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Roads in the Sand: Using Data from Modern Travelers to Construct the Ancient Road Networks of Egypt's Eastern Desert

Maël Crépy, Louis Manière, Bérangère Redon

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Maël Crépy, Louis Manière, Bérangère Redon. Roads in the Sand: Using Data from Modern Travelers to Construct the Ancient Road Networks of Egypt's Eastern Desert. Tuna Kalayci. Archaeologies of roads, The Digital Press at the University of North Dakota, pp.245-273, 2023, 979-8-9891912-8-4. hal-04268239

HAL Id: hal-04268239

<https://hal.science/hal-04268239v1>

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ARCHAEOLOGIES OF ROADS

Edited by
Tuna Kalaycı

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The Digital Press at the
University of North Dakota
Grand Forks, ND

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2023 The Digital Press @ The University of North Dakota

Library of Congress Control Number: 2023947262

ISBN-13: 979-8-9891912-8-4 (paperback)

ISBN-13: 979-8-9891912-0-8 (Ebook/PDF)

A full color digital copy of this book is available as a free download:
<https://thedigitalpress.org/roads/>

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Chapter Nine

Roads in the Sand: Using Data from Modern Travelers to Construct the Ancient Road Networks of Egypt's Eastern Desert

Maël Crépy, Louis Manière, and Bérangère Redon

The Eastern Desert of Egypt is a hyperarid desert with significant temperature variations; its western part, made up of Nubian sandstone, is sandy and low in altitude (Figure 1). After approximately 100 km, this is abruptly replaced by a rocky or mountainous landscape that extends to the Red Sea (Harrell 2022; Hume 1907). Like all margins of Egypt, the Eastern Desert has always been considered an ambivalent territory. It is reputed to be inhabited by dangerous magical powers, wild animals, and dreadful nomadic populations. However, in spite of its dangers and aridity, the Eastern Desert was identified very early on as being richly provided with natural resources, including gold (Faucher 2018; Klemm and Klemm 2013) and hard stones of great value. Finally, because of its position, the Eastern Desert is also an interface between several worlds: it links Egypt to Nubia, and, above all, it provides access to the Red Sea and to the Arabian, African, and Indian worlds (De Romanis 1996; Gasse 2012; Sidebotham 2011). The peak of regional occupation occurred during the New Kingdom (second half of the second millennium BCE) and the Greco-Roman period (Cuvigny 2003; Gates-Foster 2012). The rulers of that period invested massively in the region, founding quarries and mines and creating a network of roads and fortified wells (Cuvigny 2013; Redon 2018), as well as several harbors. The Eastern Desert has been explored for almost three hundred years by scholars, and hundreds of ancient sites have been identified. Their exploration has yielded a tremendous amount of archaeological and written material (Brun et al. 2018; Sidebotham and Gates-Foster 2019).

The project “Desert Networks: Into the Eastern Desert of Egypt from the New Kingdom to the Roman Period,” funded by the European Research Council, was launched in November 2017. It aims to study the ancient networks of the region based on the assumptions that one person cannot cross the desert alone and survive and that

sites and people were likely to have been interconnected. Three main networks are considered: physical, economic, and social. As for the first, the ancient tracks of the Eastern Desert have hardly been studied at all—no doubt, paradoxically, because the waypoints they connect are well known, at least for the Roman era: the ancient *itineraria* give very precisely the names of the stops and the number of kilometers between them, so it has not been considered useful to locate the tracks themselves. As a result, maps of the Eastern Desert show only fairly linear paths (Meredith 1958) that ignore geography, the location of environmental resources such as water, and other natural constraints including those related to the physiological characteristics of camels—the desert vessels and major medium of transportation in the Egyptian deserts from the mid first millennium BCE (Agut-Labordère and Redon 2020) to the twentieth century CE (Crépy and Redon 2020). However, the *itineraria* only provide information about the networks at specific points in time, so their duration of use is uncertain, and the networks may have been much more mobile (in time) and complex (in space, with secondary routes). Some sites thus exist outside the main roads that have been represented traditionally, and it is essential to understand how they fit into the ancient network.

To go beyond these classical representations of the movement of people in the Eastern Desert, the Desert Networks project has worked on a more integrated reconstruction of the ancient paths using a theoretical model, 3D data, and also empirical data—in particular, the large quantity of information available in the many accounts of modern travelers. This multidisciplinary method is a consequence of both the work conditions specific to Egypt and the objectives of our project. This article aims to describe the stages taken in constructing our model in order to show how travelers' and early scholars' accounts can be used to calibrate least-cost path functions. We then present two case studies using this approach: a study of the least-cost path network of the Coptos–Myos Hormos road and an analysis of the route between the Ptolemaic forts of Abu Rahal and Abu Midrik. In a broader view, this model—whose approach is reproducible and transferable to other regions—will make it possible to calculate the durations and routes used for desert crossing more precisely and to question the dynamics of occupation of the Eastern Desert. It also provides crucial insights for future archaeological surveys.

From Empirical Modern Traveler Data to Ancient Network Reconstruction

Path Determination Modeling through Least-Cost Path Analysis

Least-cost path analysis is a spatial method for finding the best way for a traveler to cross a territory from one place to one or multiple destinations, and it is used in archaeology either to find ancient routes or to evaluate route accessibility (for an overview of archaeological route modeling approaches, see [Verhagen 2018](#); [Verhagen et al. 2019](#)). The “best way” is defined as the path with the lowest cost of travel. This analysis can be done through a network as well as with a cost raster as an input, where each pixel represents the effort to cross that cell. The usual method is to classify and weight several raster data layers—each with different values that affect movement—into an overall cost raster. The main objective is to define the factors affecting travel, according to its restrictions, and then map it out. This cost raster is used to produce an accumulated cost surface or cost distance raster using geodesic distance. Then a least-cost path algorithm is used to identify the best way to link the nodes that are being analyzed.

Several difficulties arose when we first applied this traditional approach to reconstructing the Eastern Desert’s roads. The climatic and environmental conditions of the area are very specific with many natural constraints, as are the means of transportation: most transportation was done with camels at least from the Greco-Roman period, and the use of these animals requires particular practices and environments. Furthermore, the project is seeking a level of precision that cannot be achieved via traditional approaches in order to develop a model that can lead our team’s future surveys. In order to refine the quality of our model, we decided to incorporate empirical data taken from a very rich corpus at our disposal: travelers’ accounts. By identifying the factors that influenced their itinerary choices while crossing the desert—notably, in an environment and under practical conditions that have not changed very much since antiquity—we asserted that these factors can be used to calibrate the function and reconstruct the ancient paths.

Traveler and Spatial Data

This study is based on three main types of sources: data from the Desert Networks’ spatial database, a 25-m resolution digital elevation model (DEM) based on Shuttle Radar Topography Mission

Table 1. The accounts of travelers and modern scholars used to build or assess the model.

Author	Date of publication	Date of the journey	Aim of the journey	Used for
Denon	1802	1799	Military operation	Control
De Rozières	1812	1799	Military operation/geology	Control
Belzoni	1820	1818	Exploration/archaeology	Time
Flaubert	1910	1850	Sightseeing	Control
Du Camp	1860	1850	Sightseeing	Control
Colston	1886	1873	Exploration	Time/route
Floyer	1887	1886	Exploration	Control
Couyat	1910	1908, 1910	Archaeology/geology	Route
Bisson de la Roque	1922	1922	Exploration	Time/route

(SRTM) 1 Arc-Second Global data,¹ and a set of travelers' accounts and maps dating back to the eighteenth, nineteenth, and twentieth centuries.

The Desert Networks project's geodatabase gathers data on the Eastern Desert that has been found in archaeological publications, topographic and geological maps, and travelers' accounts. It combines chronological, spatial, and descriptive data about archaeological sites (from the New Kingdom to the end of the Roman period), as well as data about mountains (*gebel*) and other natural features (passes and gorges), the hydrographic network (*wadis*), and watering places (natural or artificial basins, springs, wells; see [Crépy and Redon 2022](#)), offering a comprehensive reference for more than 1,600 natural and archaeological sites in the Eastern Desert of Egypt.

Empirical data about camel routes and travel conditions in the desert are taken from accounts of European and North American

¹ SRTM data is courtesy of the US National Aeronautics and Space Administration (NASA) and National Geospatial-Intelligence Agency (NIA) and processed by ATDI.

travelers and scholars who crossed the region in the eighteenth, nineteenth, and twentieth centuries and left a description of their journey. More than 60 accounts and several dozen maps relate to our study area, but not all of them are of sufficient precision to reconstruct the routes. For example, the account of James Bruce (1790), the first European to produce a detailed account of his journey in the region in 1769, is of little help due to the lack of continuity in place naming and because his descriptions are too vague and tinged with orientalism.

This is why, among this heterogeneous documentation, only eight accounts and one map were selected to develop, calibrate, and control our function (Table 1). These sources were chosen for their accuracy and reliability (i.e. they give distances, times, and many details that allow for the identification of a precise itinerary) and because they cover different types of routes and areas in the study region. The oldest trip under consideration took place in May 1799 (Denon 1802; De Rozières 1812); the most recent, in January 1922 (Bisson de la Roque 1922). The objectives of the expeditions in the Eastern Desert were quite variable (see Table 1), as were the logistical conditions: some were made up of very small groups (e.g. five people and five camels: Du Camp 1860; Flaubert 1910), while others were large caravans of over a thousand men and camels (Denon 1802). Depending on the aim of the journey, the expeditions lasted from three and a half days (the shortest time to cross the desert with camels) up to several weeks.

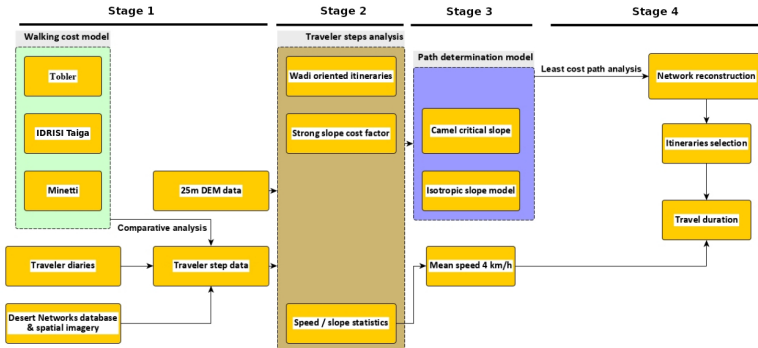


Figure 2. Conceptual scheme for data analysis and model design, from primary data to network output. © Desert Networks and L. Manière.

Path Determination Model Design and Network Reconstruction

In the following paragraphs, our method and results will be detailed. The main stages are summarized in [Figure 2](#).

- Stage 1: Plot the travelers' itineraries and extract a set of data on ancient sites; compute itineraries generated by three pedestrian cost functions. The resulting spatial data are analyzed with the help of GIS software (ArcGIS 10.5, QGIS 3.4, Google Earth Pro).
- Stage 2: Compare the itineraries generated by the pedestrian functions with the travelers' itineraries, determine the factors (including slopes influencing the travelers' choice of paths), and calculate the mean speed of the modern journeys. Calculate a critical slope for the travelers' itineraries.
- Stage 3: Create an isotropic slope function with the critical slope and via slope threshold calibration on travelers' itineraries.
- Stage 4: Reconstruct the networks of the sites in the Eastern Desert; identify the best itineraries; calculate duration from mean camel speed; compare with field data to assess the quality of the model at the regional and local scales.

Stages 1–3: Modeling the Travelers' Path-Decision Factors

In order to conduct our analysis and highlight the criteria that prevailed in the choices made by travelers who crossed the desert, it was necessary to trace the precise routes they used despite sometimes disjointed or incomplete descriptions. To do so, we used satellite imagery, the Desert Networks' database, and topographic and geological maps to find landmarks (i.e. archaeological sites, modern settlements, or remarkable natural features) that the travelers described. Comparison with other accounts in the general corpus sometimes made it possible to refine or amend the routes through cross-checking.

The nine reconstructed itineraries were divided into steps, each step corresponding to a journey between two intermediate destinations within the itinerary. This method allowed us to assume that the traveler tried to find the best path during each step without being diverted by other specific sites or watering places on the way. The diaries provide qualitative data that describe the travelers' decision process during a step.

Comparisons between Travelers' Steps and Pedestrian Least-Cost Paths

In parallel with the reconstruction of the travelers' itineraries, three well-known pedestrian least-cost functions were used to build least-cost paths for all the steps and itineraries considered in our study. The first was Tobler's hiking function—made by analyzing the Swiss military in temperate mountains (Tobler 1993)—which provides an anisotropic relationship between slope (gradient and inclination) and walking speed. The second was Minetti's anisotropic function—created by analyzing ten sportsmen walking—which observes the metabolic energy cost while walking in relation to the slope (Minetti et al. 2002). The third was IDRISI Taiga software, which provides an isotropic function between gradient and walking speed (although, nevertheless, it is important to note that the source of the data used to produce this equation cannot be found in the literature, but is referenced only in a footnote as personal communication about an example concerning cost-distance analysis in Nepal; see Schneider and Robbins 2009:Note 5).

The comparison between the least-cost paths built using these pedestrian least-cost functions and the paths the travelers followed in each of their steps is enlightening and interesting in several respects. Unsurprisingly, the pedestrian models—which were based



Figure 3. Comparison between Bisson de la Roque’s journey and the least-cost path calculated using three modern least-cost-path functions based on pedestrian movement. Imagery courtesy of Esri. © Desert Networks and L. Manière, M. Crépy.

on present-day walkers equipped with modern orientation tools—are shorter paths than those of the steps reconstructed from the travelers’ diaries (Figure 3).

This is easily explained by the two different modes of transportation and by the fact that the data on which the pedestrian least-cost functions are based are not from a desert environment. There is also a less sensitive slope factor for hikers, while heavily loaded camels are certainly more comfortable on gentler slopes. However, other factors should also be considered (see, for instance, Lewis, *this volume* or Murrieta-Flores 2014 for visibility; de Gruchy and Lawrence, *this volume* or Herzog 2014 for soil compactness, vegetation cover, etc.). In our study, one of the main factors that influenced the travelers’ choice of paths was the great affinity that the travelers showed for staying in wadis (dry rivers), even if a shorter path with equally gentle slope was available, as evidenced in many of the accounts. For example, Cailliaud described a part of his journey as follows:

We followed our way through several valleys; to the north, we left another major road to Qoceyr, on the Red Sea. [...] A

pyramidal masonry pile, placed on the top of the two mountains that border these roads, serves to distinguish them. The one on Mount Zabarrah in the east is also marked in many places; without it, the rains destroying the fugitive traces left by the caravans, we would be lost at any moment and stopped by the mountains. Indeed, we believe we see gorges from afar with the appearance of a passage, we transport ourselves there, and we find them impassable [Cailliaud 1821:59; translation by M. Crépy].

The words of Floyer (1887:663) also shed light on the difficulties of orientation and the importance of the wadis:

There is little to be seen that is not properly transferred to the itinerary. Down in a trough you rarely see far to the right or left. A glimpse now and then shows you nothing but hills, from which, if you try to select one as a landmark, you will be hidden by the next turn in the valley.

Similarly, Belzoni and his expedition—in need of water and food, and after the loss of several camels in previous days, probably from exhaustion—reached the site of Kanais by night by making a major detour to the east through the wadis; meanwhile, he reports seeing an ancient road that cut across a plateau and could have saved him 15 km (Belzoni 1820:344–345). Belzoni’s choice was probably driven by the difficulties of orientation on the plateau (which corresponds to the area mentioned in Figure 10), especially at night, because the cairns indicating the path to follow are not easily visible in low-light conditions.

In addition to having gentle slopes and representing geographic references for orientation, especially during the night, the wadis provided a cohesive sandy or gravelly walking surface. This was also critical, as emphasized by Tregenza’s (1955:4) description of walking in wadis: “It was not a straight walk, for both men and animals were winding a little as they avoided stones and surface irregularities.”

Slope Factor Determination

Two main factors that influenced the travelers’ choice of paths—slope and orientation—emerged from comparing the traveler’s step itineraries with the pedestrian least-cost functions. The slope factor appears to have been the more critical of the two.

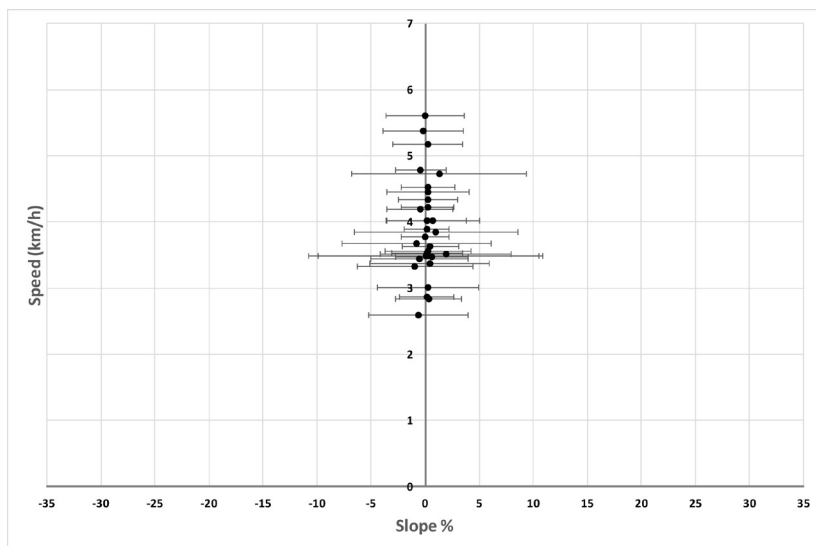


Figure 4. Relationship between mean slope and speed for the step travel models. Slope (in %) was extracted from a 25-m resolution DEM (based on SRTM 1 Arc-Second Global data) along 30 traveler steps. The average slope was used, with ± 1.96 standard deviation or 95% of the values around the mean. © Desert Networks and L. Manière.

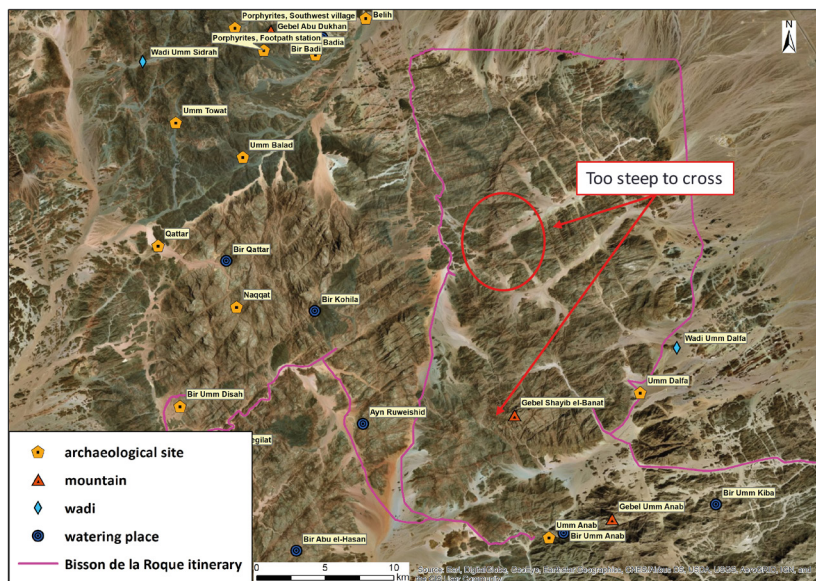


Figure 5. Bisson de la Roque's journey through the Gebel Shayib el Banat. Imagery courtesy of Esri. © Desert Networks, L. Manière, and M. Crépy.

Its effect on travelers' choices can be measured by calculating the slopes that the travelers crossed using a 25-m resolution DEM, extracting the slopes every 40 m along the travelers' paths. A very low magnitude of values is attested (Figure 4), with most slope values between +/- 5% and rarely beyond +/- 10%. This shows that the travelers stayed in flat areas as much as possible, even if it increased their travel distance and/or duration.

The journey of Fernand Bisson de la Roque illustrates very clearly the strong slope factor that emerges from reconstructing the travelers' itineraries, and it demonstrates how some slope restrictions greatly changed his path through the Eastern Desert. Bisson de la Roque was an archaeologist and explorer who was sent with a camel caravan to climb the Gebel Shayib el Banat, the highest point in the Eastern Desert. The terminal part of his ascent was planned without camels, as the slopes are very steep and the paths extremely narrow. Before that, he tried to reach the foot of the mountain with his camels, but he was forced to turn back on several occasions due to steep passes and having to make a very long detour to the north. Specifically, in reference to the al-Zarqa Pass (Figure 5), which seemed to be the shortest way he wanted to take, he wrote: "This descent does not seem practicable to me for a caravan" (Bisson de la Roque 1922:125).

Indeed, if the slope is too steep or the surface unstable, camels can slip, become injured, or even die, as mentioned by Gustave Flaubert, who made the trip from the Nile to Quseir in 1850 with Maxime du Camp, two guides, a translator, three riding camels, and two pack camels. In his account, he described seeing dead camel carcasses in a place that corresponds to one of the two steepest areas along the route he took during his journey, and he specified that they had to cross the pass by foot (Flaubert 1910:245). Regarding the passage of a difficult pass, Belzoni (1820:317) wrote:

When we reached the top of the road, our camels were exhausted; some of them had fallen on the way, and were unloaded to enable them to ascend, and the strongest camels had to return to fetch the loads of the others. I never saw the camels suffer so much on any occasion as on this. A steep and craggy road over a mountain is no more adapted to a camel, than the deep sand of the desert to a horse.

The importance of the slope factor is also shown by Ball (1912), a geologist and a particularly reliable informant, who thoroughly

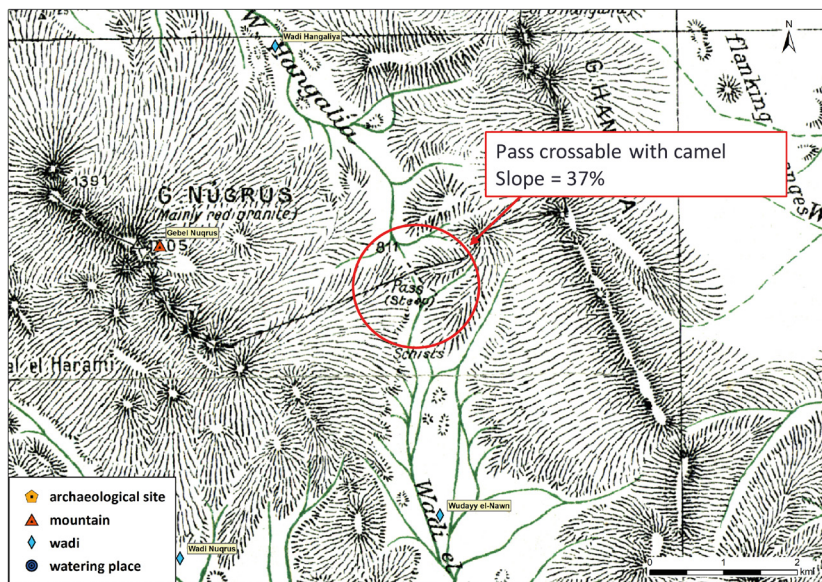


Figure 6. A pass through the Gebel Nugrus on Ball's (1912) map. © Desert Networks and L. Manière.

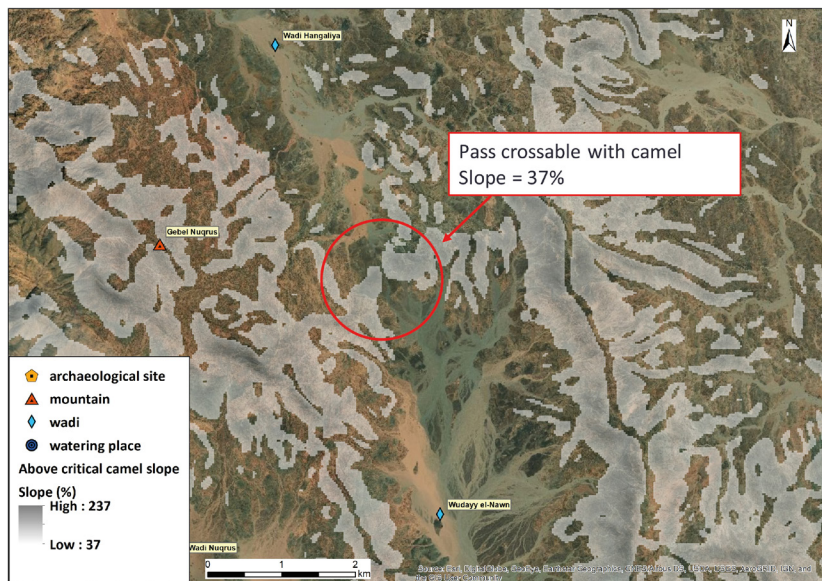


Figure 7. A pass through the Gebel Nugrus with slopes above 37% (the slope restriction for camels) highlighted in gray. Imagery courtesy of Esri. © Desert Networks and L. Manière.

surveyed the region over several months in order to draw topographic and geological maps. Traveling throughout the whole of the Eastern Desert with camels, he worked very systematically and covered each available track in his survey area. His camels were heavily loaded in the same way as the camels of the ancient caravans. On his maps, he precisely indicated the passes that could be crossed and the ones that caused difficulty (Figure 6).

From the steep slope restrictions noted in Ball's maps and drawings, along with the other accounts under study, the critical slope—that is, the slope beyond which camel caravans cannot travel—can be deduced as 37% (Figure 7).

Mean Speed Calculation

It is possible to calculate the speed of each step in the itineraries and the mean speed of all the itineraries (see Figure 3) as 3.9 km/h +/- 1.45 km/h. Because of the spatial scale of the steps (each being several kilometers long) and the fact that the travelers avoided steep terrain, it is impossible to go further and estimate the speed for each slope value, since a mathematical model cannot be fitted between speed and gradient. Nevertheless, the mean speed we calculated is consistent with other sources from modern scholars and travelers about camel speed:

- Barron and Hume (1902:3–4), two geographers who surveyed and mapped a huge part of the Eastern Desert, explained that, when their measuring wheel was out of order, they measured distance via a time scale using a camel speed of 4 km/h. The accuracy of their maps shows the quality of this method.
- Bisson de la Roque (1922:113) mentioned the mean speed of his camels as 1 km per 15 minutes (i.e. 4 km/h).
- Tregenza (1955:4) wrote: “Loaded camels move slowly, at about two and a half miles an hour, and that would be our speed for the next three months.” This rate corresponds to 4.023 km/h.

The same range of values has also been found in more recent scientific publications, with the speed of pack camels ranging from 4 km/h (camels from Mauretania and India) to 5 km/h (camels from Pakistan and Kenya; see Schwartz 1986:Table 5).

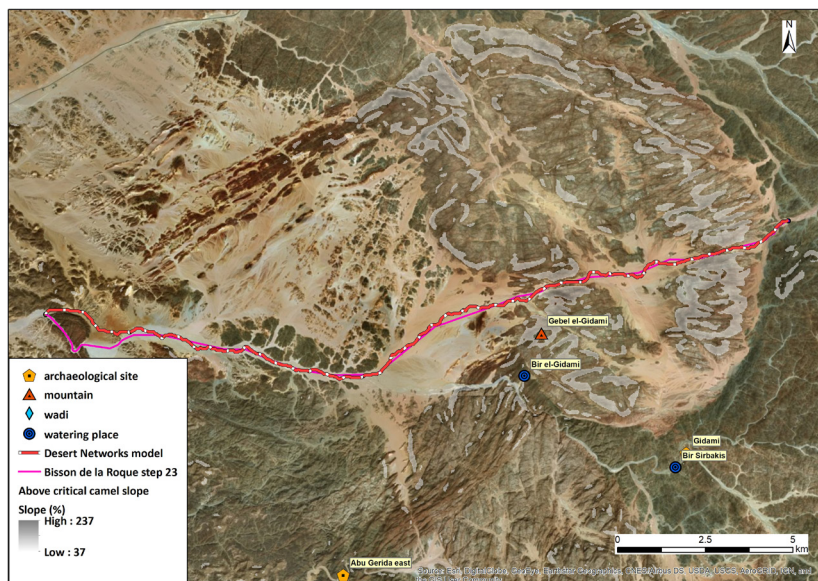


Figure 8. Example of slope-based cost function calibration of Bisson de la Roque's survey in the area of Gidami (step 23). Imagery courtesy of Esri. © Desert Networks and L. Manière.

Design of the Path Determination Model Based on Slope

Finally, having extracted slope and speed data from the travelers' accounts, the next stage in building our slope-based model was to create a slope/speed model for camels. However, as already stated, this cannot be done directly, since our data are at the scale of the itinerary steps and not the pixel due to the low resolution of our DEM (25 m). Therefore, the cost for each slope interval threshold was adapted to fit the dataset of traveler's paths using a trial-and-error process for each least-cost path computation (Figure 8). Nine steps were used for this calibration (which is still ongoing), which enabled our cost value and slope interval thresholds to gradually become more accurate and better fitted with the travelers' dataset. It should be stressed that by applying this very empirical method, the computational cost is unitless and is more a relative cost than an absolute one; thus, the route produced by a least-cost path computation based on this model is more the result of a decision process than a way to minimize time or effort. Also, it is important to note that this method is limited by the resolution of the DEM and the accuracy of the step reconstruction, which is at the wadi scale. To determine if the path calculated by the least-cost path

analysis from cost and slope interval thresholds is valid, the output path should follow the correct valley without taking into account the variability inside the wadi.

In the slope calculation, and despite the fact that our slope function is isotropic, we chose to give weight to the orientation of the slope. In the case of an anisotropic slope function, the gradient is computed with the azimuth to establish the slope orientation and apply the appropriate cost. We thought it would be crucial to apply the same process in an isotropic function even if the same gradient will produce the same cost regardless of the slope orientation. By doing so, if a position is considered at a certain altitude, the slope-based costs of adjacent cells will take this altitude into account when calculating the cost distance (therefore, the slope will not be calculated and classified before the cost distance is calculated). This method allows the computed routes to run along the slopes rather than forcing them through the thalwegs.

Stage 4: Applications of the Desert Networks' Least-Cost Path Model and Initial Results

Network Reconstitution

Once the cost and slope interval thresholds are calibrated, a network can be built by iterating the least-cost path computation (our model uses Dijkstra's [1959] least-cost path algorithm) through all the nodes in consideration: that is, the archaeological sites and watering places listed in the Desert Networks' database.

By creating a network, instead of linking only from a departure point to a final destination, intermediate nodes such as watering places (which are critical in the desert) are taken into consideration to reconstruct the roads. Indeed, these waypoints are essential elements in the reconstruction of paths; however, this point-type spatial data cannot be integrated into a cost raster. The network method also makes it possible to represent different possible routes between a source and a destination. It provides a way to calculate and visualize all the alternative itineraries between two nodes by considering all the sites known during a certain period.

The analysis of the network and the selection of intermediate nodes for modeling a specific route ensured a broader understanding of the choices that the caravans had in realizing their route.

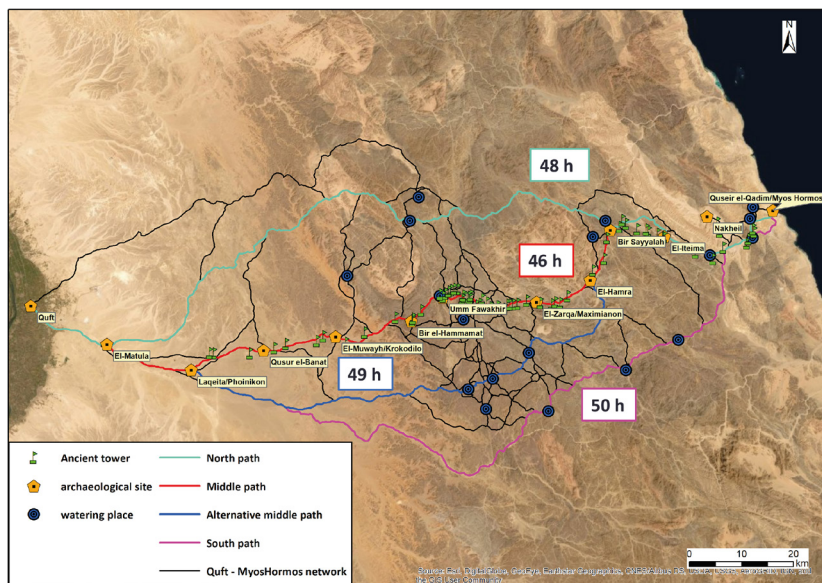


Figure 9. Network reconstitution by least-cost path iteration between sites from Quft (ancient Coptos) to Quseir el-Qadim (ancient Myos Hormos). Imagery courtesy of Esri. © Desert Networks and L. Manière.

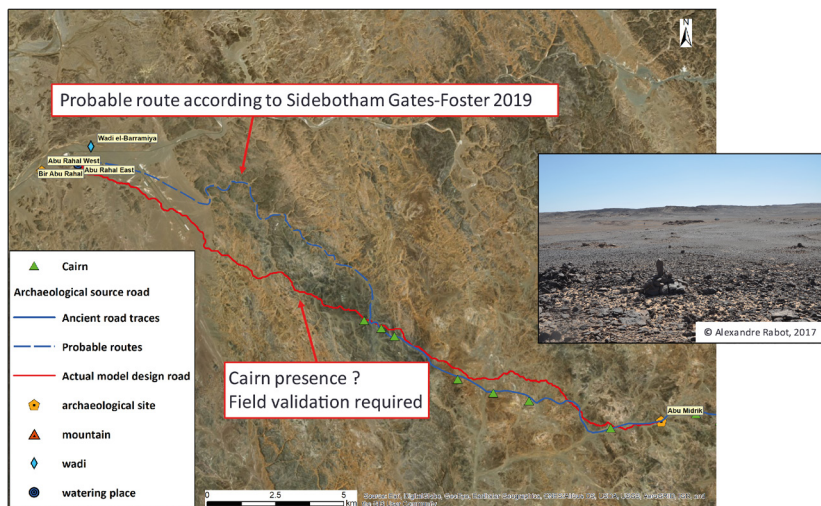


Figure 10. Comparison between the modeled path and route retraced from fieldwork between Abu Midrik and Abu Rahal. Imagery courtesy of Esri. Photograph by A. Rabot, Mission Archéologique Française du Désert Oriental. © Desert Networks and L. Manière.

Ancient Road Reconstruction: The Coptos–Myos Hormos Roman Road

To assess the quality of the newly created model, we chose to work on the road between Quft (ancient Coptos) and Quseir el-Qadim (ancient Myos Hormos), which is particularly well known and was heavily used during the Roman period (Figure 9). The network links watering places from all periods (but many of them are ancient or at least show the presence of available water in the area) and Roman archaeological sites, which also include watering places. The green flags correspond to towers that are not well dated (Brun et al. 2003) and were thus not considered as sites when building the network. Each journey's duration is calculated using 3.9 km/h as the mean traveler speed.

Four itineraries can be identified in the network generated by the model: departing from Quft, they each follow different paths into the mountains, but they all exit via the same gorge (where the natural spring of Ayn el-Ghazal is still flowing today) in the Wadi el-Ambagi, at the end of the trip to Myos Hormos. The path marked in red (the middle path) is the fastest and corresponds with the route of the Roman road that has been generally reconstructed by archaeologists and historians (Brun 2018; Cuvigny 2003). The towers are all located along this itinerary, and thus there is a good chance they were Roman; they were probably there to guide and secure travelers along the road during the apex of its utilization. The other paths show alternatives with slight differences in travel time. At least two of them (the purple [south path] and blue [alternative middle path]) were used by the travelers included in our study, as well as by pilgrims or merchants going to Mecca in modern times (Bruce 1790:169–203; De Rozières 1812:84–86). The modeled travel durations fit quite well with the durations mentioned in travelers' accounts that were not used to build our model but rather to assess it, which indicate Quft–Quseir journey durations ranging from 41 to 46 hours (Denon 1802:188, 41 hours and 55 minutes; De Rozières 1812:91, 42 hours and 30 minutes; Flaubert 1910:253, 45 hours and 30 minutes from Qena to Quseir, and 41 hours and 15 minutes from Quseir to Qena via a shorter road).

Finding an Alternative Route

After testing the accuracy and quality of our model on a regional network, a second test was carried out on a local network (Figure 10), focusing on an ancient route between the sites of Abu Midrik and Abu Rahal that was recently retraced via survey by S. E. Sidebotham and

J. Gates-Foster (2019:Figure 3.178). The first half of the road's path is secured by the presence of cairns that guided travelers. The second half, however, is absent of cairns; thus the archaeologists proposed that the road would have followed a large wadi toward its final destination of Abu Rahal.

A least-cost path was calculated with our slope-based cost model between these two locations. It reproduces quite well the first part of the road, where the cairns were spotted by the archaeologists. After the last cairn, however, it takes an alternative path that is straighter and shorter and does not follow the large wadi that could have helped orient travelers. This path will be explored in the future to look for cairns or other remains that may have been missed by our colleagues in order to validate whether this was an actual or purely hypothetical road.

Discussion: Limitations of the Desert Networks' Model and Future Improvements

Our method has several limitations or biases that are important to mention; however, it also has several advantages when compared to classical least-cost path models. Firstly, it may seem that the accounts of travelers and modern scholars are too anecdotal, imprecise, or unstructured to produce meaningful results or usable data for modeling ancient roads. However, on the condition that they are studied according to a systematic method and compared with sufficiently exhaustive geographical data (e.g. toponyms, geology, topography) and that caution is exercised with regard to orientalist trends, they are of great value for conducting a detailed analysis of routes and for highlighting the criteria that led travelers to choose those routes. Cross-referencing several accounts that span more than a century constitutes a significant element of reliability, in the sense that they allow us to distance ourselves, at least partially, from the *topoi* relative to a period—or at least to identify those *topoi*.

Secondly, taking into account the factor of water resources and the sites that could potentially be visited during a step requires considering all the sites and water points during path modeling. However, among these nodes, watering places are particularly problematic. It is very difficult to evaluate their age and decide whether they were in use during antiquity or not, since they have yielded few archaeological materials and have had fragmented phases of exploitation. The springs and wells used in the modeling of ancient networks are extracted

from 1:50,000 and 1:250,000 topographic maps (Egyptian General Survey Authority 1989–1990 and US Army Map Service 1953–1960, respectively). Many of today's watering places are ancient wells that have been rehabilitated recently. For example, Murray (1955:175–176) mentioned a well in Wadi el-Sidd that was dug by Seti I (end of the second millennium BCE) and reopened in 1905 to supply workers from a neighboring mine. It might not have been exactly the same well, but it is in the same area, and the modern workers only needed to clear the well to use it. Moreover, some wells situated at Roman stations were still in use in the nineteenth century (De Rozières 1812:85–86; Du Camp 1860:267), and it was still usual to look for a well in the center or vicinity of ancient stations during the mid twentieth century (Tregenza 1955:228). Since it is much simpler and safer to clean an old well than to create a new one, this practice is not surprising. However, it implies the assumption that these areas have had a constant ground-water resource over time. In other words, while not all the ancient wells dating to the periods of study have been found, contemporary maps locate some of them as well as other zones that may have been exploited for their water resources (e.g. surface water in natural basins, or underground water from springs and wells). This method makes it possible to link sites that were occupied during a certain period with water supply locations that were potentially in use. These watering places would have been exploited or abandoned depending on the use of the network roads.

Most of the difficulties, both for travelers crossing the Eastern Desert and for route reconstruction and modeling, are concentrated in the Red Sea Hills to the east of the region. The topography of this area includes narrow passes and gorges that constitute a challenge in implementing the model and introduce a significant bias in its results. Indeed, a pass or gorge must be at least 50 m wide at all times in order for it to be represented accurately in the 25-m resolution DEM; any passes with points narrower than this can appear closed and, therefore, are not treated as viable routes during the path calculation. The use of a DEM with a higher resolution would partially compensate for this problem, but it also would have the disadvantages of considerably lengthening processing times and generating more noise in flatter areas.

Currently the Desert Networks' cost model is based exclusively on slope. Calibrated with data from modern itineraries, it generally produces routes that follow low slopes that are particularly well adapted to

loaded camels. However, in some areas where the modeled route cuts through valleys across more rugged areas where the surface is composed of bedrock or coarse sedimentary deposits, other factors need to be considered. Among the possible criteria for determining paths, the slope factor alone cannot represent the constraints of orientation and surface conditions that encouraged travelers to follow the sandy wadis. A new cost layer weighted with the slope that distinguishes sand/gravel material surfaces from bedrock or coarse sedimentary areas will be built to integrate the wadi-tracking factor. Satellite image processing by remote sensing tools and theoretical hydrographic networks will be used in the classification of these areas.

One of the other main limitations of the method is related to the resolution of route reconstruction, possible restitution errors, and the imprecision of written sources on certain points. For example, it is impossible to determine which exact path was taken in the riverbed of a large wadi, as some of them are several kilometers wide. Similarly, it is not always possible to know by which side a modest topographical obstacle was circumnavigated, or which path was used to climb a pass when several choices were possible. Finally, in very flat areas with few landmarks, the reconstruction of routes is less precise. Fortunately, the multiplicity of sources makes it possible to obtain general rules about route selection despite the impossibility of reconstructing to perfection each of the routes followed by individual travelers. This is generally not a problem at the scale of analysis that is generally used for this type of study (and that is used in the case of the Desert Networks project). In any case, the geomorphological evolution of the area between antiquity and the present day—and the impact it may have had on local topographical changes—makes any more detailed modeling illusory.

To conclude, as it stands, and despite the limitations and biases listed above, the newly created model of Egypt's Eastern Desert, although perfectible, already opens up many new research avenues—in particular, for a finer analysis of the sectors where the ancient road that has been reconstructed from archaeological remains diverged from the modeled least-cost route. It will help us to identify factors not linked to slope or surface conditions that have influenced the route layout, such as the presence of unknown resources, sites that have escaped detection by archaeological survey, and so on. The modeled routes will also guide the Desert Networks project's next field surveys in search of new sites or roads, particularly more discreet archaeological sites with fewer built and inscribed remains (for examples, see [Manière et al.](#)

2021a). The least-cost path analysis tool developed within the framework of the project and the complete dataset (Manière et al. 2020, 2021a), as well as a data paper specifying its development conditions (Manière et al. 2021b), have been published in order to allow for wider use. The Python scripts—also available as ModelBuilder models for ArcGIS 10.5—can thus be applied to other regions where pack camels were the main mode of transport if the environmental, topographical, and geomorphological conditions are similar to those of the Eastern Desert of Egypt, particularly in some mountainous areas of the Arabian Peninsula, the Levant, the Maghreb, and Central Asia. However, it is preferable to create a local validation dataset based on travelers' accounts or other sufficiently detailed data sources in order to adjust the parameters. In order to apply it successfully, the archaeological data must be sufficiently developed to constitute the elementary nodes of the network and to offer opportunities for assessing the validity of the modeled network.

In a broader view, this chapter demonstrates the importance of taking into account the means of transportation and its specificities when applying least-cost path analysis (a point that is also emphasized by de Gruchy and Lawrence, *this volume*). It also shows that the accounts of travelers and early scholars, numerous in every part of the world, make it possible to document and take into account these specificities with sufficient finesse to succeed in creating valid route networks. While the model we have developed for camels in the Eastern Desert can only be applied to certain regions under similar conditions and with similar pack animals, the approach and process of its development can be applied almost everywhere in the world and to any kind of transportation that was still in use in the last few centuries.

Acknowledgments

This paper is part of the project “Desert Networks: Into the Eastern Desert of Egypt from the New Kingdom to the Roman Period.” The project has received funding from the European Research Council (ERC) under the European Union’s Horizon 2020 Research and Innovation Programme (grant agreement number 759078). Mapping and spatial analysis for this research was carried out with ArcGIS 10.5 and QGIS 3.4 software.

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