TRAVERSING THE TERRAIN: A LEAST-COST ANALYSIS ON INTERSITE CAUSEWAYS IN THE MAYA REGION

by:

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ABSTRACT

The study of ancient Maya causeways is crucial for understanding Maya social and spatial organization. Archaeologists have been interested in Maya causeways for decades, specifically documenting their locations. More recently, the use of Geographic Information Systems, or GIS, has been used for understanding the spatial organization of archaeological sites. GIS analyses on ancient Maya causeways however have been very limited. This thesis aims to evaluate ancient Maya causeways through GIS analysis. Specifically, five intersite causeway systems are looked at: the Mirador Basin, Yaxuna-Coba-Ixil, Uxmal-Nohpat-Kabah, Ake-Izamal-Kantunil, and Uci-Kancab-Ukana- Cansahcab. These causeway systems were evaluated using least-cost paths based on the terrain. In this thesis, I argue that the intersite causeways do not follow a least-cost path based on terrain and that the purpose of these roads varies between sites and regions.

Dedicated to the memories of John A. Hart and PFC Jalfred D. Vaquerano

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CHAPTER 1: INTRODUCTION

Studies of causeway, or *sacbeob* ("white roads" in Maya), systems in the Maya region have been very important for understanding social, spatial, and political organization. Questions such as "why were causeways built?" and "what role or function does the causeway perform in Maya society?" have been continuously investigated. As an important archaeological feature, causeways also inform archaeologists on how travelers move across a landscape, whether it is for economic, political, or ritualistic purposes. Understanding mobility in the archaeological record includes physical interaction between people, interaction between different socioeconomic classes, and access, or lack thereof, to restricted areas. This perspective on mobility has not been heavily researched among Maya archaeologists (Richards-Rissetto and Landau 2014: 366).

Mobility can be very difficult to document in the archaeological record, so hypothetical paths are used many times to make assumptions. One way this is done is through the use of Geographic Information Systems, or GIS. GIS analyses allow for the integration of software and data for evaluating and displaying geographic information in a digitized format. Maps can be manipulated, created, and displayed using a GIS- and this has been increasingly beneficial for archaeologists. For understanding movement, least-cost path analyses in a GIS can be very useful. Least-cost paths are hypothetical paths created by the user; with the right data, research questions, and software, they can provide archaeological interpretations (see Surface-Evans and White 2012). Because Maya causeways are a physical expression of movement that can be seen and quantified, researchers are at least able to conclude that mobility took place among these roads. However, researchers still disagree as to why some of these causeways were built.

Contrasting least-cost paths with causeways can help determine or debunk hypotheses on why specific causeways were built.

This thesis studies Maya intersite causeways, as well as least-cost path analysis. Intersite causeways are the longest among ancient Maya roads most of them found in the Yucatan (see Figure 1). The research question that this study addresses is: Do Maya intersite causeways follow a least-cost path based on terrain? To answer this question, the intersite causeways are compared with least-cost paths to determine if their routes differ. I argue that intersite causeway systems do not follow a least-cost path in terms of the terrain. For the most part, causeways follow relative straight and direct lines and were built for many purposes. Avoiding the terrain between two centers was not one of them. In the conclusion, I speculate on why this is, implying that causeways were used for political integration and economic purposes.

An understanding of energetics and the increased cost it would take to build causeways to travel cost paths based on the terrain is also helpful for understanding why these routes were primarily used for political integration and economic purposes. Architectural energetics represents one of the best ways possible for archaeologists to make inferences about patterned human behavior from the structures themselves (Abrams and Bolland 1999: 267). It is clear that some regions may have used these roads for ritual purposes, such as at Uxmal-Nohpat-Kabah, but a comparison of artifactual remains between the termini is also necessary to understand the purposes of these causeways, but much of this has not been done. Although this study does not calculate the labor-time investments used in energetics, it still uses some of the basic concepts to interpret why some of these causeways follow specific routes.

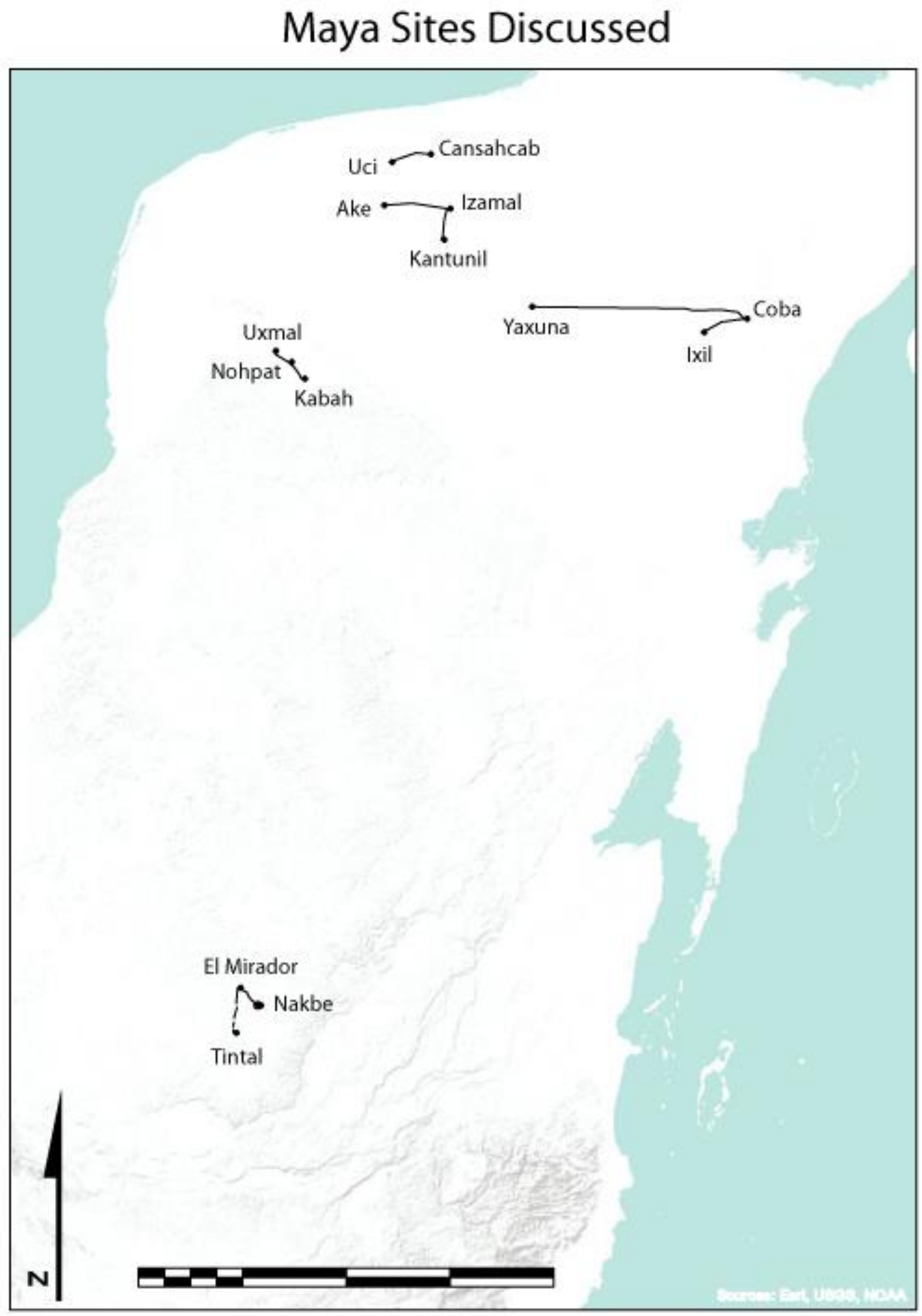

Figure 1: Map of Maya sites with intersite causeways evaluated in this thesis.

Chapter two discusses the background information on causeway research. It begins with an overview of previous scholarship on Maya causeways. Descriptions of what causeways are and of their potential functions are then provided. An archaeological and anthropological discussion of road theory in the New World is then discussed, as this is necessary for understanding Maya causeways. The chapter ends with background information and previous scholarship on GIS, energetics, and least-cost analyses. Chapter three gives an overview of the sites with the intersite causeways systems that are the focus of this research. Specifically, the background on the social organization, cultural ecology, and economic and political integration pf these road systems is reviewed. Chapter four explains in greater detail how the least-cost path analyses were conducted. This includes the type of spatial imagery and software used, the variables inputted to conduct the analyses, and how the actual data, or site locations, were obtained. Chapter five presents the results of the least-cost analyses, as well as the maps that were produced. Chapter six ends with a discussion and conclusion of the analyses, as well as possible avenues for future research.

CHAPTER 2: BACKGROUND INFORMATION ON CAUSEWAYS

This thesis gives attention to many different archaeological and anthropological studies on Maya social organization and road systems. To answer the research question on why Maya causeways were built, previous research on Maya causeways must first be considered. An understanding of the physical construction, form, and function of sacbeob is then presented. Because this thesis undertakes a GIS analysis of cost-paths, a review of GIS and cost-path studies in the Maya region is conducted. This section concludes with the larger theoretical framework of landscape theory relative to these road systems in archaeology and anthropology.

Previous Research on Maya Causeways

Initial work and documentation of Maya causeways was done through surveys and mapping, after accompanied by excavations of sections of the roads for profile views. Early efforts for the analysis of Maya sacbeob began with the expeditions of the Carnegie Institution of Washington (C.I.W). The Yaxuna-Coba causeway was of particular interest to the C.I.W. Thomas Gann (1926) wrote about the site of Coba, noting that a long causeway to the west of the site. J.E.S Thompson and his colleagues (1932) visited the site after Gann and correctly predicted that Causeway 1 at Yaxuna leads to the site of Coba. In 1933, Alfonso Villa Rojas (1934) finally conducted a more complete analysis of the causeway, and also hypothesized about the function and meaning of this causeway.

From the 1960s through the 1980s there was resurgence in sacbeob studies. Antonio Bustillos Carrillo (1964) synthesized Yucatec causeways as a class of architectural features, detailing many of the causeways. Silva Garza Terrazona de Gonzalez and Edward Kurjack

(1980) also began the Archaeological Atlas of the Yucatan project, in which a large scale systematic survey was conducted in the Yucatan peninsula. Ruben Maldonado Cardenas (1979a, 1979b) also analyzed the Izamal-Ake and Uci-Cansahcab intersite causeways. David Freidel and Jeremy Sabloff (1984) also wrote on the causeways on Cozumel.

In the edited volume *Ancient Road Networks and Settlement Hierarchies in the New World* by Charles D. Trombold (1991), researchers examined road systems in North, Central, and South America, including theoretical and methodological discussions and site specific analyses. Trombold also introduced the idea of "landscape archaeology" in the first chapter; this will be discussed in further detail later in this chapter. William J. Folan (1991) wrote a chapter in this edited book on sacbeob in the Maya region, outlining their form and possible functions, using Coba as his primary case study.

More recently, sacbeob have been incorporated into the understanding of spatial and social organization of Maya sites (Chase and Chase 2001; Cobos and Winemiller 2001; Shaw 2001). Justine Shaw (2008) has written extensively on the role of sacbeob in Maya society and also conducted her own excavations on causeways in the Yucatan. The use of remote sensing technologies for documenting and surveying roads has also been a very recent development. The site of Caracol, Belize for example has been mapped using LiDAR, which has uncovered many archaeological features, including buildings, terraces, caves, and causeways (Chase et al. 2013).

Form and Function of Maya Causeways

Ancient Maya causeways (also known as *sacbe* or *sacbeob* for plural) have been found throughout the entire Maya region. *Sacbe* is a Yucatec Maya word that can be broken into two morphemes, '*sac'* and '*be'*. '*Sac*' for the most part can be translated into 'white', with some variations including ‘clean’, ‘artificial’ and other English words as secondary translations. ‘*Be*’ for the most part is translated as ‘road’ with secondary meanings including ‘trail’, ‘destiny’, or ‘path’. Other ways of spelling ‘*sacbe*’ are also used, such as ‘*sakbeh*’ and ‘*sakbih*’. Bolles and Folan (2001) have also researched the linguistic aspects of Maya roads, specifically regarding Colonial period usage. Bolles and Follan (2001: 299) acknowledge that that sacbe became the preferred Yucatec Mayan term for these words in the late 1800s, which may have affected its usage as the primary word for causeways; this may not have been the case in pre-Columbian times.

Trombold (1991: 3) states that roads generally have three basic characteristics: a definable width, a more than casual construction, and a defined linear form or a failure to deviate due to the topographic environment. Maya sacbeob follow these general characteristics. Ancient Maya causeways were initially constructed by placing retaining walls designed to contain interior fill. The retaining walls were composed of cut or uncut stones, depending on the section of the causeway being examined. The interior fill was usually composed of boulder fill with gravel and pebbles and *sascab*, or powdered limestone. A final lime plaster was put on the surface to provide a final concrete capping. Variation of this style of sacbeob does exsist, as well as evidence for resurfacing and modifications (Shaw 2008: 64-67).

The argued functions for causeways vary for different sites. Some functions may have occurred throughout the Maya area, specifically practical transportation access. Providing a transportation route through difficult terrain and providing a means to transport a variety of goods through these difficult terrains may have served as the main reason for causeways (Shaw 2008: 106) Long intersite causeways may have been useful for practical transport, with shorter causeways useful for practical transport through densely populated areas. Increasing practicality and ease of transport was particularly important for economic exchange. Other economic functions may have been more site specific. At Muyil and Xelha, some causeways were used to connect settlements to lagoons (Shaw 2008: 107). The dendritic causeway system at Caracol served a primarily administrative, political, and economic function (Chase and Chase 2001). The causeway termini that connect to Caracol's epicenter were likely economic distribution points, and the road system was use to facilitate and manage exchange between the two areas.

The political functions of causeways serve similar roles to its economic functions. The causeways at Chichen Itza may have first served to facilitate economic exchange, with an increasing dendritic system of sacbeob serving the political and ritual functions of a centralized government. Some polities may have used their intersite causeways for boundary maintenance. This has been argued for the Izamal-Ake and the Uci-Cansahcab causeway systems (Kurjack and Andrews V 1976). This will be discussed in greater detail in the next chapter.

Causeways also served a ritual and symbolic function for many sites. Some researchers argue that many Maya centers were arranged to express statements about cosmology as well as political order. Maya concepts of directionality were many times emulated through civic architecture (Ashmore 1991; Ashmore and Sabloff 2002). Since causeways are integrated in civic centers, some of them may reflect statements of cosmology as well. Dunning (1992: 147-148) argues that the intersite causeway system of Uxmal-Nohpat-Kabah recreated the celestial serpent on the landscape. The sacbeob at Cozumel connected temples to household shrines (Freidel and Sabloff 1984). There is also an association with dieties and causeways in Maya iconography. The goddess Ix Chel is considered the guardian of mythological personages associated with causeways. Ix Zac Beliz, translated into "She Who Walks the White Road," is the maternal grandmother of the god Chac, who is being carried by Ix Chel walking on a raised road in a mural at Tulum (Bolles and Folan 2001: 309). At Coba, Ix Chebel Yax and Itzam Na are related to sacbeob associated with water. Bolles and Folan also mention a mythical passage route between the Cenote Sagrado and the Cenote X-Toloc that passes underneath the Temple of Kukulcan at Chichen Itza, Mexico. This may also be a physical manifestation, as a sacbe connects the Temple of the High Priest's Grave, which has depictions of Kukulcan, with the Cenote X-Toloc (Bolles and Folan 2001: 310).

Justine Shaw also defines three major types of sacbeob based on language, form, and system variability. This typology created by Shaw will be used to understand the causeways in this thesis, specifically those based on form and system variability.

Shaw uses a tripartite typology for causeways based on form that is specifically based on length; causeways may be local intrasite, core-outlier, and intersite. Local intrasite *sacbeob* are the most common and found throughout the Maya region. Local intrasite causeways run for less than one kilometer and constitute about 78 percent of causeways that have been recorded (Shaw 2008: 85). These causeways tend to be found in the epicenters and urban cores of Maya sites. Core-outlier causeways connect architectural groups and features to the core or epicenter of a Maya site. These causeways may be as long as intersite causeways, but are not classified as such because they are still outliers connecting to a central group. Core-outlier causeways occur in less frequency than local intrasite, but in greater frequency than intersite.

Intersite causeways are the longest among the ancient Maya at about 5 kilometers or longer. Intersite causeways extend very far from the site core, often with settlement densities lowering towards the outskirts (Shaw 2008:89). They have been mostly found in the Yucatan, with Caracol and El Mirador in the central and southern Lowlands classified as intersite causeways. Caracol may have causeways the length of those classified as intersite, but still follows a dendritic system type. This is because Caracol follows the classification of a low-density agrarian city (Chase et al. 2011; Fletcher 2009). El Mirador does have intersite causeways, but it may also be found to follow a dendritic system with more research in the Mirador Basin (discussed in the next chapter). Other intersite causeways may have also been utilized prior to modern developments. A possible causeway running over 300 kilometers long has been proposed in the northern Yucatan running from Ichcantiho to Puerto Morelos (Shaw 2008: 90). Modern development, railroad construction, and poor preservation may have erased most of the evidence of this possible sacbe. In fact, Shaw also proposed that many of these long intersite causeways may have been destroyed or been used as the basis for historic roads and railways (Shaw 2008: 90).

Another classification system for causeways is based on system variability. This typology is used for sites with multiple causeways and characterizes their spatial layout. The four basic systems are linear, cruciform, radial/solar, and dendritic. Many of these causeway systems initially take the form of one type of system and then change throughout time. Coba, for example, has a dendritic system at its urban core, but a linear intersite system is created with sacbeob leading to Yaxuna and Ixil. Additionally, many sites may actually have more complex causeway systems than are currently visible, due to variable preservation and modern impacts in the Maya area. The typology based on system variability can be used to understand hierarchical and nonhierarchical groups, as well as the cosmological landscape of different sites. Sacbe system variability can provide a more specific function of the causeways than describing them as local intrasite, core-outlier, or intersite.

Linear causeway systems tend to connect architectural groups of similar scale, and tend to show equal relationships between the groups. Most linear causeway systems are local intrasite, connecting groups within an urban core. Shaw considers the Uxmal-Nohpat-Kabah causeway as a large-scale version of a linear system (Shaw 2008: 97). This thesis evaluates the intersite causeways used for the cost-path analysis as linear systems (except for perhaps El Mirador), even though they might not show homogenous relationships.

Other causeways follow a cruciform system, with four or three roads radiating from a central location, all having ceremonial or cosmological significance. This pattern possibly relates to the path of the sun, as well as to cardinal directions, and may be related to the quincunx and the axis mundi, or a quadripartite concept. The site of Yaxhom has a cruciform system type for example, and the central architectural group is interpreted as civic-ceremonial architecture. At the site of T'isil the center of the cruciform system is a cenote, clearly implying ceremonial purposes. At Seibal, the central architectural unit is at a lower elevation than the termini of the causeways; Dunning (1992) sees this center as possibly being a representation of the underworld. The Formative period local intrasite causeways at Yaxuna also follow a variation of a cruciform system and were used to primarily to define sacred space (Stanton and Freidel 2005: 227).

The next two causeway system types are the most complex: radial/solar system and dendritic system types. Radial sacbe systems radiate from a central location similar to cruciform causeway systems, except that these urban centers tend to have more than four causeways and do not follow a possible cosmological or cardinal route. The site of Ichcantiho (Merida) may have followed a radial system, although, much of the causeway system may have been destroyed due to post-conquest development (Shaw 2008: 101).

Similar to radial causeway systems, dendritic systems also have arranged causeways in multiple directions leading to a site core. The difference between the two types is that dendritic systems have causeways leading to architectural groups and different distance intervals or concentric rings. The dendritic causeway system at Caracol, Belize exhibits this pattern with two general distances of 2.7-3.0 km and at 4.5-7.5 (or 9.5) km. The shorter causeways may have served for local exchange, as well as administrative and social functions. The longer causeways may have connected previous urban areas into that became part of the polity of Caracol in later years (Shaw 2008: 102). The causeways of Chichen Itza similarly exhibit a dendritic causeway system with causeway termini ending at different concentric ring intervals (Cobos and Winemiller 2001).

Landscape Archaeology and Road Theory

Road systems in the Pre-Columbian Americas gained interest with an edited volume by Charles Trombold, in which archaeologists began to use landscape archaeology to understand ancient roads. Trombold (1991: 1) defines landscape archaeology as "the study of civilization's imprint on or modification of the natural environment." Roads are a mode of adaptation to the environment, but they force the environment itself to change. Roads are also representative of cultural values, since intensive labor investments, including construction, engineering, and maintenance, are required to connect at least two termini. A road system then becomes a preferred mode of transportation for a group of people [or a selective group of people].

Historical approaches to the construction of roads are problematic due to limited reliable historical documents and accounts. Functional approaches are more appropriate, but they may not provide the proper emic view of the purpose of the road, as this approach may be based on our understanding of economics. The economic and political reasons behind road systems need to be first explained through transportation mechanics. Roads selectively create ties between specific areas, which is done through conscious decision making. Ross Hassig (1991: 19) proposes three factors that affect why New World roads were built: road linkages, road construction and its transportation system, and the size of the roads.

Road linkages put a focus on termini locations, as well as the settled communities and regions surrounding them. The road then alters the social situation of the area, whether it is political, economic, or ritual. Types of travel on a road also affect the construction of the road. Roads designed for wheeled vehicles and pack animals favor long and gentle routes, usually avoiding topographical issues. Without wheeled vehicles and pack animals, the Maya constructed their roads for human foot travel, which emphasizes directness of a route, whether it is tough terrain or not, over ease of travel. The construction of roads over harsher rugged terrain and weather conditions signifies large labor investments, which are usually controlled by complex, urban centers and cities. The same goes for road modification and maintenance; continual construction on any road strengthens the ties that the road facilitates as well as the centralized polity controlling it. Understanding road size allows researchers to determine the traffic volume of people and goods. More specifically, topographic obstacles and road usage determines the size of the roads (Hassig 1991: 19-24). These perspectives, however, focus on economic and political function; in the case of the Maya, causeways also performed a ritual function.

The use of the "aerial perspective," as Trombold (1991: 7) describes has also been important in the history of the study of road systems and landscape. Its initial usability was discovered by O.G.S Crawford during World War II, when distinctive patterns were seen from the air that was not visible from the ground (Crawford 1929). Aerial survey and photography then became popular in archaeology in European and New World studies. Aerial photography has been specifically resourceful for interpreting low-relief features and for areas that are not obscured by vegetation. Aerial photography is great for areas with low vegetation, as is the case in the northwest Yucatan. Kurjack and Andrews V (1976), for example, were able to use aerial photography to survey areas in the northwest Yucatan; these images aided in the identification of causeways connecting large centers to satellite communities or minor centers. Their study also showed that aerial photography not only aides in identifying features, but also enables the interpretations of political organization, as well as an understanding the settlement patterns of a given region. The aerial perspective has also influenced other techniques, specifically the use of digital remote sensing. Digital remote sensing is particularly useful in extreme environmental conditions, including arid regions and tropical rainforests. The SRTM and ASTER Digital Elevation Models used in this thesis are examples of this technique; they will be discussed in further detail in Chapter 4. More recently, the use of LiDAR, another remote-sensing technique, has shown great promise in improving archaeological survey through the aerial perspective. LiDAR used at Caracol, Belize gives a resolution of the landscape of under 1 meter (Chase et al. 2012, 2013). LiDAR, short for "light detection and ranging", produces point cloud data which in turn can be transformed into high resolution DEMs. This allows a more complete image of the landscape and has the ability to transform archaeological survey methods in the Maya region. Different resolution in spatial data also affects the output of GIS analyses, in this case the least-cost paths.

Architectural Energetics

Architectural energetics is a method of quantifying buildings or building episodes in terms of cost (Abrams and Bolland 1999: 264). Cost in this case is the same as expenditure of human energy in terms of person-days or person-hours and this unit of measurement is used to comparatively assess power or status in archaeological terms. Cost in architectural energetics must be regarded as an estimate since it is based on inferred behaviors. What is required to conduct these analyses is a general knowledge of the elements of the building itself and an identification of the major activities responsible for those elements (Abrams and Bollard 1999: 267).

Using architectural energetics may also be used to analyze social power in terms of differential access to human labor force. Expansion and emergence of new societal institutions and polities requires the construction of new architecture, and the scale and complexity of new types of architecture may also reflect the scale and complexity of the new polities. Ancient Maya intersite causeways are new architectural forms that represent emerging and expansive societal institutions.

Least-Cost Analyses

Human travel must walk through and deal with terrain features such as slope, vegetation, and waterways (Anderson 2012: 240).Humans also do not always take optimal routes for their travel and destinations. The availability of resources also affects the purpose for travel in a specific route, as well as the location of other people, sacred areas, and even serves to reinforce status (Anderson 2012: 241). Cost path analyses rarely result in straight line paths, and they vary greatly with difficult terrain. Least-cost path analyses allow for the possibility of discovering routes taken by humans in terms of efficiency and rationality. These hypothetical routes could possibly lead to new archaeological sites and features. When partial routes are discovered, cost path analysis can be used to determine the missing extensions of the route.

Least-cost analysis is a relatively new tool used in archaeology. Least-cost pathways are the assumption that humans will economize aspects of their behavior and limit the costs of traveling across a landscape (Surface-Evans and White 2012: 2). Thus, when cost increases in a specified area, the likelihood of travel to that area decreases, as does interaction in the area. When paths are known to be of least-cost, then archaeologists are able to hypothesize networks of travel, as well as estimate other locations where paths, trails, or roads may occur. When conducting a least-cost path analysis through GIS software, the problem that the cost path addresses is how to get from point A to point B in the most efficient, or least-cost, way possible. The two most important aspects to consider when performing a cost path analysis is travel direction and distance accumulation.

In order to use least-cost analyses for archaeological data, four general considerations should be taken in to account: (1) which variables are necessary to include in the model; (2)

which type of data will be needed; (3) how cost will be measured; and (4) which software tool will be used (Surface-Evans and White 2012: 4). These four considerations will be discussed more in chapter 4.

There are issues with least-cost analyses that must also be acknowledged. Least-cost paths are idealized paths of least effort; and may not reflect actual ancient paths. Comparing them with actual roads, such as what this thesis is doing, can solve this issue if the cost paths follow the same routes of the roads. Least-cost paths also assume that those traveling have a perfect knowledge of the landscape, allowing them to take the most efficient route. Travelers do not always know the most efficient route or all of the possible routes available to them. Travelers also do not always travel in the most efficient manner; they sometimes travel on simply a satisficing route. Spatial data also affects the outcome of a least-cost pathway, such as using different resolutions of Digital Elevation Models (DEMs) in LiDAR or SRTM (Branting 2012).

GIS and Least-Cost Analyses in the Maya Area

The use of GIS as a tool in archaeology has gained prominence over the years, especially due to the decreasing cost of computer software and the availability of geospatial data. This has allowed for more elaborate models and sophisticated questions on human behavior to be asked (Surface-Evans and White 2012). GIS analysis in the Maya region has very recently gotten more attention. Chase and Chase (2001) used LANDSAT data to interpret the causeway system at Caracol, Belize at a large scale. Thomas L. Sever and Daniel E. Irwin (2003) wrote on using remote sensing data for landscape archaeology in the Peten. Their goal was to investigate large-scale landscape modifications using remote-sensing, GIS, and GPS, as well as using the imagery for detecting unrecorded archaeological features (Sever and Irwin 2003: 113).

The use of the SRTM and the ASTER DEM's are of particular interest for this thesis. Doyle et al. (2012) applied cost-surface analysis to understand travel and exchange in the Buenavista Valley Corridor, specifically cost-path and viewshed analysis. Charles Golden and Bryce Davenport (2013) used these images, as well as AirSAR, for conducting viewshed and cost-path analyses in the Western Maya Lowlands (2013). Golden and Davenport (2013: 145) argue that the construction of political power and authority in Classic Maya kingdoms occurred through control of movement and vistas across the landscape. Other Maya archaeologists have used cost path analyses in their research as well.

For the site of La Corona, Guatemala, archaeologists developed a least-cost path model to determine a Calakmul-La Corona-Cancuen trade route (Canuto and Barrientos 2013). They used a least-cost path model developed from the SRTM 90-meter DEM. For cost, the archaeologists used speed of travel, or travel time. The results showed that the least-cost route followed a route that was important to known allied sites in the southern Lowlands. This possible royal route however was most likely not formed by a constructed road, or sacbe (Canuto and Barrientos 2013:2). Heather Richards-Rissetto and Kristin Landau (2014) have also conducted cost path analyses in the Maya area at Copan, Honduras. They used least-cost analysis to measure social integration between four groups in the urban core at Copan, Honduras. Instead of looking for travel routes, the researchers calculated average travel time to and from specific locations to measure social interaction (Richards-Rissetto and Landau 2014: 368). Four surfaces were created to create the cost paths: a friction surface to represent the difficulty to cross a cell; a speed surface determining speed across a cell; a travel cost surface; and a minimum accumulated cost surface to determine cost from a start location to a destination (Richards-Rissetto and Landau 2014: 368-369). Their results showed that mobility among architectural groups suggests heterarchical relationships of a middle class within a larger hierarchical polity. Thus, movement across the urban core is related to social status. The research conducted by Richards-Rissetto and Landau differs from the cost paths created in this thesis in that the routes focus on long-distance interactions rather than focusing on an urban center.

CHAPTER 3: SITES WITH INTERSITE CAUSEWAYS

This chapter provides an overview on the sites with intersite causeway systems. Justine Shaw (2008: 173) lists other sites to have intersite causeways. However, many of these causeways have not been ground-truthed or actually follow a different form. The proposed Calakmul-El Mirador causeway, for example, has not been ground-truthed. The Caracol and Chichen Itza systems follow a dendritic causeway system, not a linear intersite system that the sites in this thesis follow.

The causeway system in the Mirador Basin is an anomaly compared to the other intersite causeways. The research conducted in the Mirador Basin has not focused on spatial organization, and the causeway system might actually follow a dendritic form. Still, the research in the Mirador Basin, as well as at Coba-Yaxuna, and in the Puuc region, or Uxmal, have been very well studied and researched for a few decades. The regions and sites of Izamal-Ake and Uci-Kancab-Cansahcab, however, does not have the longevity of research as the other sites, but much can still be said about these causeways.

The Mirador Basin

Research in El Mirador Basin began with the CIW with the identification of the site of El Mirador (Ruppert and Denison 1943:49). Site maps of El Mirador and Nakbe were produced in the 1960s by Ian Graham (Graham 1967). Excavations began in the 1970s and 1980s with Ray Matheny, Bruce Dahlin, and the New World Archaeological Foundation (Matheny 1980). These excavations, however, did not contribute data on other sites in the Mirador Basin. It wasn’t until the work by Richard Hansen and the Regional Archaeological Investigation of the North Peten, Guatemala (UCLA RAINPEG) that excavations and survey have been conducted continuously in the Mirador Basin (Hansen 2012).

The Mirador Basin is located in the north-central area of the Peten in Guatemala, and overlaps into the Campeche region of Mexico. The Basin currently consists of seasonal swamps, or *bajos,* with soils of poor to medium fertility compared to the soils outside of the basin (Hansen: 2012:141-42). The landscape may initially have been perennial wetlands and shallow lakes, but were eventually transformed into seasonal swamps by its inhabitants (Hansen et al. 2002).

The Mirador Basin in Guatemala contained perhaps the earliest Maya kingdom in the Preclassic Period. Early Maya studies viewed the Preclassic Period as the era before the great construction efforts, stratified societies, and ritual florescence. The discovery and excavations of large sites such as El Mirador, Cival, Nohmul, and San Bartolo changed the theories on the origins of Maya civilizations. These sites showed evidence of large centers during the Late Preclassic period (Estrada-Belli 2011:52). El Mirador specifically exhibits the largest complexes known in the Maya area, as well as having causeways connecting to the centers of Tintal and Nakbe (see Figure 1). El Mirador is considered by some to be the first Maya state and the rise of kingship began here in the Early Middle Preclassic with the site of Nakbe (Hansen and Guenter 2005).

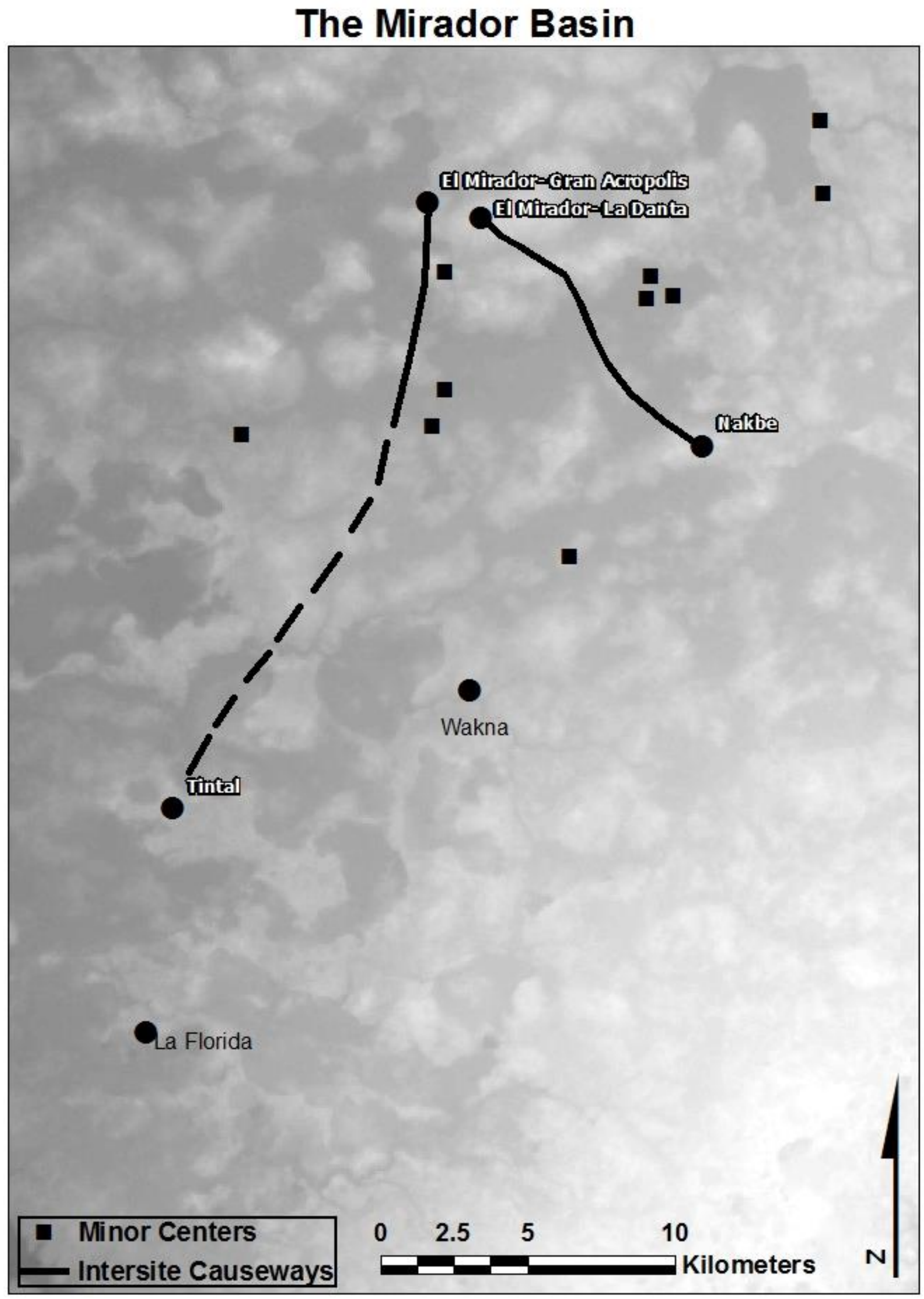

Figure 2: Map of the Mirador Basin. The map is using the SRTM DEM as a background. Map adapted after (Hansen et al. 2011: 188).

Nakbe is located southeast of El Mirador with most of the research conducted here by Richard Hansen (1992; 1998; 2012; Hansen et al. 2004). Nakbe's epicenter is composed of 2 large groups, a western group and an eastern group. The majority of construction and occupation occurred during the Middle Preclassic, between 1000-450 B.C. Nakbe is one of the earliest sites with monumental construction as well as a civic ceremonial center (Sharer and Traxler 2006:251-259). Stratification, hierarchy and early kingship were shown to exist with the importation of shell, evidence of agriculture, elite residential architecture, intrasite causeways, and an E-Group.

The site of Tintal was first visited during the 1950s by Heinrich Berlin, but it wasn't until the 1980s that ceramics and monuments were found that date to the Late Preclassic and Late Classic respectively. Excavations began again at Tintal in 2004 (Hansen et al. 2006: 740-741).

The site of Tintal is located southeast of El Mirador and is connected to that site by a 20 kilometer intersite causeway. Tintal also contains many local intrasite sacbeob connecting different architectural groups. The site has many large structures including triadic architecture, as well as a ballcourt and an artificial moat surrounding the civic center (Hansen et al. 2006: 739). Like El Mirador, this site was a major center during the Late Preclassic Period. The population of Tintal diminished during the Early Classic, and Hansen et al. (2006) suggests that a resurgence in occupation occurred during the Late Classic period.

During the Late Preclassic, a Maya state began to flourish in the Mirador Basin with El Mirador as the probable center. The Mirador Basin has the largest monumental architectural found in the Maya area as well as evidence of hieroglyphic texts (Hansen 2012:154). The triadic architectural style became dominant, with over 26 structures in this style. The site of El Mirador contains at least six causeways, with at least two intersite causeways connecting to Tinal and Nakbe. These causeways helped facilitate traversing through the bajos, as well as the flow of political and economic homogeneity, alliances, trade and transport, and ideological concepts (Hansen 2012: 155). Causeways to the sites of Nakbe and Tintal were constructed during the Late Preclassic once El Mirador was established as a large polity in the basin (Suasnavar 1994: 286-287)

In general, the causeway system in the Mirador Basin has not been very well studied. The Crossroads area at El Mirador, where three roads conjoin, was investigated, specifically the three termini and the end of the causeways (Jones 1985). These causeways however were not followed out to the other termini, so much speculation still exists as to the form of the road system. The possible intersite causeway between El Mirador and Calakmul has also not been ground-truthed, nor is the date of this causeway (or even its existence) certain.

Coba,Yaxuna, Ixil

The site of Coba was originally investigated by the CIW and was classified as a Peten-style site with many stelae, monuments, and causeways. The intrasite causeways were of specific interest in the 1970s and 1980s, when the focus was on settlement analysis and the mapping of the monuments and causeways.

Yaxuna-Coba-Ixil

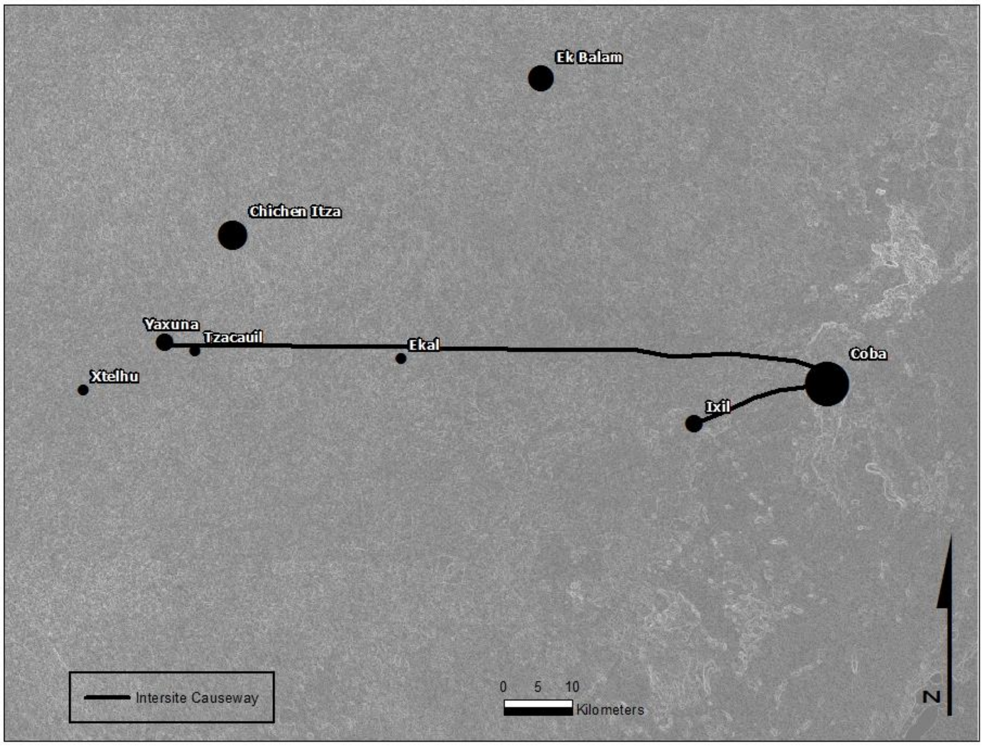

Figure 3: Map of the Yaxuna-Coba intersite causeway system. Background is the SRTM DEM, and the map is at 25% to the other maps.

Adapted after Villas-Rojas 1934.

The site of Coba is a large Maya urban center with distinct administrative, ceremonial, and habitational zones. The urban area is approximately 63 sq. km with over 40 causeways, two of which are the intersite causeways to Yaxuna and Ixil. The urban center of the site can be represented by the area between Lake Coba and Lake Macanxoc. Coba during the Preclassic Period consisted of distinct communities that eventually became conjoined due to population and urbanism. The intrasite sacbeob were constructed to integrate these distinct communities into one well-defined community, which Coba during the Late Classic Period. The majority of the causeways, as well as the albarradas (houselots surrounded by stone walls) were constructed during the Late Classic Period. Coba's suburban area extended approximately 14 km to the northeast of the center, ending in a more rural area with a scatter of small administrative-ceremonial centers (Folan 1977: 32-33). Coba reached its greatest height during the Late Classic, at about A.D. 600-800 (Loya Gonzalez and Stanton 2013: 27-28). The core-outlier and local intrasite causeways follow a dendritic form, similar to Caracol, Belize. Coba has two concentric ring intervals of causeway termini, one at 2-3 km from the site core and another approximately 4-5 km from the core (Chase and Chase 2003: 116). The Coba causeways are also associated with four types of ramps. The first type is associated with administrative architecture. The second type consists of huge ramps without architectural association and is found near the termini of causeways, including the two intersite causeways. The third type is used to pass over and provide access to sinkholes and water. The final type of ramp was possibly used for a ceremonial function, as a stela fragment and shrine were associated with it (Folan 1991: 223). These causeways were a means to organize the Coba polity into structured units that included households, neighborhoods, and the city and state, but Folan (1991: 226-227) also argues that these causeways may have also been astronomically aligned, possibly mirroring star maps. Some causeways at Coba may have been used to organize sociopolitical units, while others appear to have led to family shrines and residences (Folan 1991: 227-28).

Yaxuna represents one of the most important sites in the Central Yucatan during the Late Formative (Preclassic) and Early Classic Periods. During this time period construction efforts at Yaxuna included large triadic acropolis groups, local intrasite causeways, and an E-Group. The local intrasite causeways, as well as the architecture in the center of Yaxuna were built to help create an early geomantic plan, or cosmogram, specifically the Kan Cross. Stanton and Freidel (2005) argue that the north-south core axis was defined by the intrasite causeways, with other structures defining an east-west pattern. The E-group at the site core is also oriented towards a causeway running east-west that connects a structure in the East acropolis and dance platforms, creating the east-west axis of the cruciform plan. The site continued to have major occupation in the early part of the Early Classic. However, the focus of construction shifted to the North Acropolis and the north end of the axis. New intrasite sacbeob were constructed and others were modified to provide a new focus on the North Acropolis that was not the Kan Cross (Stanton and Freidel 2005:237). By the end of the Early Classic, Yaxuna experienced a reduction in population and construction. The Late Classic at Yaxuna is defined by the construction of Sacbe 1 (the intersite causeway to Coba) and the appearance of Arena red ceramics. Arena red ceramics are restricted to the Late Classic at Yaxuna, during the same time period that monumental architecture was decreasing in construction (Loya Gonzalez and Stanton 2013: 28). The expansion of Coba at the same time as the construction of Sacbe 1 and Arena red ceramics suggests that Yaxuna was integrated and possibly subordinated into the Coba polity. During the Terminal Classic Period, Yaxuna continued to be occupied, but without the use of Sacbe 1 and with evidence of Puuc architecture. By the end of the Classic Period, most of Yaxuna was abandoned, although some Late Postclassic burials and shrines.

At almost 100 km, the Coba-Yaxuna causeway is the longest recorded causeway in the Maya region. Constructed during the Late Classic, Sacbe 1 became physical evidence of Coba's control of Yaxuna. An idea of subordination exists because of the erection at Coba of stelae and civic architecture, combined with Yaxuna's lack of construction. Yaxuna was also producing the Arena red ceramics, and this was one of the products exported east to Coba. Coba thus maintained economic ties to the north coast of the Yucatan through Sacbe 1 (Loya Gonzalez and Stanton 2013: 38-39). Based on the investigations conducted, researchers argue that this intersite causeway functioned primarily for economic purposes that included trading with the west. Political function may have been a factor as well, if subordination of Yaxuna into Coba is the case. Sacbe 1 was then abandoned during the Terminal Classic and the arrival of Puuc architecture. Ritual purposes of the causeway are only evident during the Late Postclassic, with the causeway serving as a pilgrimage route and with no evidence of domestic occupation.

The site of Ixil and its intersite causeway to Coba is not as well understood as Sacbe 1. Ixil does not have the continuous research that the sites of Yaxuna and Coba have. H. Pollock was the first archaeologist to begin the study of the ruins of Ixil. Attempting to understand the settlement area around Coba, Pollock suggested that Ixil possibly had a causeway connecting it to central Coba. Later that decade researchers attempted to follow a causeway outside of Coba towards Ixil, but only made it to two kilometers south of Coba. The site was not visited for archaeological purposes until 1968 (Robles Castellanos 1976:18). The resesarch conducted during this expedition concluded that there was a causeway connecting Ixil and Coba, and they dated it and the site to the Late Classic Period. In 1974, INAH (Instituto Nacional de Antropologia e Historia) began conducting field research at Coba and its settlement area (Robles Castellanos 1976). This research was geared towards studying the network of causeways and termini and the topography of the Coba area.

The site of Ixil contains five major plazas, Plazas A through E. Structure 1 is the largest structure at Ixil and is located in Plaza A. Plaza A is also the terminus location of the causeway that connects to the site of Coba (Robles Castellanos 1976: 24). The excavations that took place in Plaza A contained predominantly of Late Classic ceramics, thus confirming that most of construction, including Structure 1 and Sacbe 16, date to the Late Classic. Robles Castellanos (1976: 39) argues that based on the structures at Ixil and the aguada and cenotes along the causeway, the site of Ixil was an agricultural center.

The Coba-Ixil causeway runs for approximately 20 km with a width ranging from 5.8 m to 6.4 m. The elevation of the causeway from the ground varies throughout the path, with "ramps" being associated with the elevated areas. There are two types of ramps associated with the causeway, those that function for administrative purposes and those that either avoid or provide access to natural features. The Coba-Ixil causeway represents political control of this area by the Coba polity. The intersite causeway of Ixil that leads to Coba may have been primarily for economic purposes, but it may also have served for water management purposes. Along the causeway to Coba are aguadas, drainage areas, and cenotes (Folan 1977: 35-36). This system differs from the Yaxuna-Coba causeway, which was primarily used to maintain economic ties within the Northern Yucatan.

<u>Uxmal-Nohpat-Kabah</u>

The Uxmal-Nohpat-Kabah intersite causeway system is the most complex system found in the Puuc region. The Puuc region, or hill country, located in the Northern Yucatan contains some of the best agricultural soils in the Northern lowlands and was possibly the reason for settlements in the area. Researchers also suggest that the Puuc area was supplying the northwestern coastal plain with food, due to evidence of a population higher than local agriculture could support (Dunning and Kowalski 1994: 66). Access to water was much more difficult; with only a few deep cave systems, limited rainfall during six months out of the year, and a few constructed aguadas, the inhabitants relied on chultuns for access to water. Dunning and Kowalski (1994) argue that the communities that controlled the prime agricultural soils would also control the surrounding communities as well, creating larger centers that took advantage of agricultural surplus from smaller surrounding centers.

The distinct Puuc architecture was fully developed and widespread during A.D. 771- A.D 790. Late Preclassic remains are evident in the region but have only been found in basal and residential platforms. The distinct Puuc architecture consists of lime concrete and veneer construction, with stucco and mosaic ornamentation. Puuc communities consisted of numerous platform groups of a variety of sizes with vaulted and non-vaulted architecture. The site of Uxmal is relatively late compared to other Puuc sites. The disintegration of the complex development in the Puuc region occurred after A.D. 907, long after the Nunnery Quadrangle and the House of the Governor structures at Uxmal had been built (Dunning and Kowalski 1994: 67).

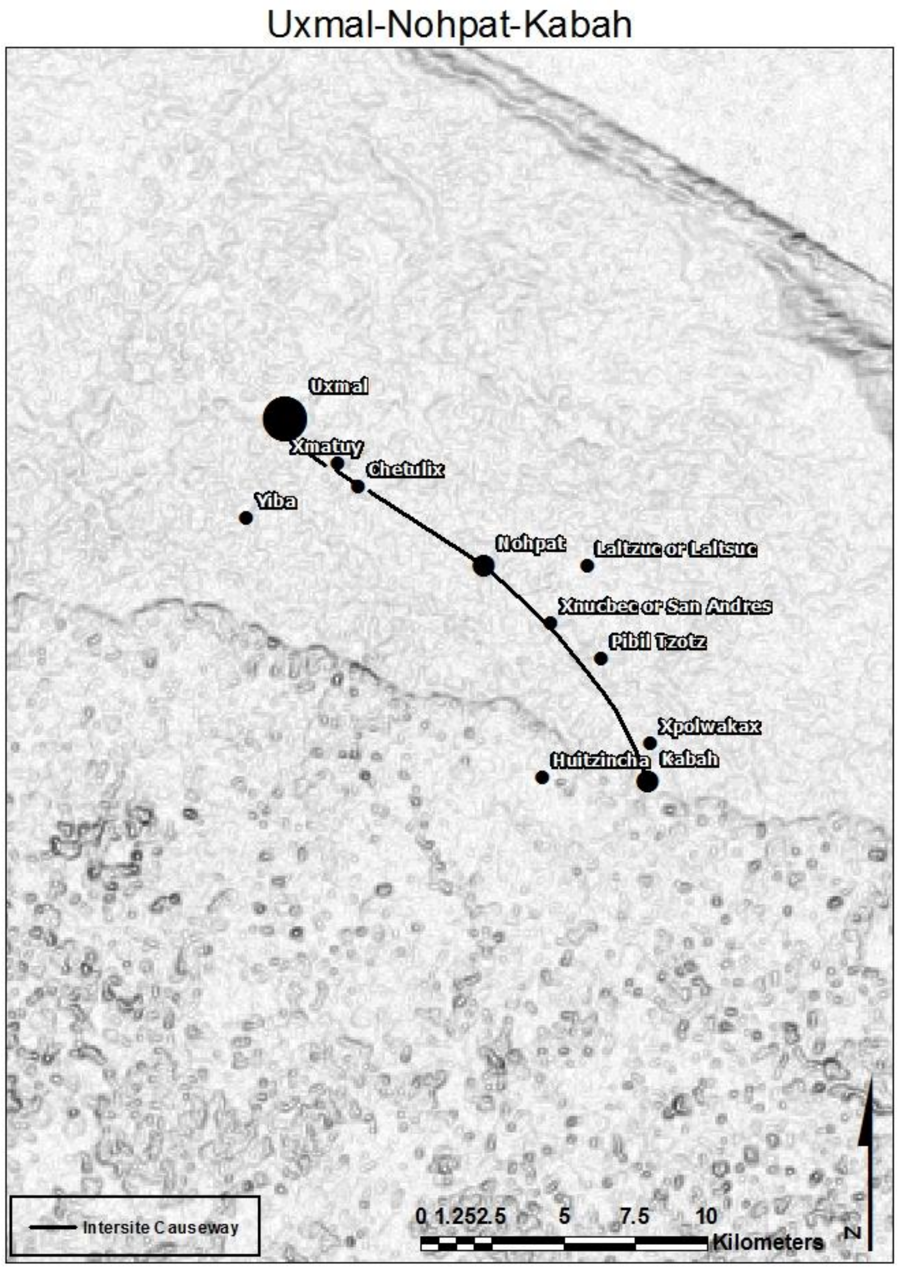

Figure 4: Map of the Uxmal region with the intersite causeway. The background uses the SRTM DEM as the background.

Adapted after Carrasco 1993: 200.

Architectural groups at Puuc sites are organized in compact courtyard complexes that take advantage of topography and fertile resources. The architectural complexes in major centers contain pyramidal structures conjoined with nonresidential structures and surrounded by elite residential compounds; some elite residences are connected by causeways. Causeways were also used to link distinct architectural nodes. Large sites have their elite architectural nodes centered on areas that had good agricultural soil, which researchers suggest is how the elites controlled intensive garden agriculture. Stratification of households may have also occurred as a result of access to prime soils and scarcity of good land in the region (Dunning and Kowalski 1994: 69). Puuc sites also have zones of rubble mounds (also known as chich mounds). These mounds are found at the limits of architectural features, with some found near the outer limits of settlement at Kabah near the intersite causeway to Nohpat. Rubble mounds are also found near the outer edge of formal architecture at the site of Sayil.

Uxmal is the largest site in the Puuc area, with a settlement area of at least 10 sq km (Dunning 1992: 168). The site contains a massive epicenter with monumental architecture, as well as two ball courts and at least 17 stelae. The site is also situated among the best agricultural soils in the Puuc region and has eight aguadas in its central area. The aguadas were probably used for construction purposes, but potable water was stored in the chultunes around the site. In a one square kilometer area at Uxmal, 122 chultuns have been found, suggesting this was the major form of rainwater storage. The epicentral area of Uxmal is organized on a north-south axis, with an acropolis-style arrangement of courtyards bounded by the North and South Groups. A low encircling wall helps to define the core area and may have been used to limit where the elite lived, as well as defining the seat of government and center of economic activity. The wall is irregular and elliptical in shape; from north to south it measures approximately 1 km long; on its east-west axis it measures approximately 600 m. Settlement outside of the central wall is also evident and is strategically located on the best soils available, being adapted to the irregular terrain of the Puuc hills. Research conducted by Alfredo Barrera Rubio (1978) has determined that all residential complexes were located in the Pusluum soil areas, which is the most fertile soil in the region and is found on hillsides and natural rises with good drainage. The more elite residences with vaulted buildings also had chultuns, while only a few of the non-elite, non-vaulted buildings contained chultuns. The site was initially a much smaller site and only became very dominant and massive late in its occupational history. The majority of the ceramic content found during Barrera Rubio's research also dated to the Terminal Classic period. The largest structures at the site, the House of the Governor and the Nunnery Quadrangle, date between A.D. 895-907, making them some of the last buildings constructed at the site. The architecture and iconography at Uxmal also supports the idea that this site was a regional capital during the Terminal Classic. Uxmal also had a relationship with Chichen Itza, whether it was in cooperation or competitive. Some research suggests that the two sites were competing for trade routes and agricultural land, while iconographic evidence implies a cooperative tie between the two regions (Dunning 1992: 150-152). Nonetheless it is clear that Chichen Itza and Uxmal were the largest polities in the Yucatan during the Terminal Classic Period.

Uxmal's role in the intersite causeway was also very late compared to the longevity found at Kabah and Nohpat. Early Puuc architecture is associated with the intersite causeway at Kabah and Nohpat, suggesting that this causeway was in place earlier than the rise of Uxmal and that that site was a later addition. Nohpat may have also been the primary center in this area at one point, with as much Early Puuc architecture at its core as Uxmal. Nohpat, however, only has one late Puuc style structure, while Uxmal and Kabah have many, suggesting that Uxmal took over politically and became the regional center of the area. The terminus of the Nohpat-Kabah causeway at Kabah is marked by an architectural arch that also marks the edge of the site center. Other gateways are also found along the Nohpat-Uxmal section of the causeway, demarcating the existence of various settlements along the sites.

The intersite causeway may have been constructed for ritualistic and religious purposes as well. Initially, researchers believed that there was an astronomical alignment between the House of the Governor at Uxmal and Structure 1 at Nohpat (Dunning 1992: 146). This alignment delineated the azimuth of the Venus rise at its maximum southerly declination around A.D. 850. Research undertaken by Ivan Sprajc(1990) determined that the House of the Governer's Palace Venus alignment was actually with a structure at the site of Cehtzuc. Cehtzuc lies between the Uxmal-Nohpat causeway, approximately 4.5 km southeast of Uxmal. A geomantic line is created with this alignment and Dunning (1992: 147-148) believes that this creates the mouth of the celestial serpent and the earth monster manifested in the landscape; Thus the intersite causeway may also be a representation of this geomantic alignment.

Ake-Izamal-Kantunil

The site of Izamal is one of the largest sites in the Northern lowlands. Recent estimates of the site claim that the city of Izamal covered 53 square kilometers, approximately a circle with a radius of over four kilometers. Excavation, restoration, and surface collection of ceramics indicate that the site dates to the Terminal Classic Period. Scott R. Hutson (2012: 119) argues that this has more to do with taphonomy and the organization of ceramic production. Recent research also suggests that Izamal became urbanized in the Early Classic, consolidating control over labor and other sites. Ceramic analysis of Izamal's Kinich Kak Moo, the second largest constructed building in the Maya Lowlands, indicated that it was constructed during the Early Classic Period; other structures in the main plaza of Izamal also date to this time. Hutson (2012: 112) also argues that Izamal follows a low density urban city plan, similar to Tikal and Caracol, which differs from other Northern Lowland settlement, such as Chunchucmil and Coba that are much denser in settlement. Earlier research has suggested that swidden farming was produced and that maize may have been imported from the south; seafood was a staple food source as well (Andrews V and Kurjack 1976: 324). In terms of architectural style the megalithic style is strongly prevalent at this site in the western core as well at Ake (Hutson 2012: 125). This style is defined by platforms with retaining walls that contain large, dressed facing stones with rounded corners. This style is also strongly prevalent at the core of El Naranjal. Megalithic architecture is also found in the settlement areas near the site of Uci, but Hutson (2012) suggests that this style of archicture originates from the Izamal area.

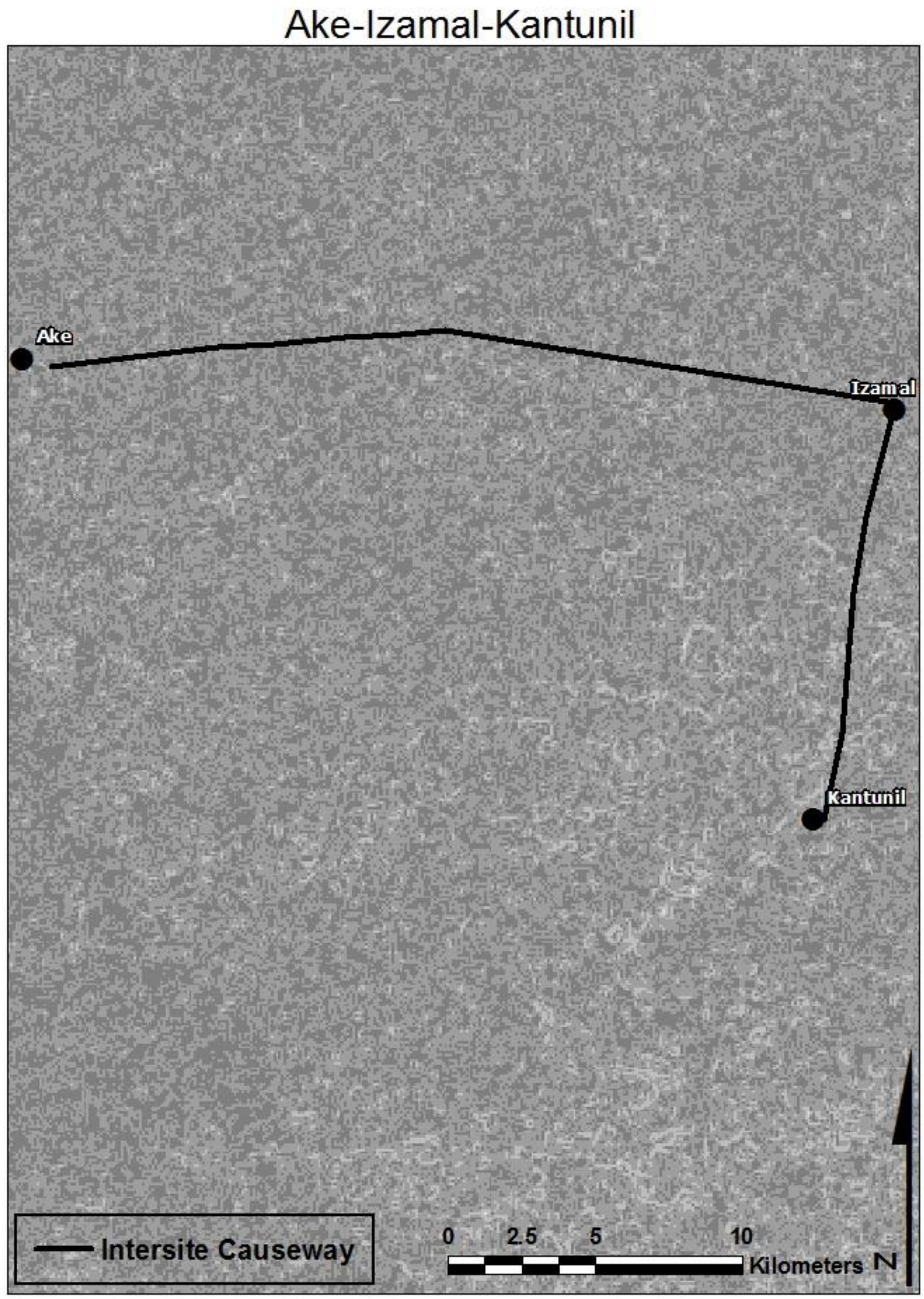

Figure 5: Ake-Izamal-Kantunil intersite causeway system. The background is the SRTM DEM Adapted after Garza Terrazona de Gonzalez and Kurjack 1980.

The site of Ake was first intensively investigated by Lawrence Roys and Edwin M. Shook. In their initial report, eight total causeways were recorded, with Sacbe 1 connecting to the site of Izamal. Edwin Shook was the first archaeologist to discover the Ake-Izamal intersite causeway (Roys and Shook 1966: 43-45). Ake is also a walled site, with the walls possibly being built from the remains of causeways. Kurjack and Andrews V (1976: 321-322) argue that the construction of the Ake-Izamal causeway dates to the Late Classic, with the Ake wall constructed as a later addition during the Terminal Classic.

The intersite causeway system of Izamal is very complex, with two intersite causeways connecting Ake and Kantunil. Izamal also has at least two intrasite causeways and two core-outlier causeways, with more that have possibly been destroyed by modern occupation. The Ake-Izamal causeway runs for approximately 32 km. The causeway to Kantunil runs approximately 15.5 km to the south. Information on the site of Kantunil, however, is very scarce. Researchers suggest that the Kantunil-Izamal sacbe was the first intersite causeway of this sacbe system; then the Ake-Izamal causeway, with the minor center of Sitpach as a medial stop, was constructed (Shaw 2008: 69). Hutson (2012: 120) argues that the causeway system may have more closely resembled Coba's causeway system. The Ake-Izamal causeway is approximately 13.2 m wide with a height ranging from 0.3 to 1.5 ms high (Roys and Shook 1966: 44). The Ake-Izamal causeway is argued to have been an early form of boundary maintenance, with stone walls constructed at a later time period. Kurjack and Andrews V (1976: 323-324) argue that continual boundary maintenance is evidence of political instability, between two major centers focused at the sites of Izamal and Uci, approximately 32 km apart. The florescence of polities in the Puuc area, such as Uxmal during the Terminal Classic, may have also weakened the polities of Izamal and Uci.

<u>Uci-Kancab-Ukana-Cansahcab</u>

Similar to Izamal, the site of Uci also contains megalithic construction. Uci and Kancab both have megalithic architecture, although not as large as at Izamal, suggesting that Izamal had control or influence over the Uci polity. Uci is the largest site along this causeway, with Kancab and Ukana being similar in size and layout. Kurjack and Andrews V (1976) estimated the size of the site at 4 sq km, but recent research suggests the size of the site is at 7.5 sq km or 11.2 sq km. Uci is sourrounded by many areas with depressions, presumably used for water storage or for quarrying limestone. Much of the large architecture at the center of Uci has been destroyed by modern development projects (Hutson and Covarrubias Reyna 2011:1291). The site of Cansahcab is now currently engulfed within modern occupation, with a church situated on top of one of the original structures. Cansahcab may have been similar in size to the other termini sites of Kancab and Ukana. The first observation of the Uci-Cansahcab causeway was reported by Kurjack and Andrews V (1976), with aerial photography. The first archaeological investigation of this region, however, was conducted by Ruben Maldonado (1979a, 1979b). More recently, Scott Hutson (2009) has been directing the Uci-Cansahcab Archaeological Project (PASUC), which began in 2008. As previously stated, earlier interpretations of this causeway system suggested that Uci was the center of one of the polities in the northwest Yucatan, with the other being at Izamal. These interpretations also suggest that Uci was at one point a part of Izamal's control of special functions (Kurjack and Andrews V 1976:323).

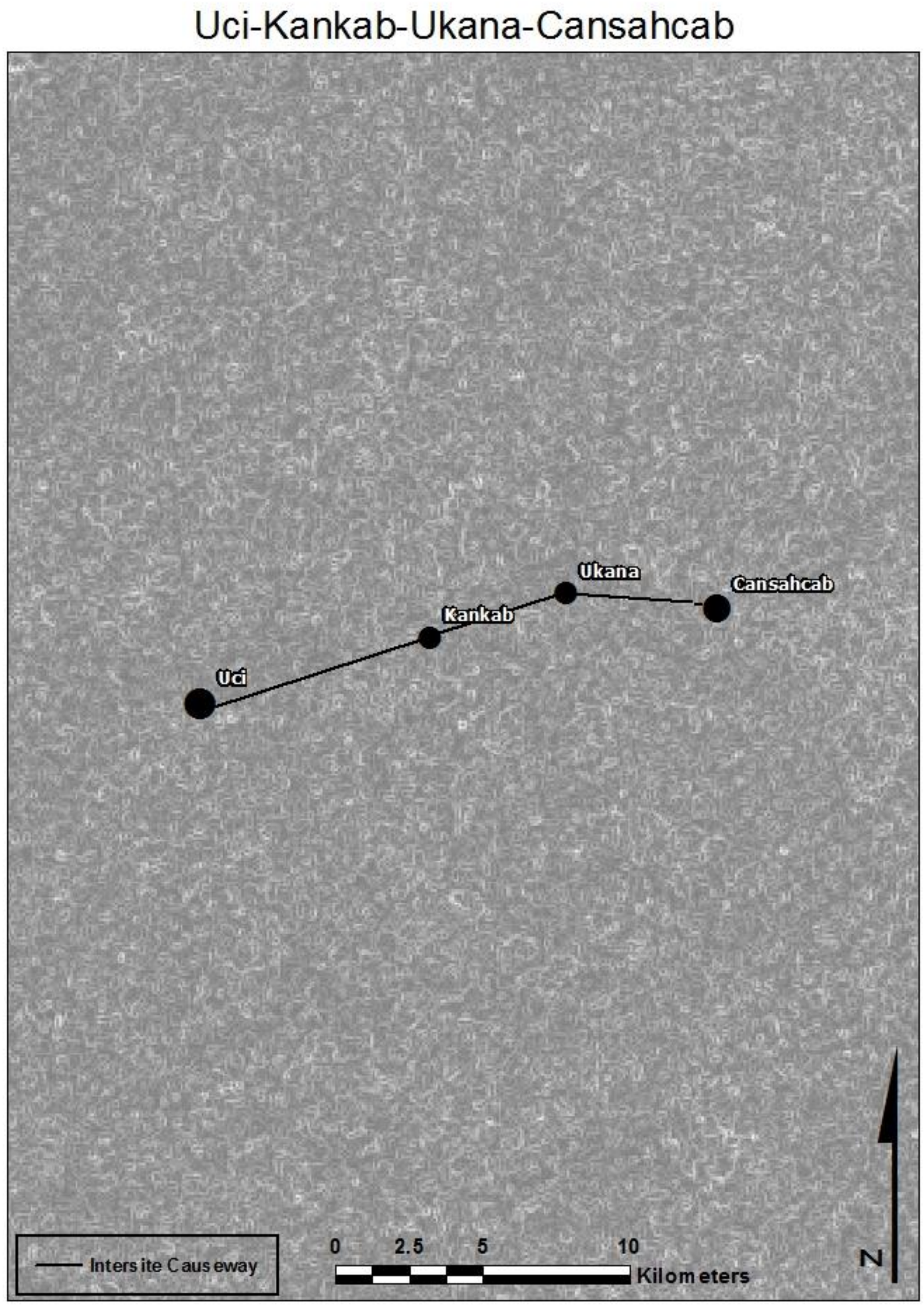

Figure 6: Uci-Cansahcab intersite causeway system. The background is the SRTM DEM. Adapted after Garza Terrazona de Gonzalez and Kurjack 1980.

The intersite causeway of Uci runs for approximately 18 km, ending at Cansahcab, and is 8 m wide and 0.5 m high. Ruben Maldonado (1979a and 1979b) argues that this intersite causeway was not initially constructed as one long sacbe, but rather as two smaller sacbeob, one connecting Uci and Kancab and the other connecting Cansahcab with Ukana. Once the polity of Uci started to grow in size, the two segments became connected with another causeway from Kancab to Ukana. Interestingly, the termini for the intersite causeway do not end at monumental architecture at the center of the sites (Hutson and Covarrubias Reyna 2011: 1218-1219).

CHAPTER 4: METHODOLOGY

Before conducting the least-cost path analysis, the four considerations that Surface-Evans and White (2012: 4) proposed have been taken into account: the archaeological data have been analyzed, the variables needed for the model/map were defined, the type of cost that will be measured was assessed, and the software used to create the least-cost paths was selected.

In this thesis, Google Earth was employed to display the archaeological site locations. Google Earth pinpoints exact site locations and these were acquired from the *Electronic Atlas of Ancient Maya Sites: a Geographic Information System* (Witschey and Brown 2008). All of the sites used in this thesis for the cost-path analysis were taken from the EAAMS and include: El Mirador, Nakbe, Tintal, Uxmal, Nohpat, Kabah, Yaxuna, Coba, Ixil, Uci, Kancab, Ukana, Cansahcab, Ake, Izamal, and Kantunil. The pinpoints for El Mirador and Nakbe, however, were adjusted due to a more accurate image of them from Google Earth. Maps for each of the causeway systems were digitized and georeferenced into ArcGIS 10.0, which was the GIS software used in this thesis.

The variable used in this research was topography, specifically the slope of the terrain. In order to conduct the analyses, two DEMs, or Digital Elevation Models were employed; the SRTM 90m DEM and the ASTERG DEM. The SRTM, or Shuttle Radar Topography Mission, flew aboard the space shuttle Endeavour in 2000 for 11 days, acquiring radar data intended for topographic maps (USGS 2000). Specifically, the SRTM data uses radar interferometry, which allows a comparison of two radar images taken at different angles. These two images are then calibrated to allow calculation of the Earth’s surface. This thesis used the DEM for global coverage, which is available at 3 arc-second resolution or approximately 90 m resolution per pixel. The Advanced Spaceborne Thermal Emission and Reflection Radiometer Global DEM, or ASTER GDEM, was released in 2009 (USGS 2009). The ASTER DEM uses high-resolution images gained from collecting in-track stereo using nadir and near-infrared cameras. This newer DEM gives a resolution of one arc-second, or a pixel size of approximately 30 m.

The cost used for this analysis was to minimize or avoid rough terrain or sloped areas. The procedures for both of these DEMs were the same for this analysis. The two DEMs were projected onto ArcMap 10.1. A slope raster layer was created for each DEM. Using this slope raster, cost-distance rasters were created for one site terminus of each intersite causeway. Once these rasters were created, they were inputted into the ArcMap cost-path function to create a least-cost path between the site locales on the intersite causeways. This was done for all of the intersite causeways, so each causeway system has two hypothetical cost paths, one based on the SRTM and one based on the ASTER DEMs.

Once the least-cost paths were conducted, a table with associated information was created to show descriptive differences (statistics) between them. The table shows the intersite causeway lengths, widths, and heights, as well as the least-cost path lengths and an estimated area in sq km between the causeways and least-cost paths.

Limitations

This analysis is not without some limitations. The SRTM and ASTER DEMs are free for download and available online for the public (USGS 2013), which is the reason they were chosen for the research conducted in this thesis. More recent spatial imagery, such as LiDAR, has recently been very useful in Mesoamerican archaeological projects. LiDAR applications used at the site of Caracol, Belize projects a resolution of under 1 meter, giving a much more accurate image of the landscape (Chase et al. 2012). This application, however, is not yet widely available.

Another issue in this analysis is the problem of modern development built on the archaeological sites. The sites of Izamal and Uci have been heavily modified or destroyed since the Colonial period and do not necessarily represent the ancient Maya landscape as it once was. However, the long intersite causeways that were chosen for this research are many kilometers long, as well as the least-cost paths, so the majority of the routes will not be affected by the modified termini sites.

CHAPTER 5: RESULTS

The results of the least cost path analyses show that none of the intersite causeways follow a least-cost path based on the terrain. The hypothetical cost path routes are not all uniform, with the cost paths in the different regions following different routes. The ASTER and SRTM least-cost pathways also differ, as the maps below will illustrate. For the Mirador Basin area, the least-cost path may actually follow ancient paths that connect minor centers, but more investigations are needed to make that definitive conclusion.

Once the paths were created, a table was assembled to organize the descriptive statistics of the intersite causeways and least-cost paths (see Table 1). The results of the analyses conducted showed that all of the causeways were shorter in distance compared to the least-cost paths created with the SRTM DEM and the ASTER DEM. There was also no consistent correlation for the differences in length between the SRTM DEM and ASTER DEM least-cost path routes.

Sites with Intersite Causeways	Causeway Length (km)	Causeway Width range (m)	Causeway Height range (m)	Least-Cost Path Length SRTM (km)	Least-Cost Path Length ASTER (km)	Area Between Causeway and Least-Cost Path SRTM (sq km)	Area Between Causeway and Least-Cost Path ASTER (sq km)
El Mirador-Nakbe	12.5	17-22	0.7-4	11.5	10.8	7	5.6
El Mirador-Tintal	20	----	----	26.5	24.2	37.9	18.9
Yaxuna-Coba	99	9.8-10.3	0.6-2.5	110	109.9	226.1	664.4
Coba-Ixil	20	5.8-6.4	----	21.7	27.3	19.7	63.6
Uxmal-Nohpat	7.3	4.5	----	10.1	9.5	1.6	3.8
Nohpat-Kabah	9.6	4.5	----	10.9	10.6	3.3	7.5
Ake-Izamal	32	13.2	0.3-1.5	34.9	32.1	49.1	20.4
Izamal-Kantunil	15.5	----	----	17.7	17.4	5.2	7.0
Uci-Kancab	8.2	5-10	0.5-1	8.8	8.8	3.7	5.7
Kancab-Ukana	4.7	5-10	0.5-1	5.1	5.1	0.7	1.2
Ukana-Cansahcab	5.1	5-10	0.5-1	5.9	5.9	0.9	3.6

Table 1: Descriptive statistics of the intersite causeways and the least-cost paths. The sections with dashes do not have their statistics available.

The Mirador Basin

The results of the Mirador Basin show that the causeways do not follow a least-cost path based on the terrain. Comparing the ASTER cost paths with the SRTM 90m DEM cost path do show some similarities. The ASTER cost paths both follow a path west of the actual causeway, while the SRTM 90m cost paths both follow a path east of the causeways.

The SRTM 90m path for El Mirador-Tintal also had interesting results. The path goes around two minor centers along the route to Tintal. This may be an actual informal route taken by the Maya, but ground-truthing would be necessary to test this hypothesis. If this is the case, then there may be more minor centers that are still unidentified along the route, which ground truthing or more advanced technologies such as LiDAR can identify.

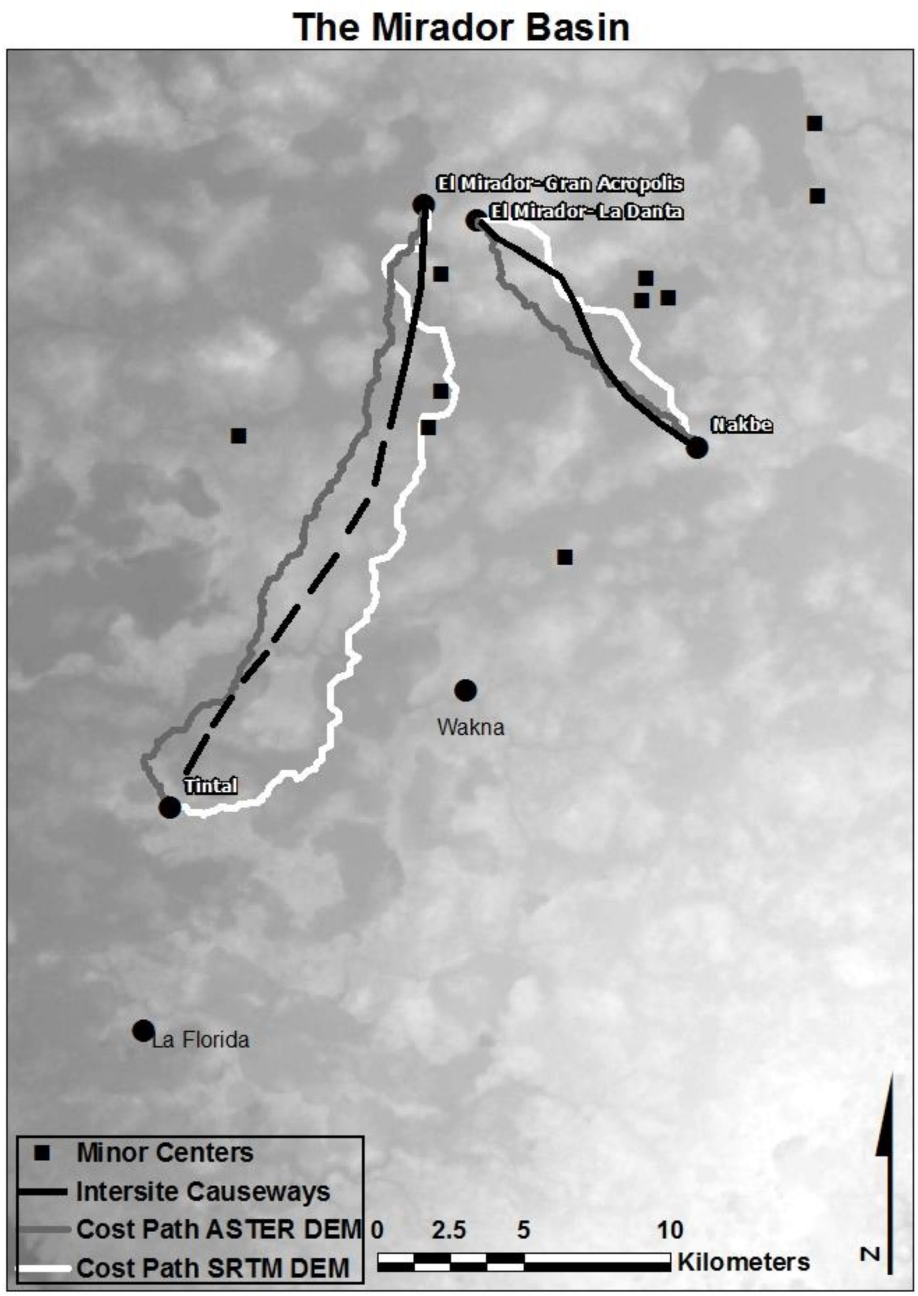

Figure 7: Map of the Mirador Basin with least-cost paths and intersite causeways.

Coba-Yaxuna-Ixil

The least-cost analyses for the intersite causeways of Coba, Yaxuna, and Ixil do not follow least-cost paths. The SRTM cost paths are both north of the ASTER cost paths, but not necessarily north of the causeways. While some of the other cost path analyses conducted in this thesis follow a pattern, the paths here do not.

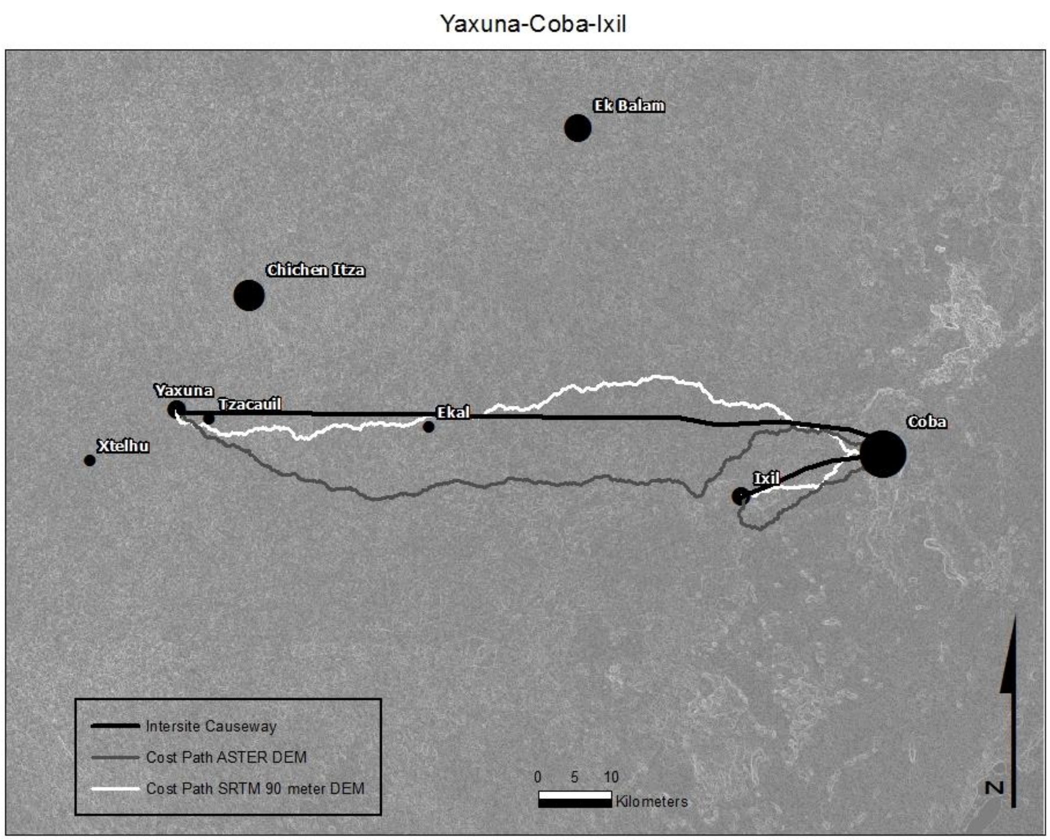

Figure 8: Map of the Yaxuna-Coba-Ixil intersite causeways with least-cost paths.

Uxmal-Nohpat-Kabah

The Uxmal-Nohpat-Kabah intersite causeway system does not follow a least-cost path. The SRTM and ASTER cost path routes travel north of the causeway from Uxmal to Nohpat, with the SRTM route occasionally dipping south of the causeway. From Nohpat to Kabah, the cost path routes travel south of the intersite causeway. There is also no association with the cost paths to the minor centers in the area.

Uxmal-Nohpat-Kabah

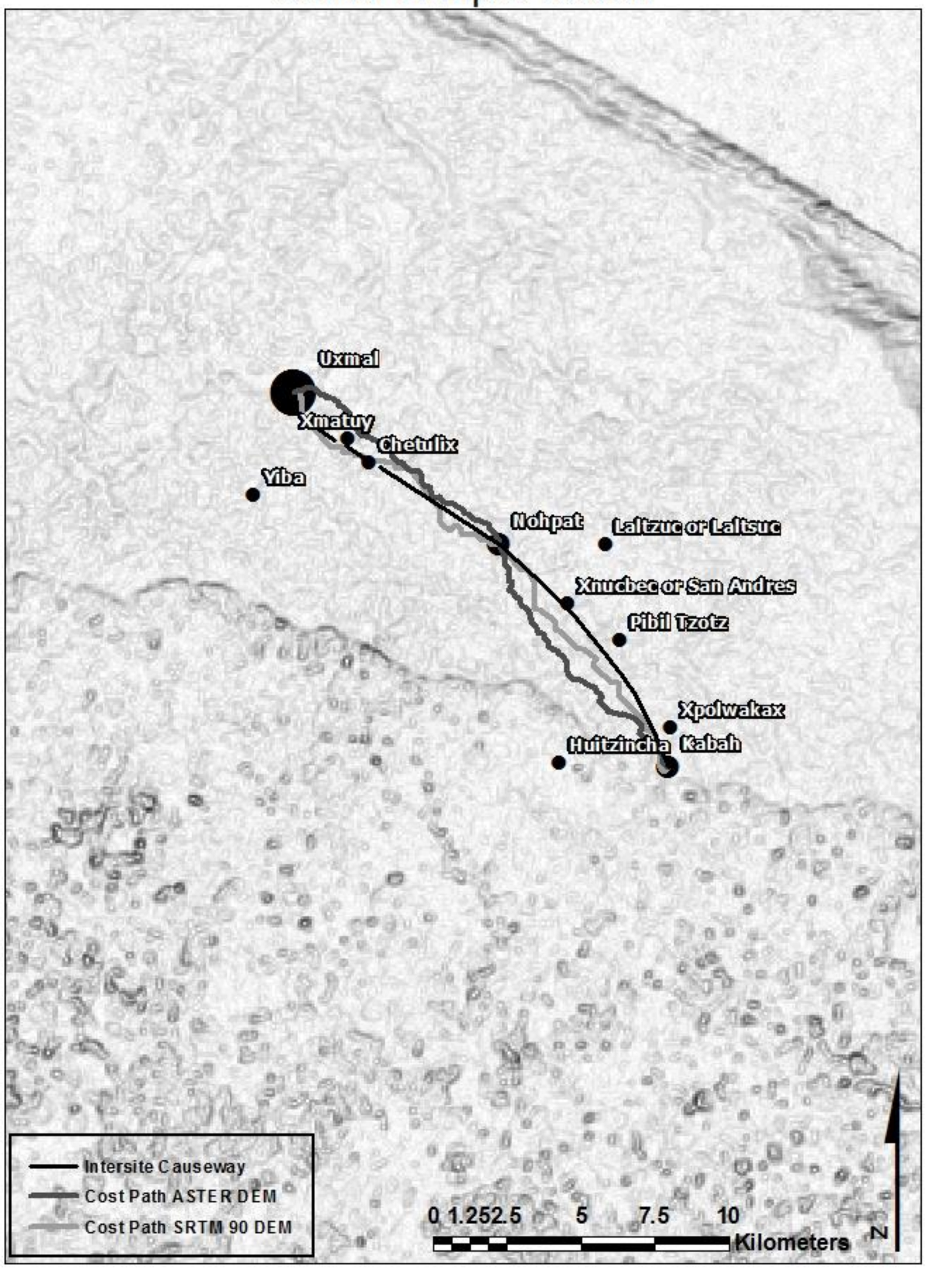

Figure 9: The Uxmal-Nohpat-Kabah intersite causeway system with least-cost paths. The SRTM cost path is not in white, due to the fact that DEM is nearly white due to the elevation.

Ake-Izamal-Kantunil

The Ake-Izamal-Kantunil intersite causeway system also does not follow a least-cost path route. The Ake-Izamal SRTM cost path follows north of the causeway for the majority of the route and, then, dips south of the causeway once it reaches Izamal. The ASTER path travels south of the causeway from Ake to the site of Sitpach and, then, moves north of the causeway on its way to Izamal. The Izamal-Kantunil route is of more interest, since both cost path routes seem to follow similar routes, only diverging from each other in some areas.

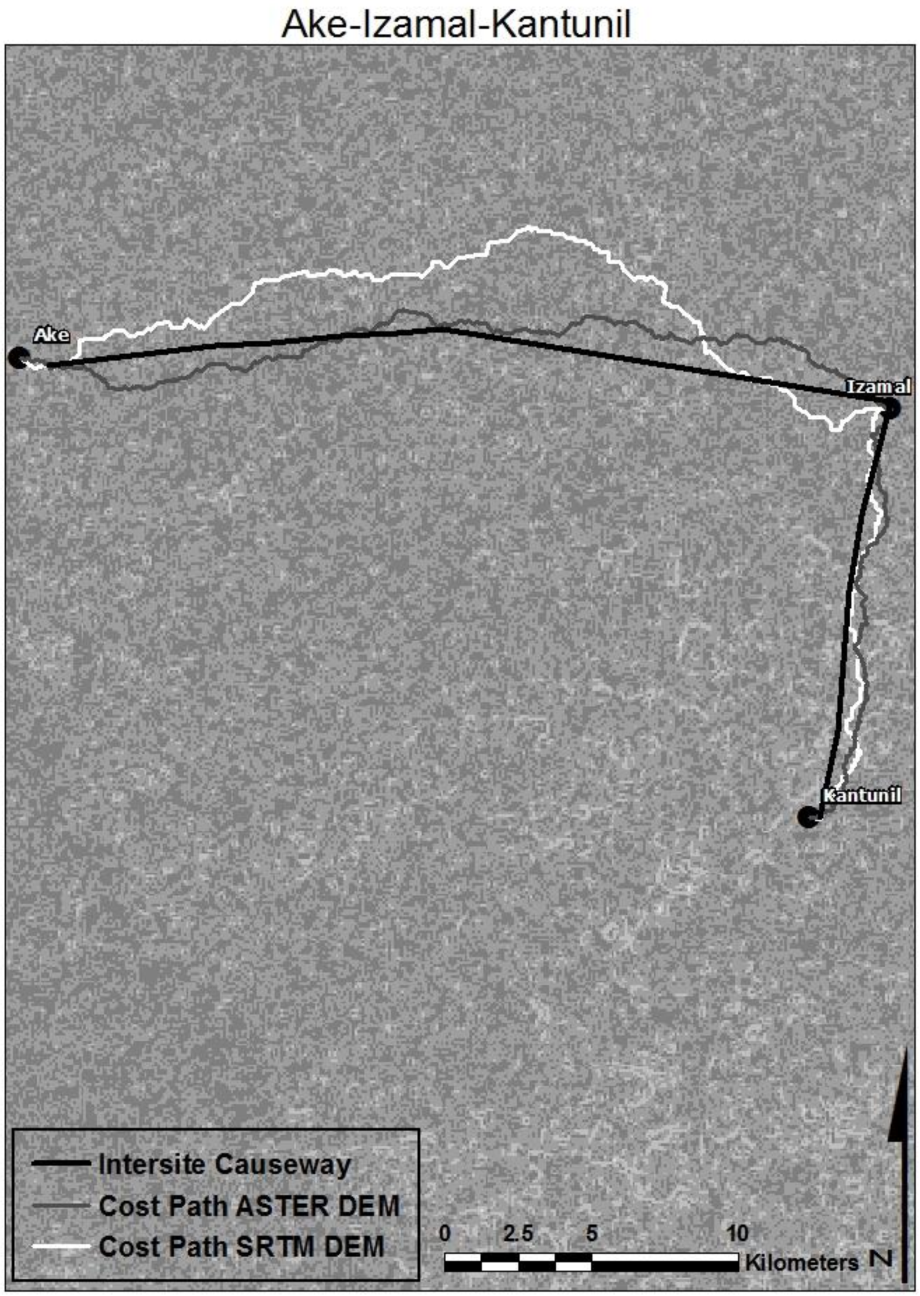

Figure 10: The Ake-Izamal-Kantunil causeway system with least-cost paths.

Uci-Kancab-Ukana-Cansahcab

The Uci-Kancab-Ukana-Cansahcab intersite causeway system does not follow a cost path route. The cost paths do not seem to follow any particular form, except from Uci to Kancab, where the ASTER and SRTM paths continue north of the causeway.

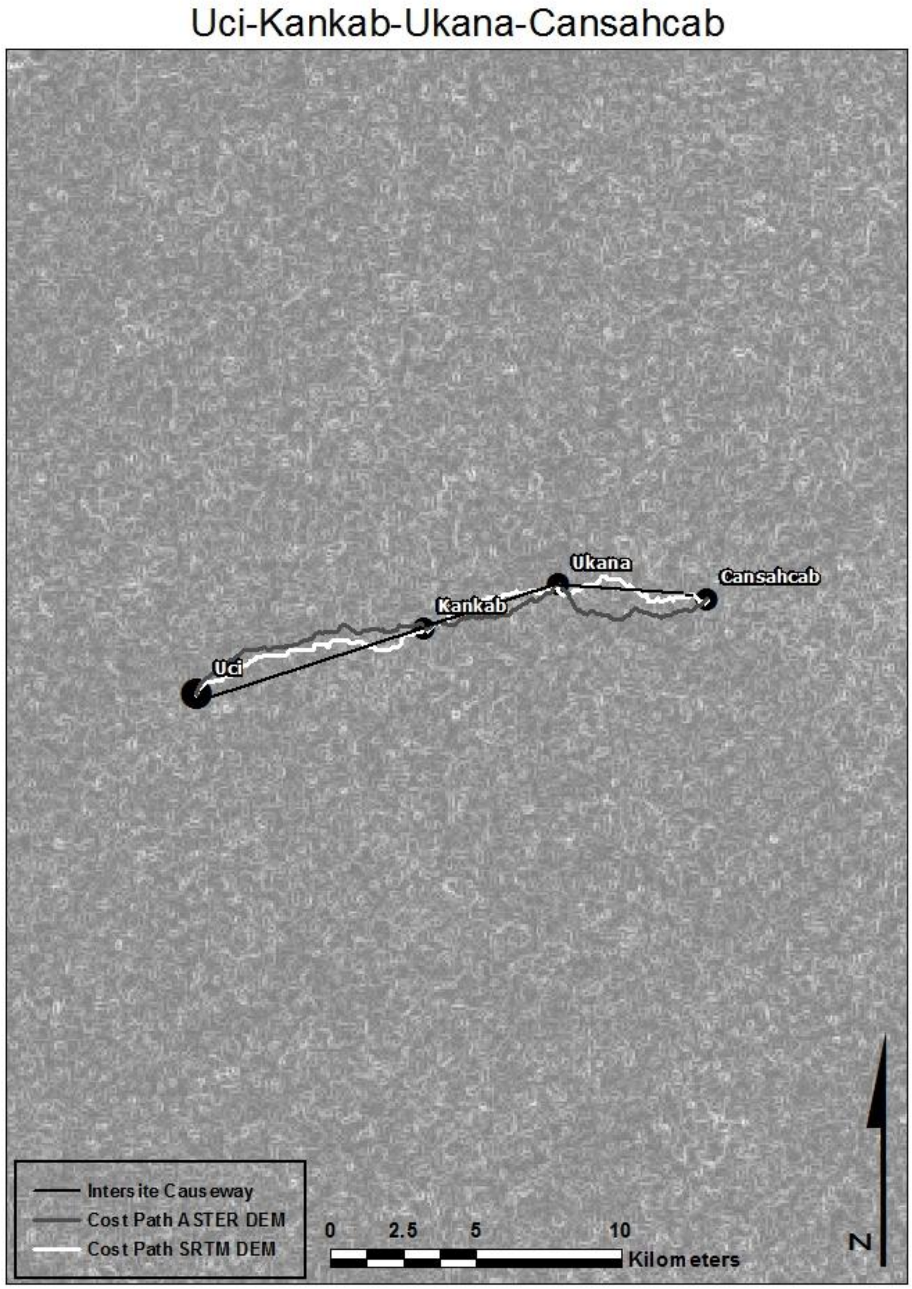

Figure 11: The Uci-Cansahcab intersite causeway system with least-cost paths.

CHAPTER 6: CONCLUSION AND FUTURE DIRECTIONS

GIS analyses have the capabilities to prove or disprove hypotheses related to landscape archaeological data. It allows for manipulation of data, as well as creating systematic analyses of spatial data. Least-cost pathways are great in archaeological studies for hypothesizing ancient travel, especially when evidence of roads is not present. Because Maya sacbeob are still present at many archaeological sites, creating hypothetical routes is not always necessary. Contrasting least-cost paths with actual causeways, though, can provide insights into how the roads were built, as well as to why they were built. Using topography as the cost variable, it is clear that Maya sacbeob do not follow the least-cost paths. This suggests that causeways were not built for avoiding problems in the terrain, but rather to follow direct straight routes between centers.

Researchers also suggest that the causeways were later additions to already largely built sites, like at Coba-Yaxuna, Uci-Cansahcab, and Ake-Izamal. The region of the Mirador Basin is the most unusual in terms of its causeway system. Although the cost path routes do not follow the intersite causeways, the SRTM 90m path from El Mirador to Tintal suggests that there may be a significant informal route connecting minor centers with each other. This path might not actually be an ancient route, but more research on settlement patterns can help answer these questions.

Based on the principle of architectural energetics, Maya architecture was redundant in design (Abrams and Bollard 1999: 286), and this is the case for the majority of the intersite causeways. The redundancy of the causeways following a relatively straight path and not the least-cost routes suggests that the intersite causeways were primarily used for political integration and economics. All of the causeways in this study are also shorter than the least-cost paths, which mean that these causeways were also built with efficient construction costs in mind.

Some of the causeways had a strong cosmological purpose to them, such as the Uxmal-Nohpat-Kabah causeway, but their primary purpose was to integrate the different polities together. This is best shown with the Yaxuna-Coba causeway, with evidence of Yaxuna ceramics being exported to Coba, and with Yacuna maintaining a subordinate relationship to the expansive Coba polity (Loya Gonzalez and Stanton 2013). This type of artifactual analysis has not been done among the other termini of the intersite causeways, which would be helpful in proving whether these routes were used for exportation and importation of artifacts or primarily for processions and cosmological purposes.

Future Directions

As shown by the analyses conducted by the research in this thesis, different spatial imagery can give different results on the analyses of least-cost paths. Because the SRTM and ASTER DEM cost paths give different results, the same may apply by using LiDAR or LANDSAT technologies. The high resolution output and on the ground accuracy that LiDAR provides may give a different, or possibly a better, result of cost path analyses.

Using other types of spatial analyses on Maya sacbeob can also give insight into ancient spatial organization. Using viewshed analysis from termini can help determine if the causeways followed lines of sight from their respective termini. Using flow accumulation analysis, found in ArcGIS other potential routes can be found. Instead of using least-cost, the emphasis is on the widest scale possible for traveling across a region, giving a ranking of preferred paths depending on the cost factor. This method has been successfully used in Central Asian archaeology to produce maps that model potential movements of pastoralists across the region (Frachetti 2006).

Because Maya causeways were used for human foot travel, ease of travel was less of a concern compared to the directness of the routes. Continued research on archaeological reconnaissance and excavations on causeways and their termini is clearly necessary to help answer why specific sacbeob were built. Combining fieldwork with analyses of spatial imagery can continue to solidify our understanding of ancient roads and social organization.

REFERENCES

Abrams, Elliot M., and Thomas W. Bolland

1999 Architectural Entergetics, Ancient Monuments, and Operations Management. *Journal of Archaeological Method and Theory* 6(4): 263-291.

Anderson, David G.

2012 Least Cost Pathway Analysis in Archaeological Research: Approaches and Utility. In *Least Cost Analyses of Social Landscapes: Archaeological Case Studies*, edited by Devin A. White and Sarah L. Surface-Evans, pp 239-258. University of Utah Press, Salt Lake City.

Ashmore, Wendy

1991 Site-planning Principles and Concepts of Directionality among the Ancient Maya. *Latin American Antiquity* 2: 199-226.

Ashmore, Wendy, and Jeremy A. Sabloff

2002 Spatial Orders in Maya Civic Plans. *Latin American Antiquity* 13(2): 201-215.

Barrera Rubio, Alfredo

1978 Settlement Patterns in Uxmal Area, Yucatan, Mexico. Paper Presented at the 43rd Annual Meeting of the Society for American Archaeology, Tucson.

Bolles, David, and William J. Folan

2001 An Analysis of Roads Listed in the Colonial Dictionaries and Their Relevance to Pre-Hispanic Linear Features in the Yucatan Peninsula. *Ancient Mesoamerica* 12(2): 299-314.

Branting, Scott

2012 Seven Solutions for Seven Problems with Least Cost Pathways. In *Least Cost Analyses of Social Landscapes: Archaeological Case Studies*. University of Utah Press, Salt Lake City.

Bustillos Carillo, Antonio

1964 *El Sacbe de los Mayas*. Costa-Amic Mesones, Mexico City.

Canuto, Marcello A., and Tomas Barrientos Q.

2013 The Importance of La Corona. *La Corona Notes* 1(1):1-5.

Carrasco V, Ramon

1993 Formacion Sociopolitica en el Puuc: El Sacbe Uxmal-Nohpat-Kabah. In *Perspectivas Antropologicas en el Mundo Maya*, edited by M.J. Iglesias Ponce de Leon, and F. Ligorred Perramon, pp 199-212. Publicaciones de la Sociedad Espanola de Estudios Mayas, Catalunya.

Chase, Arlen F., and Diane Z. Chase

2001 Ancient Maya Causeways and Site Organization at Caracol, Belize. *Ancient Mesoamerica* 12(2): 273-281.

2003 Minor Centers, Complexity, and Scale in Lowland Maya Settlement Archaeology. In *Perspectives on Ancient Maya Rural Complexity*, edited by Gyles Iannone and Samuel V. Connell, pp 108-118. Monograph 49. Cotsen Institute of Archaeology at UCLA, Los Angeles.

Chase, Arlen F., with Diane Z. Chase, Christopher T. Fisher, Stephen J. Leisz, and John F. Weishampel

2012 Geospatial Revolution and Remote Sensing LiDAR in Mesoamerican Archaeology. *Proceedings of the National Academy of Science* 109(32): 12916-12921.

Chase, Arlen F., with Diane Z. Chase and John F. Weishampel

2013 The Use of LiDAR at the Maya Site of Caracol, Belize. In *Mapping Archaeological Landscapes from Space*, edited by Douglas C. Comer and Michael J. Harrower, pp. 187-198. Springer, New York.

Chase, Arlen F., with Diane Z. Chase, John F. Weishampel, Jason B. Drake, Ramesh L. Shretha, K. Clint Slatton, Jaime J. Awe, and William E. Carter

2011 Airborne LiDAR, archaeology, and the ancient Maya landscape at Caracol, Belize. *Journal of Archaeological Science* 38: 387-398.

Cobos, Rafael and Terrance L. Winemiller

2001 The Late and Terminal Classic-Period Causeway System of Chichen Itza, Yucatan, Mexico. *Ancient Mesoamerica* 12(2): 283-292.

Crawford, O.G.S

1929 *Air Photography for Archaeologists*. Ordnance Survey Professional Papers n.s. 12. London

Doyle, James A., with Thomas G. Garrison, and Stephen D. Houston

2012 Watchful Realms: Integrating GIS Analysis and Political History in the Southern Maya Lowlands. *Antiquity* 86: 792-807.

Dunning, Nicholas P.

1992 *Lord of the Hills: Ancient Maya Settlement in the Puuc Region, Yucatan, Mexico*. Monographs in World Archaeology no 15. Prehistory Press, Madison.

Dunning, Nicholas P., and Jeff Karl Kowalski

1994 Lords of the Hills: Classic Maya Settlement Patterns and Political Iconography in the Puuc Region, Mexico. *Ancient Mesoamerica* 5: 63-95.

Estrada-Belli, Francisco

2011 *The First Maya Civilization*. Routledge, New York.

Fletcher, Roland

2009 Low-Density, Agrarian-Based Urbanism: A Comparative View. *Insights* 2(4): 2-19.

Folan, William J.

1977 El Sacbe Coba-Ixil: Un Camino Maya del Pasado. *Nueva Antroplogia* 2(6): 30-42.

1991 Sacbes of the Northern Maya. In *Ancient Road Networks and Settlement Hierarchies in the New World*, edited by Charles D. Trombold, pp. 222-229. Cambridge University Press, Cambridge.

Frachetti, Michael

2006 Digital Archaeology and the Scalar Structure of Pastoral Landscapes: Modeling Mobile Societies of Prehistoric Central Asia. In *Digital Archaeology: Bridging Method and Theory,* edited by Thomas L. Evans and Patrick Daly, pp 128-147. Routledge, New York.

Freidel, David, and Jeremy A. Sabloff

1984 *Cozumel: Late Maya Settlement Patterns*. Academic Press, New York.

Gann, Thomas

1926 *Ancient Cities and Modern Tribes: Exploration and Adventure in Maya Lands*. Charles Scribner's Sons, New York.

Garza Terrazona de Gonzalez, Silva, and Edward B. Kurjack

1980 *Atlas Arqueologico del Estado de Yucatan*. Instituto Nacional de Antropologia e Historia, Mexico City.

Golden, Charles, and Bryce Davenport

2013 The Promise and Problems of Modeling Viewsheds in the Western Maya Lowlands. In *Mapping Archaeological Landscapes from Space*, edited by Douglas C. Comer and Michael J. Harrower, pp. 145-157. Springer, New York.

Graham, Ian

1967 *Archaeological Explorations in El Peten, Guatemala*. Middle American Research Institute, Publication 33. Tulane University, New Orleans.

Hansen, Richard D.

1992 El Proceso Cultural de Nakbe y el Area del Peten Nor-Central: Las Epocas Tempranas. In *V Simposio de Investigaciones en Guatemala*, edited by Juan Pedro Laporte, Hector L. Escobedo, and Sandra V. de Brady, pp. 81-96. IDEAH, Guatemala.

1998 Continuity and Disjunction: The Pre-Classic Antecedents of Classic Maya Architecture. In *Function and Meaning in Classic Maya Architecture*, edited by Stephen Houston, pp. 49-122. Dumbarton Oaks, Washington D.C.

2012 Kingship in the Cradle of Maya Civilization: The Mirador Basin. In *Fanning the Sacred Flame: Mesoamerican Studies in Honor of H.B. Nicholson*, edited by Matthew A. Boxt and Brian Dervin Dillon, pp. 139-172. University of Colorado Press, Boulder.

Hansen, Richard D., with Beatriz Balcarcel, Edgar Suyuc, Hector E. Mejia, Enrique Hernandez, Gendry Valle, Stanley P. Guenter, and Shannon Novak

2006 Investigaciones Arqueologicas en el Sitio Tintal, Peten. *In XIX Simposio de Investigaciones Arqueologicas en Guatemala 2005*, edited by J.P. Laporte, B. Arroyo, and H. Mejia, pp 739-751. Museo Nacional de Arqueologia y Etnologia, Guatemala.

Hansen, Richard D., with Steven Bozarth, John Jacob, David Wahl, and Thomas Schreiner

2002 Climatic and Environmental Variability in the Rise of Maya Civilization: A Preliminary Perspective from Northern Peten. *Ancient Mesoamerica* 13 (2): 273-295.

Hansen, Richard D., and Stanley P. Guenter

2005 Early Social Complexity and Kingship in the Mirador Basin. In *Lords of Creation: The Origin of Sacred May Kingship*, edited by Virginia M. Fields and Dorie Reents-Budet. Scala Publishers, London.

Hansen, Richard D., with Edgar Suyuc-Ley, and Beatriz Balcarcel (editors)

2004 *Investigacion, Conservacion y Desarrollo en El Mirador, Peten, Guatemala: Informe 2003*. IDEAH, Guatemala.

Hansen, Richard D., with Edgar Suyuc-Ley, and Hector E. Mejia

2011 Resultados de la Temporada de Investigaciones 2009 Proyecto Cuenca Mirador. In XXIV *Simposio de Investigaciones Arqueologicas en Guatemala 2005*, edited by B. Arroyo, L. Paiz, A. Linares, and A. Arroyave, pp 174-191. Museo Nacional de Arqueologia y Etnologia, Guatemala.

Hassig, Ross

1991 Roads, Routes, and Ties That Bind. In *Ancient Road Networks and Settlement Hierarchies in the New World*, edited by Charles D. Trombold, pp. 17-27. Cambridge University Press, Cambridge.

Hutson, Scott R.

2012 Urbanism, Architecture, and Internationalism in the Northern Lowlands During the Early Classic. In *The Ancient Maya of Mexico: Reinterpreting the Past of the Northern Maya Lowlands*, edited by Geoffrey Braswell, pp. 117-140. Equinox Press, Bristol.

Hutson, Scott R., and Miguel Covarrubias Reyna

2011 De Uci Hasta Kancab: Reconocimiento de Una Calzada de Larga Distancia en Yucatan, Mexico. *Simposio de Investigaciones Arqueologicas de Guatemala*, edited by B. Arroyo, L. Paiz, A. Linares, and A. Arroyave, pp. 1217-1225. Museo Nacional de Arqueologia y Etnologia, Guatemala.

Hutson, Scott R., Miguel Covarrubias Reyna, and Leigh A. Ellison

2009 Un Paisaje Politico: Nuevas Investigaciones en el Sacbe Regional de Uci. *Los Investigadores de la Cultura Maya* 17(1): 287-297.

Jones, Dennis C.

1985 The Crossroads of El Mirador: Causeways and Cityscape of a Maya Site in Guatemala. Master's Thesis, Department of Geography and Anthropology, Louisiana State University, Baton Rouge.

Kurjack, Edward B., and E. Wyllys Andrews V

1976 Early Boundary Maintenance in Northwest Yucatan, Mexico. *American Antiquity* 41(3): 318-325.

Loya Gonzalez, Tatiana, and Travis W. Stanton

2013 Impacts of Politics on Material Culture: Evaluating the Yaxuna-Coba Sacbe. *Ancient Mesoamerica* 24(1): 25-42.

Maldonado Cardenas, Ruben

1979a Los Sacbeob de Izamal-Ake y Uci-Cansahcab en el Noroeste de Yucatan. *Antropologia e Historia, Boletin del INAH, Mexico*. 3 (27): 23-29.

1979b Izamal-Ake, Cansahcab-Uci, Sistemas Prehispanicos del Norte de Yucatan. *Boletin de la Escuela de Ciencias Antropologicas de la Universidad de Yucatan*. 6 (36): 33-44.

Matheny, Ray T.

1980 *El Mirador, Peten, Guatemala: An Interim Report*. Papers of the New World Archaeological Foundation no. 45. Brigham Young University, Provo, Utah.

Richards-Rissetto, Heather and Kristin Landau

2014 Movement as a Means of Social (Re)production: Using GIS to Measure Social Integration Across Urban Landscapes. *Journal of Archaeological Science* 41: 365-375.

Robles Castellanos, Fernando

1976 Ixil: Centro Agricola de Coba. *Boletin de la Escuela de Ciencias Antropologicas de la Universidad de Yucatan* 4(27): 13-43.

Roys, Lawrence, and Edwin M. Shook

1966 *Preliminary Report on the Ruins of Ake, Yucatan*. Memoirs of the Society for American Archaeology No. 20, 31(3): 1-54.

Ruppert, Karl, and John Hopkins Denison

1943 *Archaeological Reconnaissance in Campeche, Quintana Roo, and Peten*. Carnegie Institution of Washington Publication 543. Washington, D.C.

Sever, Thomas L., and Daniel E. Irwin

2003 Landscape Archaeology: Remote-Sensing investigation of the Ancient Maya in the Peten Rainforest of Northern Guatemala. *Ancient Mesoamerica* 14: 113-122.

Shaw, Justine M.

2001 Maya Sacbeob: Form and Function. *Ancient Mesoamerica* 12(2): 261-272.

2008 *White Roads of the Yucatan: Changing Social Landscapes of the Yucatec Maya*. University of Arizona Press, Tucson.

Sprajc, Ivan

1990 Cehtzuc: A New Maya Site in the Puuc Region. *Mexicon* 12:62-63.

Stanton, Travis W., and David A. Freidel

2005 Placing the Centre, Centring the Place: The Influence of Formative Sacbeob in Classic Site Design at Yaxuna, Yucatan. *Cambridge Archaeological Journal* 15(2): 225-249.

Suasnavar, Jose S.

1994 Las Calzadas de Nakbe. In *VII Simposio de Investigaciones Arqueologicas en Guatemala, 1993,* edited by J.P. Laporte and H. Escobedo, pp 284-294. Museo Nacional de Arqueologia y Etnologia. Guatemala.

Surface-Evans, Sarah L., and Devin A. White

2012 An Introduction to the Least Cost Analysis of Social Landscapes. In *Least Cost Analyses of Social Landscapes: Archaeological Case Studies*. University of Utah Press, Salt Lake City.

Thompson, J. Eric S., with H.E.D. Pollock, and J. Charlot

1932 *A Preliminary Sudy of the Ruins of Coba, Quintana Roo, Mexico*. Carnegie Institution of Washington Publication 424. Washington, D.C.

Trombold, Charles D. (editor)

1991 *Ancient Road Networks and Settlement Hierarchies in the New World*. Cambridge University Press, Cambridge.

USGS

2000 Shuttle Radar Topographic Mission (SRTM). Electronic Document, https://lta.cr.usgs.gov/SRTM2, accessed May 23, 2014.

2009 Routine ASTER Global Digital Elevation Model. Electronic Document, https://lpdaac.usgs.gov/products/aster_products_table/astgtm, accessed May 23, 2014.

2013 Global Data Explorer. Electronic Document, http://gdex.cr.usgs.gov/gdex/, accessed May 23, 2014.

Villas-Rojas, Alfonso

1934 *The Yaxuna-Coba Causeway*. Contributions to American Archaeology, Vol. 2, No.9. Carnegie Institute of Washington, Washington D.C.

White, Devin A., and Sarah L. Surface-Evans (editors)

2012 *Least Cost Analyses of Social Landscapes: Archaeological Case Studies*. University of Utah Press, Salt Lake City.

Witschey, Walter R.T, and Clifford T. Brown

2008 The Electronic Atlas of Ancient Maya Sites. Electronic document, http://mayagis.smv.org/, accessed April 5, 2014.