ARCHAEOLOGICAL LEAST COST PATH MODELING:

A BEHAVIORAL STUDY OF MIDDLE BRONZE AGE MERCHANT TRAVEL ROUTES ACROSS THE AMANUS MOUNTAINS, TURKEY

by

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LIST OF ABBREVIATIONS

ACS	Accumulated Cost Surface
AVRP	Amuq Valley Regional Projects
DEM	Digital Elevation Model
GIST	Geographic Information Science and Technology
LBA	Late Bronze Age
LCA	Least Cost Analysis
LCP	Least Cost Path
MBA	Middle Bronze Age

ABSTRACT

Since the mid-nineteenth century, excavations in southern and central Turkey have provided a bounty of archaeological records. One such excavation at the ancient site of Kultepe features preserved, clay tablets that document economic transactions that took place in the mid-to-late Bronze Age. Additional records further allude to the means and routes of transporting goods from the Amuq Valley in the south, across the Amanus Mountains to the Cilician Plain. The research objectives of this study were to utilize a Least Cost Analysis across the Amanus Mountains to map potential routes of these merchants. The study generated individual Least Cost Paths for seven sets of points using the ArcGIS Pro Path Distance tool. Five of these points pairs were used for mapping potential backways whereas two sets were used to model existing passes. The five paths identified three significant passageways across the mountains. Despite shared corridors among these routes, the modeled paths illuminated several passes across the mountains that were possibly utilized in Bronze Age merchant travel. The modeled routes were tested against the existing routes as an indicator of validity for the results. The least cost path geographies and travel time estimates demonstrated stable results.

CHAPTER 1: INTRODUCTION

As early as the 1970s, GIS has played a role in archaeological research. Given that archaeological data is primarily characterized by spatial and temporal signatures, as well as the structure of GIS providing a layered and multi-scaled spatial representation, GIS and archaeology are an ideal match (Scianna and Villa 2011; Wheatley and Gillings 2002). As GIS and computational technology have advanced, so have the potential applications to archaeology. Coinciding with these developments, more sophisticated solutions to help answer complicated research questions are possible. Using the methodology of least-cost path analysis (LCA) to model past human movement through space (Herzog 2013a) is one such solution (Surface-Evans 2012).

While LCA has been prevalent in social sciences for some time, the application to archaeology is relatively new (and has considerably increased within the past two decades (Surface-Evans 2012; Herzog 2013a, b). This growth can largely be attributed to the surge in availability of geospatial data and the prevalence of user-friendly GIS software that includes LCA functionality. Given the implications of procedural selections upon results, an advanced understanding of the functionality and associated options is required. This thesis examines these associated considerations through the execution of an LCA within a region of Turkey where significant Bronze Age settlements were located along trade routes that linked the ports and inland palatial centers where commodities and prestige goods were controlled, consumed and exchanged. Port cities, such as the one located at Kinet Hoyuk near Dortyol on the Mediterranean coast; and inland palatial centers, such as Alalakh, located on the Orontes River on the inland side of the Amanus mountain range in the Amuq plain, and Kultepe/Kanesh, located near Kayseri, Turkey were on the western edge of a trade network used by Assyrian merchants from northern Iraq and princes in Anatolia (modern day Turkey). Then, as now, political and economic factors might create incentives for one route to be chosen over another. With the knowledge of generations of traders at their disposal, and an awareness of the added time factors that were associated with various routes, ancient merchants could decide to manage risk and maximize profits by taking alternate routes. A means of quantifying this is desired by archaeologists, who typically do not wish to walk the various alternative routes in order to test them. LCA offers contemporary researchers a means of revealing this knowledge anew, that is, which of the alternate routes across the Amanus Mountains were the least time intensive.

1.1 Motivation

Since the declaration that archaeological evidence is characterized by its spatial definition (Clarke 1977), the need to model dynamic movement across historic landscapes was recognized. The development of the archaeological LCA and its incorporation into the modern GIS environment (associated data, interfaces, and functionalities) have enabled archaeologists to model such dynamic movement. It should be noted, however, that LCP tools in GIS software suites were originally developed with other intended applications, such as urban planning, shipment network modeling and military movement (Longley et al. 2015). Furthermore, GIS software has become quite user-friendly, featuring clickable icons that often conceal the intricate processes at work (Kantner 2012). While there are extraordinary benefits to a successful LCA, inappropriate (often unbeknownst to the analyst) selections in methodology can skew results. Proper implementation has the capacity to help establish links between behavioral inquiries, archaeological data, and analytical technique (Surface-Evans 2012).

Once LCA has been deemed appropriate to model a given behavioral question, the analyst is faced with a myriad of options and thus, decisions. Every decision is critical since modeled paths are hyper-sensitive to any changes in data and/or methodology. Outlining theoretical concepts and the suitability of methodological selections provides beneficial reference for potential analysts at every level of expertise. Furthermore, a successful case study demonstrates specific benefits that the proper utilization of the discussed methods can yield.

The British Museum exhibits a clay tablet (one of a many thousands housed there, "ME 113573") found at the site of ancient Kultepe, roughly 12 miles southwest of the current city of Kayseri, Turkey. This tablet is written in an Old Assyrian dialect (Akkadian) and roughly dates to 1900 BC. The tablets from the Kultepe archive all were written by merchants, chronicling Assyrian textile exchanges with Anatolian locals for silver and gold (Kuhrt 1995). The princes who ruled the Amuq Valley participated in a trade network that extended into Anatolia, and their own kingdom may have served as a potential back way for wealthy merchants travelling from northern Mesopotamia to Kultepe by funneling them across the Amanus Mountains, through the Cilician Gates or through the Goksun Valley, and then northwestward to Kultepe/Kanesh.

Successful modeling of likely paths across the Amanus mountain range provides insight into one of the first global trade networks. Generic to archaeological LCA, potential paths could help identify resting locations (potential sites) and thus allow further research initiatives to utilize resources more judiciously. This is critical considering that archaeological landscape survey in the mountains is not only costly, time-consuming and physically demanding, but also occasionally dangerous (and thus prohibited) because the small mountain pocket valleys and byways sometimes harbor anti-state terrorist activists (Dodd, 2014, pers. comm.). Thus, a LCA can contribute to a more focused analysis of ancient economic behavior.

1.2 The Archaeological LCA

A least cost path (LCP) is the theoretical, most efficient route between two locations across a landscape, with respect to a specified expense (such as energy or time) (Conolly and Lake 2006). LCA is, therefore, the application of LCP principles to aid in evaluating relationships between specified locations or objects. While there are many potential applications of LCA in addressing various modeling initiatives, the LCA methodological framework is generally consistent. Once it is established that the LCA methodology can legitimately be applied to aid in understanding a behavioral inquiry, the first task is to select the GIS data. At the very least, these data selections must include a raster representing topographic data (typically in the form of a digital elevation model [DEM]) and a pair of origin and destination points. Second, cost components are identified, combined, and repackaged so a cost/friction raster surface can be generated. This step involves selecting a cost function, currency and LCA/GIS software aimed at linking all theoretical costs while properly executing the path calculation. Third, the spreading algorithm is selected and an accumulated cost surface (ACS) is produced. The ACS is a new raster that reassigns each cell with the accumulated cost of moving from the origin(s) to the destination(s). Commonly, the LCP is traced in this step by backtracking from the destination to the origin (Herzog 2013a). Lastly, a confidence level should be assigned to the results utilizing a goodness-of-fit statistic or ground-truth comparison as a means to assess validity. This confidence assignment is rare in LCA as there are no established methods with which to do so (Kantner 2012).

1.2.1 Establishing the Modern Archaeological LCA

As Branting (2012) alludes to, several early and noteworthy studies by Irwin-Williams (1977), Plog (1977), and Ebert and Hitchcock (1980) demonstrated the value of distance analysis while employing early, developmental GIS and associated archaeological data. As Herzog (2013a) notes, two significant studies laid the foundation for the archaeological LCA advancements made in the past two decades. First, Ericson and Goldstein (1980) included energy expenditure and other costs in modeling a LCP and then subsequently evaluated the route generated against a known ancient route. Second, Gorenflo and Gale (1990) introduced the now established Tobler hiking function in an archaeological context. Gaffney and Stancic (1991) is the first study that most closely resembles the general methodology described in Section 1.2 as it is considered the first GIS, archaeological cost-surface analysis (Herzog 2013a). Further notable archaeological LCA studies include: van Leusen (1993), Krist and Brown (1994), Machovina (1996), Kantner (1996), Aldenderfer (1998), Llobera (2000), Bell and Lock (2000), and Jennings and Craig (2001). While there is no study or review that definitively establishes the academic precedent of LCA, Whitley and Burns (2008) demonstrate its fruitful and popular relationship with archaeological predictive-modeling (Herzog 2013a).

The further development of computing hardware, GIS software, and availability of more accurate geospatial data, has enabled the range of specific modeling intentions to flourish. Although modeling past routes or networks (of any time period) between sites is perhaps the most common archaeological LCA utilization (Herzog 2013a), there are many other potential and often creative applications. The most prolific uses pertain to the identification of: (1) the primary motivations for known routes; (2) resource availability to a site; (3) intra-settlement movement; (4) herding and nomadic patterns; and (5) unknown settlement locations. Less popular applications include the quantification of trade characteristics as well as military force logistics; assessment of object visibility from various aspects in the movement across a landscape; and the deduction of features' significance in a landscape (Kantner 2012).

1.3 Description of Study Area

The Amuq Valley and the Cilican coast are located in the Hatay province of southern Turkey, bordering Syria to the east and south (Figure 1).

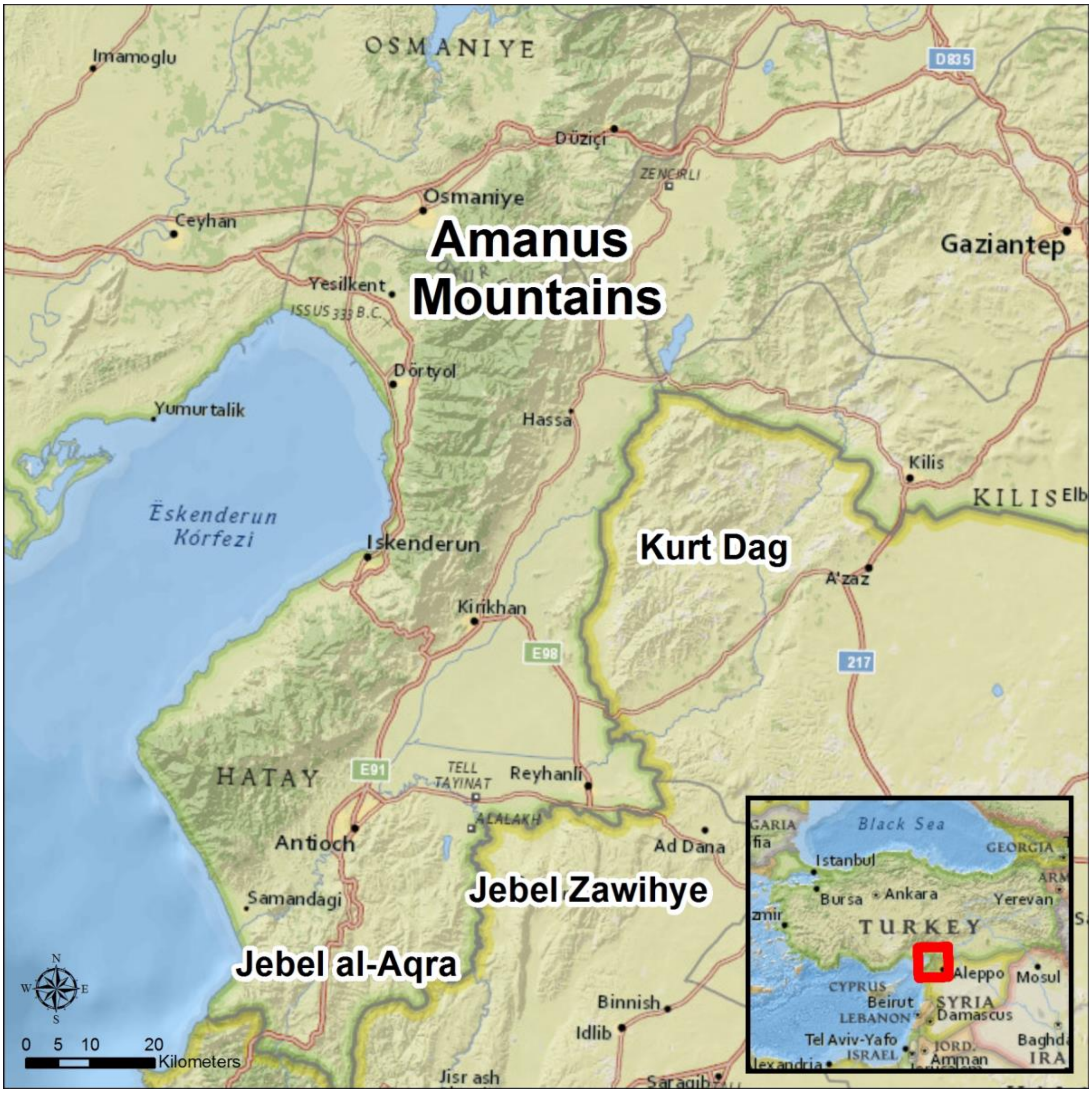

Figure 1 Map of Amanus Mountains and surrounding area within the northern Levant

Most notably, the Amuq Valley is bounded on the western side by the Amanus Mountains. The Jebel al-Aqra and Jebel Zawihye hills loosely separate the valley from Syria to the south while the Kurt Dag (Kurd Mountains) do so from the east (Casana 2013).

The Amuq Valley during the later Early Bronze Age (EBA), Middle Bronze Age (MBA) and Late Bronze Age (LBA) can be characterized by its political instability and settlement defragmentation, as well as a well-developed system of land-based trade among elites, both locally and globally.

1.3.1 Archaeology of Alalakh in the Amuq Valley

Fresh off of his groundbreaking research at Ur (1922-34), Sir Leonard Woolley discovered a plain near the ancient city of Antioch (modern Antakya) covered with ancient mounds, known locally as tells. After conducting a few test excavations, he settled on the site of Tell Atchana (Alalakh). The Tell Atchana effort was a hugely successful endeavor that revealed a sequence of Middle and Late Bronze Age palaces and temples, as well as archives of cuneiform texts pertaining to each time period, and earlier buildings that remain less known. The texts from the Middle Bronze and Late Bronze Age palace levels ("Alalakh archives") provide unique historical insight into the political, economic and social aspects of these ancient times (Casana 2009).

Around the same time as Woolley's work, Robert J. Braidwood of the University of Chicago Oriental Institute's Syro-Hittite Expedition (1932-37), began constructing a survey of the area that constitutes an important foundation for contemporary landscape survey. Instead of focusing his efforts on a single site, Braidwood attempted to catalog all tell sites. A highlight of his surveys are the phase maps that demonstrated spatio-temporal settlement pattern shifts within the landscape. While Braidwood's attempts were pioneering, his efforts were in no way comprehensive (Casana 2009).

Where Braidwood, Woolley and other past archaeologists have left off, the University of Chicago Oriental Institute's Amuq Valley Regional Project (AVRP) continued these efforts since 1995. The AVRP provides a modern survey collection of over 350 sites from all time periods

(Casana 2013; Yener et al. 2000; Dodd 2012). On the other side of the Amanus Mountains, the Cilician coastal plain was surveyed initially by Marie-Henriette Gates and subsequently by Ann Killebrew and Gunnar Lehmann. The most significant Bronze Age site in that coastal region is a mound overlooking the water on the grounds of a gas terminal in Dortyol, known now as Kinet Hoyuk. It was occupied contemporaneously with Alalakh and was a participant in the trade that linked the Mediterranean Sea routes and inland Anatolia to the caravans that crossed Syria and continued beyond.

1.3.1.1 Amuq Valley political history

Put simply, the northern Levant and southeastern Anatolia during the MBA can be characterized as an agrarian society that experienced periodic conflict when local and distant rulers sought to expand their control over resources or territory. The documents in the Alalakh archive indicate that irregularly spaced sites, mostly tells, practiced subsistence agriculture and were subjected to spatial defragmentation and political rearrangement. For instance, high crop yield in a given localized area might sway land value and create upheaval and instability. This would generate exercise of control from the ruling class creating further instability. The presence of census lists at Alalakh demonstrates the rulers attempting to preserve control over the disjointed area (Casana 2013).

In relation to distant/foreign rulers, the region was hotly contested at various times during the Middle and Late Bronze Ages. Examples of this continuous political jockeying are described by Casana (2009) who describes clashes between Alalakh, a vassal of the kings of Yamhad centered in Aleppo, Syria, and the Hittites to the north. The palace of Alalakh was destroyed at the hands of (most likely) the Hittite King Hattusili I—who claimed to have sacked Alalakh. Later, the Hittites briefly conquered much of the northern Levant, and specifically Halab, but were unable to maintain control as the Mittani—the Hurrian kingdom to the east—seized a now weakened Yahmad, Thus, a new Mittani ruling class was imposed within the Amuq Valley. This back and forth between Mittani and Hittite persisted through the end of LBA when Alalakh was finally abandoned. The riches that these competing kingdoms sought include access and control of trade routes, grain production, wine, animals and their products, military security and other resources such as precious dyes, ivory, metal, wood, resins and incense, and highly-desirable textiles that transited through this region.

1.3.1.2 Amuq Valley economic context

While subsistence agriculture dominated the Amuq Valley, tell sites also satisfied their own needs for pottery vessels and specialized craft production (Schloen 2001; Casana 2013). Palaces supported accomplished craftspeople and the exchange of prestige goods at the highest levels was a regular component of the trade in which these palaces participated (Casana 2013). Genz (2012: 625-626) offers unique insight into the trading arena in the northern Levant during the MBA. Indications of standardized vessels, production workshops, and other common ware were found, along with special products like the Tell el-Yahudiyeh juglets, painted wares and other metallic wares.

Loose trade networks have been identified in the northern Levant and southern Anatolia (Casana 2007). Exchange beyond the control of the palace in the Bronze Age was monitored and controlled by the ruling class. Genz (2012:625-626) documents the presence of foreign pottery in the area and gives credence to the assertion that international trade was growing throughout the second millennium. A complex trade network centered partly on metals, most particularly tin, copper and silver, involved elites from Anatolia, at Kultepe, on the coast of Cilicia, at Kinet

Hoyuk, in the Amuq, at Alalakh, and well-beyond to inland Syria, at Mari and to Assur in contemporary Iraq.

1.3.2 Archaeology of Kultepe-Kanesh and the "Black Market" of the Middle Bronze Age

First excavated in 1871, the Kultepe-Kanesh site has provided the most significant source of information regarding a MBA trade network centered on textiles and metal which took place, at least in part, through Assyrian trade colonies that were settlements where foreign merchants took up residence in Anatolia. . Over 20,000 tablets have been unearthed (like that in Figure 2), revealing a vast trade network that had hitherto gone undetected archaeologically.

Figure 2 Cuneiform tablet "66.245.5b" detailing ownership dispute testimony (right) and the encasing envelope (left) (Metropolitan Museum of Art)

Other incentives for trade lay in the grandiose plans for palace and temple building by elites of the Middle Bronze Age. Large-scale construction projects created the necessity for building supplies and a high demand for timber and metal resources in the treeless areas of the Near East. The Amanus and Taurus mountain ranges contained rich reserves of these raw materials and provided a means to satisfy this demand. Harbor towns on the Levantine coast, between the Cilician and Amuq plains, developed in order to access, refine, and distribute these materials. Throughout all periods, the exchange of commodities such as timber was facilitated by relationship-building gifts of sophisticated luxury goods and materials for individual elites. Some of this happened at the level of the rulers who sanctioned and taxed trade wherever possible. Other transactions surely were under-the-table, unsanctioned attempts by merchants to establish preferential access to commercial relationships which could include advance notice of conditions along a proposed trade route, and information about the most efficient trade route, and alternative paths that bypassed venues of taxation, such as palaces (Sherratt and Sherratt 1991). Furthermore, despite the bulk of trade being conducted at the palatial level, these back-door exchanges can be viewed as responsible for the development of individual enterprise. Such enterprise eventually grew into a vast, highly-complex trade network, centered at Kultepe, from 1800-1600 BC (Akar 2009). Individual enterprise trade was not subject to egalitarian distribution, as made evident by variations of goods across various residential zones in many geographic areas. There were, however, laws established to forbid the exchange of certain materials—laws in all likelihood designed to preserve royal prerogatives to maintain exclusive control over strategically significant materials. This can be seen as an indirect incentive for the development of alternative strategies in securing resources and supplies (Akar 2009). Knowledge about alternative way-stations and routes are attested in the Middle Bronze Age (MBA) as merchants made decisions about how to conduct business in that region (Dodd, 2014, pers. comm.).

Instability was a fact of life for the merchants whose fortunes could rise or fall depending on the ways that they made use of the unstable conditions in the Anatolian countryside. Princes who ruled the small kingdoms or polities of Middle Bronze Age Anatolia sometimes engaged in armed conflict or interfered with the free passage of caravans, or who rebelled against an overlord by skimming revenues. It can be assumed that back-routes were popular among elite merchant caravans. As such, modeling such routes across the Amanus Mountains is valuable.

1.4 Research Objectives

Despite the now popular implementation of archaeological LCA, there is a lack of consistency regarding information presented in case studies.

Recognizing that there are multiple ways for merchants moving from the Amuq Valley, under the control of Alalakh, to the Cilician coastal plain in the region of Kinet Hoyuk, this thesis sought to:

1) Provide archaeologists with research assistance by modeling potential back-routes for MBA wealthy merchants across the Amanus Mountains;
2) Demonstrate the implementation of Tobler's Hiking Function; and
3) Evaluate the effectiveness of the Path Distance tool in modeling LCPs

1.5 Thesis Organization

The remainder of this thesis is comprised of four chapters. The following chapter goes into further detail of the LCA methodology and reviews related work to provide a general guide to appropriate selections. Chapter 3 describes the methodology and data employed in the AVRP

LCA. Chapter 4 describes the results of that analysis and presents maps depicting each route. Chapter 5 offers some final thoughts as well as suggestions for future work.

CHAPTER 2: BACKGROUND AND RELATED WORK

This chapter begins by establishing the general considerations in potential applicability of an LCA. Next, each phase of the LCA methodology is described in terms of theoretical assumptions (where applicable), appropriateness and implications of methodological selections, and current trends in research. The plan of work for this thesis outlined in the ensuing chapter primarily calls upon the fundamental concepts and techniques described in Herzog (2013a, 2014a) and the work contained in Surface-Evans (2012).

2.1 LCA Overview

There are several conceptual assumptions that are associated with the archaeological LCA that must be considered prior to conducting the analysis. Fundamentally, LCA is predicated on the ideas presented in Zipf's Principle of Least Effort (Zipf 1949). The work gives credence to the assumption that humans will attempt to economize aspects of their behavior. When navigating a landscape, humans naturally choose the path of least resistance and therefore, interaction between humans and the landscape is directly related to the ease-of-access (White and Surface-Evans 2012). This foundation extends into further assumptions that: (1) humans have universal knowledge of the landscape; and (2) humans will select the best path as opposed to one that simply satisfies (Branting 2012).

As White and Surface-Evans (2012) note, the archaeological question of interest dictates how appropriate the LCA methodology is. For example, when introduced to a landscape and selecting paths for the first time, a substantial random element is coupled with the optimization component (Saerens et al. 2009; Herzog 2013a). This random element, while initially significant, diminishes to irrelevancy over time as the preferred routes emerge. As a result, LCP software only considers the optimal path. Thus, the application of archaeological LCA should ideally exclude attempts to model, for instance, once-in-a-lifetime journeys or initial contacts/dispersals in unknown landscapes. In such cases, agent-based modeling is more appropriate (Herzog 2013a).

Lastly, LCAs now range widely in analytical complexity and capacity of LCA incorporation—both of which are again dictated by the research question. White and Surface-Evans (2012) identified three loosely-defined levels. At the most traditional level, an analysis can feature a standalone LCA and standard GIS platforms and practices to help address a fairly straightforward question: Rissetto (2012), for example, created LCPs to assess hunter-gatherer resource procurement patterns. At a more advanced level, LCA serves in conjunction with other types of spatial analysis: Richards-Rissetto (2012), for example, used LCA with space syntax and configuration analysis to assess social hierarchy in Honduras (Monteleone 2013). At the final level, analyses employ unique, customized applications that bridge avant-garde spatial analytic techniques: Ullah and Bergin (2012), for example, integrated LCA with agent-based modeling and landscape processes to evaluate optimal agropastroal village locations for specified economic and ecological variables.

2.2 Gathering Data

As mentioned in Section 1, there are two required input datasets. The first is a continuous field topographic representation of the subject area (i.e. raster, DEM) and the second is either raster or vector representations of the origin(s) and destination(s) of interest (which will be specific to a given project). The utilization of elevation data implies that the current (when the data was created/recorded) landscape is as it was during the subject time period. This presents a challenge for subject areas that have featured significant modification and the potential problems can only be avoided with landscape reconstruction (Herzog 2014b). Selection of the topographic raster is critical as it is not only utilized for extrapolating slope and other topographic characteristics, but also serves as a lattice for the analysis. When selecting or generating a DEM, several variables (aside from the key: data availability) must be evaluated: monetary cost, spatial resolution and data accuracy (and confidence in the source), as well as the spatial extent and the topography of the subject area.

Typically, a DEM is acquired from a third-party source or generated via interpolation of elevation points. Fortunately, the growth of availability has driven down the costs of 30 m square-grid DEMs to free availability for global coverage (e.g. ASTER gDEM v2). The resolution may or may not be an issue. Coarser DEMs mean that there is a greater probability that significant landscape features will be overlooked, thus skewing data and results (Kvamme 1990). It would appear that the most desirable DEM would be that with the finest spatial resolution; however, case studies have been presented that highlight the lack of significant variation in modeled paths from 30 m resolution and finer. For instance, Doyle, Garrison, and Houston (2012) execute an LCA in the Mayan lowlands while evaluating 90 m SRTM, 30 m ASTER, and 5 m AIRSAR DEMs. The study displays minute differences between the results of the ASTER and AIRSAR DEM. If still committed to a finer DEM, there are a few trade-offs to consider. A finer DEM (e.g. 1 m resolution) is traditionally expensive, especially those pertaining to areas outside the U.S. and in remote locations. Second, the finer the DEM, the more computationally intensive processing tasks will become (Herzog 2014b). Actions like generating topographic-derivative datasets such as slope and aspect rasters, executing raster recalculations and of course, distance analyses, become much longer processes. Since the DEM itself and any associated derivatives serve as the foundational data drivers of the LCA—the validity of the results can be viewed as contingent on the problem at hand and the accuracy of the input data.

Given the aforementioned considerations, DEM selection varies significantly across recent research. Herzog (2014b) describes a few instances in which these considerations characterize the analysis. Most notable is Rademaker, Reid, and Bromley (2012) which opts for using the SRTM 90 m data over the ASTER 30 m data, citing a data accuracy assessment of vertical bias using GPS (Racoviteanu et al. 2007). This implies that the benefits of vertical accuracy outweigh that of finer spatial resolution, however the authors cite the significance of a ~10 m-wide steep-walled canyon—a 90 m grid cell is not capable of capturing such a feature.

2.3 Generating a Cost Surface

The cost surface is a raster that defines the effort of traversing from one cell to another and eventually moving to and from specified locations. In order to produce this raster, several tasks must be completed. Initially, an appropriate projected coordinate system must be identified, the DEM processed (if necessary) and further interpolated (if desired), and an intended cost currency must be established. Next, all cost components must be calculated and subsequently combined into the cost model. Lastly, a cost-surface algorithm is employed to estimate the cost of traversing across each cell from location A to B. The selection of this algorithm and the ensuing cost model are perhaps the most important components of the analysis (Kantner 2012).

Costs, and cost models, can be defined as isotropic (independent of direction of movement) and anisotropic (direction-dependent). Typical isotropic cost components are those derived from vegetation, land cover, and water features since the cost is uniform regardless of direction. Isotropic cost models, thus, consider each cell to be equally costly in all directions. Such models would be best implemented in situations where slope is near zero such as a barren landscape, or plains somewhat covered by tracks, loose sand, gravel, or grass (Herzog 2013b). Anisotropic costs are those that differ based on direction; essentially slope (Conolly and Lake 2006; Herzog

2013a). Slope is often times used exclusively as a proxy for cost, representing almost literal degrees of difficulty. Associated slope-based cost models/functions are used in nearly all archaeological LCP studies since topography is generally diverse in archaeological landscapes.

Selecting a cost function goes hand-in-hand with selecting a currency and GIS software. The user-interface that features push-button execution and relative software stability offered by Esri's ArcGIS makes it the most user-friendly software for the average analyst to execute an LCA. As a result, the most popular GIS software is Esri's ArcGIS suite, followed by the less popular GRASS and TerrSet, as well as custom built software (White and Surface-Evans 2012). Given the popularity of Esri's ArcGIS for LCA, the default cost function is the most popular, followed by Tobler's hiking function and the Langmuir cost function (implemented in GRASS GIS r.walk) in that order. It is likely that the Esri default cost function is most prominent because it is the easiest method to go from data to path results (Herzog 2014b). Esri's anisotropic cost model ("Path Distance") is much more complex, however, involving eight parameters and introducing many opportunities for error.

Nearly all cost-surface algorithms attempt to minimize one of two currencies: time or energy, with the former being the seemingly preferred approach. When estimating time, Tobler's hiking function is more appropriate than Esri's default option, primarily because as flat surfaces generate a zero slope, a zero cost per flat surface cell is extrapolated (Kantner 2012). Tobler's hiking function negates this, assigning a temporal cost per slope degree. The main drawback of Tobler's hiking function is that it is generally misunderstood. Common misapplication of the function comes in the mathematical conversion of degree slope to the time intensity of crossing a raster cell. As a result of the confusion regarding successful implementation and recalculation, several case studies have generated faulty results. For instance, Phillips and Leckman (2012) seem to utilize percent slope and overestimate the slope by 100, resulting in uncharacteristic paths with long detours. Surface-Evans (2012) notes that the modelled routes excessively minimized the effects of travel barriers, which would not have been the case if it had been implemented properly.

2.4 LCP Calculation

The actual LCP modelled route(s) is typically generated by first, stipulating the origin and destination points again, and second, implementing a spreading algorithm across the previously generated cost surface in order to create the ACS. The ACS tallies the accumulated cost of moving from a given origin cell to all neighboring cells until reaching the destination, while storing backlinks of each step moved. Again, the analyst must maintain an isotropic or anisotropic approach within the given GIS software. The primary spreading algorithm is Dijkstra's algorithm (Dijkstra 1959) and it is embedded in some way in nearly all LCA software. Essentially, the algorithm converts the raster into a weighted graph with positive weights and associated links, all proportional to the travel cost. Utilizing the cell centers as nodes, links can be formed as potential moves are explored; the least costly links from the origin to the destination can then be extrapolated (raster-to-vector calculation) to identify the LCP. This process arises from the primary concern of conceptual drawbacks of raster-to-graph conversion and associated neighboring node consideration techniques (Herzog 2013a).

Dijkstra's algorithm is referred to as a greedy, brute-force algorithm (White and Surface-Evans 2012) that, while very computationally intensive (modifications like A* [Hart et al. 1968] have been introduced to reduce this burden), produces the globally optimal path if implemented correctly (Herzog 2014a). This claim has produced confusion, for instance Kantner (2012) declares that it only favors the locally optimal path and would go on zero value cells forever.

This is not relevant because proper implementation requires positive weights and thus no zero (or negative) values are present.

2.5 Validity Assessment

Assessing the validity of the LCA results can prove to be a very challenging task, primarily because no standardized method, such as a goodness-of-fit statistic, currently exists. As such, most case studies avoid doing so altogether; over half of the case studies that comprise White and Surface-Evans (2012) do not contain such an assessment. When an assessment is considered, there are a handful of methods that are employed, often in combination. Sensitivity analyses like introducing minor errors in data or slightly changing parameters in the utilized cost model (Herzog 2014b) have been used. For instance, Rademaker, Reid, and Bromley (2012) introduces slight variations in energy expenditure variables. This can be especially useful to assess paths that might not have performed as expected. Next, typically in research endeavors that attempt to identify the most appropriate cost model for a specific research initiative, juxtaposed comparison against paths of different cost functions is often attempted (Kantner 2012, Verhagen and Jeneson 2012). Lastly, some form of ground truthing is evaluated, either digitally or physically, on the ground. Phillips and Leckman (2012) compared artifact distribution with modeled paths whereas White and Surface-Evans (2012) physically verified digitized road segments.

CHAPTER 3: METHODS

The LCA developed for this thesis project maps paths across the Amanus Mountains between specified points within the eastern and western foothills. The cost surface is generated using Tobler's hiking function, converting slope values to time intensity. The function is employed in the popular Esri ArcGIS software suite, specifically the Path Distance tool in ArcGIS Pro 1.1 and Cost Path tool in ArcGIS Desktop 10.3. In order to calculate Path Distance and implement Tobler's hiking function, this LCA required a DEM, origin and destination points (vector or raster), a slope raster, and a vertical factor table that would be used to translate the slope (cost) raster into time.

The ensuing chapter further describes the nature and means of the LCA execution for the passes across the Amanus mountains which would have served to link the coastal Cilician plain to the territory of kingdoms lying to the east. The first section describes the data that were acquired and/or created, and the means of preparation for analysis. The second section illustrates how the LCA was executed and assessed.

3.1 Data

3.1.1 Acquiring the DEM

The ASTER GDEM V2 (ASTER DEM) most closely matched the DEM requirements being freely available for download and roughly 30 m in spatial resolution. The ASTER DEM was downloaded from USGS LPDAAC (http://gdex.cr.usgs.gov/geoportal_data_cache/20151228172819_1066319930.zip) in order to: (1) utilize the bounding box function that creates customized-tile tiff DEMs; and (2) export these data using the WGS 84 UTM Zone 37N projection. The UTM projection was employed in this step as well as each additional function since there is a uniform distance relationship (which is not necessarily the case for angular coordinate systems). To adequately cover both sides of the Amanus Mountains, the following spatial extent for data extraction was stipulated, as shown in Figure 3: 187292.194, West (Left); 3974308.134, South (Bottom); 365020.437, East (Right); and 4178136.263, North (Top).

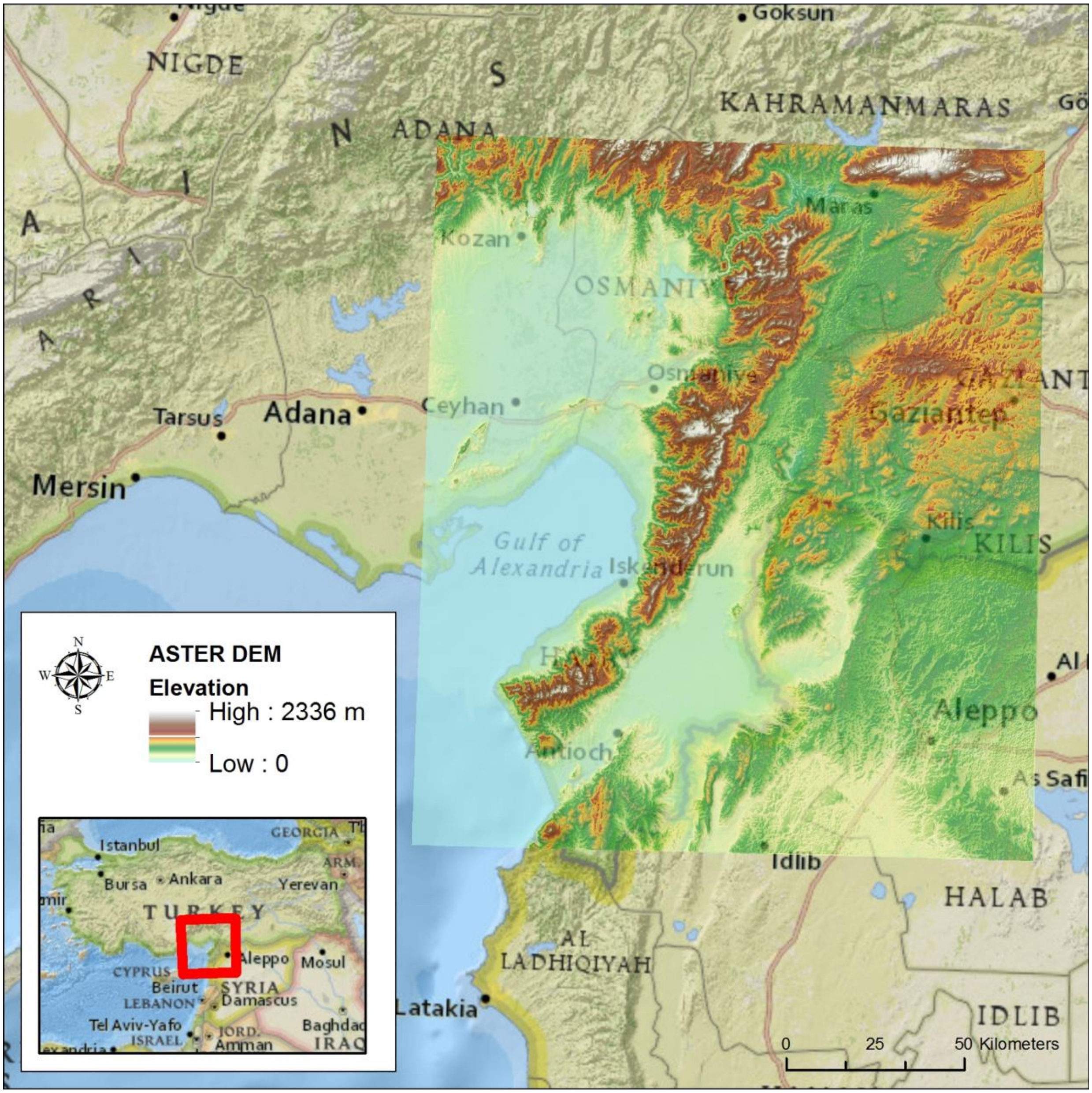

Figure 3 ASTER DEM downloaded from USGS LPDAAC

3.1.2 Generating Origin and Destination Points

Origins and destinations were selected based on Dodd (2014, pers. comm.) such that they were located between the known Bahce and Belen paths and relatively even in distribution with regards to current settlement. Figure 4 illustrates this selected distribution.

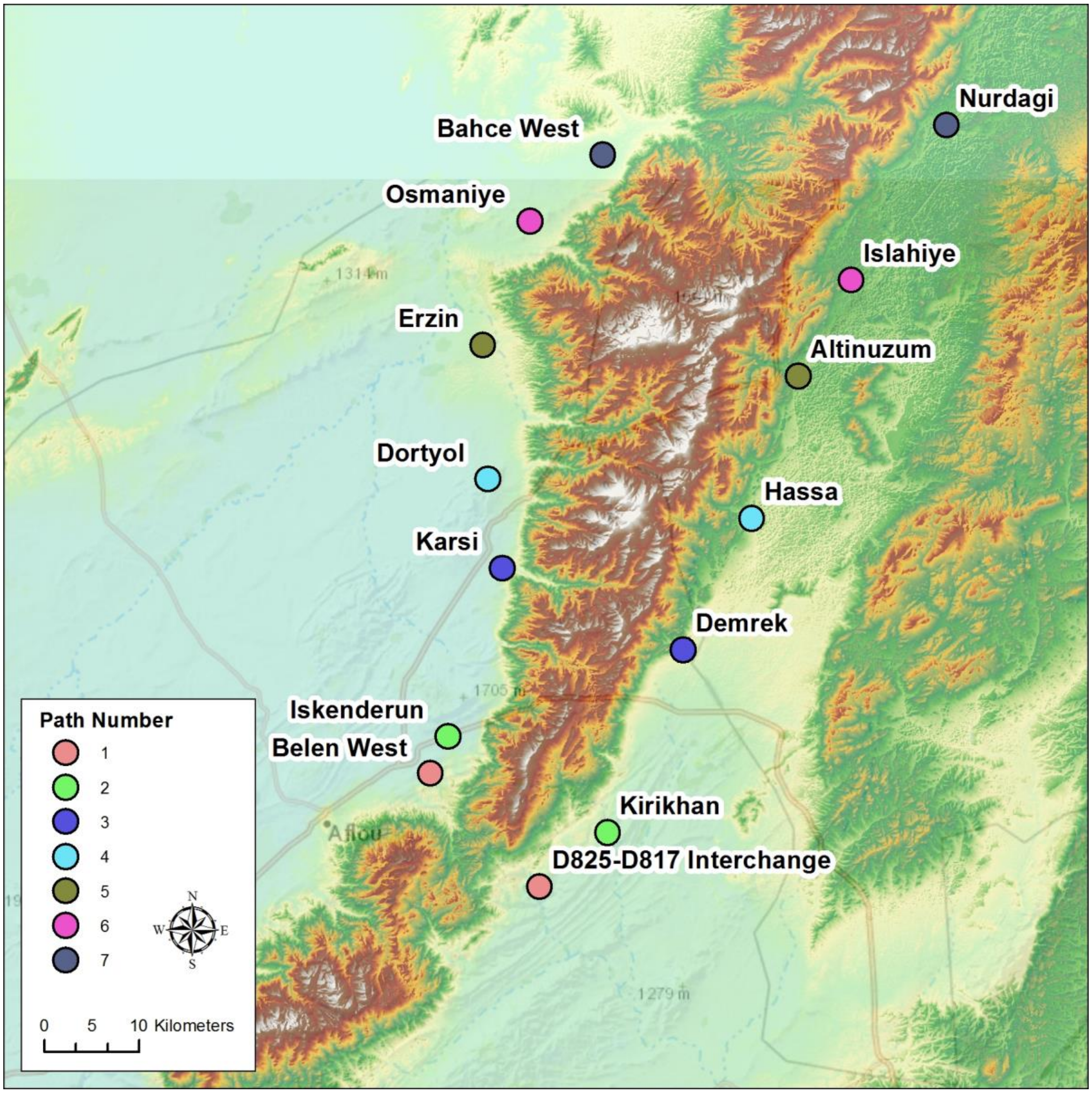

Figure 4 Distribution of origin/destination points, symbolized by path.

Points were digitized in ArcMap 10.3 as a single, point feature class with three fields, as shown in Table 1.

Table 1 Attribute fields and site names for site feature class

Name	PathNum	O_D	DigitizeMethod
D825-D817 Interchange	1	E	National Geographic basemap
Belen West	1	W	World Imagery basemap
Kirikhan	2	E	National Georgaphic basemap
Iskenderun	2	W	National Georgaphic basemap
Demrek	3	E	World Imagery basemap
Karsi	3	W	Google Maps estimation against Streets basemap
Hassa	4	E	National Geographic basemap
Dortyol	4	W	National Geographic basemap
Altinuzum	5	E	Google Maps estimation against Streets basemap
Erzin	5	W	World Imagery basemap
Islahiye	6	E	National Geographic basemap
Osmaniye	6	W	National Geographic basemap
Nurdagi	7	E	D-825 & D-400 Interchange on World Imagery basemap
Bahce West	7	W	Generalized location of consistent level topography

First, a “Name” field (text) was used to indicate specific locations. Second, a “PathNum” field (short integer) was used to indicate the specific path-set that each point belongs to. Third, a “Foothill” field (text) was added that indicates the eastern or western foothill, populated by either a “W” (West) or “E” (East). Fourth, a “DigitizeMethod” (text) field was added to indicate how points were plotted. Locations that referred to a town/city were placed using one or other of three methods. Points were placed on the point location on the National Geographic basemap, the generalized center indicated by the reference text on the World Imagery basemap, or the estimated location identified by cross-referencing Google Maps and the Streets basemap.

3.1.3 Removing 0-Values and Creating the Slope Raster

Before deriving the slope raster, it was necessary to remove all 0-values (sea level) from the DEM. Since the subject area entirely sits above sea level and sea travel is not included in this LCA, extracting all values that did not equal ‘0’ is acceptable. In ArcMap, an attribute table was built for the DEM (simply by calculating unique values). Then, the “Extract by Attributes” tool was utilized with the where clause “Value <> 0.” As shown in Figure 5, the resulting DEM removes all seas (i.e. those areas with elevations recorded as zero to signify mean sea level) and preserves all land values.

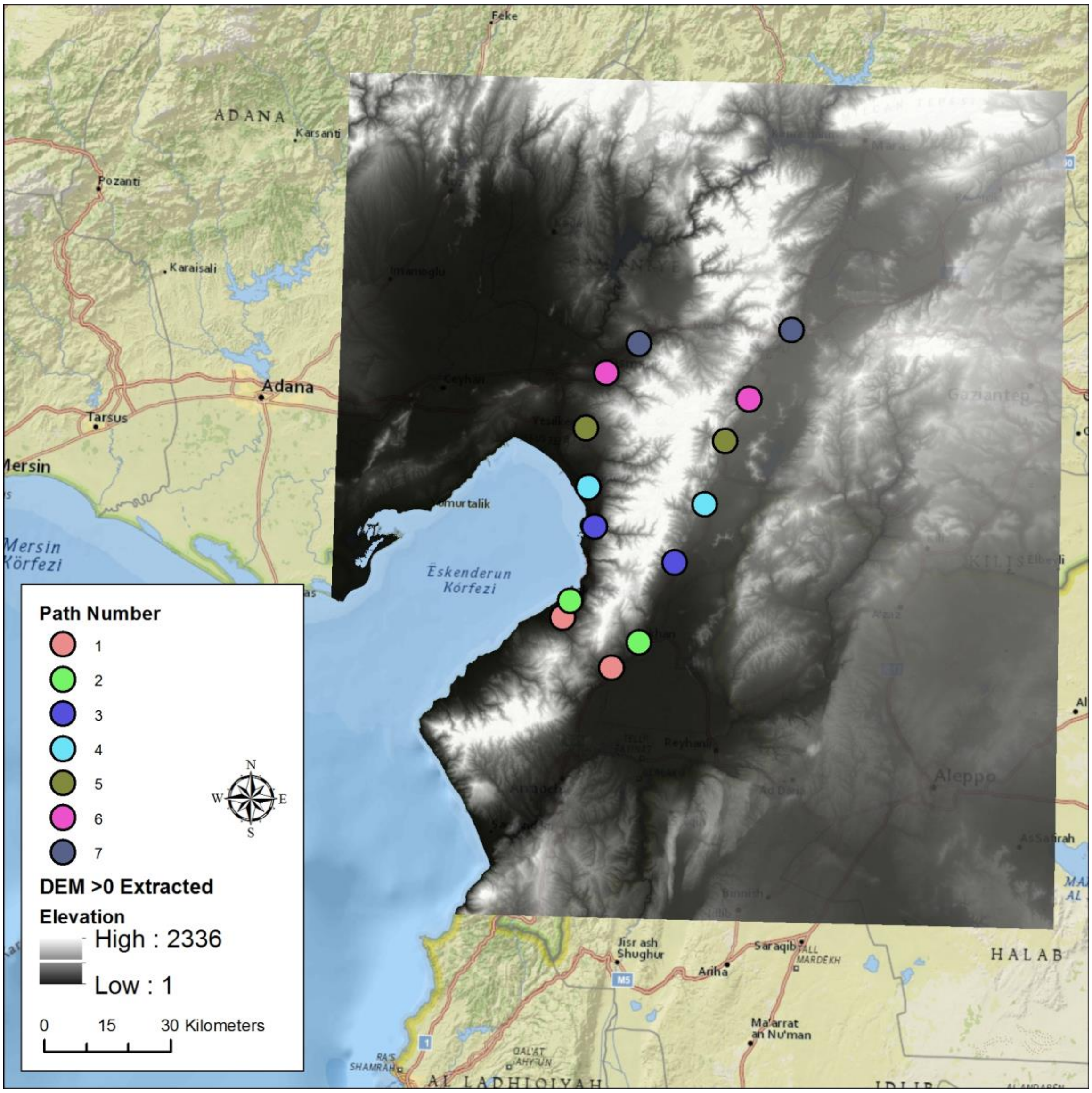

Figure 5 DEM after 0-Value removal

The slope raster was then generated using the “Slope” tool in the Spatial Analyst toolbox of ArcGIS 10.3. The raster is created using degrees as the output measurement (Figure 6).

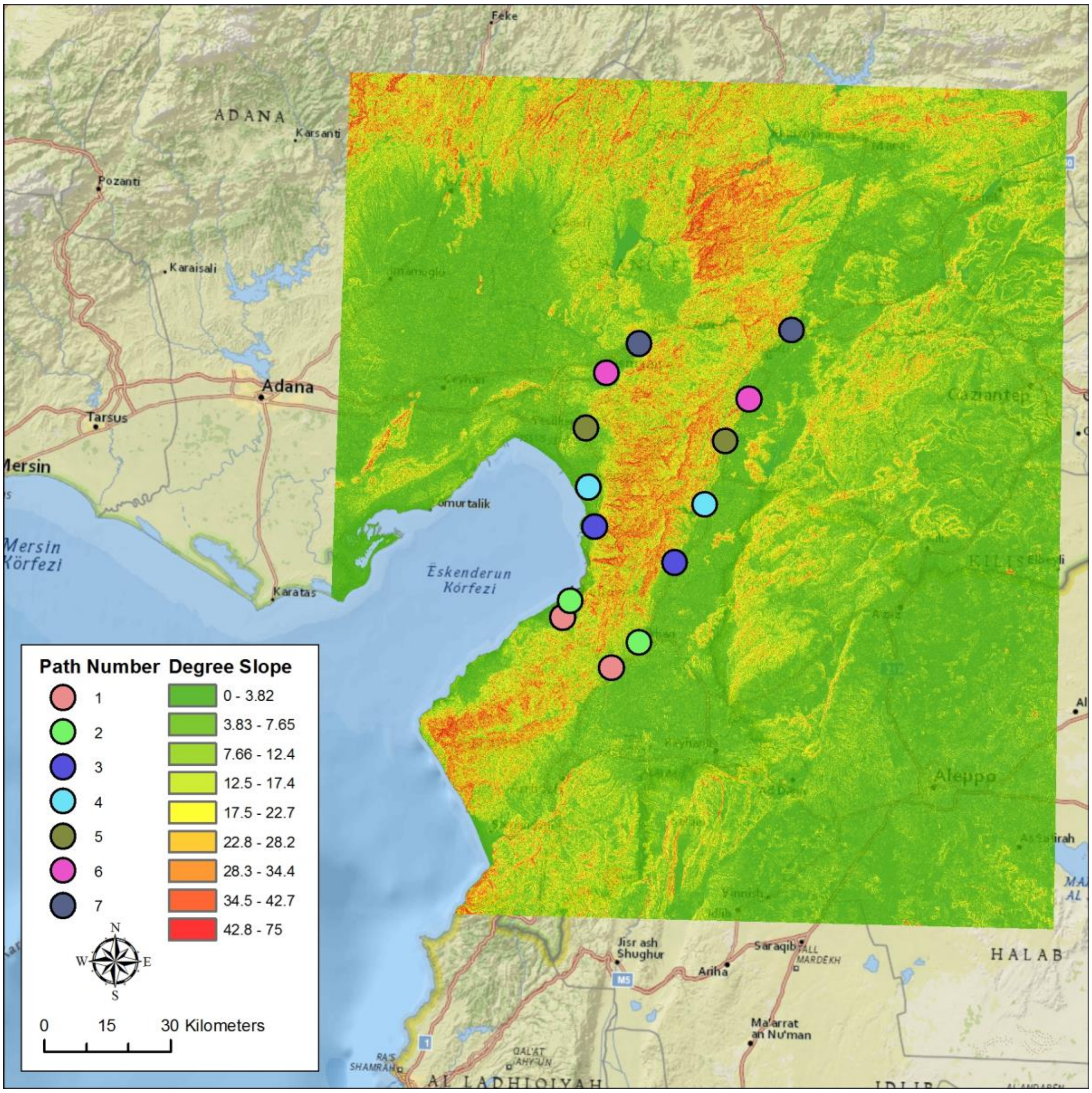

Figure 6 Slope raster

3.1.4 Vertical Factor Table

The vertical factor table that is used by the Path Distance tool to convert slope to time using Tobler’s hiking function comes from Tripcevich (2009). Tripcevich (2009) calculated the reciprocal of Tobler’s hiking function in Microsoft Excel using the following equation:

TIME (HOURS) TO CROSS 1 METER =

0.000166666*(EXP(3.5*(ABS(TAN(RADIANS(slope_deg))+0.05)))) (1)

Table 2 is an abbreviated version of the text file that holds the vertical factor table calculated with Equation (1).

Table 2 Abbreviated Vertical Factor Table

Slope (deg)	Vertical Factor
-90	-1
-80	-1
-70	2.099409721
-50	0.009064613
-30	0.001055449
-10	0.00025934
-5	0.000190035
-4	0.000178706
-3	0.000168077
-2	0.000175699
-1	0.000186775
0	0.000198541
5	0.000269672
10	0.000368021
30	0.001497754
50	0.012863298
70	2.979204206
80	-1
90	-1

3.2 Methodology

After acquiring and generating the necessary data (dark blue ovals and left branch in Figure 7), the data must be prepared for the Path Distance tool.

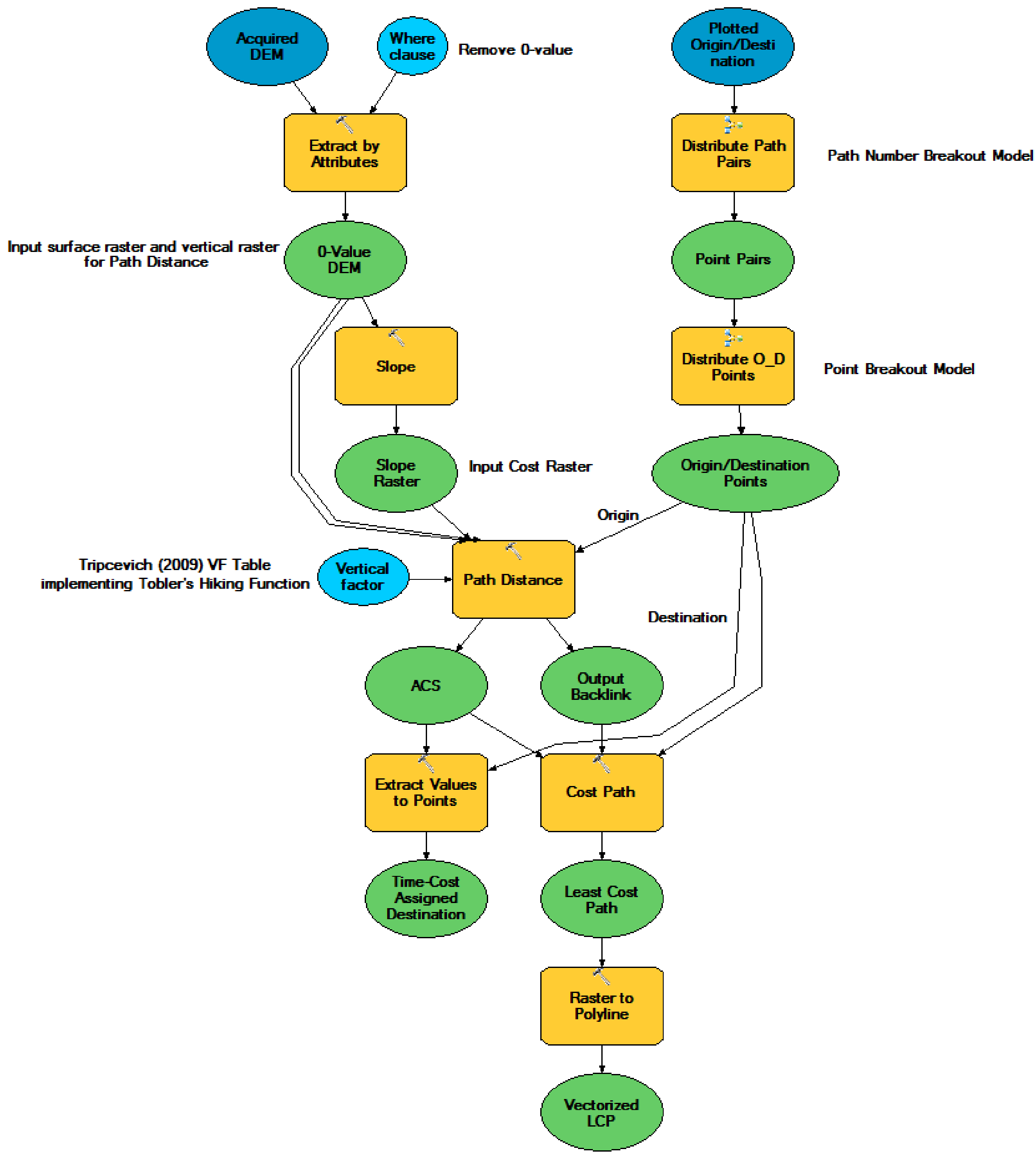

Figure 7 Methodological flowchart for path distance execution

As shown in Figure 7, the origin and destination feature class must be broken out into single-individual point feature classes. Once each required input has been properly formatted, the Path Distance tool can be executed for each point feature class in both directions. The Path Distance tool generates the ACS raster and backlink raster for each point and direction, necessities for generating LCPs. LCPs are generated by executing the Cost Path tool. Further, the raster output is converted into a polyline feature class using the Raster to Polyline function.

3.2.1 Preparing for Path Distance Tool

Since this LCA generates one path per path set of points, it became necessary to breakout each set of points. Furthermore, the nature of the Path Distance and Cost Path tools utilize the origin source data and the destination source data, respectively. Therefore, it is most effective to create feature classes for each point of each pair. Before breaking out each point, path-specific, individual feature-geodatabases were created to house all data produced. Next, each pair of points was broken out from the "global" feature class by utilizing the "Iterate Feature Selection" function in ArcGIS Modelbuilder. As shown in Figure 7 below, the model selected each pair of points from the original dataset ("Site Warehouse") by selecting those consistent with the originally stated path number.

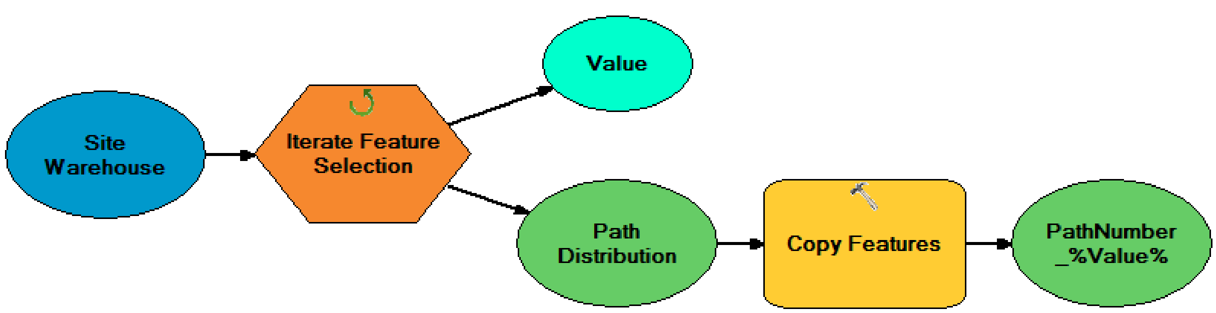

Figure 8 Path Number Breakout Model

Next, a feature class was generated from each pair of points selected and named with that specific path number. Once feature classes for each pair of points were created, the model was reconfigured to distribute the origin and destination points based on the name of the location, as shown in Figure 8.

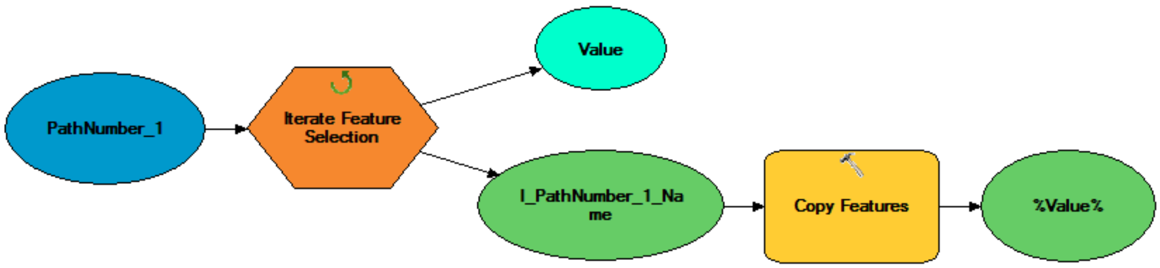

Figure 9 Point Breakout Model

The subsequent "Point Breakout Model" model iterates each point from the previously broken out path-specific points, generates a feature class for both the origin and the destination, and names the feature class based on the value of the "Name" field. Lastly, the foothill direction was added manually as a prefix to each point. For instance, in Path Number 1, the points were named "East_D825_D817_Interchange" and "West_Belen_West."

3.2.2 Executing the Path Distance Tool

The Path Distance tool was executed in ArcGIS Pro 1.1 for each pair using the following inputs, as demonstrated in Figure 9: "Input raster or feature source data" was the eastern foothill point of a point-pair, "Input cost raster" was the generated slope raster, "Input surface raster" and "Input vertical raster" was the 0-value removed ASTER DEM, and the Tripcecvich (2009) text file was implemented for the "Vertical Factor."

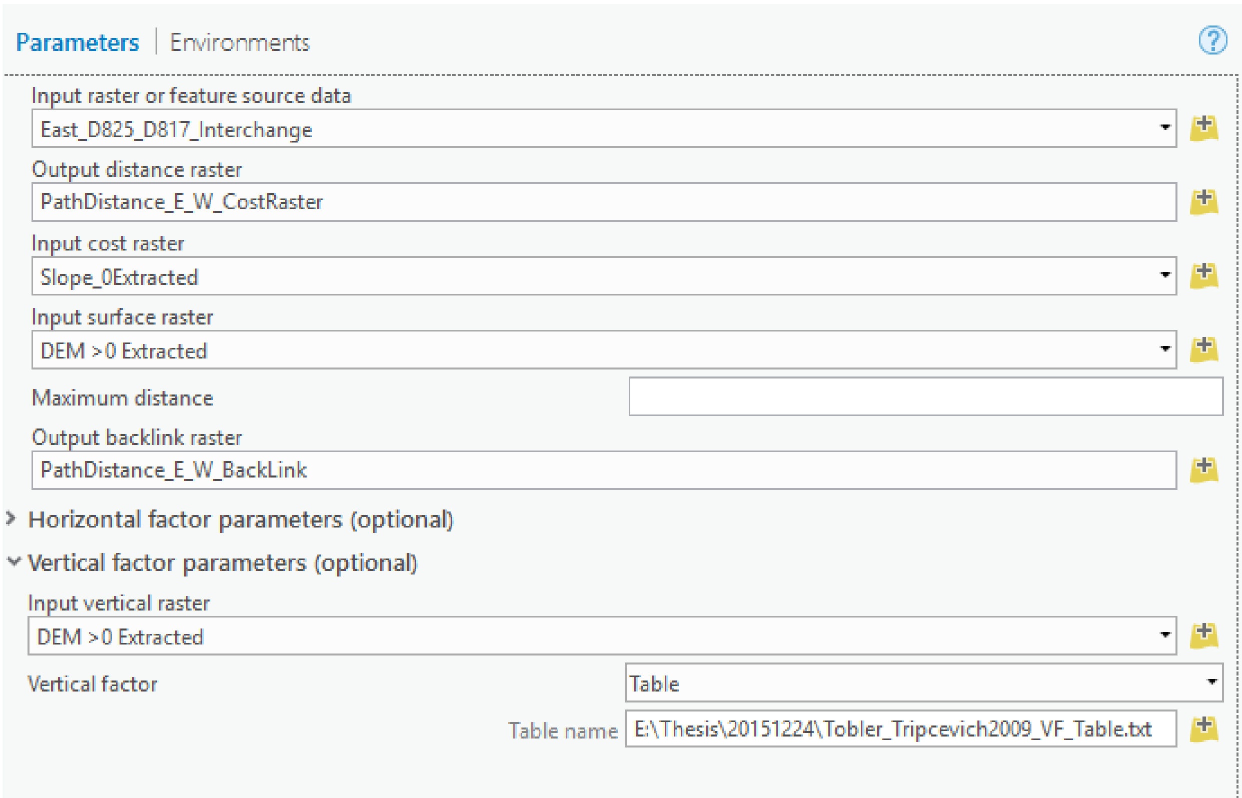

Figure 10 Path 1, east-west Path Distance tool inputs (captured in ArcGIS Pro 1.1)

The WGS 1984 UTM Zone 37N output coordinate system was also stipulated in the Environments tab. Finally, in order to reduce the computational load, the extent used for the analysis was limited to the "Current Display Extent." The output generated by the Path Distance tool is the ACS and the backlink raster, both of which are needed to generate LCPs.

3.2.3 Generating LCPs

LCPs were generated from the ACS and backlink by using the Cost Path tool in ArcGIS Pro 1.1. The "Input raster or feature destination data" was the western foothill point of the point-pair, the ACS was applied as the "Input cost distance raster" and the backlink raster was applied as the "Input cost backlink raster." Lastly, the path type was left as default to "each cell." The output of the Cost Path tool is a raster that contains only the cells needed for the LCP between the specified origin and destination points. The last step in creating a LCP is to convert these rasters to vector lines using the Raster to Polyline tool. Finally, the process (starting with the Path Distance tool) is restarted, switching the origin/destination points from eastern/western to western/eastern. Additionally, the modeled time required to reach a destination was assigned to each destination point via the “Extract Value to Points” tool. This tool linked the raster value of each ACS with its respective and appropriate destination point.

3.2.4 Conducting the Validity Assessment

A validity assessment was executed using two methods: a sensitivity analysis and a comparative analysis between modeled and existing paths. The sensitivity analysis was conducted by first, randomly selecting two pairs of points. Next, the spatial location of the origin/destination points were adjusted by 250 m northward and southward along the foothills of the mountains, in a topographically similar location. New paths were then generated from these points and compared to those previously modeled.

The comparative analysis juxtaposed the two known paths to those that were modeled. The modeled Path Number 1 was compared to the Belen Pass and the modeled Path Number 7 was compared to the Bache Pass. First, each pass was digitized in individual line feature classes from the World Imagery and Streets basemaps in ArcGIS. Since multiple transit routes have now been paved, digitized paths were drawn from all highways that now exist (omitting tunnels). As displayed in Figure 11, for instance, the Bahce Pass included both D-400 and O-52.

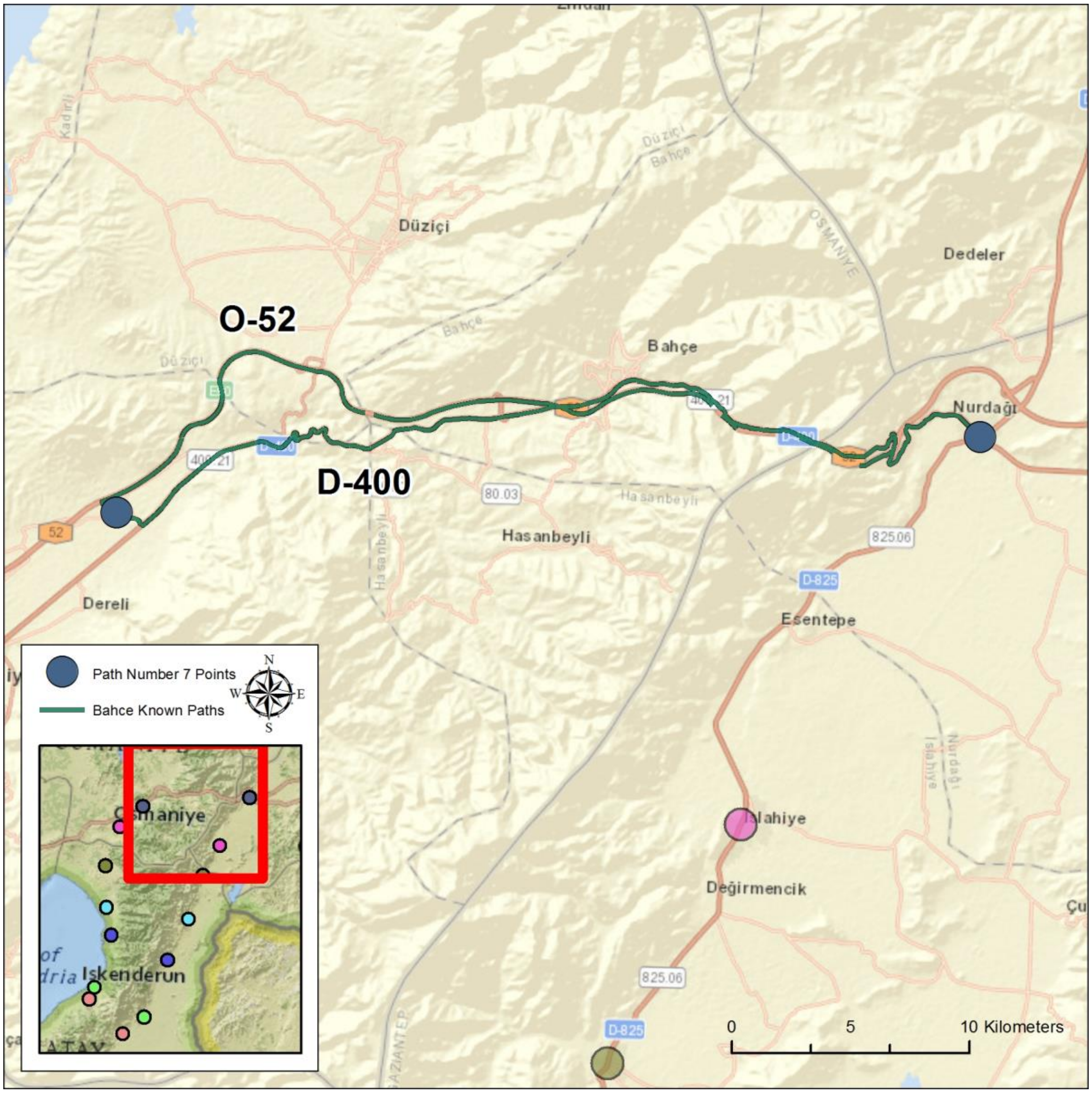

Figure 11 Digitized Bahce Pass routes

Each mapped route in a given pass was merged together to form a single feature. Next, a multi-ring 250 m buffer of the known path was generated. Lastly, the modeled paths were intersected with the rings, and the percentage of the modeled path length per ring was extracted.

CHAPTER 4: RESULTS

This chapter presents the results of the previously described AVRP LCA methodology. Results include the modeled paths, their associated travel times, a further inspection of paths that share common corridors, and the validity testing. These results are presented in a series of sections that discuss the modeled paths, their relationships with the environment, and the validity of the model.

4.1 Modeled LCPs

As shown in Figure 12, there are four main corridors across the mountains that were exploited.

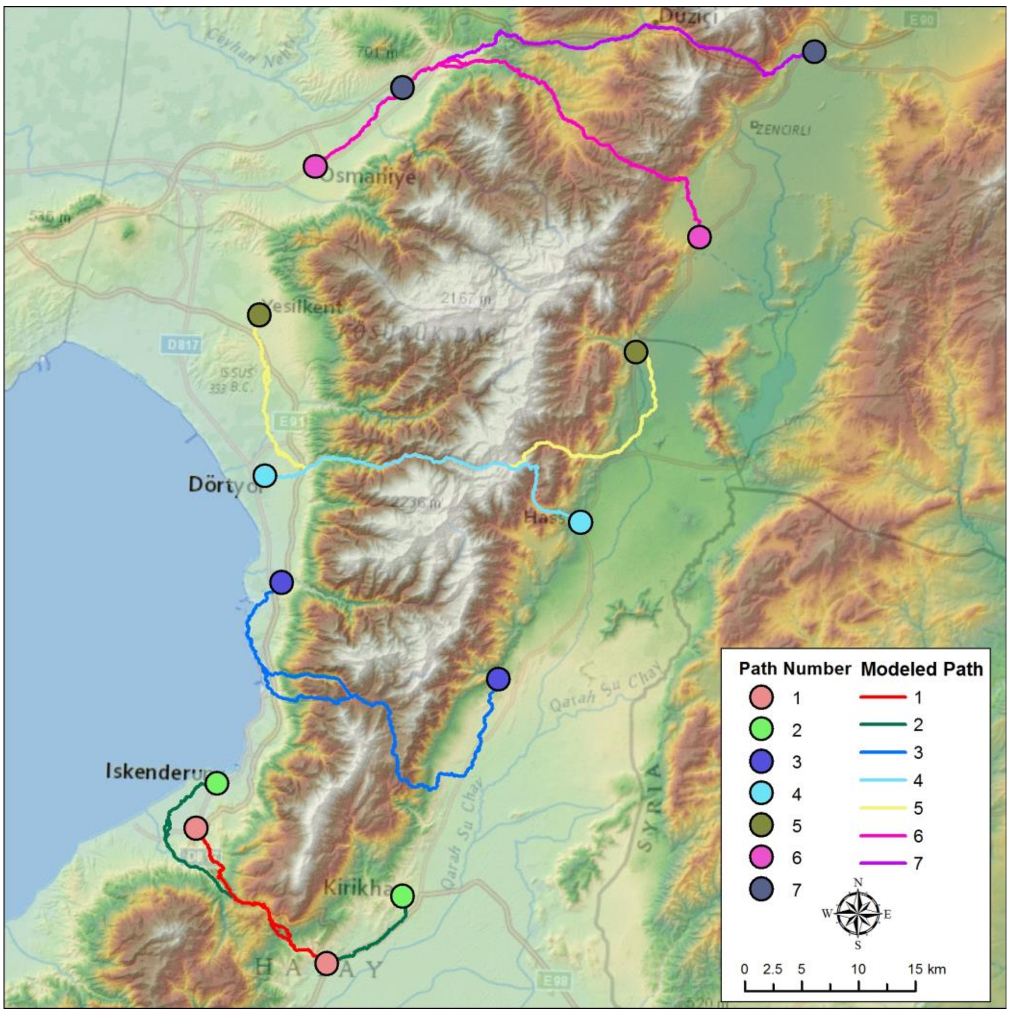

Figure 12 Resulting LCPs generated using proposed methodology

Paths 1 and 2 share the Belen Pass corridor toward the southern extent. Further north, Path Number 3 does not share its route with any additional paths. It should be noted that each path in Figure 12 is colored to the path number and indifferent to the orientation; hence, the split on the western half of Path Number 3. Paths 4 and 5 share a modeled corridor in the generalized center of the mountain range between the Belen and Bahce Passes. Lastly, Path Number 6 merges into the general area of the Bahce Pass (Path Number 7).

The estimated travel times for each Path Number in each direction are presented in Table 3.

Table 3 Modeled Path Travel Times

Path Number	Name	Point of Origin	Travel Time (hrs)
1	D825_D817_Interchange	E	35.15
1	Belen West	W	35.54
2	Kirikhan	E	41.87
2	Iskenderun	W	41.81
3	Demrek	E	78.36
3	Karsi	W	75.68
4	Hassa	E	78.79
4	Dortyol	W	77.77
5	Altinuzum	E	87.77
5	Erzin	W	86.36
6	Islahiye	E	57.22
6	Osmaniye	W	55.26
7	Nurdagi	E	46.01
7	Bahce_West	W	44.76

As expected, the known paths (1 and 7) were the least time-intensive, followed by Path Number 2 which utilized the known Belen Pass. These modeled travel times indicate that regardless of route, a backway (excluding Paths 1, 2, and 7) across the mountains was at least a 48-hour journey. Furthermore, the variation of estimated travel times between east and west oriented paths is insignificant.

4.1.1 LCP Corridors

Figure 13 is the first of four LCP corridor maps. As shown below, Figure 13 shows how Path Number 2 merges/continues (depending on orientation) with Path Number 1 at the D825-D817 Interchange location as well as a point near the center of Path Number 1.

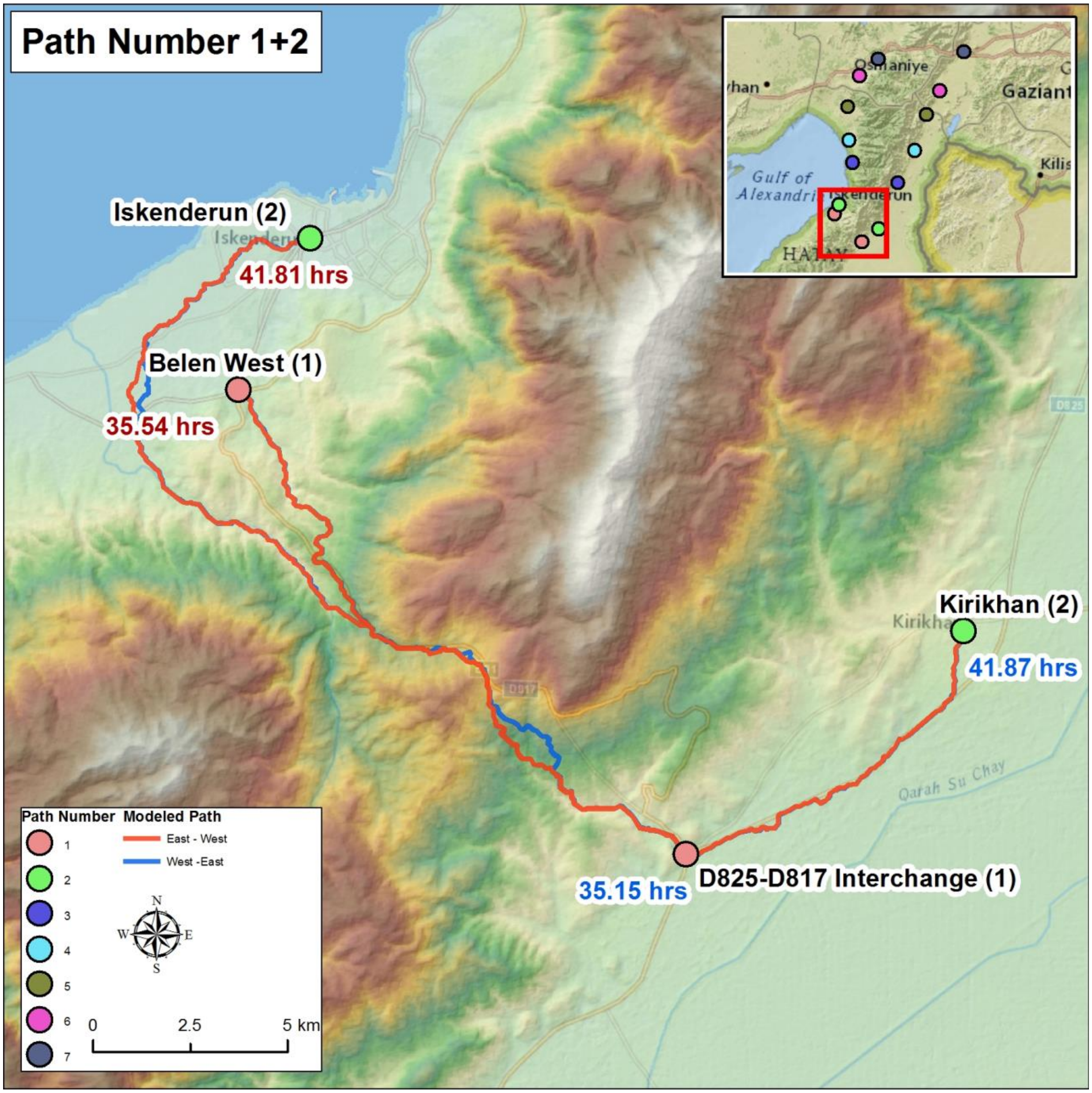

Figure 13 LCP Corridor - modeled Paths 1 and 2

In addition, the segment of Path Number 2 that precedes the merge at the D825-D817 Interchange sits atop the D825 highway (shown in faded orange on the basemap, southwest of the interchange). Lastly, neither path utilized the gradually-elevating D817 highway on the southern side (shown in brighter orange adjacent to the higher elevation area east of the modeled paths).

Figure 14 displays the environment in which Path Number 3 was modeled.

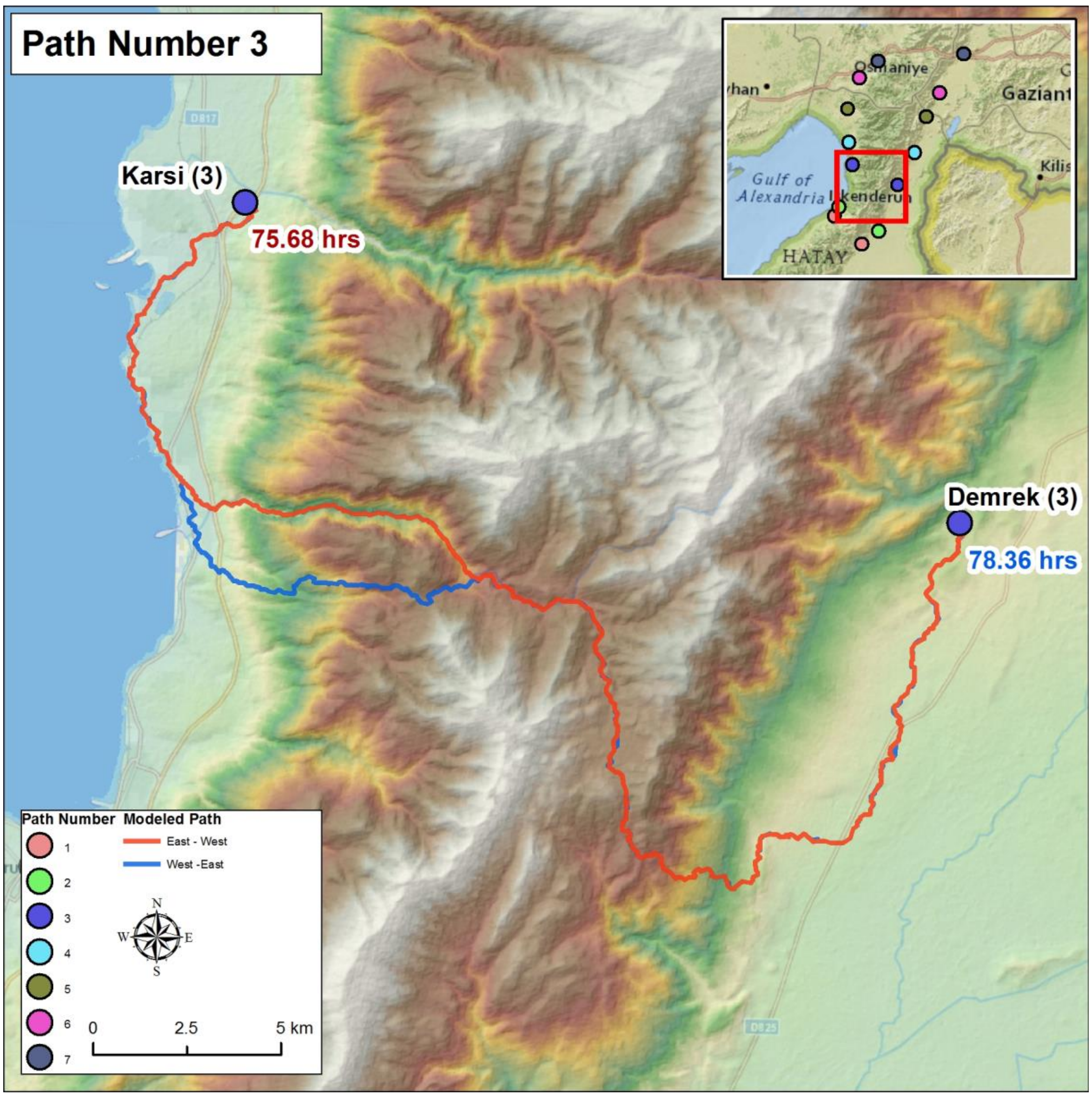

Figure 14 LCP Corridor - modeled Path Number 3

Path Number 3 has the largest discrepancy in modeled time between the east-west and west-east calculations. On the western side of the mountains, both modeled routes travel along the coast and ascend to the town of Kaledibi, but using widely different avenues at the divergence at Sanseki. In that differing area, the west-east route utilizes the corridor of a current roadway whereas the east-west route shares its route with a hiking trail.

Figure 15 demonstrates the common area between Paths 4 and 5.

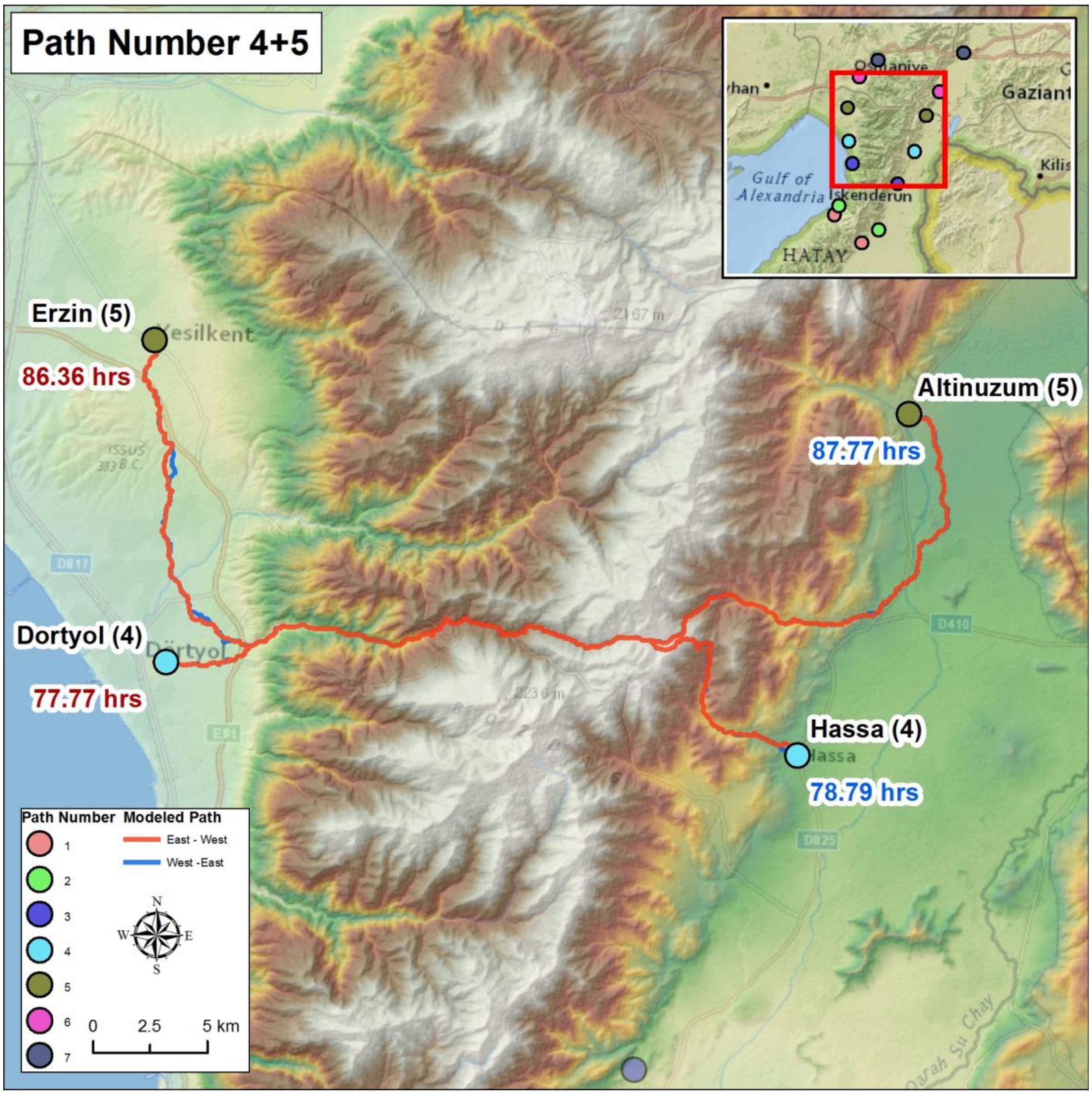

Figure 15 LCP Corridor - modeled Paths 4 and 5

While not specifically adhering to the most popular routes, almost all areas of these modeled routes share paths with current ones. There is very little variation between differing orientations in both sets of modeled paths. In the general area of high topographic intensity (in the mountains where Paths 4 and 5 merge) there are very few existing roads or even trails and the modeled paths occupy one of these very minor roads.

Figure 16 shows the Bahce pass area, the modeled Bahce pass (Path Number 7) and the merged Path Number 6.

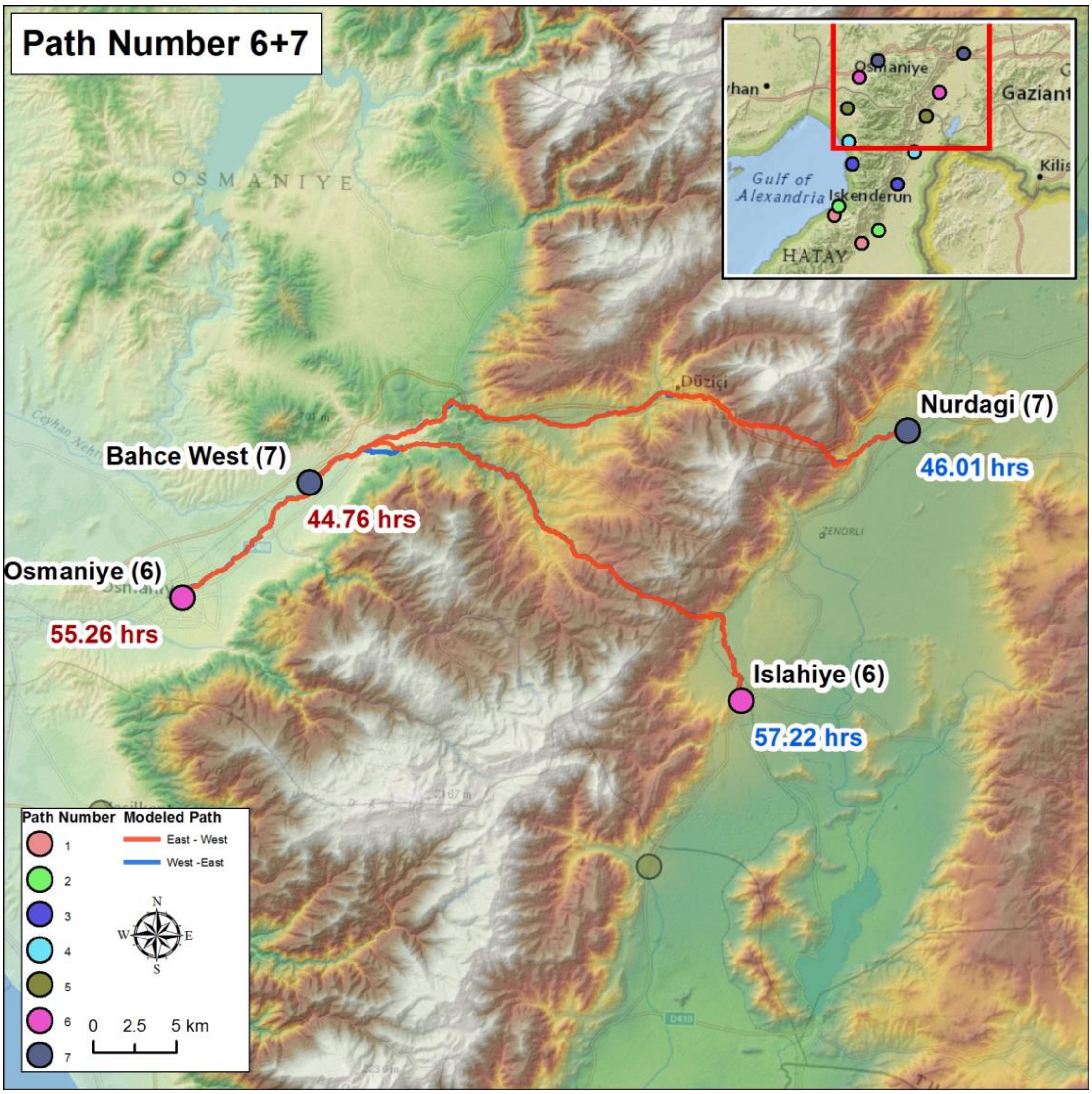

Figure 16 LCP Corridor - modeled Paths 6 and 7

Once again, there is very little variation between differing orientations in both sets of modeled paths. The discrepancy in estimated travel times, however, is attributed to the general slope direction in the mountainous area. As shown in Figure 16, in the southern third of Path Number 6, for instance, the traveler would be traversing downward if heading west, upward (and thus, more costly) if heading east. Since there was no specific location to utilize for the western point of the Bahce pass and a point was arbitrarily placed, there is potential for significantly greater merged route length between Paths 6 and 7, through Osmaniye.

4.2 Validity Test Results

The following section presents the results of the sensitivity analysis and the known-path testing. The sensitivity analysis is broken out by path and further by orientation, considering the number of lines that occupy the same general space. The known-path comparison highlights how close the modeled Paths 1 and 7 were to those that currently occupy the Belen and Bahce passes, respectively.

4.2.1 Sensitivity Analysis

The sensitivity analysis was performed by spatially adjusting the origin and destination points by 250 m for Paths 3 and 5 and executing the LCA methodology. Since the varying distance is relatively small, there should not be any significant changes in the modeled paths. A lack of these changes would lend support to the idea that the model is stable, whereas the presence of substantial changes would lead to the conclusion that the model is inconsistent and thus, unreliable. As shown in Figures 17-20 and Tables 4-5, there are no substantial changes in the modeled paths.

4.2.1.1 Sensitivity Analysis for Path 3

As shown in Figures 17 and 18, the sensitivity paths for each orientation deviated slightly from the originally modeled route near each point, but are otherwise followed each other closely throughout.

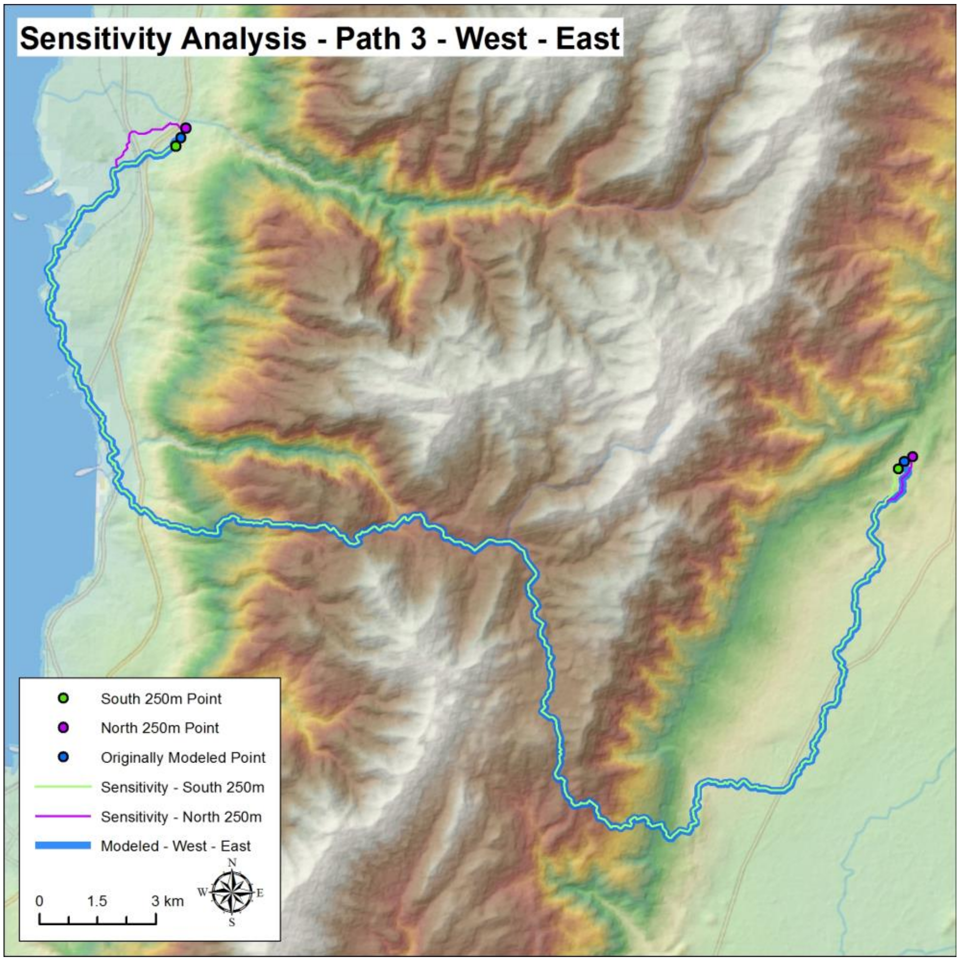

Figure 17 Sensitivity Analysis for Path 3, east – west orientation

Figure 17 displays how the sensitivity paths generally behave as expected. Since they are oriented east to west, one would not expect the northern 250 m path to head east and closely follow the rising slope of the foothills. This path extends westward towards areas of level slope before merging with the LCP, south of Karsi. On the eastern side, the paths simply trail off to the appropriate destination with minimal variance. Figure 18 displays a similar pattern with inverse orientation.

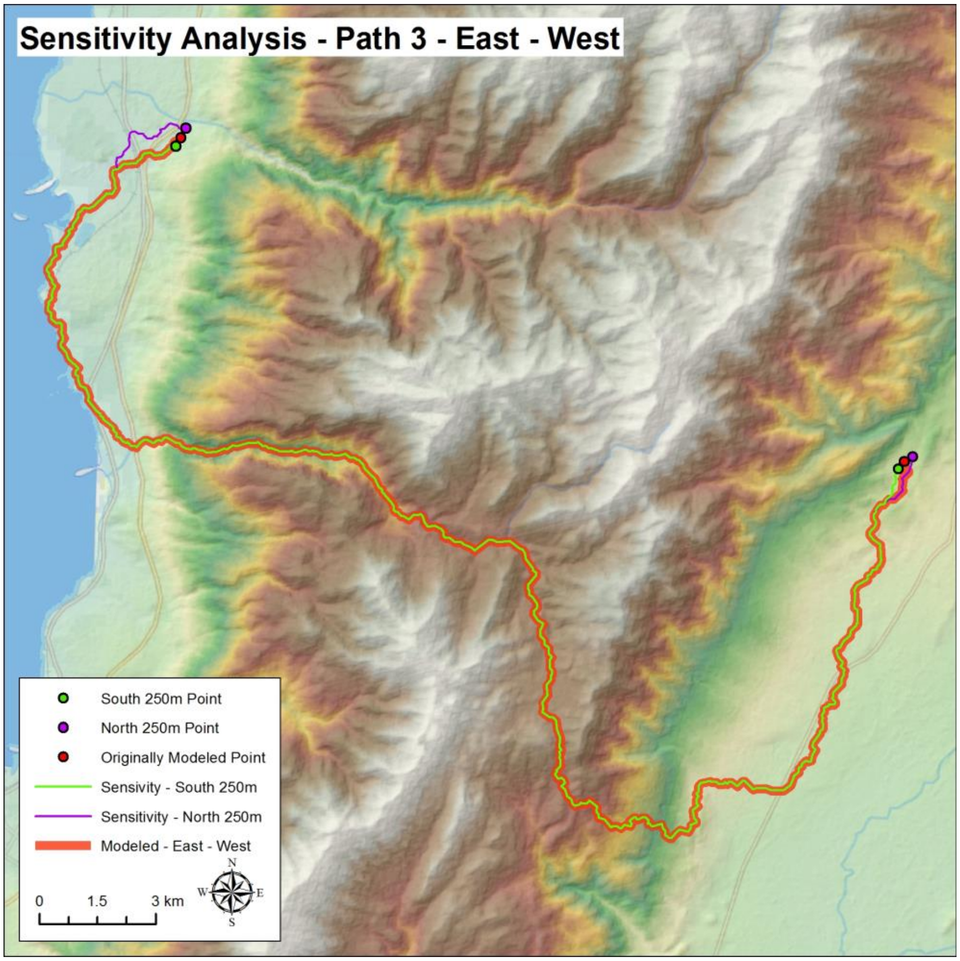

Figure 18 Sensitivity Analysis for Path 3, west – east orientation

The sensitivity analysis here further supports the notion of consistent output generation as documented by orientation-dictated deviation in the western third. The east-west routes navigate through the northern ravine whereas the west-east routes favor a southern path. Lastly, as shown in Table 4, travel times behave as expected. Since the mountain passages of all routes trend southward, the southern 250 m paths were slightly shorter in estimated time.

Table 4 Path Number 3 Sensitivity Estimated Time Comparison

Origin Location	Path Direction	Project Phase	Adjustment	Time (hrs)
Demrek	East - West	Original Modeling		78.36
Demrek	East - West	Sensitivity	N250	78.4
Demrek	East - West	Sensitivity	S250	78.14
Karsi	West - East	Original Modeling		75.68
Karsi	West - East	Sensitivity	N250	75.67
Karsi	West - East	Sensitivity	S250	75.39

4.2.1.2 Sensitivity Analysis for Path 5

As shown in Figures 19 and 20, the northern 250m paths are nearly identical to the modeled path while the southern 250 m paths deviate on the eastern foothill side for over five kilometers.

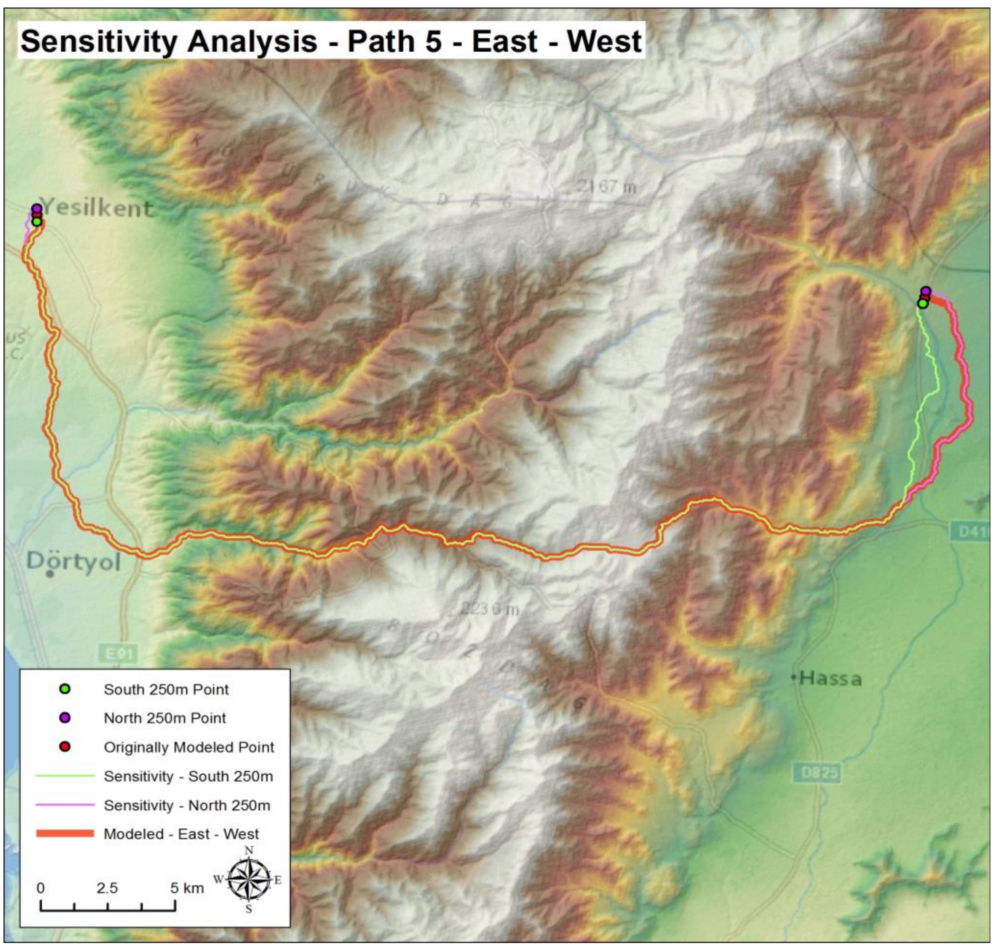

Figure 19 Sensitivity Analysis for Path 5, east – west orientation

As was the case in the Path 3 sensitivity analysis, these paths generally behave as expected. The modeled paths do not stray significantly far from the originally modeled path. The southern 250 m routes seem to stick closely to the eastern foothills.

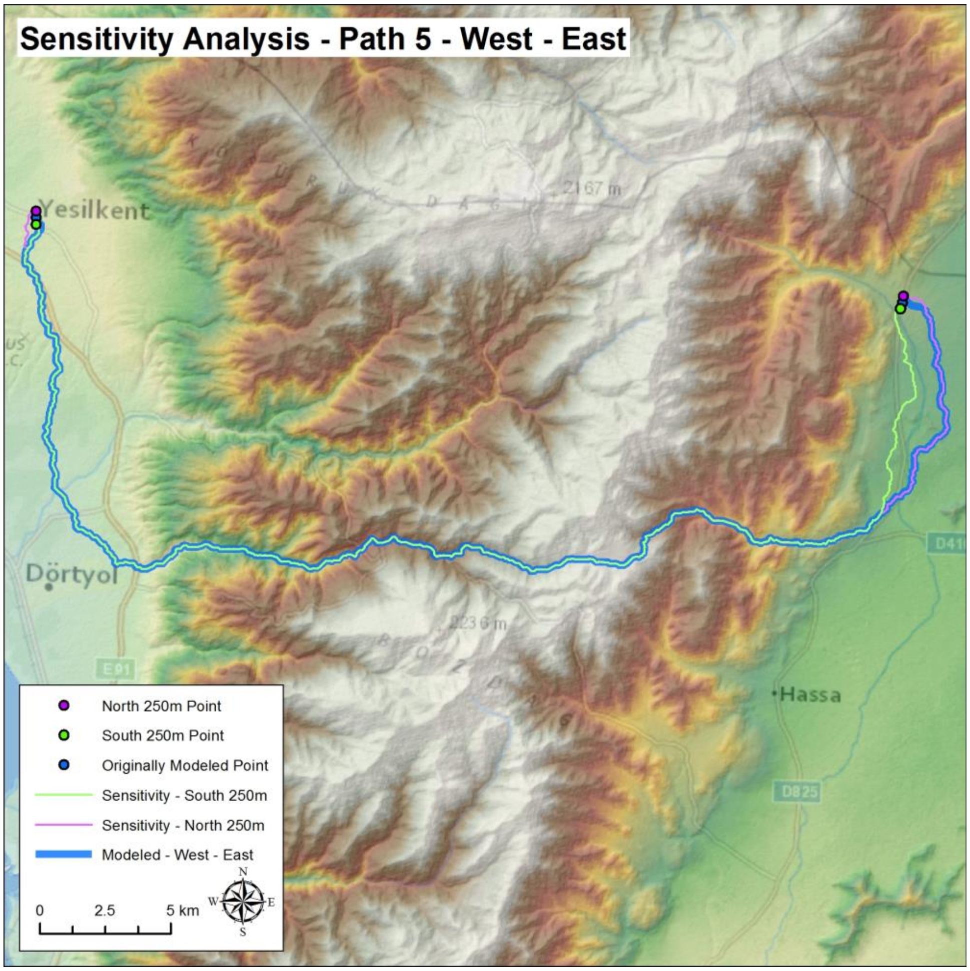

Figure 20 Sensitivity Analysis for Path 5, west – east orientation

The southern 250 m paths closely follow the D410 highway north whereas the original and the northern 250 m paths extend eastward into more consistently level terrain. Even though the 250 m distance is relatively small, the algorithm maintained that it would be more beneficial to accept some marginally higher slope levels closer to the foothills than to travel further eastward. The modeled time-estimate values in Table 5 further support this prioritization.

Table 5 Path Number 5 Sensitivity Estimated Time Comparison

Origin Location	Path Direction	Project Phase	Adjustment	Time (hrs)
Altinuzum	East - West	Original Modeling		87.77
Altinuzum	East - West	Sensitivity	N250	87.93
Altinuzum	East - West	Sensitivity	S250	87.54
Erzin	West - East	Original Modeling		86.36
Erzin	West - East	Sensitivity	N250	86.46
Erzin	West - East	Sensitivity	S250	86.08

Since the mountain passage of Path 5 trends southward, like that of Path 3, the values in Table 5 behave as expected. One would expect the northern 250 m paths to take slightly more time than the southern 250 m paths.

4.2.2 Known Path Comparison

The known path comparison was performed by buffering the digitized known path routes by 250 to 2,000 m and assessing the percentage breakdown of the modeled routes. Since the Cost Path algorithm is a "greedy" algorithm that will select the optimal path and not necessarily the simply acceptable path, there are some places of significant deviation from the known paths. This is particularly relevant in areas where slope is close to zero or elaborate switchbacks have been erected.

4.2.2.1 Belen Pass validity test

As shown in Figure 21 and Tables 6 and 7, there is significant overlap between the modeled and known paths in the center, more topographically-intense mountainous area. Nearly half of the modeled routes are within 250 m of the existing routes.

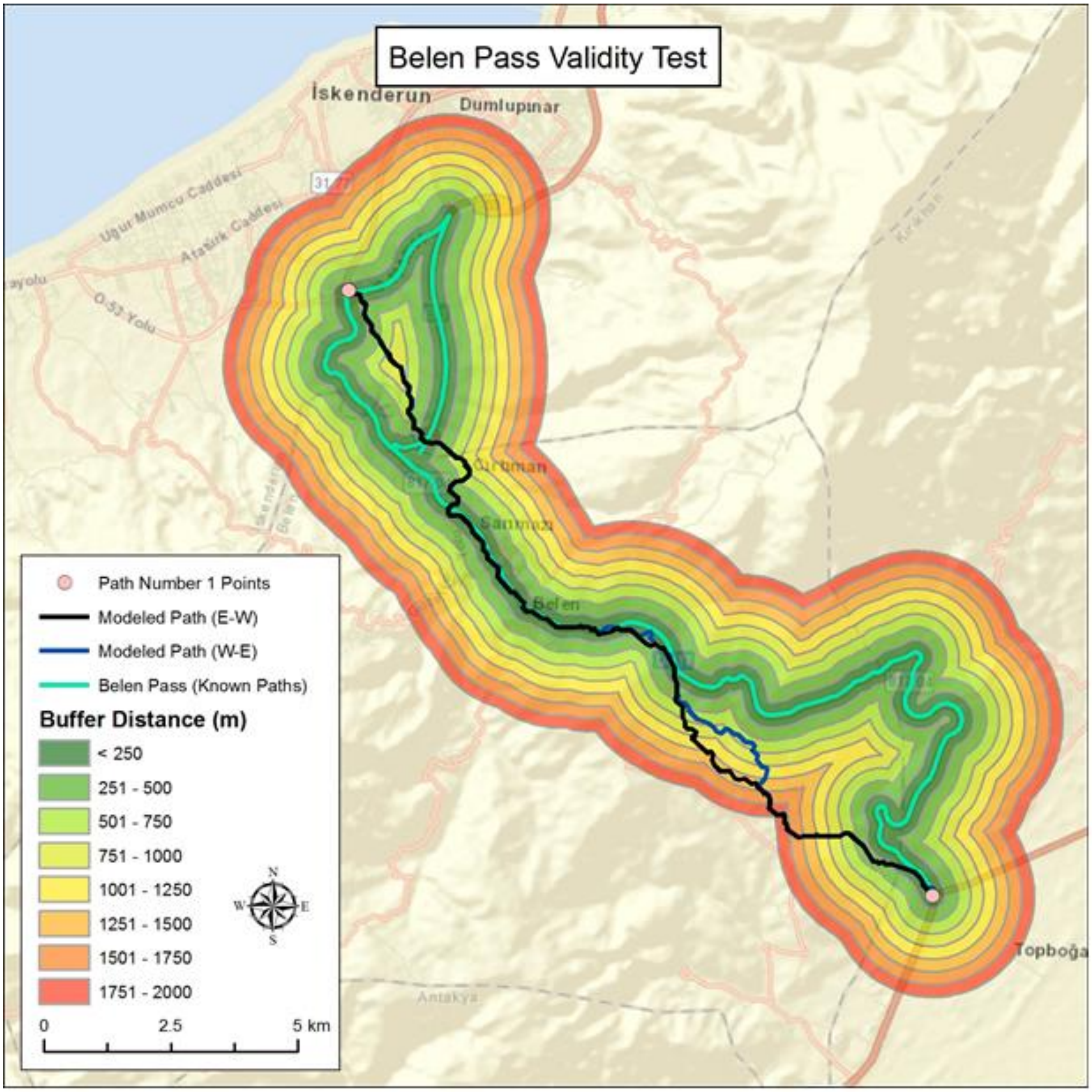

Figure 21 Belen Pass validity test against modeled paths

In addition, there is significant deviation of the modeled paths from the known routes in the southern third, ascending/descending the southern foothills, as reflected by the percentages of the modeled routes that deviated by one kilometer or more from the present-day routes in Tables 6 and 7.

Table 6 Belen Pass Validity Test Percentage Breakdown (West-East)

Buffer Class (m)	Length in Dist Range (m)	Percentage in Dist Range
< 250	9,563	45.32
251-500	3,512	16.65
501-750	3,589	17.01
751-1,000	1,782	8.45
1,001-1,250	626	2.97
1,251-1,500	608	2.88
1,501-1,750	609	2.89
1,751-2,000	810	3.84

Table 7 Belen Pass Validity Test Percentage Breakdown (East-West)

Buffer Class (m)	Length in Dist Range (m)	Percentage in Dist Range
< 250	9,056	43.33
251-500	3,540	16.94
501-750	2,654	12.7
751-1,000	1,530	7.32
1,001-1,250	711	3.4
1,251-1,500	1,918	9.18
1,501-1,750	642	3.07
1,751-2,000	851	4.07

The prevalence of elaborate switchbacks in the known paths to reduce sharp increases/decreases in slope skew the data towards a farther distance, for instance, nearly 10% of the east-west route is located some 1,251 to 1,500 m from the existing routes. In the southern foothills, shown in Figure 21, the greedy cost path algorithm modeled a much more direct route in favor of minimizing the horizontally-accumulated cost. This algorithmic result is also shown at the northern ends of the modeled paths.

4.2.2.2 Bahce Pass validity test

Similar to the validity test for the Belen Pass, the presence of elaborate switchbacks near the points of origin and destination (as shown in Figure 22) lends to the greedy element of the cost path algorithm.

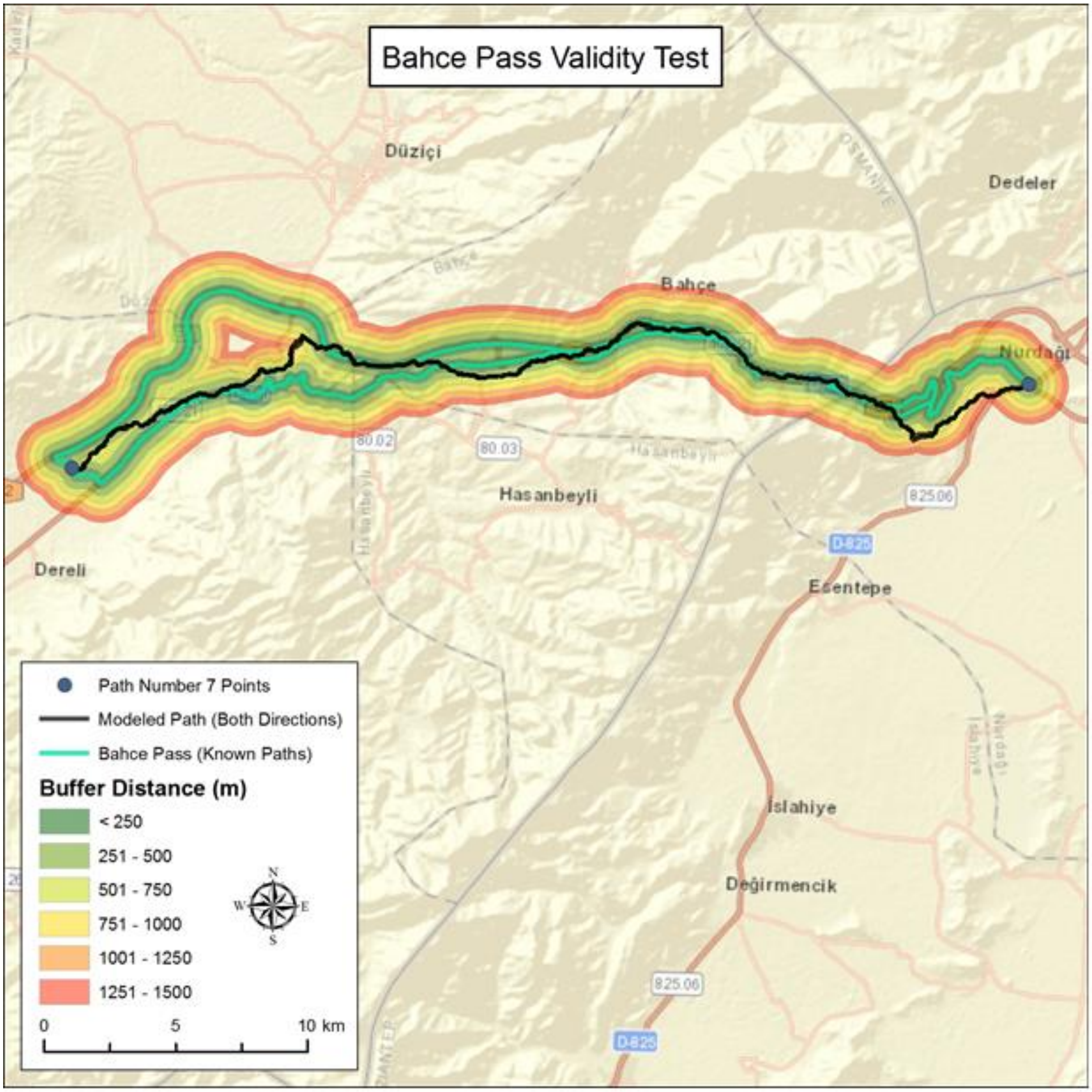

Figure 22 Bahce Pass validity test against modeled paths

As shown in Tables 8 and 9, over 60% of the modeled routes were within 250 m of the existing routes. Also, the maximum distance deviation threshold is within 1,500 m, 500 m shorter than was the case for the Belen validity test.

Table 8 Bahce Pass Validity Test Percentage Breakdown (West-East)

Buffer Class (m)	Length in Dist Range (m)	Percentage in Dist Range
< 250	27,663	60.67
251-500	9,659	21.18
501-750	4,457	9.78
751-1,000	2,233	4.9
1,001-1,250	1,255	2.75
1,251-1,500	331	0.73

Table 9 Bahce Pass Validity Test Percentage Breakdown (East-West)

Buffer Class (m)	Length in Dist Range (m)	Percentage in Dist Range
< 250	27,379	60.22
251-500	9,525	20.95
501-750	4,256	9.36
751-1,000	2,442	5.37
1,001-1,250	1,540	3.39
1,251-1,500	319	0.7

With the exception of the switchbacks in the eastern foothills and bulge northward in the western third, the modeled paths generally adhere closely to the existing routes. As shown in Tables 8 and 9, less than 5% of the length of the modeled path deviated by more than one kilometer from the existing routes.

CHAPTER 5: DISCUSSION AND CONCLUSIONS

The objectives of this LCA study were to generate LCPs across the Amanus Mountains while demonstrating the appropriate implementation of Tobler's hiking function, and evaluating the effectiveness of the modeled paths generated by the Path Distance tool. This final chapter presents a discussion of the data, methodology and results, as well as concluding remarks and suggestions for future work.

The ASTER DEM was selected over coarser resolution data like the SRTM 90 m and proved very useful. With regards to the spatial resolution, the finest DEM available was selected since the topographic features in the mountainous areas could get amalgamated in a coarse DEM. There was not a need to acquire a DEM finer than the 30 m ASTER, especially since case studies like Doyle, Garrison, and Houston (2012), demonstrate a lack of significant variation among paths generated from DEMs of 30 m and finer.

With regards to data accuracy, this ASTER DEM is the GDEM V2 which features many corrections for the voids in its predecessor and exhibits an absolute vertical accuracy of 0.20 m on average (ASTER GDEM Validation Team, 2011). Water masking and incorporation of new data acquisition played a pivotal role in reducing and eliminating voids brought on by cloud control. The voids are most significant at high latitudes with data anomalies and poor coverage, but were irrelevant to the success of this particular project. Despite these corrections, there are possible problems that may have gone undetected without the possibility of discovery beforehand.

The data, available for free, was downloaded via a unique extent box based on user input. Since most services provide downloadable tiles, this skipped several potential preparation steps like mosaicking all the tiles together. Furthermore, the vendor allowed for UTM (best for distance analyses) export upon download and thus the opportunity to skip one or more tedious re-projection steps. Lastly, the computational speed of conducting the analysis was not held back in any way by the spatial resolution.

Plotting the origin/destination points in individual feature classes using a feature class template could have been slightly faster. Later in the analysis, all points could have been merged together for statistical analysis after the ACS values were extracted to each point. The preference of initially having one global feature class with all points proved convenient, however, especially for generating the cartography used throughout the documentation process.

The specific point locations plotted are subject to error, especially those that pertained to the known passes. Specifically, the “Belen West”, “Beach West” and Nurdagi points were subject to bias. Since the tool is most relevant in areas of high topographic diversity, the points were intended to be placed adjacent to the foothills. The existing routes however, do not have a significant points of origin/destination in either foothill (with the exception, perhaps, of the D825-D817 Interchange). Therefore, the placement of these points was left to user preference of perceived origin/destination locations. Furthermore, the placement of each point in both the sensitivity analyses and the comparative validity tests could have been adjusted to more statistically significant intervals. The point distribution in the sensitivity analysis would have been more appropriately placed at thresholds based on the cell size (30 m). For instance, the points could have been placed 300 m north and south for 10 cells in either direction. In the comparative analysis, the percentage of validity within 250 m would have been greatly increased had the placement of the origin and destination points been placed at the end of the switchbacks in the foothills.

Given the topographically diverse landscape, LCA was an appropriate choice for modeling some important behavioral questions related to MBA-LBA merchant travel. Upon undertaking this LCA, the original desire was to conduct a robust analysis of one or more different algorithmic applications, intended for modeling time and energy minimization routes.

The implementation of an energy expenditure model is contingent on several factors that did not align. Since the merchant travel featured donkey (*equus asinus*)-led caravans, empirical data of energy expenditure per degree slope, while incorporating the added cargo weight, were required. Fortunately, two studies provide such work. Dijkman (1992) provides empirical data for this exact request, but only at select negative gradients (0%, -10%, and -15%). Additionally, Mueller et al. (1994) provides oxygen consumption and wattage rates produced on a treadmill with varying load weights, but only at 10% slope. To produce an algorithm suitable for an LCA, one would first need to consolidate the findings of both works with a slope-based equation that fits that data and minimizes energy consumption. Next, that formula would have to be inverted (similar to the inverse of Tobler's hiking function employed in Tripcevich (2009)) in order to match up with the slope input. Lastly, that inverted function would be used to generate a vertical factor table to be implemented in the Path Distance tool. Further evaluating the implementation of energy expenditure as the primary cost, Herzog (2014a) highlights several variables to consider, as well as the required consideration of the limitations of human walkers of these caravans. Such variables include: (1) varying load weights; (2) sex, age and height/weight of animals and walkers; (3) a subjective state of physical fitness of human walkers; (4) the climate and conditions of the physical landscape; and (5) velocity.

LCAs based on time are quite applicable to those in an archaeological setting. As Livingood (2012) notes, throughout history, there have been more devices to measure time than distance or energy expenditure—for instance, the movement of the sun and time-pieces (Montello 1997). Furthermore, Livingood (2012) cites Malaysian and Siberian practices in which distances were described in units of time—for instance, the distance one can travel on reindeer-back in one day, “as far as a gunshot can be heard,” “the distance covered by a day’s walk,” and “the distance you can travel before your hair dries.” Lastly, Livingood (2012) cites Harrison’s (2007) findings of the Sherpa and Vantawa Rai people of mountainous Nepal, whose maps and language emphasize vertical profiling as the primary indicator of travel time and effort.

As shown in Figures 22 and 23, a study-area wide Path Distance execution could have been implemented to illuminate probable paths in a more streamlined approach.

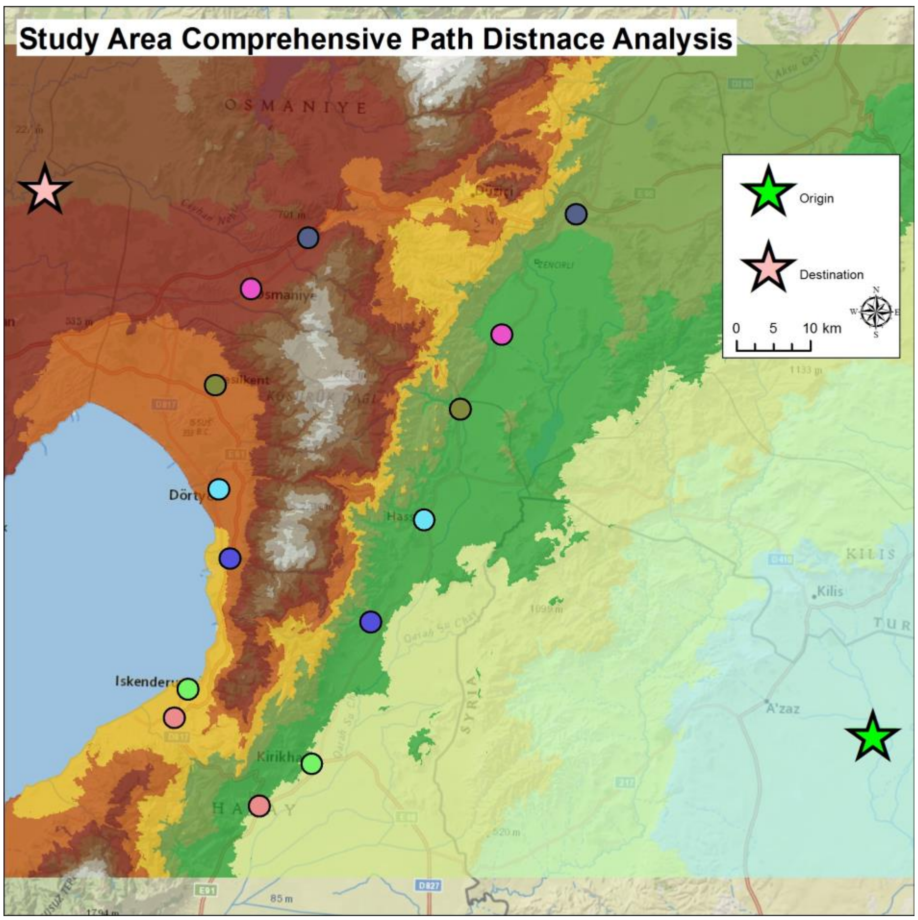

Figure 23 ACS of entire study area from east to west

With regards to the specific methodology employed in this LCA, the primary aspect that could be reevaluated is the element of starting with preconceived origin/destination points and building out unique LCPs. The corridor that Path Number 3 exploited is visible between the Belen Pass points and the corridor that Paths 4 and 5 shared is prominently defined as well.

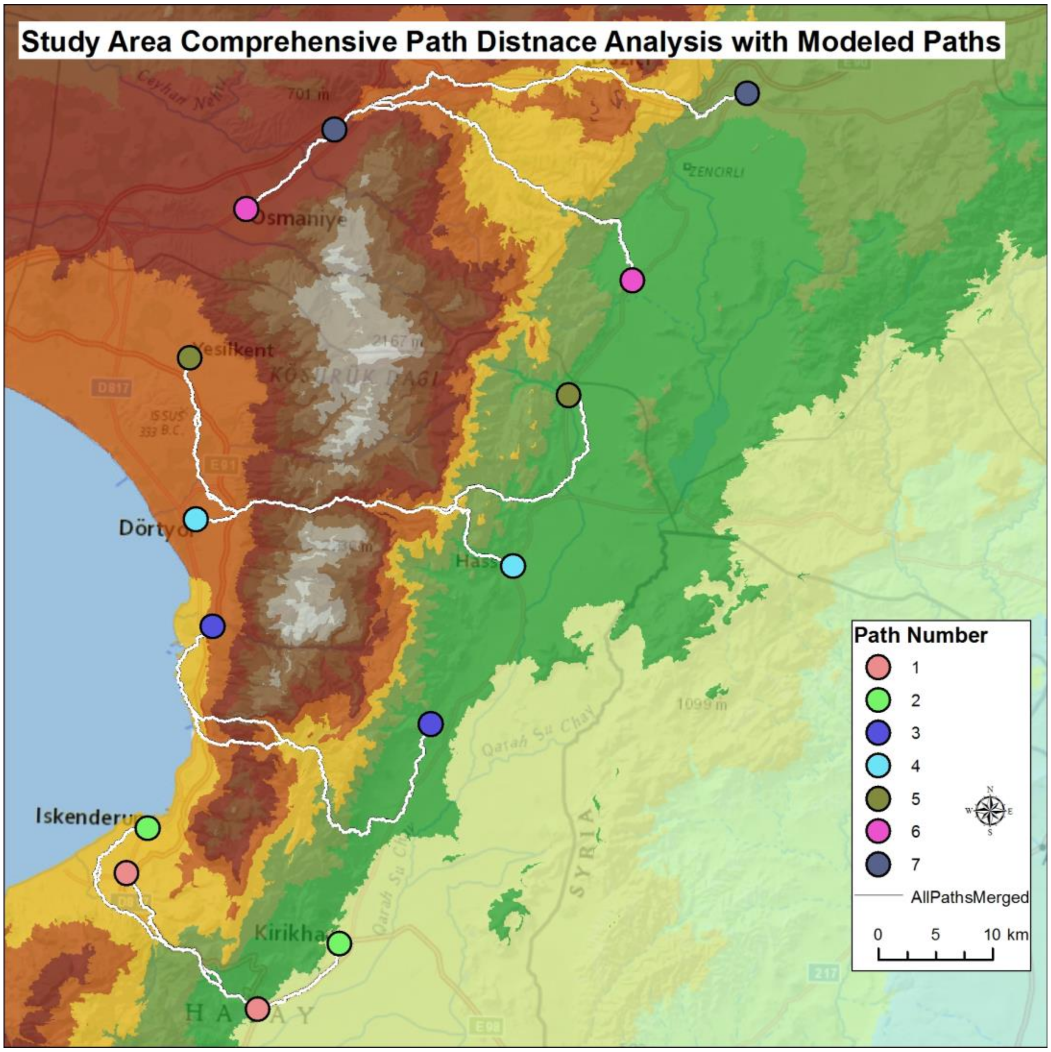

Figure 24 ACS of study area from east to west with previously modeled LCPs

Considering the spatial resolution of the DEM that is chosen, this exploratory analysis would be a very useful first step. Of course, if the spatial resolution was finer (e.g. < 10 m), the analysis would be very time consuming. If applicable, however, several points would not necessarily need to be mapped. This is because the significant variation between, for instance, Paths 4 and 5, exist in the Amuq Valley to the east and in the Cilician Plain to the west (Figure 23). This land was more accessible and susceptible to continued anthropogenic effects on topography for millennia. Therefore, the results of modeled paths in these specific areas are not as valuable as those in the mountainous areas.

An additional problem encountered was the introduction of bias over the "Current Display Extent" environment utilized for the data subject to the Path Distance analysis. Originally, this was intended to maximize processing time and to eliminate any additional strain on the once finicky Path Distance tool. This strategy was also implemented in order to force routes across the mountains and not back through the known passes. It should be noted that since using the exploratory analysis would eliminate redundant paths, this bias might not be relevant since the corridors would have been identified. If an analyst wanted to estimate a travel time between locations farther within the Amuq Valley and Cilician Plain through a specific corridor, he/she would have two primary options. He/she could either simply mask out the other passes or add an additional route from each point in the foothills of the corridor to the respective extended areas eastward/westward.

Lastly, there were significant inhibitions presented in the form of software malfunctions. The original intent was to utilize the GRASS r.walk function. This function is noted as more accurate than other algorithms since it includes knights-moves (similar to a chess board) when calculating an ACS (Herzog 2013c). Unfortunately, executing the analysis in GRASS would have involved substantial startup costs for the work at hand due to the lack of familiarity with the toolbox as a whole. Preceding the execution of this LCA, there had been many reports of difficulties with the Path Distance tool among Esri users of the ArcMap Desktop (https://geonet.esri.com/thread/108931). These reports also suggested that the newly released ArcGIS Pro is quite reliable in analyzing anisotropic costs via the Path Distance tool. The only hiccup was that ArcGIS Pro was not Windows 10 certified at the time of this project. Expediting the utilization of the program using Windows 10 was achieved after testing different Windows 10 machines. The first was a custom PC with an Intel i5 CPU, 32-bit OS, 16 GB installed RAM, previously upgraded from Windows 8.1. The second machine was an HP Spectre x360 Convertible with an Intel i7 CPU @ 2.4 GHz, 64-bit OS, and 8 GB installed RAM. Finally, ArcGIS Pro 1.1 was able to run consistently on the third machine: an HP 23-m210qd with an Intel i5 CPU @ 2.9 GHz, 64-bit OS, and 12 GB installed RAM and the results reported in this thesis were developed on top of this computing (i.e. hardware/software) platform.

Despite the identified areas of potential improvement, this project was overall very successful. The effective demonstration of the Path Distance tool provides a framework for further LCA. The implementation of Tobler's Hiking Function illuminated corridors across the Amanus Mountains that were identified as likely routes for merchant travel. In light of the successful modeling, archaeologists will be able to more prudently allocate resources and utilize these results to support field research in the future.

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