Explanatory Models in Archaeology: Are Least Cost Paths the Way to Go?

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Within the framework of the interdisciplinary Project "Ancient Cartography" carried out at the Karman Center for Advanced Studies in Humanities of the University of Bern (Switzerland), we dealt with the issue of modelling the road network of the Roman Province of Lycia (modern South-Western Turkey), as it has been documented by an epigraphic source dating to the first century AD, the so called "Stadiasmos of Patara". In order to analyse this dataset we used a GIS-based approach, modelling the Lycian road system by the meaning of a Cost Distance and Least Cost Paths modelling procedure. This case study can provide an example of both advantages and intrinsic theoretical and technical problems of using raster cost surfaces and a LCP's-based procedure as an explanatory model in archaeology.

Keywords: Cost Distance, Least Cost Paths, Roman Road Systems.

1. Introduction

According to the recent literature, the study of landscape movement and its related features has been transformed by the use of GIS (SNEAD *et al*., 2009:11; BEVAN forthcoming). Cost distance and Least Cost Paths (LCP) analysis has become a very popular approach, as it allows, on one hand, to predict the course of paths and roads on the basis of topography, and on the other hand, to approach the ancient cognitive geography and long term decision making processes by the meaning of analysing influencing environmental and cultural factors.

This short paper aims to consider the potential and limits of Least Cost Paths analysis, by using a case study, dealing with the issue of modelling a Roman regional road system. The use of LCP modelling in Roman Archaeology involves critical aspects related to the risk of environmental deterministic reconstructions of long distance communication systems and traffic networks. The building of Roman primary roads (*viae publicae*) depends, on the one hand, on the regional landscape features, and on the other hand, overcomes environmental constraints in order to exploit territories and connect places as fast as possible.

2. Case Study

This research has been carried out within the framework of the interdisciplinary Project "Ancient Cartography" at the Karman Center for Advanced Studies in Humanities of the University of Bern. Our main case study concerns the road network of the Roman Province of Lycia (modern South-Western Turkey: Fig.1), as it has been documented by an epigraphic source dating to the first century AD, the so called "Stadiasmos of Patara" (SAHIN and ADAK, 2007; GRASSHOFF and MITTENHUBER, 2009). This document, listing a sequence of connections as well as the corresponding distances in stadia between the main Lycian urban settlements, provides incomparable information about ancient settlement patterns and connectivity, and can be a relevant source to the understanding of roman landscape learning and planning issues.

3. Methodology

In order to analyse this dataset we used a GIS-based approach, modelling the Lycian road system by the meaning of a cost distance and Least Cost Paths procedure (GIS-Software: ESRI ArcInfo 9.2). This allows us to elaborate and support reconstruction hypotheses about the paths and to compare the modelled paths to the existing regional archaeological information (roads remains, bridges, milestones, rural settlements pattern).

In order to build a raster- based model we considered at the first stage the impact of the topographical constraints to the creation and development of the regional road system. The model building procedure involves some critical steps, which have already been analysed in the recent literature (HERZOG and POSLUSCHNY forthcoming), as the results are affected by the resolution of the used digital elevation model (Fig.2), by the slope calculation method, by the adopted algorithm and cost function and by network-related problems. We focus here mainly on conditional surfaces and network issues: especially this last aspect seems to be most relevant to our purposes, due to the nature of the analysed dataset, providing the position of the nodes in the web, as the settlements could be localised, and the lengths of the existing ancient connections between the nodes. In order to model the connections between the Lycian settlements we first used an isotropic slope-based formula (LEUSEN VAN, 2002: Ch.6-6 *Effort=(percent slope)/10*) as cost raster in the cost distance calculation, providing the effort of moving over the landscape, aiming at identifying the most suitable primary and secondary topographical corridors (Fig.3).

In order to evaluate the reliability of the results, we compared the models to the georeferenced archaeological evidence at the local scale and tested the correlation by using the linear regression between the traditional distances - converted in km - and the modelled paths lengths (Fig.4); additionally the correlation between the air-line distances and the modelled paths as well as between the distances of the "Stadiasmos of Patara" and the calculated length of the Byzantine Roads (HELLENKEMPER and HILD, 2004) have been verified. It allowed us to identify groups of well fitting and not fitting paths in relation to their lengths (GRASSHOFF, 2009: 160-165).

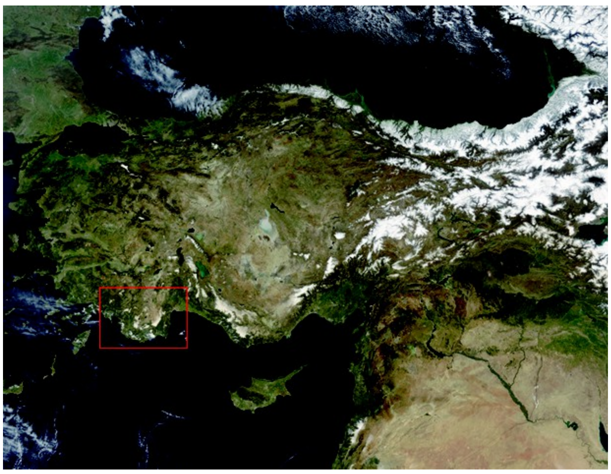

Figure 1: *Satellite image of Turkey with indication of the research area (source: NASA, http://visibleearth.nasa.gov/).*

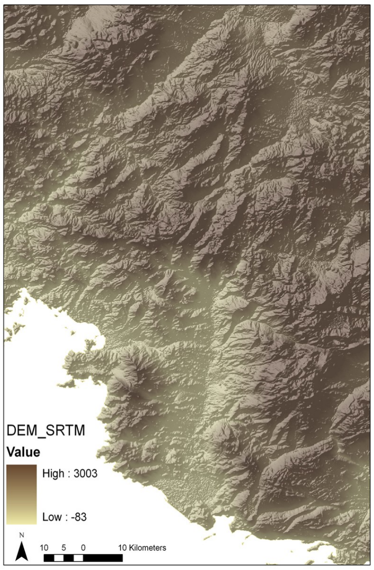

Figure 2: *Digital elevation model of the region (DEM Source: NASA SRTM, 90m res.).*

3.1. Evaluation and Implementation of the Model

In order to approach validation issues and to describe in a formal manner an ancient dataset, we applied a Least Cost Path analysis for modelling a well preserved Roman *via publica* (QUILICI and QUILICI GIGLI, 1997), the *via Salaria*, used as objective function (FIZ and ORENGO, 2008 on the model of a Roman communication route in an alluvial plain; KAY, WITCHER 2009 on the use of predictive modelling for descriptive and exploratory issues referring to the Roman *via Flaminia*). In this case, where only point A and B are used in the model building and where we know nodes and edges lengths from ancient itinerary sources (CUNTZ, 1929) we first applied a slope-based cost function, where slope in percent (S) has been iteratively calibrated by a multiplier factor (f) and implemented by addition of an empirically obtained parameter (p):

$$\text{Cost} = f\,(S) + p$$

By comparing the best fitting results to the objective function, we defined the most relevant deviations of the obtained model from the real path, also affected by using isotropic costs of movement through a corridor (Fig.5: deviation type 2). Diachronic issues related to long term settlement patterns as movement attractor as well as regional resources exploitation and transport purposes can also overcome high topographic costs (Fig.5: deviation type 1).

The main problem we had to deal with is the meaning of heuristically implementing the cost-function with additional influencing factors that are different in nature (physiological, environmental and cultural: FAIRÉN JIMENEZ, 2004) and of being able to control the dependent results.

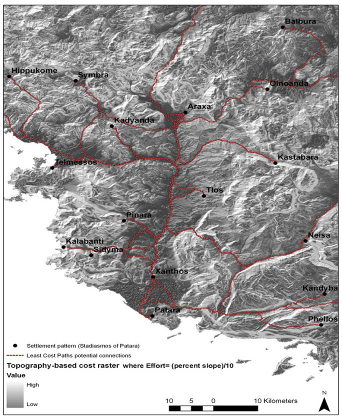

Figure 3: *Topography-based corridors and least cost paths connecting the settlements in the Valley of the Xanthos River (today Eşen Çay).*

The model building for the Lycian regional road system shows further critical aspects in the use of LCP's techniques, as they are not satisfactory in connectivity and representation of networks coherence and in avoiding redundancy. It is a general problem of raster-based cost paths analysis as an isolated optimization of paths between two points.

The results of the raster model, where the networking problem can be partially solved by connecting every node of the network to every other node (Fig.3), have to be discussed and implemented by the definition of the topological properties of the road system.

In the case of unsatisfactory modelling results not fitting the distances listed on the monument, we can assume the existence of a network with crossroads, minimizing the sum of roads length, probably depending also on the diachronic development of rural settlement patterns (about the Lycian settlement history see: HELLENKEMPER and HILD, 2004; SAHIN and ADAK, 2007).

In order to identify additional topological nodes, two solutions for connecting three points can be defined: (a) three direct connections from every point to every other, whereas every two connections can share the same pathway as long there is not only one single crossroad between all three places, or (b) a single crossroad consisting in three interdependent connections (Fig.6). On the basis of the traditional length of the paths, an elliptical radius can be traced around the known points, so that the probable pathway has to be contained within the resulted ellipse, which has been compared with the created cost distance surface from the same sites. If two connections from one place to two different places share the same path, the common pathway must lie within the intersection of the areas, within the ellipses defined by the lengths of these connections. The intersections between three or more ellipses provide the potential reliable area, where junctions can lie, if a single crossroad between all places is assumed. In case of single crossroads between three places (case b) the results can be refined on the basis of the known road lengths by calculating the distances between the cross point P and the adjacent places, as the intersections of the areas around the adjacent places with smaller linear distances define the even narrower potential areas for these crossroads (Fig.6).

The application of the Delaunay-Triangulation on the recorded settlements pattern also represents a valuable method for identifying connections in a two-dimensional space by creating non overlapping triangles (GRASSHOFF, 2009: 154-155).

A vector-based Linear Reference System approach seems to be a meaningful solution to enhance the results of the Least Cost Paths model of a road network, as it is a system where features (points as intersections or segments) are localized by a measure along a linear element (BLAZEK, 2005).

Conclusions

The geographical dataset provided by the "Stadiasmos of Patara" contains explicit information about settlements and distances as well as implicit information about the Roman regional road network as a coherent infrastructure, also involving construction and maintenance costs (SNEAD *et al.,* 2009: Appendix 2, setting comparative variables for movement features; see also BELLAVIA, 2006:187 on roads typology and aims). Due to this convenient database, this case study allows us to consider both advantages of using raster cost surfaces as an explanatory model of the formation and transformation of the long term movement practices and features, also in relation to diachronic dynamics of settlements distribution, density and hierarchy, - and intrinsic problems of LCP's-based procedure especially with regard to networking issues. This is a relevant aspect concerning Roman road systems, and has theoretical implications in the study of connectivity, political and economic functions, as well as phenomenology of the Roman Provincial roadscape (LAURENCE, 1999).

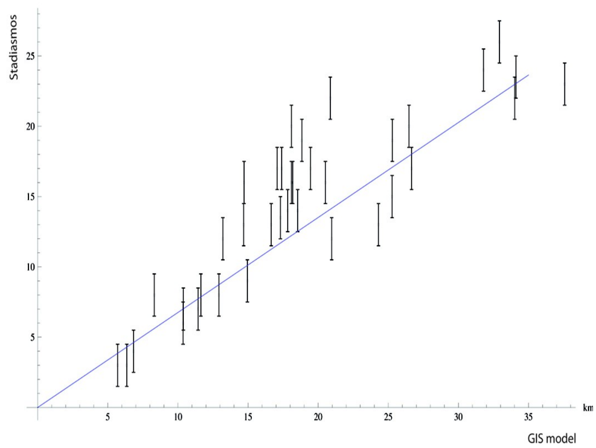

Figure 4: *Correlation and error vectors between "Stadiasmos of Patara" distances and modelled paths lengths.*

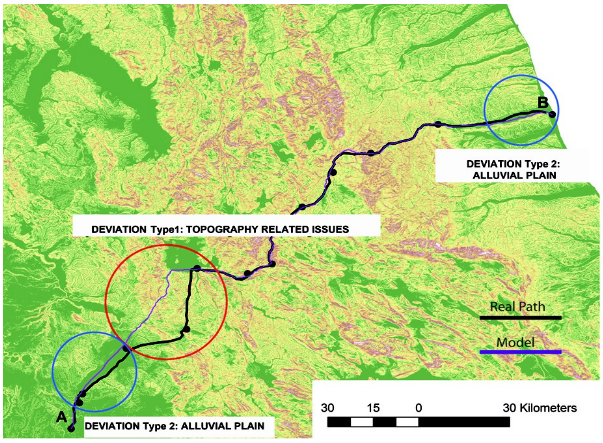

Figure 5: *Visualization of the main deviations of the test-model of a Roman via publica as objective function.*

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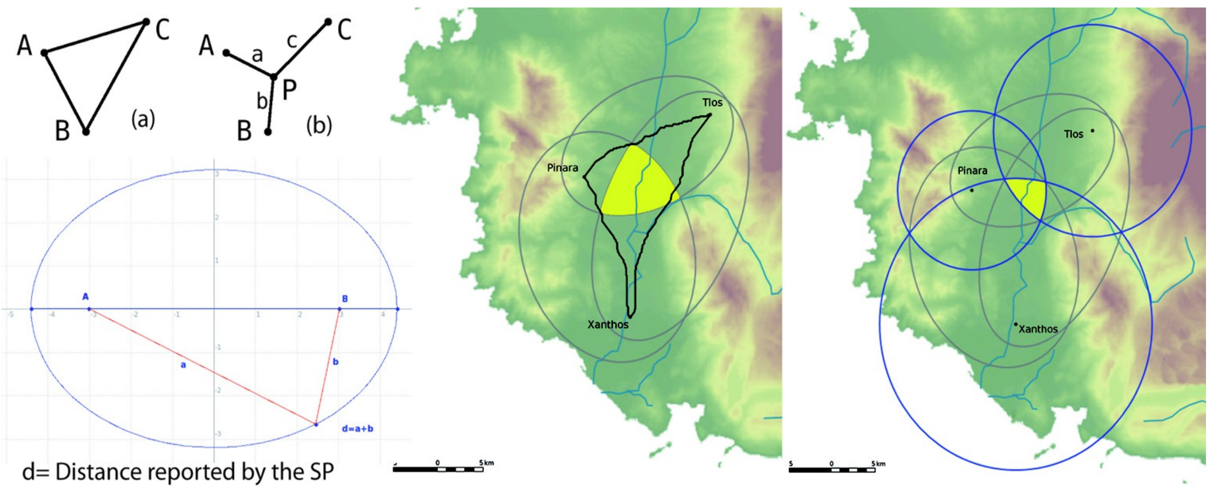

Figure 6: *Networks topology issues and the definition of crossroads according to the traditional information of the "Stadiasmos of Patara" (SP).*