the Aztec Empire that is characterized by a non-contiguous territory. Figure 2(b) presents the most likely road

sections that correspond to ancient routes based on local and regional historical attributes. Local attributes suggested a large number of short and straight roads that replicated the most efficient way for traveling by foot between hierarchical places. In this case, around the city of Tenochtitlan the network of routes implied a well-connected system among neighboring settlements. On the other hand, the regional attribute, which represents the political control of settlements based on a small number of long-distance routes of commerce, indicated a vulnerable network where few routes provided access to distant places and water resources. Specifically, towards the Golf of Mexico, there were localized routes that spread over southern Veracruz and Tabasco, even further along the coast of Central America [9], but in the direction of the Pacific Ocean, long-distance routes were difficult to create and maintain because of the heterogeneous topographic surface and environmental conditions. Furthermore, Aztec settlements along this coastline could follow other type of spatial network to connect them to Tenochtitlan and distance places, specifically water routes, i.e., river and ocean transportation.

5 Conclusion

The proposed retrospective method provides an alternative process to identify some road networks that correspond to ancient routes. It points out the importance of actual road network information to decipher and understand the initial condition in the evolutions of road infrastructures by combining different types of data and scientific fields.

The case of Mexico presented some road sections highly related to ancient routes in the Aztec Empire. Such roads suggested an efficient local mobility and accessibility among close settlements, but, at regional scale, they implied a low degree of robustness representing high vulnerability to failures and attacks. This result can explain the success of Spaniards in conquering the Aztec Empire with a limited number of soldiers and resources.

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