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A Roman Puzzle. Trying to Find the Via Belgica with GIS

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Abstract

In this paper we address the issue of using least cost path (LCP) modelling for a practical case study: the prediction of a 7 km stretch of Roman road (the Via Belgica) in the Dutch province of Limburg. Despite extensive archaeological research, the nature of the evidence is such that it does not allow us to project the route with sufficient confidence. LCP modelling can then be helpful to develop possible scenarios, departing from the available evidence and general assumptions about Roman road building. Using these scenarios, we managed to come up with a few plausible routes that we hope to test in the near future. Developing the scenarios made us think harder about the nature of Roman road building strategies and the interpretation of the available evidence. However, we also had to conclude that the available tools and theories are not very well suited for the kind of models that we would like to produce.

Keywords: Least Cost Paths; Via Belgica; Roman Roads; Openness.

1. Introduction: the Via Belgica

The Roman road between Boulogne-sur-Mer (France) and Cologne (Germany) is nowadays generally referred to as the Via Belgica. However, it was never known by this name in Roman times. The term was coined in the early 20th century by archaeologists who tried to reconstruct the Roman road system in the province of Germania Inferior. From the Peutinger Table and various other sources (such as milestones found at several locations along the way) it is clear that a major Roman road existed between the naval port of Boulogne-sur-Mer (Gesoriacum) and the frontier city of Cologne (Colonia Claudia Ara Agrippinensis). After the conquest of the region around 50 BC and its subsequent usurpation into the Roman empire, the familiar formula of towns and roads was implemented here. The Via Belgica was constructed under August and initially its main purpose was to connect the new territories in the North to the rest of the empire. In the second century AD its role as a transportation axis between the Rhine and Meuse and beyond became even more important, as it led through rich loess soils where large quantities of cereals were produced for both the military and civilian markets. It passed through various towns that were all founded under August, including Tongres (Atuatuca Tungrorum), Maastricht (Traiectum ad Mosam), Heerlen (Coriovallum) and Jülich (Juliacum) (Figure 1). In this paper we will focus on the Dutch stretch of this route, that is running through the southern part of the province of Limburg, from the Dutch-Belgian border near Maastricht through the valley of the Geul river on to Heerlen, and from there to the Dutch-German border at Rimburg, over a total distance of approximately 40 km (Figure 2). This stretch has been the subject of a substantial research project carried out in 2003 (Demey and Roymans 2004). To establish the exact position of the road all historically documented archaeological finds were analyzed, and fieldwork (augering and trial trenching) was carried out to find evidence for the existence of the road in various locations. Despite this effort, the published reconstruction of the road remains speculative in many places. A particularly hard nut to crack is the 7 km stretch between the villages of Valkenburg-aan-de-Geul and Voerendaal, for which various alternatives have been suggested. This is all the more surprising since in many places, especially in the German Rhineland, the road runs a very straight course and should therefore not be too difficult to reconstruct. The fact that the landscape in Dutch Limburg varies strongly from that in the Rhineland, due to a strong relief, could be a contributing factor.

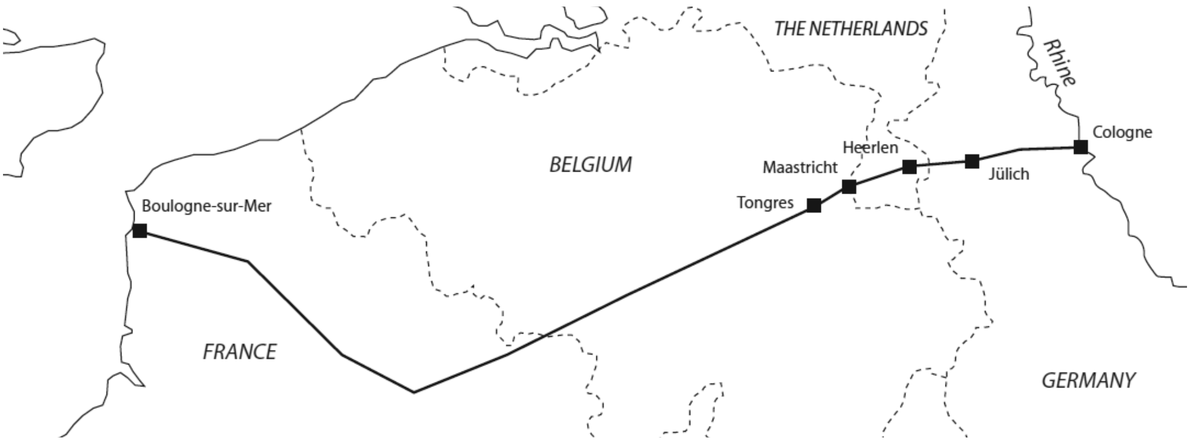

Figure 1 Approximate route of the Via Belgica from Boulogne-sur-Mer to Cologne.

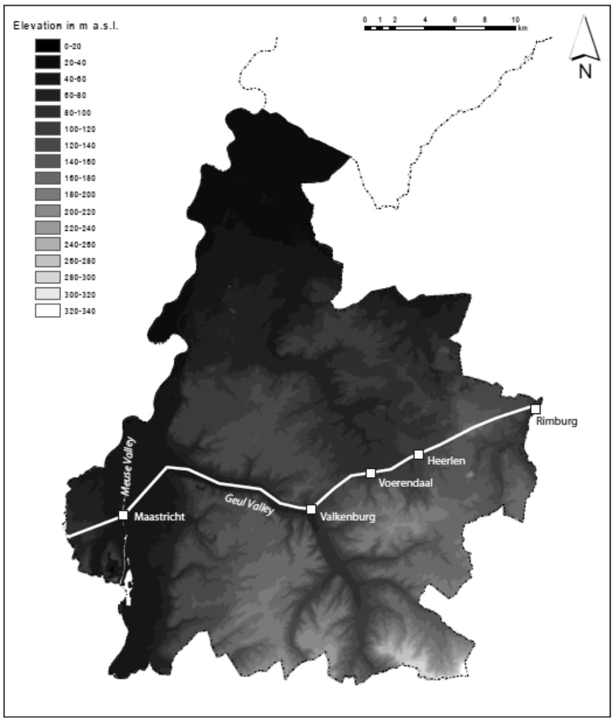

Figure 2 Approximate route of the Dutch stretch of the Via Belgica

2. Roman road building: what do we really know?

As far as can be judged from the archaeological evidence, the Via Belgica is not the archetypical Roman road paved with slabs of stone. In Dutch Limburg, in those places where it has been found, it manifests itself as a layer of gravel up to 1.5 m thick and approximately 8 m wide. The gravel was used as paving material and the talus (or *agger*) is somewhat convex to allow water to drain more easily from the road (Figure 3). On each side, a zone of approximately 8 m wide is found that is bounded by a ditch. No paving is found here, but it is supposed that these zones were used for transport as well, though presumably not for 'official' purposes. This implies that the total width of the road is approximately 25 m, of which only the 8 m wide talus can be easily recognized in the field when digging trenches or test pits. Since the main survey methods used in the region are augering and field walking, it may not come as a surprise that the chances of actually finding it in a standard reconnaissance survey are not very high. This is particularly the case in Dutch Limburg, where the marked relief in combination with the loess soils there can lead to serious soil erosion, so that the road could either be covered in colluvium, or be washed away. In addition to this some parts of the road are known to have been used as a gravel quarry as recently as the early 20th century.

Figure 3 Cross section of the Via Belgica in the vicinity of Voerendaal.

Concerning the criteria used by the Romans to decide where to put the road, we have to go with some general guidelines that can be deduced from the fact that over the whole Roman Empire we often encounter straight roads, pointing to a preference for speedy connections with relatively low construction and maintenance costs. However, many exceptions to this rule are observed in places where the landscape offered challenges to the Roman engineers that had to be overcome by either taking a different course, or by choosing alternative solutions like bridges, switchbacks, dikes or even tunnels. The study area does not seem to offer extreme difficulties to Roman engineering skills, even with the marked relief indicated earlier. However, Demey and Roymans (2004, 37) conclude:

‘The way in which it is built shows a fundamental knowledge of the terrain. During road construction, a creative compromise was sought and found between following the straight line and evading difficult parts, like a marshy hollow near Voerendaal.’

Which parts of the landscape constitute the difficult bits is, however, largely a matter of conjecture. The attested route of the road suggests that wet areas were avoided. Apart from the marshy hollow mentioned near Voerendaal, the crossing of the river Worm at Rimburg at the current Dutch-German border is located at an eccentric northerly location, presumably because the river valley was too wide and wet to cross comfortably further south. Apart from that, it seems that Roman roads almost never take slopes over 15%, and in many cases not even over 8%. The main reason for this may have been the challenges that steep slopes offer to wheeled transport. The Roman army relied on supply trains with wagons, and these are obviously difficult to get moving again once they get stuck. A typical Roman army cart is the *carpentum*, drawn by 2 mules with a supposed maximum load of 500 kg (Roth 1998, 208-212). According to the figures given by Raepsaet (2002, 23), such a cart cannot move up a slope of more than 9% on a well-paved road when loaded. While the equation given by Raepsaet[1] is probably not very realistic, it gives us some idea of the limitations of using wheeled transport at the time.

3. A case for least cost path modelling?

Given the uncertainties regarding the way in which Roman engineers chose routes through difficult terrain, it seems logical to apply least cost path (LCP) models to try to find the most plausible ones. Least cost paths can be used to find the optimal connection between two or more locations based on both the distance between these points and the effort that is needed to cover this distance. On steeper slopes and wet ground, the time needed to cross the terrain increases and it may therefore take less time and energy to take a detour over easier ground. The basis of the calculations is a raster surface that specifies the costs of traversing a single grid cell. From this, the cumulative costs of accessing a specific location from anywhere in the landscape can be calculated. This principle has been applied to archaeological case studies on numerous occasions (e.g. Bell and Lock 2000; Bell et al. 2002; Howey 2007; Fiz and Orengo 2008). However, since the evidence for (pre-)historic roads and routes is usually very limited, it is in most cases hard to judge whether these models are actually very good at predicting past routes. Modelling studies on issues of movement and transport in archaeology have mostly focused on the effect of slope on walking speed and energy expenditure (Bell and Lock 2000; Llobera and Sluckin 2007; Herzog 2010). So, despite the utility and popularity of LCP models to explore the potential for movement through the landscape, very little work has been done that has resulted in a predictive success (but see Becker and Altschul 2008). No case studies have taken into account the effect of terrain costs on wheeled transport, basically because of a lack of empirical data that could be used for this.

Furthermore, it has repeatedly been stressed (Llobera 2000; Bellavia 2006; Zakšek *et al.* 2008; Lock and Pouncett 2010; Murrieta Flores 2010) that the choice for a particular route is not only dependent on whether it constitutes the shortest connection, but will also be influenced by other factors. Especially for military routes like the Via Belgica it seems probable that visibility may have played an important role. Locations that are more vulnerable to ambush may have been avoided, and strategically placed watchtowers may have been employed to supervise stretches of road. This was acknowledged by local amateur archaeologist Harry van Aken, who published a number of possible reconstructions of the Via Belgica between Valkenburg and Voerendaal (Figure 4). Van Aken stated in an interview with Dagblad De Limburger on 7 Feb 2009:

‘Vicar Crutzen of Klimmen and Ransdaal wants to investigate whether the 11th century tower of the St. Remigius church was a Roman watchtower. This is plausible, since this is a strategic viewpoint. From this spot at an elevation of 140 m you can see the whole Eastern Mining Area. The Goudsberg near Valkenburg had such a tower as well. Its foundations were found. From there you can oversee the whole Geul valley.’

In their 2004 report, Demey and Roymans also indicated the route across the Goudsberg as being the most probable, due to the presence of the watchtower. However, as is often the case in archaeology, the situation is less clear-cut than that. The available archaeological evidence for this hypothesis is in fact fairly limited. The only place where the road has actually been found is near Voerendaal, and we can assume that it passed through Valkenburg because of a substantial number of burials located in close proximity to eachother west of the town, indicating a small necropolis that would have developed alongside the road at this location in the Geul valley. The existence of a Roman watchtower at the Klimmen church is completely unconfirmed, and the interpretation of the tower on the Goudsberg is not certain either.

[1] $T = kP + Pi$
where
T = traction force needed for movement
P = weight of loaded cart in kg
k = rolling coefficient
i = slope in m/m
The rolling coefficient k is composed of a pavement friction factor and an axle friction factor

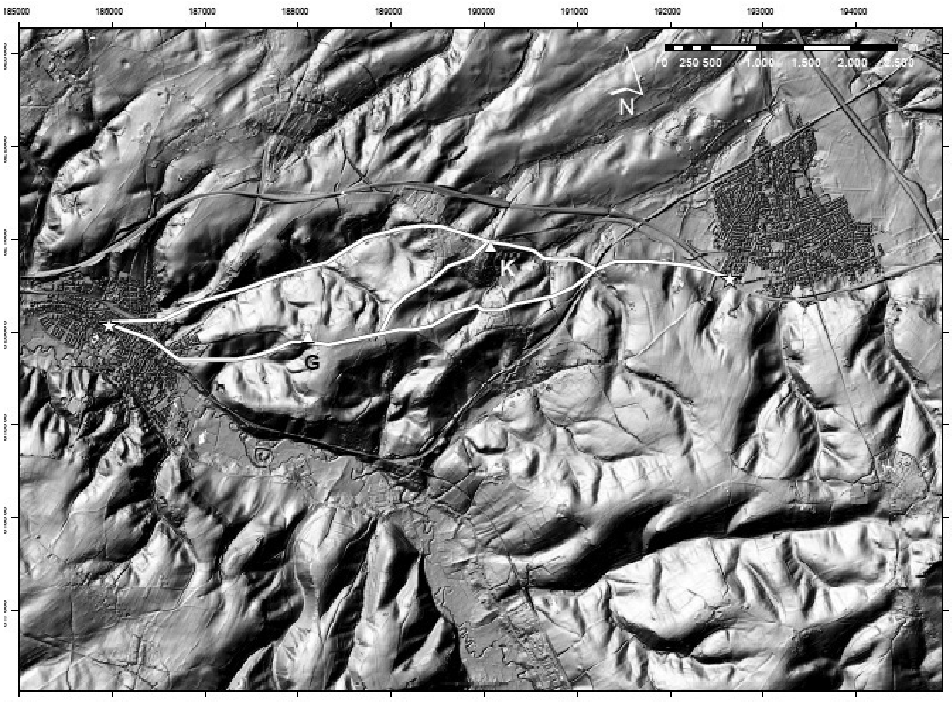

Figure 4 Suggested routes for the Via Belgica between Valkenburg-aan-de-Geul and Voerendaal. G = Goudsberg, K = Klimmen church
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The structure that was excavated there in 2002 (Bazelmans *et al.* 2004) is of Late Roman origin (310-360 AD) and may very well have been a so-called *burgus*, a civilian construction in the form of a tower where the population could flee to in the case of enemy raids. While it is logical to assume that such a tower would be built close to the existing road, this could not be established with certainty; and furthermore, it does not prove that the route was originally chosen because of the potential to place a watchtower at this specific location.

We are basically dealing with a fairly common situation in archaeology here: scant and disparate data sets, interpretations of the available data that highly depend on expert judgement, and a lack of formal definition of the problem at hand. As such, it forms a typical case where quantitative modelling can be helpful because it will force us to think about these issues from a more formalized point of view, and experiment with the variables involved to see how they influence optimal route finding. Both the heuristic element in this (learning by experimenting with the different options) and the spatial visualisation of the model results are the most important contributions that GIS-based modelling can offer to archaeological research questions. It is therefore all the more surprising to see that LCP modelling in GIS is actually not very well adapted to executing this approach.

4. Modelling issues

As indicated above, a model trying to predict the location of the Roman road between Valkenburg and Voerendaal should take into account at least the physical conditions limiting transport, as well the potential influence of visibility on the suitability of the road for military purposes. Conceptually this is rather straightforward: various models should be constructed to connect the start and target location in which a varying importance will be attributed to slope, wetness and visibility. In the execution of these models we are however confronted with several problems.

First of all, as already mentioned, almost all published studies in archaeology on LCP models and movement have used walking speed as the parameter that determines the suitability of a route. Several authors have pointed out that the available equations specifying the effects of slope on walking speed will result in different outcomes of the LCP models (Gietl *et al.* 2008; Herzog and Posluschny 2008). Furthermore, alternative equations for wheeled transport seem to be absent. The abovementioned equation provided by Raepsaet (2002) seems to be unsuited. While it provides figures for determining the traction force needed to get a cart with a certain amount of load moving on different surfaces and slopes, in practice it is severely limiting the slopes that can be negotiated with the type of carts that the Roman army is supposed to have used. When introducing this equation into a LCP model, it tends to produce large detours. For this reason we have not used this equation, and have settled for the most popular walking speed equation that was originally published by Tobler (1993).

$$W = 6e^{-3.5|s+0.05|}$$

Where
W = walking speed in km/h
e = the base of natural logarithms
s = slope in m/m

A comparison of Tobler's equation with other hiking functions shows differences, but, from a practical point of view, they are not that big. The major factor determining whether a different route will be chosen by the LCP algorithm is the difference in cost values encountered. Applying Tobler's walking speed-based hiking equation in the study area will give ranges between 1.3 km/h and 5.0 km/h, a difference of 3.7 km/h. However, the change in cost between cells usually shows much less variety; the mean range of speed values in a 3x3 cell neighbourhood is 0.7 km/h, with a standard deviation of 0.37. It is only by substantially modifying this *change* in cost between cells that different routes will be created, especially since the different walking equations all follow more or less the same pattern of speed reduction with increasing slope (see also Herzog 2010).

A second issue is the accuracy of the digital elevation data that can be used to create the cost surfaces based on slope. While there is a nation-wide elevation coverage of the Netherlands obtained through LiDAR (Actueel Hoogtebestand Nederland or AHN), the derived product that is most commonly used is a 5x5 m filtered DEM that has most of the vegetation removed, but leaves most standing buildings and a considerable amount of other man-made structures, like railways and highways. In this particular case, the highway connecting Maastricht to Heerlen runs just north of Valkenburg in the direction of Voerendaal and crosses the possible location of the Roman road just to the southwest of this village. A test using the filtered AHN and Tobler's hiking function resulted in a LCP that moved up the highway talus and followed it for much of the stretch. The only other easily available product is the Aster DEM, which has a coarser resolution of approximately 35x35 m and a reduced vertical accuracy with elevations in meters, not in centimers. Nevertheless, this DEM is better suited for our purpose since the influence of man-made structures on the cost surfaces and LCPs is much reduced. It gives a better approximation of the relief in Roman times, but at the same time cannot make claims to extreme accuracy.

A third issue, also identified by various authors, is the use of different cost distance algorithms for path finding (Conolly and Lake 2006; Herzog and Posluschny 2008). Most GIS packages use a version of Dijkstra's algorithm to calculate the cumulative costs. However, in most cases these costs are isotropic: it does not matter whether one moves in one direction or another, since the cost is dependent on the slope value in each raster cell. Since slope values are always averages of slopes in 8 directions, this means that slope maps will almost never give the true value of slope in the direction of movement. Even though several authors have warned for this and even provided alternatives (Conolly and Lake 2006; Zakšek *et al.* 2008), most GIS packages deal with this in a highly unsatisfactory way. Only the Path Distance module in ArcGIS seems to be able to calculate movement costs directly from a DEM and combine these with hiking functions and other cost specifications. Unfortunately, the documentation provided with the software is not specific on how this is achieved. The difference between using isotropic and anisotropic cost distance calculations is however considerable, even in a not very mountainous area like South Limburg (Figure 5).

These problems only become more complex when trying to incorporate measures of visibility into the cost surface. Very little consensus exists about what constitutes a good indicator for terrain visibility. Viewshed analysis, much like LCP modelling, has resulted in a number of archaeological publications (Wheatley and Gillings 2000; Llobera 2003; Llobera 2007; Lock and Pouncett 2010) pointing to the importance of including the scale of visibility into the analysis. The total viewshed, while a seemingly popular measure of overall visibility of a location, is in practice still a complex parameter to calculate, especially when trying to include multiple viewing distances. For reasons of practical performance, we decided not to use total viewsheds for our assessment of visibility, but a measure known as openness (Yokoyama *et al.* 2002), which measures the angles of zenith and nadir within a selected neighbourhood. It gives a readily interpretable image of the degree in which a location is sheltered or open to vision, and as such is a quicker alternative to total viewshed calculations. However, a comparison between this method and other options such as the skyview factor (Watson and Johnson 1987; Kokalj *et al.* 2010) has never been performed, let alone that we can be sure that it actually captures what we want to model, i.e. the potential that a position in the landscape offers for visual control.

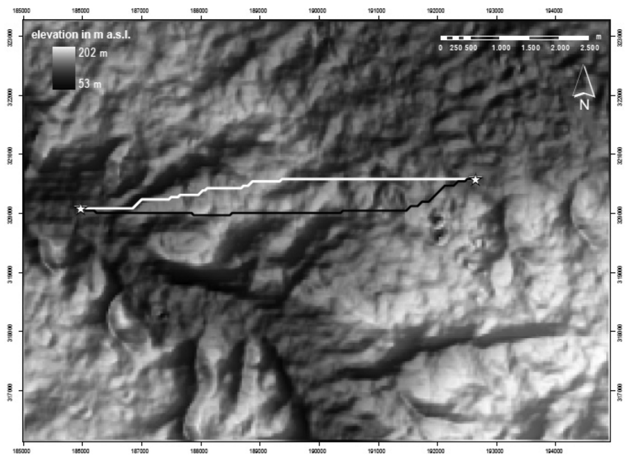

Figure 5 Least cost paths based on Aster DEM using Tobler's hiking function. The black path was created using isotropic costs, the white path using anisotropic costs

5. Results

Despite the limitations of the available data set and modelling procedures, the modelling resulted in some quite interesting results. First of all, as already shown in figure 5, it makes a difference whether we assume isotropic or anisotropic costs. Both options produce fairly straight lines between Valkenburg and Voerendaal. The anisotropic route however takes advantage of the terrain by slowly moving uphill and following the plateau ridge, whereas the isotropic path tries to follow the valleys before crossing the plateau at a relatively low elevation.

All this changes drastically when we let the LCP depend solely on the openness factor (Figure 6). It creates a route that consequently takes the ridges and avoids all valleys. However, this result could only be achieved by first calculating the mean openness value within a 3-cell circular neighbourhood and then normalizing (contrast stretching) the values obtained. In this way, a pattern of openness 'cost' values was created that would force the LCP to follow the ridge. Subsequently introducing slope into the equation did not produce very different results. This again poses serious questions about what methods are the most suitable to model visibility, and how to combine the results with other cost parameters.

The route eventually modelled largely coincides with the preferred option suggested by Demey and Roymans and van Aken, passing close by the Klimmen church and the Goudsberg watchtower. This in itself indicates that van Aken's ideas on the position of the watchtowers are correct: both the church and the Goudsberg are positioned in locations with good visibility. However, if we look more closely at the viewsheds from both locations (Figure 7), it seems that they are hardly intervisible. If we assume that the watchtowers were 10 m high (and allowing for some inaccuracy of the DEM) it might just be possible that each tower controlled about half of the possible route over the plateau, but it is highly improbable that they could see each other very well. As the main purpose of watchtowers was that the people manning them could communicate with each other, by means of signalling with torches for example, the fact that the location of these two supposed towers prohibits such communication surely weakens the argument in favour of them.

Another important question is the efficiency of each modelled route, both in distance and in speed. A comparison of modelled route distances and speeds to a straight line results in the following figures:

Route	Length	Walking Time
straight line	6700 m	1h 20'
isotropic slope	6840 m	1h 24'
anisotropic slope	7440 m	1h 30'
openness	7730 m	1h 33'

The difference between the shortest and longest variant is 13% (890 m). In terms of walking speed it is 11.5% (9 minutes). It will of course be very difficult to judge what would be the financial consequences of construction and maintenance of a detour to the Roman administration. However, the difference does not seem to be prohibitive, and we can conclude that a route following the most visible locations in the landscape may have been a feasible option for the Romans. The only possible bottleneck on this stretch is the slope just to the west of the Goudsberg that may have been too steep for wheeled transport.

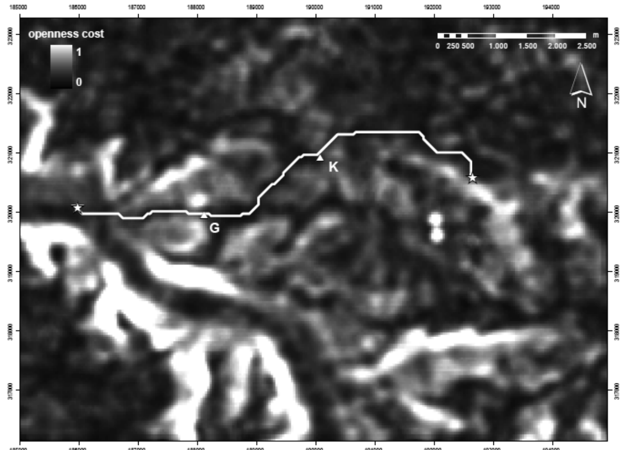

Figure 6 Least cost path based on openness factor. The modelled route passes close by the Klimmen church (K) and the Goudsberg tower (G).

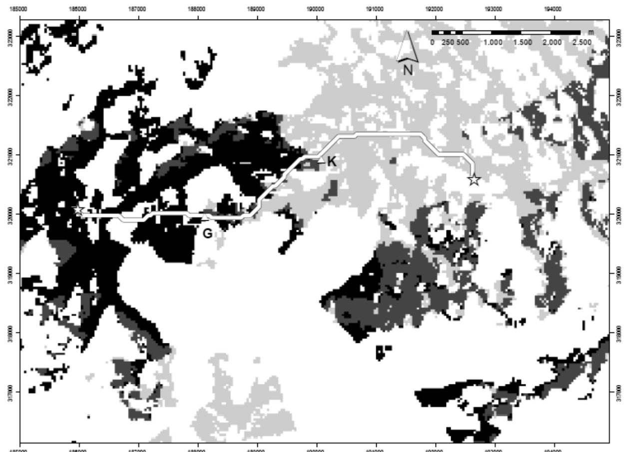

Figure 7 Viewshed from Klimmen (K) and Goudsberg (G), based on Aster DEM and an assumed height of 10 m for Roman watchtowers. Dark grey= Goudsberg viewshed, light grey= Klimmen viewshed, medium grey = overlap of viewsheds.

6. Thinking beyond the tool?

While working on this case study, we have tried to maintain a pragmatic approach to the issue of finding plausible routes of the Roman road section between Valkenburg and Voerendaal. In contrast to the existing theories, we have tried to be specific about the factors involved, using LCP models to find the optimal connections based on slope and visibility. However, in the process we were forced to think more about the tool than beyond it. Several issues in LCP modelling are not solved from a practical point of view. The software is a major limiting factor in this. Comparison of LCPs and the manipulation of the different variables involved should be much easier than it is now, and algorithms should be open and more versatile. In theory, building different models with different weights attributed to the various factors should not be that difficult. In practice, it takes a number of convoluted steps to get to this point. Since ArcGIS is the only package that will more or less accurately deal with anisotropic costs from DEMs, we were also stuck with all the other aspects of using the accompanying interface. For example, if we want to know the actual costs of each LCP instead of its length, this is not automatically produced by ArcGIS. We also have to be aware that LCP models only provide a single solution. We cannot specify what will be the second best, third best or n-best path on the basis of a single cost surface.

Theoretical concerns had to be confronted as well: the modelling of movement speeds for (pre-) historical wheeled transport is an area where no previous work is done, and it would seem fairly difficult to take this much further without a form of experimental archaeology. An additional problem is found in the modelling of visibility and its possible impact on movement. For pragmatic reasons we have used the openness parameter for this and with some manipulation succeeded in creating a visually prominent route that intuitively seems to make sense. However, this was more based on trial and error than on a good understanding of the interplay of the factors involved.

Having said this, we also see clear positive sides to using a GIS-based approach for trying to predict the location of the Via Belgica. First of all, we were able to shed some light on the plausibility of the hypotheses of Demey and Roymans and van Aken on the possible location of the route. While the latter concluded that the road should have connected the two watchtowers, in fact the route suggested by him is favouring good visibility all along the stretch. Interestingly, the suggested watchtower locations may not have been in the best position to control the road. If they really were watchtowers, there may have been a third one in between. Secondly, thanks to the modelling we were able to compare options, not just in length, but also in walking speed. A route favouring good visibility is longer and slower than a route taking the flattest areas, but it is not prohibitive.

Within the constraints of the current case study - which had to be carried out on a very limited budget - it was however impossible to seriously tackle the fundamental theoretical issues concerning GIS-based modelling of (pre-) historic movement. Most of these issues have been, and still are, the subject of long-standing debate in archaeological (computing) literature, without a real consensus having emerged on the best way to deal with them. And those studies that have reported successes have not yet resulted in the development of specific software tools that are available to a wider archaeological community. In a sense, we are still lacking the appropriate ‘spatial language’ and accompanying toolboxes to adequately approach questions like where the Romans put their roads. And while we don’t want to suggest that archaeologists should stop theorizing about fundamental notions on how people moved in the past, we do feel that more energy could and should be invested in developing software tools that will allow us to more easily compare different theoretical perspectives.

We hope to use the models developed to guide field testing using ground penetrating radar in the near future. Ultimately, ground truthing is necessary to establish the validity of the modelling results, something which is all too often neglected in predictive modelling exercises. After all, GIS-based modelling is only one of the options available to try to predict archaeological remains. It can only be considered successful if we can actually prove that it did a better job than an approach based on expert judgement alone.

Acknowledgments

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