The Suitability of Using Least Cost Path Analysis in the Prediction of Roman Roads in the Highland and Lowland Zones of Roman Britain

Joseph Lewis
MSc GIS
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What is Least Cost Path Analysis?

- Based on the Principle of Least Effort (Zipf, 1949), which assumes that humans will naturally choose the path of least resistance when travelling in a landscape.

- LCP analysis computes the optimal route between two locations that minimises the effort needed to cover the distance.

- Most commonly computed using Dijkstra's algorithm (Herzog and Posluschny, 2011).

- Widespread use of LCP analysis to reconstruct ancient roads (e.g., Verhagen and Jeneson, 2012), and identification of factors governing the construction of known roads (Bell and Lock, 2000).

Herzog, 2013a, p.1
Why Roman roads in Britain?

Long history of interest in the study of Roman roads in Britain e.g., Codrington (1918) and Margary (1973)

Roman Britain road network is particularly well understood (Orengo and Livarda, 2016)

• Roman Britain is often divided into two zones:
  – The Lowland zone
    • large areas of flat land in the South and East
    • Road network developed to provide communication for expanding civilian economy
  – The Highland zone
    • steep sloped and mountainous North and West
    • Road network facilitated quick and effective movement of troops and supplies

• LCP analysis thought of as environmentally deterministic, as cultural or social variables are difficult to model

• Hypothesised that LCPs computed in the Highland zone will predict the location of Roman roads more accurately than LCPs in the Lowland zone
Methodology

Methodological Contention?

- **LCP analysis** represents a **well established** methodology within archaeological GIS (Rahn, 2007)

- The application of LCP techniques are **inadequately applied** in some cases (Herzog, 2013a)

- Wide variety of parameters used to calculate LCPs is a **“sign of immaturity in the field”** (van Leusen, 2002, p.6.5)

- **LCP validation** is the most important component of LCP analysis, however this is **uncommon** (Vermeulen, 2006)

Herzog, 2013b, p.182
Methodology – Cost Components

Cost components numerically express the difficulty of moving between individual cells in a raster grid

DEM (slope) – OS Terrain 5m

Nearly all archaeological LCP studies are based on slope (Herzog, 2013b)

OS River Network

Higuchi viewshed
Methodology – Cost Functions

Cost functions allow for the calculation of the cost of each move from a raster cell to its neighbour

**Tobler’s Hiking Function** *(Tobler, 1993)* - Time-based

- Cost = $6 \times \exp(-3.5 \times \text{abs}(S + 0.05))$

**Modified Hiking Function** *(Márquez-Pérez et al., 2017)* - Time-based

- Cost = $4.8 \times \exp(-5.3 \times \text{abs}((S \times 0.7) + 0.03))$

**Sixth Degree Polynomial** *(Herzog, 2010)* - Energy-based

- Cost = $1337.8 S^6 + 278.19 S^5 - 517.39 S^4 - 78.199 S^3 + 93.419 S^2 + 19.825 S + 1.64$

*Where S are Slope values

Due to the accuracy of LCPs being sensitive to the algorithm used, multiple cost functions should be compared *(Mlekuž, 2014)*

Cost Functions are arguably the most important component of a successful LCP analysis *(Kantner, 2012)*
The implementation of LCP analysis into GIS software has led to many studies using default settings, unaware of methodological issues (Herzog, 2014b)

- e.g., Number of neighbouring cells considered

Use of gdistance (R package) to overcome limitations with software such as ArcGIS and GRASS
Methodology – LCP Validation

Although there is no established method (Kantner, 2012), the best option is to compare the LCP results to remnants of old routes (Herzog, 2014a)

• Validated by determining the percentage of the LCPs within buffer distances from the known Roman roads

• Proposed the use of Flow maps as a way to visualise LCPs and understand the distribution of accuracy

Without validation, LCP results are “mere guesswork” (Herzog, 2013b, p.205)
Results – Highland zone

Cost function comparison

- **Sixth Degree Polynomial** (energy-based) least accurate at predicting the location of the Roman road in the Highland zone study area.

- Findings agree with Livingood (2012), who recommended the use of time based cost functions, as historical accounts were recorded in time rather than energy expenditure.

### Higuchi viewshed incorporation

- Increased accuracy of LCP

- Further strengthens the conclusion that the road location was dictated by the need to control the road.

<table>
<thead>
<tr>
<th>Cost Function</th>
<th>Within 250m (%)</th>
<th>Within 500m (%)</th>
<th>Within 1000m (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sixth Degree Polynomial</td>
<td>56</td>
<td>67</td>
<td>100</td>
</tr>
<tr>
<td>Tobler’s Hiking Function</td>
<td>64</td>
<td>98</td>
<td>100</td>
</tr>
<tr>
<td>Modified Hiking Function</td>
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<td>98</td>
<td>100</td>
</tr>
<tr>
<td>Higuchi Viewshed inclusion</td>
<td>77</td>
<td>98</td>
<td>100</td>
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Results – Lowland zone

Environmental Determinism

- LCP analysis predicts the Lowland zone Roman road less well
- Limited by inability to model social or cultural phenomena adequately

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<tbody>
<tr>
<td>Lowland zone study area</td>
<td>31</td>
<td>50</td>
<td>62</td>
</tr>
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<td>Highland zone study area</td>
<td>77</td>
<td>98</td>
<td>100</td>
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Percentage of LCP from known Roman roads is a coarse representation of the accuracy.

Flow maps

Line thickness denotes distance from LCP to known location of Roman roads.
### Significance

<table>
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<th>Contribution to the study of LCP analysis</th>
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<tr>
<td>- Use of gdistance to allow for greater flexibility in the calculation of LCPs</td>
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<td>- Identified the Modified Hiking Function as an alternative to the widely used Tobler’s Hiking function</td>
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<td>- Higuchi viewsheds effective at determining whether the need for visibility dictated the location of Roman roads</td>
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<td>- Flow maps allow for greater exploration of LCP results, and clarity when comparing multiple cost functions</td>
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<tr>
<td>- Unless social factors of the study area in Roman Britain are well known, the use of LCP analysis is recommended for the Highland zone</td>
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</tbody>
</table>

| Many studies use default settings to calculate LCPs, unaware of alternative and methodological issues (Herzog, 2014b) |
| - Little work in evaluating which cost function best models real human movement (Kantner, 2012) |
| - Visibility analysis is complex, with many methods not representing the sensory experience |
| - Current validation methods coarse and lack interpretability (Ali, 2003) |
| - LCP analysis is thought of as being environmentally deterministic, and overemphasises environmental factors on cultural activity |
Future Developments

- Incorporate artefacts into LCP calculation (e.g., distance from tombs, milestones)
- Combine LCP analysis with network analysis techniques in order to describe the patterns of communication of Roman roads in Roman Britain
- The use of Approximate Bayesian Computation to simulate multiple parameter combinations in order to generate LCPs that best match known paths

Herzog, 2013b, p.182
Thank you

Any questions?
References

- Ahlrichs, J.J. Gries, P. Schmidt, K. (2016) „Distance relationships or does distance matter – calculating a non-isotropic spatial relationship by integrating human energy expenditure in terrain based estimations“, Technical note 3: Collaborative Research Center 1070 – Geoscientific and archaeological research. University of Tübingen


