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Modelling Routes and Communications

> "Those who have thoroughly studied military affairs maintain
> that more dangers are likely to arise on the march than on the field of battle"
> Flavius Vegetius Renatus, *Epitoma Rei Militaris* III 6.

Ray Laurence poses the engaging question "why should we write about Roman roads", as the first line in his excellent book on Roman roads in Italy. To some the answer to such a question might seem self-evident. The significance of roads to Roman imperialism and governance seems reasonably clear (Finley 1973, 126–127), although the economic significance of formal communications has been a moot point following Finley's seminal comments, more than 30 years ago. More recently, debate on communications and economy has been transformed and permits some appreciation of the positive role of roads in economic terms, irrespective of the original intention behind their construction (Laurence 1999, chapter 7). Today, the fundamental position of formal communication either for the facilitation of governance, the support of military activity, encouragement of trade or cultural contacts, in historical terms, hardly seems controversial. However, what may be more problematic, when considering Laurence's pithy enquiry, is whether a study of roads is a sufficient response to our broader questions relating to communications more generally. When this does occur we are frequently forced to acknowledge the paucity of our knowledge in respect of general communications for many, if not most, periods of history.

It is clear that our knowledge of ancient routes may derive from several sources. There are, of course, a number of itineraries and maps that have survived from the ancient world. Issues associated with their use are, however, considerable. Few sources can claim adequacy in terms of the geographical questions that most historians would like to ask and many sources, such as the Peutinger table or Antonine Itinerary, have survived imperfectly in the copies we possess today. Errors of transcription or, in the case of Ptolemy's geography, calculation frustrate our efforts to use such references in a coherent manner. The nature of the sources may also reflect the reasons for their compilation if, for instance, the Antonine Itinerary reflects in part the imperial progress of Caracalla.

On the basis that absence of evidence is not, in fact, evidence of absence we should be aware that the sources available were never the sum of ancient geographical knowledge nor even representative of what may have been available. A reading of Flavius Vegetius Renatus' *Epitoma Rei Militaris,* emphasises that the Roman military, at least, had access to significant amounts of geographic information and given the sophistication of surviving geographical treatises we should not be surprised at this fact. Vegetius notes that a General should have:

> "itineraries of all those regions … so that he may become fully acquainted with the distances between places in terms not only of mileage but also of the quality of the roads, and may have at his disposal reliable accounts of short cuts, alternative routes, mountains and rivers: indeed the more able generals are said to have had not only annotated but pictorial itineraries of the provinces in which they were operating".
> Flavius Vegetius Renatus, *Epitoma Rei Militaris* III 6.

Renatus's statement not only reminds us of the close historical link between the military and cartography, it also emphasises the potential information that we have lost over time. Of course, we are not reliant simply on the sparse survival of cartographic representation as our knowledge of the past in geographic terms. Material survival is significant and this may include roads, which may exist either in relic form or remain in use through the modern transport network (figure 1). It is also important to recognise that we frequently have data on the destinations and points of departure represented through archaeological settlements; cities, towns and rural communities. See, for instance, the recent Populus volumes on the Archaeology of Mediterranean landscape and especially Francovich and Patterson (2000). This is a substantial database across the ancient world although the thousands of field records relating to villas, for instance, can be contrasted with the correspondingly sparse reference to such features in formal geographical texts. The Antonine Itinerary, for example, lists only eight examples of named villas including one in Italy and seven in North Africa (Rivet and Smith 1979, 499). In conflating these historic databases, cartographic, geographic and material, there is a sense in which we might say that our current knowledge of routes in the ancient world data fits where it touches. That is, we tend to know many of the major points of departures of routes and, to a lesser extent, the major routes of communication but beyond this our available information is only rarely a reasonable representation of past route networks overall. Given the reasonable assumption of the significance of communications, this must be regarded as a problem.

Such issues become even more intractable if we consider the potential significance of minor rather than major routes. It is a fact that the latter are, effectively, the subject of most academic research in the absence of any other information. Yet, where conditions allow, it is clear that the countryside of the past was as complex as any rural landscape today and would have been criss-crossed with minor roads, trackways and other paths. These would, one suspects, never have been the subject of a formal itinerary, except under exceptional circumstances. We do, however, have an inkling of the potential complexity through landscape features identified primarily through aerial photography or geophysics. Celtic fields in North Western Europe are perhaps amongst the best exemplars of such features. The field systems have been mapped across many parts of the United Kingdom for over a century and comparable features are now frequently recorded in many other parts of Europe (Crawford 1924). However, when considering communication the fields themselves are not so important to us in comparison to the trackways frequently associated with these features and, by implication, the less formal communication routes that must have existed alongside field boundaries or, in the case of pasture, even across the fields themselves. These observations are not limited to pre-Antique societies as later formal field systems display similar characteristics and on occasion can be demonstrated to have been laid out with respect to public roads and trackways (Stančič and Slapšak 1988 and figure 2). The significance of these paths in respect of the landscape should be fairly obvious. Formal routes which may, or may not, have been recorded by ancient geographers clearly could never provide an adequate description of the potential routes available across any landscape should this have actually ever even been the intention of the sources!

Recognition of this fact clearly presents us with significant problems. If we are to make sense of complexity on routes and communication, it may be that we should reformulate some of our concepts concerning the nature of routes themselves and explore the significance that may be derived for our research.

At an intuitive level, it might be appropriate to distinguish between the following characteristics that may be associated with any mode of interaction:

- Routes may be defined as generalised channels along which communications and materials may pass. These may have a broad significance, as in the larger concept of trade routes, or be defined by permanent physical characteristics including a defined or dense road or track network and associated infrastructure including *mansiones* or other specialist settlements.
- Roads, trackways or paths. These linear routes usually have some degree of permanence, formal recognition or distinct physical characteristics including paved surfaces or simply wear associated with frequent use (often the case with rural sunken trackways).
- Accessibility is a more general characteristic with respect to the landscape. It is a measurement of the relative ease or difficulty with which one may cross or communicate across or within an area of land. This may involve formal routes but should incorporate extensive, open spaces.
- Communication, or connectivity, may take advantage of either routes or the general accessibility of a landscape but may take a static or mobile form. You may travel to communicate but you do not have to do so! Note the values of visual communication via watchtowers or using signals including smoke or fire.

The characteristic of these phenomena is that behavioural significance may vary not only according to the subject of study but also according to the scale at which any analysis may be undertaken (figure 3). It is clear that different processes may operate at different scales. If looking at the significance of communications within urban form then scales associated with site and intra-site would be appropriate, whilst a study of trade routes associated with amphorae may be intercontinental in scale. Analytical methodologies would, of course, also vary as a consequence. An old adage relating to mapping is relevant here. Maps are neither 100% accurate nor precise; they are, at best, fit for purpose. This is an important point as we can derive from this that mapping, irrespective of the content of any document, is not an objective optic on the past or indeed the present. Rather the nature and significance of mapping draws from our own research goals and that we take an intellectual risk every time we create, or use, a map.

With respect of the significance of methodology relating to the study of routes and communication, it should be stressed that the impetus for writing this paper emerges through participation by two authors in the Princeton/Birmingham Medieval Logistics project (Web Citation 1) and that our primary concern is to consider the requirements of a study of routes and communications that might support the digital modelling of military campaigns. However, it is asserted that many of the general theoretical and methodological issues involved have a wide applicability and can be presented as part of this volume.

Initially it is worth noting that the general issues of digital modelling in relation to medieval logistics were discussed in a seminar held at the University of Birmingham (United Kingdom) in 2003 and subsequently published as a dedicated monograph (Haldon 2005a). The case for digital modelling in respect of army activity more generally was made in several papers in that volume (Gaffney H. 2005; Gaffney V. 2005), along with the technical description of some of the components of such a model (Bellavia 2005; Wilkes 2005) and it is not required to repeat such detail. Essentially, it is enough to note here that:

- Military logistical problems, as in most human situations, are essentially spatial. If spatial they are also numeric and open to mathematical description and manipulation
- In a complex historic environment that is ultimately unknowable the best that we can aspire to is to provide numeric/graphical representation of past realities in a variety of permutations to provide a best fit for, or to test, alternative scenarios.

Whilst it is accepted that such models are, at best, a simplified description of a complex entity or process, the general operating parameters of a model were defined in the earlier volume (Gaffney V. 2005, 38). In essence these are:

- The contemporary settlement landscape
- The contemporary political and social landscape
- Composition of forces
- The nature of terrain
- Knowledge of roads, paths and routes
- The contemporary natural landscape
- The role of the individual in respect of personal action and larger consequence.

Setting aside, for the moment, issues associated with the actual progress of a campaign it is apparent that a number of factors can be conflated within the primary issue of military route analysis. These include factors related to the terrain itself, the contemporary natural environment, the settlement landscape and the pre-existing route network. Terrain is clearly a formative factor and the increasingly widespread availability of digital terrain models is becoming central to communication research. The emerging use of LiDAR (high resolution laser altimetry) as a source for very detailed terrain models is also providing enhanced data with enormous potential in the area of route analysis (Wilkes 2005; Challis 2006 and figure 4).

The availability of such high-resolution terrain models poses many interesting questions and opportunities for research. In the past research into routes and communication tended to presume the significance of traditional network analysis for such work (Jones 1997, 224–227; Wagstaff 2005). It is a fact that many technologies now used by archaeologists and historians, including GIS, are indeed well placed to implement analysis of networks associated with full topological attribute data. However, perhaps in contrast to many of these studies, extensive terrain data facilitates the integration of notions of accessibility and connectivity, as defined above, within our research programmes. The plethora of papers, within archaeology art least, related to visual communications is one aspect of such a development. See Conolly and Lake (2006) and Chapman (2006) for reviews of this literature. The re-invention of site catchment analysis through derived cost-surface models demonstrates not just the reinstatement of a previously discredited methodology but the practical application of a notion of accessibility to archaeological and historical research. Despite this, it is probably correct to note that many published examples of these methods tend to be isolated exemplars rather than integral to large-scale research programmes.

Reconstructing contemporary vegetation and environment is frequently more problematic and the methodological issues relating to proxy indicators are substantial (Eastwood 2005). Where reconstruction is viable the output tends to breakdown into studied providing extensive, generalised models with relatively poor value to analyses demanding high levels of specificity, including route analysis (Eastwood 2005, figures 11 and 12), or studies with high resolution but which may not be used beyond the location of specific sites or, more likely, sampling points (Chapman 2006, 116–119; Gearey and Chapman 2006). Ultimately, this may not be a resolvable problem as the conditions required to provide the full range of proxy environmental data required for a viable approximation of localised vegetation conditions are unlikely to be achieved for every point of interest. Moreover, even within landscapes where significant environmental analysis has taken place there are reasons to be cautious about the level of detail provided by palaeoenvironmentalists who, in the end, are almost always working with a less than adequate sample (Allen 1997).

This does not, of course, suggest that we need abandon our goal of reconstructing routes or communication models. New data are always emerging that will support such studies and, as Koder (2005, 181) reminds us, there are substantial amounts of traditional historical and archaeological data that can be used for the reconstruction of both settlement and economy with some degree of confidence. We are also encouraged to carry out such studies specifically through the adoption of a modelling strategy, as this makes no claim to veracity but merely act as a test of potential value against existing data or interpretation.

At this point we may begin to turn to the issue of military logistics. There are many excellent examples of logistical studies. Donald Engels' analysis of the logistics of the Macedonian Army is, for instance, correctly recognised as a seminal attempt to investigate these issues for a specific historical context (Engels 1978). However, such studies have been hampered by the tendency to be self-referencing to a small number of historical texts or presumed orthodoxies. Of course the basic parameters and issues associated with such studies have long been recognised. Supply is the basis of many ancient army leader's strategy and tactics. The problems of marshalling, transportation and distribution of supplies, often in deserts and barren terrain, do not have simple solutions. Long- and short-range planning and preparation were essential before any army could advance. Consequently, the choices made for a campaign route were often determined by taking into account stockpiles of supplies in desolate regions, forced-marching to conserve supplies and the synchronising of the march with the harvest dates throughout conquered regions. Not only were these considerations important to ancient armies but obviously the climate and geography of their route. Often the army's movements were determined less by political or military events as by the severity of the winter, amount of snowfall or rainfall or other geographical or topographic factors (Haldon 1999). It is a reasonable assertion that academics with an interest in this area of research have been limited by their lack of either an adequate methodology to test alternative assertions or the technology to implement such tests.

The historic basis for path analysis may be contrasted with the literature for digital routes studies as these may have little to do with an historical or even real world context. Indeed a primary driver for many pathfinding algorithms has been the gaming industry (Yap 2002; Salomon et al. 2003; Botea et al. 2004; Bjornsson 2005). Yap, for instance, introduced the idea of using the A* algorithm on various grids using 4-way tiles, 8-way tiles and hexes. He was particularly interested in the trade-offs for different grid representations and argues that these pathfinding methods have a number of applications including military simulations. Salomon (2003) refined these ideas using complex 3-dimensional artificial environments. Their algorithm simply entails the use of terrain geometry, the orientation of the avatar together with parameters relating the avatar size to the model size. Following this Botea's hierarchical pathfinding method claims to be much faster than A* while still finding paths that are within 1% of the optima and Bjornsson developed this further by implementing the 'Fringe Search' algorithm which is claimed to run significantly faster than A*.

In contrast to these abstract studies route determination within historical research has tended to be a practise within the GIS, community. Reviews of the literature including that by Conolly and Lake (2006) provide a number of examples of how GIS may be used to support the finding of networks and cost paths. Chapman (2006) also discusses how routeways may be modelled using GIS procedures. Direction, slope angle and cost movement across terrain tend to be key factors in these analyses. The simplest models use unidirectional models with little consideration of important factors such as anisotropy or multiple points of origin (Conolly and Lake 2006, 419 and figure 4). The early use of Pandolf's equation for movement by archaeologists is a specific example of a limited isotropic algorithm (Marble 1996 and figure 5). It is clear that simple least cost surface analysis is not likely to predict routes with any degree of accuracy and studies carried out to replicate known paths, even when highly constrained, have demonstrated that GIS standard modules may not replicate human behaviour. For a concise account of Bell and Lock's (2000) attempts to predict the route of the English "Ridgeway" and issues associated with this study see Conolly and Lake (2006, 420–422).

Alternative algorithms, frequently derived from hydrology applications offer other options to determining "natural pathways" that human beings might use or form when they move through a landscape. One model proposed by Bellavia, and derived from GIS based hydrological modelling techniques developed by Jenson and Domingue in 1988, provides one option for extracting 'natural pathways' from a digital elevation model (Bellavia 2001, 2005). These pathways could be defined by the natural constraints of traversal across a landscape and are generally the routes of minimal constraint (Bellavia 2001). This concept does not unequivocally mean that such routes were used as paths, but only that they had the potential to be used as such.

The procedure advanced by Bellavia requires a cost surface grid to be generated based on the slope of each cell in the Digital Elevation Model. Once derived, data sinks must then be filled. Sinks are cells or connected cells whose flow direction cannot be assigned to one of the valid values in a flow direction grid (Jenson and Domingue 1988). Only then can flow direction be determined to generate a path direction grid. The flow direction algorithm outputs a grid showing the direction of flow out of each cell that determines the direction of best gain to the smallest cost value. If a cell has the same change in cost value in a number of directions and is not part of a sink then the direction of flow is allocated a lookup table giving the most likely direction (Greenlee 1987). A path accumulation grid is then produced of the accumulated flow in each cell by accumulating the flow from upstream cells using the method described in Jenson and Domingue (1988) and Bellavia (2001). The grid is derived from the flow direction. Potential pathways in the landscape are those where the cells in the grid have a high flow accumulation.

A purely hypothetical implementation of this algorithm, carried out for this paper, is the generation of a landscape derived from seismic data used by the North Sea Palaelandscapes Project (Fitch et al. 2005, Gaffney, Fitch and Thomson 2006). Here a terrain model has been derived to represent the Holocene land surfaces from seismic data and constraints added relating to the presence of significant water bodies (figure 6). In the case of the North Sea data, the natural pathways can be seen following the landscape's ridges and valleys. The large river (the "Shotton") palaeochannel is clearly avoided as a route. In contrast, major routes follow contours often either side of the steep hills and in at least two places there are distinct crossroads. The latter positions might well have been in interpreted as potential settlement nodes in other historical contexts.

The work by Bellavia and the above data above suggests that the derivation of relatively sophisticated routes can be attempted using terrain models modified by constraints and other data. However, the area used from the North Sea barely covered only 1200 square kilometres. Following the comments made in respect to scale in the introduction to this paper it is clear that this corresponds to the regional or micro-regional scale and the data better interpreted as putative tracks rather than significant routes. An example related to a larger scale problem can be presented in respect to the route to the battle of Manzikert. Here we are dealing with the generation of routes that stretched across the majority of Anatolia. The route to the Battle of Manzikert in 1071, south of the Murad Chai River and north of Lake Van is, of course, of great interest to Byzantine historians. The Byzantine army lost this battle to the Seljuk Turks apparently following a combination of treachery and tactical blunders and this then precipitated the civil war thereafter. Haldon's study of the Byzantine Wars in the eleventh and twelfth centuries investigates the lead-up to this battle in excellent detail (Haldon, 2001, 2005). Whilst the historic outcome of the battle of Manzikert appears clear, its wider significance is contentious. There is uncertainty concerning the nature and disposition of Byzantine forces prior to battle and even aspects of the route taken to Manzikert. Clearly, our interpretation of this important event is limited if we cannot establish, with some certainty, the parameters of the military forces involved, the nature of the action and, ultimately, the wider historic context of the defeat. However, repetitive argument over sparse references within mediaeval texts gets us no closer to understanding these issues, and even results produced by competent and wide-ranging scholars remain subjective. Although the context of the battle has been frequently debated it may be useful to provide some supporting information here and following Haldon's previous publications cited above.

In the winter of 1070–1071, Romanos IV prepared a major expedition directed against the Seljuk garrisons that had been placed in the Byzantine border fortresses at Khliat and Manzikert in the east. It seems that his intention was to re-establish the frontier defences as far as possible. By March or April 1071 Romanos IV's preparations were well advanced. At this point the emperor proposed a treaty with the Turkish Sultan, who was engaged upon the siege of Edessa, by which the latter would stop his siege and the former would return to the city of Hierapolis to the Sultan's authority, taken by the emperor during his campaign in 1068. Romanos' first offer of a truce was reinforced by a second embassy, which arrived in Aleppo in May, demanding the exchange of the towns named in the first offer and threatening war if no agreement was reached. Romanos had already left Constantinople and begun mustering his troops in late February and March. By the time the Sultan received the second embassy, he must also have received news of the imperial advance towards his Armenian territories. He then appears to have headed back east, crossing the Euphrates with his own guards and a small retinue, to take command of the forces in Armenia and Mesopotamia and deal with the threat from Romanos.

Romanos then decided to leave the general Nikephoros Botaneiates behind. Nikephoros was a capable officer whom he assumed was disloyal. Instead, he chose to take Andronikos Doukas with him, the eldest son of John Doukas, one of his rivals for the imperial throne, who certainly was disloyal to him. At the same time, the emperor began to distance himself from his troops and officers, ultimately establishing a separate baggage train and encampment for the imperial party, refusing to share in the hardships of the campaign but taking with him intricate resources for his own accommodation.

By late June the imperial forces had reached Erzurum where a decision had to be made as to which direction the army should proceed and how exactly the Emperor wished to implement his strategy. There appears to have been some dissention. Some of the generals suggested he should move on, try to outflank the sultan and take the war into Seljuk territory and bring him to battle. Others argued that the emperor should wait, fortify the surrounding towns and strengthen their garrisons, lay waste the countryside to deprive the Turks of necessary supplies when they approached, and await events. The latter course of action seemed inappropriate, especially as the army was in danger of running out of supplies if it waited in one place for too long. Therefore the order was given to move on.

An estimate of the emperor's forces at this point is difficult. However, it is clear that he had not used up all available troops for the campaign. Of the units that accompanied the emperor, some are mentioned in the sources by name but the total of the forces assembled can only be guessed at. The medieval Islamic sources reckon it is anything from 100,000 to 300,000; unlikely given the demography of the empire and the logistics involved. Haldon believes that a grand total of perhaps 40,000 may be reasonable.

The Emperor's plan seems to have been to take both Manzikert and Khliat, which lay to the south on the western shore of Lake Van. However, he was completely misinformed of the movements of Alp Arslan and his troops, who had, in fact, not returned to Iraq at all. Instead, he had marched directly towards the Armenian border. His Vizier proceeded to Azerbaijan to raise further troops, while he himself, having collected some 10,000 cavalry from his allies and vassals en route, had by now assembled a force of some 30,000 horsemen. He was actually only just over 100 miles away from the Byzantine emperor, with his scouts covering and reporting their every move. From Erzurum the Emperor advanced eastwards. The troops were ordered to collect enough provisions for two months. This is a considerable amount that necessarily entailed the use of large numbers of pack animals and, possibly carts, slowing the army down considerably.

A substantial body of the Pecheneg allied force, closely followed by Frankish troops under Roussel de Bailleul, were ordered ahead to the region around Khliat, which Romanos clearly perceived as the more difficult of his first objectives, with instructions to collect fodder and provisions, prevent more enemy damage to the harvest and, presumably, to secure it for the imperial advance. The emperor must have continued his march east along the same route before turning south to cross the Araxes, and then east, either along the valley of the Murat Su, or a little further south at Muş, towards Manzikert itself.

Before reaching this first objective, he detached a further substantial force with orders to assist Roussel in taking and garrisoning Khliat. According to Attaleiates, this included most of the superior, battle-hardened units. Also the troops left over with the emperor were now fewer than those he had sent off to Khliat. The likely remaining imperial forces must have numbered some 20,000 or so. Therefore they were barely superior in numbers to the main Turkish host. This was contrary to Romanos' expectation and assumptions.

The detachment of troops under Roussel and then Tarchaneiotes proved to be a major blunder. Unaware of the closeness of the Seljuk forces, which were by now approaching both Khliat and Manzikert from the east, the two Roman commanders were suddenly confronted by what seemed to be a substantial enemy force. What happened next has no explanation in the sources. Both forces appear simply to have about turned and moved with great alacrity away from the Seljuks, whom they seem neither to have reconnoitred, nor to have reported to the emperor, a mere 50 km or less to the north (Haldon 2001). Both divisions marched towards Melitene on the Euphrates and took no further part in the campaign.

There are two possible routes between Manzikert and Khliat, and it is likely that the troops under Tarchaneiotes took the slightly quicker, more easterly route, across the plain stretching southeastwards from Manzikert. Since they were clearly able eventually to reach Melitene, they must certainly have got as far as the junction with the westerly road down from Manzikert, just north of Khliat, where they perhaps also joined up with troops under Roussel. It can, therefore, only have been at this point that the Seljuk troops appeared in strength, forcing the imperial forces to turn north along the westerly route back towards Manzikert, before turning westwards after a few kilometres. Whether or not treachery played a role is unclear.

At this point, the Emperor had now lost some of his best units. Unaware of the events to the south, he carried on to Manzikert, which capitulated without a struggle. The garrison was released without punishment. Romanos set up his camp outside the fortress and on the banks of a small tributary of the Murat Su. The city was located on the north-western edge of a roughly rectangular rocky steppe region, which stretches for some ten miles along a northwest – southeast axis, before rising gradually to the foothills, north-east of Khliat. This was an area thoroughly known to the Turks, but less familiar to both Romanos and his commanding officers, a fact which again proved to be a significant disadvantage to the Romans. The disastrous events that followed concern the battle itself and are not of relevance to a discussion on the logistics of the campaign.

Figure 7 illustrates the route to Manzikert at Lake Van, according to accepted historical assumptions. The results derived form applying a natural path algorithm, as described above, are provided in figure 8 for Central Anatolia. The superimposed natural pathway data shows a natural pathway that follows quite closely the suggested route but only in parts. This, it should be noted, is an unconstrained model unlike that in figure 6 which has the rivers added as barriers to movement. The Manzikert example, therefore derives only from the terrain itself and variation should be expected as it is not a true representation of the landscape and non-terrain constraints.

However, given the scale at which this data is derived (1:250,000), there should be some general value in considering the data alongside the presumed route and existing historical assumptions. It is interesting, at the least, to consider the significance of other routes emerging in the data as there is the possibility of an alternative campaign marching route for this battle (Haldon 2001). One possible route that the Byzantine army may have taken on its campaign march to the battle in 1071 could be the northern pathway that heads towards the coast. The disadvantage of the longer distance may have been outweighed by the easier terrain, especially when one considers that somewhere in the region of 20,000 men and many pack animals would have had to traverse this extremely difficult landscape (Haldon 2005).

This model could be refined considerably using the data currently available to the larger logistics project teams. This includes hydrology and vegetation as well as early and late Byzantine topographic and demographic data collated by the *Tabula Imperii Byzantini*. Indeed, this work is currently being planned as part of a larger research project, combined with a more complex agent-based study and involving multiple tests of route projections. However, what is to be derived from this pilot is that there is much that can be done with the historical and environmental data that we have available and that we should not be cautious in implementing further research.

This paper began with Ray Laurence's rhetorical question, "Why study Roman roads?" We should conclude with the suggestion that the study of roads is a right and proper undertaking but that such research is only part of many larger (and smaller) questions. These may range from the investigation of trade routes or troop movements at a continental scale through to the prediction of paths within a rural hinterland. It may also be more appropriate to frame our research with respect to communication more broadly and to the problems of scale specifically. Scale is critical to geography and most aspects of geographical research. It guides and informs our research questions and constrains or enables our methodologies. In the study of routes and communications specifically scale is and should be everything.

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Figure 1: The Roman road from Wroxeter to Gloucester and Usk cutting through the Church Stretton gap and now forming the modern A49.
(CUCAP Y-84, July 1947).

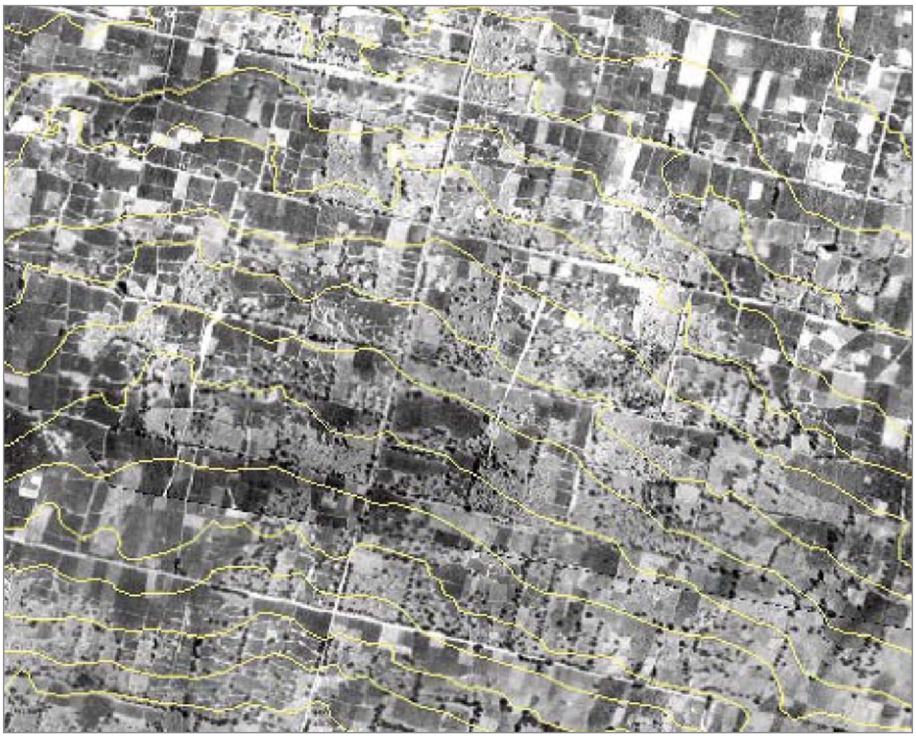

Figure 2: Greek field system
on Hvar (Croatia).

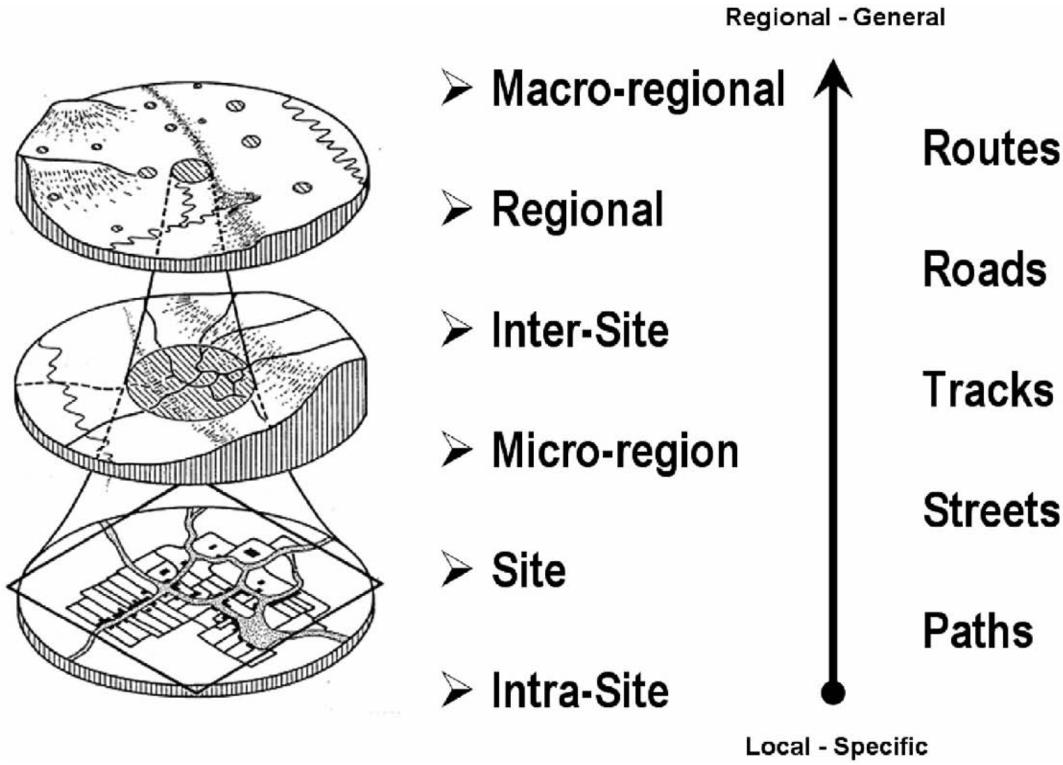

Figure 3: The significance of scale
(modified from Roberts 1996, figure 2.2).

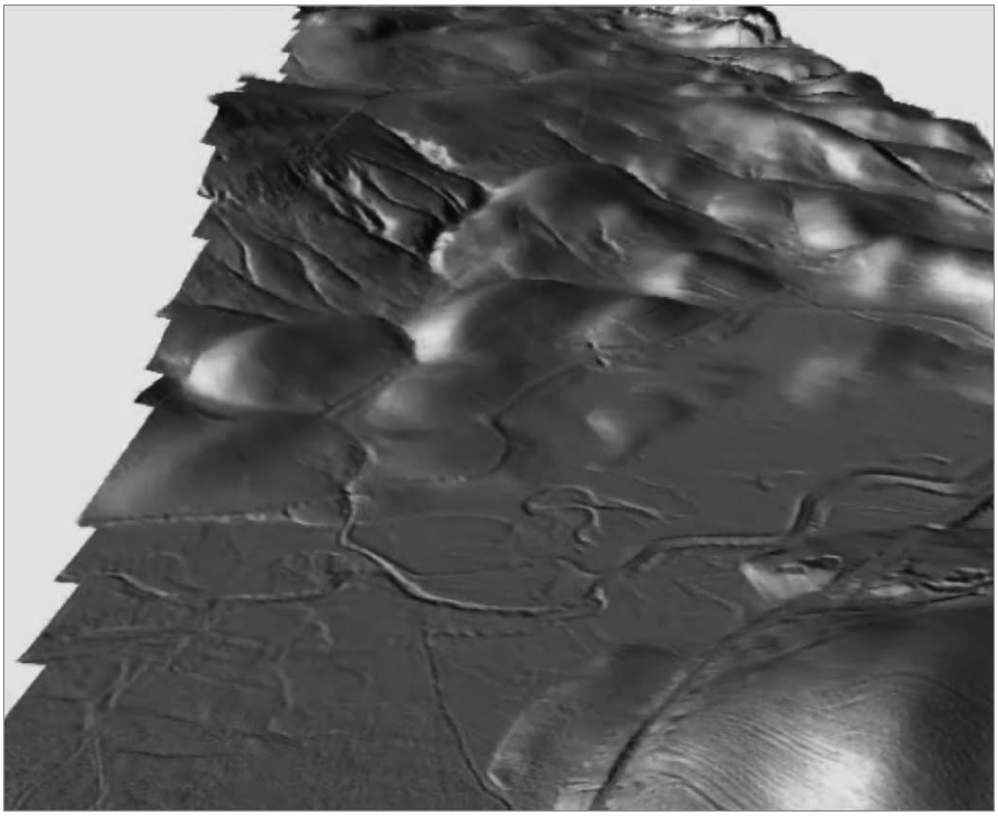

Figure 4: LiDAR terrain model showing modern and relic fluvial features, recent communication cuttings and medieval ridge and furrow cultivation. Source Keith Challis.

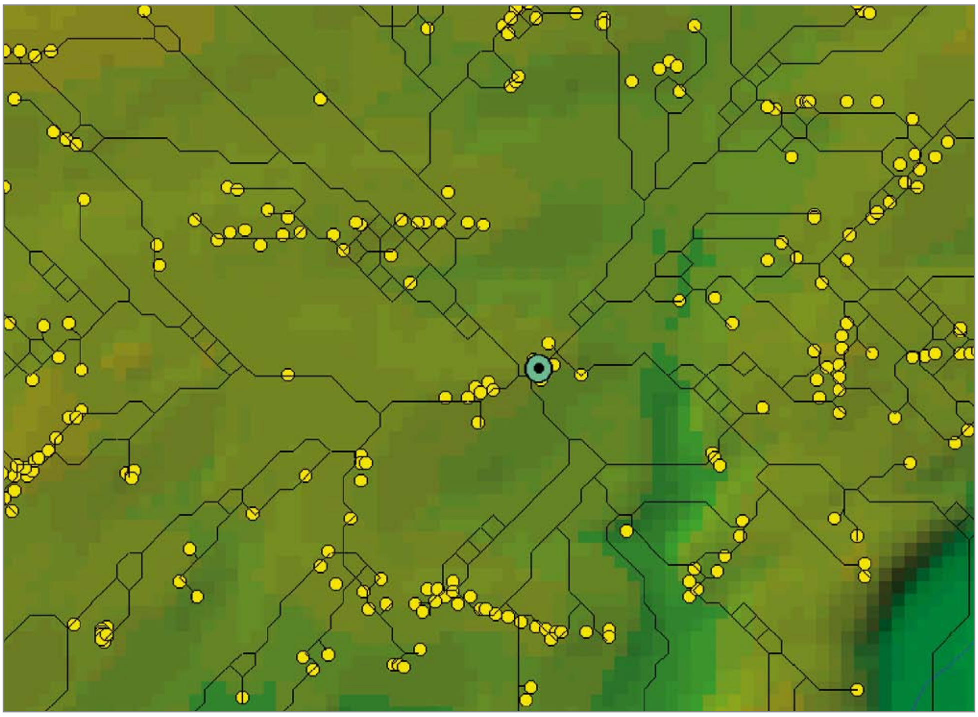

Figure 5: Traditional least-cost path network drained to Stonehenge and generated using the GRASS GIS (Exon et al. 2001).

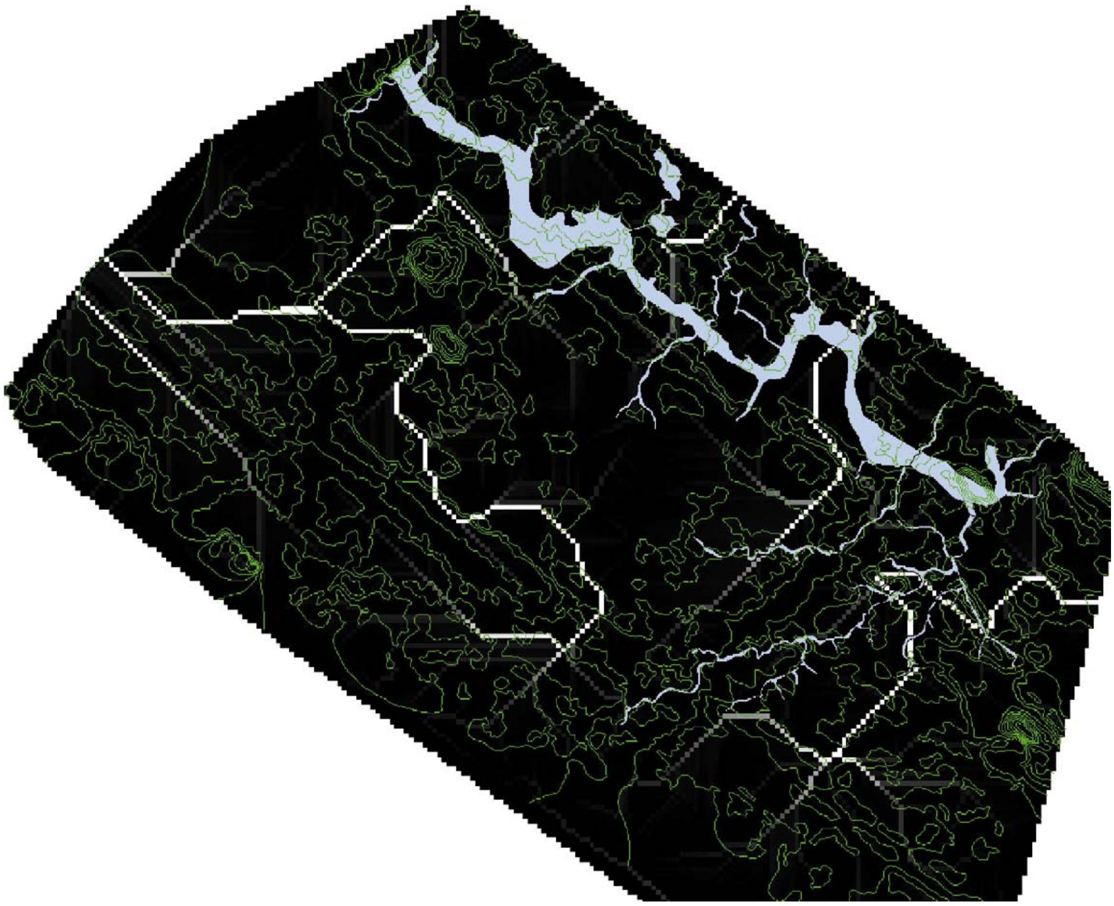

Figure 6: Natural paths overlain on a derived terrain model and with rivers acting as constraints.

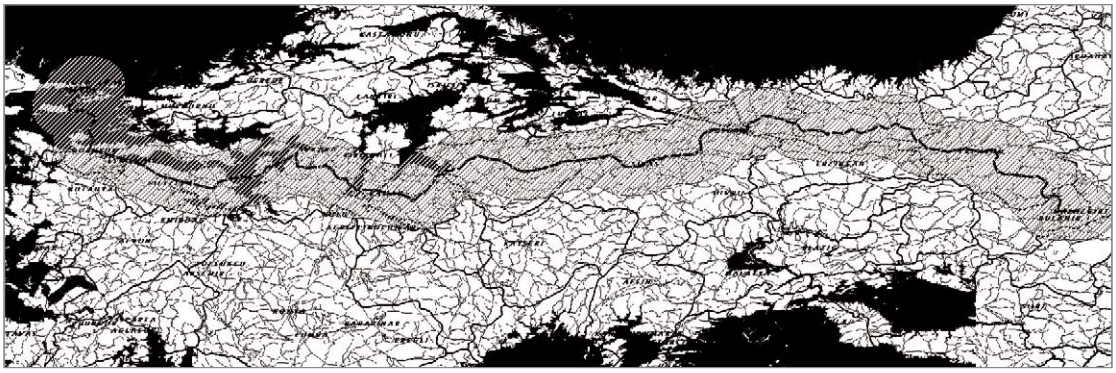

Figure 7: The route to Manzikert
(Haldon 2005).

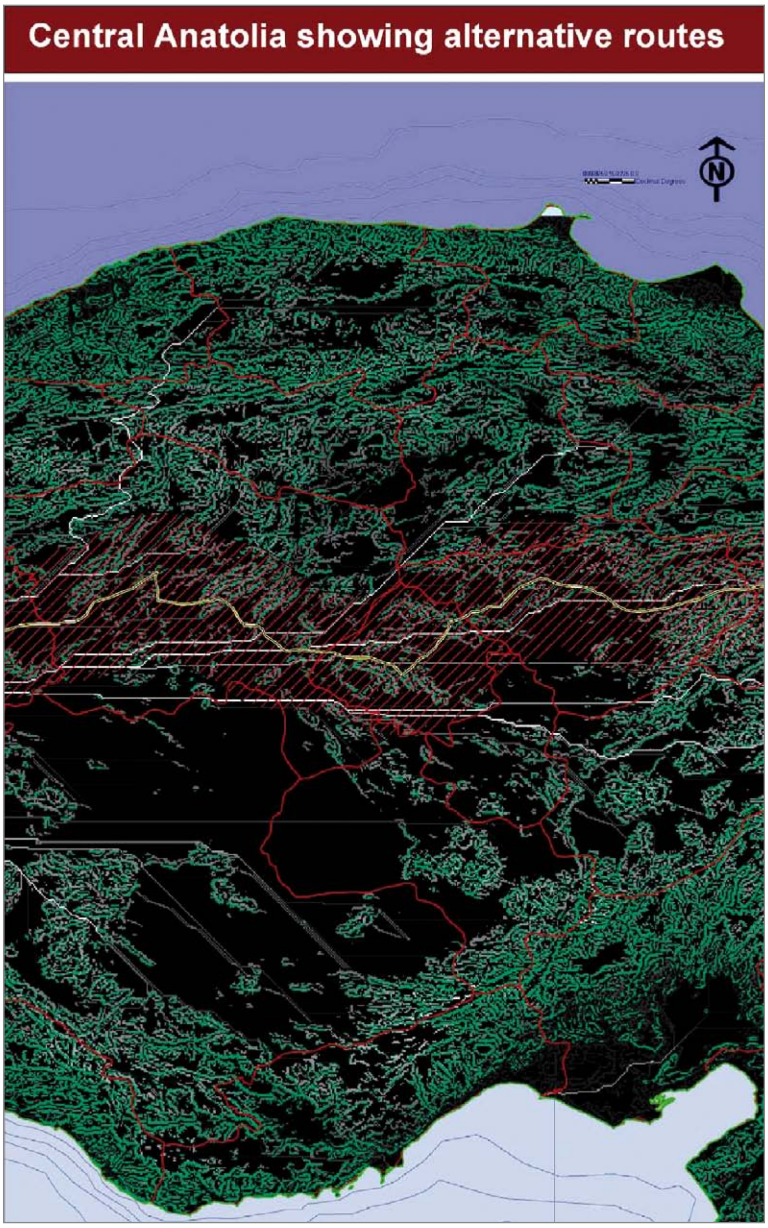

Figure 8: Results of a natural path (white) compared to the
assumed Manzikert route (yellow) in Central Anatolia.