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

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Summary

This paper examines the suitability of using least cost path (LCP) analysis in the prediction of Roman roads in Roman Britain. Although LCP analysis is thought by some to represent a well established methodology, others reflect that more investigation into the parameters is needed. This paper describes the effect of using different cost functions on the computed LCP, including the newly developed Modified Hiking Function. Furthermore, this paper outlines the use of *gdistance* as a way to overcome limitations with off-the-shelf GIS software packages. Lastly, the use of flow maps as a new way to visualise LCPs is introduced.

KEYWORDS: Archaeological GIS, Least Cost Path Analysis, Viewshed analysis, Least Cost Path Visualisation, Roman studies

1. Introduction

In the last two decades, the reconstruction of ancient roads (e.g., Verhagen and Jeneson, 2012) and the identification of factors governing the construction of known roads (e.g., Kantner and Hobgood, 2003) using Geographical Information Systems (GIS) has increased (Lanen et al., 2015), with Least Cost Path (LCP) analysis, which finds the optimal path connecting two geographic points (Hardin et al., 2012), becoming widespread in its usage (Orengo and Livarda, 2016). As stated by Rahn (2005; 2007), the application of LCP analysis represents a well established methodology within archaeological GIS. Van Leusen (2002, p 6.5), disagrees, reflecting that the wide variety of parameters used to calculate LCPs is a “sign of immaturity of the field”. Therefore, as noted by Herzog (2013b), it is still necessary to investigate the parameters used in LCP calculations, and to assess the how adequately LCP models fit archaeological reality.

In order to investigate LCP analysis as a suitable technique, this study will examine the accuracy of LCPs in the prediction of the location of Roman roads in two distinct zones of Roman Britain: the South and East, and the military dominated North and West (Millet, 1990). According to Salway (2001), this division is in reference to the terrain of Britain, with the south and east, also known as the Lowland zone, being characterised by gentle slopes (Collingwood and Myres, 1936), which allowed for easier land communication (Salway, 2001) and less limited travel (Ottaway, 2007), and the north and west, also known as the Highland zone, being dominated by steep slopes (Collingwood and Myres, 1936), posing significant challenges to constructing straight roads (Knapton, 1996).

Due to LCP analysis being thought of as environmentally deterministic (Gaffney and van Leusen, 1995; Llobera, 1996; Wheatley and Gillings, 2002), with cultural or social variables being difficult to model within LCP calculations (Herzog, 2013b), this study hypothesises that the LCPs computed in the Highland Zone will better predict the location of Roman roads, compared to the predicted location of Roman roads in the Lowland zone, which have greater topographical freedom in their location.

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2. Method

In order to assess the suitability of LCP analysis for predicting the location of Roman roads, three study areas were chosen in the Highland zone (The Gask Ridge; The Stanegate; and Tomen Y Mur – Caer Gai), and one within the Lowland zone (Benenden – Canterbury) (Figure 1). By choosing a greater number of study areas within the Highland zone, the environmental determinism of LCP analysis can be assessed.

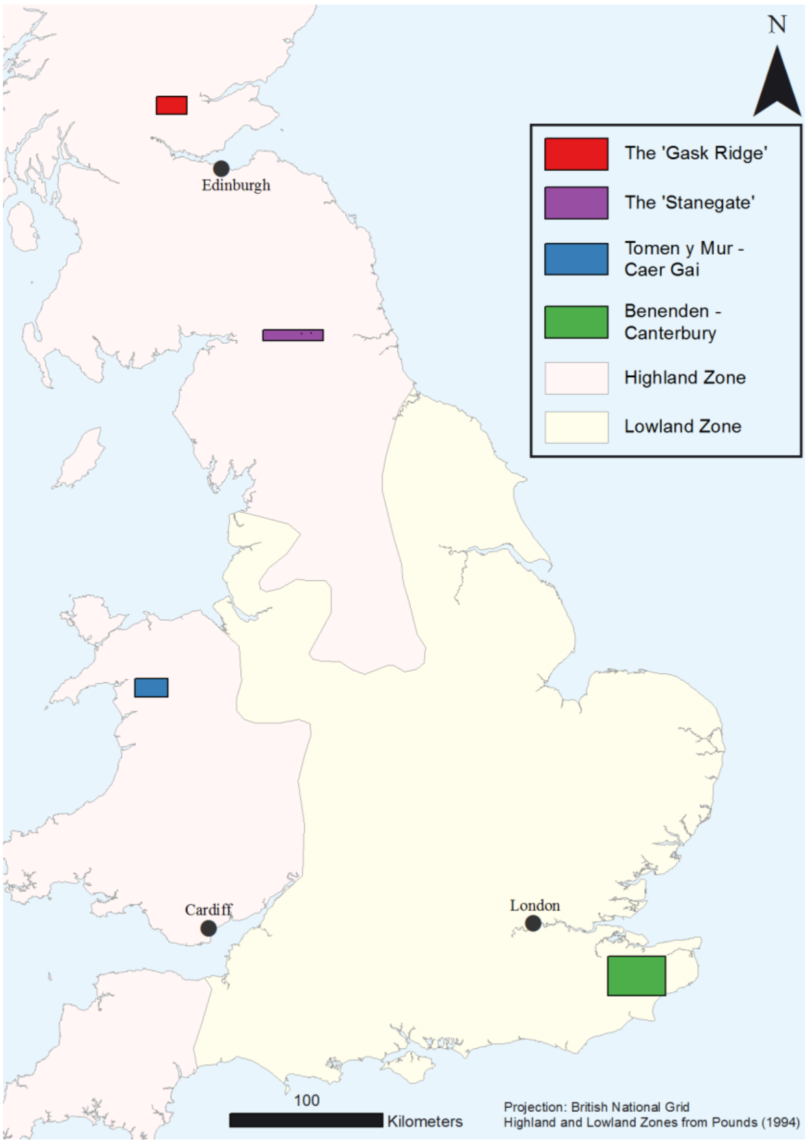

Figure 1 Overview of study areas and the Highland and Lowland zones of Roman Britain

In order to provide a representation of real-world topography, digital elevation models (DEMs) were used (Kantner, 2012). According to Kantner (2012), DEMs with a resolution of over 30 metres are too coarse to adequately represent the real world as experienced by humans travelling over a landscape. Therefore, this study utilised the Ordnance Survey Terrain 5m resolution DEM (Ordnance Survey, 2017b). Furthermore, the Roman Britain road network and pre-Hadrian forts detailed by Margary (1973), and digitised by Bishop (2014), were used (Figure 2).

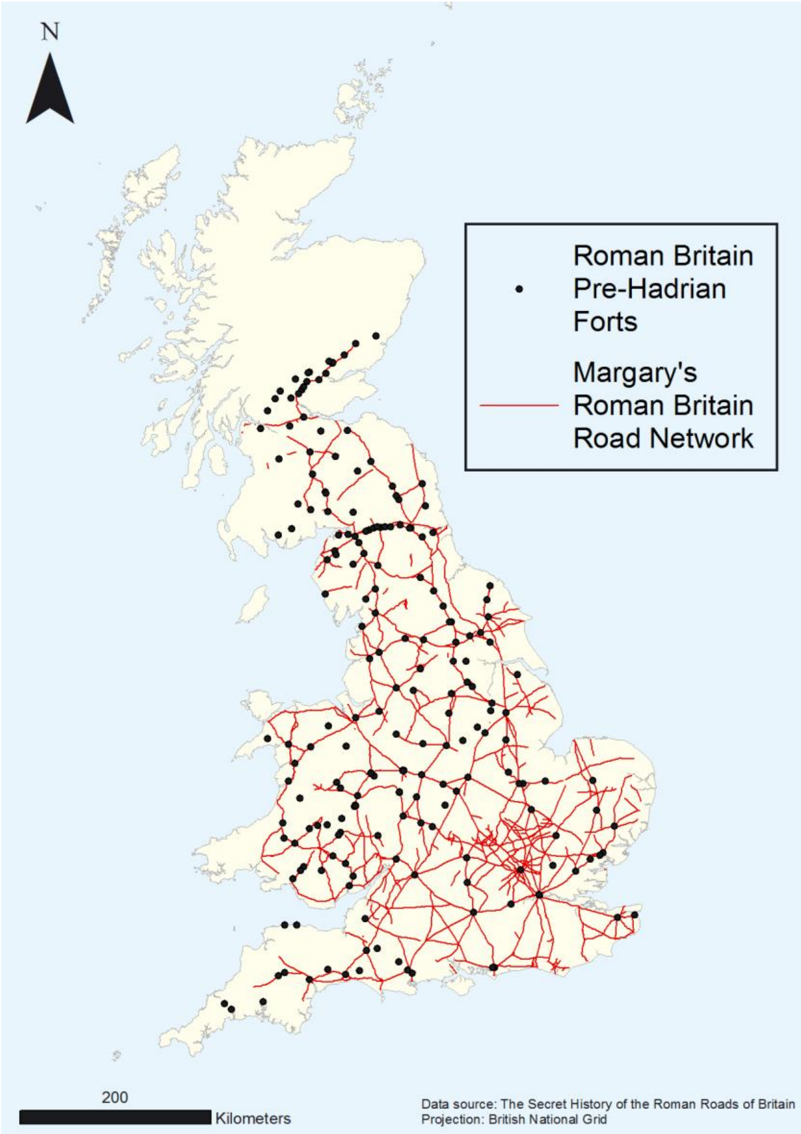

Figure 2 Margary’s Roman Britain road network and location of Pre-Hadrian forts digitised by Bishop (2014)

Due to rivers acting negatively on movement across a landscape (Wheatley and Gillings, 2002), the Ordnance Survey Open Rivers network was used (Ordnance Survey, 2016). To ensure that the LCPs were forced to cross bridges, which were commonly used in Roman Britain to cross rivers (Bishop, 2014), gaps in the river network were introduced (Figure 3).

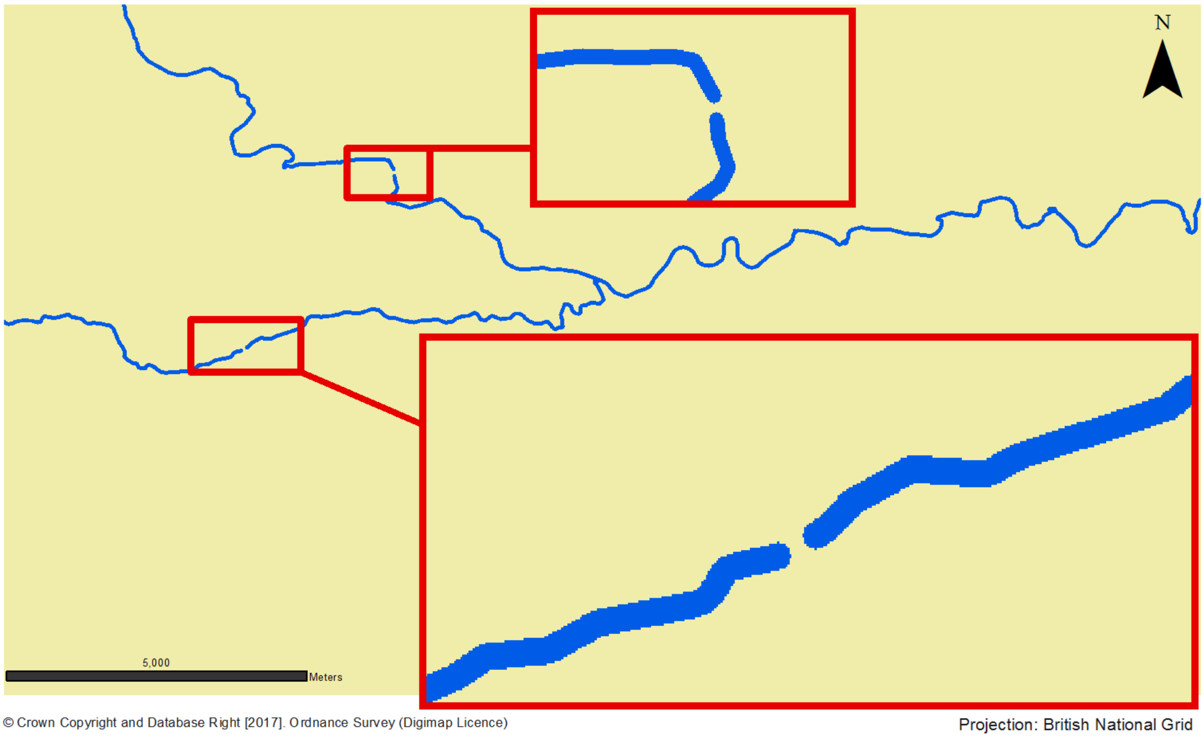

Figure 3 Ordnance Survey Open Rivers network, with gaps signifying the location of bridges.

Furthermore, the Higuchi viewshed, which classifies visible areas based on the visual appearance of objects (van Leusen, 2002), and yet to be used in LCP analysis, was utilised in order to assess whether the location of Roman roads in two of the study areas in the Highland Zone were dictated by the location of Roman Forts and the need to control movement along and across the roads (Figure 4).

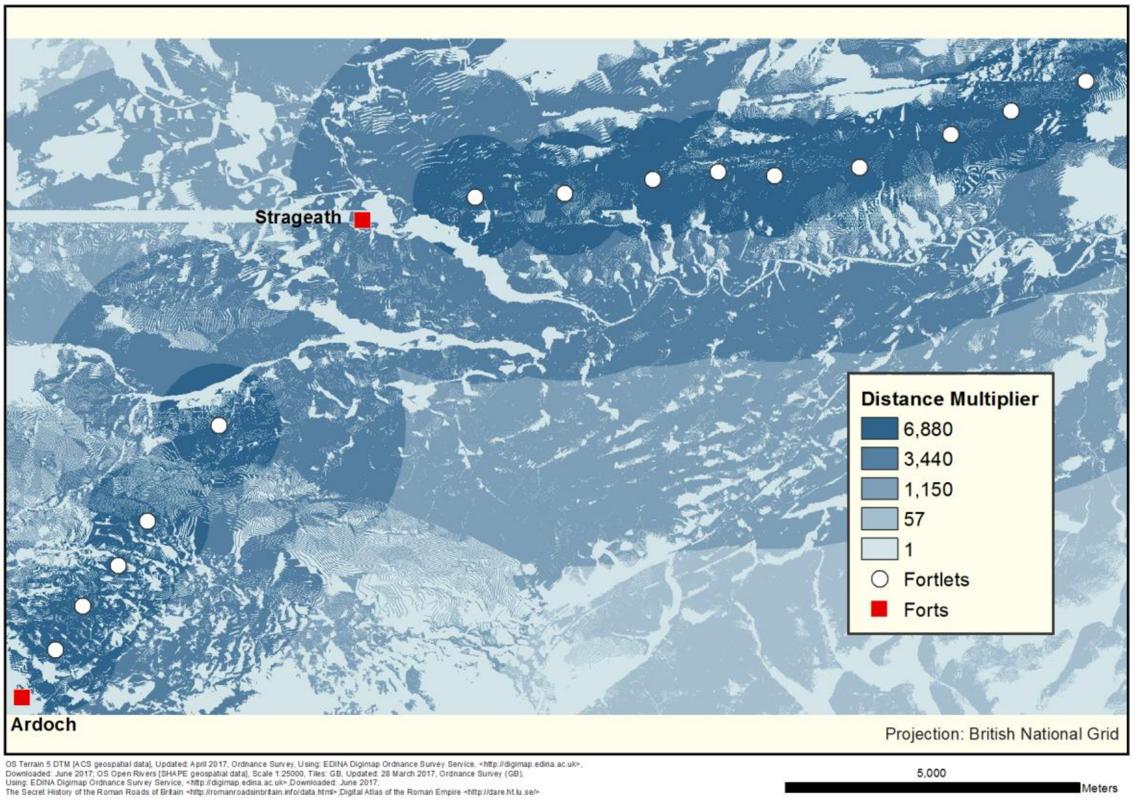

Figure 4 Higuchi viewshed cost surface for the Gask Ridge study area

Due to the cost function, which allows for the calculation of the cost of each move to its neighbouring raster cell (Herzog, 2014a), being regarded as the “backbone to any archaeological least-cost analysis” (Herzog, 2010, p.375), multiple LCPs using different cost functions were compared. Namely, Tobler’s (1993) ‘Hiking Function’ (Equation 1.A), which is perhaps the most widely used cost function (Wheatley and Gillings, 2001), Herzog’s (2010) ‘sixth degree polynomial’ (Equation 1.B), based on energy expenditure detailed in Minetti et al. (2002), and Márquez-Pérez et al. (2017) ‘Modified Hiking Function’ (Equation 1.C), which combines the precision of the MIDE rule (París Roche, 2002) and the continuity of Tobler’s ‘Hiking Function’, and has yet to be used in an LCP analysis.

$$Cost = 6 * exp(-3.5 * abs(s + 0.05)) \quad (1.A)$$

$$Cost = 1337.8\, s^6 + 278.19\, s^5 - 517.39\, s^4 - 78.199\, s^3 + 93.419\, s^2 + 19.825\, s + 1.64 \quad (1.B)$$

$$Cost = = 4.8 * exp(-5.3 \times abs((S \times 0.7) + 0.03)) \quad (1.C)$$

Although LCP analysis has been implemented in GIS software, such as ArcGIS (Surface-Evans and White, 2012), this has led to many studies using default settings, unaware of methodological issues (Herzog, 2014b). For instance, the number of neighbouring cells considered when using ArcGIS is limited to 8, which Harris (2000) states can result in incorrect LCPs. To overcome these limitations, the LCP analysis was conducted within R, using the spatial analysis package *gdistance* (van Etten, 2017), which allows for up to 16 directions (Figure 5), and provides greater flexibility in the calculation of LCPs (van Etten, 2017).

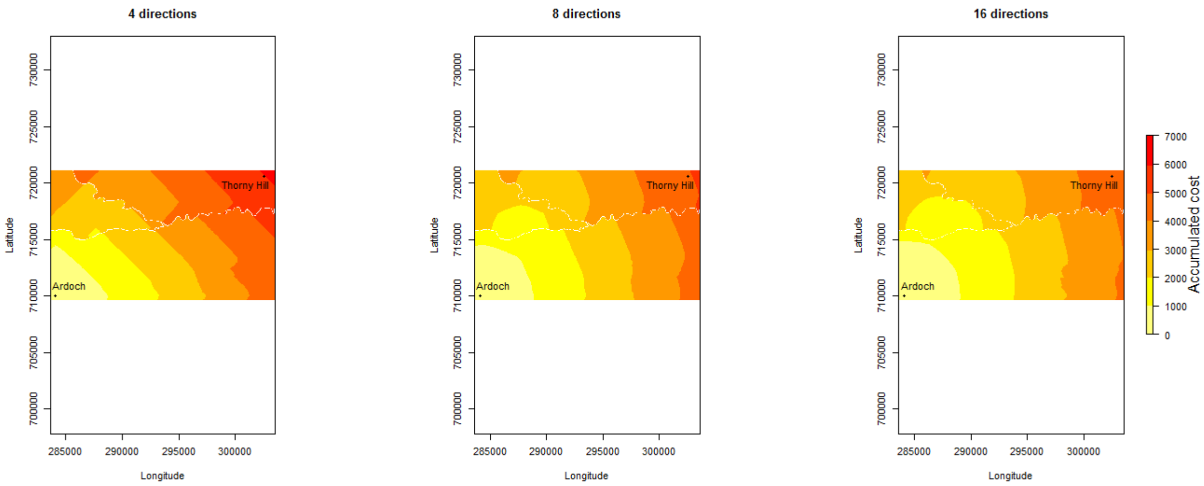

Figure 5 Accumulated cost surface for the Gask Ridge study area when using 4, 8, and 16 directions

In order to validate the predicted LCPs, the LCPs were compared to the Roman roads digitised by Bishop (2014). Following the validation method outlined in Güimil-Fariña and Parcero-Oubiña (2015), a buffer of 250m, 500m, and 1000m was created from the Roman roads. From this, the percentage of the LCPs that intersected the buffers was calculated. Furthermore, the worst case distances (Herzog, 2014b), which is the distance between the optimal straight line and the LCPs, was calculated. To provide greater interpretive potential, flow maps, which have yet to be used in LCP analysis, were utilised in order to visualise the differences in distance from the known and predicted Roman roads.

3. Results

By comparing the computed LCPs using the different cost functions, it was found that the least accurate was the energy based sixth degree polynomial (Herzog, 2010), whilst Tobler’s Hiking Function (Tobler, 1993) and the Modified Hiking Function (Márquez-Pérez et al., 2017) produced similar LCPs (Figure 6), with 64% of the predicted LCP lying 250m from the known Roman road (Table 1).

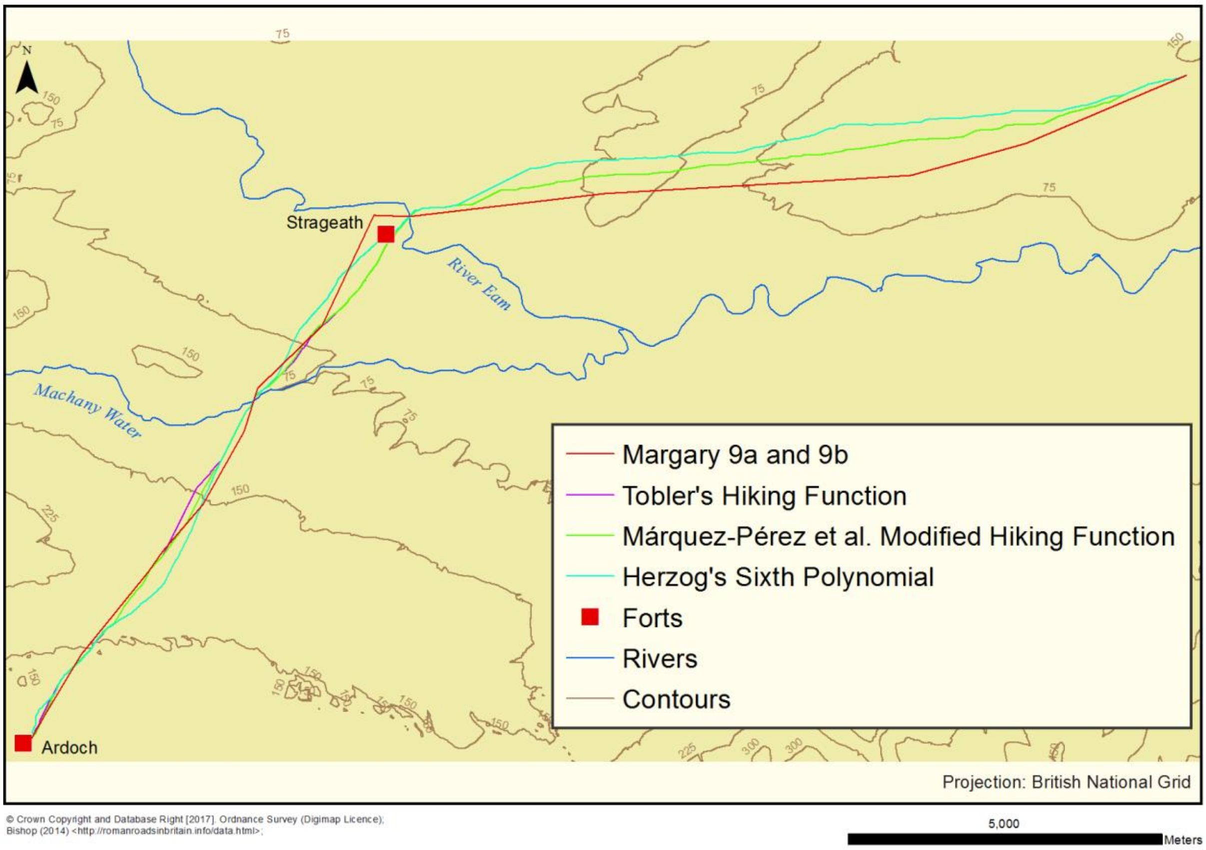

Figure 6 Computed LCPs in the Gask Ridge study area using different cost functions

Table 1 Predicted LCP lying within distances from the known Margary 9a and 9b Roman road when using different cost functions

Cost Function	Within 250m (%)	Within 500m (%)	Within 1000m (%)
Herzog's Sixth Polynomial	56	67	100
Tobler's Hiking Function	64	98	100
Márquez-Pérez et al. Modified Hiking Function	64	98	100

By utilising flow maps, the most significant deviation from the predicted LCP using the Márquez-Pérez et al. (2017) Modified Hiking Function and the known Roman road was shown to be between Parkneuk and Moss side, with a distance greater than 250m (Figure 7).

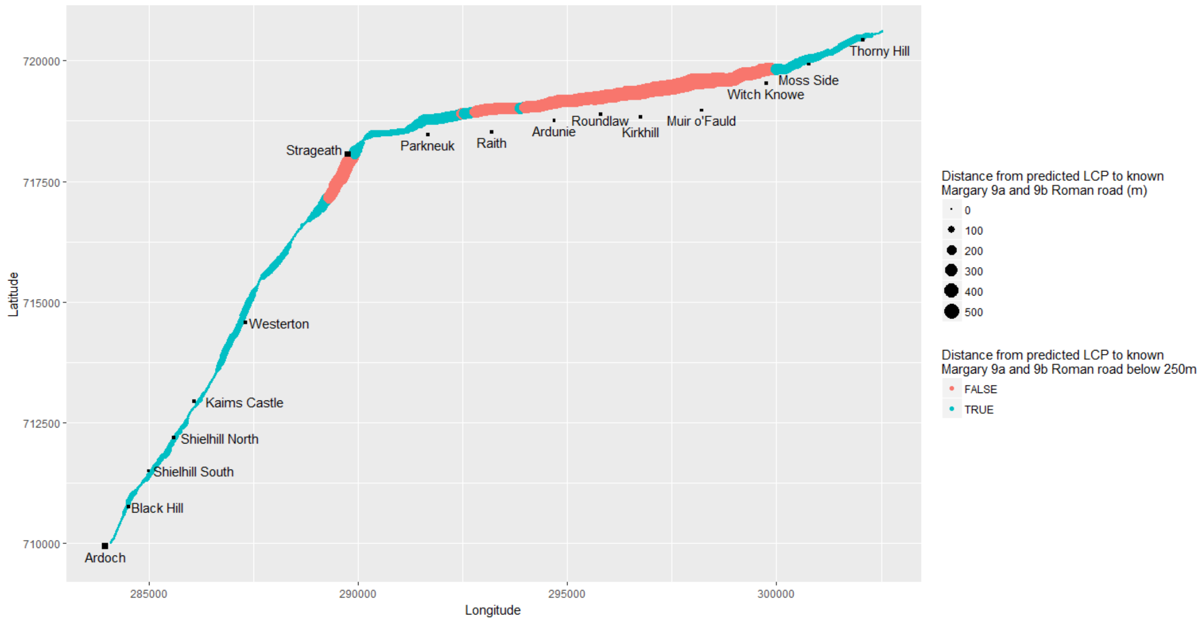

Figure 7 Flow map of the LCP in the Gask Ridge study area

Furthermore, the LCP in the Highland zone Gask Ridge study area which incorporated the Higuchi viewshed resulted in an increased predictive accuracy (Figure 8), with 77% of the LCP lying within 250m from the known Roman road (Table 2), and further strengthens the conclusions by Hanson and Maxwell (1986) and Breeze (1982), who suggested that the location of the road was dictated by the need to control the road.

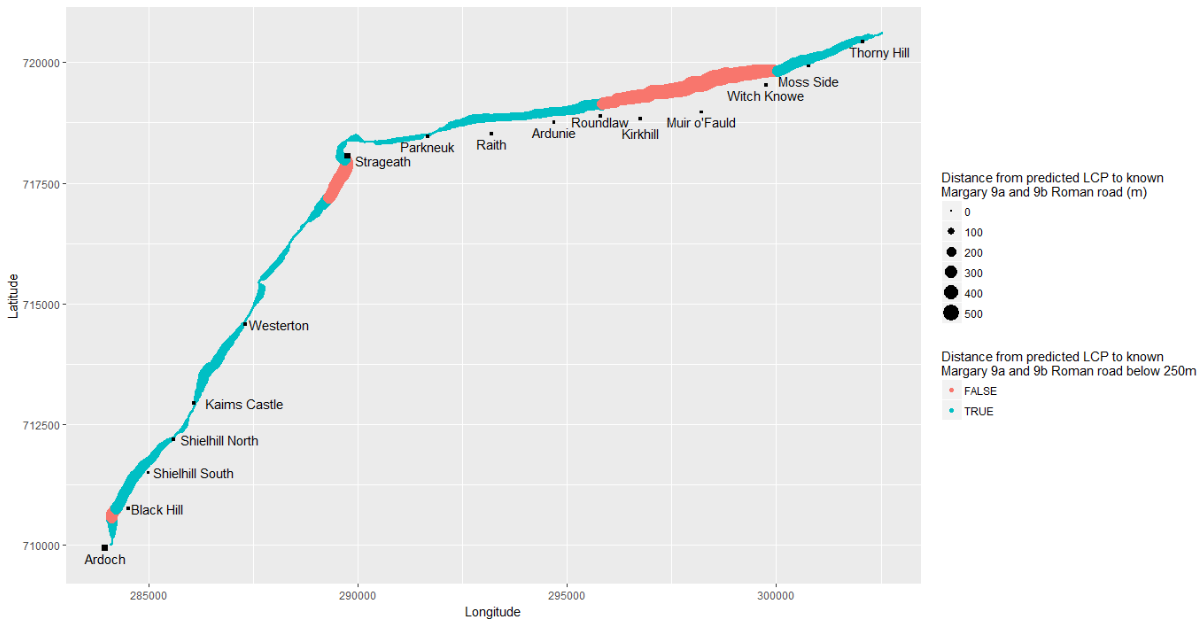

Figure 8 Flow map of the LCP in the Gask Ridge study area when Higuchi viewshed

Table 2 Predicted LCP lying within distances from the Gask Ridge Roman road when using 16 directions, Márquez-Pérez et al. Modified Hiking Function and the Higuchi viewshed

Cost Function	Within 250m (%)	Within 500m (%)	Within 1000m (%)
Márquez-Pérez et al. Modified Hiking Function	64	98	100
Higuchi Viewshed inclusion	77	98	100

Conversely, the LCP predicted in the lowland zone Benenden-Canterbury study area (Figure 9) resulted in 31% lying within 250m from the known Roman road (Table 3), showing the environmental deterministic nature of LCP analysis, with its limitations in modelling social or cultural phenomena adequately (Herzog, 2013b).

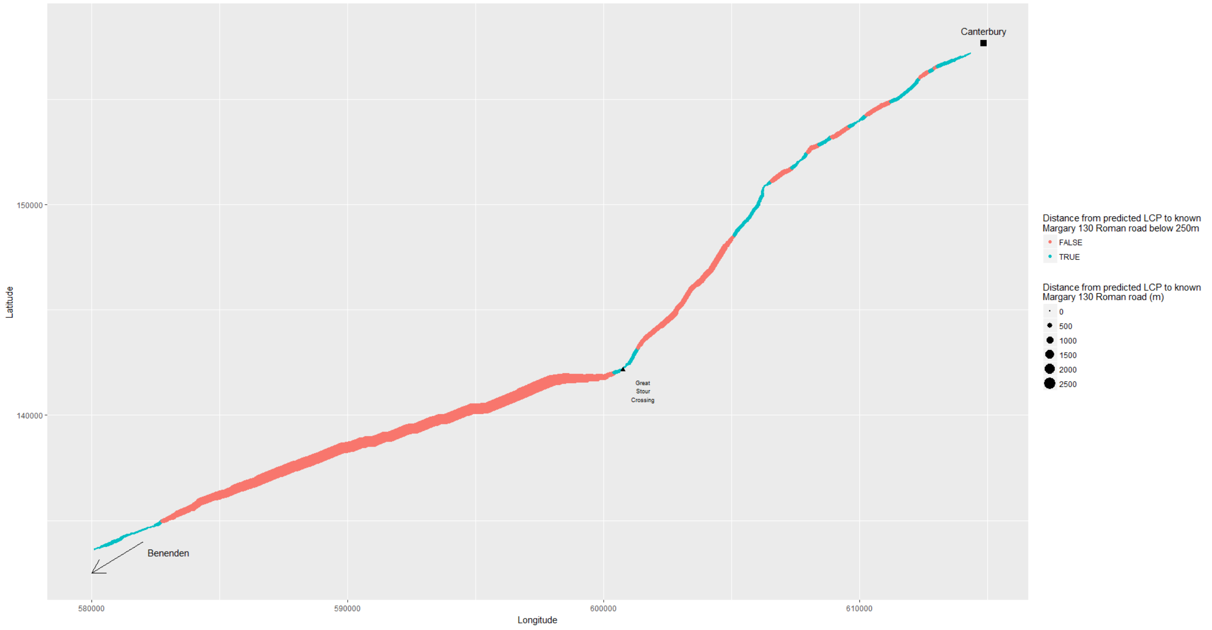

Figure 9 Flow map of the LCP in the Benenden - Canterbury study area

Table 3 Predicted LCP lying within distances from the Benenden - Canterbury Roman road when using 16 directions and the Márquez-Pérez et al. (2017) Modified Hiking Function

Cost Function	Within 250m (%)	Within 500m (%)	Within 1000m (%)
Benenden-Canterbury study area	31	50	62

This environmental determinism is also evident when comparing the worst case distance from the predicted LCPs to the Roman roads in the four study areas, with the accuracy of the predicted LCPs dividing into two groups: namely, the study areas in the Highland zone (The Gask Ridge; The Stanegate; and Tomen Y Mur – Caer Gai) and the Lowland zone (Benenden – Canterbury) of Roman Britain (Figure 10).

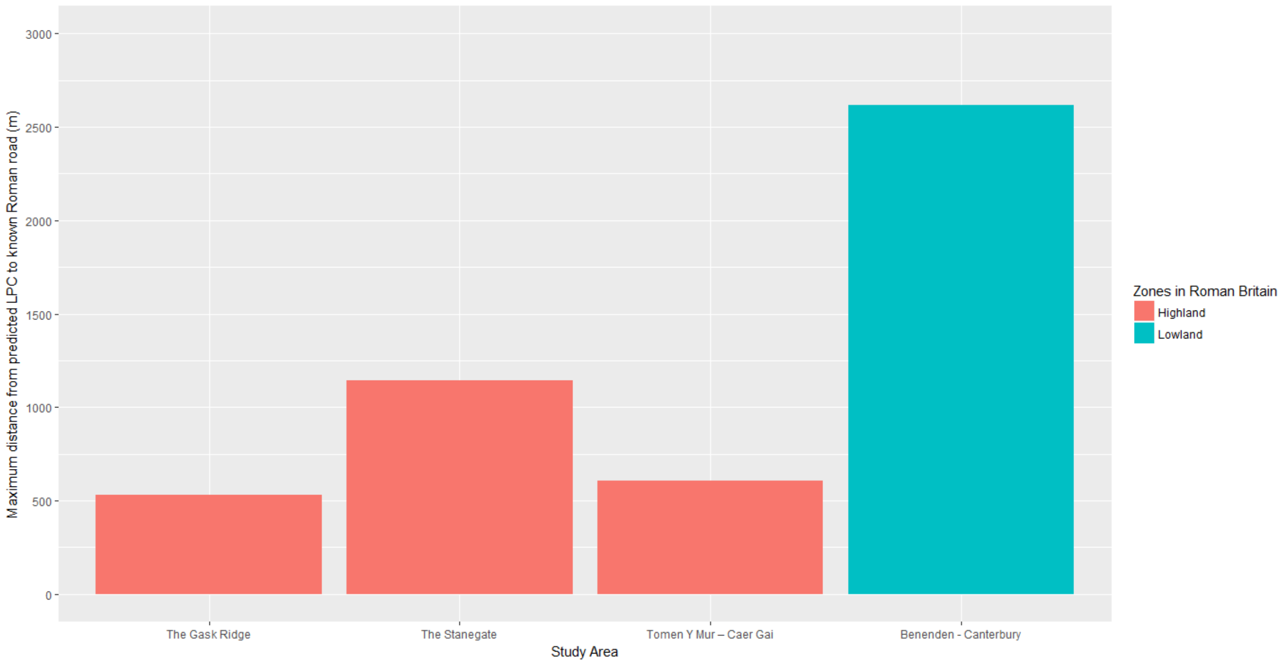

Figure 10 Worst case distance from the computed LCPs to the Roman roads in the four study areas

4. Conclusion

This study assessed the suitability of LCP analysis for the prediction of the location of known Roman roads in Roman Britain. As hypothesised, the LCPs generated for study areas in the Highland zone of Roman Britain were more accurate at predicting the location of known Roman roads than the LCPs computed in the Lowland zone.

Furthermore, three main points have been concluded, each offering recommendations for future LCP analyses. Firstly, unless social features of the study area in Roman Britain are well known, and able to incorporated into the calculation, the use of LCP analysis should be limited to predicting Roman roads in the Highland zone. Secondly, comparisons of multiple cost functions should be done, ensuring that the most accurate is used in the LCP calculations. Lastly, the integration of the Higuchi viewshed within the LCP calculation has been shown to be effective at determining whether the location of the Roman roads were dictated by the need to be near fortlets, and enable the control of the roads. Therefore, it is recommended that future LCP analyses that explore visibility use the Higuchi Viewshed.

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Biography

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