Using an Urban Street Network and a PGIS-T Approach to Analyze Ancient Movement

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Abstract

Applications of network methods for investigating ancient transportation and movement have seen little use in archaeology. Far and away, raster-based, least-cost methods have been the tool of choice by archaeologists for explicitly modeling movement. This paper will introduce a suite of network-based tools widely used by geographers and transportation planning agencies—transportation geographic information systems (GIS-T), as well as a pedestrian-based implementation of them, PGIS-T—that was developed to investigate the urban landscape of the massive Iron Age city at Kerkenes Dağ, Turkey. It will also take a look at raster-based, least-cost methods in light of the reconstructed street network at Kerkenes Dağ and will compare the results attained by these methods using digital elevation models (DEM) of varying spatial resolutions.

1 Introduction to Kerkenes Dağ

Set on a ridge above the northern reaches of the Cappadocia Plain, the ancient city at Kerkenes Dağ commands a magnificent view of major transportation routes running north-south and east-west through the Anatolian Plateau (Figure 1). Its placement is no mystery for the importance of this area and these routes in central Turkey have been attested to over and over again through time. Visible on a clear day on the southern horizon from Kerkenes Dağ is the snow-capped mountain of Erciyes Dağ. At its base, Assyrians plied their early 2nd millennium BC trade from Kaneš (Kültepe) and Persians, Greeks, Romans, Byzantines, and Seljuks ruled through later millennia at what is now the modern city of Kayseri. While to the north and west of Kerkenes Dağ the large cities of Hattuša, the 2nd millennium BC capital of the Hittite Empire, and Tavium, a 3rd century BC capital of the Galatians, both lie within a radius of 50 km. As is attested by these settlements, this region and the routes running through it have throughout time supported large capitals and central cities with connections to both the East and the West.

While the position of Kerkenes Dağ is not surprising, its size and brevity of occupation certainly are. At 271 ha the city at Kerkenes Dağ is the largest of all cities in Anatolia prior to the classical periods, and is even larger than most of its contemporaries and earlier cities elsewhere in the world. Great effort went into its construction on what was largely a virgin site. The roughly one-square-mile area of the city was filled with buildings and walled-in urban blocks, as well as carefully laid out water collection systems and an extensive network of streets and alleys. Yet while great effort went into its creation, it was only inhabited for a very brief time, at most 100 years (ca. 650-550 BC). It met its end in a violent destruction, with the city being intentionally put to the torch and the population presumably led off into captivity (Summers et al. 1996; Summers 2000; Summers et al. 2005). There is no evidence that the population ever returned, and overburden from later occupation is restricted to two relatively small areas within the city's tumbled walls. With little overburden, and in vast areas no real overburden at all, it is relatively easy to reveal horizontal exposures of buildings and streets 50 cm below the modern surface of the ground. All these structures were roughly contemporaneous, with only a modest amount of phasing observable throughout this brief period of habitation.

Despite its obvious importance and visible remains, the city remained in obscurity until first mentioned during the travels of J. G. C. Anderson (1903). Then in 1926-1927, Hans Henning von der Osten and a small team of researchers from the Oriental Institute of the University of Chicago visited and produced the first map of the tumbled remains of the 7-km circuit of the city's walls (von der Osten 1928). In 1928 the Oriental Institute sent Erich Schmidt, who was excavating at neighboring Alişar Höyük, briefly back to the city to undertake test excavations in the hopes of answering several burning questions. What was this massive city? Who had built it? Why had they invested so much in its construction? How had it been destroyed or abandoned and why not reoccupied? Employing scores of workmen, Schmidt was able to excavate an incredible 18 trenches in only eight days over the hilly terrain of the city (Schmidt 1929). But in a city so vast, finding just the right place to excavate in order to answer particular questions about the city and the everyday lives of its inhabitants was like trying to find the proverbial needle in the haystack. He was able to place the city after the Hittites and before the classical periods, in other words somewhere within the 800 year span of the Iron Age, but learned little more than that. Still, it was not a bad return for eight days of effort. What he lacked was a way to see and understand the city as a whole and thereby choose where to concentrate his efforts to answer specific questions.

In 1993, when the current project (www.kerkenes.metu.

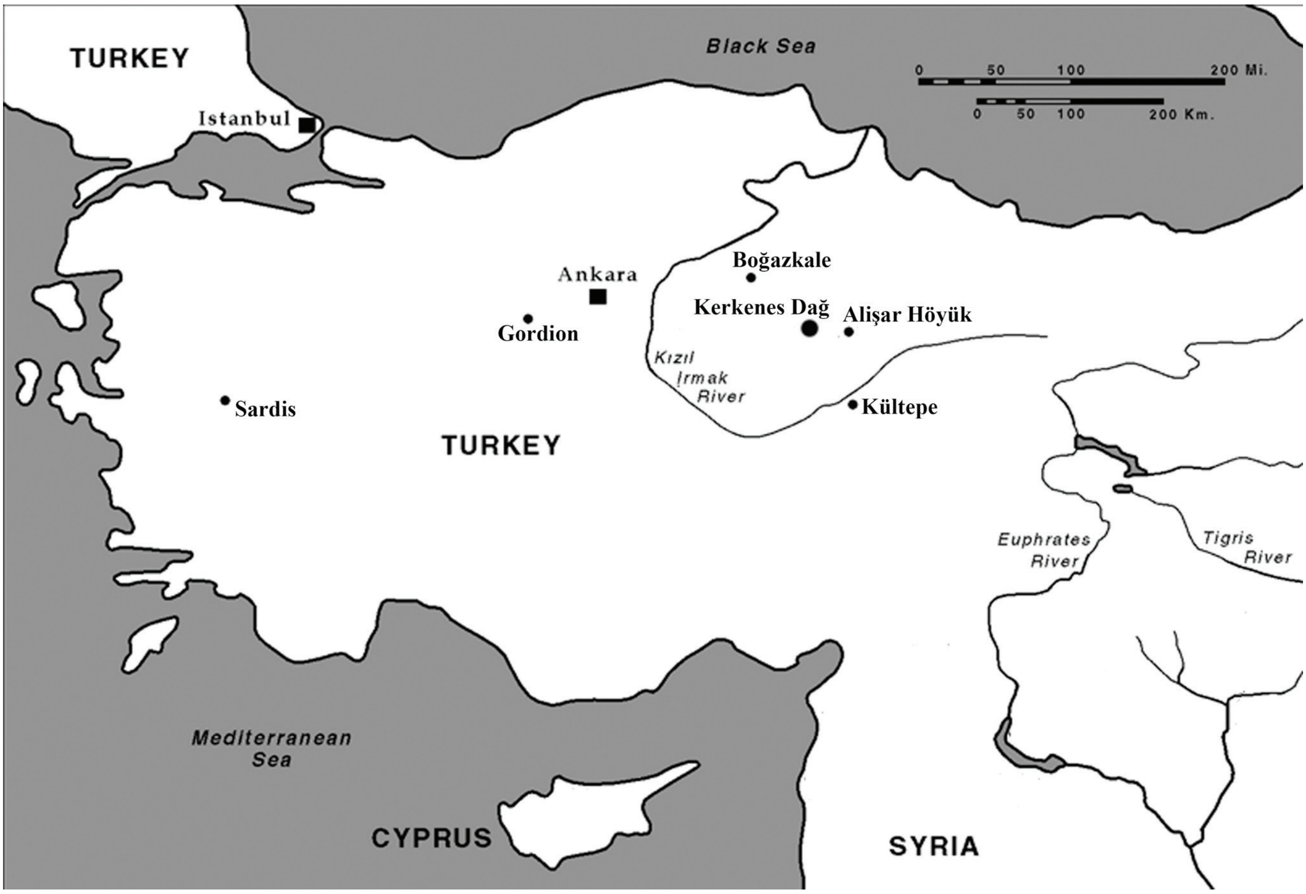

Figure 1. Location of Kerkenes Dağ in Turkey (Basemap courtesy OI Map Series).

edu.tr) returned to work once more at Kerkenes Dağ, a clear strategy was implemented to avoid this problem. Rather than rushing out and digging blindly, a large-scale program of remote sensing was begun to do everything possible to understand the layout of the city prior to excavation (Summers and Summers 1994). Initial work was focused on aerial photography from manned and unmanned balloons, later supplemented with orthorectified aerial photos and eventually high-resolution satellite images such as those from the Quickbird satellite made available by DigitialGlobe. When mosaiced together these images of the ground surface provided an early glimpse of the layout of the various urban blocks and structures that lay buried just beneath the surface.

Work was also undertaken, starting in 1993, using geophysical techniques to see beneath the modern surface of the ground. Over a seven-year period a geomagnetic survey covering over 240 ha of the city was completed (Summers et al. 2002). While these methods were being used on other projects at this time, the scale at which they were employed at Kerkenes Dağ remains unmatched and has attracted considerable attention (Kvamme 2003:437). Geomagnetics worked extremely well, in part because of the high level of burning when the city was set to the torch. But in other areas of the city, where the burning had not swept through so heavily on that fateful day, the use of data from the ongoing resistivity survey continues to reveal in greater detail portions of the urban plan that were obscured in the magnetometry data. These two sets of data, the magnetometry and the resistivity, offer complimentary views of the subsurface features and provide a highly detailed, contextualized glimpse of the form and sometimes function of places throughout this ancient city.

A third line of large-scale survey was undertaken between 1997 and 2001. As survey grade global positioning systems (GPS) started to become available, four Trimble 4600LS receivers were used at Kerkenes Dağ in kinematic collection mode to measure 1.4 million points covering the entire 271 ha area of the city (Summers et al. 2000; Branting and Summers 2002). With a tested accuracy of the post-processed points at ± 10-25 cm, the GPS survey was able to construct an extraordinarily detailed micro-topographic terrain model of the modern surface of the ground across the entirety of the city. As excavation and clearance has shown, this terrain model not only reveals the modern surface but also accurately reflects the slopes and aspects of the Iron Age paleo-surfaces buried just below. This micro-topographic terrain model remains remarkable in both the breadth of its area extent and its high resolution, and it is an important source of data within the simulations that follow.

All three of these independent lines of evidence were drawn together within ArcGIS, a Geographic Information System (GIS), and were used to produce a remarkable plan of nearly the entire ancient city (Branting 2004). The locations are now known of all the urban blocks that comprise the layout of the city (Figure 2), and the streets and alleyways that run between them (Figure 3).

The process of ground-truthing and checking this plan

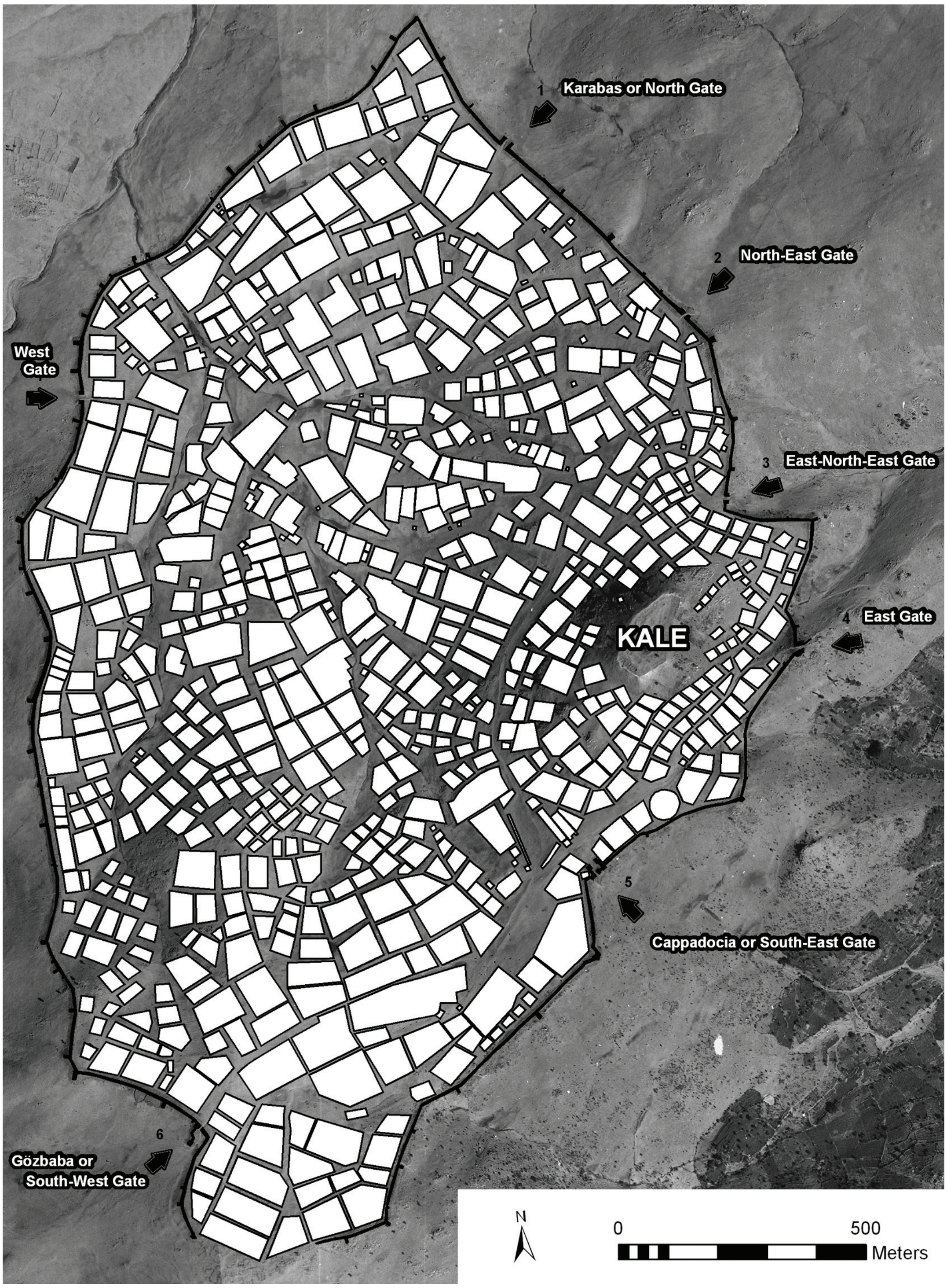

Figure 2. Urban Block Plan of the Iron Age City at Kerkenes Dağ.

through precision excavations and surface survey continues, as it has for the past 14 years, and some revisions in the details of the plan might well be forthcoming as interpretations of the data are sharpened. Work is also underway on a building by building plan of the city, which should provide important knowledge to guide excavation and contextualize understandings of the overall urban landscape.

The strategy of investing the time and effort upfront to collect these illuminative datasets has already begun to yield impressive dividends. Rather than blindly digging small holes all over the city, the project possesses the necessary knowledge to make optimal use of present and future investments of time and available funding. The power of this approach has already been well illustrated during excavation. By recognizing potential architectural forms in the combined data sources that were not visible on the surface, such as megarons and columned halls, excavations were able to be undertaken within specific portions of these structures to begin to answer some of the historical and social questions involving this ancient city (Summers and Summers 1998; Summers 2000; Summers, Summers, and Branting 2004).

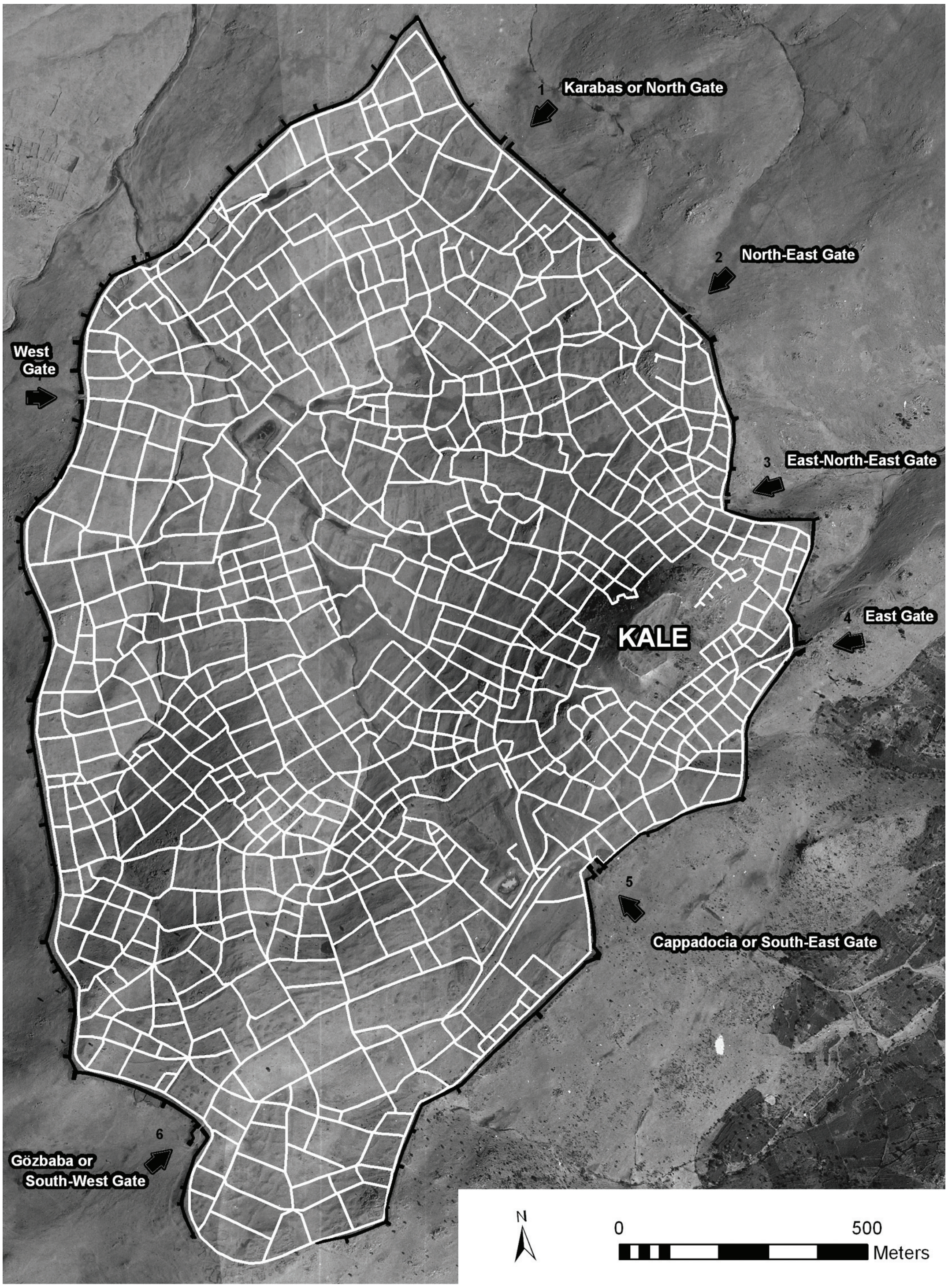

Figure 3. Street Network for the City at Kerkenes Dağ.

The strategy has also provided the opportunity to locate and excavate critical locations within the city for investigating aspects of its history, institutional memory, and the making of place. For example, this data was used to locate the palace compound within the city and to narrow down the location of its primary entrance, an entrance that can be seen to have been built on a monumental scale. It was expected that in such a place, where people entering the palace would have been required by the form of the architecture to pass through a given space at a particular perceptual perspective, that one would most likely find evidence of dynamic ideological claims to power (Morrison and Lycett 1994; Lefebvre 1991). By excavating here, clues were expected to be found to shed light on the methods and motives of those who constructed and controlled the city during its brief life as well as, perhaps, of those who destroyed it. This strategy has proved very successful. Trenches dug between 2002-2005 and situated within this gateway uncovered monumental architecture and reconstructable fragments of statuary, relief, and the first Old Phrygian inscriptions in the city (Summers, Summers, Stronach, and Branting 2004; Summers et al. 2005).

The presence of carved inscriptions is particularly exciting as very little information from contemporaneous textual sources has apparently survived pertaining to this ancient city. There is a fair degree of circumstantial evidence that the city might be, as suggested as early as 1929, equated with ancient Pteria, a city briefly mentioned by Herodotus (Przeworski 1929; Summers 2000). From the account of Herodotus (1987, I.76) we learn that Pteria is a city connected in some way with the Medes. Its capture by the Lydian king Croesus in 547 BC is given by Herodotus as the *causus belli* for the war between Croesus and Cyrus the Great that ended in the conquest of the Lydian Empire by the Persians. Whether or not excavations bear out this equation, much can be learned from this important city which was no doubt involved in some way in the major political upheavals in the Near East in the latter part of the 7th and first half of the 6th century BC. Excavations hold the promise of throwing light not only on this particular city and on ancient cities more generally, but also on larger historical questions including, perhaps, the nature of the Median presence in Anatolia during the decades prior to the rise of the Persian Empire (Lanfranchi et al. 2003; Tuplin 2004).

These results in but a few years of excavation are only the first fruits born of an initial dedication to understanding the city as a whole through non-invasive methods. But this strategy has yielded more than merely an impressive map with which to plan precision excavations in this city. The presence of this data has allowed the development of further innovative means by which to utilize this knowledge about the city as a whole in order to maximize returns. In this vein, the last several years were spent developing ways to use transportation geographic information systems (GIS-T) to explore the often overlooked evidence contained in the street network of an ancient city. For any city is the intersection of numerous social, political, and personal desires enacted in the activities of its builders and inhabitants (Smith 2003). Much as examining the circulatory system can tell one a great deal about the organization and function of the human body, examining the transportation system of a city can help one to understand how the city was organized and used by the people that once built it, inhabited it, and thereby gave it life.

2 GIS-T Techniques

Since the inhabitants of this ancient city have long since departed, how can one explore the dynamic forces of movement within the city or more generally within an archaeological landscape? A place to start would be in looking at streets and paths, the places where ancient movement and activities occurred on a daily basis. Since these were channels along which people created and recreated places, if these routes and paths could be mapped and the activities and motion of people that would have inhabited the landscape modeled, important information about how the areas around them functioned could be gleaned from the form of the network and simulations of movement through it.

Tools to accomplish this are available in other disciplines. GIS-T is one such set of tools that could productively be used in archaeology at both local and regional scales. It developed in the fields of geography and transportation planning during the 1990s, and is a merging of transportation modeling and simulation packages with GIS (Thill 2000; Goodchild 2000; Spear and Lakshmanan 1998; McCormack and Nyerges 1997). Currently it sees widespread use in most major transportation planning agencies. Since GIS-T is a relatively new tool there are areas in which it has seen little research or application. This includes the incorporation of studies of non-mechanized modes of transportation such as animal-drawn carts and chariots, long distance camel caravans, or even pedestrian walking. But it is precisely these transportation modes, and ones like them, that will be of the greatest interest for archaeological investigations.

Some of the ways in which GIS-T can be modified for such use in archaeology have been demonstrated and described previously (Branting 2004). Since GIS-T relies primarily upon movement through explicit networks for modeling transportation, it has a number of important benefits over other systems that would rely more heavily on raster models of movement. Segments along the lines of the transportation network do not need to be of uniform length, and thus one could vary the length of a segment to fit the different basic units of movement as they vary in response to elements such as topographic slopes. In addition, directionality is implicitly encoded within the segments themselves. Therefore, it is very easy to give bi-directional costs to a given segment for factors such as topography depending on whether one is going up or downhill or somewhere in between (Plog 1977:130). Finally, since network models actively use and investigate the linear paths and tracks along which movement and activities take place—for people and things move in linear fashion rather then jumping around from square to square like chess pieces—these models map very well to the theoretical framework of time-geography and taskscapes (Branting 2004; Hägerstrand 1970; Pred 1986; Ingold 1993).

3 Evaluation of Raster Least-Cost Methods

A key component of network-based methods is the network itself. By identifying beforehand the streets and paths that were the locations of much of the movement in the past, more detailed and powerful analysis can be undertaken. Yet within archaeology it has been by far more common to generate raster-based least-cost paths for looking at movement through a landscape. Such methods have seen increasing use with the arrival of new and readily available forms of free topographic data for most of the world, such as the Shuttle Radar Topography Mission (SRTM) dataset (srtm.usgs.gov) with its corrections and digital elevation models (DEM) derived from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) stereo-pairs (asterweb.jpl.nasa.gov). But how useful are the results? How close do they come to approximating paths where movement once took place?

With the street plan of the city at Kerkenes Dağ and the micro-topographic GPS, surface comparisons can be made between these methods. The GPS dataset can be aggregated up to a DEM of nearly any raster size, and the fidelity of the results attained, from running least-cost paths across these

DEMs, can be compared to the different segments within the known street network. Kerkenes Dağ can thus provide an excellent test case for investigating breakpoints in raster size above which significant variations in the landscape that might impact movement are obscured (Kvamme 1990), or below which additional greater fidelity to the known paths are not worth additional investments of labor in collecting increasingly more detailed DEMs.

Using a natural neighbor algorithm for aggregating different rasters from the underlying GPS point data, and then using the commonly applied least-cost pathway algorithms found in ArcGIS based on a slope-cost surface, an identical analysis of a least-cost path from Gate 5, also known as the Cappadocian Gate to each of the other six gates, was performed on seven different-sized DEMs. These different spatial sizes were: a 90 m DEM (Figure 4) such as would be common for most of the world in the SRTM dataset; a 30 m DEM (Figure 5) such as would be available from ASTER stereo-pairs or SRTM data in the United States' a 10 m DEM; a 5 m DEM; a 1 m DEM (Figure 6); a 50 cm DEM (Figure 7); and a 25 cm DEM.

As can be seen in the figures, the fidelity of the least-cost paths to the actual streets varies quite widely depending on the raster size of the respective DEM. For the 90 m DEM (Figure 4) very little fidelity can be observed, with least-cost routes even criss-crossing the massive city wall still prominent today on the surface of the ground. In the Iron Age this wall would have stood up to seven meters high, including the massive sloping stone glacis. This was obviously not something that could have been walked over without considerable difficulty, and draws into question the usefulness of 90 m DEMs, including the widely used SRTM data, for analyzing transportation routes and activities with any precision.

On the 30 m DEM (Figure 5), least-cost paths are at least staying within the massive city walls, but significant deviations still exist from the known street plan. One quite significant problem is that some paths cross right over the Kale, a 20-m high, later Byzantine fortification built up within the city at one of its highest points. This is one of the small portions of the ancient city with significant later overburden, but even in the Iron Age it was a formidable high point as is evidenced by bedrock protruding from it not far below the Byzantine walls. It is a significant problem to have least-cost paths generated from this DEM that largely ignore this massive obtrusion. As with the 90 m DEM this draws into question the level of generalization found in 30 m DEMs for undertaking detailed transportation analysis.

This problem persists at the 10 m and even 5 m DEMs, with features such as the Kale only being really taken into account at the 1 m DEM level (Figure 6). At the 1 m DEM level of generalization, least-cost paths begin to avoid such features, though there are still notable and significant differences from the known streets of the city. It isn't until the 50 cm DEM level (Figure 7), that least-cost paths not only avoid major obstructions but also begin to converge with

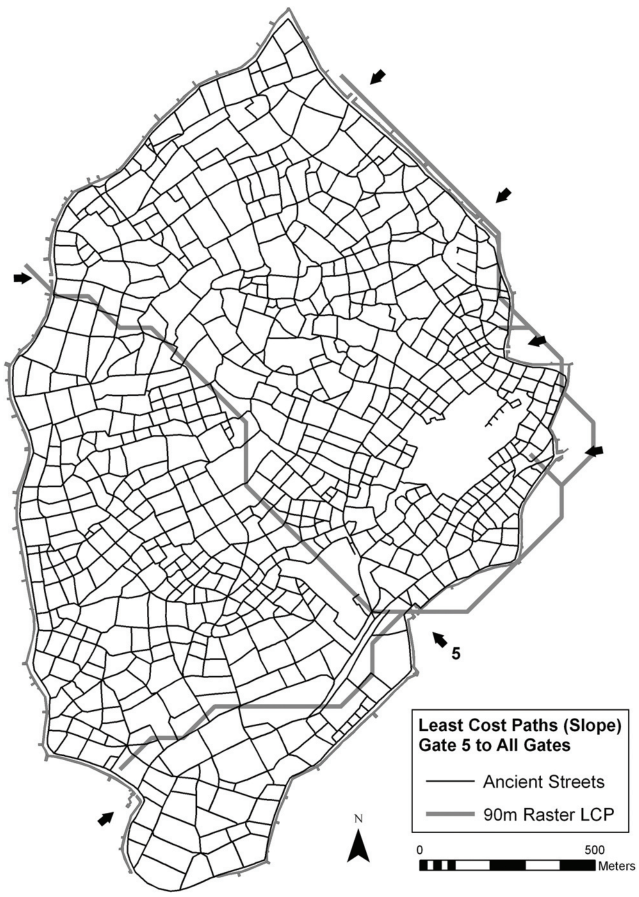

Figure 4. Comparison between the Street Network and the Raster-Based Least-Cost Paths from Gate 5 Using a 90 m DEM.

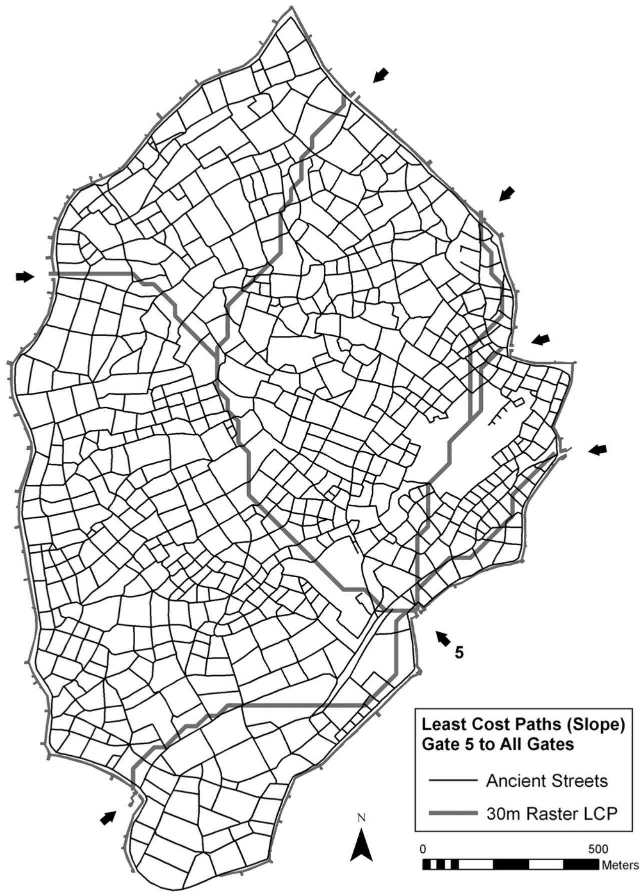

Figure 5. Compared Least-Cost Paths Using a 30 m DEM.

the known city streets. Yet even at the more fine-grained scale there are numerous interior walls being crossed over and movement running right through compounds and urban blocks with no sense that these would be places that people would not have easily traversed.

This brief analysis shows significant problems with the commonly employed raster methodology, and throws into question in particular its usefulness for detailed transportation analysis when using the commonly found larger raster sizes such as those of the SRTM (90 m/30 m) and ASTER stereo-pair (30 m) datasets. A much better way, as long as data can be collected to accurately reconstruct ancient routes and streets, would be to locate all or part of the actual transportation network at the outset. However, this will not be possible in all cases. There will no doubt be many areas for which the best data available will be the SRTM or ASTER stereo-pair-based DEMs. While these raster-based, least-cost path methodologies on 90 m or even 10 m DEMs will continue to be used, they should only be used while keeping in mind the significant difficulties noted here, and with careful consideration of their impact upon the results of the analysis.

4 PGIS-T Simulations

In addition to circumventing these issues of network fidelity through a careful consideration of where the streets and paths actually ran, network-based methods also allow the implementation of a wide range of new forms of analysis. Yet surprisingly, very few archaeologists have undertaken studies that utilize network methods such as these (Irwin-Williams 1977; Gorenflo 1996; Branting 2004). One such implementation that draws together developed GIS-T techniques with ancient modes of transportation is the pedestrian transportation Geographic Information System (PGIS-T) that I developed for analyzing movement and communication at Kerkenes Dağ (Branting 2004). The focus of this tool is on modeling the act of walking, by far the most common mode of transportation in the past as well as the present. Simulations of different types of people walking around within the city can then be used as a tool to parse the design and utilization of the transportation infrastructure of that place, the political control that was exercised along those routes through that place, and even the social fabric of the various neighborhoods of the ancient city that were connected in their actions and activities through the network of streets and alleys.

The PGIS-T methodology follows a three-stage process: elucidation of the road network, assignment of the costs of movement, and simulations of traffic for the assignment of traffic and passing traffic volumes (Branting 2004). For those familiar with the classic four-stage transportation model, most of the modeling effort at this time falls within the trip generation, trip distribution, and assignment stages (Ortúzar and Willumsen 2000:24). As with GIS-T analysis

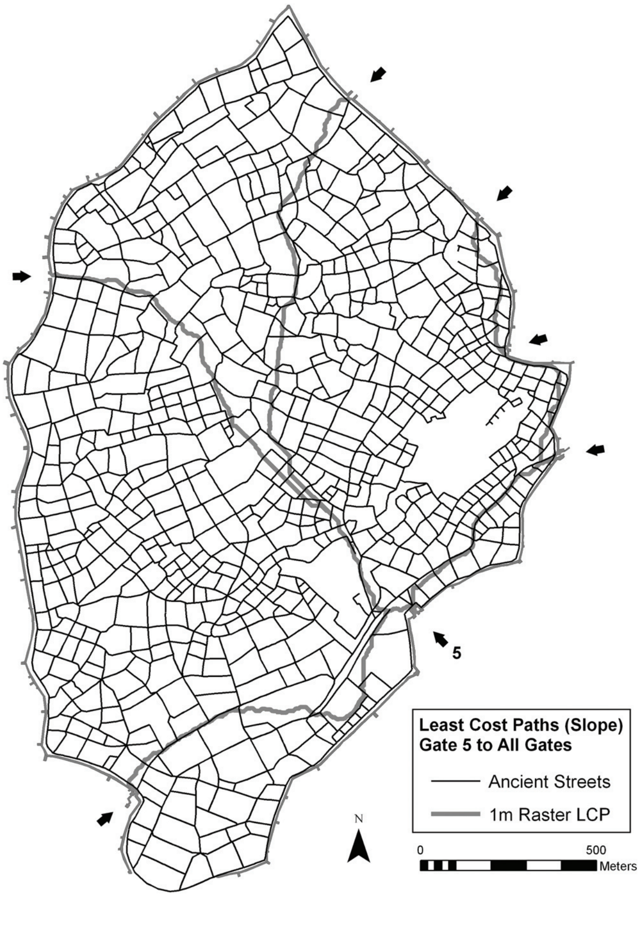

Figure 6. Compared Least-Cost Paths Using a 1 m DEM.

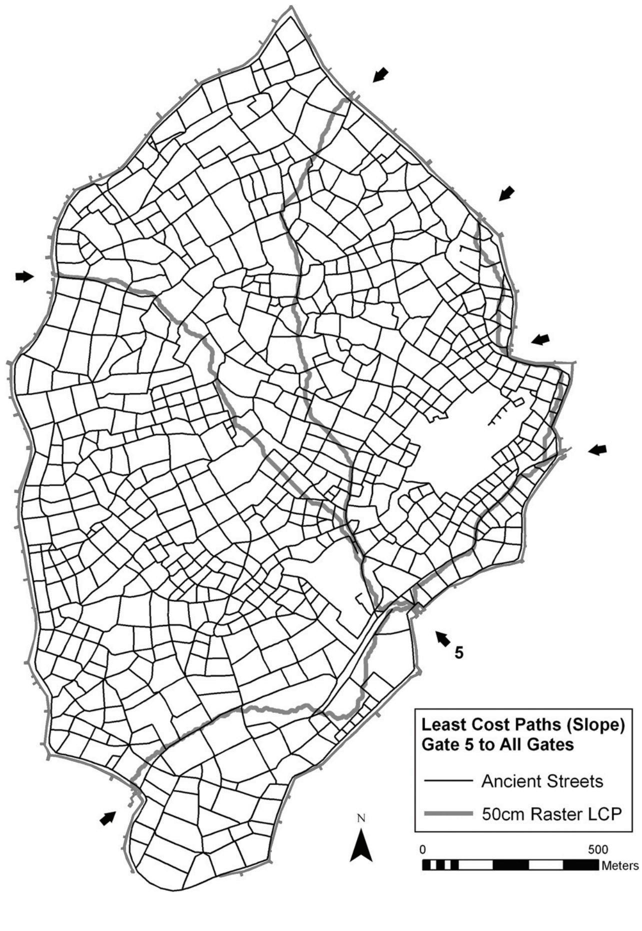

Figure 7. Compared Least-Cost Paths Using a 50 cm DEM.

Figure 8. Simulated Traffic Volumes of Pedestrians on the Street Network at Kerkenes Dağ.

more generally, the assignment of virtual pedestrians to particular routes within the network can be done with either stochastic or strict cost-minimization methods. This allows for a departure from the restrictions and drawbacks of pure least-cost principles (Zipf 1949). The PGIS-T can also make use of a variety of different costs. In Branting (2004), the main costs used were time and energy expenditures broken down by factors for individual pedestrians such as sex and age. However, there is nothing to preclude the use of more cognitive or social "costs" as the basis for route decision making. Once the simulation of a given scenario has been run, with the origins and destinations for each virtual trip set in advance, outputs of the counts of simulated traffic volumes along each street segment provide a picture of how the network functioned as well as which buildings and structures saw the most traffic passing by them.

The initial use of the PGIS-T at Kerkenes Dağ was undertaken using a simulation scenario in which each urban block within the city served as both an origin and destination to every other urban block. In such a scenario, no *a priori* notions of the use of space at any of these urban blocks is incorporated in the simulation. All urban blocks are treated equally, and thus it provides a good first look at the overall street network. The counts of simulated pedestrians along each street within the network, as allocated in this initial use of the PGIS-T, revealed which streets within the network were likely the main streets and which were not part of the major routes through the city (Figure 8).

It also allowed the identification of key points and urban blocks within the urban environment, points where control could be exerted on people passing by or where key activities would have most likely taken place (Figure 9). Both the Palace Compound (699), the site of political power in the city, and the Büyük Göl (192), the main water source, were identified through this initial, equally apportioned analysis of the street network as two of the most critical points within the city. Other urban blocks also were shown to be critical junctures within the city, yet unlike the Palace and Büyük Göl, they await future excavation to demonstrate why this was the case.

Additional simulation scenarios were also undertaken, some with variations introduced to reflect the different ways that different types of people walk. These could be differences based on gender, age, or even on social preferences for different types of footwear. Those simulations based on different demographic groups revealed statistically significant differences in the overall use patterns across the network as compared to the patterns of the other groups (Branting 2004:136-147). In this manner the PGIS-T can use the information contained within the form of the street network, and an expanding understanding of the function of the places through which the streets ran, to provide larger contextual views of aspects of the social or gendered urban landscapes that once filled this ancient city.

4.1 Testing of the PGIS-T Simulations

The results of the PGIS-T simulations have been tested against more than just the admittedly incomplete knowledge of the urban landscape of the ancient city at Kerkenes Dağ. Initial testing was carried out prior to its archaeological application on a living city filled with observable urban pedestrians. For this purpose, the city center of Cambridge, England was used to see how well the results of the PGIS-T conformed to observations of pedestrian traffic patterns and activities within this urban landscape. Comparison of the simulation results versus a baseline of expected traffic flows collected via independent observation yielded very promising results. A two-sample Wilcoxon matched pair rank sum test, of the similarity of the observed patterns and the patterns predicted by the PGIS-T, proved to be significantly similar with a p-value = 0.0047 (Branting 2004:105-107). Locations within this urban landscape were also compared to the results of the simulations in order to test both the general results as well as those for simulations of different subdivisions of individuals based on age and gender (Branting 2004:116-117).

New ways have also been found to test the results of the simulations archaeologically. A series of test trenches were excavated in 2004 across a number of the city streets at Kerkenes Dağ (Summers et al. 2005). Micromorphological and loose soil samples were taken from loci above and below the street surface as well as from the street itself. These samples were sent to Dr. Charles French at the Charles McBurney Laboratory for Geoarchaeology at the University of Cambridge for analysis, and several tests showed excellent correlations with the predicted traffic flows from the PGIS-T simulations. These include results from the micromorphology, laser particle size analysis, loss-on-ignition analysis to produce percentage calcium carbonate values, and electro-chemical measurement of redox potential. With an expanded sampling strategy of the city streets in the years ahead, it is the hope that these tests will provide a suite of tools for independently estimating traffic frequencies from ancient roads and paths.

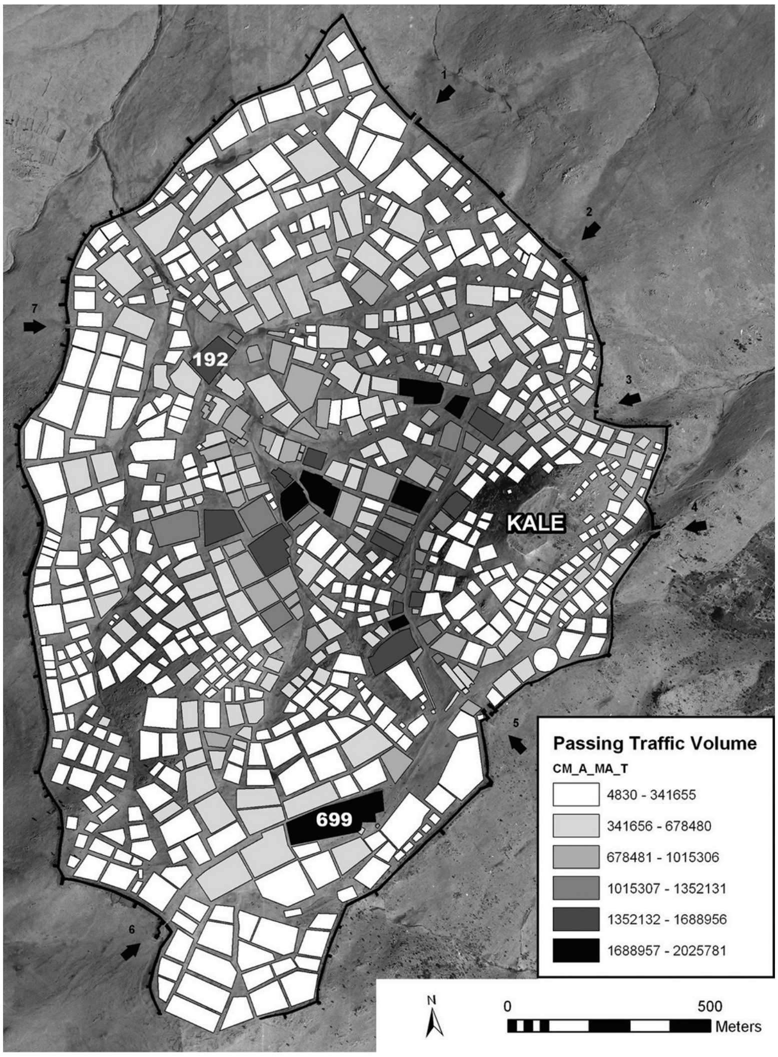

Figure 9. Simulated Volumes of Pedestrians Passing each Urban Block.

5 Conclusion

This paper has presented a brief introduction to GIS-T and PGIS-T methods for analyzing ancient movement and transportation. Using the expansive program of remote sensing undertaken by the Kerkenes Dağ Project, the network of streets for this ancient city was reconstructed. This provided the basis against which the PGIS-T was used to offer a glimpse of the urban landscapes that once existed in this place. In addition, this street network offers the opportunity to evaluate the usefulness of the raster-based, least-cost methods that are more popular in archaeology for modeling movement. The results called into question the usefulness of 90 m, 30 m, or even 10 m DEMs for modeling ancient movement, specifying in more detail the concerns raised by Kvamme (1990) almost two decades ago. In so doing, this paper has sought to offer both a word of caution and a vision of a new future for the modeling of ancient movement through landscapes long forgotten.

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