

Walking the Ridgeway Revisited: The Methodological and Theoretical Implications of Scale Dependency for the Derivation of Slope and the Calculation of Least-Cost Pathways

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Abstract

The rapid expansion of use of GIS within landscape archaeology during the 1990s went hand in hand with changes in archaeological theory which fetishised the “experience” of the past and the “perception” of landscape. The widespread availability and ease of use of “push button” functionality for cost surface and viewshed analysis has resulted in the proliferation of movement and visibility studies seeking to immerse the contemporary observer within the archaeological landscape. Despite their interpretative merits, these studies are largely uncritical, even though the algorithms employed in cost surface analysis and the calculation of least cost pathways have become increasingly sophisticated. With a few notable exceptions, however, there has been little wider consideration of the methodological implications of the raster datasets (DEMs and their slope derivatives) which underpin this analysis. This paper builds on those presented in sessions at CAA2006 (Fargo) and CAA2008 (Budapest) which highlighted the potential implications of the cell size or resolution of these datasets. The issue of scale lies at the heart of this apparent contradiction, highlighting the need to respect local topographic detail on the one hand and the importance of the underlying topography on the other—long - before the advent of GIS, topographic features such as ridges and rivers were highlighted as important axes of movement. Calculations of slope, cost surfaces and least-cost pathways are based on cell neighbourhoods or $n \times n$ windows and have traditionally been reliant upon the comparison of the cells immediately adjacent to the location for which an attribute is calculated, i.e. a 3×3 window. Whilst algorithms such as the “Knight’s move” increase the size of the cell neighbourhood, expanding the number of cells used in a calculation to 24 cells (equivalent to a 5×5 window), emphasis continues to be placed on small scale or localized topographic features. This paper seeks to consider the methodological and theoretical implications of using larger cell neighborhoods or window sizes with reference to a classic case study based on the Hillforts of the Ridgeway Project and published in 2000. It also introduces some new theoretical considerations into movement and visibility studies including the “corridor of intentionality” and using cultural landscape features as mid-distance waypoints.

Keywords: *affordance, corridor of intentionality, least-cost pathways, mid-distance waypoints, slope*

1 INTRODUCTION

In his influential review of cost surface analysis and its applications in archaeology which attempt to model human movement, van Leusen stated that “current GIS can only make local decisions as to which neighboring cell has the highest or lowest value—they incorporate no global knowledge of the landscape.”¹ This statement captures the essence of the problem we are attempting to address in this paper.

When mapped onto the human experience of movement, walking in particular, the shortcomings of cost surface analysis (and the related calculation of least-cost pathways) become clear. While we obviously pay attention to the few meters of ground immediately in front of us when walking, this near-distance terrain is to a large extent overridden by mid- and far-distance

considerations. Intentionality is a key element in that we usually know where we are going and where we want to end up, and, therefore, the direction of travel is to a certain extent pre-determined. Within this far-distance intentionality there are also often mid-distance considerations; for example, topographic and cultural features within the landscape can act as signposts or waypoints guiding towards the final destination. Integral to this is vision, being able to see mid- and far-distant features so that movement and vision become one and influence each other. Here we will address these issues through a combination of a developing new methodology and its application to the Ridgeway area in Oxfordshire, England, a case-study already used to illustrate the potential of modeling movement.

Before getting into the detail of our methodology it is worth exploring some of these background issues a little more. It is generally argued, and seems to be generally accepted, that “technical accuracy” is of fundamental importance when modeling movement. By this we mean the attention paid to trying to achieve the best DEM resolution and the most “accurate” and “objective” algorithm to calculate a least-cost pathway (see below). This quest for accuracy is counter-intuitive when

¹ Martijn van Leusen, “Viewshed and Cost Surface Analysis Using GIS (Cartographic Modeling in a Cell-Based GIS II),” in *New Techniques for Old Times. CAA 98. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 26th Conference, Barcelona, March 1998*, ed. Juan A. Barcelo, Ivan Briz and Assumpcio Vila (Oxford: BAR International Series 757, 1999) 218.

compared with the subjective decision-making involved in walking across an open stretch of landscape.

The combination of directional intentionality based on a known destination and the visibility of intermediate waypoints creates a “corridor of intentionality” through which movement proceeds, rather than a well defined pathway. Progress is based on mid-distance targets which aggregate to achieve the final aim even if each waypoint is not actually reached but is bypassed once it gets close enough for the next one to be in view and become the next aim. This solution based on a “least-cost corridor” has been suggested by Kondo and his colleagues,¹ resulting from both practical experimentation and the comparison of different algorithms.

Our approach is grounded in the ecological psychology of James Gibson² concerning movement and visual perception and his suggestion that movement and vision are inextricably linked within the human “perceptual system.” Movement and vision work together and influence each other in the process of human understanding of the surrounding environment and, while vision can be static, it is much more likely to be part of a moving and active observer.

Vision can revolve through 360 degrees by spinning on a single point, although it is more realistic to think of a cone of vision facing in the direction of view, and more importantly here, the direction of travel. This has obvious implications for any viewshed analysis, most of which tend to be the “all seeing” version rather than utilising directional viewsheds as suggested several years ago by Wheatley and Gillings.³ Here we work with this idea of a cone of vision which, as movement proceeds, takes in mid-distance waypoints to guide the direction of travel.

There is a further connection with the work of Gibson and this is his notion of affordance and that we make sense of the world through the possibilities for action that things offer us. He argues that properties are afforded within the context of practical action and that any understanding of affordance is a dialectic between

the perceiver and the environment. Here we can understand waypoints, whether topographic as in landscape features or cultural as here with hillforts, as affording movement towards the final destination.

2 BACK TO SQUARE ONE—RETHINKING WALKING THE RIDGEWAY

Despite increasing recognition of the importance of scale in archaeology,⁴ there has been little consideration of the implications of scale with regard to the calculation of least-cost pathways. The notion of scale dependency has been highlighted in viewshed analysis through the use of Higuchi, or banded, viewsheds⁵ which take into account the impact of distance on the “quality” of vision. Equally, distance, or scale, plays a significant role in the recognition of topographic features that may facilitate or inhibit movement, i.e. the perception of affordance as outlined above.

Recent studies have highlighted the impact of the resolution of DEMs on the calculation of least-cost pathways. Simulations based on the Iron Age city of Kerkenes Dağ in Turkey showed that least-cost pathways calculated using DEMs with smaller cell sizes provided a closer approximation to the known street network.⁶ Although interesting, this is not directly comparable to our situation, owing to the tight constraints imposed by an urban environment and the street network being modelled. More appropriate are the experiments carried out in the rural landscape around the Iron Age hillfort at Glauberg in Germany, which showed that least-cost pathways calculated using DEMs with larger cell sizes were shorter and followed a more direct route.⁷

In both instances, clear differences could be seen between the least-cost pathways calculated using DEMs

¹Yasuhisa Kondo et. al., “FIELDWALK@KOZU: A Preliminary Report of the GPS/GIS-aided Walking Experiments for Re-modeling Prehistoric Pathways at Kozushima Island (east Japan),” paper presented at the 36th Annual Conference on Computer Applications and Quantitative Methods in Archaeology, Budapest, Hungary, April 2–6, 2008.

²For a good introduction to Gibson’s work and its relevance to archaeology, see Alan Costall “On Being the Right Size: Affordances and the Meaning of Scale,” in Gary Lock and Brian Molyneaux, *Confronting Scale in Archaeology. Issues of Theory and Practice* (New York: Springer, 2006) 16–26, and specifically James J. Gibson, *The Senses Considered as Perceptual Systems* (London: George Allen and Unwin, 1968).

³David Wheatley and Mark Gillings, “Vision, Perception and GIS,” in *Beyond the Map: Archaeology and Spatial Technologies*, ed. Gary Lock (Amsterdam: IOS Press, 2000) 20–23.

⁴Gary Lock and Brian Molyneaux, *Confronting Scale in Archaeology. Issues of Theory and Practice* (New York: Springer, 2006).

⁵David Wheatley and Mark Gillings, “Vision, Perception and GIS,” in *Beyond the Map: Archaeology and Spatial Technologies*, ed. Gary Lock (Amsterdam: IOS Press, 2000); Vuk Trifković, “Persons and Landscapes: Shifting Scales of Landscape Archaeology,” in *Confronting Scale in Archaeology. Issues of Theory and Practice*, eds. Gary Lock and Brian Molyneaux (New York: Springer, 2006)

⁶Scott Branting, “Using an Urban Street Network and a PGIS-T Approach to Analyze Ancient Movement,” in *Digital Discovery: Exploring New Frontiers in Human Heritage. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 34th Conference, Fargo, United States, April 2006*, ed. Jeffrey Clark and Emily Hagemeister (Budapest: Archaeolingua, 2007) 99–108.

⁷Irmela Herzog and Axel Posluschny, “Tilt—Slope-Dependent Least Cost Path Calculations Revisited,” paper presented at the 36th Annual Conference on Computer Applications and Quantitative Methods in Archaeology, Budapest, Hungary, April 2–6, 2008.

with different resolutions. The least-cost pathways calculated between two of the sites in the area of Glauberg followed different topographic features; the least-cost pathway calculated using a DEM with a 25m cell size followed the line of a ridge, while the least-cost pathway calculated using a DEM with a 100m cell size followed the line of the valley to the north of the ridge.

The earlier work of the Hillforts of the Ridgeway Project focussed on a series of hillforts positioned along the ancient trackway, the Ridgeway, in central southern England (see fig. 1). Barbury Castle is the western-most site, with the modern Ridgeway running eastwards and passing close to Liddington Castle, Hardwell Camp, Uffington Castle, Rams Hill and then Segsbury Camp. The details of this work, including discussion of the algorithms used, will not be repeated here, although the aim was to use movement and visibility studies to throw light on the date and positioning of the hillforts in relation to moving along the Ridgeway.¹

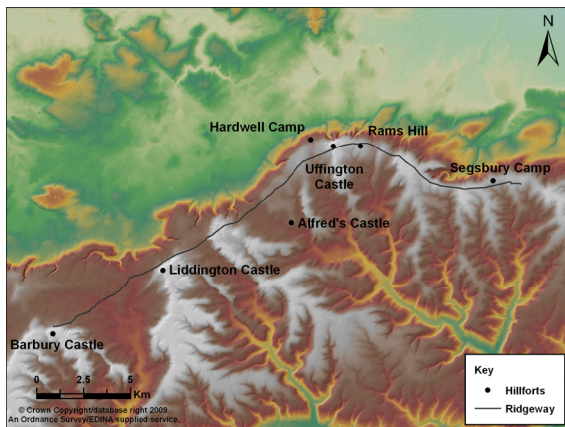


Figure 1. Location map showing the Ridgeway and Iron Age hillforts within the study area.

Here, the initial least-cost pathways calculated between Barbury Castle and Segsbury Camp were affected differently by topographic features, with the initial unconstrained least-cost pathway following the line of a valley to the north-east of Barbury Castle and “falling off” the Ridgeway (see fig. 2). This valley is the dominant topographic feature in the lower-lying area between Barbury Castle and Liddington Castle, where the Ridgeway is poorly defined.

To counteract this an east-west topographic bias was introduced, representing the intentionality inherent within moving from a known starting point to a known finishing point. The subsequent constrained least-cost pathway followed the approximate line of the Ridgeway, passing close to the sites of Liddington

¹Tyler Bell and Gary Lock, “Topographic and Cultural Influences on Walking the Ridgeway in Later Prehistoric Times,” in *Beyond the Map: Archaeology and Spatial Technologies*, ed. Gary Lock (Amsterdam: IOS Press, 2000) 85–100.

Castle, Uffington Castle, and Rams Hill. These hillforts are likely to have acted as mid-distance waypoints as movement progressed eastwards towards Segsbury Camp.

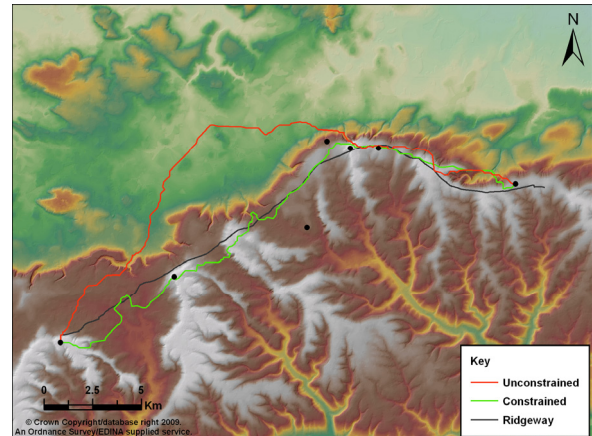


Figure 2. Initial least-cost pathways between Barbury Castle and Segsbury Camp (after Lock and Bell 2000, figs. 5 and 6).

The topographic features followed by least-cost pathways are closely related to the scale at which analysis is carried out. Landforms and the parameters which describe topographic surfaces are scale-dependent.² Parameters, such as slope and aspect, are calculated for the cell at the center of an $n \times n$ window. For computational ease, they are typically calculated using a 3×3 window, i.e. the cells which are immediately adjacent to the cell at the center of the window (see fig. 3).

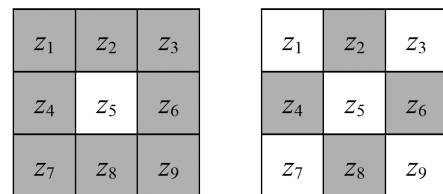


Figure 3. Notation for the elevations of the cells in a 3×3 window with the neighborhoods used in Horn’s algorithm (left) and Zevenbergen and Thorne’s algorithm (right) shaded in grey.

The algorithms used in the calculation of least-cost pathways are functions of slope, regardless of whether costs are evaluated in terms of energy expenditure³ or

²Ian Evans, “Scale-Specific Landforms and Aspects of the Land Surface,” in *Concepts and Modeling in Geomorphology: International Perspectives*, ed. Ian Evans et al. (Tokyo: Terrapub, 2003) 61–84.

³Marcos Llobera, “Understanding Movement: A Pilot Model Towards the Sociology of Movement,” in *Beyond the Map:*

travel time.¹ Slope is a 1st order derivative of elevation. The maximum gradient of a slope (hereafter referred to as “the slope”), the angle of inclination to the horizontal in decimal degrees, is perhaps the most common measure of slope. It is defined by the expression:

$$\text{slope} = \arctan \sqrt{\left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2} \quad (1)$$

The partial derivatives of this expression can be calculated using a variety of different methods. Horn² defines these partial derivatives as the west-east and north-south components of the slope. These components of the slope can be estimated by calculating weighted averages for the slope at the central point of each of the rows and columns in the 3 x 3 window,³

$$\frac{\partial z}{\partial x} = \frac{(z_3 + 2z_6 + z_9) - (z_1 + 2z_4 + z_7)}{8\Delta x} \quad (2)$$

where: Δx = cell size

$$\frac{\partial z}{\partial y} = \frac{(z_1 + 2z_2 + z_3) - (z_7 + 2z_8 + z_9)}{8\Delta y} \quad (3)$$

where: Δy = cell size

In contrast, Zevenbergen and Thorne⁴ fit a partial quartic surface through the data points corresponding to the centroids of each of the cells in the 3 x 3 window. The constants which define the partial derivatives of the slope at any point on this surface can be determined using Lagrange polynomials:⁵

$$\frac{\partial z}{\partial x} = \frac{(z_6 - z_4)}{2\Delta x} \quad (4)$$

Archaeology and Spatial Technologies, ed. Gary Lock (Amsterdam: IOS Press, 2000) 70–71.

¹Larry Gorenflo and Nathan Gale, “Mapping Regional Settlement in Information Space,” *Journal of Anthropological Archaeology* 9 (1990): 242–245.

²Berthold Horn, “Hill Shading and the Reflectance Map,” *Proceedings of the IEEE* 69.1 (1981): 18.

³The notation used by Horn has been substituted for the more conventional notation used in fig. 3 and the cells corresponding to each of the rows and columns in the 3 x 3 window have been re-ordered to read from left to right and top to bottom respectively.

⁴Lyle Zevenbergen and Colin Thorne, “Quantitative Analysis of Land Surface Topography,” *Earth Surface Processes and Landforms* 12 (1987): 49–50.

⁵Although the partial quartic surface is defined by nine data points, only the elevations of the data points corresponding to the centroids of the cells in the middle row and central column of the 3 x 3 window are actually used in the calculation of the slope using this algorithm.

$$\frac{\partial z}{\partial x} = \frac{(z_2 - z_8)}{2\Delta y} \quad (5)$$

Both of these algorithms are generally considered to be robust⁶ and consequently have been widely used in GIS applications: Horn’s algorithm is implemented in ArcGIS and GRASS through the *slope* procedure and the *r.slope.aspect* module respectively, while Zevenbergen and Thorne’s algorithm is implemented in Idrisi as part of the *Surface* routine.

The methodological and theoretical implications of the algorithms used to calculate slope have been largely neglected by archaeologists.⁷ Considerable variation has been noted in the values of slope calculated from digital elevation data using different algorithms.⁸ The magnitude of this variation is highlighted by the slope values calculated for the Ridgeway study area using Horn’s algorithm (see fig. 4) and Zevenbergen and Thorne’s algorithm (see fig. 5).

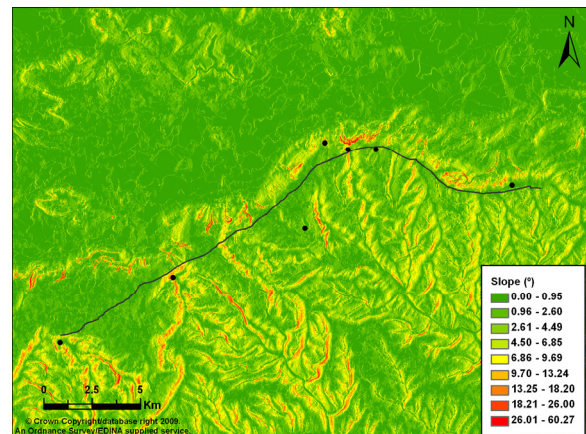


Figure 4. Slope calculated using Horn’s algorithm.

A marked difference can be seen between the ranges of the slope values calculated using Horn’s algorithm and those calculated using Zevenbergen and Thorne’s algorithm (60.27° and 48.32° respectively). The slope values calculated using each of these algorithms could vary by as much as ±14.49°, with over 250,000 (2.86%) of the values varying by more than ±5° and over 2,750,000 (32.78%) of the values varying by more than ±1° (see fig. 6).

⁶Peter Burrough and Rachael McDonnell, *Principles of Geographic Information Systems*, second ed. (Oxford: Oxford University Press, 1998) 192.

⁷Irmela Herzog and Axel Posluschny, “Tilt—Slope-Dependent Least Cost Path Calculations Revisited,” paper presented at the 36th Annual Conference on Computer Applications and Quantitative Methods in Archaeology, Budapest, Hungary, April 2–6, 2008.

⁸Steven Warren et al., “An Evaluation of Methods to Determine Slope Using Digital Elevation Data,” *Catena* 58 (2004).

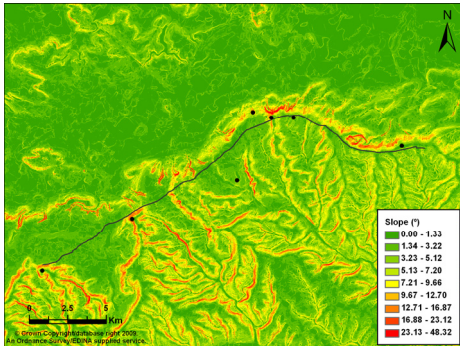


Figure 5. Slope calculated using Zevenbergen and Thorne's algorithm.

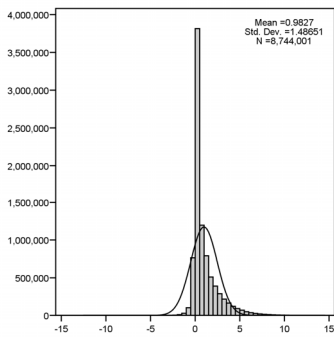


Figure 6. Residuals for the slope values calculated using Horn's algorithm and Zevenbergen and Thorne's algorithm.

Ordnance Survey Land-Form PROFILE™ DTM data, a DEM with a 10m cell size or resolution and a height accuracy of $\pm 2.5\text{m}$,¹ was used for the slope calculations which form the basis of the analysis presented in this paper. This dataset is interpolated from 1:10,000 Ordnance Survey mapping, which was recontoured between the early 1960s and 1987 using photogrammetry, supplemented by ground survey methods in areas which were not visible on aerial photographs.

The errors inherent in DEMs interpolated from contour data are well-documented. Errors are often most prevalent in low-lying areas or areas where there are large gaps between contours. "Ghost" contours and interpolation artifacts such as "terracing" can be seen in the slope data for the Ridgeway study area. Similar "ghosting" and "terracing" can be seen in the spatial distribution of the residuals for the algorithms which were used to calculate the slope values (fig. 7).

Variation in the values of the slope introduced as a result of errors in the digital elevation data can be eliminated by increasing the size of the $n \times n$ window used to calculate the slope. The analysis of larger

window sizes, however, requires functionality that supports complex map algebra and is computationally intensive. Slope calculations based on the analysis of an $n \times n$ window are supported by the implementation of Evans' algorithm in Landsferf.

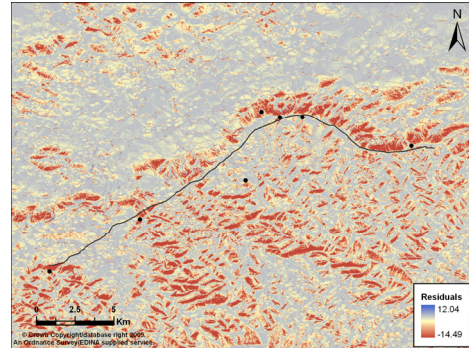


Figure 7. Spatial distribution of the residuals for the slope calculated using different algorithms.

Evans² uses quadratic approximation to calculate the partial derivatives of the slope which, like Zevenbergen and Thorne's algorithm, is based on trend surface analysis. A quadratic trend surface is fitted through the data points corresponding to the centroids of each of the cells within the $n \times n$ window. This surface is defined by the equation:

$$z = ax^2 + by^2 + cxy + dx + ey + f \quad (6)$$

Where: x = x-coordinate
 y = y-coordinate
 z = elevation

Solution of this equation is simplified by the arrangement of the data points on a square grid. The partial derivatives of the slope at any point on this surface can be estimated by differentiating equation (6) with respect to x and y :

$$\frac{\partial z}{\partial x} = 2ax + cy + d \quad (7)$$

$$\frac{\partial z}{\partial y} = 2by + cx + e \quad (8)$$

Calculation of the partial derivatives of the slope is simplified by establishing a local co-ordinate system with an origin ($x=0$ and $y=0$) at the center of the $n \times n$ window. Where $x=0$ and $y=0$:

$$\frac{\partial z}{\partial x} = d \quad (9)$$

¹Ordnance Survey, "Land-Form PROFILE™: User Guide," Ordnance Survey Technical Information, www.ordnancesurvey.co.uk/oswebsite/products/landformprofile/pdf/profil_w.pdf

²Ian Evans, *An Integrated System of Terrain Analysis and Slope Mapping*, Final Report on Grant DA-ERO-291-73-G0040 (Durham: University of Durham, 1979).

$$\frac{\partial z}{\partial y} = e \quad (10)$$

In the case of a 3 x 3 window, the constants which correspond to the partial derivatives of the slope at the center of the window are defined by the expressions:

$$\frac{\partial z}{\partial x} = \frac{(z_3 + z_6 + z_9) - (z_1 + z_4 + z_7)}{6\Delta x} \quad (11)$$

$$\frac{\partial z}{\partial y} = \frac{(z_1 + z_2 + z_3) - (z_7 + z_8 + z_9)}{6\Delta y} \quad (12)$$

A matrix solution is required for the general case of an $n \times n$ window. The coefficients which define a quadratic surface can be calculated using a set of six simultaneous equations.¹ These expressions can be expressed in matrix form and can be solved through matrix inversion²:

$$\begin{pmatrix} \sum x_i^4 & \sum x_i^2 y_i^2 & 0 & 0 & 0 & \sum x_i^2 \\ \sum x_i^2 y_i^2 & \sum x_i^4 & 0 & 0 & 0 & \sum x_i^2 \\ 0 & 0 & \sum x_i^2 y_i^2 & 0 & 0 & 0 \\ 0 & 0 & 0 & \sum x_i^2 & 0 & 0 \\ 0 & 0 & 0 & 0 & \sum x_i^2 & 0 \\ \sum x_i^2 & \sum x_i^2 & 0 & 0 & 0 & N \end{pmatrix} \begin{pmatrix} a \\ b \\ c \\ d \\ e \\ f \end{pmatrix} = \begin{pmatrix} \sum z_i x_i^2 \\ \sum z_i y_i^2 \\ \sum z_i x_i y_i \\ \sum z_i x_i \\ \sum z_i y_i \\ \sum z_i \end{pmatrix} \quad (13)$$

where N = total number of points (i.e. n^2)

By increasing the size of the window used to calculate slope, the scale of analysis becomes independent of the cell size or resolution of the DEM. Analysis can be performed at a variety of different scales using the same dataset, without the need to resample the DEM at a smaller cell size or lower resolution.³ Whilst a degree of smoothing is inevitable, this is preferable to loss of data as a result of resampling.

¹David Unwin, "An Introduction to Trend Surface Analysis," *Concepts and Techniques in Modern Geography* 5 (Norwich: Geo Abstracts Ltd, 1975) 17.

²The simultaneous equations have been reordered to simplify the inversion of the matrix, and expressions without even exponents are reduced to zero due to the symmetry of the coordinate system; after Jo Wood, *The Geomorphological Characterisation of Digital Elevation Models* (Ph.D. diss., University of Leicester, 1996) 91–93.

³Cf. Axel Posluschny, "GIS as a Means to Investigate 'Princely Sites,'" *Space and Environs. New Ways to Answer Old Questions,* in *ArchaeDyn—7 Millennia of Territorial Dynamics, Settlement Pattern, Production and Trades from Neolithic to Middle Ages. ACI 'Spaces and Territories' 2005–2007,* ed. Cristina Gandini, François Favory and Laure Nuninger (Preprints Final Conference, Dijon, 23–25 June 2008) 169.

3 MULTISCALAR PATHWAYS

Cost surfaces were generated for the study area using slope data calculated from a range of window sizes.⁴ The least-cost pathways that were calculated from these cost surfaces were compared against the line of the Ridgeway and the initial constrained least-cost pathway between Barbury Castle and Segsbury Camp, i.e. the least-cost pathway calculated after the introduction of an east-west topographic bias.

Slope values were calculated using window sizes between 3 x 3 and 101 x 101. The ranges of the slope values decrease exponentially as the size of the window increases (see fig. 8). Whilst the maximum value of the slope is dependent upon the window size, the cost surfaces that are generated from the slope data are based on relative costs, i.e. comparison of the values of the slope within an individual dataset.⁵

As the size of the window increases, so does the number of cells used in the calculation of the slope. The slope values that are used to generate cost surfaces begin to incorporate global knowledge of the landscape, and the related least-cost pathways are based on the assessment of topography over longer distances (up to c.500m in the case of a 101 x 101 window), rather than the few meters of ground immediately in front of the person walking (10m in the case of a 3 x 3 window).

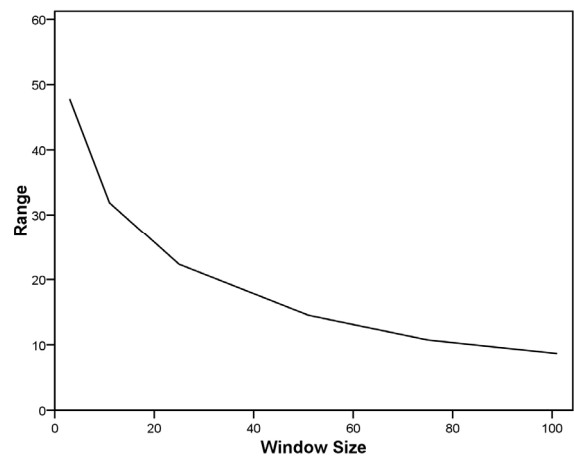


Figure 8. Ranges of slope values calculated for different window sizes.

⁴The methods used to generate the cost surface are described in Tyler Bell and Gary Lock, "Topographic and Cultural Influences on Walking the Ridgeway in Later Prehistoric Times," in *Beyond the Map: Archaeology and Spatial Technologies,* ed. Gary Lock (Amsterdam: IOS Press, 2000) 85–100.

⁵The maximum value of the slope calculated using Evans' algorithm was 47.78° (based on a 3 x 3 window). For slopes < c.50°, the relationship between the angle of slope and the relative cost is almost linear (see Bell and Lock 2000, fig. 3). Below this threshold, the error introduced by variation in the maximum value of the slope is considered to be negligible.

Clear differences can be seen between the least-cost pathways calculated using slope data for different window sizes (see figs. 9 to 12). These differences are largely confined to the western part of the study area, where the Ridgeway is poorly defined. In the eastern part of the study area, the least-cost pathways converge upon the line of the current Ridgeway and the corridor of movement in Later Prehistoric times can be defined with a high degree of confidence.

The least-cost pathway based on slope data calculated using quadratic approximation for a 3 x 3 window (see fig. 9) provided a closer match to the current Ridgeway than the initial constrained least-cost pathway, which was based on slope data calculated using Zevenbergen and Thorne's algorithm.^{1, 2} The differences between the least-cost pathways effectively amount to a choice between different topographic features. For instance, the least-cost pathway based on slope values calculated using a 3 x 3 window (see fig. 9) followed the northern edge of a ridge to the east of Barbury Castle, whereas the least cost-pathways based on slope values calculated for the other window sizes illustrated here (see figs. 10 to 12) followed the southern edge of this ridge.

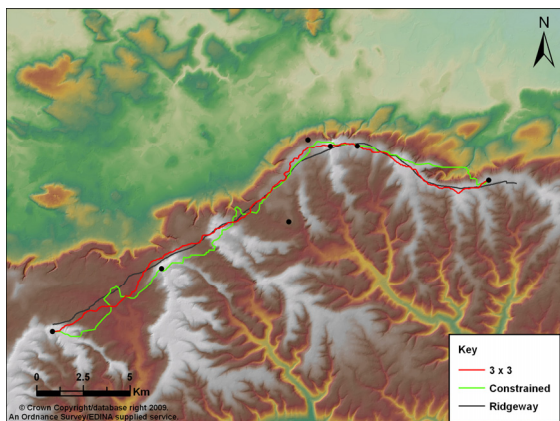


Figure 9. Least-cost pathway between Barbury Castle and Segsbury Camp based on slope values calculated using a 3 x 3 window.

Despite the similarities in the initial sections of each of these least-cost pathways, dramatic differences can be seen in the routes which were taken across the lower-

¹Tyler Bell and Gary Lock, "Topographic and Cultural Influences on Walking the Ridgeway in Later Prehistoric Times," in *Beyond the Map: Archaeology and Spatial Technologies*, ed. Gary Lock (Amsterdam: IOS Press, 2000) 91.

²Subtle differences can be seen between the least-cost pathways in the eastern part of the study area, immediately to the west of Segsbury Camp. Unlike the initial unconstrained least-cost pathway, the least-cost pathways calculated using different window sizes all followed the approximate line of the Ridgeway.

lying area between Barbury Castle and Liddington Castle:

- The least-cost pathway based on slope data calculated using a 25 x 25 window "fell off" the Ridgeway,³ following the line of a channel to the west of Liddington Castle (see fig. 10);
- The least-cost pathway based on slope values calculated using a 51 x 51 window rejoined the Ridgeway, following the line of the ridge upon which Liddington Castle was built (see fig. 11);
- The least-cost pathway based on slope values calculated using a 101 x 101 window traversed the area of lower ground, crossing a pass to the south of Liddington Castle (see fig. 12).

This section of the Ridgeway is poorly defined and similar problems have been encountered in low-lying regions, such as the coastal plains of Georgia, where the landscape is homogeneous and there is little or no topographic differentiation.⁴

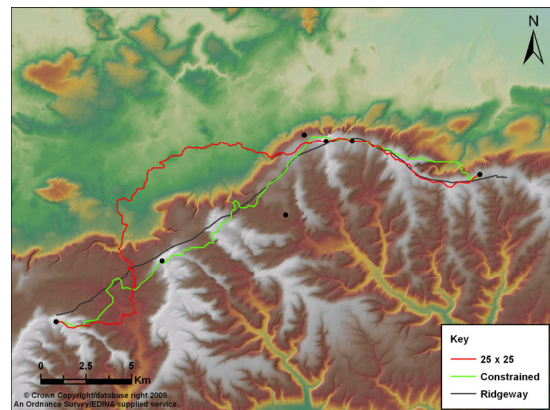


Figure 10. Least-cost pathway between Barbury Castle and Segsbury Camp based on slope values calculated using a 25 x 25 window.

Like the initial unconstrained least-cost pathway calculated between Barbury Castle and Segsbury Camp, the least-cost pathway based on slope data calculated using a 25 x 25 window can be attributed to the way in which costs are accumulated.⁵ The algorithm used to calculate the least-cost pathway is based on the assumption of steepest descent and seeks the most rapid reduction in accumulated cost. It typifies van Leusen's

³Cf. the initial unconstrained least-cost pathway calculated between Barbury Castle and Segsbury Camp (see fig. 2).

⁴Thomas Whitley, Inna Burns Moore, and Gitisha Goel, "Beyond the Marsh: Settlement Choice, Perception and Decision-Making on the Georgia Coastal Plain," paper presented at the 37th Annual Conference on Computer Applications and Quantitative Methods in Archaeology, Williamsburg, Virginia, March 22–26, 2009 (published in this volume).

⁵James Conolly and Mark Lake, *Geographical Information Systems in Archaeology* (Cambridge: Cambridge University Press, 2006) 254.

assertion that the algorithms used in current GIS do not take into account global knowledge of the landscape (see above).

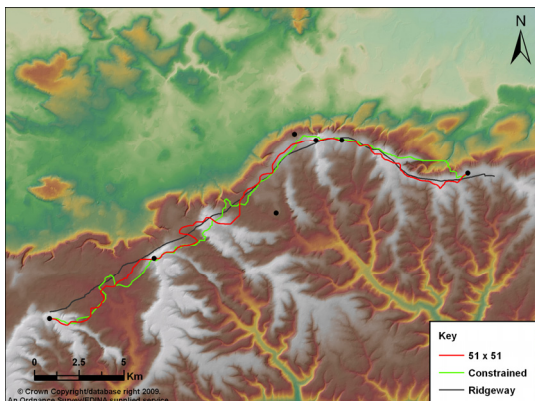


Figure 11. Least-cost pathway between Barbury Castle and Segsbury Camp based on slope values calculated using a 51 x 51 window.

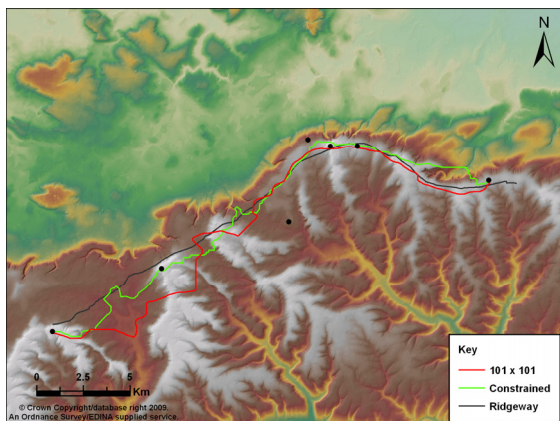


Figure 12. Least-cost pathway between Barbury Castle and Segsbury Camp based on slope values calculated using a 101 x 101 window.

The default behaviour of the algorithm can be overridden by increasing the size of the window used to calculate the slope, forcing the algorithm to “look beyond” the channel followed by the least-cost pathway and make a decision based on knowledge of the topography on the far side of the channel.¹ Similarly, the least-cost pathway based on slope data calculated using a 101 x 101 window incorporated global knowledge of the landscape into the decision-making process, by taking into account the topography beyond the pass to the south of Liddington Castle.

Just as values of the slope will vary according to the method by which they are calculated (see above), so the cost distances and least-cost pathways which are derived from slope data will vary according to the algorithm used. The dangers of push-button solutions

¹These decisions assume both previous knowledge of the landscape and a detailed understanding of the scale at which landforms are defined.

have been demonstrated convincingly by Gietl and his colleagues, who generated least-cost pathways using the popular packages ArcGIS, GRASS and IDRISI with remarkably different results.² While specific details of the algorithms used are not always available for proprietary software, it seems that modifications of Dijkstra’s shortest path algorithm³ provide the most popular solutions.

Dijkstra’s algorithm is explained in detail by Herzog and Posluschny⁴ and was used by Llobera as the basis of his accessibility model.⁵ According to Harris,⁶ this algorithm was available in early versions of ESRI software, although in the latest version as used here (ArcGIS 9.2), it is not explicitly acknowledged even though the logic appears to be very similar.⁷

One aspect of Dijkstra’s algorithm that has potential interest here is that the eventual least-cost path solution should in theory be based on the cell values for the entire raster dataset, thus appearing to incorporate “global knowledge” and possibly invalidate the statement by van Leusen with which this paper opened. This is supported by Llobera’s modification to produce his variable “radius of search” although his interest was in modeling surfaces of accessibility rather than specific pathways or corridors of movement. The logic is based on the cell-by-cell establishment of the shortest path and

²Robert Gietl, Michael Doneus, and Martin Fera, “Cost Distance Analysis in an Alpine Environment: Comparison of Different Cost Surface Models,” in *Layers of Perception. Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA), Berlin April 2–6, 2007*, eds. Axel Posluschny, Karsten Lambers, and Irmela Herzog (Bonn, Kolloquien zur Vor- und Frühgeschichte, vol. 10, 2008) 342.

³Thomas Cormen, Charles Leiserson, Ronald Rivest, and Clifford Stein, *Introduction to Algorithms*, Second Edition, (Cambridge: The MIT Press, McGraw-Hill Book Company, 2001) 595–99.

⁴Irmela Herzog and Axel Posluschny, “Tilt—Slope-Dependent Least Cost Path Calculations Revisited,” paper presented at the 36th Annual Conference on Computer Applications and Quantitative Methods in Archaeology, Budapest, Hungary, April 2–6, 2008.

⁵Marcos Llobera, “Understanding Movement: A Pilot Model Towards the Sociology of Movement,” in *Beyond the Map: Archaeology and Spatial Technologies*, ed. Gary Lock (Amsterdam: IOS Press, 2000) 76.

⁶Trevor Harris, “Session 2 Discussion: Moving GIS: Exploring Movement within Prehistoric Cultural Landscapes Using GIS,” in *Beyond the Map: Archaeology and Spatial Technologies*, ed. Gary Lock (Amsterdam: IOS Press, 2000) 121.

⁷The Path Distance and Cost Path algorithms in ArcGIS 9.2 were used to calculate the least-cost pathways presented in this paper. ESRI, ArcGIS 9.2 Desktop Help, Cost Distance Algorithm, http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Cost_Distance_algorithm.

the capability to modify the solution as more distant cells and routes are evaluated and is quite different from the notion of wider landscape understanding being modelled here. We are trying to move away from the quantitative calculation of the shortest route as a product of “efficiency”, which is the basis of Dijkstra’s algorithm, towards a more nuanced and subjective understanding of movement that may result in pathways that are not equivalent to Dijkstra’s efficiency logic.

4 MID-DISTANCE WAYPOINTS

Having developed a better understanding of the relationship between movement and topography, it is possible to begin to factor in the “cultural landscape” through the use of mid-distance waypoints. The corridor within which movement would have taken place in Later Prehistoric times is well-defined in the eastern part of the study area where the Ridgeway is well-defined. In the western part of the study area, where the Ridgeway is poorly defined, movement is likely to have been influenced by other factors.

A correlation can be seen between the locations of Iron Age hillforts and topographic features, with several of the hillforts occupying prominent positions along the Ridgeway. Hillforts, such as Liddington Castle and Uffington Castle, are likely to have been mid-distance waypoints, acting as fixed points of reference within the landscape. In areas where the Ridgeway was poorly defined, the locations of these hillforts would have been particularly important in defining a “corridor of intentionality” through which movement took place.

Viewsheds were created for each of the hillforts along the line of the initial constrained least-cost pathway calculated between Barbury Castle and Segsbury Camp (see above). These viewsheds were calculated using polylines corresponding to the ramparts of the hillforts digitized from the 1:10,000 Ordnance Survey map sheets. The horizontal angle of the viewsheds was restricted to a cone of vision determined by the centerline of the corridor of intentionality, i.e. the projected lines of sight between each of the hillforts along the line of the least-cost pathway.

Conceptually, the journey represented by the least-cost pathways calculated between Barbury Castle and Segsbury Camp can be split into four legs: 1) Barbury Castle to Liddington Castle; 2) Liddington Castle to Uffington Castle; 3) Uffington Castle to Rams Hill, and 4) Rams Hill to Segsbury Camp. Viewsheds were generated in the opposite direction to the axis of movement along the Ridgeway so that the hillforts did not continue to exert an influence on movement after the corresponding legs of the journey had been completed (see figs. 13 to 16).

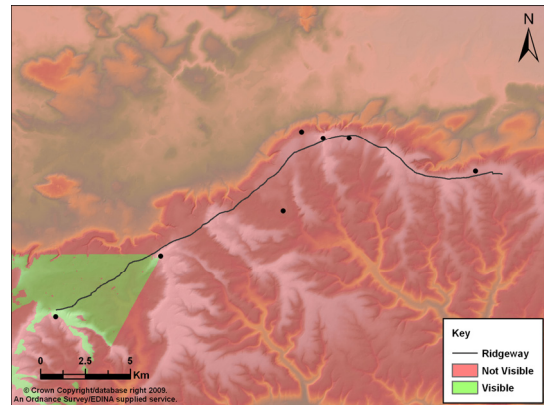


Figure 13. Binary viewshed for the leg between Barbury Castle and Liddington Castle.

Liddington Castle (see fig. 13) would have been visible from Barbury Castle and at least one point on the ramparts would have remained in view for the majority of the first leg of the journey. The next hillfort along the Ridgeway, Uffington Castle, would have been visible from Liddington Castle and as movement progressed eastwards (see fig. 14), with the ramparts of the hillfort providing a constant landmark over the final third of the second leg of the journey.

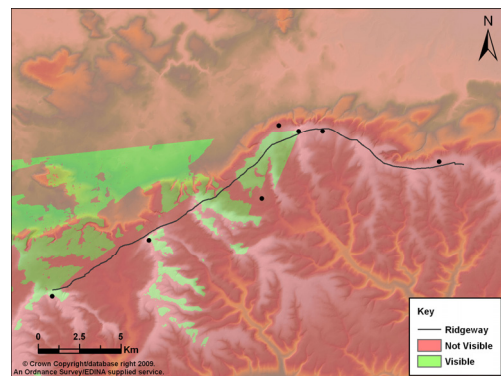


Figure 14. Binary viewshed for the leg between Liddington Castle and Uffington Castle.

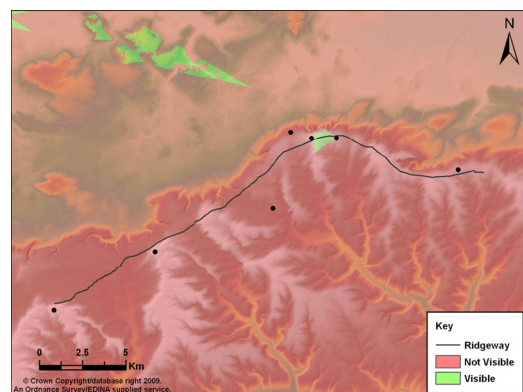


Figure 15. Binary viewshed for the leg between Uffington Castle and Rams Hill.

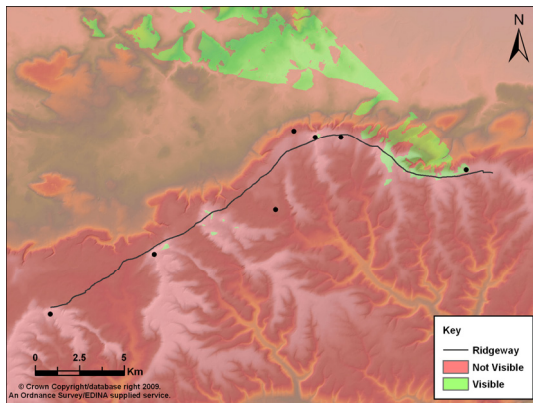


Figure 16. Binary viewshed for the leg between Rams Hill and Segsbury Camp.

Again, the next hillfort along the Ridgeway, Rams Hill, would have been visible from Uffington Castle and, although it has a restricted viewshed, it would have remained in view for all of the third leg of the journey (see fig. 15). In contrast to the previous hillforts, the final hillfort along this stretch of the Ridgeway is not visible from Rams Hill. However, this section of the Ridgeway is well-defined and Segsbury Camp would have come into view shortly after commencing the final leg of the journey (see fig. 16). Continuous surfaces were generated for each of the hillforts with values corresponding to the Euclidean distance between every cell and the closest point on the ramparts. These surfaces were inverted so that the distances increased towards the hillforts and were combined with the binary viewsheds¹ for each of the hillforts to create distance banded viewsheds. The distance banded viewsheds were combined to create a continuous surface representing the proximity to the closest visible hillfort.

This surface was used to weight the slope values used to generate the cost surface from which the least-cost pathways between Barbury Castle and Segsbury Camp were calculated. Where a cell was visible from a hillfort, the relative cost of movement was reduced in proportion to the proximity to that hillfort. Although a linear function was used for the purposes of this paper, step-wise functions could be used to model the reduction in cost associated with the transition from mid- to near-distance visibility.²

The influence of mid-distance waypoints on movement can be illustrated with reference to the least-cost pathway between Barbury Castle and Segsbury Camp

¹The viewsheds for each of the hillforts were reclassified using numeric values (where: 0 = not visible from any point on the ramparts and 1 = visible from one or more points on the ramparts).

²Cf. Marcos Llobera, "Understanding Movement: A Pilot Model Towards the Sociology of Movement," in *Beyond the Map: Archaeology and Spatial Technologies*, ed. Gary Lock (Amsterdam: IOS Press, 2000) 71–75.

based on slope data calculated using a 101 x 101 window (see fig. 17). In the western part of the study area, where the Ridgeway was poorly defined, the initial least-cost pathway traversed the area of lower lying ground to the east of Barbury Castle, crossing a pass to the south of Liddington Castle

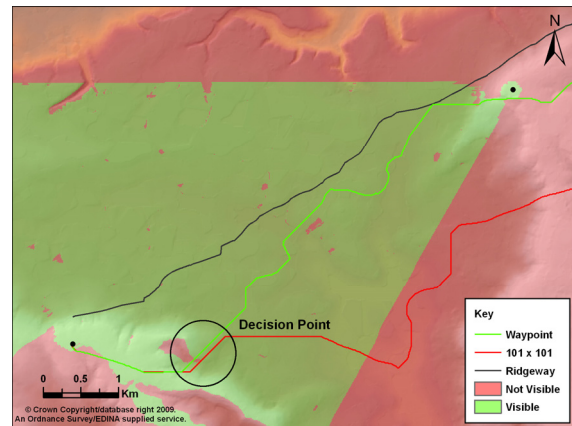


Figure 17. Least-cost pathway between Barbury Castle and Segsbury Camp (first leg only) using Liddington Castle as a mid-distance waypoint.

When the slope values were weighted using the proximity surface, the least-cost pathway followed a more direct or intuitive route. The initial sections of the least-cost pathways followed the same route and the mid-distance waypoint only influenced movement beyond the edge of the lower-lying area to the east of Barbury Castle. A decision was made at this point to head towards the next hillfort along the Ridgeway rather than follow the path of least resistance heading in a completely different direction.

5 CONCLUSIONS

We have attempted to address van Leusen's opening statement that cost surface analysis and related least-cost pathways do not incorporate knowledge of the landscape. This modeling of movement demonstrates the tension that underlies many GIS applications in archaeology, that the quantitative objective algorithms of GIS are not designed to represent the subjective decision making that is central to much of human action and existence.

By deconstructing the inter-connectedness of human movement and visibility we have explored the role of intentionality and scale within the process of walking across an area of landscape. The importance of DEM resolution has been downplayed by using scalable windows of analysis to imitate the intentionality of mid- and long-distance movement. Through this, the visibility of cultural markers in the landscape, for example a hillfort as used here, can be modeled as waypoints that guide the walkers towards their final destination.

This is a work in progress and we have three further aspects which are being developed. Firstly, the use of variable window sizes is to be built into cost-distance and least-cost algorithms. Similarly, visibility is to be integrated into the generation of cost surfaces and least cost pathways, so that both cost and view work together

to determine movement. Finally, topographic features will be utilized as mid-distance waypoints, in addition to cultural features as demonstrated here.

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We would like to thank Tyler Bell for his advice on the algorithms used to calculate the initial least-cost pathways as part of the Hillforts of the Ridgeway Project and for granting access to the original datasets. We would also like to thank the anonymous reviewers of this paper for some useful comments and suggestions.

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