GIS-based Cultural Route Heritage Authenticity Analysis and Conservation Support in Cost-surface and Visibility Study Approaches

HE, Jie

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Thesis/Assessment Committee

Professor TSOU Jin-Yeu (Chair, Thesis Supervisor)
Prof. LIN Hui (Committee Member)
Prof. HO Puay-peng (Committee Member)
Prof. Lin Feng-Tyan (External Examiner)

ABSTRACT

The concept of the cultural route, which emerged in the mid-1990s in the context of an expansion of heritage conservation interest from a concern with individual monuments to broad landscapes, is an innovative approach to understanding cultural exchange. Nevertheless, there are many uncertainties surrounding basic concepts and definitions; as such much confusion has arisen with regard to conservation implementation, such as questionable property inscription or inadequate protection zones. This study provides a system for investigating cultural route authenticity and introduces assessment results to support decision making on heritage protection planning by delineating different levels of authenticity in cultural route properties and settings.

This system reifies cultural route authenticity as spatial layouts and structures of, as well as the functionalities associated with, tangible cultural route elements, including paths, constructions and natural contexts in continuous scales through spatial analyses in the geographical information system (GIS) approach. The investigation firstly replicates movement to locate the routes and then interprets spatial-related historical functionalities of cultural route elements and their spatial performance or influence in order to reveal their authenticity and map degrees of authenticity for such heritage assets. Finally the investigation and assessment results, e.g. those spatially-distributed authenticity levels and heritage authenticity significance are translated into a four categories in cultural route properties, core areas, and two levels of buffer zones, as conservation delimitation to support planning decision making.

Cost-surface and visibility analyses are introduced as the basic methodological approach. Cost-surface analysis on the one hand is used to locate movement paths in context integrated topography, land use and magnetism of historical assets and functions, on the other hand, it also creates accumulative cost surface which can be considered as the inventory of spatial influences of cultural route property. Visibility, generally demonstrated by accumulative viewsheds, reveals specific functions like observing, weapon shooting, place identifying, and so on is introduced to make descriptive interpretation on spatial relationship, landscape perception, special control power, and even natural worship or ritual characteristics and integrated in cost-surface model as one of the anisotropic parameters.

A case study on the Great Wall of China is implemented in this research. Firstly, as the central frontier in the Ming Dynasty for defending against Mongolian nomadic invasion, it is investigated by replicating the most probable large scale invasion routes and strategic defensive locations. Then the natural context, route and military facilities of the Juyongguan Pass defensive system and their interrelationships are investigated by means of visibility mapping and comparative cost-surface analyses in regional scale. Spatial control of the Badaling Great Wall and Juyongguan Fortress are mapped and reclassified into conservation delimitation for the Fortress.

The significance of this study is that it provides a mechanism applicable to cultural route studies and conservation. Meanwhile, the originality of this study consists in the invention of the schematic system and its implementation in mapping and delimiting the spatial distribution of cultural route historical functions to support conservation planning on a scientific basis.

自上世紀九十年代中期，關注整體文化交流作用的“文化綫路”概念，在遺產保護從關注獨立遺存逐漸擴展至更大環境考慮的大背景下作爲文化遺産保護的一種創新模式開始勃興，但迄今仍存在諸多基本概念的混亂，導致實踐操作上出現誤判遺產價值或緩衝保護區域不足等問題。此論文研究則提出一個針對文化綫路“原真性”調查和評估的系統，并將研究所得的原真性價值等級轉化爲保護規劃决策的支持。

該系統將文化綫路的原真性通過道路、建築設施和自然環境等實存元素的空間布局、空間結構和歷史功能加以解釋，并通過以地理信息系統的支持進行空間分析。研究過程中首先模擬文化綫路空間中具體的行動路徑來確定道路位置，然後對各種設施與空間相關的歷史功能及空間影響或表現加以闡釋，并標識爲設施原真性空間分布的地圖，最後評估結果會被轉化爲四種等級的保護地界劃分可能作爲規劃决策支持。

本研究將采用“成本表面”和視覺分析作爲主要的分析手段。“成本表面”分析一方面通過模型融合地形、用地類型與設施機能上的引力影響來確定行動路徑的位置，同時生成“累積成本距離”描述文化綫路設施對空間的影響能力。視覺分析則主要通過“累計可視性”表達瞭望、觀察、射擊區域、空間場所認知等特殊功能及相關的文化綫路機制，同時作爲各向异性的成本表面參數之一引入“成本表面”模型運算。

本研究中采用了中國長城的案例。首先通過大尺度上軍隊行進的可能路綫和策略性重要地點的審視，對明長城中部前綫抵禦蒙古游牧民族入侵的能力進行分析。在區域尺度上則選擇居庸關區域的防禦系統，以視覺分析和不同情況下成本表面距離的對比分析其自然環境、道路布局和軍事設施和他們之間的相

互關係。最後對八達嶺長城和居庸關關城的空間控制區域進行製圖，并據此提出居庸關關城的一系列保護劃界。

此一研究的意義在于爲文化綫路研究和保護提供一種可操作的機制，其創新性表現在系統的建立并以科學化的手段依據遺產歷史功能的空間分布來支持遺產保護規劃的決策。

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Chapter 1

INTRODUCTION

In recent decades, interest in heritage and conservation has expanded from individual monuments to broad landscapes. The concept of the cultural route is an innovative approach to understanding cultural exchange that emerged in the mid-1990s. Yet despite the development of this concept over more than a decade, many uncertainties still surround cultural route concepts and definitions. Because of this, much confusion has arisen over the conservation limits of such heritage sites, as demonstrated by the indiscriminate inscription of questionable properties and inadequate protection zones. This study investigates cultural route authenticity and introduces assessment results to support decision making on planning issues by delineating different levels of authenticity in cultural route settings.

This study reifies cultural route authenticity as spatial layouts and structures of, as well as the functionalities associated with, tangible cultural route elements. Geographical information science (GIS) can be used to support a detailed and innovative interpretation of authenticity and heritage values, and can be applied to enhance such analysis.

1.1 Background

Interest in cultural heritage has gradually expanded from "monuments in isolation" to broader, more extended scales such as sites, ensembles, and cultural landscapes (Ducassi 2005a). In recent years, a notable development has been the concept of the cultural route, which represents a new approach to the notion of heritage conservation. Following the development of this doctrine over the course of more than a decade, the International Committee on Cultural Routes (CIIC) of the International Council on Monuments and Sites (ICOMOS) eventually defined this concept as follows:

> *A cultural route is a land, water, mixed or other type of route, which is physically determined and characterized by having its own specific and historic dynamics and functionality; showing interactive movements of people as well as multi-dimensional, continuous and reciprocal exchanges of goods, ideas, knowledge and values within or between countries and regions over significant periods of time; and thereby generating a cross-fertilization of the cultures in space and time, which is reflected both in its tangible and intangible heritage.* (CIIC of ICOMOS 2003)

This definition was intended to be a revision of the *WHC Operational Guidelines* that would act as a substitute for the original term "heritage routes". The latest revision of the *Operational Guidelines* made in February 2005 adopted the CIIC's suggestion of introducing the concept of heritage routes from a cultural heritage perspective. The fact that heritage routes have been recognized as one of the four special types of heritage properties indicates that many professionals from around the world have taken a keen interest in cultural route heritage and its significance (Ducassi 2005a).

1.1.1 The Development of the Cultural Route Concept

The origins of cultural route research can be traced to the "Expert Meeting on Routes as a Part of our Culture" held in Madrid in November 1994 (UNESCO 1994) as a step to follow up on the inscription of the Spanish section of the Route of Santiago de Compostela on the World Heritage List in 1993. This meeting established the basic concept of and criteria for cultural routes. After the official establishment of the ICOMOS International Committee on Cultural Routes (CIIC) in 1998, several meetings (Table 1) were held and related documented studies were carried out in the period before 2002 to develop an international consensus and doctrine on this topic (Martorell-Carreño 2003). In 2003, the "Meeting of Experts on Cultural Routes" held in Madrid proposed a revision of the *WHC Operational Guidelines* to consolidate the position of cultural routes as a World Heritage category (CIIC of ICOMOS 2003). The document produced represents a summary of the professional research carried out in previous years.

Since 2003, trends in cultural route studies have become more diversified. The CIIC organized fewer technical meetings or structured research projects than in the preceding decade. It held only one scientific meeting in 2004, which facilitated detailed discussions on cultural routes in Africa, America, Asia and Europe. Despite this, the significance and anthropological aspects of settings have become popular topics of discussion in this field. Cultural route heritage is mostly discussed in an evolving context. For instance, the three recent scientific symposiums held by ICOMOS have all concentrated on topics relevant to this area. The Fifteenth General Assembly and Scientific Symposium of ICOMOS proclaimed a broader interest in and investigation perspectives on cultural routes. Cultural routes comprised one of the four sub-topics for these symposium discussions. Altogether, there are 45 research papers on general concepts, methodologies, specific topics and case studies on cultural routes, which have made the conference proceedings the most important literature on cultural routes since 2003.

Following developments over the course of more than a decade, a working document as a draft of the *ICOMOS Charter on Cultural Routes* was presented for discussion at the General Assembly held in Xi'an (ICOMOS 2005). Furthermore, a paper written by the CIIC President, Ms. Suárez-Inclán Ducassi, was presented at the symposium to provide further explanation (Ducassi 2005a). After further minor revisions, this document will be submitted for adoption at the Sixteenth General Assembly of ICOMOS to be held in September and October this year.

Table 1

Milestone conferences for the development of cultural routes

Conference name	Conference topic	Date and Venue
II ICOMOS Iberoamerican-Mediterranean Days: the Canary Islands: a Cultural Crossroads between Continents	Intercontinental cultural crossroads, cultural routes, legislation and cultural tourism	September 1998, San Cristóbal de la Laguna, Canary Islands, Spain
The cultural route of Vines and Wine Among the Peoples of the Mediterranean		May 1999, Santo Domingo de la Calzada, La Rioja, Spain
International Seminar on Hispano-Portuguese Bastioned Fortifications, a Cultural Route Across Five Continents		May 1999, Ibiza, Spain
Methodology, Definitions and Operative Aspects of Cultural Itineraries (1st part)		May 1999, Ibiza, Spain
International CIIC/ICCR Seminar	Methodology, Definitions and Operative Aspects of Cultural Itineraries	October 1999, Guanajuato, Mexico
International Congress of the ICOMOS CIIC	Intangible heritage and cultural routes in a universal context: steps towards making a pre-inventory of cultural routes	June 2001, Pamplona, Navarra, Spain
ICOMOS 13th General Assembly Meetings and the scientific meeting of the International Committee on Cultural Routes (CIIC)	The Conceptual and Substantive Independence of Cultural Routes in relation to Cultural Landscape	December 2002, Madrid, Spain
Encuentro Científico Internacional	An Inventory of Cultural Routes;	October 2004,

sobre Itinerarios Culturales [1]	The Identification and Promotion of Cultural Routes: Fortifications and port cities as components of cultural routes; control and use of land; trade routes; pilgrimage routes	Ferrol, Spain
The 15th General Assembly and Scientific Symposium of ICOMOS[2]	Monuments and sites in their settings: conserving cultural heritage in changing townscapes and landscapes	October 2005, Xi'an, China

1.1.2 The Delimitation of Heritage Definitions and Conservation

From the implementation perspective, a delimitation program is an important aspect of heritage conservation. The primary and first task of protection is heritage property recognition. The boundaries of a heritage property should be clearly defined as part of the heritage inscription. To conserve heritage settings and reduce the impact of outside influences, a buffer zone is generally introduced as a spatial solution through legislation or planning measures implemented for the purpose of conservation. Both of these two approaches require the unambiguous delimitation of cultural route spaces, a difficult task in the current academic and professional environment (Ducassi 2005a; Martorell-Carreño 2005; Martorell-Carreño 2006).

The World Heritage Convention (WHC) approach

The *WHC Operational Guidelines* generally considers the introduction of a buffer zone to be obligatory. Clearly defined boundaries that include both property boundaries and buffer zone(s) are an essential undertaking for a World Heritage nomination. The *WHC Operational Guidelines* state that a clear delineation of

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[1] A record of the proceedings of the meeting entitled "Encuentro Científico Internacional sobre Itinerarios Culturales (Ferrol, España / Spain, 1, 2 y 3 de octubre de 2004)" was published by ICOMOS in 2005 as *Identification, Promocion e Inventario de los Itinerarios Culturales: Fortificaciones, puertos y ciudades en la estructura de los Itinerarios Culturales. Rutas de Comercio, Control del Territorioy Peregrinaje, (Monuments and Sites: X).*

[2] Relevant information and papers can be found at http://www.international.icomos.org/xian2005/home_eng.htm .

heritage boundaries ensures the authenticity and integrity of the heritage site. The boundaries for cultural heritage sites "should be drawn to include all those areas and attributes which are direct tangible expressions of the outstanding universal value of the property, as well as those areas which in the light of future research possibilities offer potential to contribute to and enhance such understanding" (UNESCO 2005, paragraph 100, p.25).

The legislative intent of the *WHC Operational Guidelines* is that the distinction between the purpose of boundaries and a buffer zone is as follows: a boundary is set to express heritage value and sustain authenticity and integrity, whereas a buffer zone is a delimitation to allow for conservation action to be taken, rather than being part of a nominated property (Staneva 2006). Although both of these delimitations have the purpose of effective heritage protection, a boundary implies a preservation approach, while a buffer zone is aimed at conservation.

The establishment of buffer zones to conserve heritage sites is a developing approach. The first version of the *WHC Operational Guidelines* issued in 1977 referred to the heritage setting protection concept, but did not deal specifically with the establishment of buffer zones. In the 1980s version, the buffer zone concept was clearly defined as "an area surrounding the property which has an essential influence on the physical state of the property and/or on the way in which the property is perceived" (from Kono 2006). Nomination documents were required to include detailed plans based on technical studies. In the 1988 version, the definition of "buffer zone" was amended slightly to an area that "has restrictions placed on its use to give an added layer of protection," in which an emphasis was placed on the active utility of the buffer zone, as opposed to its characteristics. The use of the term "restriction" is considered a milestone in the implementation of buffer zones (Kono

2006). In the most recent version, the definition of "buffer zone" has been modified to "include the immediate setting of the nominated property, important views and other areas or attributes **that are functionally important as a support to the property** and its protection" (UNESCO 2005, p. 25).

1.2 Research Questions

Despite the developments in the cultural route field over more than a decade, many theoretical, methodological and technical problems remain, such as the critical shortcomings in the assessment of cultural route significance through in-depth and scientific approaches discussed by Ducassi (2005a). The hazy definition of "value" also leads to conservation problems.

In an official summary of developments in the cultural route discipline over the previous ten years, conceptual confusion is highlighted as the main cause of the depressing fact that many sections of significant cultural routes have been ignored and have not been inscribed in the World Heritage List (Ducassi 2005a). The recognition of cultural routes and interpretations of cultural route characteristics and their significance have been seriously affected. In addition, conceptual innovations in the heritage and conservation field may lead to inconsistencies in value assessment and difficulties in inscription, especially for the more complex cultural route cases (Martorell-Carreño 2006).

1.2.1 Shortcomings of Delimitations and Their Implementation in Cultural Routes

The most well-known example of a cultural route, the Route of Santiago de Compostela in Spain, illustrates this identification problem resulting from the lack of conceptual clarity, as shown in Martorell-Carreño's analyses (Martorell-Carreño 2005, 2006). While some of the inscribed assets are questionable in terms of their interrelationships with the pilgrimage route, other more important facilities are not included. Meanwhile, more than 1,800 separate structures have been inventoried and are considered to be associated with the route. Nevertheless, their locations and borders cannot be inspected and there are no clear judgment criteria. This lack of clarity in the spatial description of these structures eventually leads to uncertainty over the boundaries or scope of the route (Martorell-Carreño 2006). These problems have had a very negative influence on heritage recognition and conservation.

Identifying the significance of cultural route heritage certainly involves difficulties and complexities. The first such difficulty or complexity is the fact that heritage can vary in scale and be extended over time. Cultural routes can be tangible heritage components distributed over areas that are local, national, regional, continental or intercontinental in scale (Ducassi 2005a; ICOMOS 2005). Secondly, because cultural routes imply heritage structures located in large spaces, their settings may include various types of cultural and natural landscapes (Conti 2005). It is impossible to understand heritage in isolation without considering the wider context. The most important issue is that cultural routes are formed by a large number and different types of tangible and intangible, spatial and temporal phenomena. Facilitating a mechanism that allows for an understanding of the whole system may involve an effort significantly greater than that required for other types of cultural heritage or individual sites.

Problems in heritage delimitation

Fulfilling delimitation requirements for properties and buffer zones also requires an in-depth assessment of heritage value. According to statistical data provided by heritage legislation researchers, inadequate delimitation is a common and serious problem, as illustrated in Figure 1 and Figure 2.

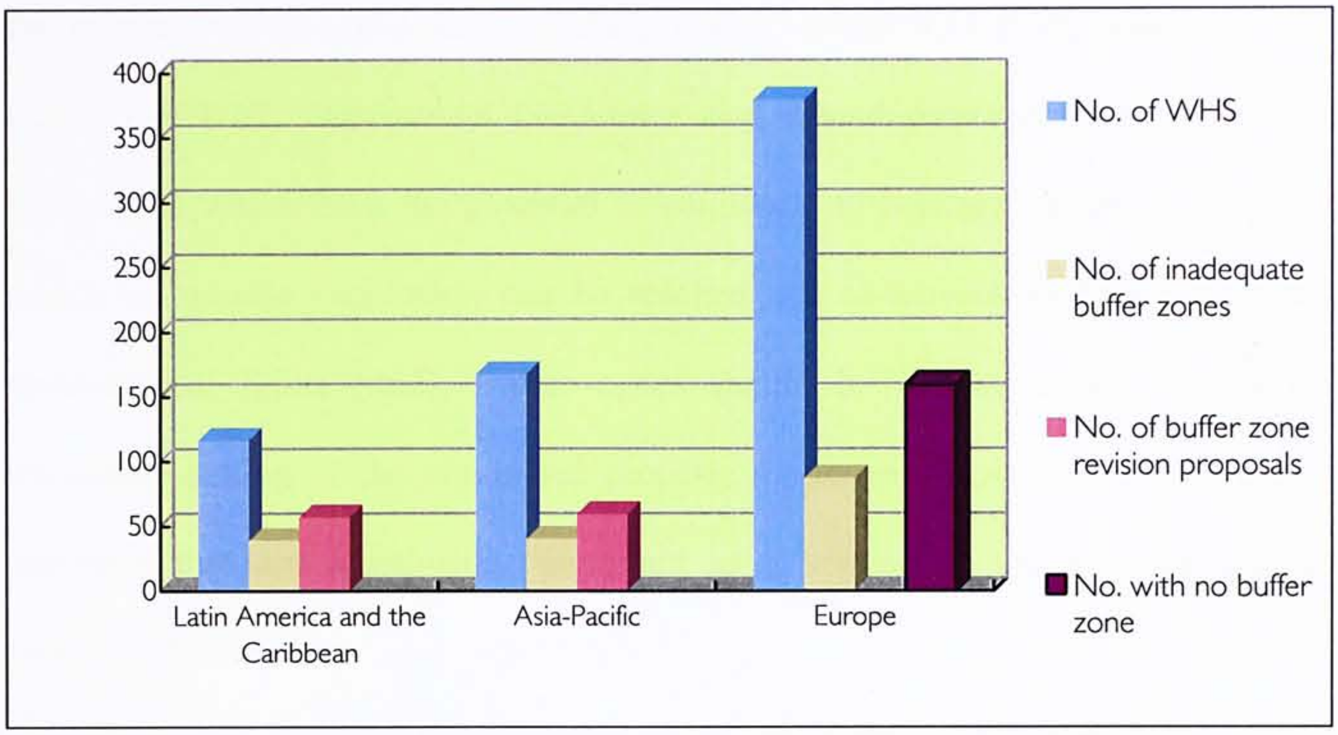


Figure 1

Numbers of World Heritage sites in Latin America and the Caribbean, Asia-Pacific and Europe for which inadequate delimitations and other relevant problems were identified in 2006 (summarized from Martorell-Carreño (2006))

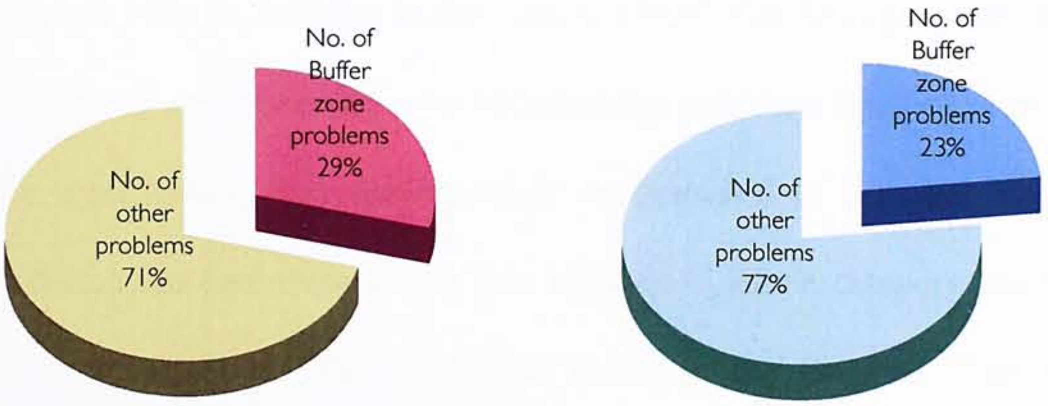


Figure 2

Proportion of buffer zone problems: (left) based on sites included in the List of World Heritage in Danger in 2006; (right) based on problems indicated in State of Conservation reports on 99 sites in 2006 by the World Heritage Committee (summarized from Staneva (2006))

For conservation management, the delimitation of a heritage property boundary should "include all those areas and attributes which are direct tangible expressions of the outstanding universal value of the property" (UNESCO 2005, paragraph 100, p.25). The *WHC Operational Guidelines* also extend preservation boundaries to those areas which have the potential to contribute to heritage significance but for which no reliable conclusion can be reached due to current methodological and technological limits (ibid). Buffer zones should be delineated to "include the immediate setting of the nominated property, important views and other areas or attributes that are functionally important as a support to the property and its protection" (ibid).

In practice, the majority of buffer zones are simply delineated as an offset a certain distance from the property boundaries. Although this is a rational mechanism, it is not sufficiently mature and is not to be recommended for cultural routes in particular (Martorell-Carreño 2006). In addition, confusion can potentially be caused by the use of a criterion as ambiguous as "functionally important" (UNESCO 2005, p.25, paragraph 104) in defining buffer zones. Given that both property and buffer zone delimitations are concerned with both settings and their functional contribution to heritage significance, how the boundary or threshold of functional importance should be defined to determine which area belongs to which category has become a serious practical problem. The celebrated threat to the Dresden Elbe Valley in Germany that has arisen in recent years is illustrated by the fact that the Verkehrszug Waldschlößchenbrücke (Waldschlösschenbrücke Bridge) is actually located within the property boundary (the core zone) of the heritage site, which is a cultural landscape, rather than simply impacting the buffer zone. Nevertheless, it is clear that in this case inadequately defined heritage legislation left a loophole that could be exploited by new developments (Institute of Urban Design and Regional Planning of RWTH Aachen University 2006).

Professionals have now reached a consensus that a further review of the *WHC Operational Guidelines* is necessary (Martorell-Carreño 2006; Staneva 2006), and that assessments of property and setting significance need to be improved and conducted both qualitatively and quantitatively (ICOMOS 2005). Therefore, further development of the heritage boundary and buffer zone delineation mechanism based on a sophisticated investigation of heritage significance is an immediate priority in the heritage conservation field.

Problems in cultural route delimitation

Alberto Martorell-Carreño has reviewed several cultural routes and concluded that there are many shortcomings in current cultural route delimitation practices. These shortcomings mainly center on confusion over property boundaries and buffer zones (Martorell-Carreño 2005, 2006). Although several kinds of mechanism have been established for legislation or planning purposes, such as level delimitation for the Route of Santiago de Compostela in Spain (Martorell-Carreño 2005) and the approaches taken for the Sacred Sites and Pilgrimage Routes in the Kii Mountain Range in Japan (Sugio 2005), few improvements can be found in the system as a whole.

1.2.2 Authenticity as a Subject of Investigation and Planning Support

Due to the abovementioned shortcomings in cultural route study and management, it is reasonable to consider a mechanism for evaluating heritage value that will allow conservation sites to be managed on the basis of a reliable value assessment. A review of two basic heritage and cultural route conservation documents, the *WHC*

Operational Guidelines (UNESCO 2005) and the *5th Draft of the Charter on Cultural Routes* (ICOMOS 2005), reveals that authenticity can be used as the key value and main criteria for value assessment to enable an understanding of cultural route significance, as well as forming the objective for the implementation of conservation and management measures.

According to these conceptual texts, for the value assessment, the *WHC Operational Guidelines* have defined criteria *i* to *vi* to illustrate their outstanding universal values. Authenticity is the most decisive identification criterion that has to be fulfilled by a heritage site (UNESCO 2005). Authenticity is also emphasized in the cultural route doctrine for heritage identification. The contribution of authentic value to both the significance assessment and conservation is also accentuated in the draft *Charter on Cultural Routes* (ICOMOS 2005). In addition, the principle of WHC heritage protection is to maintain and even recover or enhance authentic value. Given that protection boundaries for cultural heritage sites have to cover all valuable properties (UNESCO 2005), authenticity also serves as a protection delineation criterion. Therefore, the interpretation of cultural route authenticity is set as the objective of the proposed mechanism.

1.3 Research Definition

In light of the issues raised, this study investigates cultural route authenticity and uses the assessment results to support planning decision making by delineating different levels of authenticity in cultural route settings. The study reifies cultural route authenticity according to the spatial layouts and structures of, as well as the functionalities associated with, tangible elements of cultural routes.

1.3.1 Research Objectives

The objectives of this study are to:

1. Replicate possible movement through natural contexts or cultural landscapes to investigate route or trail selection, which is the key function of a cultural route, and define the basic authenticity or integrity of sections of cultural routes that are studied.
2. Interpret the spatially-related historical functions of cultural route elements and assess their spatial performance or influence to reveal their authenticity and map the degree of authenticity of such heritage assets.
3. Translate these spatially-distributed authenticity levels and heritage authenticity significance into different categories of conservation delimitation to support conservation planning.

1.3.2 Significance of the Study

The significance of this study is that it provides a mechanism that is applicable to cultural route studies and conservation. Firstly, the scheme offers a systematic investigation procedure for studying cultural route substratum in physical constructions and paths, and for analyzing historical functionalities to reveal the authenticity of heritage sites, thereby enhancing the level of knowledge on the cultural route being studied. Secondly, this mechanism serves as a bridge between research and cultural route management. It provides scientifically based delimitations to improve the validity and utility of the cultural route heritage protection task, which is generally challenging. Both of these benefits will contribute to both the knowledge discipline and conservation practice. The originality of this study can be described in the following two ways:

1. It involves the invention of a cultural route study scheme as a methodological approach by integrating GIS-based cost-surface and visibility analyses; and
2. It maps and delimits the spatial distribution of cultural route asset functions to support conservation planning on a scientific basis.

Chapter 2

LITERATURE REVIEW

The initial part of this literature review consists of a detailed discussion of previous academic research on cultural route and heritage site delimitation. Subsequently, to facilitate the proposed study against the background of the shortcomings in existing research, several methodological approaches that can be used to support the scientific investigation to be undertaken in the course of analyzing the proposed research objectives, including landscape archaeology and the geographical information system (GIS), are presented and discussed.

2.1 Cultural Route Heritage Disciplines and Protection Practices

Although "cultural routes (or heritage routes)" have been discussed as an evolving heritage type for more than a decade, other than the documents issued following several expert meetings and symposiums organized by the technical advisory bodies of the World Heritage Committee, such as CIIC and ICOMOS, there are still very few scientific papers on this topic. Most of the papers issued to date concentrate on the description of cultural route inscription candidates rather than on in-depth theoretical, methodological and technical studies. The few exceptions can be found in Martorell-Carreño (2003) and several technical reports such as CIIC of ICOMOS (2003) and UNESCO (1994).

2.1.1 Theoretical and Methodological Investigations

The most up-to-date discussions in the cultural route discipline can be found in the discussions of the 15th Scientific Symposium of ICOMOS. Among the 45 papers presented in a thematic session called "*Cultural routes: the challenges of linear settings for monuments and sites,*" only six discuss theoretical and methodological aspects, among which the presentations given by Ducassi (2005a) and Prieto (2005) are notable contributions to the literature. The other papers concentrate on case studies in a variety of dimensions around the world (Conti 2005; Ducassi 2005b).

The paper presented by the CIIC President, Ms. Suárez-Inclán María Rosa Ducassi (2005a) included the most authoritative doctrinal review in the context of the development of the cultural route discipline. The President noted that key questions on the current developmental status of cultural routes are conceptually ambiguous, an observation that has been included in the research question section of this thesis. Her paper also proposed the main contents of the draft *International Charter for Cultural Routes*, which indicates the future approach to be taken to cultural route development.

Rodriguez-Villasante Prieto Juan Antonio's (2005) paper proposes a research methodology for investigating fortifications and cultural route logistics. In this scheme, he categorizes cultural route properties into tangible elements (such as monuments), intangible relationships among these elements based on the cultural route's functions in transportation and communication, and geographical and defensive settings. Their historical functions can be investigated through "control" as assessed on a political, social-economic and military basis. Antonio uses four tangible and intangible components, which are communication methods (via), means of movement (vehicles), connecting points (terminals), and logistical cargo or load, to interpret the historical functions of cultural routes by means of logistical analysis. In his paper, Antonio has revealed several noteworthy facts. Firstly, the historical and present-day functions of a cultural route have to be distinguished from one another.

The historical evaluation scheme for heritage inscriptions suggested in this paper also considers the "instrumental" value which may have become detached due to the difference between the function fulfilled historically and that fulfilled currently. Secondly, historical evaluation has to be split from the other significances such as universal, national, regional and local values. These concepts reflect the emphasis on authenticity and the consequences of requirements applicable to the lucubration of historical interpretations. Furthermore, an approach based on transportation and logistics studies, which concentrates on the key original functions of cultural routes, provides another perspective that enables cultural route heritage significance to be assessed in an effective manner.

In addition to these two papers that deal with purely theoretical concerns, Jing Feng assesses the Silk Road in a theoretical context and from a perspective based on the dynamics of heritage significance and value appreciation (Jing 2005). He suggests that settings and physical environments, and ecology in particular, have to be emphasized when assessing authenticity in terms of both tangible and intangible functional or historical aspects. For example, difficulties caused by Silk Road landscapes were taken into account in setting the value of silk as a commodity (Jing 2005).

2.1.2 Delimitations and Case Studies

The most recent discussions on preservation delineation can be found in the ICOMOS scientific symposium "*The World Heritage Convention and the Buffer Zone*" (ICOMOS 2006). Staneva's (2006) paper argues that the current WHC heritage buffer zone paradigm is inadequate, and proposes criteria for buffer zone delimitations based on functionality, visual aspects, spatial aspects and vulnerability to fulfill protection requirements. However, from the conceptual perspective, these criteria are simply a summary of relevant conservation documents and are too abstract to be implemented. Martorell-Carreño (2006) highlights similar aspects of the cultural route discipline. The original suggestion he makes is to recommend that different delimitation treatments be used for distinct contexts or settings, an approach that will be reviewed in detail later.

The approaches taken to the delimitation of WHC heritage property buffer zones can be categorized into three kinds. The first and most common approach is simply to offset a certain distance around a heritage property. The second approach is to define the buffer zone according to geographical or environmental context. The third method is to introduce ranking systems in which the delimitation region is classified to meet the dynamics of heritage protections.

Buffer zones and delimitations using the "buffer" operation

The criteria for offsetting a buffer distance from a heritage property boundary to offer protection is still the main heritage property approach used by the WHC. In the WHC List, it is not only applied to solitary monuments, but is also adopted to guard against damage to serial or integrated heritage properties such as cultural landscapes, historical towns and heritage routes, like the examples given by Umezu (2006) (Figure 3(a)). Digital technologies promoted in the *WHC Operational Guidelines* (UNESCO 2005, Annex 5, 1.e) allow buffer zones to be easily delineated through a simple "buffer" operation in GIS or CAD software. The convenience afforded by this technology appears to have reduced the delimitation exercise to a straightforward decision on buffer distance.

However, according to the definition given in paragraph 104 of the *WHC Operational Guidelines*, the "buffer" approach merely delineates the "immediate setting," and does not take other attributes into consideration. Therefore, firstly, this approach departs from the intent of the legislation. Moreover, defining the length of the offset distance can be very complicated. Umezu (2006) does not provide the reasons for adding an extra distance of 500 meters on top of the originally sophisticated conservation and urban planning requirements applicable in Kyoto, Japan.

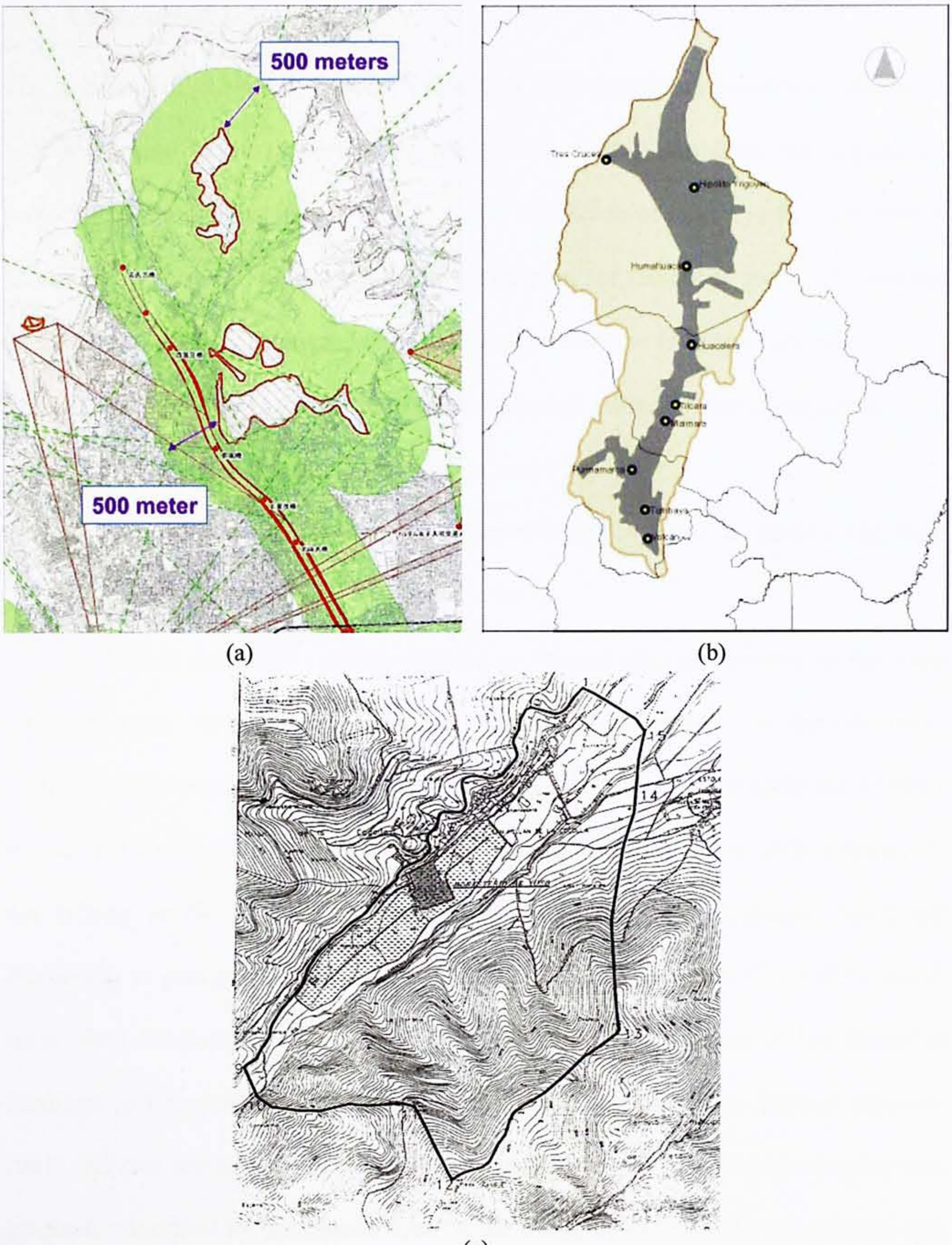
In practice, the inadequacy of buffer zone areas has had an enormous impact on cultural heritage protection in recent years (Martorell-Carreño 2006; Staneva 2006). The validity and utility of buffer zone delimitations should be a source of concern. In addition, certain indefinite weaknesses can be identified in the delimitation of heritage boundaries themselves, as well as in the theoretical bases for such delimitations, such as the identification of their significance ((Martorell-Carreño 2006). Offsetting from an uncertain boundary will make the situation even worse.

The current buffer zones for the Route of Santiago de Compostela in Spain

A more typical example of this "buffer" distance method and its limitations can be found in the first cultural route inscribed in the WHC List, the Route of Santiago de Compostela in Spain. The area within 30 meters either side of the route has been nominated as a protected historical complex and defined in the nomination document. However, experts consider that these 30 meters buffer areas should actually be viewed as a delimitation of heritage boundaries rather than as buffer zones (Martorell-Carreño 2006). Moreover, Martorell-Carreño (2006) has listed the complexities involved in the protection regulations for typical sections that fall within the jurisdiction of different administrative regions. The delineations set by five autonomous governments vary from 3 to 100 meters either side of the route. Only La Rioja has legislated for a 250-meter buffer zone either side of the route in addition to the first protection layer. According to Martorell-Carreño's analysis, a 30 meter protection zone is implemented as a temporary solution without any technical design input, and cannot fulfill the protection function (Martorell-Carreño 2006). Other defined distances such as the 100 meter regulations in Castile-Leon cannot be rationally explained, either in terms of the distinction between the distance for this part of the route as compared with other sections or how the absolute value has been set. A much better job is done on the part of the route that passes through La Rioja through the introduction of clear setting and landscape protection objectives for the buffer zone, although the validity of the 25 meter offset is still open to question. The protection planning measures taken in La Rioja also offer a parallel mechanism for justifying or modifying buffer zone extensions, which is appreciated by the author. In summary, the establishment of a standard buffer zone for the entire length of a cultural route is considered unfeasible (Martorell-Carreño 2006).

Delimitations based on geographical context

This approach is normally based on site investigations and specific research on the environmental context of a protected heritage property. Compared to a simple offset, this context-oriented delimitation approach has the potential to fulfill the visual impacts or functional concerns required by the *WHC Operational Guidelines*. Along the Argentinean cultural route of La Quebrada de Humahuaca, a buffer zone has been established in a relatively enclosed valley accommodating vernacular habitation and a natural environment that provide a cultural landscape and visual features (Figure 3(b)). Nevertheless, criteria other than those that simply follow the integrity of geographical morphology may be used in delineating buffer zones for heritage sites located in valleys. The buffer zone for the San Millan, Yuso and Suso Monasteries in Spain is demarcated according to the skyline formed by the mountains southeast of the property site, but totally excluded the northwestern slopes (Villanueva 2006) due to certain special factors (Figure 3(c)) that may include gradient or landscape quality, but which cannot yet be determined from the available literature.



(a) (b)

(c)

Figure 3

Examples of buffer zones: (a) Kamowakeikazuchi-jinjya (Kamigamo Shrine) in Kyoto (from Umezu (2006)); (b) Quebrada de Humahuaca: core area in gray and buffer zone in light orange (from Martorell-Carreño (2006)); (c) San Millan, Yuso and Suso Monasteries: property in dark shade, core area in light shade and buffer zone in bold outline (from Villanueva (2006))

Categorized delimitations

The basic rankings used in heritage protection delimitation are definitions that serve to discriminate between core areas and buffer zones. Based on the experience provided by the *Special Plan of La Rioja* for the Route of Santiago de Compostela, Martorell-Carreño (2006) proposes a modular plan for the entire Route of Santiago de Compostela and categorized protection areas into three levels as follows:

1. Core areas: heritage properties that are authentic cultural route components;
2. Secondary areas of special significance; and
3. Buffer zones used for conservation purposes and that may be justified by their contexts.

The second category is strictly defined as "sacred sites not located on the route but meaningful for pilgrims" (Martorell-Carreño, 2006, p.11). On the one hand, regions that belong to this category can be considered as settings outside the property boundaries. On the other hand and from an authenticity perspective, although they do not belong to the heritage property, they nevertheless have relevant functions. According to paragraph 104 of the *WHC Operational Guidelines* (UNESCO 2005), these sites function as buffer zones. Therefore, the delimitation of the Route of Santiago de Compostela can be considered to be composed of the heritage property itself and two levels of buffer zones. However, given that the second category was originally designed for the special case of the Route of Santiago de Compostela, this may limit its validity and mean that it is utilized less than other categories in general cultural route delimitation.

Sugio (2005) proposes a scientific analytical process to define the settings of cultural routes. This process includes five steps, in which the last four of which involve the demarcation of the heritage setting and the simultaneous division of setting regions defined into four segments. The criteria for the four levels of delimitation are as follows:

1. Setting category 1: Physical location and form of cultural route;
2. Setting category 2: The inscribed properties as core areas;
3. Setting category 3: The primary buffer zone includes areas that have or may have a potential impact on heritage conservation, or in which the value of the relevant setting is either affected now or may be affected in future; and
4. Setting category 4: The secondary buffer zone encompasses other elements or areas that make a physical or intangible contribution to the formation of the route. This category ensures that the cultural route is inclusive in nature.

This system has been adopted in the conservation measures taken for the Sacred Sites and Pilgrimage Routes in the Kii Mountain Range in Japan (Ono 2005). Although more scientific approaches such as GIS has been used in the delimitation process for this case (Ono 2005; Sugio 2005), the planning is still inadequate. Martorell-Carreño (2006) briefly discusses both the implementation deficiencies and the inspiration for this system.

The first two categories in Sugio's classification scheme can be combined, as they are both used for the delineation of properties. In this sense, Sugio's approach and the Santiago de Compostela case share very similar classification criteria. Compared to the buffer zone doctrine, both of these models can be used to fulfill WHC requirements (Table 2). One fact worth noting is that the secondary areas of the Spanish route and the approach taken to secondary buffer zones in the Japanese approach both respect the functional contributions of settings and separate them from ordinary conservation concerns to secure a kind of intrinsic authenticity. Unfortunately, these attributes are normally ignored in practice. This is one of the main reasons for CIIC experts advocating categorized delimitation and case-by-case or even section-by-section justifications in the implementation of buffer zones.

Table 2

WHC Operational Guidelines delineation criteria and their fulfillment following the approaches used in the Spanish and Japanese cases

WHC Operational Guidelines **boundary & buffer zone criteria**	**Route of Santiago de Compostela**	**Sugio's approach**
Property Boundaries		
Tangible expression of outstanding universal value (OUV)	Core areas	1st category of settings 2nd category of settings
Potential support of OUV understanding	nil	1st category of settings
Buffer Zones		
Immediate surroundings	Secondary areas Buffer zones	3rd category (preliminary buffer zone) 4th category (secondary buffer zone)
Important views	Buffer zones	Not available
Functional importance to authenticity	Secondary areas	4th category (secondary buffer zone)
Functional importance to property protection	Buffer zones	3rd category (preliminary buffer zone)

2.2 Routes and Associated Landscape Studies carried out by Archaeologists

There is no doubt that archaeological studies play an important role in heritage conservation, especially in authenticity investigations. Despite excavation of artifacts, archaeologists have developed post-processual and cognitive based approaches such as "landscape archaeology" to investigate large-scale environments and interpret the lifestyles of people associated with these spaces over the course of history. Both tangible and intangible cultural route features can be included within the scope of archaeological research.

2.2.1 Archaeological Route Studies

Based on the abovementioned landscape archaeological perspective, although prehistoric or historic routes are not necessarily cultural routes, they are usually considered as proxies in regional studies to allow social, cultural, economic , and historical phenomena to be reconstructed through an assessment of their functions in transporting people and goods, linking monuments, facilities and settlements, or fulfilling other historical functions (Kantner 2004).

A number of archaeological studies have focused on reconstructing past economic behavior through an analysis of route network patterns, e.g., Bell and Church (1985); Bell, Church, and Gorenflo (1988); Ebert and Hitchcock (1977); Kantner (1997); and Santley (1991). A further example is Gibson's (2000) interpretation of the sociopolitical significance of tower-houses linked by routes used in late medieval Irish chiefdoms. Particular node locations are normally the main attributes used to assess the whole network (Kantner 2004), for example, see Gorenflo and Bell (1991) and the alternative approaches discussed by Bell, Church, and Gorenflo (1988).

Another group of studies focuses on routes instead of nodes, and emphasizes the analysis of the rationale for road construction from the social-cultural perspective. These studies introduce multiple spatial features, including the abovementioned reconstructed network nodes such as settlements, ritual sites, monuments, etc., as spatial analytical parameters used to simulate route locations. GIS technology can also be used to facilitate such paradigm capabilities and simulate broader landscapes, as well as to factor in multiple social and cultural aspects (Kantner 2004).

2.2.2 Landscape Archaeological Module and Cases

The studies undertaken by Scott L. H. Madry and colleagues (Madry and Crumley 1990; Madry and Rakos 1996) of the Celtic road network in the Arroux River valley in the Burgundy region of France are typical examples of the investigation format used in the 1990s, although they are very simple (Kantner 2004) and has been criticized from both a methodological and technical perspective (see van Leusen (2002) and Fisher et al. (1997)). Madry's group has established a GIS database to integrate various data sources including current and archival aerial photos, satellite images, historical maps, etc., and provided both analytical functions and visualizations (Madry date unknown; Madry and Crumley 1990). From an archaeological interpretation perspective, interesting spatial analyses of distance, viewsheds and cost-surfaces were carried out to study the roads and their relationship to hillforts (Madry date unknown; Madry and Crumley 1990; Madry and Rakos 1996). The visibility studies carried out show that nearby hillforts were very significant to the Celtic roads and that these defensive facilities may have been built with the intention of keeping the transportation system under constant surveillance (Madry and Crumley 1990; Madry and Rakos 1996). In addition, cost-surface based optimum path selection enabled a better understanding of the network in a broad environment and helped researchers to draw conclusions on road location (Madry and Rakos 1996). Moreover, the spatial phenomena revealed assists researchers to undertake more detailed investigations of other social and cultural activities associated with the route, such as the trade and settlement functions of particular towns and their roles in the regional life (Madry and Rakos 1996).

Other case studies

The Arroux River valley study has illustrated a common approach to the study of routes in landscape archaeology, in which GIS-based viewsheds and cost-surface technologies support landscape perception or historical function interpretations. Other similar archaeological studies have been undertaken, such as Bell and Lock (2000) used of least-cost path analysis to locate a ridgeway and introduce viewsheds from viewpoints at equal intervals along a path to investigate the hillforts' relationship to the path. The conclusion reached in this paper is that the location of hillforts should be attributed to visual connection to a lesser degree, especially where they are located within close range of the route. It also concludes that the hillforts were constructed later than the ridgeway and served as entities used to fulfill a control function along the route. Nevertheless, the validity of Bell's path generation procedure has also been questioned (Harris 2000).

Pure least-cost path approaches

Kantner (1996, 2004) compares the spatial locations of calculated least-cost paths with the historic road remains of Chaco Anasazi roadways in New Mexico, US and concludes that the deviations could be explained by the road functions. Most Chaco-era road segments only served local functions, largely in a substantial function of integrating settlements and a religion meaning in cosmography (Kantner, 2004). While Vermeulen (2006) introduces a similar approach that uses multifactor cost-surfaces to reconstruct and map Roman paths by integrating segmented relics and calculated paths.

Chapman (2006) uses least-cost path approaches to calculate possible path locations by varying the weighting of different landscape factors. These computerized paths are then compared to sections of Roman roads that had been excavated and observed in Bath in the UK. This study reveals locations that filled gaps in current records. Chapman (2006) also introduces the concept of the "significant place" for which multi-factor modeling is used to interpret the characteristics of a least-cost path based only on slope constraints. Since regions through which the route passed were controlled almost entirely by defensive structures, the route was declared unlikely to have been invaded.

Some unique studies have been carried out on historic routes and their associated human life. In a study that used an approach similar to those based on viewsheds and cost-surfaces, Krist and Brown (1994) simulates animal movement paths, as opposed to human paths, across terrain, and reconstructed through prehistoric hydrograph phenomena. The visibilities of Paleo-Indian settlements on caribou migration routes are investigated to interpret site location and spatial catchment. Barrett (1994) and Thomas (1993) interpret pure social and cultural phenomena such as power relations and social reproduction through an analysis of visible regional changes when moving along the prehistoric avenue which leads to Avebury Henge in England.

Network path simulation approaches

Landscape archaeologists have also introduced more complicated route simulation methods by generating route networks instead of ordinary single paths, such as in the pioneer work by De Silva and Pizziolo (2001) in Neolithic settlements in the Biferno Valley in Italy. Bell and colleagues' study on Samnite uses a similar method, but introduces "cumulative pathway analysis" to refine the optimum network taking into account all possible reciprocal routes (Bell, Wilson, and Wickham 2002). Van Leusen

(2002) demonstrates another network generation approach in a case study of the late Iron Age and the Roman landscape around Wroxeter, Shropshire, in England. He invented a hierarchical network system by defining different start and end locations according to the historical functions of Wroxeter and surrounding settlement sites using three independent least-path calculations, and then combined the locations defined into multiple least-path networks for social and cultural interpretations.

2.2.3 Methodology and Technology

A notable similarity between all the archaeological studies referred to above is that they share the same spatial analytical approach, normally GIS-based cost-surface and viewshed analyses, and go beyond the spatial phenomenon for in-depth social-cultural interpretations within the landscape context. This might inspire the building of a unique paradigm for cultural route investigations. The following section discusses the main technical trends for route and movement investigations in cost surface analysis (CSA), as well as visibility, which is a parallel approach that relates to more human aspects. In addition, these technologies are considered to be important to the processual / post-processual and cognitive archaeological debate (van Leusen 2002). The theoretical and methodological issues surrounding landscape archaeology and its relationship with GIS will be briefly reviewed.

2.3 Landscape Archaeology and GIS applications

According to Renfrew and Bahn (2004), landscape archaeology can be defined as "the study of individual features including settlements seen as single components within the broader perspective of the patterning of human activity over a wide area" (ibid, p.583). Landscape archaeology is commonly referred to as archaeological research and interpretation that considers site issues (Chapman 2006).

2.3.1 Landscape Archaeology through the Cognitive Paradigm

Chapman (2006) discusses three principle philosophical approaches that comprise the mainstream of landscape archaeological research. While the first two approaches are both concerned with archaeological surveys of physical remains, the notable development is the third and most recent trend, which "concentrates on the interpretation of the qualitative aspects of archaeological landscapes" (ibid, p.14). This approach focuses on human experience in a landscape and the human-landscape interrelationship, rather than concentrating on physical or material archaeological resources as in the two other methods.

The cognitive paradigm as an anthropological perspective

In recent decades, innovative archaeological paradigms have continuously emerged. Cognitive archaeology is a new trend which is more concerned with the social and cultural significance of geographical and human landscapes (van Leusen 2002). Cognitive archaeology attempts to study the 'past ways of thought ... from material remains' (Renfrew and Bahn 2004, p.580), and an important domain of this discipline involves the study of "place" establishment (Renfrew and Bahn 2004). These studies stand on a hypothesis that there are generalities of the human mind or psychic unity. Past peoples shared similar thinking processes on "common sense knowledge and an understanding of causation" (Zubrow 2006, p.18). Archaeologists are interested in representing social spaces by tracing more "subjective" indicators such as ancient peoples' experiences and perceptions of their physical and social environments. Human thoughts can therefore be imitated and thus modeled to allow for an understanding of individuals (Zubrow, 2006).

2.3.2 Information Technology and GIS Support

Cognitive archaeology also benefits from information technology (IT). IT has had a significant influence on the development of archaeology, especially over the last half century. Zubrow (2006) discusses the impact of IT on the "traditional" archaeological paradigm in terms of data management, quantitative analysis, modeling and simulation, virtual representation and communications. However, in the context of the rise of processual and post-processual archaeology, computers have acted as active agents of archaeologists' thoughts, rather than merely as passive tools (Lock 2003). Lock (2003) also argues that digital technology and archaeological theory had interacted with each other and that computers have become involved in the process of archaeological interpretation (ibid: p.7). Zubrow (2006) reaches a similar conclusion, noting that so-called "digital archaeology" not only had a methodological function, but also a particularly profound theoretical impact.

Archaeological GIS

The potential of GIS in archaeology has been increasingly recognized since the mid-1980s. An awareness of this technology and its potential for much of the archaeological world has been developed through a series of conferences (see: Lock and Stančič 1995); Aldenderfer and Maschner (1996); Allen, Green, and Zubrow (1990); and Lock (2000)) held primarily in North America and to a lesser extent in the UK (Harris and Lock 1995; Kvamme 1995). Given continuing growth in the number of archaeological projects that make use of GIS, it would now be difficult to conceive of a regional survey project or spatial modeling exercise that was not based around spatial technology.

Kvamme (1989) indentifies five wide-ranging, but clearly somewhat overlapping, themes consisting of the integration of archaeological GIS applications into regional data management, the management of remotely sensed data, regional environmental analysis, simulation, and location modeling. In the interests of brevity, I will not discuss all of these trends will be discussed in this review, but which will concentrate on the GIS applications that are most closely related to the study in the following review.

GIS for landscape archaeology

The use of landscape archaeology in an increasing number of relevant interdisciplinary approaches and quantitative methods is considered as one of the key reasons for adopting GIS technology (Lock 2003). Chapman (2006) explains the historical context and concludes that the following three requirements are important to the emergence of GIS for landscape archaeology:

1. The use of 'normative' information sources to avoid criticism based on the inherent deterministic problem of descriptive interpretation.
2. The use of 'scientific' archaeological landscape interpretation, which relates to the development of the 'new archaeology'.
3. A 'theoretical' basis which, in contrast to item no. 2. above, is based on a humanistic approach and the "post-processual" and "cognitive archaeology" contexts.

From the methodological perspective, Lock (2003) divides GIS applications used in landscape archaeology into two categories, namely cultural resource management (CRM), which reflects the concern with "landscape as now" (ibid: p.164), and the use of landscape analysis to explain or interpret "landscape as then" (ibid: p.164). This thesis study adopts both of these approaches. The following two detailed review sections in 2.4 and 2.5 follow these two parallel approaches.

2.3.3 GIS Support for Heritage

Over the past one or two decades, in addition to its application to archaeology, GIS has been broadly adopted to support heritage interpretations related to anthropology, history, and other inter-disciplinary studies, to deal with spatial issues. Furthermore, Aldenderfer (1996) notes that anthropologists share the same methodologies with archaeologists in research involving spatial considerations. Stonich (2002) also reviews the use of state of the art GIS applications in anthropology, a majority of which are also used by archaeologists. The quantitative, analytical, spatial-referenced and multi-scale capabilities provided by GIS have also been applied in social sciences and historical studies to gain a specific advantage (Goodchild 2000; Gregory and Healey 2007). However, further efforts need to be made to enhance the discrete spatial perspectives of these knowledge domains (Goodchild 2000; Gregory and Healey 2007). Within these two disciplines, the paradigms for dealing with the relevant research problems raised in this thesis can also be found in landscape archaeology studies, for which the use of GIS applications is still at a preliminary stage.

GIS in the WHC system

GIS has become an important technology for heritage conservation, especially for planning and spatial management purposes. GIS mapping is the only IT approach specifically mentioned in the *WHC Operational Guidelines* (UNESCO 2005, Annex 5). GIS technology was firstly adopted in UNESCO World Heritage Site (WHS) management in 1992 to establish the Angkor Zoning and Environment Management Plan (ZEMP) (Fletcher et al. 2007; Wager 1995), just as the initial archaeological GIS blossomed. Other space technologies, such as remote sensing (RS), also subsequently became a popular part of WHC practices (Hernandez 2006).

The preference for this type of IT may be due to the fact that the main task for WHC properties at present is still to focus on documentation and delimitation, in which GIS (along with other spatial technologies) is mostly effective. A GIS-based heritage management manual published by UNESCO, which is edited by the UNESCO GIS consultant Paul Box (1999a), demonstrates the knowledge on and broad level of interest in GIS technological and methodological developments among the most cutting-edge groups working on heritage conservation. It is clear that that methodologies and case studies presented in this manual mainly involved the use of archaeological approaches. It can also be seen that fewer breakthroughs were dedicated to specific heritage site conservation and management questions if these GIS-based management approaches are compared to a series of archaeological GIS studies from the same period, such as the papers from the first Ravello Conference held in 1993 (Lock and Stančič 1995), the same year in which UNESCO introduced GIS technology for heritage works, and the second Ravello Conference held in 1999 (Lock 2000), when the abovementioned manual was published, and other momentous archaeological GIS conferences held in year 1992 (Aldenderfer and Maschner 1996), 1993 (Maschner 1996a), and 1995 (Gillings et al. 1999). It can be concluded that archaeological GIS is still dominant in GIS studies and heritage conservation practice.

2.4 GIS for Cultural Resource Management

From the application perspective, the WHC system assigned individual countries, so-called State Parties, to implement cultural heritage conservation measures and supervise relevant stakeholders in heritage management (UNESCO 2005). Before the

WHC legislation, which is rooted to archaeological salvage trends in North America and Europe that began around the time of World War II, a conservation and legislation system based on the identification and protection of heritage sites had already developed in those countries. Cultural Resource Management (CRM) is the term invented by archaeologists in 1970s to describe these systems including laws, standards, and practices, such as inventories and decision supports, that guide the management of heritage properties within the context of modern research, preservation, and land planning. Cultural Resource Management, which is generally known as Cultural Heritage Management (CHM) in Europe, is considered as a holistic approach for managing tangible or intangible cultural properties based their values or impacts (King 2002). It is widely used by national and regional administrative or other individual parties for conservation applications.

Since the early 1990s, spatial technologies have been widely touted as the ideal tool for the management of heritage information to assist cultural resource managers. As a "spatial toolbox" (Wheatley and Gillings 2002), GIS provides a database as well as a deep understanding of archaeological sites and their environments. It also allows for an innovative perspective that is used to reveal the human-environment relationship to archaeologists, and facilitates CRM. GIS also facilitates visualization, analysis, and quantification and modeling capability for generating and processing of metadata. The contribution it makes to CRM might not be achieved by other approaches or technologies (Wheatley and Gillings 2002; Chapman 2006).

2.4.1 Gap between Practice and Research

CRM requirements have accounted for the strongest growth area of GIS in archeology (Miller 1995; Lang 2000; van Leusen 2002). Lang (2000) notes the symbiotic relationship between CRM and research. Heritage data and the totality of knowledge included in such data are essential for research initiation. In addition, research outcomes provide enhanced or new knowledge and data, a process that acts as a feedback loop and completes the cycle of knowledge transfer and development. Furthermore, CRM potentially fosters academic progress through the dynamic dialogue between researchers and CRM managers, in which their collaborations provide a test bed for existing hypotheses and generate innovative research questions (Lang 2000).

Nevertheless, Lang (2000) points out that there is a gap between CRM and analytical research. CRM professionals are often criticized for becoming too enmeshed in data management to accelerate "new discoveries" or even for isolating themselves from the leading edge of academic development (Lang 2000). While although Verhagen (2000) has already proclaimed that CRM will follow the developments whereby decision-making processes in a planning context demand more and more digital information on archaeological resource data, impact assessments, and other integrated planning support tools around the end of last century[1], the reality is that the CRM developments mainly involve a more sophisticated database, data process technology and standardization, and still focus on data aspects. On the other hand in-depth spatial studies have contributed very little to the digital CRM system.

Recent exceptions may be found in several decision support systems (DSS) that use archaeological site predictive models and have been applied to highway planning in North Carolina (Madry et al. 2006) and the Pomurje region of Slovenia (Veljanovski and Stančič 2006). These two systems share a similar idea in that they

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[1] At the second Ravello conference held in 1999. See (Lock 2003), p.167

using models to predict archeological site locations and delineate potential archaeological resource distributions. These spatial distribution data and maps then become a constraint for compromises on highway corridor site location or planning alternative scenario selection. A similar approach based solely on methodological investigation is also presented in Naunapper's (2006) paper.

By contrast, Wheatley (2004) voices a totally opposite opinion and makes the astonishing claim that predictive CRM models either do not work well or their predicted results are rarely used. Even worse, other than for two previous problems in which CRM models have been used, their results are usually detrimental, as they introduce bias and produce less representative archaeological samples and archives. Wheatley considers that the design of a correlative model is impossible because of the complexity of archaeological landscapes. His suggestion is that a more problem-oriented model should be carefully defined, rather than taking a comprehensive predictive approach to management practice (Wheatley 2004).

2.4.2 The Potential of GIS for Conservation Planning in CRM

GIS is usually introduced as in the form of a database in CRM and DSS (Madry et al. 2006). Its capacity as a platform that could be used to provide an interface with other systems such as EIA is also noted by archaeologists and heritage managers (Naunapper 2006). However, in order to develop CRM into a self-contained DSS or planning support system (PSS), the GIS spatial analytical capability is a key function required by the computational components of such a system. On the other hand, the development of a planning support system (PSS) has also been urged to allow for a problem-oriented approach to be followed in system design instead of starting from a particular technology (Klosterman 2001). The need to establish how this inherent advantage of GIS can be leveraged efficiently to serve the heritage conservation system is a rationale of innovative PSS or CRM investigations. Such an approach also represents a potential solution that can be used to bridge the gap between practice and research.

The principal role of many GIS analyses undertaken in the archaeology and heritage fields is to enhance management and conservation (Chapman 2006). Box (1999a) divides the planning supports offered by CRM into three hierarchical categories, namely protection planning, development control and impact assessment (ibid: 63-54). The first two categories are usually integrated into a CRM format compatible with WHC requirements, in which heritage resource conservation plans themselves serve as primary material for community, regional or national legislation introduced for development control purposes. The last category of planning support, which is often called "cultural environmental impact assessment (C-EIA)" (Box 1999a), is a normal function of many CRM systems (Chapman 2006), including the DDS systems referred to above. C-EIA implementation is based on the first two planning actions, which set prescriptive requirements or evaluation criteria.

The gap between research and practice is manifested in different ways in these three planning approaches. C-EIA seems more receptive to cutting-edge GIS technologies and archaeological GIS research contributions. Location modeling or archaeological predictive modeling is introduced to situate potential archaeological resources (Box 1999a; Naunapper 2006) as in the archaeological sensibility model for Banff National Park in Canada[1] (Perry 1999) and previous DDS reviews. Cumulative visibility analyses (which will be discussed in detail later) of Stonehenge at Avebury[2] (Batchelor 1999) also illustrate an impressive GIS capacity in sensitivity

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[1] As part of the Canadian Rocky Mountain Parks inscribed on the WHC List in 1984.

[2] Inscribed on the WHC List in 1986.

mapping, and support for both specific EIA projects and general planning control prescription. ZEMP (see (Box 1999b; Wager 1995)) is another excellent example of GIS control planning support within the WHC framework. However, the lack of any contribution from spatial analysis is also apparent, although the situation has improved in light of the new developments in the "Greater Angkor Project" in Evans et al. (2007) and Fletcher et al. (2007).

2.4.3 Problems in Conservation Planning Relating to Heritage Value

The most difficult part of CRM may be conservation planning, in which the key process is the valorization of assets (see also LeBlanc and Myers (2007) and de la Torre (2005)) and the vulnerability of the heritage resource (Box 1999). The *WHC Operational Guidelines* prescribe that the value attributed to a cultural heritage site is the root of conservation. The value of a cultural heritage site is derived from its authenticity (UNESCO 2005). However, more sophisticated studies on value-based heritage management reveal that the WHC concept of value, although emphasized by the use of the term "outstanding universal value", is actually very dynamic in terms of interpretation, knowledge, stakeholders' interests or concerns, and temporal evolution (LeBlanc and Myers 2007; de la Torre 2005). Therefore, research work has been recognized as a basis for heritage and cultural route identification and relevant fundamental management efforts in both the *WHC Operational Guidelines* (UNESCO 2005) and the proposed *Charter of Cultural Routes* (ICOMOS 2005).

Frontier GIS and RS-supported landscape and environmental archaeological studies of urban history applied in the Great Angkor Project represent some of the most successful examples so far of how intensive research can facilitate heritage identification and recognition, and how research outcomes can consequently improve management capacity (Evans et al. 2007; Fletcher et al. 2007). However, not all heritage sites are as lucky as Angkor, which is a highly unique case that has benefited from contributions from international top experts for several decades. In practice, most heritage conservation plans have not adopted or benefited from the latest developments in archaeological and environmental studies, as illustrated by the CRM contradiction referred to above. Heritage delimitations and their GIS applications are still in a very primitive stage, especially in the Asia Pacific region.

2.5 Perceptual Archaeology and GIS Applications

According to Lock (2003), the numerous GIS applications can be grouped into three main categories. The first and simplest approach is "quantifying space," which refers to the management of spatial data and the overall presentation of the physical characteristics of a space within the terms of landscape analysis. The earlier Hvar (Croatia) study carried out by Gaffney and Stančič (1991) is a typical example. The second category, the "predicting the past" approach, assumes that past peoples did not locate their sites at random, but employed logical decision-making processes. Predictive models can be established through the digital interpretation and organization of the interrelationship between archaeological site locations and certain quantified landscape parameters (Lock 2003).

The most difficult challenge is establishing how the relationship between people and landscape can be modeled within GIS. The "digital places" approach concentrates on the anthropological implications of places and uses GIS to provide quantitative and qualitative phenomena which can illustrate the anthropological contexts of people's surrounding environments (Lock 2003). As discussed in section 2.2, visibility and cost surface analysis are the two main approaches in this kind of research and are considered “twin tools for cognitive landscape analysis” (van Leusen 2002, p.6-3). These two technologies are similar in terms of both methodological and underlying theoretical principles within the context of processual – post-processual archaeological debates. These two kinds of analyses both define social space, or “place,” around the observer by interpreting human experience of being and moving in a landscape (van Leusen 2002). Wheatley and Gillings (2002) also introduce Gibson’s psychological theory of “perceptual systems” to further build the argument that perception is only meaningful to a moving and active observer. This integrated approach is also reflected in many typical practical studies such as Belcher, Harrison, and Stoddart (1999); Gaffney et al. (1996); Gaffney, Stancic, and Waston (1996); Llobera (2000, 2005, 2007b); and Madry and Rakos (1996).

2.5.1 Archaeological Visibility

Recognition of the significance of archaeological monument visibility can be traced back to as long ago as the early 1800s (van Leusen 2002). Since then, visibility has been an acknowledged factor in monument and landscape studies. In the 1970s, when archaeology adopted spatial analysis, visibility was accorded a more significant status in archaeological interpretation. During the late 1980s and early 1990s, innovative theoretical debates emerged in which visibility came to be introduced as a purposeful agent of a past person’s experience of environmental appreciation (Wheatley and Gillings 2002). Tilley’s landscape archaeological studies illustrate this approach (Tilley 1993, 1994). Digital tools introduced to archaeological visibility studies around the end of the 1980s, and GIS in particular, not only offered archaeologists enhanced efficiency and capability in visibility analysis, but eventually also "breathes new life into the study of landscape perception or cognitive archaeology" (van Leusen 2002, p.6-9) as heuristic tools (Llobera 1996).

Basic algorithms for visibility analysis in GIS are based on line-of-sight (LOS) and viewshed analyses, both of which determine whether two locations in a DEM are indivisible. In earlier, relatively simple applications such as Bell (1999); Bradley, Harding, and Matthews (1993); Gaffney and Stančič (1991); Moscatelli (2000); Ozawa, Kato, and Tsud (1995), LOS and single viewshed are always interpreted as "intervisibility" characteristics among two or more monuments or sites.

Cumulative viewsheds or visibilities

In addition to LOS and single viewshed calculations, a series of single viewsheds can been merged into binary multiple viewsheds (Ruggles, Medyckyj-Scott, and Gruffydd 1993; Ruggles and Medyckyj-Scott 1996). However, a more common approach is the use of "cumulative viewsheds" (Gaffney et al. 1996; Wheatley 1995, 1996), which is also known as "times seen" (Fisher et al. 1997) for more complicated landscape or socio-cultural interpretations. Wheatley (1995) invents this term and an algorithm for the summing up of two or more binary single viewsheds. The value of each map cell in a cumulative viewshed records the number of viewpoints from which it is visible. It represents the numbers of viewpoints that can see a location, or how many viewpoints can be traced back from the location in spite of the "projective-reflective viewshed" effects noted by Fels (1992).

Marcos Llobera has persisted in exploring visibility parameters for landscape archaeological research. In Llobera (1996), he invents the "gradient view" using cumulative viewsheds that involves the combination of viewpoint viewsheds at 50m intervals. He also establishes a milestone in this discipline through his creation of "total viewsheds" in Llobera (2003) to facilitate the study of visibility characteristics distribution across a whole site by calculating the cumulative viewsheds for all locations. In a further development in the total viewsheds field, Llobera (2007b) proposes a quantitative approach called "co-visibility," which looked to be the most sophisticated approach so far from a methodological perspective and enabled the visual structure of Bronze Age round barrows in Yorkshire, England to be studied. Llobera uses a categorized index based on visual distance to make detailed delineations of intervisibilities and cumulative viewsheds and reveal the relationships between barrow clusters. The author uses a matrix to illustrate the average percentage area in each category in one cluster that intersects with visibility categories in the other cluster(s). The percentage value is regarded as the probability (or sensibility according to Lake (2007)) that can be used to interpret the degrees of relationship among clusters within specific spatial ranges. Most of the author's interpretations based on these complex indices are narratives of the intervisibility phenomena illustrated by the data, as well as primary interpretations of landscape structure and what could be visually experienced during movements. However, some interesting facts also have emerged, such as the fact that the chronological sequence of barrows has little effect on the visual spatial structure, which is revealed through the statistical method used to imitate the growth pattern of barrow constructions and can be explained by the fact that the visual relationship with the preceding barrow is not a major concern for later barrow site selection (Llobera 2007b). Another original contribution that should be taken into account is his observation of the fact that uncertainty may increase the threshold of these kinds of visual studies (Lake 2007; Llobera 2007b).

Both single and cumulative viewsheds involve the same validity problem of viewpoint sampling (Wheatley 1995; Wheatley and Gillings 2000; van Leusen 2002).

The validity of a single viewshed in reflecting the "real" viewshed is discussed in detail in Wheatley and Gillings (2000). There are also operational assumptions involved in introducing further viewing parameters such as palaeoenvironmental reconstructions (see Tschan, Raczkowski, and Latałowa (2000) and Llobera (2007a)) and innovative algorithms such as those used in Peter Fisher's (Fisher 1991, 1992, 1994, 1995, 1996) explorations of the uncertainty of using viewsheds (or probable viewsheds) to overcome the inherited problem of binary viewshed. A more reliable approach and a promising development in the field of accumulative viewsheds is to calculate a cumulative visibility index (CVI) for all locations in the study region. Examples can be seen in Lake, Woodman, and Mithen (1998) and Llobera (2000, 2003, 2005, 2006, 2007b).

Interpretation methodologies

Cumulative viewsheds is usually introduced as a proxy used to gain an understanding of the "social" placement of archaeological sites or monuments in a landscape context. Whether such sites and monuments are deliberately placed in areas of relatively high visibility (or low visibility, see the later discussion on "significance of invisibility") indicates their significance (van Leusen 2002). This topic is a research interest developed over a period of fifteen years from monument and landscape perception or experience studies from a phenomenological perspective (Lake 2007). Tilley (1994) establishes the theoretical premise based on theories from phenomenological philosophy and humanistic geography. Some of the earliest studies concentrated on significant rituals and political landscape features, e.g., Boaz and Uleberg (2000); Fisher et al. (1997); Gaffney, Stancic, and Waston (1996); Llobera (1996); Nunez, Vikkula, and Kirkinen (1995); and Wheatley (1995).

A sound theoretical justification for using visibility for perception and cognition interpretation has been given by Vincent Gaffney and colleagues (Gaffney et al. 1996):

> *A viewshed represents the area in which a location or monument may communicate visual information. Viewsheds may overlap, producing zones in which an observer might be aware of the presence of many such locations, all of which may carry information. The increased density of such information can in some circumstances be interpreted as a measure of the importance of a particular area. It provides a spatial index of perception, mapping the cognitive landscape within which the monuments operated.*

However, Witcher (1999) also reminds us of the complexity of perception and indicates that simplistic assumptions based solely on information gained through GIS analysis cannot be interpreted as perception at all (Lock 2003). It has also been argued that interpolation would not be conducted if there were no prior experience or understanding on such landscapes (Chapman 2006). Fitzjohn (2007) opines that the difficulty or cost involved in moving between spaces is highly personal and inconstant.

Baldwin et al. (1996) suggests that more cognitive criteria be introduced to improve the validity of viewsheds. Higuchi's landscape structure theories (Higuchi 1988) have been widely adopted in recent archaeological visibility studies. Wheatley and Gillings (2000) invent the "Higuchi viewshed" by introducing his visual indices. Llobera (2007b) also references these classification criteria but uses a more sophisticated approach in his simulations.

Llobera (2006, 2007b) also set out to vindicate the utility of archaeological 'interpretative' visibility studies. He points out that a physiological advantage in spatial information collection and permanence of vision are important reasons why visibility studies cannot be ignored or even downgraded in phenomenological archaeological landscape studies.

Other sensations and the significance of invisibility

Social science disciplines other than archaeology suggest that visibility serves as the principal sensation when people relate to and interpret their landscapes. However, although the original assumptions made in phenomenology and humanistic geography ostensibly indicate that perception is more than visibility, but in the archaeological context, it is clearly much easier to reconstruct visual sense to simulate a location than it is to simulate other sensations like smell and sound. Nevertheless, the hypothesis that vision has primacy over other senses in space perception has been challenged by both experiments and simulations carried out in case studies on auditory sense (sound) (Gillings and Sbonias 1999; Mlekuz 2004), the olfactory sense (smell) and the haptic sense (touch) (Dawson et al. 2007), and even on further integrated sensations or multi-sensorial perceptions such as thermal or climatic comfort (Fitzjohn 2007), as well as from a broader theoretical perspective (Gillings and Goodrick 1996; Frieman and Gillings 2007).

In addition, while viewshed show visible areas, they also illustrate areas hidden from a particular location. Multiple or cumulative viewsheds highlight invisible areas more reliably and rank them into different levels by measuring the degree of seclusion (van Leusen 2002). Tilley (1994) highlights this concept and discussed potential regional or ritual significance. Real case studies and in-depth investigations carried out by Lock and Harris (1996) and Fontijn (2007) offers salutary reminders to the archaeological visibility paradigm and extended the scope of visibility-based interpretation of archaeological landscapes.

2.5.2 Cost Surface Analysis

Cost surface analysis (also called "accumulated cost-surface analysis" by Conolly and Lake (2006)) models the "cost" of moving through a space by assigning a cost value to each cell in a raster map and accumulating all the values along the trail for traveling over the map. Cost surface analysis is rooted in the traditional archaeological spatial analyses of "catchment" and "tessellation," which involve studying the delineation of an area within a given focus[1] . The earlier approaches involved the derivation of a territory using a Euclidean or geometrical buffer distance or Thiessen polygons. The development of cost surface analysis offers both geographical characteristics to territoriality approaches and provides anisotropic parameters in spatial analysis (van Leusen 2002).

Catchments and tessellations

Spatial allocation has been introduced into archaeological studies to allow for the investigation of spatial association and territoriality interpretation. Earlier site catchment analyses (SCAs) uses "buffering" or simple "distance" attributes to imitate spatial interrelationships (Kvamme 1999). Another method that involves the attempted partitioning of an entire region and its distribution among different entities is tessellation, in which the Thiessen (also known Voronoi or Dirichlet) polygon is the most commonly used approach (Wheatley and Gillings 2002). Thiessen tessellation was introduced to archaeology by the "New Archaeology" school and was applied in spatial analyses in the 1970s and 1980s (Ruggles and Church 1996; Wheatley and Gillings 2002). In landscape archaeological applications, catchments are usually introduced to express economical phenomena, whereas tessellations

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[1] In archeological nomenclature, "focus" means a point-like location of the protagonist with archaeological meaning or significance within a broad spatial context.

interpret social, political and cultural structures (van Leusen 2002).

Thiessen tessellation has been criticized for being based solely on geometric characteristics and unrealistic isotropic conditions, and for resulting in hard choropleth map boundaries which cannot be used to reflect the complexity of spaces and places and gradually changing social and economic phenomena along distances. It has therefore been replaced by cost surface analysis in the last two decades (Kvamme 1999; Wheatley and Gillings 2002). Some researchers have continued to use Thiessen tessellations to assess site weights or the costs of landscape features, such as Ruggles and Church (1996), who use the advantages of GIS to explore flexibilities and alternatives for improving Thiessen tessellation in a study of the Late Horizon Basin in Mexico by introducing different weighting schemes and comparing them with catchment results. Stead (1995) presents a similar discussion on friction surface, the origins of which can be traced back to "XTENT modeling," which was introduced by Renfrew and Level (1979). These studies illustrate the potential for remedying the shortcomings of tessellation through the introduction of more complicated attributes using GIS.

However, the use of tessellation in implementing CSA is very rare in practice (van Leusen 2002). Most of the approaches use cost-derived catchments. The most well-known example of these new methodologies can be found in Gaffney and Stančič (1991). Verhagen et al. (1999) calculates cumulative transport time to create an "accessibility catchment" used to predict cultivation lands in the Rio Aguas Valley in Spain. Hunt's methodological examination overlays physiographic data to create a cost surface (Hunt 1992).

Cost surface algorithms

To create a cost map, most published research has relied exclusively on topography, given that its effect on human behavior is supposed to be overriding. Such a cost determination approach can be found in typical studies such as Gaffney and Stančič (1991) and Bell and Lock (2000) and others that focus on movement. However, it is also possible to employ costs that represent social and cultural influences, such as gravity or magnetic force. Harris (2000) declares that movement seeking should also go beyond the generation of optimal path only bases on physical landscape features and address ancient peoples' perceptual and cognitive behavior. The three papers he reviews (Bell and Lock 2000; Boaz and Uleberg 2000; Llobera 2000) are typical examples of this approach. The most notable of these papers is Llobera's, which demonstrates how to introduce the cultural influence of monuments to the energetic cost of traversing an area. His intention is to combine landscape feature effects with physiological impact to facilitate a cumulative cost calculation. Another approach can be found in van Leusen (1993), in which different weightings are assigned to the site to refine the cost-surface. A similar method is also applied by Llobera (2000) for monument ranking to create gravities.

Another issue in the assignment of cell costs is the direction impact. Moving costs and cell attributes can be isotropic, partially anisotropic or fully anisotropic (Collischonn and Pilar 2000). Typical isotropic costs can be derived from land cover, while partially anisotropic refers to the direction of maximum cost in which all the map cells are the same, such as the wind effect. Earlier cost surfaces were always isotropic, (see: for example, Savage (1990)), partly because of the technical limits of GIS software (van Leusen 2002). However given that most archaeological cost-surface analyses are related to movement, both isotropic and anisotropic costs are included (Conolly and Lake 2006). Llobera's diagram (2000, see Figure 2) translates physiological data directly associated with slope value to create an "effective slope"

(Conolly and Lake 2006). Bell and Lock (2000) derives relative slope-related costs from slope magnitude and then introduce anisotropic costs by interposing aspect parameters as "relative energetic expenditure" (Conolly and Lake 2006). A similar approach is applied by Krist and Brown (1994) in studies of Native American trails. Van Leusen (2002) adapts Krist's formula to calculate "absolute energetic expenditure" (Conolly and Lake 2006) for the trade networks of Wroxeter.

2.6 Problem-oriented Applications of Visibility and Cost-surface Analysis

In this section, archaeological applications of visibility and cost surface analysis will be reviewed according to the research problems they are designed to solve. Cost-surface approaches focus more on route or path locations, while applications of visibility are more diversified. Visibility and cost-surface approaches can also be integrated as perceptual-oriented movement investigations.

2.6.1 Single Factor Approaches

Tangible functional or geographical interpretations based on visibility are obviously the most straightforward application. Site catchments exclusively based on topographical features and directly interpreted as the cost value itself, as in Gaffney and Stančič's (1991) delimitation of space scopes within one hour's walk of a settlement. Ordinary environmental impact assessments (EIAs) for archaeological and heritage sites also usually involve physical characteristics only, such as viewsheds to minimize the visual impact of modern developments on an archaeological landscape, which has been discussed in Batchelor's (1999) work.

Functionalist interpretation

Explaining physical visual characteristics is a direct interpretation of viewshed(s), e.g., whether or not a location or entity can be physically seen, such as view scope of a watch tower in Gaffney and Stančič's (1991) study on Greek settlements. This approach, which has been criticized by Lake and Woodman (2003) as the mere use of common sense rather than explicit inference, and is entitled "functionalist applications" by Wheatley and Gillings (2002, p.212) is one of the two main strands in earlier archaeological visibility applications. There are common, simple and direct hypotheses to explain the viewshed phenomena, for example, two or more indivisible monuments might be within the same "system" (van Leusen 2002). Military and defensive sites are evidently more suitable for investigation using this approach (see Bell (1999); Gaffney and Stančič (1991); Ozawa, Kato, and Tsud (1995). Gaffney and Stančič (1991) add cost-surface parameters to analyze accessibility and integrate accessibility with visibility to locate optimal paths.

Landscape description

Aside from the "direct" functionalist approach, more interpretative applications of viewsheds and cost-surfaces also emerged during the same period. Several studies discuss landscape features in terms of both physical and social-cultural aspects and introduce visibility as an agent. One of the earliest examples is the archaeoastronomy work carried out by. Ruggles, Medyckyj-Scott, and Gruffydd (1993) in which an extended visibility concept is used to interpret the locations of prehistoric constructions and their interrelationships with landscape settings to manifest astronomical phenomena. However, Wheatley and Gillings (2002) criticize their approach for ignoring archaeological visibility considerations. Wheatley's study is expanded by Fisher et al. (1997) through the application of several validating approaches. Later more methodologically reliable research can be found in Lake and Woodman (2003) in which visibility is used to test the hypothesis that prehistoric monument forms echo their landscape settings and create the "impression of circularity" (ibid, p.689) .

The descriptive paradigm places a greater emphasis on physical landscape characteristics and their functionalities or performances in place creation. This fact differentiates itself from the successive discussion on the perceptual approach. However, some more recent studies have taken a more unified approach, such as Llobera's cognition attributes series on "affordance", "prominence" and "exposure" by both physical features and phenomenological recognitions of monuments and landscapes (Llobera 1996, 2001, 2003).

2.6.2 Social and Cultural Interpretations

There are also approaches that involve the exploration of social or cultural aspects of archaeological theories. Visibility and movement as perception is the basic hypothesis of these approaches. Methodological concerns have been reviewed in section 2.5.

Typical examples can be found in Maschner's (1996b) exploration of the hypothesis that vision is a deliberate objective in settlement site selection. Whilst a cost-surface and viewshed study by Belcher, Harrison, and Stoddart (1999) indicates that selection of tomb sites in a pre-Roman town was undertaken in a way that aimed to respect the town by selecting visually immediate but spatially remote and inaccessible sites. There are more cases that involve the use of both cost-surface and visibility to explore ritual landscapes from the ideological perspective instead of physical landscape features (see Ruggles and Medyckyj-Scott (1996) and Wheatley

(1996). Wheatley (1995) and Fisher et al. (1997) also discuss visibility-dominated interpretive cases.

Critiques of visualism

Briault (2007) examines the environmental determinism possibilities in visibility studies by reexamining the criteria for identifying Bronze Age peak sanctuaries, and finds that the previous interpretations of these places, which are mainly based on natural topographical characteristics, ignore the diversity of landscape experienced through other aspects. She declares that spatial settings are not the evitable configuration of these ritual places and that the rationale for archaeological site locations that seem to be visually arresting may not always have to be interpreted as the dominant visual experience. That is to say, a deeper understanding of the nature of archaeological site functions is another important premise of introducing visibility studies (Briault 2007). This study represents case-based support for Wheatley and Gillings' (2000) more theoretical critiques on this perspective.

However, there are also studies that reveal places from complicated contexts and multi-approach interpretations that are not, or at least are less, predisposed to visibility effects, such as the ritual functions in the community of Nasca Lines (Lambers and Sauerbier 2006a, 2006b; Sauerbier 2006). The reason for this might be that the visibility phenomenon is more usually involved in ritual landscapes, and archaeologists are more experienced with respect to such topics (van Leusen, 2002).

2.6.3 Path Studies

Replication and prediction of routes is the most familiar applied archaeological field for cost-surfaces and their integration with viewsheds. The replication process facilitates an in-depth understanding of the rationale for route location. The same methodology and technology can also be applied to predict the location of an unknown route (Conolly and Lake 2006). Most of the relevant cases have been reviewed in section 2.2. The following reviews are from a methodological perspective.

Madry and Rakos (1996) use several different cost parameters to build a model incorporating topographical concerns and visual control to replicate Celtic roads and reconstruct missing segments. Very similar research can also be found in Bell and Lock's (2000) study and Kantner's (1996, 2004) work that involves a study of the Anasazi road remains in Chaco Canyon, New Mexico.

The tracing of disintegrated roads using a method that relies more on least-cost paths can be found in van Leusen's (2002) reconstruction of Wroxeter and in Bell, Wilson, and Wickham (2002), which almost eliminated the visibility effect in settlement studies of the Biferno Valley in central Italy. The use of sophisticated technologies and methodologies to integrate cost-surfaces and viewsheds and simulate movement are explored in Lee and Stucky (1998) and Llobera (2000, 2003, 2007b). The application of path studies is illustrated by Chapman's (2003) interpretations of Neolithic monuments and their setting in the Great Wold Valley in East Yorkshire, UK, which emphasizes cost-surface and visibility through GIS analysis. Movement and visibility are also combined to explain hunting activities as in van Leusen (1993). Krist and Brown (1994) introduce a very similar approach, but assess the visibility of hunters in relation to the calculated paths of their quarry.

2.7 Visual Resource Management Researches by the Author

Besides the aforementioned work carried out by researchers in different disciplines, the present author has also engaged with relevant visual resource management (VRM) researches that have appeared over the past few years, which may proved useful in the execution of this study.

The present researcher's experience of GIS-based visibility investigation in urban natural landscape evaluation and planning support began in 1999. Accumulative viewsheds of certain viewpoints, viewpoint groups or characteristic landscape features were used to evaluate the modern urban developments' impacts to a landmark natural landscape in a rapid developing Pearl River Delta city scope and to propose planning suggestions in order to sustain the natural landscape as valuable urban visual resources resulting in a Master of Philosophy dissertation (He 2001). Moreover, the methodological and technological development of viewshed calculation, like the introduction of visual parameters, had been already involved in these earlier works, for example, in He (2001); and He and Tsou (2001, 2002).

The second stage of the development of these visual research interests involved a switch to landscape evaluation and visual/landscape resource management in urban planning. This is illustrated in He, Tsou, and Lam (2002); and He and Tsou (2003, 2004), in which planning delimitations based on multiple landscape evaluation including landscape visual qualities derived from viewshed and visibility model calculation are suggested. Later development of this GIS-based visual study has introduced more quantitative approaches, like CVI of neighborhood communities for proposed urban development, as well as the quantitative modeling of the visual quality evaluation of natural landscape resources in urban contexts (He et al. 2005; Tsou, He and Xue 2005).

Although this thesis deals with rural landscapes, the proposed methodology and technology are still applicable. Furthermore, technological advances in former landscape visibility calculations and the research experiences arising from methodological consideration contribute to this study. Some of the visibility calculation parameters are also referenced in this study and will be discussed in detail in Section 4.3.3.

2.8 Summary and Discussion

It can be concluded from the above review that cultural route heritage research is still at a very primitive stage in terms of both its theoretical basis and practical methodology. The landscape archaeology paradigm can be used to support both the theoretical and methodological aspects of this field of study. Movement and trail studies and their technical strengths have been implemented and can be used for subsequent research. The framework for case studies on trails has also been explored. The feasibility of the cost-surface and visibility approaches has been demonstrated in investigating either the physical settings of archaeological sites or ancient people's perceptions of them.

However, although landscape archaeology methods may offer the potential for improvements to be made in analytical approaches, at its current stage of development, the integration of conservation with in-depth scientific investigations would seem to be difficult and problematic. CRM and the GIS platform it provides generally involve a gap between practice and research. Although the most common and applicable approach is site prediction, this method has also been criticized in terms of both validity and utility. Aside from basic visual impact assessment, CRM does not appear to have been used successfully so far in planning or development decision-making and management in a way that bridges the historical significance of ancient constructions and landscapes with suitable planning treatment of remaining relics in a broad context in which such relics are threatened by the spatial impact of modern urbanization. Therefore, to protect fractal heritage assets such as cultural routes, it is not feasible to rely solely on existing approaches to investigation, and especially on existing conservation methods. The introduction of new developments that link historical interpretations of heritage significance to the forces of conservation is essential.

Chapter 3

SYSTEM DESIGN

This thesis research intends to propose a schematic system for studying the authenticity of cultural routes and providing planning delimitations. In this chapter, detailed research questions are defined, including the authenticity and attributes of cultural routes, as well as research scopes and targets. Furthermore, this chapter presents the entire framework of the study as well as specifies the detailed objectives of each procedure. Details of methodological description and technical support will be given in Chapter 4.

3.1 Research Questions

Sections 1.2.2 and 1.3.1 conclude that authenticity is the intrinsic value of the cultural route heritages to be dealt with in the proposed research. Therefore, the proposed research firstly needs to define the attributes of authenticity, in order to form the basis for the proposed methods of practical investigation and delimitation. The detailed research questions cover the reconstruction of historical phenomena and reveal their associated values by means of analytical approaches. Finally, these authenticity values are translated into spatial parameters and mapped into regions or catchments for the purposes of future planning. Detailed questions are listed below in a hierarchical structure and answers are provided in the following sections:

1. How is the authenticity of a cultural route defined?
    a) Do the spatial attributes of cultural routes need to be defined? If the answer is yes, then

   b) What are those attributes?

2. How should these authenticity attributes be investigated?
   a) What is the essence of each of the attributes? Are they tangible or intangible?
   b) What role do tangible attributes perform in a cultural route? How should its value be assessed? Does the value need to be evaluated in a broad context?
   c) How should intangible attributes and their value be interpreted? Could the value be assessed through relative tangible elements?
   d) How can the assessments of attributes be combined into an integrated perspective on cultural route authenticity?
3. How can the characteristics of authenticity be quantified and spatialized?
   a) Can authenticity values be quantified or mapped? If yes, then
   b) What will be the methodological approach, and
   c) What technologies or algorithms will be applied?
4. How to translate the mapped regions into planning delimitations?
   a) What is the conservation planning scenario?
   b) What will be the scheme of the planning delimitations?
   c) How should the thresholds and boundaries of different conservation regions be defined?

Answering these research questions will bring about a framework for cultural route authenticity investigation.

3.1.1 Authenticity and the Reified Attributes

The authenticity of a cultural heritage is derived from the truthfulness and credibility of several attributes, including historical functions, "location and settings", "spirit and feeling" and other intangible characteristics and heritage forms (UNESCO 2005, p.21). A clear set of authenticity assessment criteria are prescribed in the draft *Charter on Cultural Routes* as follows:

> *Every Cultural Route should fulfill authenticity criteria in terms of both its natural and built environment...*
>
> - *These criteria should be applied to each section under study to assess its significance in relation to the overall meaning of the Route throughout its historical development, and to verify the authenticity of its structural layout through the **vestiges of its path**.*
> - *Authenticity should also be evident in the **natural context** of the Route, as well as in the other tangible and intangible heritage elements included within its **historic functionality** and its **setting**.*
> - *For the purpose of its comparative evaluation, the temporal duration and **historic significance** of the different sections of the Route in relation to the whole should also be taken into account.*(ICOMOS 2005, 4-5, emphasized in bold by the author)

The *WHC Operational Guidelines* also points out that the authenticity of "heritage routes" has to be revealed by means of the critical investigation of basic elements like "form and design; materials and substance; use and function; traditions, techniques and management systems; location and setting; language, and other forms of intangible heritage; spirit and feeling; and other internal and external factors" (UNESCO 2005, p.21).

Authenticity attributes

The above-mentioned heritage criteria imply that authenticity elements can be regarded as equivalent to tangible elements or heritage assets, together with their locations, spatial layouts and structures as they exist within landscape contexts, and all the tangible and intangible functionalities that are associated with these. All of these factors can be seen to determine the properties of cultural route heritage "as a whole" (ICOMOS 2005, p.3). The reification of authenticity is illustrated in Table 3, in which WHC criteria are interpreted in terms of cultural routes topologies.

Table 3

Authenticity attributes and interpretations of cultural route contexts

WHC heritage authenticity attributes *	Reified category	Cultural Routes authenticity attributes
Form and design	Tangible elements; spatial layout	Facility itself; route section; route "as a whole"
Materials and substance	Tangible elements	Facility itself
Use and function	Functionality	Associated functions; phenomenological aspects
Traditions, techniques and management systems	Functionality	Temporal development; facility itself; evolved functions/intangible elements; phenomenological aspects
Location and setting	Spatial layout	Natural context
Language, and other forms of intangible heritage	Functionality	Evolved functions/intangible elements
Spirit and feeling	Functionality	Phenomenological aspects

* From UNESCO (2005), paragraph 82.

3.1.2 Definition of Attributes

As pointed out above, authenticity can be investigated in terms of tangible elements and their spatial and functional interpretation. The relationship between cultural routes and tangible elements is that the latter "provide a confirmation of existence" of the formation of a cultural route (ICOMOS 2005, p.3) and serve as the substratum of its cultural authenticity. Nevertheless, these elements do not make sense in isolation, and thus the loss of a context for these elements may result in a large part of their authenticity (Ducassi 2005a; ICOMOS 2005). Thus, the holistic definition of these attributes is discussed in this section. However, the task of giving such a definition brings up the question of how to interpret the authenticity and value assessment approach outlined in 3.1.3.

The tangible elements

According to the *5th Draft of the ICOMOS Charter on Cultural Routes*, four kinds of key elements are combined in order to form a cultural route. They are "context, content, cross-cultural significance as a whole, and dynamic character" (ICOMOS 2005, p.3), of which the former two are tangible components. Whilst "natural context" is the basic cultural landscape setting, the cultural route's "content" is composed of the physical elements, including the "communication route itself" and their related facilities, like "staging posts; customs offices; places for storage, rest, and lodging; ports; defensive fortifications; bridges; markets; hospitals; urban centers; cultural landscapes; sacred sites, places of worship and devotion" (ibid: p.3). These indispensable physical elements possess other intangible characteristics, including the last two defining features of cultural routes. Intangible elements supplement and enrich meaning, thus contributing towards the integrated significance that is emphasized in the phrase "as a whole". These physical substratum of route structure and associated functional properties contain implicit "historical data about its use" (ibid: p.4) are all designated as authenticity assessment indicators. Therefore, the proposed study scheme will focus more on the tangible element of cultural routes.

On the basis of previous reviews, in the proposed scheme, the natural context (setting), the thoroughfare (i.e. the route itself) and the relevant facility are considered to be the basic tangible attributes. Both these attributes and the historical functionalities derived from their interrelationship are the objects of investigation.

Spatial and functional authenticities

The spatial layout or structure of a cultural route emphasizes the "location and setting" aspect of heritage authenticity indicated in *WHC Operational Guidelines* paragraph 82 (UNESCO 2005, p.21). Functionality interpretations are intimately associated with the spaces. Antonio (2005) concludes that the historical function of cultural routes is "control of the territory" which is implemented by means of a number of political, socio-economic and military methods. Although these functions are always intangible, they are associated with physical assets and material relics, such as buildings, infrastructure, and modifications of the environment and cultural landscape, all of which can be investigated spatially.

The authenticity attributes of cultural routes and their functional expressions are outlined in Table 4. In this study, the tangible elements of cultural route are investigated from the perspective of the holistic routes and spatial interrelationship of elements instead of isolated properties.

Table 4

Authenticity interpretation approaches and attributes to be investigated

		Functionality interpretation approaches *			
Cultural route authenticity attributes	**Spatial relation-ships**	**Dynamic & exchange**	**Cultural phenomen on & places**	**Mobility**	**Cultural practices & places**
Natural contexts	X	--	X	X	X
Functionality	X	X	--	X	X
Temporal development	X	X	X	--	--
Facilities	X	--	X	--	X
Structural configuration	X	X	X	X	--
Phenomenological aspects	X	X	X	--	X
Route sections	X	--	X	X	X
Route "as a whole"	X	X	X	X	--

* The functionalities interpretation approaches are adapted from cultural route identification criteria and evaluation approaches in ICOMOS (2005).

3.1.3 Authenticity Interpretations through Spatial Interrelationships

The proposed study intends to use the cultural landscape perspective on "physical constraints and/or opportunities" (UNESCO 2005, p.83) to investigate the man-made facilities and movement thoroughfares by revealing the interrelationships between settings, routes, and facilities, and their specific roles in fulfilling the historical functions of a cultural route. All of them are spatially relevant, and interrelationships can be derived from permutations of either two or all the three (Figure 4).

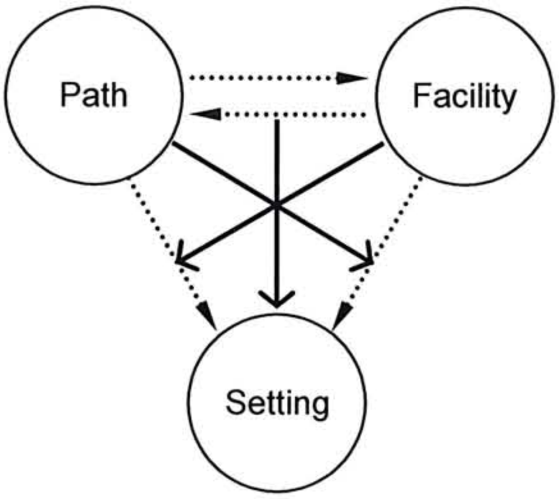


Figure 4
Diagram of a cultural route's tangible components and their interrelationships

However, of these three elements, the setting constitutes the main background, while the other two are more dynamic in space. Interactions between the facility and the pathway only take place in their context, and the settings cannot be framed within the scopes of individual facility or infrastructure belonging to the other two categories. Therefore, all the interrelationships are examined against the setting background.

Pair-elements relationships and associated functionalities

Relationship within any pair of the above-mentioned substantial cultural route components can explain the logic of the original construction strategy or historical functions and thus need to be clarified. All elements are sorted into different consequential pairs to denote the relationships by considering the first element within the context composed by the second one. The following list outlines the possible construction and functional authenticities that need to be explained.

1. Path within settings: This confines the path location within its environmental context and illustrates the topographical opportunities assigned to cultural route facilities for fulfilling their historical functions. Moreover, the path selection can also be interpreted from the geo-strategy perspective emphasized by Antonio (2005).
2. Path within facilities: Facilities may generate gravity, attraction or repulsion within a spatial range and affect the location of paths. Meanwhile, some spatial control, service, or network aspects, like accessibility, can also been investigated through this interrelationship.
3. Facility within settings: This is similar to the "path within settings", and also depicts the original construction criteria. Thus, topographical opportunities offered by the settings are introduced. Another reminder of the facility-setting interrelationship is that cultural landscapes could be generated by human activities (UNESCO 2005). In this study, such kinds of cultural landscapes with diverse cultural significance and physical artificial contributions in their development, e.g., assets belonging to the first and second categories of cultural landscapes given in Annex 3 of UNESCO (2005), will be categorized as specific cultural route facilities.
4. Facility within paths: Facility location is also relevant to the path distribution. From the functionality perspective, facilities control the path spaces and provide services to the path users.

Triple-elements interrelationships and associated functionality

All of the three elements can also be integrated in order to study the functionalities derived from their interactions. Compared to the "paired" approach, this explains path selection, facility location, spatial control and topographical or geo-strategic performances from a more complex perspective. Cost surface analysis can be applied through multi-factors modeled to situate the movement and spatial usage respecting spatial interaction between cultural route facilities and the natural environment.

3.1.4 Authenticity Interpretations through Functionalities

It has to been kept in mind that the discussion of the research questions that has defined these analyses should concentrate on the tangible cultural route elements in order to investigate their spatial connections and functional performances. The provision of paths and supporting facilities for human mobility are the fundamental functions of cultural routes and these eventually result in cultural exchange. The criteria of property and path constructions as well as the historical function provided by them for facilitating mobility are two critical aspects that assist understanding the substantial condition of the cultural route as a historical phenomenon and help to reveal its authenticity.

Movement and mobility

From a historical perspective, cultural routes were intended to facilitate movements or other exchange related actions (ICOMOS 2005). The functions of "control" or "service", which created all the relevant tangible and intangible elements, also focus on the movements that take place within a space during a certain historical period. The cross-fertilization achievements, the effect on cultures, the "dynamic system, the historic relations and cultural properties associated with its existence" (ibid: p.3) are all the consequence of both the involvement of the cultural route and the impact of mobility. In other words, although cultural exchange is the kernel of the value of heritage inscription, it is only a collateral phenomenon associated with and caused by the substance of the cultural route rather than their original intended purpose (Ducassi 2005a). Therefore, investigation of the movement of peoples and goods in the context of "true spatial and historical dimensions" (ICOMOS 2005, p.4) is considered to be the central premise for revealing authenticity in the proposed scheme.

The concepts of movement and mobility can be introduced into the study of all three attributes in addition to the interrelationships between most of the elements. Movement can be studied in order to replicate or predict path location, analyze facility catchment, reveal the effect of setting and context, evaluate transportation and assessing efficiency, and simulate phenomenological perception in order to explain elements and the structure of landscape as well as the functionalities relevant to these spatial characteristics

Construction and functionality interpretations

The construction of a cultural route is also a process of evolution for the fulfillment of specific functions. Most of the construction criteria indicators, such as the "the influence of physical constraints and/or opportunities" (UNESCO 2005, p.14, paragraph 47), are usually introduced to improve service performance of cultural route functions in historical periods. Construction criteria can be discovered through investigations of path and facility locations in a given context by means of what-if analysis. Functional performance of the investigated cultural route, like travels or military actions, can be simulated and explained by comparing the current conditions with the situation that would exist in the absence of the paths and facilities or even by assuming the random location of infrastructures and facilities.

3.1.5 The Scale Issue

Cultural routes may extend across various territorial scopes, local, provincial, national, regional, continental and even intercontinental (ICOMOS 2005). On the other hand, conservation and planning of a cultural route needs to be designed and implemented both comprehensively and in fine detail, for example, professionals have suggested the consideration of conservation plans separately section by section in order to facilitate efficient protection (Martorell-Carreño 2006). Therefore, the proposed study scheme needs to offer flexibility at several scales, e.g. they need to understand the cultural route "as a whole" (ICOMOS 2005, p.3) on a large-scale, and implement conservation with regard to individual sections at the regional or local scale. The framework, therefore, proposes different analytical approaches taking into account the requirements of the large, medium and small scales. The analytical results of the upper scale levels are also introduced at the lower levels as basic data inputs and boundary conditions.

At the larger scales, as well as from the perspective of entire cultural route extending to at least hundreds of kilometers, the main task is to locate the routes within both the natural and artificial contexts. Geo-strategy is a unitary significance and authenticity interpretation approach in such scope. In addition, spatial allocations which may help to define further study boundaries and conservation management sections at smaller scales can be derived from the influence of the scopes of different facilities, route sections or setting features. Due to the methodological limits of this stage of the study, intercontinental routes which pass across oceans or pure maritime waterways systems, like the Maritime Silk Road, are excluded from the scope of this research. Water-based cultural routes are only considered if they are part of the physiographical regions, for example canals.

Investigation regions of the middle-to-small scales can be inherent in the upper level's allocations. Furthermore, possible routes and facilities which are already mapped in larger scalar contexts can also be introduced. However, more sophisticated authenticity investigations concerning the tangible characteristics of cultural routes will be applied in regional and local contexts. The construction criteria of both paths and facilities can be interpreted from the aspect of environmental constraints and opportunities. Meanwhile, functional significances of path and facility settings can be deduced through spatial analyses on detailed geographical features. Other than these "passive" setting contributions, relative "positive" functions of the facility can also be mapped. Both the passive and positive features are combined into spatial catchments to reflect their effect distribution in nearby spaces, and their spatial relationships and possible interactions, or in other words, the authenticity level associated with specific heritage assets or their groups. Planning supports and their relevant delimitations are derived from these.

3.1.6 Technical Potentials in GIS

GIS provides spatial tools as analytical and planning supports. Sophisticated GIS analysis is also able to support investigations based on historical geography in order to remedy the shortcomings of those traditional historical and geographical studies that are mostly based on only archival and static map interpretations. However, if there is a lack of documentation, archaeological GIS paradigms based on landscape studies are available to reveal people's activity from the evidence provided by geographical characteristics.

Theoretically, as discussed in the literature review, landscape archaeology studies offer varieties of perspectives on the anthropological consequences of spatial configurations and geographical environments and GIS works as a "spatial toolbox" (Lock 2003). Furthermore, Zubrow (1994) declares that cognitive archaeology plays an important role in showing that people had preferences independent of economic necessity, and that some decisions are independent of utility. These subjective and intangible characteristics might reflect the social and cultural phenomena of cultural routes, which are emphasized in cultural route doctrines. Moreover in practical aspects, the above-mentioned two authenticity aspects in spatial relationships and functions are also the strongpoint of GIS analysis. Therefore in the proposed system, GIS spatial analyses are employed as investigation methodology. Details of GIS support will be discussed in Chapter 4.

3.2 The System Framework

The standardization of the investigation cultural routes has been suggested by WHC heritage managers (see Antonio (2005)). The proposed framework also intends to contribute to this topic by inventing several procedures and spatial analysis approaches in order to study the physical elements and historical functions of different kinds of cultural routes. These procedures include functional interpretations and spatial analyses conducted according to continuous scales, and conservation planning implementations.

The proposed cultural routes investigation framework and its implementation in a scalar system are illustrated in Figure 5 . The system includes the following steps or components leading to one of the methodological approach with respect to the research questions:

1. Data acquisition.
2. Path modeling: This is a complicated stage due to different circumstances of cases. Main components of this step include:
   a) Inventory and mapping of cost features.
   b) Establishment of cost models and the creation of cost-of-passage surfaces.
   c) Model implementation and path prediction or replication, and mapping.
3. Spatial analysis of spatial structures and functionalities. The approaches are:
   a) Defining relationships between the facilities and mobility paths according to their specific historic functions.
   b) Creating specific cost surfaces for different facilities.
   c) Catchment and region analysis of path and facility relicts for spatial control assessment.
   d) Interpretation of spatial characteristics and functional performance as authenticity.
4. Delimitations. The predicted paths and facility catchments can be mapped into varies thematic maps. Four categories of conservation criteria are introduced in order to delimitate the conservation scopes into cultural route 'property', core areas, and two levels of buffer zones according to evaluations of authenticity.

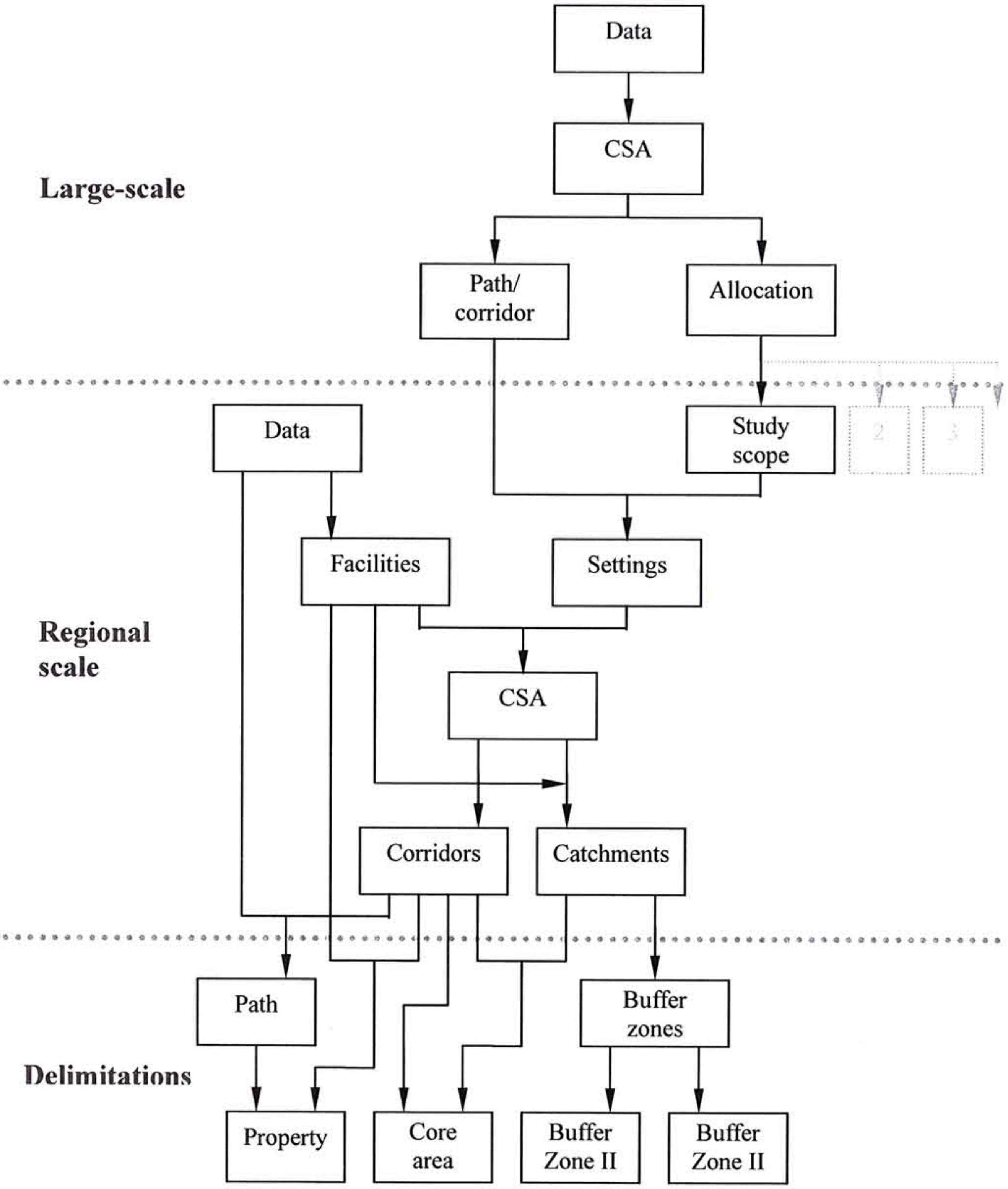


Figure 5

The system framework

3.2.1 Path Replication and Prediction

In the proposed system, path selection interpretation reveals the interactions among natural contexts and "the route as a whole" (ICOMOS 2005, p.4), or sections of route at different scales. Investigations of path location are conducted by cost-surface analysis by means of GIS. The technical details will be discussed in the next chapter.

Path locating simulation

Path locating simulation of this research follows the popular archaeological route locating approaches based on GIS cost-surface modeling. Cost attributes of the model are adapted from characteristics of natural settings and facilities, including topography, hydrology, land cover features, facility service scopes, municipal boundaries, cultural or religious allocations, and so on.

In order to accommodate the different purpose of cultural routes, besides the standard cost attributes like physiographic features, different costs relevant to social, economical or cultural effects shall be integrated to simulate different historical functions and thus account for different types of movements, for example caravans, pilgrims, troops, and immigrants (Ducassi 2005a; ICOMOS 2005). Meanwhile, for different activities within the same route spaces, simulation models may need to be refined with regard to different activities. For example, fortifications along a route may attract caravans, whilst at the same acting as barriers to invasion. These differentiations should be taken into account in model making.

Topographical opportunities and constraints

The "influence of the physical constraints and/or opportunities presented by their natural environment" is a basic criterion for cultural landscape definition (UNESCO 2005, p.14). Since cultural routes are also considered to be cultural landscapes both as a whole and in terms of component sections (UNESCO 2005; Rössler 2006; Ducassi, 2005a), these criteria can be regarded as fundamental construction concerns.

At regional or local scales, natural contexts can be derived more effectually and accurately. On the other hand, the "route as a whole" only illustrates the general characteristics of cultural routes. Substantial cultural route construction activities are only executed at regional or even smaller scales. Therefore, it is more appropriate to interpret cultural route construction criteria at this level. Previous researches of landscape archaeological studies also have proved the validity and utility of locating simulation within these scales (see Kvamme (2006)). Meanwhile, efficient conservation schemes also need to operate at the same level in order to ensure that conservation is executed efficiently. Therefore, in the proposed system, the "passive" reactions of path and facility to their natural context in their construction history, or in other words, the authenticity of context effects on the cultural route construction, needs to be investigated at these medium to small scales.

Path selection in this respect is also investigated in terms of similar approaches at a larger scale, although there is less complexity in the cost variables to be introduced in the cost-surface modeling and analysis algorithms. Usually only topographical features are applied and artificial impact can only be mapped roughly as cost distributions.

Path structural configurations and corridor calculations

GIS-based least-cost-path simulation always reveals a linear path from a location to a destination. Sophisticated design in selecting these starting locations and destinations is able to simulate the different shapes of path systems of cultural routes i.e. linear, circular, cruciform, radial or network shapes (ICOMOS 2005). As demonstrated in van Leusen (2002), even weighted path networks can be constructed by means of this approach.

Van Leusen (2002) also suggests the use of the lowest-cost corridor under particular circumstances. The cost-surface based path predictions applied in this research delimitate possible movement corridors within certain cost ranges instead of determining a single "optimum" path between the starting point and destination. This approach allows for flexibility in archaeological excavation as well as tolerance of modeling errors. Meanwhile, cultural routes can also be defined as areas (Martorell-Carreño 2003) rather than just linear shapes. This approach is able to fulfill the path locating requirements of cultural route authenticity more effectively.

Path relics for interpretation and modeling

The path selection criteria can be investigated through comparing cultural route path relics or historical documentation (e.g. historical maps or texts descriptions) with the calculated optimum path or corridor (van Leusen 2002). The consistency assessment can be used to calibrate interpretation strategies. In addition, the cost attributes of the path remnants can be analyzed through regression model in order to refine the cost-surface or location models. Kantner's (2004) study demonstrates a statistics-based interpretation approach from which the proposed scheme could benefit.

Facility location modeling

Although revealing the possible site location of the annihilated cultural route facilities is important for conservation, such archaeological site prediction approaches will not be fully applied in this scheme. The main reason is because of the limitations of location modeling methodologies and the practical considerations of the proposed scheme.

The main problem concerned with the application of predictive model in this research is that location prediction modeling is usually only able to map very broad zones in the search for annihilated archaeological sites (Kvamme 2006; Lock and Harris 2006). On the one hand, in the analytical framework of this system, cultural route facilities have an important cost effect on movement paths, precise location of these cost factors is needed in order to create reliable cost-of-passage surface for movement studies. A wide range of homogenous environment characteristic will redefine all the cell costs within this area under unrealistic circumstances which cannot reflect the spatial distribution of facility gravity at all. Since the facilities might only be sited in a few places, the location cost of the other will be severely distorted because of this approach. Moreover, conservation delimitations based on the authenticity of properties also require relatively accurate site locations. Probable areas can usually only be protected as buffer zones instead of being considered as more significant cultural route heritages (ICOMOS 2005; UNESCO 2005).

The path location models applied in the proposed investigation can also provide probability maps. Since the spatial factor "distance to the path" is normally applied in site prediction models to reflect the sites' spatial or functional relations to the route (Kuna 2000; van Leusen 2002), like Rajala, Harrison, and Simon's (1999) distance bias for revealing correlated settlements to Roman roads, the calculated cost value corridors or cost-surface catchments along the predicted paths actually already cover most of the most important site location areas.

Therefore in this research, no specific cultural route facility sites will be predicted unless they can be located reasonably accurately. However, some of the strategic locations revealed by spatial analytical results of the movement paths and remaining facilities might be highlighted and considered in conservation mapping.

3.2.2 Control of Space

The hypothesis in this investigation is that facilities belonging to cultural routes must fulfill their economical, military and social functionalities, which can be interpreted as controlling a scope of territory (Antonio 2005). These controlling phenomena can be illustrated through catchments based on different aspects of cost surface analysis, like allocation, distance, accessibility, network structure, visual relationship, and so on. This approach investigates the substantial function of facilities at regional or smaller scales, thus disclosing heritage authenticity directly. Meanwhile, the revealed controlling phenomena are mapped features which can be demarcated into conservation zones according to authenticity levels. Therefore, investigations of spatial control are a crucial component of the proposed authenticity study and planning support scheme.

Facility types and historical functions

A list of assets mentioned in the updated cultural routes doctrines as well as former researches like Antonio (2005); Martorell-Carreño (2003, 2005); and Rössler (2006) will be given here. The four categories into which the facility functions concerned with services, logistics, defense, and worship may be classified are mentioned in Table 5. Each category is concerned with a different scenario for investigating historical functions by means of spatial analyses.

Table 5

Types and functions of cultural route facilities

	Functions			
Types of facilities	**Service**	**Logistics**	**Defense**	**Worship**
Economy				
Cargo storage	X	X	x	--
Rest and lodging	X	X	x	--
Markets	X	X	--	--
Municipals				
Staging posts	X	X	x	--
Defensive fortifications	x	--	X	--
Customs offices	X	X	x	--
Multi-function / others				

Settlements/towns	X	X	X	X
Urban centers	X	X	X	X
Hospitals	X	--	--	--
Ports	X	X	X	--
Transportation				
Bridges	--	X	--	--
Lighthouse	--	X	--	--
Socio-cultural				
Places of worship and devotion	x	x	x	X
Sacred sites	x	--	x	X
Cultural landscapes				
Designed landscapes	--	--	--	X
Farmlands	--	X	--	--
Mining areas	--	X	--	--
Breeding areas	--	X	--	--
Sacred landscapes (associated landscapes)	--	--	--	X

Note: Lower-cased "x" indicates there are collateral or lesser significant functions.

From the perspective of element interaction discussed in section 3.1.3, all the spatial control functions can be interpreted by the spatial characteristics of their facilities in conjunction with the natural context and the overlaying path locations. The service, logistical, defense and worship function fulfilled by the facilities listed in Table 5 can be reflected by the spatial characteristics for quantitative control performance, for example in accessibility, allocation, and visibility.

Municipal, administrative or control tessellation

Cost-derived Voronoi-like tessellation of a studied scope can interpret spatial control distribution (Conolly and Lake 2006; Wheatley and Gillings 2002; van Leusen 2002). Tessellation maps delimitate the functional availability scopes of certain groups or all facilities. These territorialities can be interpreted as the municipal, administrative, or economical, cultural or religious centers in historical periods if relevant cost surfaces can be applied reliably. Therefore, this approach is concerned with reconstructing a cultural route's authenticity in terms of its territorial aspects. Moreover, the same method of tessellation can be applied in dividing management sections for conservation planning, which will be discussed in section 3.3.

Cost surface based catchments

All facilities must be accessible if they are to fulfill their service and logistical functions. Worship facilities and cultural landscapes also required a certain level of accessibility according to their different religious or ritual requirements. Defensive facilities are ambiguous with respect to accessibility requirements since they combine the functions of military frontier with those of logistical supply. There are also other complicated accessibility requirements for multi-functional facilities, such as towns or cities, which also have to consider the issues of defensive performance and balance these with other economical, political or cultural functions.

Accessibility can be inferred from the cost distance to the objective facility and calculated through cost surface analysis (Conolly and Lake 2006). Cost surfaces are modeled on the basis of both basic cost features (topography and land cover) and tangible facility effects or perceptual characteristics. Cost distances of each facility can be derived by GIS-base calculation to illustrate accessible territoriality. Lower costs indicate easier access to the objective facility. Further spatial control analyses or functional interpretations like spatial allocation, conjunction, network performance, and so on can also be processed on the basis of these cost-distance analyses.

Visibility in perceptual and functional interpretations

Visibility definably serves as one of the cost effects. It is obvious that visibility can help to identify facilities in cultural route movements. On cultural route paths, the visibility of certain physical assets, like church belfries for pilgrim routes, gives clear guidance towards the predefined destination.

Another functionalist interpretation relevant to movement is that visibility is extremely significant for defense. For attacking and defensive purpose, visibility can be interpreted from two main perspectives: the need to observe and the potential range of the weapons employed. Observation control can also be understood from both the points of view of the attacker and defender, and calculated through either single-point view or accumulative viewsheds. For defensive purposes, observable ranges cover larger scopes, thus enabling more effective information collection and warning systems. Meanwhile, if a strategic location can be observed from the more individual infrastructures of a defensive system, it can be seen as being in more effective control. Conversely, the attacking side needs to find a suitable path by which to sneak as close as to the fortification as possible without being detected; at the very least, they need to avoid the high-visibility regions. The shooting range is another attribute derived from the scope of visibility and the existing level of control. Thus, the shooting range of certain defensive facilities can be illustrated by references to the visibility scopes that are within the capabilities of certain weapons. The principle is to define the available scope of an accurate shot taking into account both aiming and available firepower. Therefore, long-range archery attacks and ability of shots to reach an invisible area by means of mortar-like trajectory are not taken into account.

Both the single viewpoint approach, such as investigating the spatial performance of a watchtower or sentry, and accumulative viewsheds like the level of control of the defensive scopes, or intervisibility among information transfer facilities like beacons, can all be calculated through GIS visibility analyses. Shooting ranges can be defined by overlaying single or cumulative viewsheds within defined buffer distances from shot points or defensive frontier lines. These approaches to the investigation of defensive spaces are able to reveal the authenticity of military functions both in detail and scientifically. Especially in the case of cultural route, the defensive spaces can be overlaid with paths or cost corridors. The defensive capability acts on the route locations and can be demonstrated directly and interpreted as interactions among tangible cultural route elements.

Besides theses tangible functions, gravities of visibility also have phenomenological significance. Theories of archaeological visibility for landscape perception have been reviewed in Chapter 1Chapter 2. Visibility affects the "intentionality" of human beings moving within landscapes (Llobera 2000, 2003), Higher cumulative viewshed levels may cause anisotropic effects by either defining important sites, or in a more abstract interpretations, by being more highly preferred by people because these regions provide more opportunity for people to recall their experience for enhancing current landscape perception (Tuan 1979; Cosgrove 1989). Because they allow people to be "absorbed" more efficiently into the relevant facilities, larger visible areas and high accumulative visibility values may enhance the spatial control ability of the objective facilities.

3.2.3 Cultural Landscapes in Cultural Route Spatial Analysis

Cultural landscapes, that are not appropriately to be simplified as point features in spatial analysis, are defined as one of the basic components of both the cultural route structure and its functionality (ICOMOS 2005). Specific functional land uses, like farming, mining, manufacturing, or phenomenological environments such as religious or sacred places, represent the kernel of significant assets in most of the currently WHC-nominated Heritage Routes (Rössler 2006). These cultural landscapes are even more important than other old-fashioned heritage properties like individual monuments or historical towns.

Since cultural landscapes represent both the natural setting of cultural routes and their facilities, and the paths may traverse within these scopes, the interactions between substantial elements may actually occur internally. In such circumstances, their spatial performance has to be assessed according to special criteria. For example, some of the topographical and natural context features which can be irrespective in point-shape facility, such as aspect and radiations which are critical for agriculture, have to be recognized and introduced into cost-surface modeling. And itineraries or cost-derived paths within these landscapes should be integrated with the entire route structure.

Worship and phenomenological landscapes

Phenomenological perception is crucial to the facilities or cultural landscapes with worship functions. As far as ordinary places of worship with less natural contexts, such as temples and churches in townscapes, are concerned, religious implications are mostly associated with the building itself. Spatial control of these architectures can be interpreted on the basis of the same accessibility, allocation and visibility studies listed in Table 5.

However, the issue of phenomenological perception becomes more complicated when natural landscapes are taken into account. Many cultural landscapes are made up of cultural routes that have phenomenological significances, especially organically evolved landscapes and associated cultural landscapes, which are actually themselves natural settings that are imbued with religious, artistic or cultural significances (UNESCO 2005). There may also be individual worship facilities within these cultural landscapes. But they are all integrated within the explicit significance and authenticity of their landscape contexts. Natural landscapes and route and temple system of the World Heritage Site Sacred Sites and Pilgrimage Routes in the Kii Mountain Range, the three sacred mountains as Yoshino and Omine 吉野・大峯, Kumano Sanzan 熊野三山, Koyasan 高野山 with temples and shrines are typical example of these phenomenological landscapes (Rössler 2006; Wakayama Prefecture 2006) (Figure 6) . The whole site also involves composing a pilgrimage route system leading from the Nara to Kyoto (UNESCO and Agency for Cultural Affairs and Ministry of the Environment Government of Japan 2004).

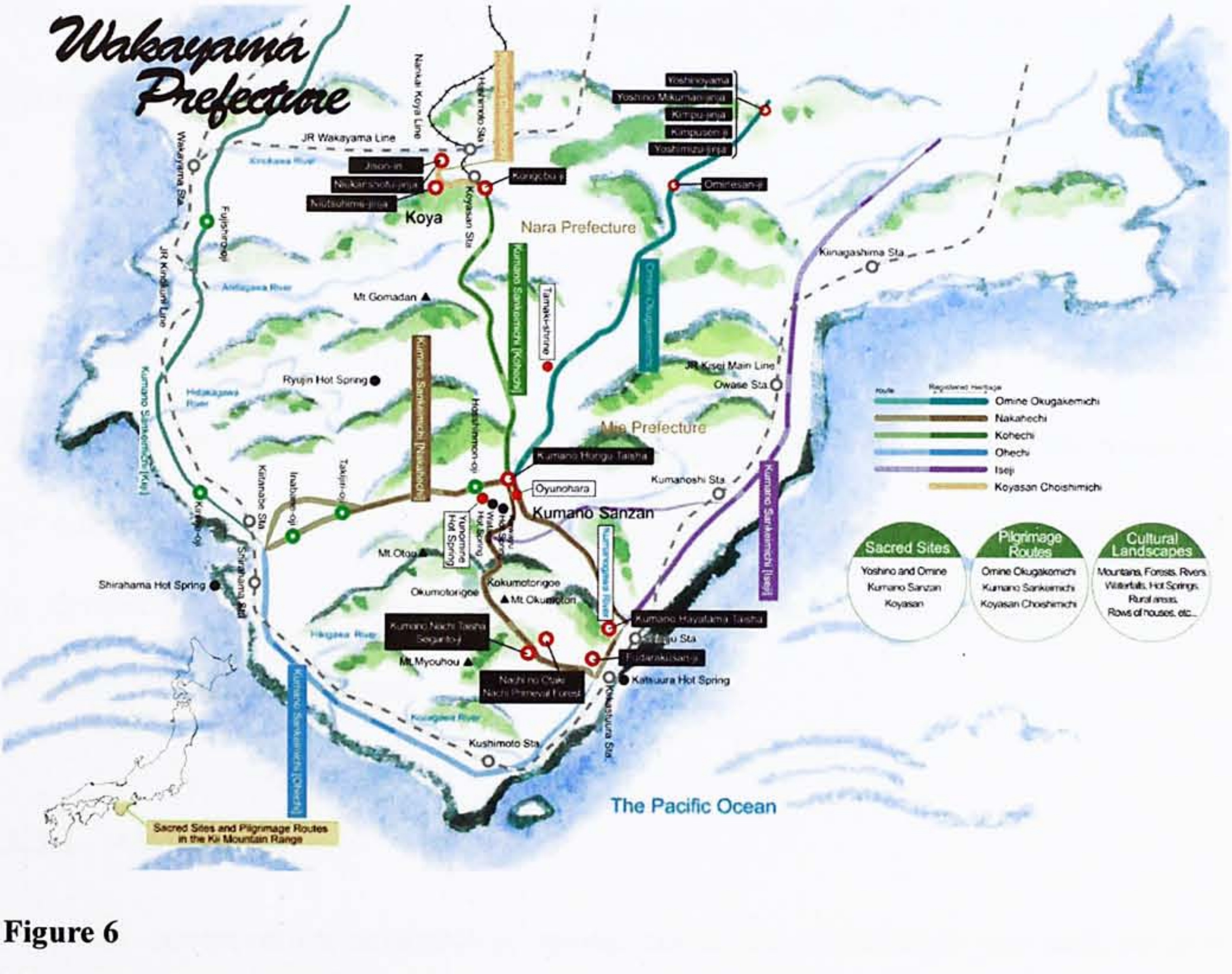


Figure 6

Map of the Sacred Sites and Pilgrimage Routes in the Kii Mountain Range (adapted from (Wakayama Prefecture 2006))

The over-reliance on visibility in the study of landscape perception has been criticized in a number of different studies (Tschan, Raczkowski, and Latałowa 2000;

Wheatley and Gillings 2000). However, since the proposed investigation scheme can only evaluate landscape perception within limited scopes and linear spaces instead of larger scopes of landscape, visibility still needs to be introduced as the main attribute. Nevertheless, unlike the normal interpretations that consider visibilities to be the only associated spatial control parameters in ritual cultural landscapes, all scenes that can be perceived along the paths or from key viewing points become setting elements rather than merely spatial relationship factors. The visible areas and sceneries are integral to the authentic characteristics of the paths. Therefore, they should be integrated with the observation locations as extensions of the property or core areas (like suggested in Martorell-Carreño (2006) and Sugio (2005)) in conservation delimitations.

3.3 Management and Delimitations

The above-mentioned cultural routes element analyses can carry out thematic maps in path selection and spatial distribution of functionality performance. Delimitation for conservation planning support introduce these maps and convert the spatial data to demarcate properties and protection zones based on the authenticity levels revealed through these maps.

3.3.1 Allocations

From the conservation perspective, spatial allocation of facilities and path section also illustrate the relationship between settings and property. These tessellations can be employed as references to define management boundaries. For example, a cultural route has to be managed and its conservation plan has to be implemented based on different sections (Ducassi 2005a; Martorell-Carreño 2006). To delineate these sections, archaeological remains of the path or facilities which are the central heritage properties can be assigned as the sites to tessellate a defined entire management scope, such as, within certain buffered distance of the whole cultural route or a corridor of designated cost range. Associated areas belonging to each site can be considered as the available administrative scope for the designated heritage property.

3.3.2 Delimitations in Categories

For categories of protection levels are introduced to delimitate the conservation scopes into cultural route properties, core areas, and two levels of buffer zone:

1. Heritage property: This category provides principal heritage protection and includes relics of path and facility.
2. Core area: Core area suggested in the proposed mechanism has to fulfill two protection requirements, one follows *WHC Operational Guidelines* on "direct tangible expression" (UNESCO 2005, p.25) and the other is further possible contribution of property authenticity (UNESCO 2005). Meanwhile, a core area also serves part of the functions designated to buffer zone in the *Operational Guidelines* as immediate setting of properties. Furthermore, in some cultural route cases discussed in section 3.2.3, like pilgrim routes in sacred landscapes, "important views" are also has to be designated as core area instead of buffer zone legislated in the *Operational Guidelines* (UNESCO 2005).
3. Primary buffer zone: This encloses areas "functionally important as a support to the property" (UNESCO 2005, p.25) except the areas already included in core areas.
4. Secondary buffer zone: This level of buffer zone is actually introduced to satisfy

the requirements of the additional protection layer intended in the *Operational Guidelines* (UNESCO 2005). Since there are too many uncertainties and shortcomings in defining this protection layer through subjective judgments (Martorell-Carreño 2006), in the proposed scheme, the degree of authenticity and its mapping by catchments are introduced as rationalization.

Property identification and locating

Former studies in interactions among settings, paths, and facilities are able to reveal authenticity in the locations and levels of spatial control. For conservation purposes, establishing whether a property belongs to cultural route could be a challenging task if only the old-fashioned approaches are adopted (Martorell-Carreño 2006). In the proposed investigation scheme, the scope with higher authenticity, which implies the existence of closer relationships or closer catchment values to routes and facilities in these locations, can be revealed through movement studies and site modeling. Relics or assets can be evaluated by referring to the authenticity values of their locations.

For path protection, corridors in both large (provincial, inter-provincial, national, international, or even intercontinental) and regional scales can be revealed through cost surface analysis. The optimum path can also be calculated within these spatial corridors. Relics of paths which located within the corridors should have a closer relationship with the "route as a whole" and possibly be one of the organic components of the studied cultural route system.

Facilities inscription can also be initially filtered by the calculated path corridors. But questionable facilities also need to be tested in terms of space control performances, in which the methodology is the same as path cost corridor but implemented inversely to evaluate the route within the facilities control scopes in order to explicate their spatial and functional relations in terms of the facility itself.

On the basis of certain functions of the investigated facility, cost distance and visibilities from this facility can be mapped and overlaid with path maps. If the paths are included within certain levels of cost distance or accumulated visibility, the facility can be considered to belonging to the route. Moreover, other properties might get be seen to be involved by only merely because of the visibility relationship, although they are but spatially remote. Such cases can only be considered in visibility analysis because there is no cost of movement engagement.

Lost sites and conservation scope

Apart from relic properties, annihilated monuments and possible archaeological sites of the cultural route also need to be preserved. Site modeling approaches can be introduced in practice but will not be discussed in this thesis. By overlaying the possible site scopes, or other predictive regions with the movement corridors of the cultural route, the possible areas can be contracted. Since cultural routes are more appropriately protected by enlarged buffer zones from the heritage element (Martorell-Carreño 2006), a probability scope with a high authenticity of movement is enough for protection purposes. But instead of being designated as property, these scopes can only serve as core areas or buffer zones.

Core area and buffer zone definition

Core areas and buffer zone can be defined from the cost surfaces and spatial control catchment of both paths and properties and their overlaid maps. Borders differentiating these delimitations types are defined by reclassification of these cost-distance thematic maps into degrees of controlling performances.

Core area designation by means of this mechanism relies on the substance of the authenticity zones associated with cultural route elements. Besides the clear descriptions in the above introductions, further interpretations can also be introduced to define different protection zones. For example, spatial control catchments can be overlaid with movement corridors in order to study the significance of the setting significant in fulfilling both mobility and static facility factions. If there are calculated corridors passing through a facility catchment, these overlapped scopes reveling kernel functionalities for both and may deserved to be regarded as core areas. Since both the movement cost and facility control cost are all scaled factors of people's movements, these two cost maps can be overlaid to show integrated significant values or authenticity degrees more clearly.

There could also be external references that help to define these boundaries. In the heritage preservation laws of different countries, it is common to have regulations governing the core area, for instance the requirement for certain buffer distance to protect the immediate heritage settings. Core area of a cultural landscape can introduce this protection bottom line as the nearest boundary and then find the smallest cost distance value which can fulfill the requirements. The contours of this cost value can be defined as the core area border.

Buffer zones in the proposed scheme are established in order to protect a cultural route that is extended as far as possible and to maintain heritage settings of secondary significance. There are no explicit criteria for separating buffer zone levels one and two. Differentiation should be based on individual cases and consider property functions as well as external limitations by land use. In general, facility catchments extend into certain cost value and scopes within a path's cost-distance which covers all of its relevant facilities have to be delimitated as the primary buffer zone. The secondary buffer zone may contain areas with less authenticity within certain cost value of cultural route corridor according to the specific case, or areas that have a potential impact or influence on cultural route elements.

3.4 Summary

The proposed cultural route authenticity investigation scheme follows the procedure illustrated in Figure 5. Firstly the overall path system is represented or reconstructed by cost-value corridors or optimum paths. Facilities associated with the route can be identified. Then the entire route and its settings are divided into different administrative regions to be further investigated on regional and local scales. In order to make conservation planning implementable by local municipal agencies, it should be possible to “zoom” in on the regional scale for further investigation.

At regional or local scales, the spatial construction logic of paths and properties are examined according to cost surface contexts. Path locations are reevaluated with more precise cost-of-passage maps and DEM in high resolution. Value choropleth corridors of possible movement locations are mapped as routes according to integrated landscape costs. A property’s spatial relationship to the route is defined by cost-derived spatial catchments and interpreted into authenticity levels reflecting historical functionalities of cultural route. Finally four categories of protection zones are delimited according to the route corridors and property catchments of different degrees of authenticity.

Chapter 4

RESEARCH METHODOLOGY

The investigation scheme is based on GIS spatial analysis and mapping. Cost-surface and visibility analysis are employed as the main approaches for revealing historical paths and their relevant historical functions, and to map authenticity catchment levels. Given the tremendous variations in the conditions of different cultural routes, this chapter discusses only the basic methodologies and technologies involved. Further details are illustrated in a case study outlined in Chapter 5 to explain the implementation of the system.

4.1 Background Dataset

In this study, analyses of environmental constraints and opportunities, mobility and cultural routes, and spatial structures and functions, as well as consequent planning supports, are all based on GIS. A digital dataset is required for each heritage case study. The proposed system introduces digital elevation models (DEMs) as basic datasets through which other physiographical characteristics can be derived. Remote sensing and other geoinformation technologies are also introduced for land cover data collection and facility mapping. Cost surfaces are modeled on the basis of topography and land use data. Furthermore, historical maps and reconstructed historical landscapes are used in the analyses.

4.1.1 DEM

Digital elevation models (DEMs) have been used as basic datasets for several kinds of spatial analysis, particularly for analyses on a local to regional scale. Conolly and Lake (2006) summarizes the contributions made to various somewhat overlapping archaeological applications through DEM computation. A matrix of analytical methodologies and supporting technologies than can be used is shown in Table 6.

Table 6

DEM-based spatial analyses and the applications introduced in the thesis research

	DEM-based calculations					
GIS spatial analyses applied in the proposed investigation system	**Slope**	**Aspect**	**Curvature**	**Irradiance**	**Viewshed**	**Watershed**
Topography	X	X	X	--	--	--
Movement /cost-surface	X	X	--	X	X	X
Landscape perception	--	--	--	--	X*	--
Sediment movements: Erosion/artifact movement; taphonomic modeling	X	X	X	--	--	X
Vegetation modeling	X	X	--	X	--	X
Site location modeling or Predictive modeling	X	X	--	X	X*	X

Adapted from Chapman (2006); Conolly and Lake (2006); and Wheatley and Gillings (2002)

The proposed investigation scheme mainly adapts first-order DEM derivatives and viewsheds. For special cases that require problem-oriented analysis, extra applications may also be introduced. For example, for analyses of cultural routes with agricultural functions, or in forestry contexts, such as the cultural landscape "Quebrada de Humahuaca" (inscribed in the World Heritage List in 2003), which follows the "Camino Inca," or the "Incense Route - Desert Cities in the Negev" (inscribed in 2005), vegetation and land capacity shall be considered and calculated according to slope, aspect and irradiance features in combination with other non-terrain features such as soil type.

Another valuable aspect of DEM is its application to data representation. Aside from 3D terrain representations, other data sources or analytical results can be draped on a DEM surface or integrated into a DEM in create a non-elevation based surface (Chapman 2006) as a scientific visualization. However, given that only analytical aspects are discussed in this thesis, DEM visualization will not be demonstrated.

Creating DEM

The need to create DEMs is declining due to the availability of high resolution commercial products from surveying agencies and other mapping services (Conolly and Lake 2006). In addition to off-the-shelf DEMs, ordinary topographical data resources include digital and sheet maps. However, due to the remote or undeveloped locations of many cultural heritage sites, as well as the extent to which cultural route properties are distributed, various other sources such as satellite stereo pairs of images, interferometry, radar and laser scanning (Conolly and Lake 2006) can also support DEM derivation if the "traditional" approaches are not available (Hernandez 2006). These alternatives provide flexibility for investigating cultural route heritage sites that feature a variety of geographical or natural contexts. The schematic methodological framework can therefore be applied in a broad range of situations.

DEMs can be processed in GIS through either raster grids as "altitude matrices" (Conolly and Lake 2006, p.100), or through a triangulated irregular network (TIN). Different GIS software and analytical processes require different formats, although raster-based DEMs are the most popular form of elevation data (Conolly and Lake 2006) and TIN may have advantages in some special usages such as viewsheds (van Leusen, 2002). Both formats can be derived from either elevation points or vector hypsography, such as contour lines, or from a combination of these two datasets. Interpolation methods applied in the creation of DEMs from data sources for archaeological analyses are investigated in Kvamme (1990), and more details are given in Wheatley and Gillings (2002) and Conolly and Lake (2006) to describe the appropriateness of dealing with various types of data and generating different kinds of results for a specific purpose. Popular GIS packages such as ArcGIS, MapInfo and GRASS, which are mostly used in archaeological GIS, provide most of these interpolation functions for analyses carried out for different purposes and in different circumstances.

DEM errors

DEM accuracy is significant because it controls both the first-order landform representation and the secondary data or analyses derived from it (Kvamme 1990). DEM errors that may affect analytical reliability are generally caused by systematic errors and user errors made through an inadequate understanding of the limits of a DEM. The technologies used to reduce such errors are broadly discussed and well developed in the GIS discipline and, other than two approaches used in edge effects and DEM resolution, are excluded from this study.

To reduce the edge effect, extensions from the cultural routes and regions being studied have to be embodied in the DEM. Given that the edge effect also occurs in other types of spatial analysis, extra buffer zones must be prepared in DEM surface and the valid DEM need to be clipped onto the desired extent to serve the dependent analyses.

DEM resolution

Resolution is another important issue in archaeological GIS and is discussed in a separate section. It is one of the major concerns to be taken into account in estimating system error. GIS and other geoinformation studies indicate that the coarser cell size used in DEM greatly affects the analytic and modeling capabilities inherent in the GIS system (Madry and Rakos 1996). An obvious example of user error is the disregard of data scale limitations resulting from the use of DEM data produced by low resolution data sources in a high resolution application (Conolly and Lake 2006).

From a practical perspective, earlier attempts at archaeological GIS suggest that DEM data should be pursued to as high a level of accuracy as possible (Kvamme 1990; Warren 1990). Nevertheless, at the same time, Madry and Rakos (1996) note that data availability and relative cost are also important concerns. However, due to timely enhancements to of DEM products and recent developments in topographical data quality, more data source options are now available. Developments in computing ability also offer more alternatives in when it comes to the considering consideration of resolution issues selection.

USGS 7.5 Minute Series DEM data were first introduced to the landscape archaeological GIS field by U.S. researchers in the late 1980s (for example, see Harris (1988) and Kvamme (1990)), and research in this area has been ongoing (see, for example, Dore and Wandsnider (2006); and Whitley (2006)). The data from the Shuttle Radar Topography Mission (SRTM) and One Arc Second Mission (SRTM-1) have recently been used to substitute for USGS 7.5 Minute Series DEM data because of the high quality of both 30m DEM resolutions and due to the map scales, which are equivalent to about 1:24,000. This kind of resolution is applied in various landscape archaeological and GIS analyses for research areas of 100 to 200 km^2. Nevertheless, there are also researchers who indicate that 30m DEMs result in the loss of significant topographical features, which may affect the conclusions reached (Harris 1988; Madry and Rakos 1996).

As this "standard" SRTM-1 DEM is still not publicly available outside the United States, archaeologists have to pursue other data sources and introduce DEMs in differentiated scales. There is an example of a precedent for coarser 50m resolution models being used for study areas of less than 50 km2 (Kvamme 1990), and there are also rough models of around 100m resolution for areas of more than 1,000 km2 (Madry and Rakos 1996). Other finer resolution DEMs have also been introduced, such as those with a 20m resolution or a scale of 1:20,000 (Madry and Rakos 1996). All of these DEM resolutions have be examined for their ability to provide or facilitate visibility, cost-surface analysis, and location modeling, as well as other ordinary DEM calculations made for archaeological landscape interpretation purposes.

Most landscape archaeology GIS projects involve the use of a DEM resolution of less than 30 m to analyze landscapes of between one hundred and several hundred square kilometers, using the DEM-derived spatial analyses listed in Table 6. However, for cultural route projects, topography has to be investigated on a larger scale. For "road as a whole" studies, it may not be necessary to use a DEM resolution as fine as that required when dealing only with a section of a road. For example, Madry and Rakos (1996) demonstrate the application of a 97m DEM resolution when studying the Celtic road network in the Arroux River Valley of France, which covers an area of more than 1,000 km^2. Tate (2007) uses SRTM Three Arc Second (STRM-3) data with a 90 m resolution to compute the Hajj pilgrimage route in the Sinai, which is around 300 km in length. In this study, I introduce two kinds of DEM datasets to differentiate large scale "road as a whole" studies from regional investigations. The details will be discussed in section 4.1.2.

4.1.2 Mapping Scales

DEM resolution also affects mapping scale for analytical results and the consequent conservation plan scales. For heritage conservation, the *WHC Operational Guidelines* do not include detailed instructions on scale selection for property and buffer zone mappings or plans included with nomination documents. Looking at local practice, China's heritage legislation system requires a conservation plan of 1:10,000 to 1:50,000 in scale for heritage properties of more than 50 km^2 (國家文物局 2005), a requirement that can be fulfilled by a DEM with a cell size of 30 meters. According to item 19(9) of the same code, the plan scale of larger conservation areas can be determined by reference to other planning legislation. According to the *城市規劃編制辦法實施細則* (中華人民共和國建設部 1995) and the *Code for Scenic Area Planning 風景名勝區規劃規範* (中華人民共和國建設部城市建設司 1999) which suggested to be followed in heritage conservation planning by 國家文物局 (2005), 1:100,000 and 1:200,000 are alternative scales that can be used to study cultural routes that cover a wider area.

STRM-3 terrain data

The Shuttle Radar Topography Mission overseen by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA) of the United States provides worldwide DEM data at a resolution of 90 m, and the International Centre for Tropical Agriculture (CIAT) provides void-filled products to the public free of charge (CGIAR-CSI 2004). The SRTM-3 DEM is considered to have a scale of 1:250,000 according to USGS SRTM standards (USGS 2006). However, there is also another specious debate over whether the SRTM-3 is able to capture more topographical details than a DEM generated from a 1:50,000 map (Jarvis, Rubiano, and Cuero date unknown). The SRTM-3 has also been interpolated to a resolution of 20m for landscape archaeological visibility research in a 100 km2 area (Llobera 2007b). Therefore, due to its high quality and accessibility, SRTM-3 data is a good data source enabling heritage conservation requirements to be met for both GIS analysis and mapping in China, on both a national and regional level.

Other data sources

Other data sources can be employed in a Chinese context. Standard topographical maps of 1:10,000 and 1:50,000 in scale, either in digital format or digitized from sheet maps, can be used as a reliable basis for generating DEMs, as proven by archaeological work carried out in China (劉 2007). If topographical maps are difficult to obtain due to security concerns, or surveying records are unavailable because of the remoteness of a particular location, photogrammetry and commercial satellite images can provide alternative solutions at a reasonable cost. For example, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) offers DEM with a horizontal resolution of 25 to 30 meters (Land Processes Distributed Active Archive Center 2006; Jet Propulsion Laboratory 2006), while Satellite Pour l'Observation de la Terre (SPOT) data is available at a resolution of 20 to 30 meters (SPOT Image date unknown) through stereo pair image processing (Conolly and Lake 2006).

4.1.3 Historical Topography and Landscape Reconstruction

One group of critics has questioned the validity of DEM-based spatial analysis and has focused mainly on its visibility and mobility aspects, raising the fact that while DEM is based on modern topography, this may be very different from historical topography (Wheatley and Gillings 2000; Kvamme 2006). While this concern has not normally been examined in previous studies (Wheatley and Gillings 2000; Kvamme 2006), several exceptions can be found in Boaz and Uleberg (2000); Gillings (1995); Nunez, Vikkula, and Kirkinen (1995); and van Leusen (1993).

Terrain

Terrain form is usually considered to be relatively stable over time (Kvamme 2006). However, human activity and erosion such as that caused by hydrological dynamics can still change landform over time. Although erosion and depositional models can be introduced, practitioners still indicate that the reconstruction of historical topography is problematic due to the lack of sufficient and reliable data support. In addition, the validity of erosion and hydrologic models is still open to debate (Kvamme 2006; Lock and Harris 1996). Therefore, as suggested by Kvamme (2006), the spatial analysis undertaken in this study rely on less sensitive landscape variables, and present-day DEMs are employed as appropriate in an attempt to maintain a balance between validity and practicality.

For landform reconstruction, the existing topography is used as a basic DEM model due to the stability and relatively short history of the topography on which the cultural route investigation is concentrated. Moreover, given that the specific objective is to study environmental constraints and supports, landform transformations caused by human activity such as cultivation are automatically eliminated from the selected cases. Natural erosion is also disregarded. Nevertheless, special consideration is given to some specific analyses, such as the approach suggested by Kvamme (2006) for introducing the proximity of water supplies, which uses alternative hydrologic morphology or floodplains instead of existing rivers or streams.

Historical environments

Another major concern is the palaeoenvironment and palaeovegetation, which offer additional, richer features to the basic DEM and seriously affect landscape perception, especially for the viewshed-based interpretation (Chapman 2006; Wheatley and Gillings 2000; Kvamme 2006). However, it is clear that uncertainty is a factor due to the non-availability of archaeological data and the related problems of vegetation modeling, such as resolution and temporal variations in historical environmental reconstruction (Chapman 2006; Wheatley and Gillings 2000; Kvamme 2006). Vegetation is a factor that has an unavoidable impact on cost-surface modeling and archaeological visibility studies. Several approaches have been formulated to deal with this challenge, ranging from simple radiation models to a complicated algorithm suggested by Llobera (2007a).

The reconstruction of vegetation maps can be simulated through vegetation models built using DEM features, environmental reconnaissance such as pollen analysis, or through the integration of these two approaches. However, Wheatley and Gillings (2000) state that because palaeovegetation phenomena are too dynamic, vegetation maps are less effective as part of an interpretation methodology. Therefore, vegetation maps are only introduced at a very coarse level in this schematic methodological framework.

For friction cost applications, there are several land use types defined by vegetation features, which are forest, marsh, agricultural fields, meadow and non-vegetation regions. These can be simulated from DEM calculations of slope, aspect, radiation, altitude and hydrology. Land cover interpreted from modern RS data can also serve as a reference.

Wheatly and Gillings (2000) have suggested several methodological approaches to eliminate the "tree effect" on visibility. In this study, the impact of this effect is first assessed on a qualitative basis. For example, if strategic visibility concerns have an impact on the ability to gain an understanding of the cultural route spaces to be studied, such as affects on intervisibility of properties with an important historical function, the DEM can be modified to add an offset topography that simulates forest canopy features or plant heights. If visual landscape is the vital aspect, as it is for many pilgrimage routes with animistic contexts in which the natural landscape is a sacred object and the views of natural features are considered ritual spaces, a more complicated evaluation model can be introduced to allow for the borrowing of further visual attributes (such as distance blur as noted by Higuchi (1988) and introduced in Wheatley and Gillings (2000), vegetation characteristics (for example, employing forest closure from the ecological discipline), or an integrated approach such as the permeability calculation proposed by Llobera (2007a).

In practice, the palaeoenvironment and palaeovegetation may be less than critical in cultural route research, because paths and facilities are usually located in certain types of artificial contexts with lower-density vegetation. However, environmental archaeology and paleoethnobotany are very specific research domains. In this study, it will only be possible to adopt the reconstruction results from these domains for cost-surface modeling.

Land use and historical geographical data

Other basic geographical data such as modern and historical administrative boundaries, hydraulic networks, roads, inhabitant locations, land cover, etc., are mapped as GIS layers to establish background maps. Other raster data resources, including rectified RS images and projected and rectified historical maps, can also be employed.

Another key category of the basic dataset is the mapping of cultural route assets and archaeological sites, including "staging posts; customs offices; places for storage, rest, and lodging; ports; defensive fortifications; bridges; markets; hospitals; urban centers; cultural landscapes; sacred sites, places of worship and devotion; etc." as listed in the *5th Draft of the ICOMOS Charter on Cultural Routes* (ICOMOS 2005), as well as relics along paths. These tangible elements will be mapped as points, polygons or polylines in ArcGIS and differentiated into detailed categorized layers.

4.2 Cost Surface Analysis

Cost surface analysis is used to locate movement paths in a broad context, in which topography, land use and gravity of facilities are integrated. On the other hand, it also can be considered to be an inventory of different aspects of heritage settings including spatial influence and other tangible functions such as efficiency of services. In this study, cost surface analysis (CSA) is implemented through GIS. Cost-surface modeling, cost distance calculations, corridor analysis and the reclassification of travel costs are discussed and illustrated through case studies. Accumulated cost-surfaces are introduced to evaluate movement expenditure and delimit discrete regions such as territorialities and site catchments.

Cost-surface analysis involves the study of human land-use patterns according to opportunities and constraints on movement through landscapes or places and the subsequent illustration of such patterns in terms of accessibility (Conolly and Lake 2006). This explanatory approach matches the cultural landscape concept of "the evolution of human society and settlement over time, under the influence of the physical constraints and/or opportunities presented by their natural environment and of successive social, economic and cultural forces" (UNESCO 2005, p.83, Annex 3, paragraph 6). It is also perfectly consistent with the CIIC's interpretation of the relationship between cultural routes and cultural landscapes (Ducassi 2005a).

4.2.1 Movement Simulation

Movement is modeled using the ArcGIS Spatial Analyst module. The main processes include defining starting points and destinations, modeling cost-of-passage maps, and cost model formulation and analysis.

Defining the starting and destination points or districts

This parameter can either be a single place, such as Chang'an 长安, which is the starting point for the Silk Road (see Figure 7), or a series of places with homogenous cultural route performance, and can be analyzed simultaneously, as in the case of the Silk Road, along which Wuwei 武威, Zhangye 張掖 and Jiuquan 酒泉 are three of "The Four Cities of the Hexi Corridor 河西四郡" that act as cultural route relay stations. The fourth city, Dunhuang 敦煌, is an intersection on the Silk Road which has a different spatial structure when compared with the other three cities (see also Figure 7). This city is more properly considered a network knot or specific starting point for a network system instead of being analyzed as a destination with the same characteristics and processed in the same layer. Cases such as the Silk Road can be investigated by reference to the categorized "start-end location" sets for the Wroxeter settlement and the economic networks suggested by van Leusen (2002).

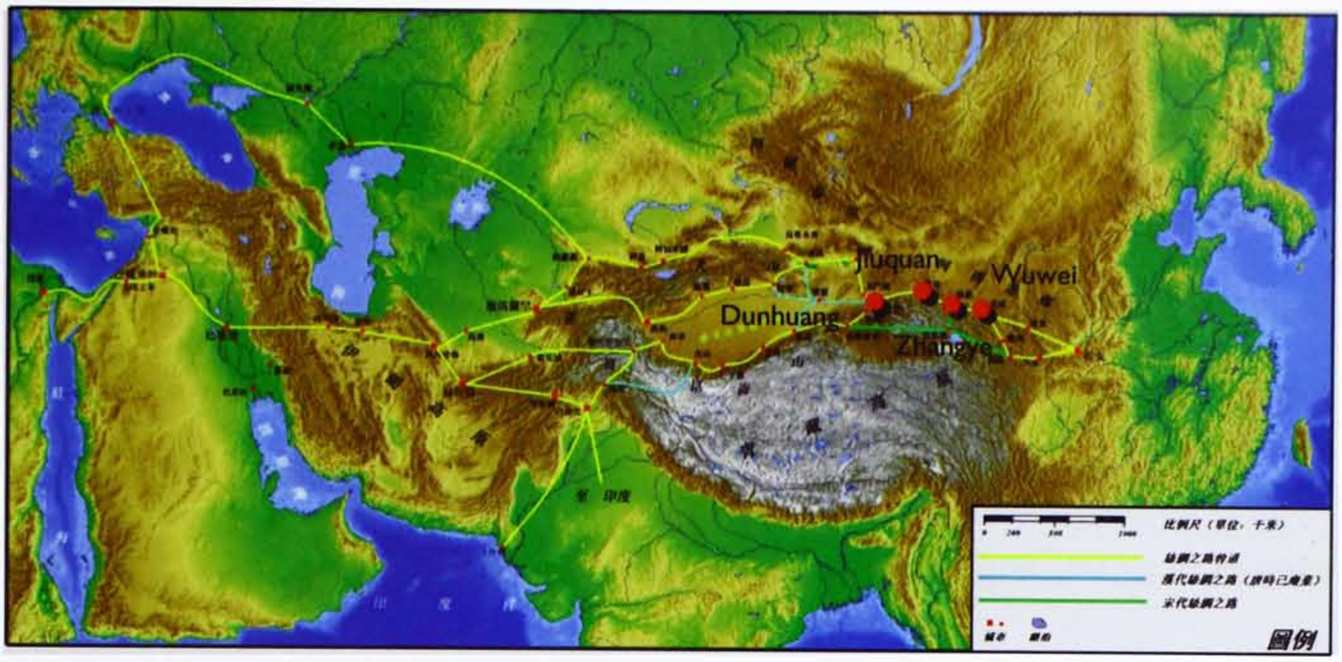


Figure 7

Map of Silk Road (Source: Refrain. Image: Silk-Road course.jpg. 2005. [cited June/14, 2008] Available from http://commons.wikimedia.org/wiki/Image:Silk-Road_course.jpg?uselang=zh.)

Destinations should be placed in the same layer in either raster or vector format. In large-scale analyses, the destination can be represented in point or polyline format shape files. However, in a regional analysis or for a smaller analytical scope, the destinations being studied should be considered polygonic in form.

Cost factors

Basic cost factors in movement calculations are mainly created from reclassified land cover. Other topographical and facility aspects, such as slope and facility gravity, can be introduced through a separate topography layer and horizontal or vertical influential factors using ArcGIS software. More details will be discussed in the following sections.

Analysis

ArcGIS provides several cost-surface analytical functions in the ArcToolbox "Distance" modular, among which the "Path Distance" tool is applied in most circumstances in this study. In simple cases, if there is no anisotropic cost consideration, it may not be necessary to introduce a horizontal factor, and therefore the “Cost Distance” tool can be employed in such circumstance. For example, inputting only a basic cost-of-passage raster, such as the reclassification of land cover, DEM and DEM-derived slope, is the normal approach for computing a path across a natural environment. A direct “Cost Weighted” calculation of the Spatial Analyst function can be applied in an even simpler way if an integrated cost-of-passage surface is modeled on a cost raster map.

4.2.2 Path Selection

In this study, the “Shortest Path” or “Cost Path” calculation function offered by ArcGIS is adopted to a lesser extent. The main reason for this is that the path function only selects an optimized lowest cost path. However, in reality, movement is considered to be more complicated (Wheatley and Gillings 2002; van Leusen 2002). Furthermore, locating a path as an element of a cultural route is different from investigating a path that is a heritage asset in itself. While path analysis relies more on relics, this study is aimed at delineating the scope for the entire historical phenomenon. Therefore, it is more reasonable to locate the movement within a high probability region to accommodate modeling or calculation errors. This threshold is more important for calculations on a regional scale.

The “Corridor” calculation in ArcGIS is designated as a path locating approach. Its algorithm overlays cost-distance maps of two or more destinations and adds the cell values together (ESRI (Environmental Systems Research Institute) 2006). Classified areas with the same costs between destinations can be illustrated on a cumulative cost map using choropleth mapping of cost value. By defining a cost value threshold, refining the legend, or reclassifying the cumulative cost raster layer, areas with certain range of higher costs can be eliminated and areas which cost less to traverse and are mapped as cascade layers out to central lowest cost regions to create a corridor. Another advantage and important function of a cost corridor is that a cumulative cost map also shows a comparison of accessibility among a series of paths. Historical interpretation may be stimulated through these simulations.

The Bell, Wilson, and Wickham's (2002) approach of "cumulated pathways" is considered capable of enhancing the reliability of a movement path or corridor. Paths or corridors between multiple sites can be overlapped through GIS to create cumulative parts (Figure 8). This approach can be adopted in path or network implementation and can also be considered a pragmatic model for cost-corridor creation. In path accumulation, common cells in two or more calculated paths receive a value of the sum of pixels (Bell, Wilson, and Wickham 2002), while least-cost corridor calculations twist this value assignment process by calculating the cumulative values of cost surfaces associated with multiple sites. Lower value costs can be equated with higher value costs on accumulated paths along which more frequent movements may occur. The fact that corridor calculations share the same approach as accumulated pathways also gives them a greater degree of validity in reflecting moving phenomena in landscapes.

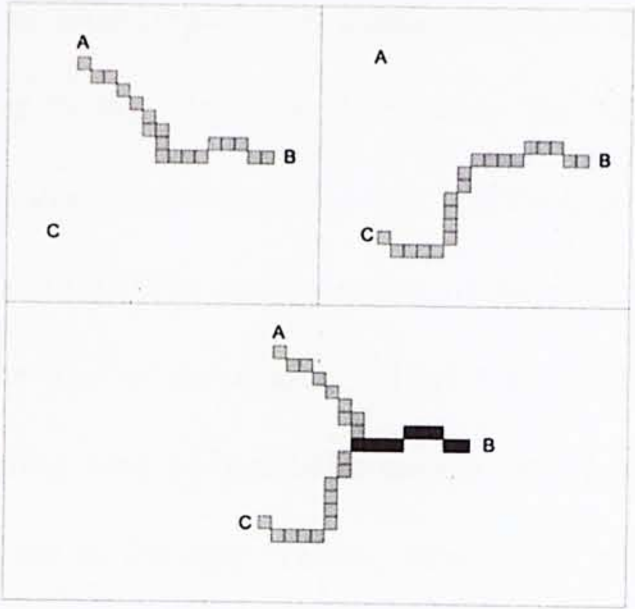


Figure 8

A hypothetical example of cumulative pathway generation by Bell, Wilson and Wickham (2002). The darker cells illustrate the overlapping parts with a given value of 2 (source: ibid, p.178, Fig.8)

The mapped scope of accumulated costs considered to be a possible movement corridor may vary from case to case. Definitional criteria can be cogitated according to the scale of analysis or the areas covered by the corridors calculated. If the spatial scope of the least-cost-corridor is too narrow, this may lead to a similar problem of the introduction of a short-distance-path calculation. In these circumstances, it may be necessary to introduce more cascade higher cost layers as corridor regions. By contrast, in lower resolution analyses of provincial, national, international, continental or even larger domains, the least value corridor may already cover all possible areas. No further buffer layers should be applied or few layers should be used.

4.3 Cost Surface Modeling

Cost surface modeling refers to the creation of a cost-of-passage map that assigns the cost of traversing the location in each cell. A cost map can integrate isotropic, partially anisotropic, or anisotropic phenomena to reflect different cost attributes (Collischonn and Pilar 2000). However, combining the effects of physiological, landscape and social features in a cumulated cost surface is a very difficult task (van Leusen 2002; Llobera 2000). The incorporation of physical and social (cognitive) costs may result in the loss of the objective intrinsic meanings of traditional cost surfaces such as traveling time or metabolic energy (van Leusen 2002). Instead, it brings more connotations to the cost surface, which may add more realism to the movement simulation such as by assimilating the knowledge and experience of travelers in selecting alternative routes (Conolly and Lake 2006; Wheatley and Gillings 2002; Bell and Lock 2000).

4.3.1 Attributes Introduced

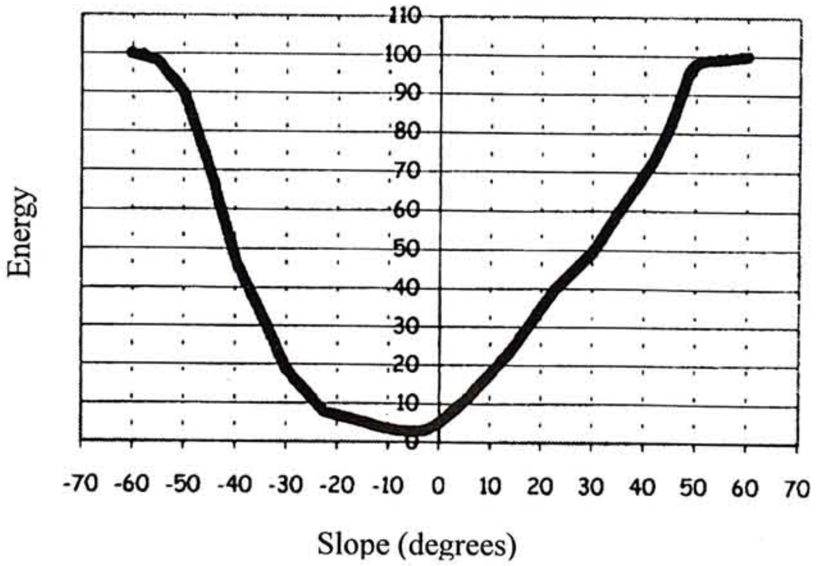
Isotropic cost-of-passage is mostly defined by surface roughness and land cover, which affect energetic expenditure. Isotropic attributes, such as land cover and terrain, serve as basic cost-of-passage surfaces for movement and site catchment and are introduced in this study. Terrain is used to calculate the real surface traversing distance, while land cover explicates traversing friction.

Another physiographical attribute that is anisotropic in nature is slope. Slope definitely adds to cost when compared with flat areas in terms of movement. Cells with steep slopes are designated with costlier values when compared with cells for more gentle gradients. Bell and Lock (2000) suggest the isotropic effect encountered on both descending and ascending slopes. However, Llobera (2000) and van Leusen (2002) provide more convincing anisotropic slope cost algorithms (see Figure 9).

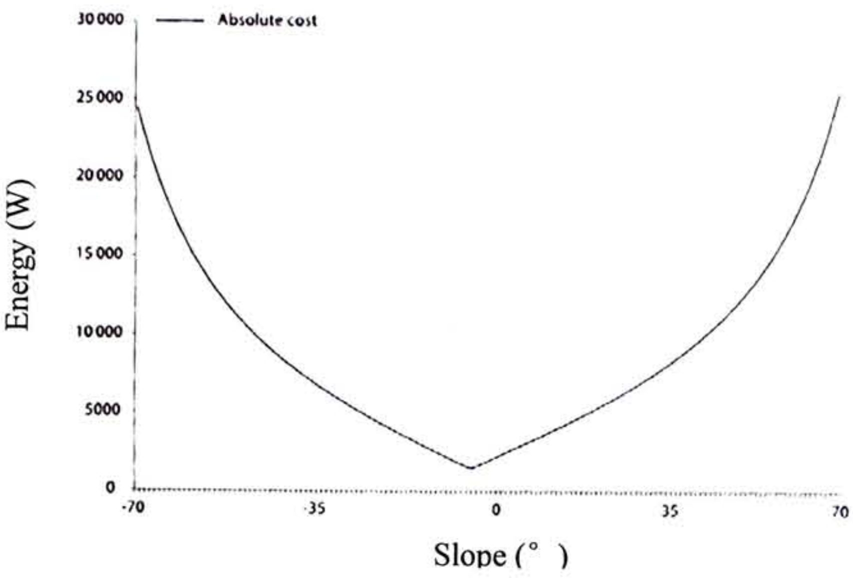
Most researchers agree that travel costs are determined by both isotropic and anisotropic phenomena. The former are exemplified by costs relating to topographical cover features such as vegetation, soil type, moisture, etc., and the latter by costs relating to slope, streams, location gravity, perception distributions, and similar factors (van Leusen, 2002).

Anisotropic attributes

Anisotropic cost-of-passage takes both cell characteristics and the potential difference between travel in each direction into consideration (Conolly and Lake 2006; Bell and Lock 2000). The slope-affected cost of energetic expenditure is an inevitable feature of the study of landscape movement. Conolly and Lake (2006) undertake a comprehensive review of "effective slope" algorithms using different approaches. Energetic cost, a concept put forward by Llobera (2000) in which physiological data are brought together (Figure 9(a)), is introduced in the proposed cost-surface model. This approach is also supported by van Leusen's (2002) research (Figure 9 (b)), which slightly modified Krist and Brown's (1994) formula of the Iron Age and Roman trade network model. Anisotropic cost can also be extended from topographical features to social and cultural effects, such as in the discussions in Llobera (2000). The details will be discussed in the next section.



(a)



(b)

Figure 9

Energetic cost of traversing different slopes: (a) suggested by Llobera (2000, p.71, Figure 2); (b) suggested by van Leusen (2002) (redrawn by Conolly and Lake (2006), p.221, Figure 10.10)

4.3.2 Cost-Surface Model Making

In this section, detailed attribute selection and cost assignment are discussed in light of section 4.3.1. The models and attributes selected in this study are differentiated in terms of scale and CSA purpose. A GIS cost-surface algorithm based on basic cost parameters is introduced. Intrinsic factors in some of the complicated costs, such as gravity and perception phenomenon, are discussed separately.

Cost features of large-scale modeling

In large scale modeling, variables relating to context and facility impacts on movement cost and path location can be simplified into limited attributes which are sensitive or can validly be used to interpret spatial characteristics on a large scale. After testing several attributes in maps scaled to less than 1:1,000,000, the author has identified the following characteristics of cultural route location modeling:

1. Terrain: Slope and terrain surface are the basic elements of path modeling and

cost-surface calculation. Specific elevation ranges can be introduced as isotropic costs, such as for highlands above a certain altitude, which can be given a very high cost weighting to reflect the difficulty of travel.

2. Land cover: Land cover attributes in movement calculations are classified according to features that cause differences in accessibility. In large scale assessments, forests, wetlands, deserts, cultivated fields and other vegetation or non-vegetation areas are assigned different costs or weightings to reflect land cover concerns.
3. Hydrological features: Lakes and rivers may have complicated effects on movement and path selection. In general, large water bodies may represent barriers to movement. This is especially true for rivers with erosion effects that create riverbank access difficulties, such as for the Yellow River 黄河 on the Loess Plateau 黄土高原 in China. However, lakes and rivers may become the easiest pass in winter after they freeze. Therefore, in the standard procedure to be applied in this study, large-scale hydraulic attributes will be considered to represent obstacles only in the cases of a few major rivers and ice-free lakes, and will be subject to high traversing cost modeling or integrated into land use maps. There are also other possibilities in large scale contexts, such as the attractions of water supply in deserts or drought prone areas, which may affect horizontal movement phenomena due to gravity in anisotropic conditions. These effects need to be investigated as separate variables.
4. Boundaries and regions: These effects are calculated only where they are associated along the boundaries of two different spatial territories, such as municipal boundaries, religious or cultural regions, restricted boundaries (such as sacred areas), and similar.

5. Facilities and their service scopes: Facilities also cause complexities in spatial gravities. In large-scale analysis, facilities are usually simplified into points. The variability of facility effects is depicted by the distance to the facility multiplied by the facility weighting. The positive or negative value of a point closer to a certain facility depends on the nature of either the facility or the movement, which are cultural route functionalities. For example, fortresses are welcomed by caravans, but may need to be avoided by marching troops that plan an invasion. Therefore, the different kinds of possible characters that use the path and types of movement along the path should also be taken into consideration in model formulation.

Variable selection in regional analysis

As discussed in geo-strategy related path location modeling, cost surface analysis is also used to study contextual opportunities and constraints. The following variables, which while similar to those used for large-scale modeling, but are more detailed, are suggested for cost surface creation of regional or local analyses.

1. Terrain features: Similar to those used for large-scale investigations. In addition to topographic surface, slope and elevation, aspects such as isotropic costs may be introduced or integrated into cost-of-passage mapping to, for example, simulate soil and radiance into vegetation density in friction assessment.
2. Land cover and land use: On a regional or local scale, land cover can be categorized into the following features, starting with the lowest cost:
    a) Path or road relics
    b) Built-up areas
    c) Vegetation and non-vegetation areas: From the lowest cost to the highest cost, these areas can be divided into the subcategories of meadows, cultivated land,

deserts and forests. For the last two subcategories, the proposed sequence is quite objective. The costs assigned may be reviewed according to the circumstances of each case, such as where different caravan vehicles are drawn by camels, packhorses or other means.

d) Streams and water bodies: More detailed hydrology analysis shall be applied to locate small streams. However, the present researcher's experimental calculations show that the cost of a stream of around one cell in width has very little effect on the cost surface.

e) Marshes/wetlands: Historically, these have been the most difficult places to access for normal movement.

3. Gravities of facilities and other resource supplies: The attraction or repulsion of facilities or other natural resource supplies such as water bodies in drought prone areas, oases, etc., can be illustrated by Euclidian or cost distances. As in geo-strategic studies, cultural landscapes with relevant functions are considered to be facilities and their features are calculated using polygon features in spatial analysis. However, municipal boundaries, which are significant in geo-strategic analysis, will not be delaminated into high-cost borderlines or confined regions in mid-to-small scale studies. Instead, they will be illustrated by the functionality distribution of substantial facilities, e.g., defense fortifications, customs offices, ports, and so on. Facility influences can also be designated as costs according to the performance of spatial control, which will be discussed in the next section.
4. Perceptions: These can be mapped onto homogenous or choropleth catchment maps. Visibility, which is the main feature of landscape perception studies, will be discussed in the following sections.

Cost-of-passage value assignment and weighting

These attributes or cost factors can be translated into cell values in different thematic cost maps. Such cost effects are usually reclassified into different cost–level categories to reflect movement expenditure. However, although physiographical costs have relatively objective quantitative criteria, e.g. physiological experiences (see van Leusen (2002); Llobera (2000); Bell and Lock (2000); Krist and Brown (1994); and van Leusen (2000)) and the reviews in Conolly and Lake (2006), weighting the cell's costs in terms of other aspects such as social or phenomenological factors may be quite subjective (Chapman 2006).

A cell's cost value may also be quite different or even converse across various functions accommodated within the same space or performed by the same facility. For example, a marshland with high passing costs may also demonstrate a possible preference for a special type of movement, such as fugitive activities. Similar situations may also reverse or redefine other land cover costs in different functional contexts, such as towns' defensive functions, or the abovementioned caravan vehicles. Therefore, a cell's values in terms of land cover, gravity and perception have to be carefully reviewed and redefined if necessary in each analysis of different moving entities.

4.3.3 Visibility as a Cost

As discussed above, visibility characteristics create gravity or repulsion in movement or spatial control effects. Therefore, visibility costs must be considered anisotropic in nature. Cumulative viewsheds are the main approach used to study visibility and create a consequent cost-of-passage surface.

Accumulative viewsheds

Higher value accumulative viewsheds allow for more opportunities to be seen by investigated facility sources or other viewpoints and facilitate better recognition of destinations in terms of perception. A cumulative viewshed map categorizes cell values and records the number of viewpoints from which the cell is visible (Wheatley 1995). The differences between these values are used to define the horizontal frictions in an anisotropic cost-of-passage map.

The accumulative viewsheds method can also applied in "total viewsheds" or CVI calculations to build an inventory of the visibility characteristics of the entire study region. However, the total viewshed approach is usually employed to investigate landscape cognition, which is useful for studying cultural routes or sections of such routes for natural worship purposes, whereas accumulative viewsheds with specific viewpoints are more suitable for cultural route property studies.

Accumulation algorithm

Accumulative viewsheds are calculated by adding multiple single binary viewsheds together (Wheatley 1995). This can be carried out through GIS overlay analysis. The ArcGIS package also offers a modeled algorithm called "observer points," which records the individual resource viewpoints of each raster map cell instead of the cumulative viewshed value. Cumulative values can then be calculated individually using the "field calculator" on the attribute table. However, the observer points syntax supports a maximum of only 16 viewpoints and supports only point features. If the number of viewpoints is greater than 16, or if polylines or polygons are introduced as view sources, the overlaying method is still the best method.

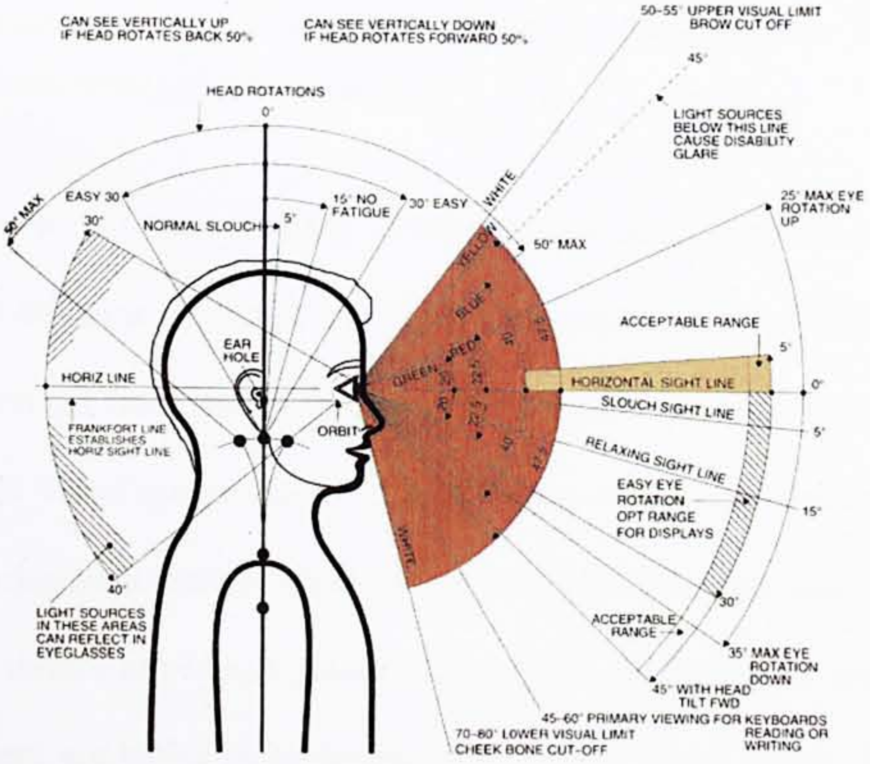
Attributes and parameters

Introducing detailed visibility parameters of visual characteristics is an approach to enhancing validity that is recommended by many researchers (Conolly and Lake 2006; Wheatley and Gillings 2002, 2000; van Leusen 2002; Lake and Woodman 2003) and has been used in a variety of cases (see: Llobera (2007b); Wheatley and Gillings (2000); van Leusen (1993)). The author also has introduced several physiological and spatial parameters to refine viewshed calculations made in previous studies (He 2001; He and Tsou 2002, 2004; He et al. 2005; Tsou, He, and Xue 2005) based on visual physiology or psychological perception data from other disciplines (Higuchi 1988; Gibson 1986; Ashihara 1983, 1970; Tilley and Henry Dreyfuss Associates 2002). The following parameters will be introduced into GIS viewshed calculations in this study.

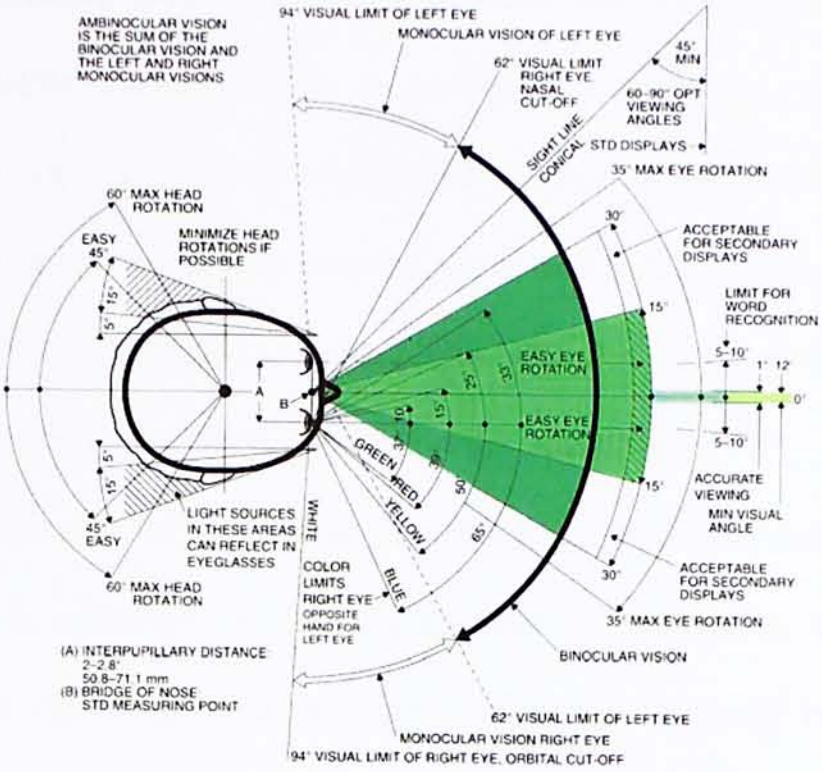
1. Physiological parameters: physiological data define visual characteristics from people's visual physiological data in Gibson (1986) and Tilley and Henry Dreyfuss Associates (2002).
    a) Viewpoint height: The viewpoint height of a typical person is 1.60 meters. However, to allow for non-ground-level viewpoints to be studied, an altitude level is added to this height to represent the viewpoint of a person standing on a specific facility such as a watchtower or city wall. Other absolute observation point height values may be assigned to special types of viewshed calculations, such as in visibility studies for caravan riding or for those on horseback or camels. Viewpoint height is assigned as the z-value of the observation point, or "Spot" in the viewshed function of the ArcGIS 3D Analyst Tools module, using the attribute "OffsetA."
    b) Vertical view angle: Vertical view angle is defined by the physiological ability

of eyeball and head movement in the vertical view (Tilley and Henry Dreyfuss Associates 2002). The upper vertical view angle is 55 degrees and the lower vertical view angle is 80 degrees (Figure 108(a)). These values are defined by "Vert1" and "Vert2" in the attribute table of the viewpoint layer.

c) Horizontal view angle: In this study, all viewpoints are considered to allow for a full-range view in the horizontal view, i.e. 360 degrees. In attribute tables, the starting angle "Azimuth1" is 0 and the end angle "Azimuth2" is 360. However, in some cases, the horizontal view angle may be redefined to meet special investigation considerations, such as "Higuchi's Direction Viewshed" explored by Wheatley and Gillings (2000). The author has also introduced horizontal view angle limits ranging from 12 minutes to 60 degrees from physiological conclusion by Tilley and Henry Dreyfuss Associates (2002) to simulate a stable view from a fixed viewpoint, or to assess visual quality for perception landscapes taking horizontal range into consideration (He and Tsou 2002) (Figure 10(b)).



(a)



(b)

Figure 10

View angle definitions introduced in the viewshed algorithm to be used in this study (a) vertical view angles: deep red indicates the vertical visual angle range from -80° to 55°, light red marks the "acceptable range" of 5°which will be introduced in vertical landscape perception parameters; (b) horizontal view angle limits for fixed viewpoints and view directions (without any head movement): dark green indicates a 60°horizontal view; light green and lighter blue-green are the 30°to 1°horizontal view perception parameters, and the object in the yellow area (12') is too small to recognize (adapted from Tilley and Henry Dreyfuss Associates (2002), p.47, drawing 24)

2. Visual distances: Other visibility considerations such as visual distance can be defined as different landscape or spatial parameters, although some of them are actually derived from psychological effects. Visual distance ranges are used to differentiate visual quality decay caused by atmospheric perspective, such as the "object-background clarity" phenomenon noted by Wheatley and Gillings (2000). While the threshold of each spatial region may vary from one study to another, most of them are based on horizontal and vertical visual angles (Higuchi 1988; Ashihara 1983). These regions can be introduced as visual quality assessments

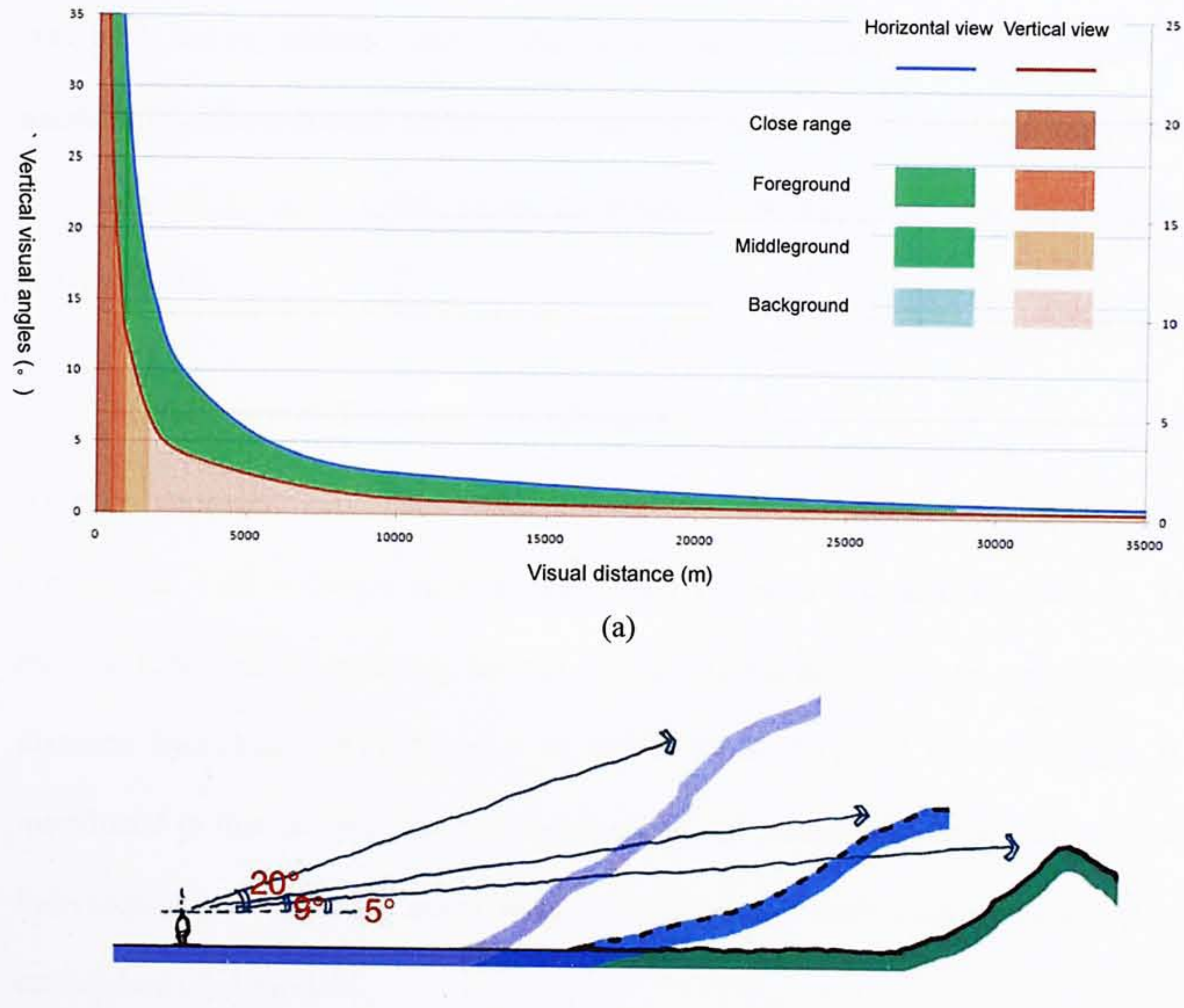
or visibility-related relationships categorized by catchment costs. Although there are no absolute distance limits in viewshed calculations, ArcGIS can still generate the scan areas within a subtended distance as the “Radius2” value using the characteristic of visibility purpose, such as finding specific objectives like towns or artificial landmarks, appreciating natural scenery, or being alert to the appearance of marching troops or beacon fire and smoke.

a) Visual distances for horizontal perception: Categorized visual distances in foreground, middleground and background are defined by the threshold of horizontal view angles of the visual objectives (Higuchi 1988; Tilley and Henry Dreyfuss Associates 2002). For visual perception to single object, usually an horizontally extending artificial property, like walled towns or buildings, the angle ranges are defined as follows by adapting Llobera’s (2007) format (α_h refers to the horizontal visual angle occupied by the objectives to the view point) (Figure 13(a)):

- Foreground: $\alpha_h > 30^\circ$;
- Middle ground: $30^\circ > \alpha h > 1^\circ$;
- Background: $1^\circ > \alpha h > 12'$;
- Not relevant: $12' > \alpha h$.

b) Visual distances for vertical visual perception: If the object is too wide, such as for a natural feature such as hills or a forest, or is a group of facilities distributed over a large area, the aforesaid division is no longer valid. Therefore, this study also introduces another set of foreground, middle ground and background definitional criteria by assessing vertical visual perception angles. These usually serve the landscapes view, but may also be applicable in perceiving vertical extended monuments such as towers. The vertical angle thresholds (α_v) are adapted from Higuchi (1988) and Ashihara (1970; 1983) as follows:

- Close range: αv > 20° (too close to perceive the landscape in general, only details or textures of slope or facade can be recognized);
- Foreground: 20°>αv > 9°;
- Middle ground: 9°>αv > 5°;
- Background: 5°>αv (landscape skyline can be identified, landscape features are more significant in the horizontal extension if visual distance increases to infinite).



(a)

(b)

Figure 11

Visual distance divided by visual angle and subtended by visual perception: (a) the horizontal (blue line) and vertical (red line) views to a hill 500 meters wide and 150 meters in height; (b) vertical view threshold angles (source: He (2001), p.102, Figure 4.16)

4.3.4 Algorithms

There are two methods for creating a least-cost surface for an individual site or a group of locations. The more straightforward task is to first assign an integrated cost value to each cell and produce a single cost-of-passage map. A cost surface is then derived by carrying out cost distance calculations taken directly from the single cost raster map, as in the "Cost Weighted" function in ArcGIS. A typical example can be found in Vermeulen (2006). The main debate surrounding this approach is how the integrated cost-of-passage raster should be modeled. Given that cost values have to be set using a relative scale (ESRI 2006), different factors have to be reclassified and weighted before adding them to the raster map. In addition, both isotropic and anisotropic effects should be taken into account in the cost-of-passage map. This is very difficult to achieve due to the modeling shortcomings of this approach (van Leusen 2002).

ArcGIS "Patch Distance" calculations

Another approach may take advantage of the modeling functions provided by commercial GIS software such as the "Path Distance" module of ArcGIS. This module functions by grouping several spatial analyst tools such as cost, Euclidean distance, hydrologic network and so on (ESRI 2006). As noted in section 4.2.1, it is introduced in this study as the main method of path simulation, in which up to four individual cost-of-passage maps work in conjunction with each other using pre-established CSA models.

The cost surface algorithm of Path Distance gives the cost distance of traveling from cell *a* to one of its eight directly adjacent neighbors. Cell *b* can be expressed as in the following [Formula 1] and [Formula 2] adapted from ESRI (2006):

$$Cost = CS * SD * \{[Fr\ (a) * HF\ (a) + Fr(b) * HF(b)] / 2\} * VF * InD$$

[Formula 1]

where: *Cost*: the cost distance;

CS: basic cost-of-passage map cell value in the "cost raster" parameter;

SD: the surface distance derived from the "surface raster";

Fr: the friction factor, which is the cell value of the "cost raster";

HF: the "horizontal factor";

VF: the "vertical factor";

InD: the diagonal index. *InD* = 1.414214 if movement is diagonal; otherwise *InD* = 1.

and the accumulated cost of moving from cell *a* to *c*, passing through cell *b*, is:

$$Acuum\_Cost = Cost(ab) + SD * \{[Fr\ (b) * HF\ (b) + Fr(c) * HF(c)] / 2\} * VF * InD$$

[Formula 2]

where: Accum_*Cost*: the accumulated cost distance; and

Cost(ab): the total cost from cell *a* to cell *b*.

The friction factor

The friction factor, or the "cost (distance) raster," of the Path Distance calculation parameter is normally an isotropic raster cost-of-passage map. Land cover, land use and other regions are usually introduced and reclassified into integer values to express basic movement difficulties. The elimination of the basic cost-of-passage raster supports the hypothesis of movement on a homogenous surface.

Terrain

The "surface raster" parameter is used to calculate actual surface distance from one place to another. The topographical surface or DEM in raster format is the only choice in this attribute. The surface raster can be omitted if movement is assumed to take place in a totally flat area.

The vertical factor

The vertical factor is actually the same as the "effective slope," which takes into account the uphill or downhill energy expended when traveling between two cells. A slope raster map derived using DEM surface analysis can be introduced. Another important issue is the magnitude of cell values. In this study, Llobera's (2000) relative energetic cost function (see Figure 9(a)) is employed to customize the predefined curve for the cost of overcoming the least-cost movement director known as "Vertical Relative Moving Angle (VRMA)" in ArcGIS (ESRI 2006). The existing formula provided in the CAS model that is both available and has the most similarities to Llobera's suggestion is the "Symmetric Inverse Linear" graph (Figure 12), in which the upper and lower cut angles will be reset to 50 and -55 degrees respectively in accordance with Llobera's data. A vertical factor ASCII table programmed by the author is introduced as a custom graph for cost-surface modeling (Table 7).

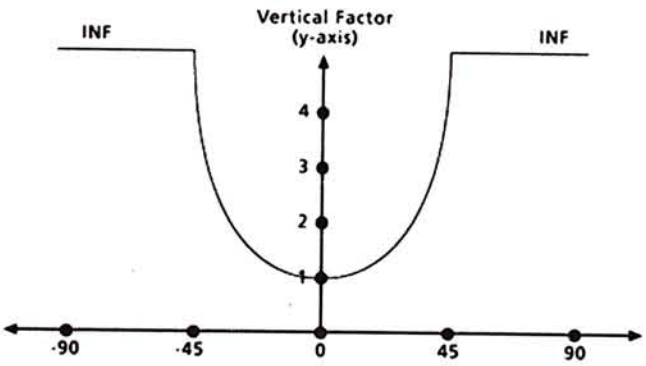


Figure 12

Symmetric Inverse Linear vertical factor graph of ArcGIS Path Distance model (source:

ESRI 2006)

Table 7

ASCII table for translating Llobera's (2000) topographic cost curve into a vertical factor graph

Slope angle (°)	-90	-80	-70	-60	-55	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
Energy expend -iture vale	100	100	100	100	10	4	2	0.84	0.36	0.16	0.22	0.8	1.56	2.22	3.11	10	100	100	100	100

The horizontal factor

The horizontal factor is the most dynamic cost-surface modeling parameter to be used in this study. The application of the horizontal factor is an original contribution and represents an innovative practice. Horizontal factors indicate anisotropic horizontal frictions, which affect the cost of moving from cell to cell. The Horizontal Relative Moving Angle (HRMA) gives the degree between the least-cost direction and the current direction of movement. The "Linear" horizontal factor graph defined by the software is adopted to interpret cost from the HRMA (Figure 13).

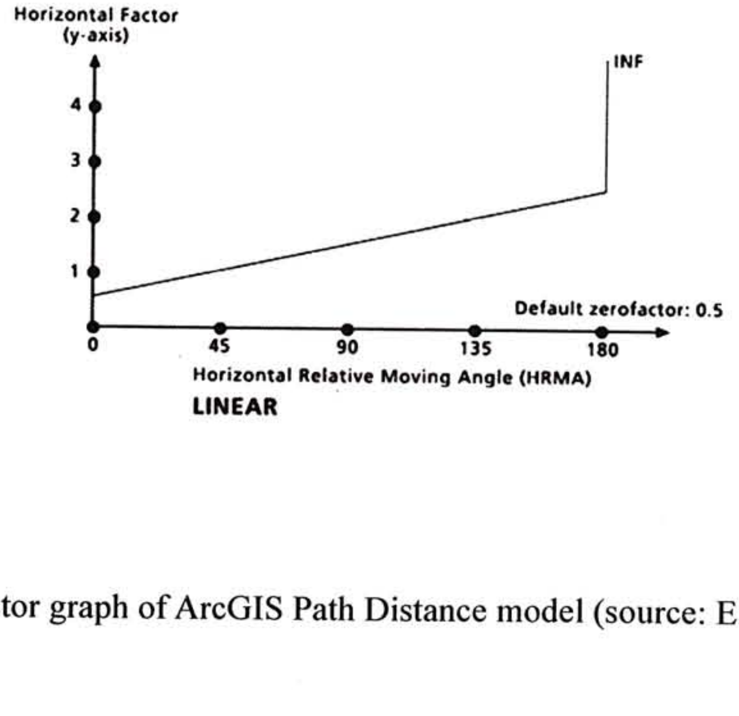


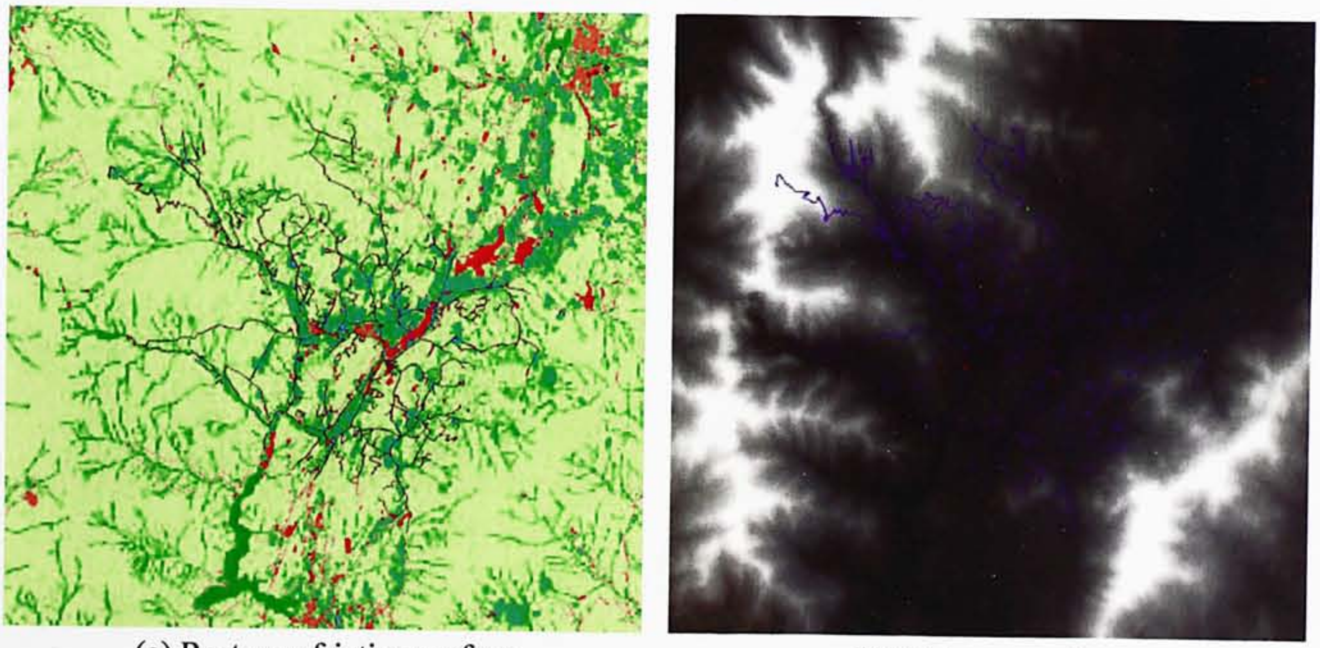
Figure 13

Linear horizontal factor graph of ArcGIS Path Distance model (source: ESRI 2006)

Many social, economic and political effects, such as site gravity or magnetism, municipal boundaries, etc., as well as landscape perception and experience indicators, such as visual attractions and the familiarity of specific landscape features as perception experiences, can all be introduced as horizontal factors for cost-surface modeling. The horizontal factor can be categorized into fragmented regions, patches, or tessellate titles of the whole study region, or at least incorporated by way of a binary spatial distribution map. Partially anisotropic cost-of-passage maps, such as those for wind direction, are not considered in this study. Section 4.3.5 further discusses the introduction of visibility as a horizontal factor for catchment studies.

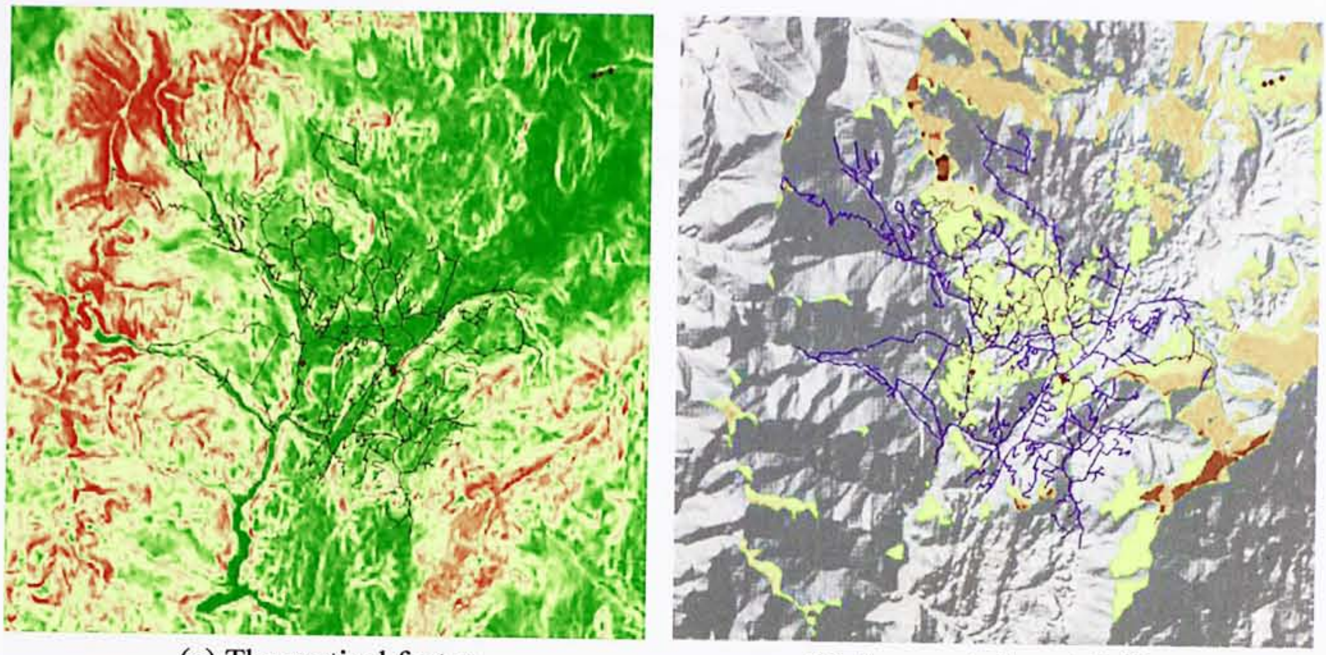
A methodological test

Figure 15 illustrates cost-surface modeling and movement study procedure and compares different algorithms or methodological approaches. Profound methodological effect can be found by comparing the Path Distance method to with the single cost-of-passage map approach (Figure 15(a) and (b)). On the other hand, the horizontal factor has a salient influence on cost-surface modeling results (Figure 15(f)).



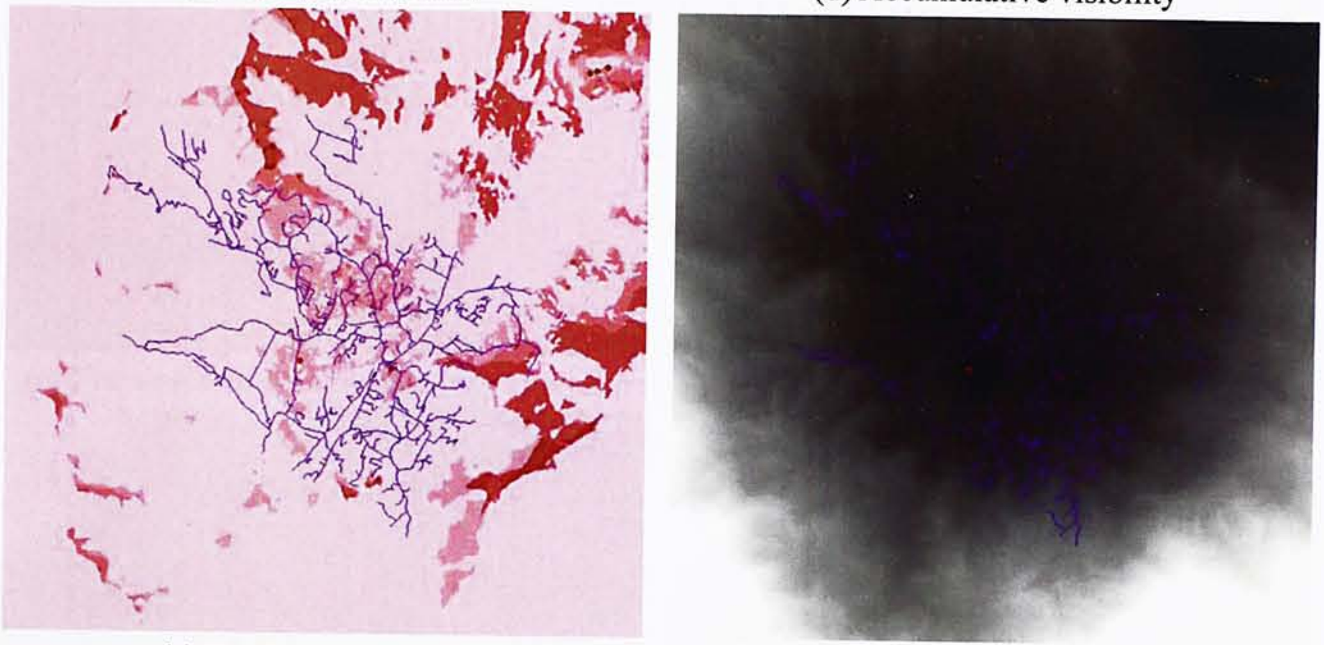
(a) Raster or friction surface

(b) Distance surface



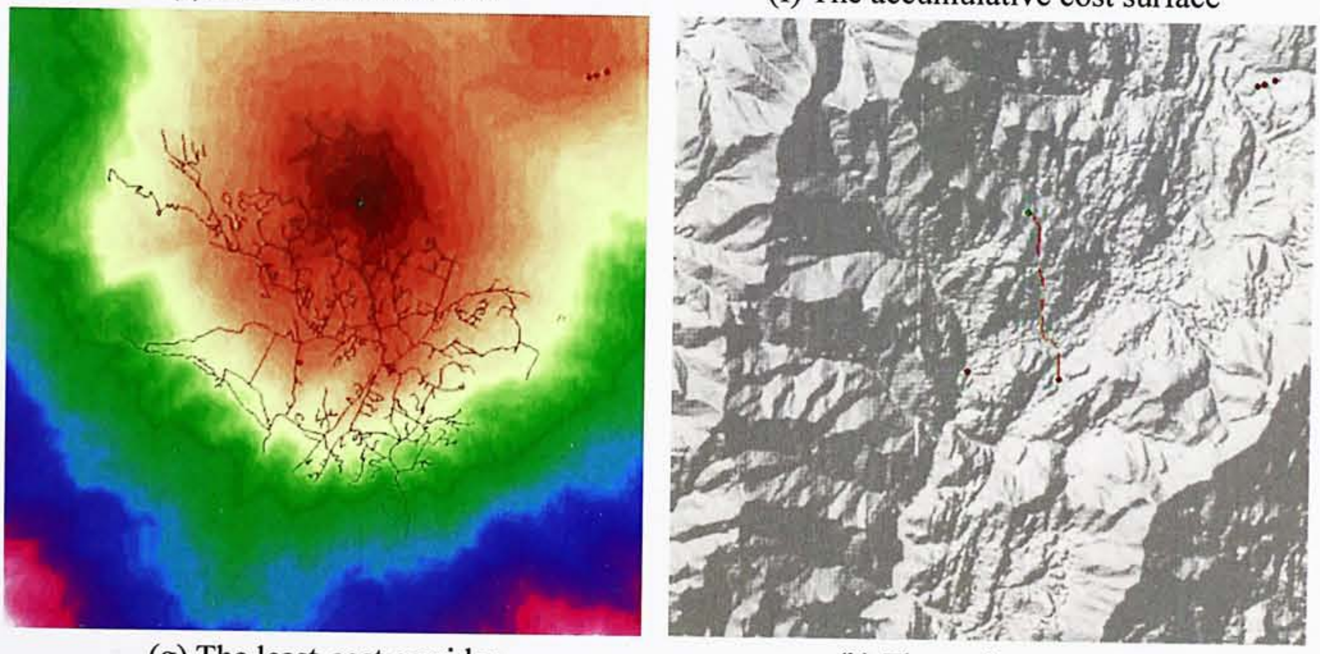
(c) The vertical factor

(d) Accumulative visibility



(e) The horizontal factor

(f) The accumulative cost surface



(g) The least-cost corridor

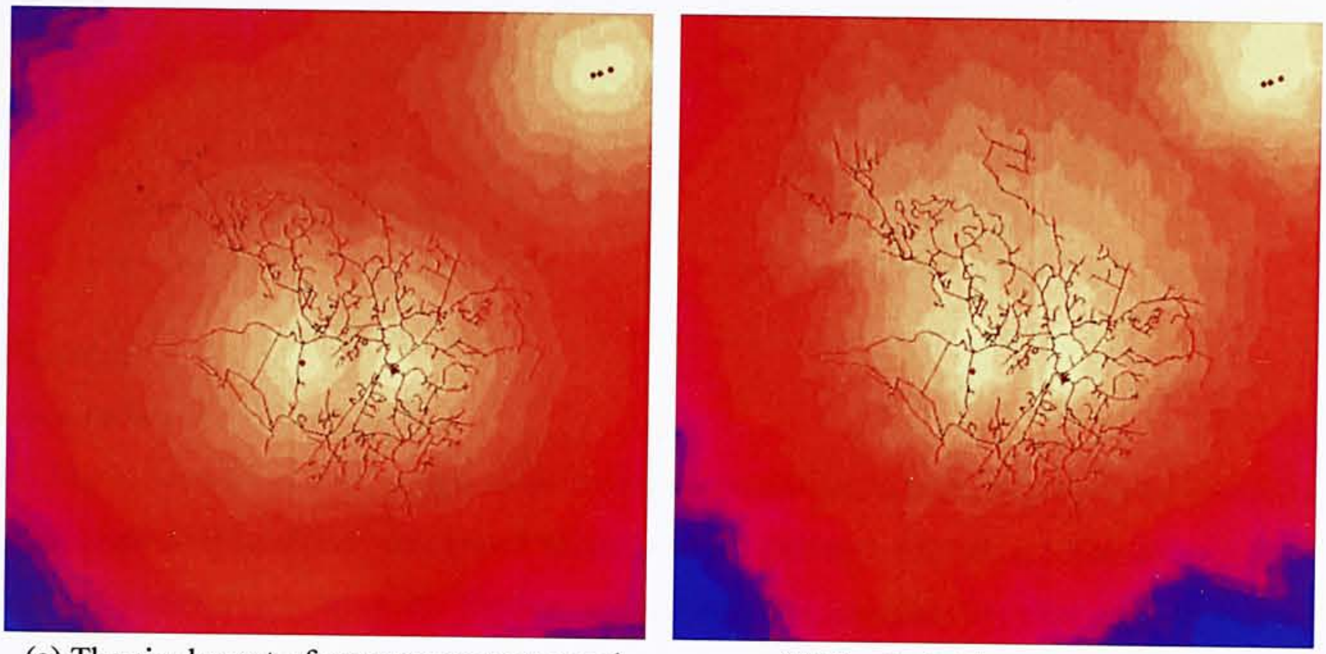
(h) The optimum path

Figure 14

Cost-surface modeling process

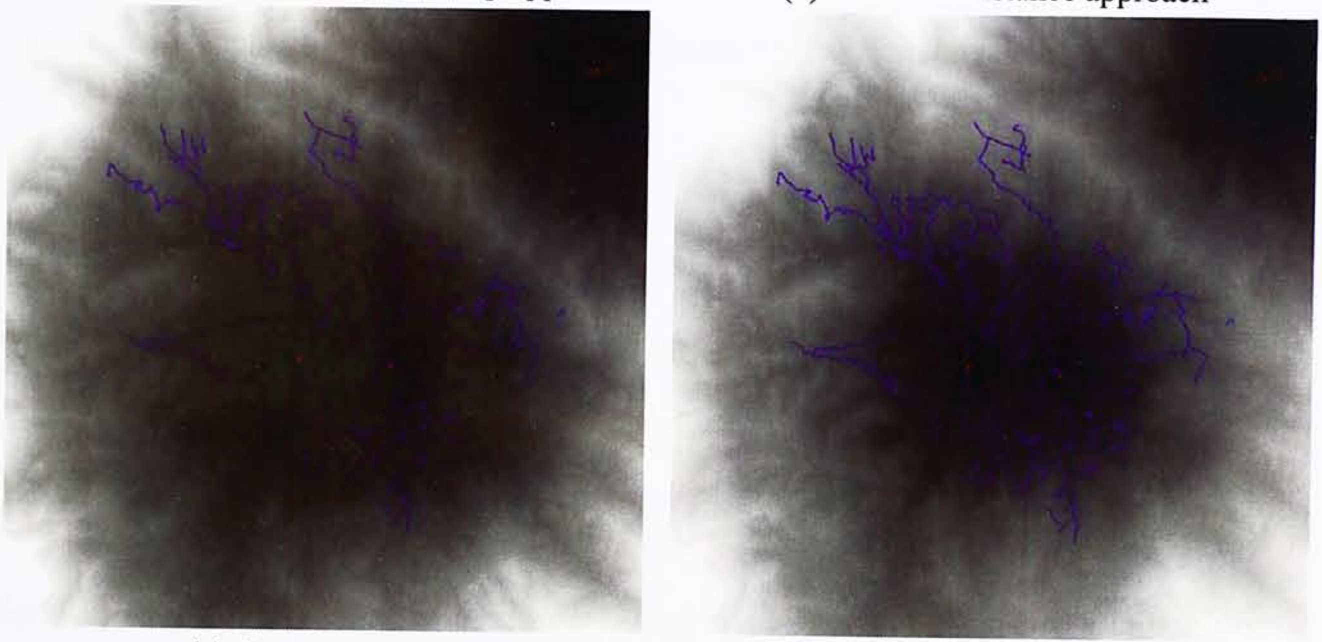
(a) The main cost-of-passage map derived from land cover; (b) DEM; (c) Slope map; (d)

Accumulative visibility of the facilities; (e) Reclassification as visibility attractions mapping; (f) Accumulative cost surface modeling by means of the Path Distance function; (g) Least-cost corridor mapping, and (h) The optimum least-cost-path location.



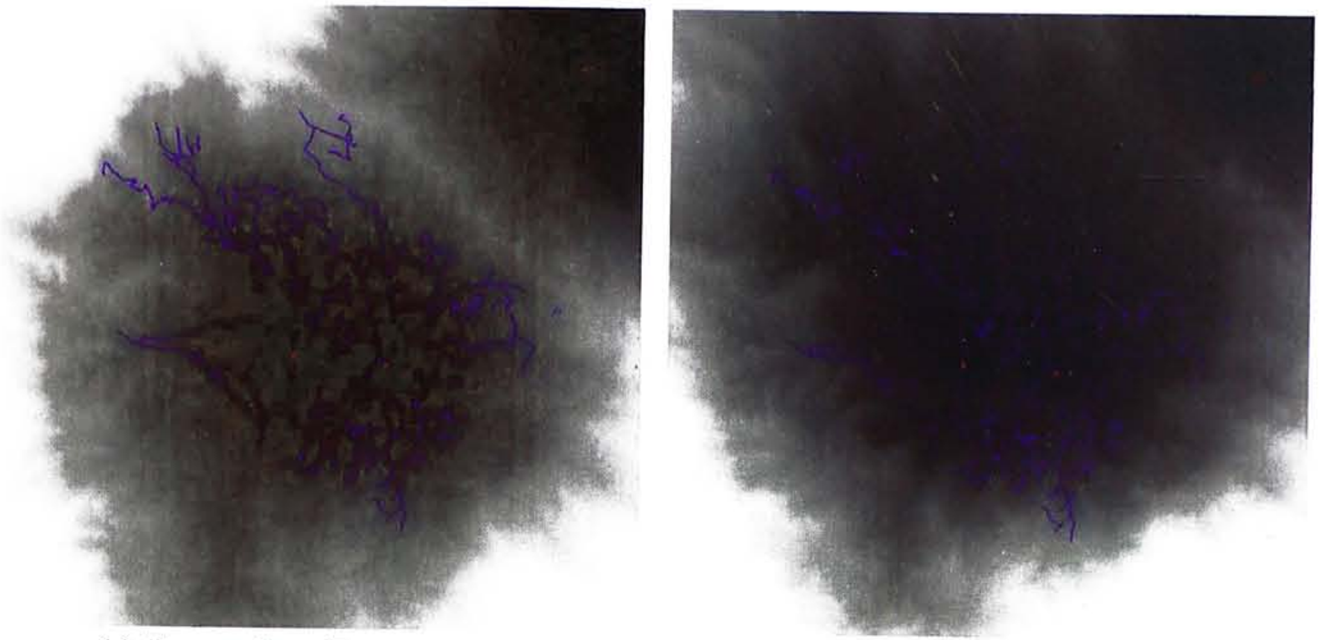
(a) The single cost-of-passage map approach

(b) The Path Distance approach



(c) Cost surface (Fr)

(d) Cost surface (Fr and SD)



(e) Cost surface (Fr, SD and VF)

(f) Cost surface (FR, SD, VF and HF)

Figure 15

Comparison of CAS approaches

(a) The accumulative cost surface calculated from an integrated cost-of-passage map; (b) The accumulative cost surface calculated using the Path Distance model; (c) The accumulative cost calculated solely from the friction surface; (d) The accumulative cost calculated from surface distance and friction; (e) Accumulative cost surface modeling using friction, terrain surface and slope, but ignoring the horizontal factor; (f) Accumulative cost surface modeling with all four parameters.

4.3.5 Spatial Control of Property

In the proposed investigation scheme, catchments or regions with values of less than an accumulative cost distance (threshold) to a cultural route facility can be interpreted as spatial control of the facility over its environment, as discussed in Section 3.2.2. Since spatial control can be interpreted from both physical accessibility and possible landscape perception, it can also be calculated using a similar cost surface modeling approach. The process of spatial control mapping is illustrated in Figure 16.

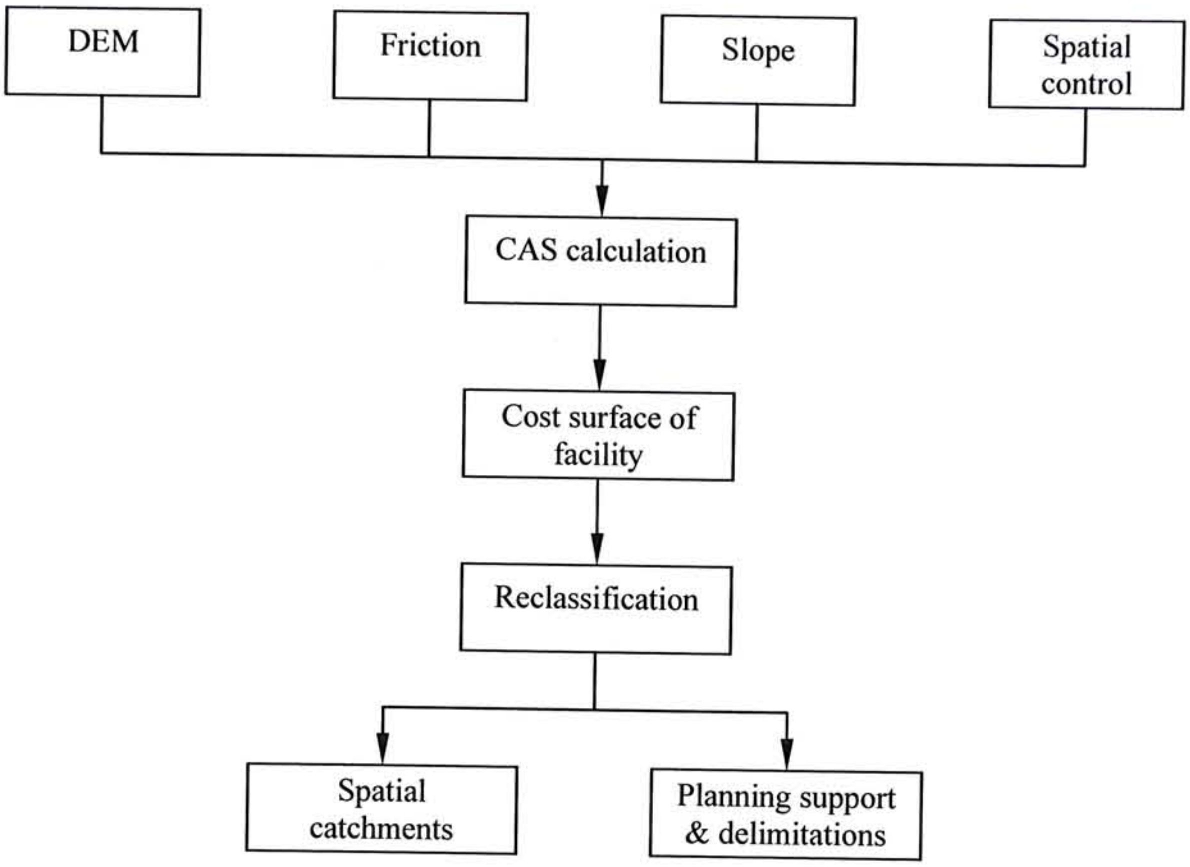


Figure 16

Spatial control cost mapping procedure

Output catchments illustrate the choropleth cost of moving from the facility sources under investigation to pass through each cell. Lower cost indicates greater "accessibility" (Conolly and Lake 2006; van Leusen 2002) or lower consumption when travelling the same Euclidian distance from the source location. Therefore, a smaller cell value can be interpreted as indicating a closer relationship between the cell and the source location, or in other words, indicates that the source facility under investigation exerts a higher degree of spatial control (see also Figure 18).

Catchments through GIS-based cost surface analysis can map the most effective scopes of a facility or group of facilities. The different types of facilities listed in Table 5 can be used to create separate catchment maps. In addition, for a specific facility or single asset group, cost-surface analysis can be applied on a customized cost surface basis by introducing optional cost-value attributes for one of the four specific cultural route and property functional concerns shown in Table 5. Therefore, a set of catchments can be produced for every kind of facility associated with individual functionality.

Region analysis methodology

Spatial allocation (or regional territoriality), the method used to associate a site with territorial scope (Kvamme 1999) is applied in this study to map spatial catchments. Regions or catchments can be created and analyzed using GIS through data capture, map query and modeling calculations. Regions can be objectively viewed as territories delineated by social and political factors or according to cultural distributions and site catchments, or can be defined using natural or analytical processes (Conolly and Lake 2006). The definition of regions is a critical step because not only does it illustrate the spatial structure of cultural route elements and support authenticity recognition, but most importantly, regions can be directly translated into management delimitations.

Regional analysis may allow geometrical or topographical catchments to be determined in this study. In previous research, geometrical catchments have most commonly been produced by buffering (or proximity analysis) and traditional Thiessen tessellation. The topographical approach is labeled as such because elevation and its products significantly affect catchment definitions, regardless of whether they are natural or anthropologic processes. Two main streams of topographical region category (Conolly and Lake 2006), one being accessibility, which is derived from topography-dominant cost surfaces, and the other being viewsheds, which interpret space control and administrative territoriality, are used in this study.

As discussed in the literature review, the use of CSA to define regions or catchments has been suggested in existing research, because it allows for the inclusion of effects that serve accumulated costs (van Leusen 2002). Cost-derived catchment and tessellation are employed in this study. Catchment analysis using a choropleth map is used to allocate spatial control characteristics on gradual attenuation surfaces around properties. The tessellation approach splits the whole space under investigation into tiles based on the gravity of source locations and landscape costs (Wheatley and Gillings 2002; van Leusen 2002). The tessellation method can be used to reconstruct historical municipal or administrative boundaries, or to divide the administrative sections of a cultural route and allocate the possible boundaries of each study region.

Cost-surface modeling parameters for catchment calculations

Cost-surface modeling of designated facilities can take into account the same essential or optional attributes as those used in movement modeling. For basic cost-of-passage features, topography and land cover work in the same way as in the aforementioned local-scale cost-surface analyses. Supplementary cost features are optional as horizontal factors. In certain types of facility or for specific investigation purposes, horizontal factors can be derived from gravitational or magnetic effects based on the costs of other facilities, as calculated through buffer distances and facility importance weightings, or through perceptual phenomena such as accumulative viewsheds, which are endowed with additional access cost concerns for certain activities such as worship, leadership or sieges.

Historical facility cost considerations

In addition to the typical applications of the aforesaid movement model, in which DEM is used as a parameter for surface distance, slope surface can be used for vertical factor calculations, and reclassified land cover work can be used to define a basic cost-of-passage surface. The key dynamic parameter in the calculation of spatial control indicators is the horizontal factor, which can be defined as the attraction/repulsion or friction exerted by spatial perception or extra physical accessibility effects other than terrain and land cover, such as shooting range in defensive functionality. These indicators can be applied in defining different types of assets, as shown in Table 8.

Table 8

Path distance parameters applied in spatial control cost analysis of different types of assets

	Path distance calculation parameters			
Types of assets	**Friction surface**	**Surface distance**	**Vertical factor**	**Horizontal factor**
Economy				
Cargo storage	Land cover	Terrain	Slope	Shooting range
Rest and lodging	Land cover	Terrain	Slope	Visibility
Markets	Land cover	Terrain	Slope	Visibility
Municipals				
Staging posts	Land cover	--	--	Visibility/ Shooting range
Defensive fortifications	Land cover	Terrain	Slope	Visibility/ Shooting range
Customs offices	Land cover	Terrain	Slope	Visibility/ Shooting range
Multi-function / others				
Settlements/towns	Land cover	Terrain	Slope	Visibility/ Shooting range
Urban centers	Land cover	Terrain	Slope	Visibility
Hospitals	Land cover	Terrain	Slope	--
Ports	Land cover	Terrain	Slope	Visibility/ Shooting range
Transportation				
Bridges	Land cover	Terrain	Slope	--
Lighthouse	--	--	--	Visibility
Socio-cultural				
Places of worship and devotion	Land cover	Terrain	Slope	Visibility
Sacred sites	Land cover	Terrain	Slope	Visibility

Cultural landscapes				
Designed landscapes	Land cover	Terrain	Slope	Visibility
Farmlands	Land cover	Terrain	Slope	--
Mining areas	Land cover	Terrain	Slope	--
Breeding areas	Land cover	Terrain	Slope	--
Sacred landscapes (associated landscapes)	Land cover	Terrain	Slope	Visibility

Attraction of accumulated visibility

The magnetism or attraction of landscape perception is translated from the accumulative viewsheds map into a reclassified cost raster layer. The scenario is that moving from a location with less opportunity to see landscape to a higher visibility cell reflects human preference when traveling within a landscape. It also reveals the person's experience of spatial perception, which is considered an important phenomenon of landscape archaeology (van Leusen 2002; Wheatley 2004). The horizontal factor of accumulative viewsheds is negatively correlated to the visibility value of repulsion. Therefore, in the reclassification of accumulated visibility to the horizontal factor, higher values in accumulative viewsheds are assigned lower costs, and vice versa. In addition, the invisible areas are assigned the highest costs. A hypothetical example is shown in Figure 18 (d) to (f).

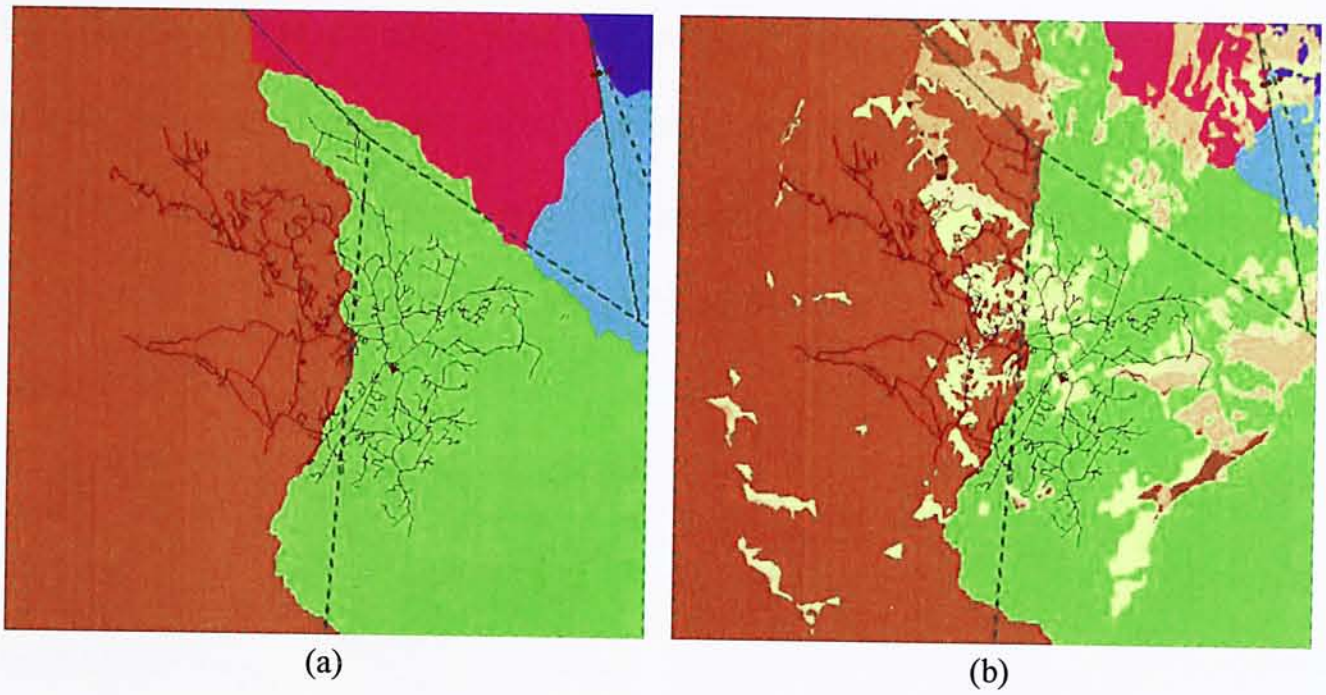
The horizontal factor of defensive functions

As discussed in previous sections, viewsheds can also be interpreted in terms of the military and defensive aspects of observation and shooting. Observation capability can be integrated using accumulative viewsheds and visual distance, a process that can be conducted on the basis of accumulative viewshed cost distance calculations to produce a single cost-of-passage map (see the example in Figure 18(c)). In addition, visibility can be mapped within a visual distance scope defined by critical values for significant view character changes, such as the modular view degrees suggested by Yoshinobu Ashihara (1983, 1970) for viewing facades or recognizing urban skylines, or through its landscape applications put forward by Tadahiko Higuchi (1988). For the defensive side, observation capability performances are the same as in the attraction approach and can be investigated using an equivalent process. By contrast, when investigating invaders' movements or spatial use, the cost of the horizontal factor map is positively correlated to original accumulative visibility if no visual distance attribute is introduced.

Shooting range is similar to observation but points a shorter distance from the facility location. Range can be defined directly through point-based viewsheds or accumulative viewsheds within a certain radius that serves as the parameter "Radius2," which refers to data on different weapons from military history and is used as a bias. Spaces within shooting range can either be mapped into accumulated visibility to indicate "dangerous" as a description of the probability of the cell being attacked from various firebases, or by introducing a binary visibility map to interpret a homogenous spatial control factor instead of defense efficiency.

Spatial tessellation using ArcGIS

In this study, spatial allocation is used to divide cultural routes into sections for detailed investigation or conservation management. Spatial authenticity attributes should be taken into account to ensure the partition is rational. "Cost allocation" or "path allocation" calculations using ArcGIS can introduce further weighting surfaces including geographic or morphological features, as well as other spatial parameters which can indicate intangible factors such as phenomenological or social phenomena. Cost allocation only requires that extra consideration be given to the weightings of a raster cost surface to modify the Thiessen algorithm, while path allocation also introduces terrain and slope values, along with horizontal factors other than the main cost surface. An experiment involving the territoriality of five facilities around a valley is demonstrated in Figure 17.


(a)

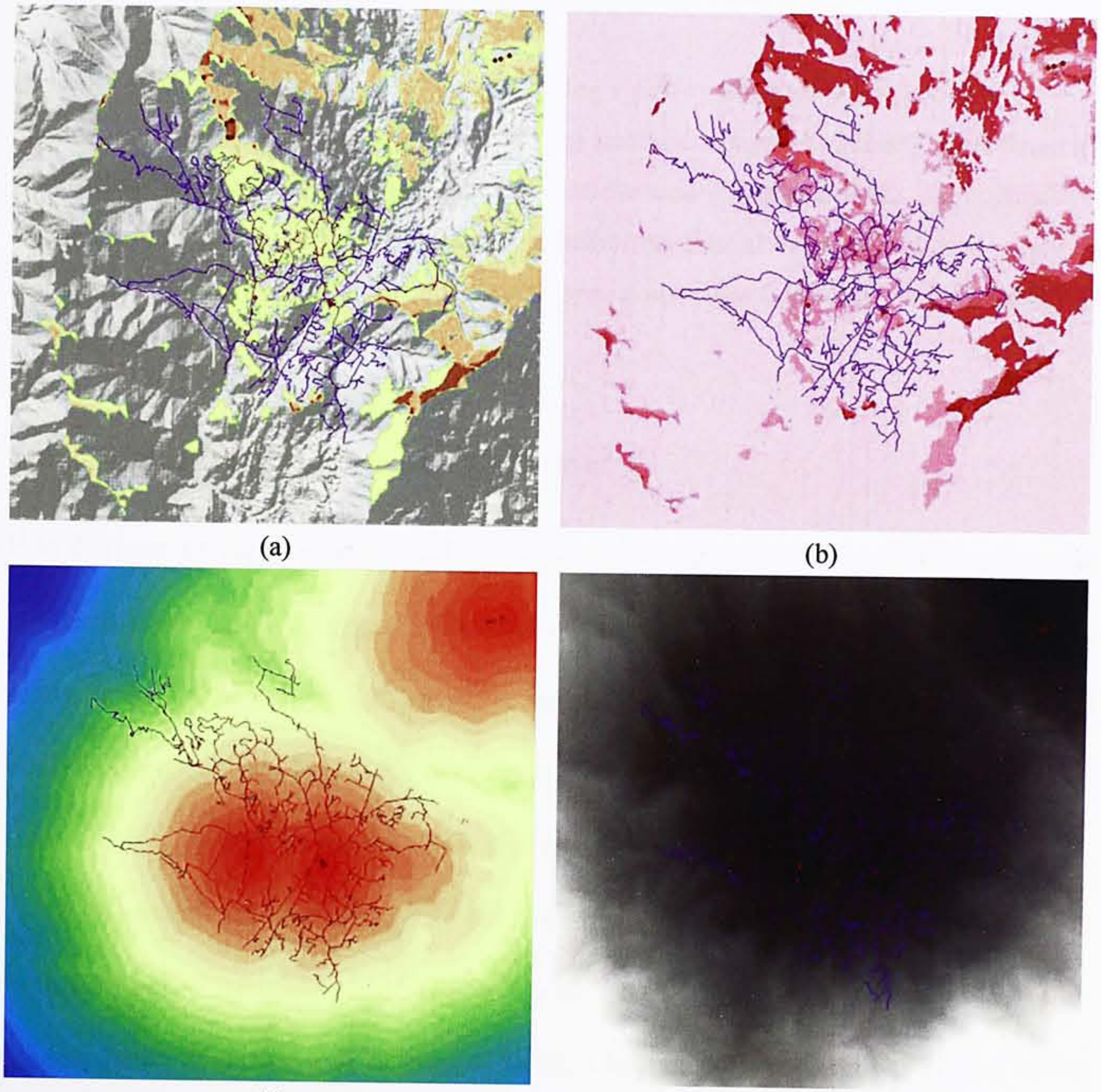
(b)

Figure 17

Examples of spatial allocations (gray broken lines indicate Thiessen tessellation): (a) cost allocation with land cover costs; (b) path allocation taking into account land cover, terrain, slope and visibility attraction; the brown patches are accumulative viewsheds.

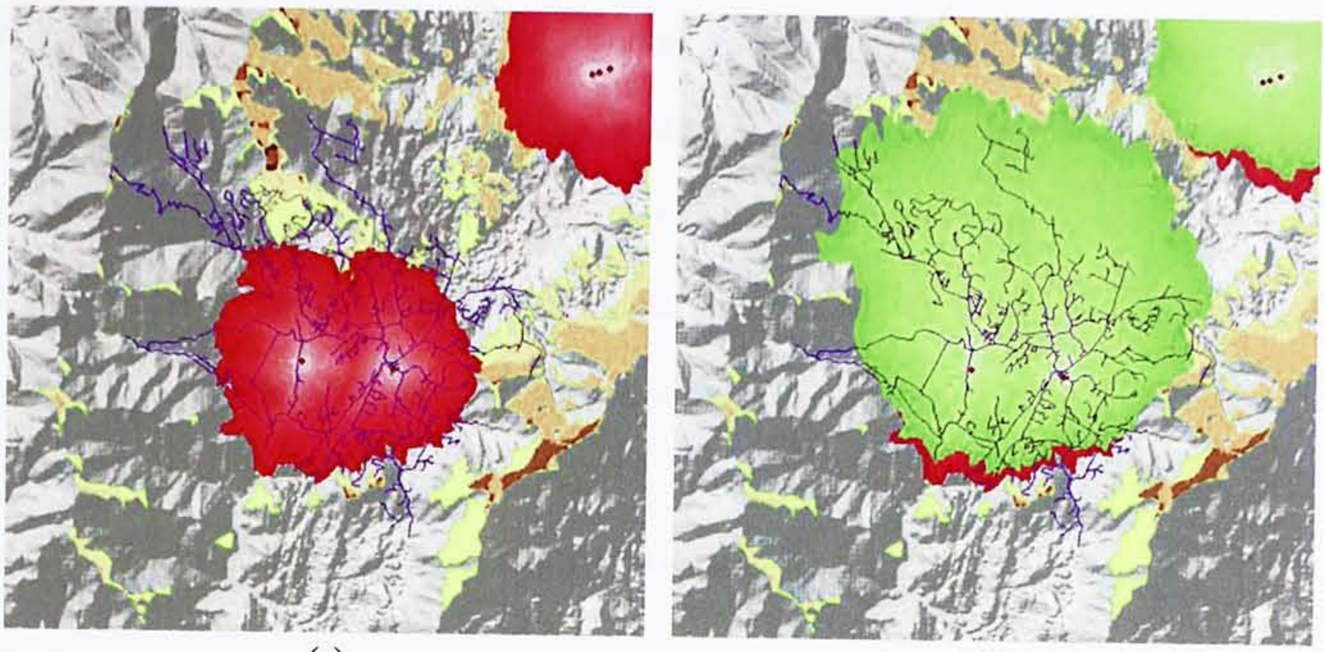
Spatial allocation parameters are suggested in this study to allow for the use of factors similar to those applied in cost-surface analyses. The surface raster and vertical factor are topographical features, while the cost raster and, in particular, the horizontal factor can introduce more flexibility to reflect either physical landscape features or social and economic quantitative interpretations. In addition, given that tessellation will deal with an entire scope, an analytical space boundary should be applied. For linear features like paths, "maximum distance" in the path allocation model can be defined as a buffered management zone. In other cases, an analytical mask, such as that derived from the raster layer mapping the whole cultural route management scope, can be used to delineate the allocation boundaries.

The calculation shown in Figure 14 illustrates the obvious effects of the horizontal factor of visibility on spatial structure mapping. Lower-cost trends are found between the facility locations and the highly visible areas. Figure 18 demonstrates a CSA on spatial control using ArcGIS path distance analysis for five facilities located in a valley, which act as landmarks and have different building heights and significant ranks within a complicated topographical environment. It is clear that the introduction of visibility attractions has a serious effect on spatial structure mapping. Lower-cost trends are found between the facility locations and the highly visible areas.



(a) (b)

(c) (d)



(e) (f)

Figure 18

Example of facility spatial control mapping taking visibility attractions into account

(a) Accumulative viewsheds of the facilities; (b) Reclassification as visibility attractions; (c) Detailed visibility attraction mapping taking cost distance into account; (d) The cumulative-cost surface derived using a full-model calculation; (e) Spatial catchments based solely on isotropic cost features; and (f) Comparison of spatial structure following the introduction of visibility attractions.

4.4 Technical Issues and Validation

It is difficult to validate analytical results and the consequent conservation planning unless massive archaeological excavations are made or current developments are ready to be implemented. However, to enhance research reliability, the validity of analytical procedures has to be considered. Analytical assumptions and technology introduced must take methodological and technical limits into account.

Fundamental limitations have been addressed in previous research, including both GIS-based landscape analyses (see Lock (2000)) and cost surface and visibility studies (see: Wheatley and Gillings (2000); Llobera (2000); Baldwin et al. (1996); and Fisher (1999)). Van Leusen (2002) and Conelly and Lake (2006) have involve comprehensive reviews of the technical limits of archaeological CSA and LOS analyses. These issues may cause inherent errors, such as edge effects and DEM accuracy, in the application of GIS, as already discussed at the beginning of this chapter. Furthermore, CSA and LOS applications involve more specific problems that need to be considered. Cares have to be taken in this study to deal with the technical issues raised in the abovementioned critiques.

4.4.1 Technical Issues of Visibility Studies

As noted in Chapter 2, these debates cannot be ignored. This study takes account of each of abovementioned critique and provides possible solutions. This section follows the list provided by Wheatley and Gillings (2000) to indicate the methods implemented in the investigation to improve the validity of the conclusions reached.

Computational issues

These kinds of issues arise as a result of the way in which GIS operates. For algorithm issues, "the undifferentiated nature of the viewshed" has been discussed in various studies (e.g.Wheatley and Gillings (2000); Fisher (1993, 1994, 1995)); as already discussed in section 4.3.4, accumulative viewsheds already serve as a common solution. Other algorithm errors to be wary of include those caused by the fact that GIS software packages that differ from one another may cause differences in calculation results (Fisher 1993) and errors caused by introducing the curvature of the earth (Ruggles and Church 1996). The ArcGIS software package provides solutions to both of these two issues.

Experimental issues

Experimental issues arise from the way in which visibility analyses are processed. Such issues depend on the degree of rigor the user applies in dealing with parameters, data and other methodological and technological issues in the course of analysis (Wheatley and Gillings 2000; van Leusen 2002).

The edge effect is an inevitable technical concern for which adjustments are required and has been the subject of several previous discussions (Conolly and Lake 2006; Wheatley and Gillings 2000; van Leusen 2002; Lake, Woodman, and Mithen 1998). Accumulated visibility analysis is profoundly affected by the edge effect. Section 4.1.1 has proposed a solution consisting of trimming the study region from a broader DEM. It has been suggested that the distance be reduced to the longest visual distance used in the viewshed analyses (van Leusen, 2002).

Another point that has been discussed is the inherent limitations caused by DEM quality (Wheatley and Gillings 2000; Fisher 1994, 1995), as mentioned in section 4.1.1. However, Wheatley and Gillings (2000) declare that the relationship between DEM accuracy and visibility calculation validity is not simply correlative, because the effects of DEM accuracy are not evenly distributed. Their suggestion is that triangulated irregular networks (TIN) be used instead of an altitude matrix such as a raster terrain, because the TIN mechanism can be used to increase the level of detail in high topographic variation areas such as crests and hilltops, where the DEM quality has more impact on viewshed analytical reality (Wheatley and Gillings, 2000).

Theoretical issues

Theoretical issues relate to the intrinsic concerns surrounding GIS-based visibility studies. These issues are technological determinism, visualism, and perception interpretations of visibility aspects (Wheatley and Gillings 2000; Lock and Harris 1996). It is suggested that these issues can be balanced through careful analysis and design and prudent research assumptions (Whetley and Gillings, 2000; van Leusen, 2002). Mobility is another problem that does not appear to have been completely resolved in the current archaeological visibility framework. However, mobility can be integrated with the CSA approach, the approach on which this study will concentrate. Cumulative viewsheds of sequential viewpoints along the movement trail are also helpful (Wheatley and Gillings, 2000).

Substantive issues

Substantive issues are affected by the introduction of parameters and data. Zamora (2002) uses onsite experiments to compare real viewsheds with viewsheds calculated under different temporal and directional conditions, an area that Wheatley and Gillings (2000) also identify as one of the pragmatic issues. It has also been suggested that the palaeoenvironment and palaeovegetation be taken into account in the course of analysis (Wheatley and Gillings 2000; Chapman and Gearey 2000), an issue discussed in detail in section 4.1.3.

Issues respecting to visual distances

Several minor issues can be resolved by careful experimental design in the setting of visual parameters (Conolly and Lake 2006). View reciprocity for viewpoints and sites to be seen is a pragmatic issue (Wheatley and Gillings, 2000). Study in Loots, Nackaerts, and Waelkens (1999) is a good example of the design of projective (views-from) and reflective (views-to) viewsheds according to different functionality concerns to allow for the interpretation of defensive systems. Loot and colleagues' approach can also be introduced for the dynamic visibility phenomena of cultural routes.

This issue also indicates a procedural or substantive concern over the robustness and sensitivity of viewer uncertainty and object heights (Wheatley and Gillings, 2000). In visibility analysis, the observer's height has been proven to have a profound impact on cumulative viewsheds (Lock and Harris 1996). Because of this, it has been suggested that viewsheds should be calculated for a range of heights (Wheatley and Gillings, 2000). The visual height attributes can be defined by "OffsetA" for different values using ArcGIS calculations, as indicated in previous discussions. The definition of target height varies from case to case. Different height values may be assigned to people, constructions and landmarks, tree heights in natural landscapes, or other special values according dynamic factors, such as beacon smoke increasing the original structure height. The theoretical critiques of landscape acuity and abstract landscape perception, or diurnal and seasonal differences and climate conditions, are all related to the decrease in visual perception quality caused by visual distance. The visual distance parameters introduced in section 4.3.3 can be introduced as proxy (Lock and Harris 1996).

4.4.2 Cost-Surface Analysis Concerns

In comparison with visibility computations, CSA involves less technical issues but has to be considered more methodically. Van Leusen (2002) points out several concerns, such as physiological, biological and anthropological issues, that cannot be fully reflected here. However, the human knowledge and experience that lead travelers to select the optimum path in a "global" manner can be partly simulated by the ArcGIS cost-surface model by introducing the horizontal factor. Further concerns include question design, assumptions and the interpretation of analytical results. In light of potential errors from both data sources and models, probabilistic interpretation is preferred (van Leusen, 2002).

Conolly and Lake (2006) and Harris (2000) have referred to several problems commonly encountered in CSA modeling. The path-tracing profile concern is not relevant here because this study introduces a lower cost corridor for movement simulation. In anisotropic cost modeling, the multiple destinations model can be solved using the current cost-surface analytical framework. Furthermore, although the definition of ratio-scaled cost values relies on sophisticated cost-of-passage modeling techniques, an algorithm based on the ArcGIS modular which provides four cost-of-passage surface layers can be used to simplify surface modeling and reduce error. The reclassification of land cover as basic friction surface and of visibility or property weights as horizontal factors can be translated into scaled values by referring to previous studies, following previous experiments, or relying on professional experience.

4.4.3 Validations

Several methods can be employed as validation tests for visibility and CSA analyses. Landscape archaeological studies generally use comparison checks between the attributes of significant locations with random selected samples. This approach is more likely to be applied in visibility studies, examples of which can be found in Wheatley (1995); Fisher et al. (1997); Lake, Woodman and Mithen (1998); Lake and Woodman (2000); and Lambers (2006). The Kolmogorov-Smirnoff goodness of fit test can be utilized for statistical testing, as demonstrated in these studies.

Another visibility test for CSA-based simulations consists of a comparison with independent archaeological evidence, such as in the typical case involving a simulation of a known route along a ridgeway demonstrated by Bell and Lock (2000). Harris (2000) also suggests that a comparison with manually generated results can verify the accuracy of the automated routing product.

4.5 Summary

Viewshed and cost-surface analyses are introduced in movement and catchment modeling for cultural route historical replication. The key technology is the cost surface model, which introduces four kinds of cost effects, namely surface friction, topographical surfaces for both traversing distances, and energy consumption, in addition to horizontal factors for expressing different possible effects. Cost surface modeling is conducted through the operation of the ArcGIS “path distance” function with customized parameter settings. Using this modeling process, accumulative cost surfaces can be created for different cultural route properties and destinations. Lower-cost corridors can then be calculated to replicate possible movements or path selection through overlaying, and the spatial catchments of cultural route facilities can be derived directly from such cost surfaces.

Chapter 5

CASE STUDY OF THE GREAT WALL

This case study investigates the Ming dynasty Great Wall of the Ming Dynasty of China on both an interprovincial scale and on a regional scale for a with particular reference to an important pass, the Juyongguan 居庸關, which formed the northern entrance to Jingshi 京師 (“capital,” of the name given to Beijing during the Ming Dynasty). This chapter illustrates the process for modeling possible Mongolian invasion routes and demonstrates the defensive function of Great Wall on both scales. Spatial allocations and site catchments are also tested for management and conservation planning utilizations.

5.1 Background

The Great Wall of China was inscribed in the World Heritage List in 1987 as a cultural heritage monument. It is not only a defense or military structure but also serves as a link for cultural exchange, especially between cultivators and nomads (馮, 程, and 徐 1995; 金 1985). Therefore, archaeologists and heritage protectors are also interested in considering the Great Wall together with its associated historical towns, cultural and natural landscapes and other assets as a cultural route (Zoslt 2005; 單 2006).

5.1.1 Previous Research

A tremendous amount of research on relevant topics has been carried out both in

China and overseas, the extent of which makes a detailed review impossible. There are two main streams in Great Wall studies (林 2006)). Firstly, from the perspective of research scope, a majority of the previous research has concentrated on the entire Great Wall system on a large scale (see 羅, 沈, and 張 (1994) as an example). Another trend is more related to methodology. Former historical or archaeological studies on the Great Wall have usually relied on either evidence revealed by historical documentation or first-hand data collected through site surveys, or a combination of the two. Studies carried out by several top Chinese "Great Wall experts," such as Dong Yaohui 董耀會, Luo Zhewen 羅哲文 and Cheng Dalin 成大林, are typical examples of both approaches. However, their comprehensive coverage of this topic has meant there is a lack of in-depth investigations on specific topics, such as construction, landscape context and military activities (田 and 毛 2005).

Focusing on the research questions for this study, I briefly discuss several sub-topics instead of discussing these "general works." The fields reviewed include the military performance of the Great Walls, innovative research methodologies, and major studies in Juyongguan, the location on which the detail-scale case study focuses.

Another topic that must be mentioned is the Ming Dynasty Great Wall, as the case study is based on the constructions that existed during this period. However, because the remaining Ming Dynasty Great Walls are in the best condition, and are also the longest remaining sections of the Great Wall, and represents the most complicated defensive system when compared to constructions from other periods, previous research on the Ming Great Walls covers too broad an area to be reviewed. Dong Yaohui and his colleagues, Mr. Wu Deyu 吳德玉 and Mr. Zhang Yuanhua 張元華, publish a very significant historical geography study for which historical documentation was inspected and site surveys were carried out along the entire Ming Great Walls (華夏子 1988). Other comprehensive studies have also been undertaken for specific sections of Ming Dynasty military municipal regions, such as Guyuan 固原, Gansu 甘肅, Ningxia 寧夏, and Yansui 延綏 (or Yulin 榆林) (see 田 and 毛 2005; 艾 1990; 範 1991; 高 and 張 1989) of Northwestern China, and Datongzhen 大同鎮 (陳 2002), Liaodong 遼東 (劉 1989) as sections within the Jiubian 九邊 (Nine Frontiers and Eleven Military Defense Stations) system of Ming Great Walls, and other specific locations (see 艾 (1993) as example).

Military functions

Studies on the Great Walls of Northwestern China, a strategic defensive region under serious Mongolian threat during the Ming period, have been much more fruitful than those that focus on other areas (田 and 毛 2005), among which Shi Nianhai 史念海's paper, *論西北地區諸長城的分布及其歷史軍事地理* (史 1999), is extremely important. This paper analyzes the landscape characteristics of this area to establish the rationales for military activities, such as invasion trails and strategic defensive areas, in both spatial and temporal dimensions. Unlike in most other studies, citations of historical literature was only serve as supporting background, and historical landscapes were highlighted to interpret historical phenomena in Shi's paper.

In recent years, other more in-depth and relatively small-scale studies on the military functions of the Great Wall have been carried out, for example, a series of papers published in a special issue of *文物春秋* (孟 1998; 兆 1998; 魯 1998; 魯 and 李 1998) on the Great Walls of Hebei Province that contained less historical narrative but concentrated on material cultural relics such as constructions, facilities, and weapons that fulfilled the defensive functions of the Great Walls. Zhang Yukun 張玉坤's group works on fortresses along the eastern half of the Great Wall defensive systems (張 and 李 2005a, 2005b; 李 and 張 2006; 苗 2004). Guo's thesis also aims at recovering the Great Wall's systematic performance in capital defense (郭 2006).

Innovative paradigms using RS and GIS

The Great Wall is one of the most popular ground objects in remote sensing image interpretation researches. Investigation projects have been implemented in two typical Great Wall construction regions in Ningxia 寧夏 and Beijing (Guo and Wang 2004; 張 2007; 曾 and 顧 1987; 聶, 楊 and 王 2005; 地址礦產部 1985; 黎 and 順 1994; 尹 et al. 2005; Nie 2006; 代, 聶, and 張 2007; 代 and 聶 2007; 彭 et al. 2007; 張 et al. 2007). Another RS-based investigation covering the entire extent of the Ming constructions is currently being undertaken (光明日報 2007; 中國長城學會 2005). There are also some preliminary GIS datasets and simple WebGIS systems have worked on by both the Australian Centre of the Asian Spatial Information and Analysis Network (ACASIAN) of Griffith University, through the Electronic Cultural Atlas Initiative (ECAI) platform (ACASIAN 2003) and a group of amateur researchers (長城小站 2004). However, these approaches are still limited to data collection and/or management. Few analytical attempts have been made, although a minor exception can be found in the planning support attempted in Zhang's master thesis (張 2007) through a landscape weighting model to provide sophisticated Great Wall delimitations.

5.1.2 Great Wall Conservation

Great Wall conservation is facing a significant challenge due to rapid development in China and erosion caused by climatic changes (Waldron 1983; 成 and 李 2007). Some efforts have been made in both municipal conservation legislation, such as the *北京市長城保護管理辦法* (北京市文物局 2003) and *關于劃定長城臨時保護區的通知*(北京市人民政府 2003) in Beijing, and physical heritage maintenance requirements implemented for several sections of the wall (examples in Beijing can been found in 李 (2000) and 晉, 北京市古代建築研究所, and 密雲縣文化文物局 (1992)). Moreover, two milestone events in this field occurred at the end of 2006, namely the passing of the *長城保護條例* (中華人民共和國國務院 2006), a piece of national legislation, and the launch of the *Great Wall Conservation Project (2005-2014)長城保護工程(2005-2014 年)*(中華人民共和國國務院辦公廳 2006a). These two initiatives are creating a framework for Great Wall protection in terms of inventory, conservation planning, legislation, heritage management, public communication, scientific research, maintenance and reconstruction, monitoring and financial support (中華人民共和國國務院辦公廳 2006b). A *Great Wall Conservation Plan 長城保護總體規劃* is expected to be issued at the end of 2009 (ibid). One of the important tasks raised in this framework is to establish a conservation mechanism by clearly defining the conservation assets and protection levels for Great Wall heritage using sophisticated heritage identification and delimitation techniques (中華人民共和國國務院辦公廳, 2006c).

However, 成 and 李(2007) have pointed out that there is still confusion over most of the basic questions surrounding Great Wall conservation, such as inventory and recognition criteria. Another serious issue is that even the updated research framework still only focuses on the physical substratum of the Great Wall relics. Intangible attributes and heritage settings have not yet been taken into account in conservation planning. Therefore, there is still no room for cultural landscapes or the cultural route concept to be introduced to the current conservation framework. Planning support that involves value assessments of Great Wall heritage undertaken without considering comprehensive heritage authenticity could be dangerous.

5.2 Case Study Design

The above background analysis indicates that the proposed cultural route investigation mechanism is suitable for being used in Great Wall conservation studies and may contribute to remedying its inadequacies for significant heritage recognition and scientific planning support. The following investigation procedures have been customized for the purpose of Great Wall investigations:

1. Firstly, the entire central frontiers from Gansu to Beijing, which were used for defending against Mongolian nomads during the Ming Dynasty, are replicated to locate the most probable invasion routes. Switching of invasion traces and accessibility to inner China may illustrate the functional authenticity of the Great Wall on a large scale and its performance as a strategic property in a cultural route system.
2. After defining several of the most vulnerable large-scale corridors, the Juyongguan area is selected for detailed investigation. Several possible invasion routes and trails are calculated between Yanqing Plain 延慶小平原 and Jingshi. Using a functionality approach, the defense performance of facilities along the Pass Valley 關溝 and nearby walls are mapped as traversing costs. What-if analyses are implemented to simulate invasion movement and the effects of this

defensive system.

3. The cost distance distribution of each relic of the Juyongguan defensive system is also calculated to indicate spatial control functionality. These maps are reclassified into authenticity levels and landscape and setting conservation scopes are eventually suggested.

5.3 Data Sources and Data Preparation

The case study introduces multiple data sources, which include radar DEM, digital topographic maps, satellite images and historical maps, which are used to reconstruct historical landscapes and cultural route areas on both an inter-provincial and regional scale.

5.3.1 DEM

There are two types of DEM employed in the spatial analyses in different resolutions for large or regional scale applications. For the scale level of interprovincial construction, the analytical scale is defined as 1:2,000,000 to 1:4,000,000, in which SRTM-3 data is introduced. On the regional scale, 1:50,000 digital maps of modern-day Yanqing County 延慶縣 in Beijing are converted through GIS to create TIN and raster topography maps.

SRTM-3 data and resampling

For the case study dataset, ten patches of STRM-3 DEM data are input (Figure 19), covering the area including the territories of Oirat 瓦剌 and Tatars 韃靼 in Mongolia tribes during Ming Dynasty, to the inner North China extending to the southern brim along Shandong, Shanxi, and eastern end of Hebei to around the western boundary of

Gansu (Figure 20). The original STRM-3 DEM input into the case study dataset has a resolution of 3 arc seconds (around 90 meters). To cooperate with other datasets in lower resolutions as well as improve calculation efficiency, the patches are combined and resampled into a DEM of 30 arc seconds in resolution (a cell size of about 1 kilometer). All the raster analyses are implemented in this resolution in large scale. Other reference background maps, like province boundaries and places of habitation, are introduced from the "China Dimensions" data collection's administrative regions using GIS data in 1:1,000,000 and according to the 1990 boundary from the Socioeconomic Data and Applications Center (SEDAC) of Columbia University (SEDAC date unknown).

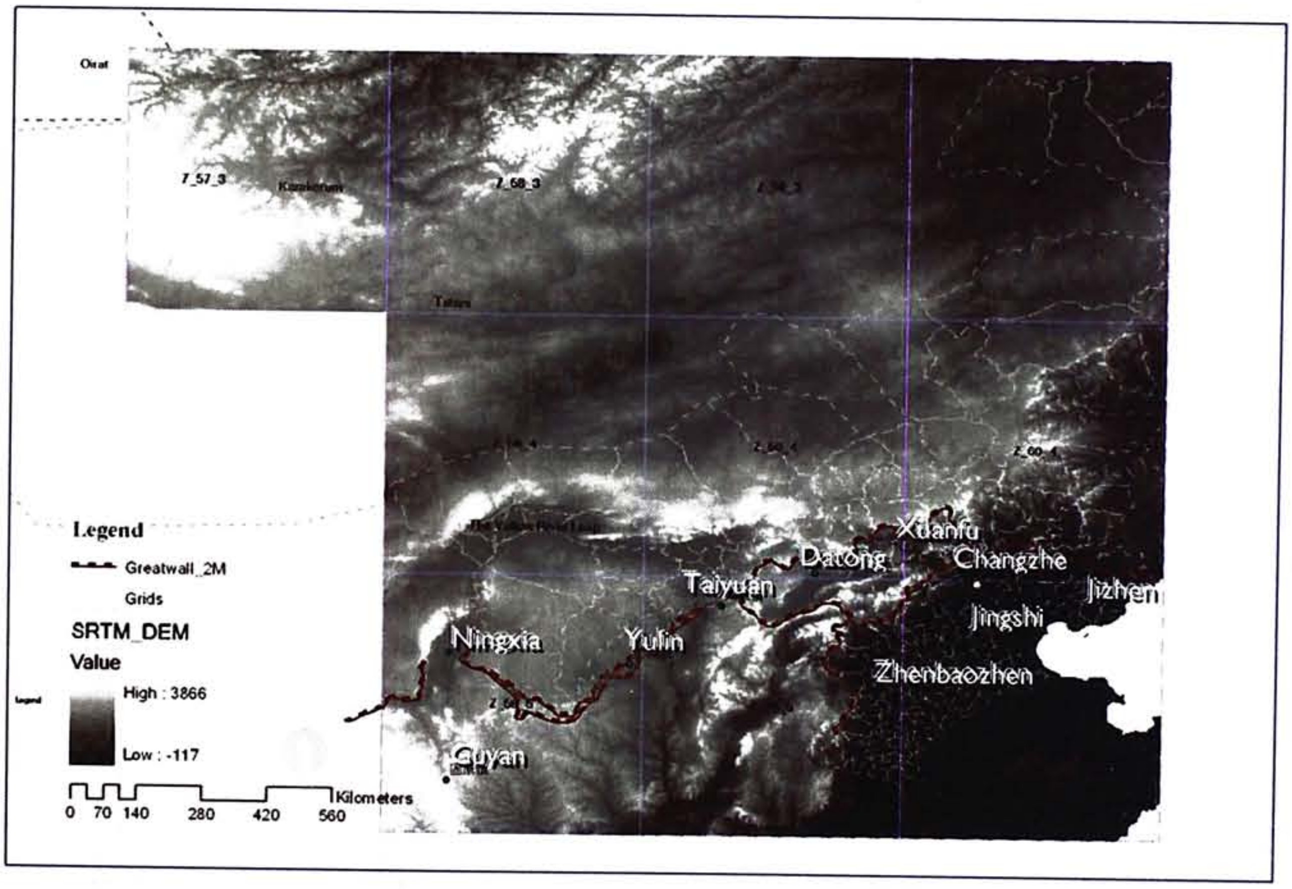


Figure 19

SRTM-3 DEM patches introduced in the large-scale case study region

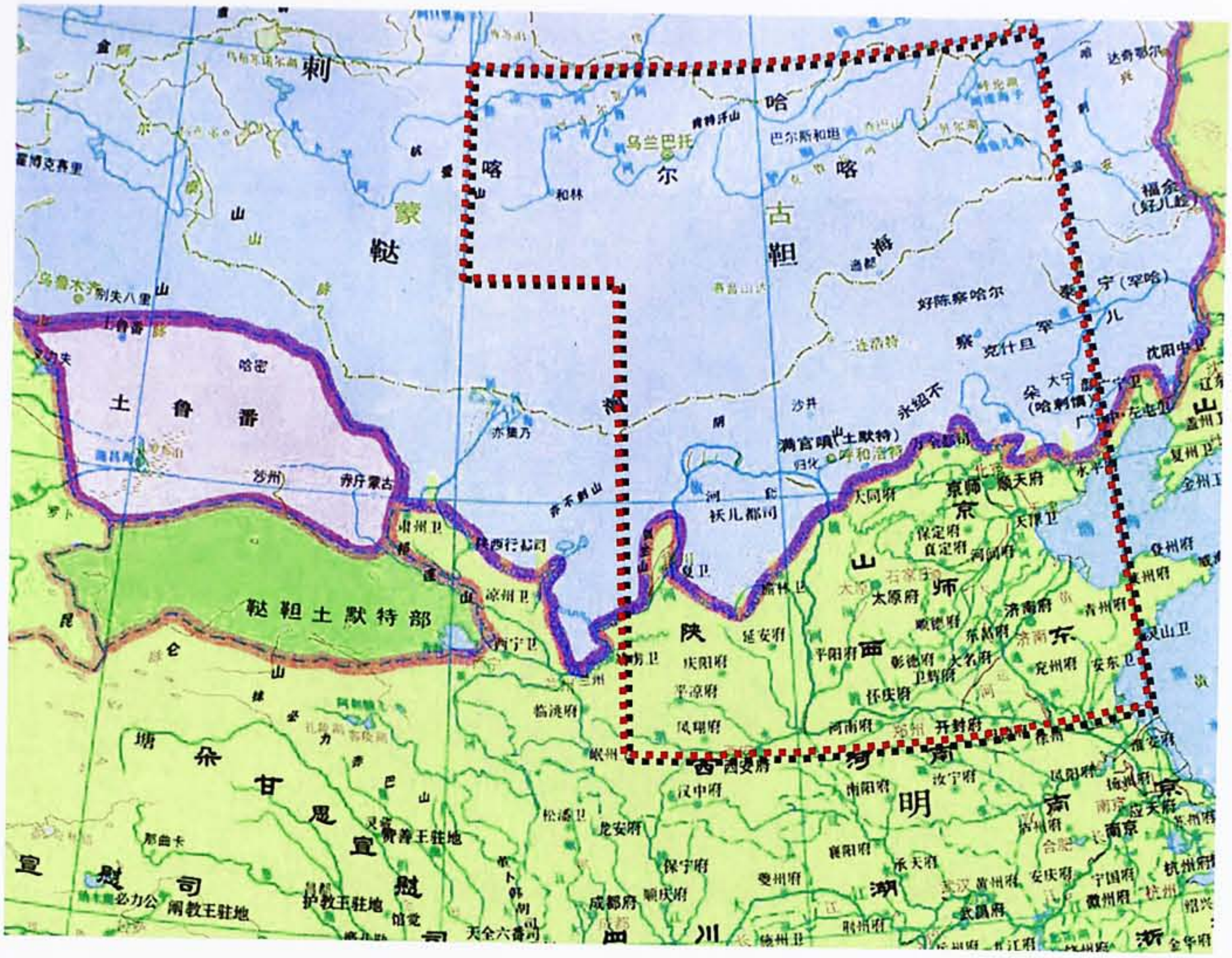


Figure 20

Historical map of the interprovincial-scale case study area (marked by red dashed-line boundary) in Ming Dynasty (background map adopted from 譚 (1982), 42-43)

Regional scale digital maps

This case study uses standard China national primary scale topographic maps on a scale of 1:50,000 in which almost all of Yanqing County in Beijing is covered (Figure 21). The data available on a regional scale covers about 1,400 square kilometers and centers on the Juyongguan Pass system. It covers the southeastern part of Yanqing, most of the eastern half of Huairou 懷柔, and part of the mountainous area of Huailai 懷來 in Hebei Province. High resolution DEM is created using TIN based on contours and elevation points on the 1:50,000 maps and is then resampled into 30 x 30 meter cells in a raster analysis (Figure 22). Meanwhile, a 1:10,000 MapInfo dataset is also introduced to provide more accurate location references such as roads and intersections for remote sensing data rectification (Figure 23).

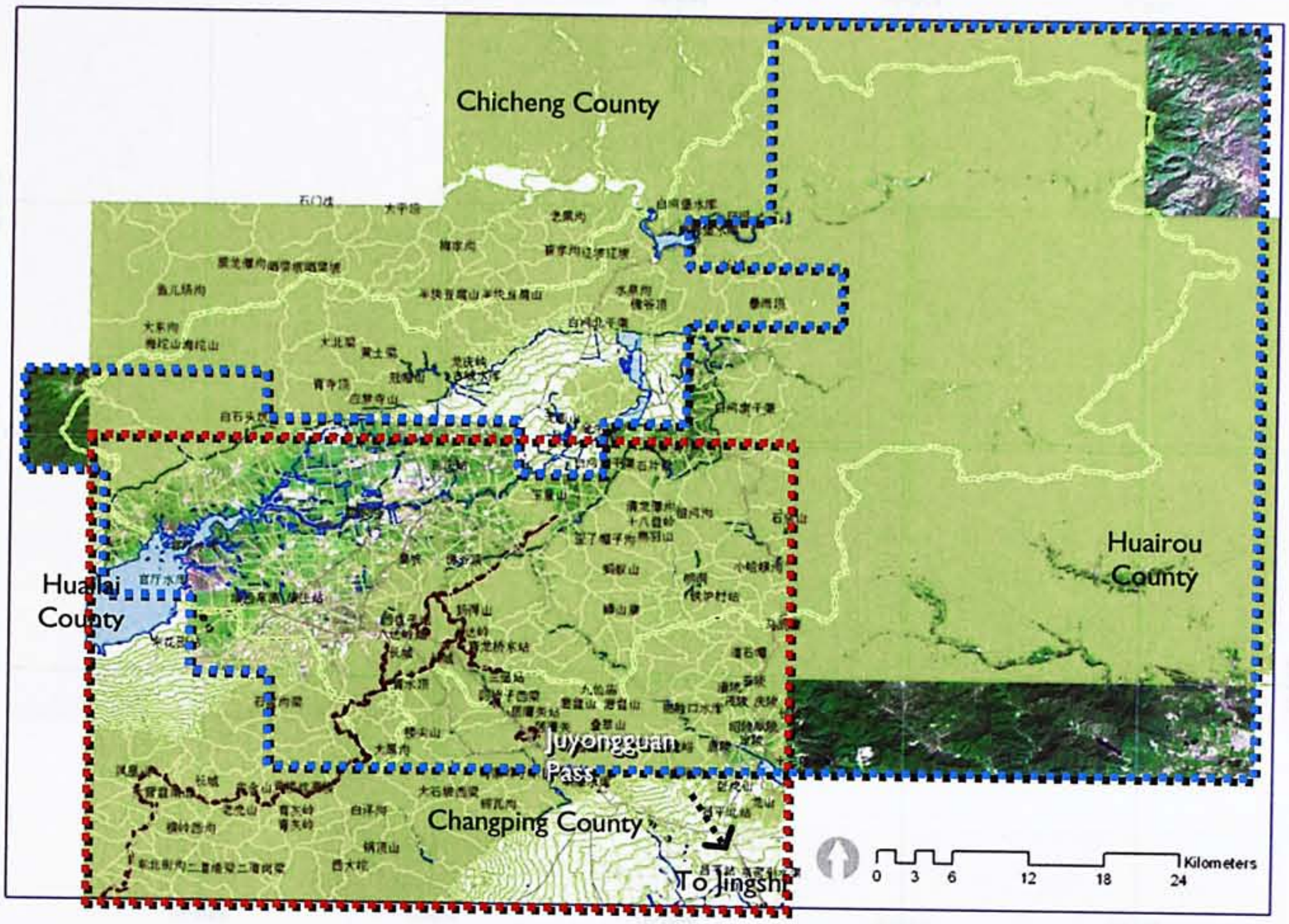
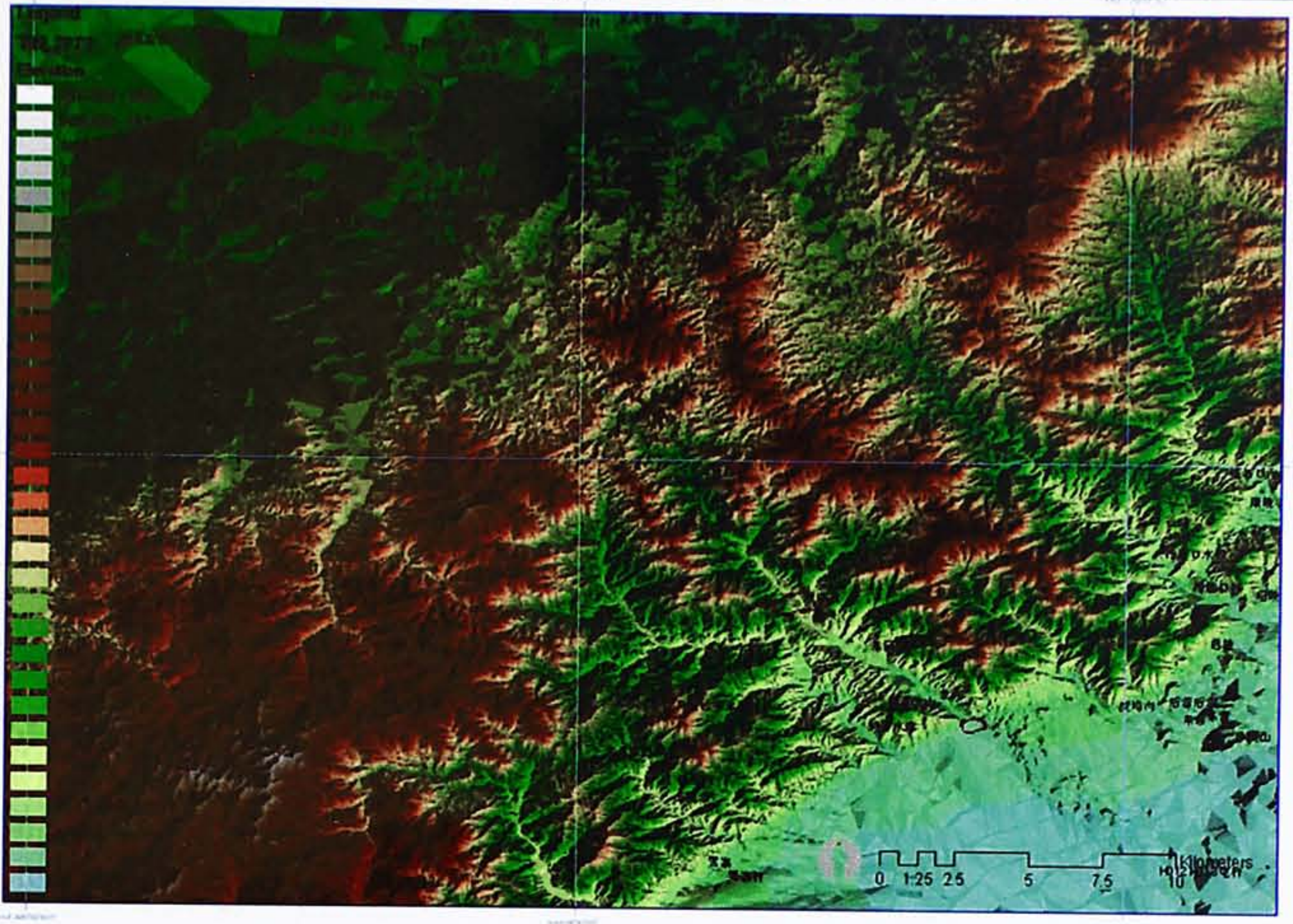
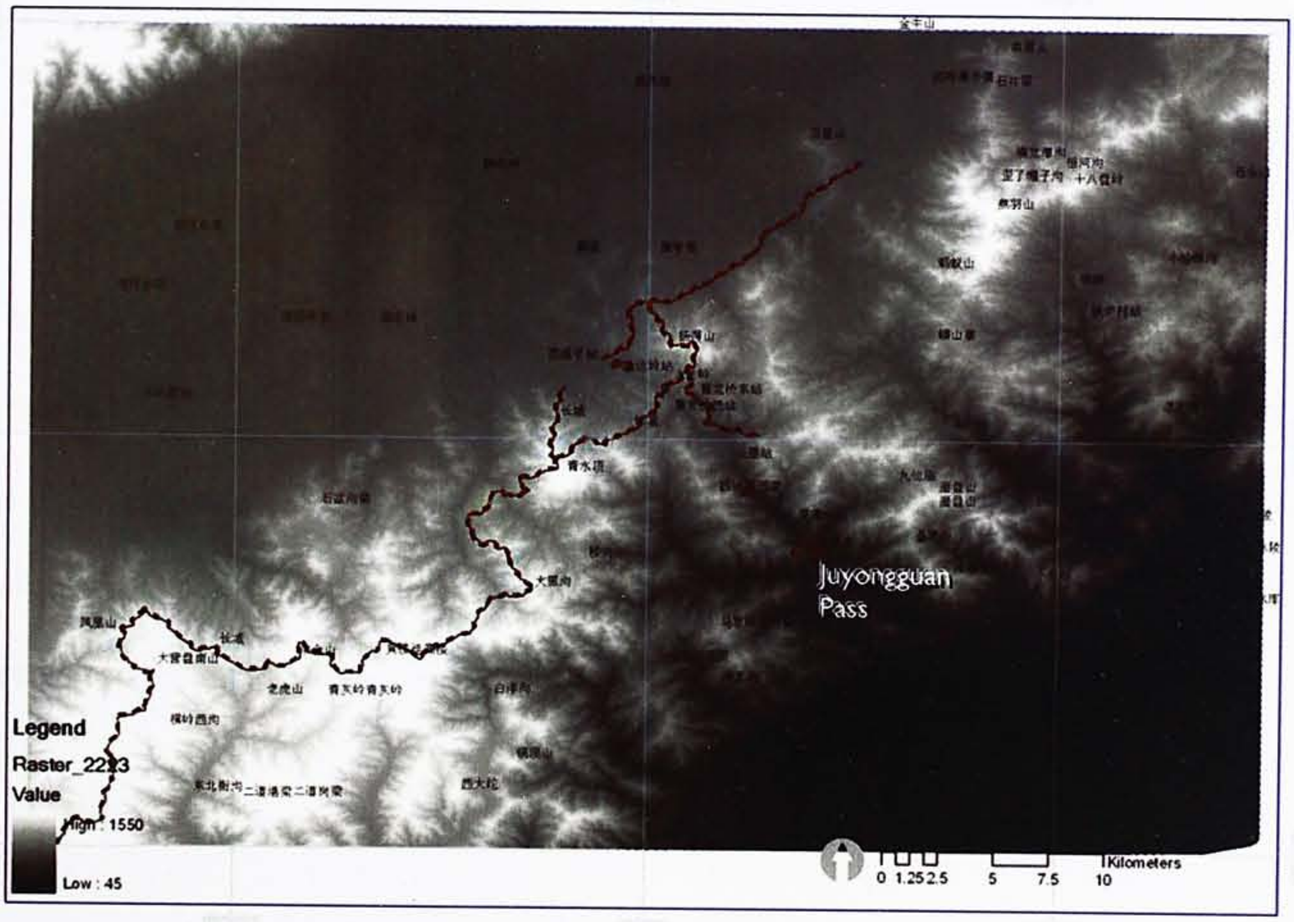


Figure 21

The 1:50,000 topographic maps with the modern Yanqing County (illustrated by the yellow dash-dot boundary), the regional-scale analytical area (marked by red dashed boundary) and the available SPOT RS image coverage (in blue dashed boundary)



(a) The TIN surface



(b) The raster surface

Figure 22

DEM surfaces created through 1:50,000 topographical maps

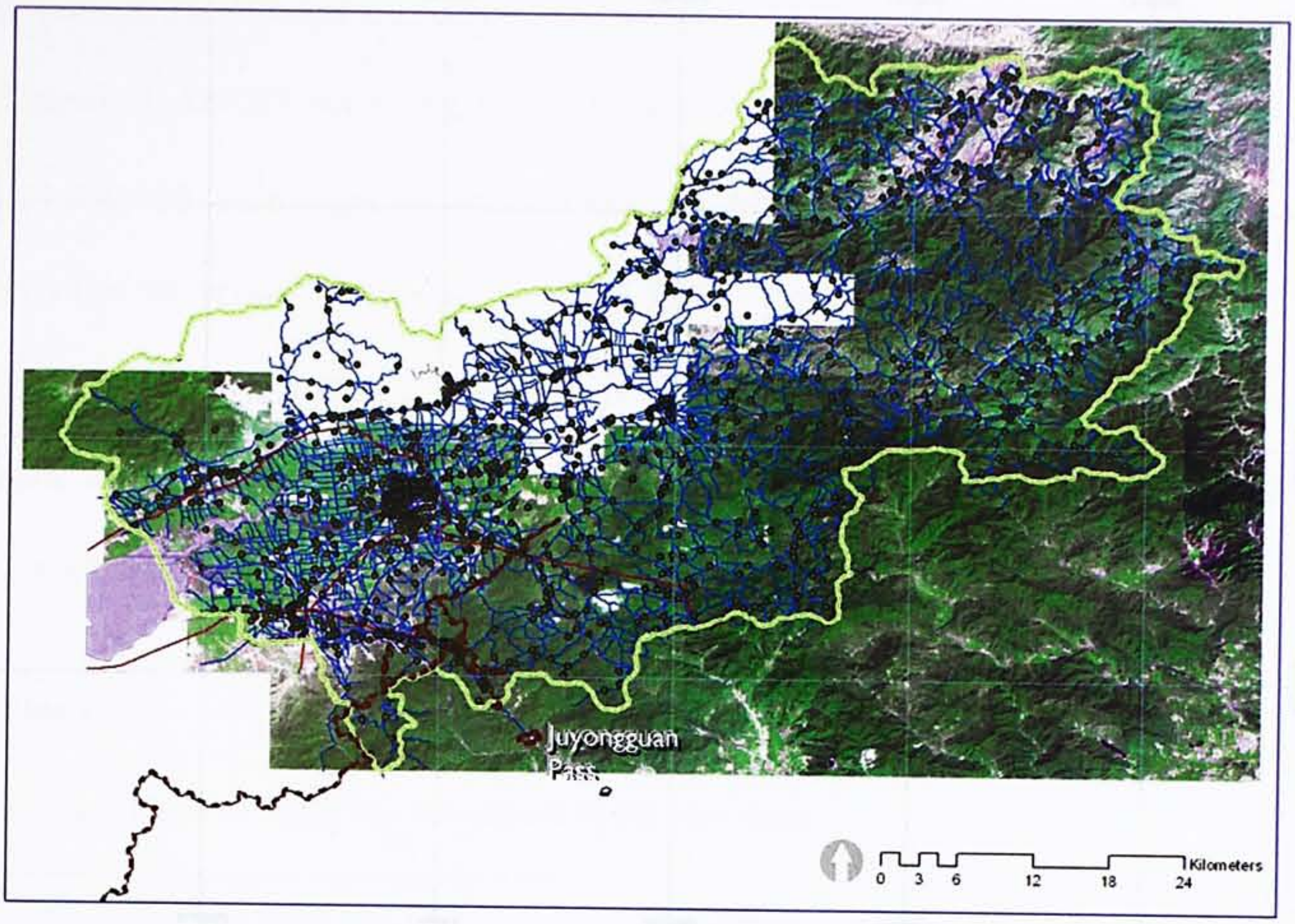


Figure 23

The 1:10,000 MapInfo dataset reference

5.3.2 Historical Reconstructions

For the case study, historical phenomenon must be mapped, including municipal boundaries, towns and settlements, historical land cover and landscape features (such as rivers and water bodies), and, in particular, the location of the Great Wall. Several resources including historical maps and current satellite images are introduced for landscape reconstruction.

Historical maps for large-scale studies

Given that no reliable large-scale digital map of the Great Wall is yet available, it has been necessary to use the traditional mapping method whereby historical paper sheet maps are digitized. The historical maps in *中國歷史地圖集：第七冊（元、明時期）* by Tan Qixiang 譚其驤 (譚 1982) are introduced as background maps, as shown in Table 9. These maps are scanned and projected in Regional Conformal Projections (China) in ArcGIS according to the parameters provided by 滿 (2001). The two 1:21,000,000 scale maps are used to map the Mongolian regions and the scope of activities of several tribes, such as the Oirat, the Tatars, and the Taokou 套寇 (enemies from the Yellow River Loop) (Figure 24). The other maps are employed to mark the local municipal headquarters in Jiubian and to digitize the Great Wall location by reference to the China Great Wall maps drawn by 董 (1988) (Figure 25).

Table 9

Historical maps by 譚 (1982) introduced in this case study

Map contents	Name of map in Chinese	Original page numbers in 譚 (1982)	Time period illustrated in the map	Year	Map scale
Entire country during the Ming Dynasty, 1443 A.D.	明時期全圖一	40-41	宣德八年	1443	1:21,000,000
Entire country during the Ming Dynasty, 1582 A.D.	明時期全圖二	42-43	萬曆十年	1582	1:21,000,000
Shanxi in 1582 A.D.	山西一	54-55	萬曆十年	1582	1:2,450,000
Shaanxi in 1582 A.D.	陝西一	59-60	萬曆十年	1582	1:3,500,000
Near Shuntianfu and the capital	順天府附近	p. 46	萬曆十年	1582	1:2,100,000

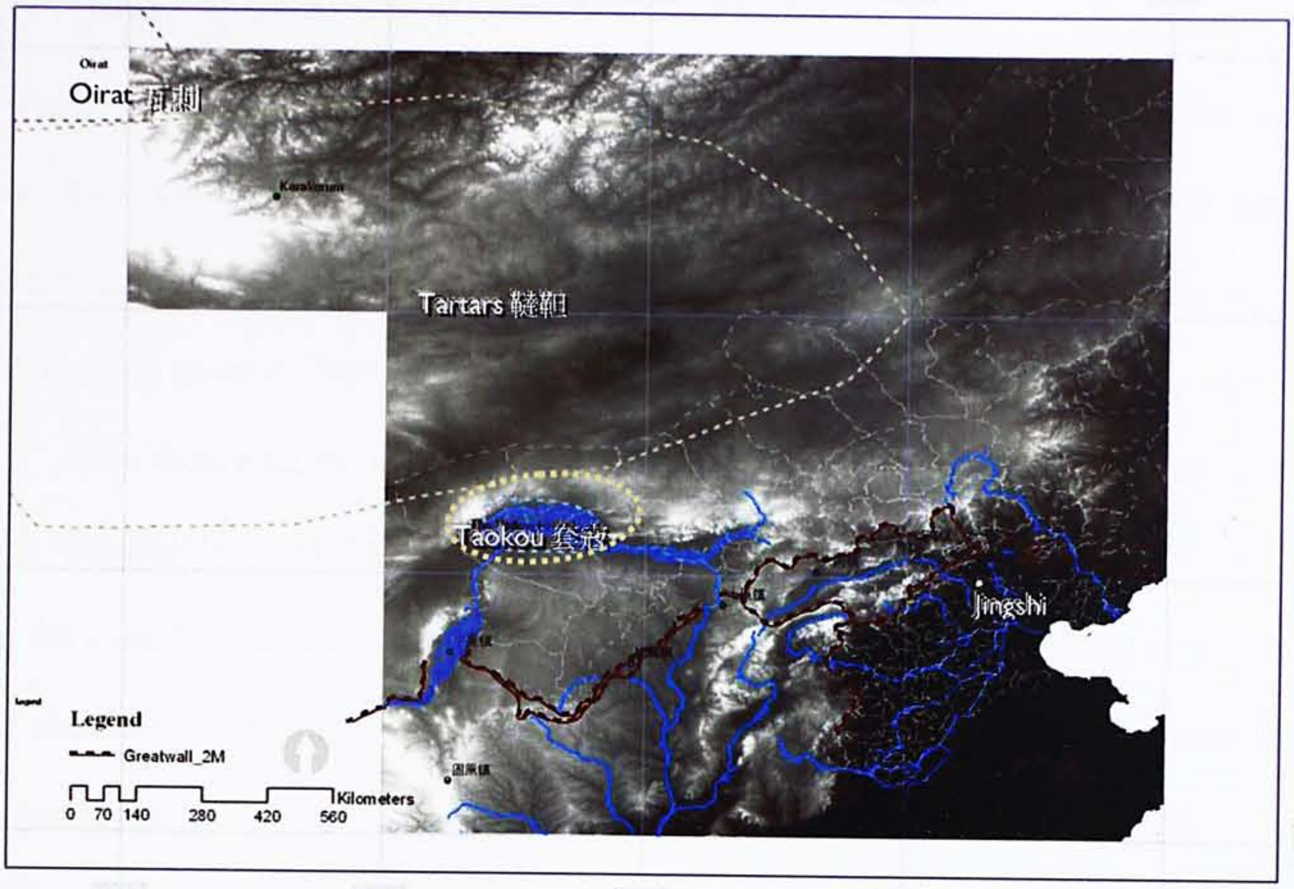


Figure 24

Digitized locations of Mongolia tribes and the Great Wall defensive system in Ming Dynasty around 1582 A.D.

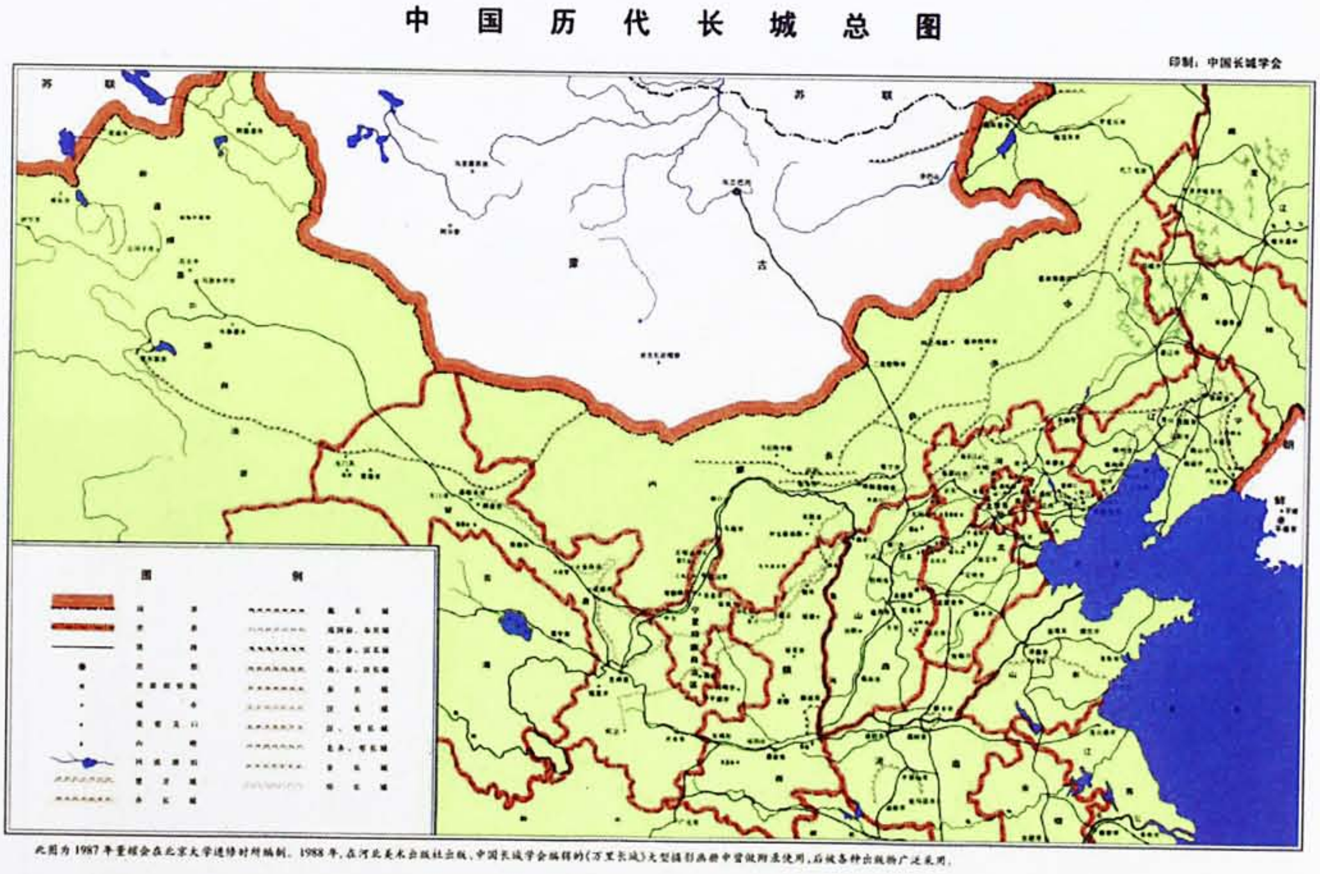


Figure 25

Maps of Great Walls in different historical periods (source: 董, 耀會. 1988. *中國歷代長城圖*. 北京: 中國長城學會.)

Regional scale maps of Great Wall and fortresses

Neither 1:10,000 nor 1:50,000 digital maps provide any information on Great Wall facilities. Other data sources therefore have to be employed to allow for these facilities to be mapped on a more detailed scale. A mosaiced SPOT-5 satellite image of Yanqing taken in 2003 collected from our collaborator is provided for this purpose.

After rectifying the image using ERDAS Imagine software with the reference to the MapInfo data and digital maps, it was found that mapping errors are more serious in the mountainous area. Owing to time and budget constraints, the RS data could not be reordered for reprocessing. Therefore, as an initial step, the Great Walls within the Juyongguan system, the Juyongguan Pass and the Chadaocheng Fortress 岔道城 are all manually interpreted into polylines and polygons based on their relics as shown in the SPOT-5 image. Secondly, these interpreted features are overlaid with TIN and then the walls locations are manually modified to fit the mountain ridges (Figure 26).

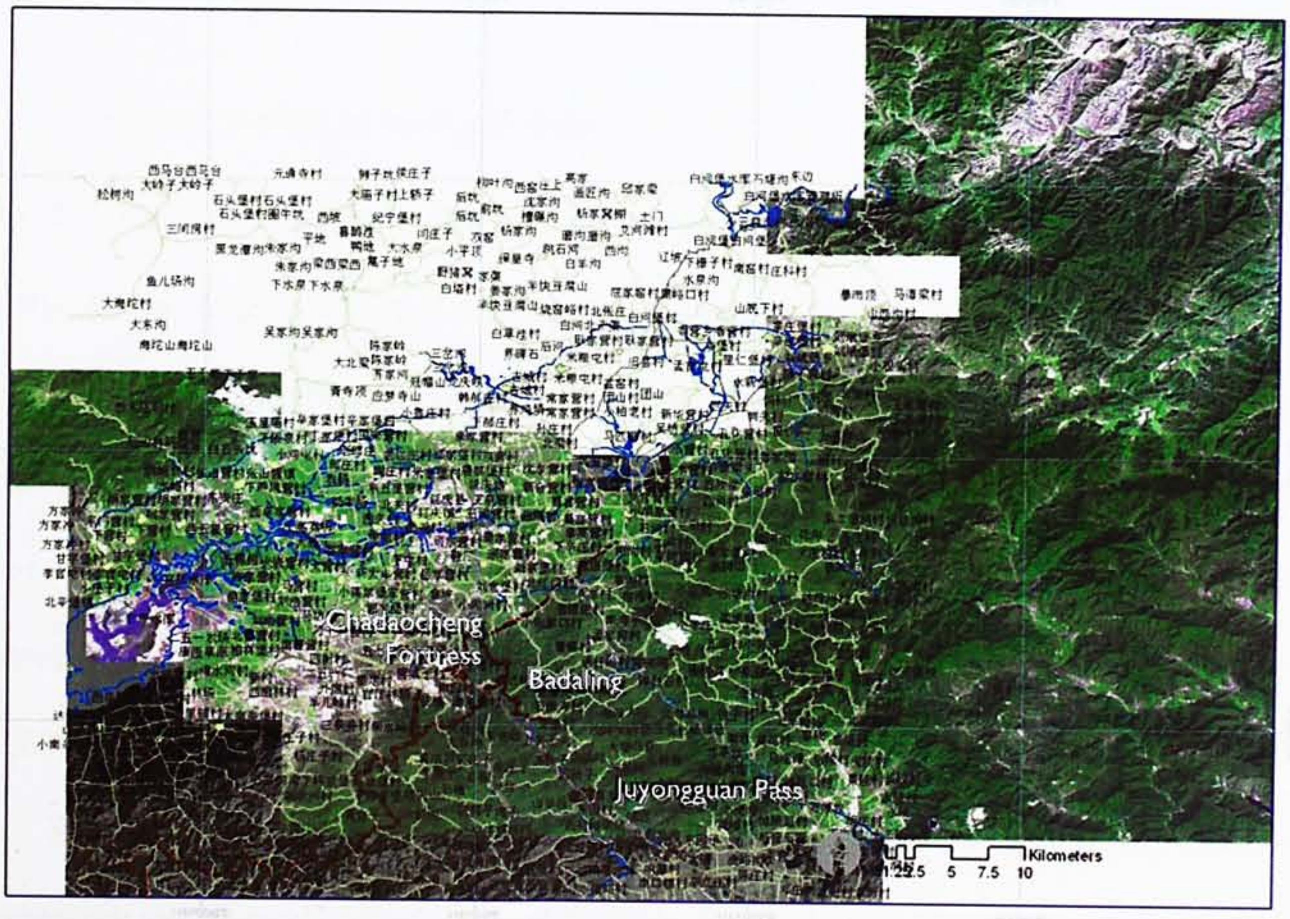


Figure 26

The mosaiced SPOT-5 image, the overlaid dataset and interpreted Great Wall system in the

ArcGIS database

Furthermore, there is no digital map data or RS information available to map the adjacent Great Walls in Huailai. This section of the walls is traced along the ridges on TIN surface through a comparison with the images available from the Google Earth software, which is used as a reference (Figure 27).

Figure 27

The Google Earth illustration of Huailai Great Walls near Hengling 横岭 (left) and the traced location on TIN surface (right)

Reconstruction of land use data

As discussed in Chapter 4, the reconstruction of historical land use data is a very difficult task. Due to a lack of valid resources for mapping historical land cover types such as deserts and swamps in northern China during the Ming Dynasty, only rivers and water bodies are introduced in land-use-based large-scale cost raster mapping. For regional scale maps, a simple vegetation growth model that uses slopes and aspects as biases to classify possible vegetation density is introduced (see Section 5.5.3).

Another problem is the mapping of historical facilities such as small defense fortresses and barracks. One method that can be used is to filter using their modern names such as "fortress 堡," "barrack 營," "castle 寨/屯," "pass 關," etc., and map the historical military towns selected in the ArcGIS database using both 1:50,000 and 1:10,000 scale digital maps. However, after several tests, it was found that effects of these historical places are very limited if they were smaller than a certain size, especially in the plain area in which most of these towns were located. On the other hand, given that the polygon features of these places only reflect their current shape, the definition of certain shapes for these facilities as historical reconstructions is questionable. Even the basic identification question of whether or not these locations are indeed genuine historical facilities associated with the Ming Great Wall defensive system cannot be answered unless sufficient effort can be made in reviewing historical records and implementing site visits. To balance available resources and research objectives, most of the uncertain and smaller historical towns are excluded from cost-surface analysis.

Reconstruction of terrain changes

To demonstrate historical landscape construction, a topography recovery test is carried out in the western foothills of Nankou 南口, the southern end of the Pass Valley. This is a limestone mining area. Because the southern foothills of Jundushan Mountain 軍都山 are almost in a straight line and have similar slopes, the reconstruction refers to its neighboring terrain and recovers the contours into natural shapes beyond the current mining surfaces (Figure 28).

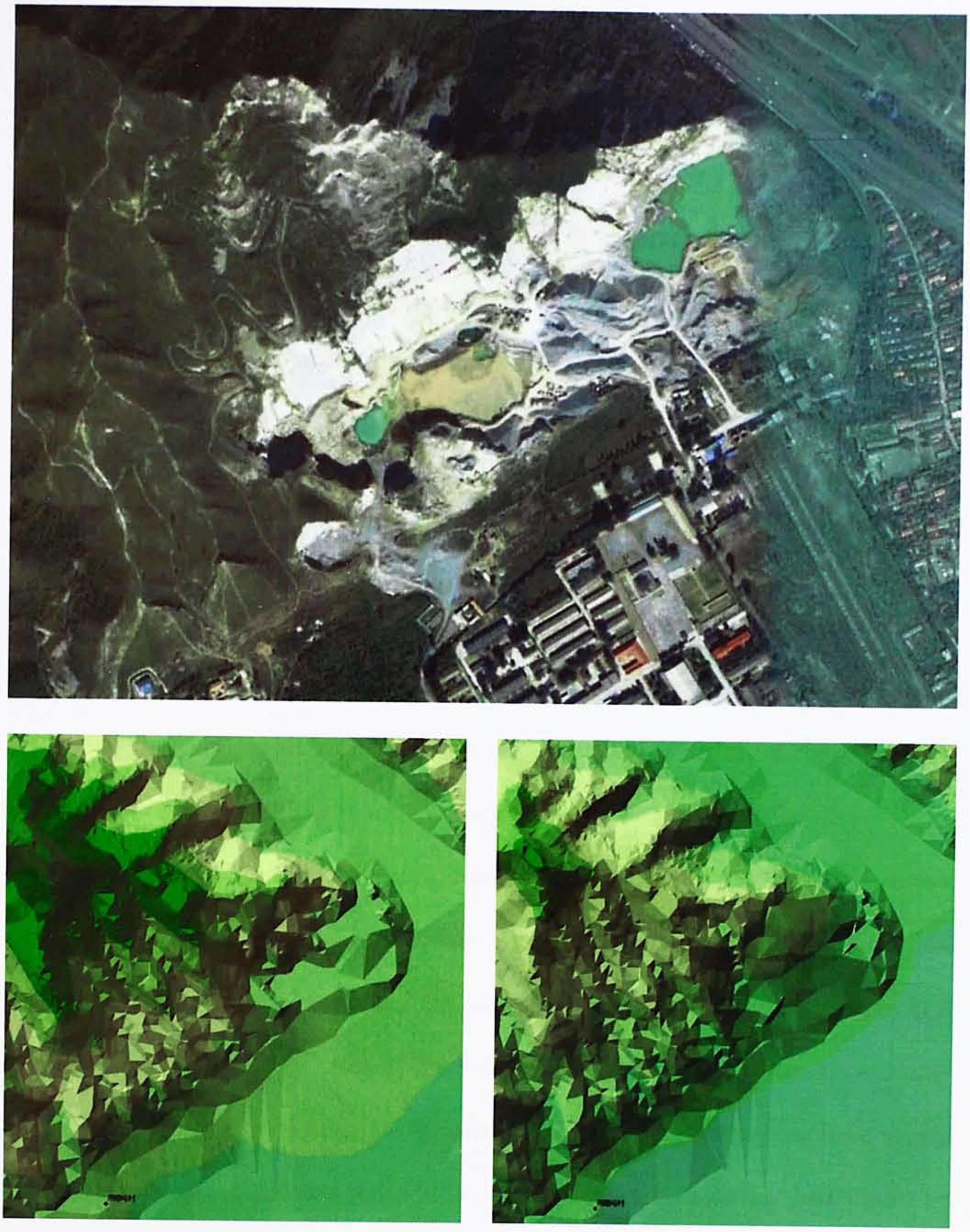


Figure 28

Reconstruction of foothills near Nankou: the remote sensing image of the limestone mining area in Google Earth (above); the terrain derived from the original digital topographical map (left bottom) and the reconstructed terrain (right bottom)

5.4 Large-scale Analyses

The large-scale case study is aimed at replicating the threat posed by northern nomads and associating this threat with the military function of the Great Wall to investigate the authenticity of this possible “military-trading” cultural route (馮, 程, and 徐 1995; 金 1985) as the north frontier during the Ming Dynasty. The methodology used for the large-scale study firstly involves the use of cost-surface analysis to locate possible invasion routes, followed by overlaying the strategic military facility locations of the Great Wall defensive system to assess their distribution and construction rationales in the face of the threat of invasion.

5.4.1 Cost-surface Modeling

The large-scale cost-surface analysis introduces terrain, slopes and land use frictions to calculate the least cost corridor. The combined and resampled DEM is employed directly as the topographic surface, and the slope surface is derived directly from the original 3-arc-second surface to improve accuracy.

It should be noted that horizontal forces that are usually caused by cities, towns, fortresses and other military facilities may not work effectively in this low analytical resolution. The effects of historical towns cannot be mapped because the physical defensive performances of most of these point-shaped towns or fortresses are only one or two cells in size. Several CSA experiments in this particular case have shown that value changes in isolated cells within a homogenous cost surface had almost no effect on the analytical results. The horizontal factor is therefore disregarded at this stage of the study.

Furthermore, as mentioned in the previous section, the lack of landscape reconstruction data sources means that a very limited number of features can be considered in constructing land use surfaces. Only hydraulic features and the Great Walls are mapped on the basic cost-of-passage surface.

Land use reclassification

As suggested by Chapman (2006), the use of hydraulic analysis to recover historical streams is more reliable than simply using current river maps. The large-scale case investigation uses the "Stream" analysis function of ArcGIS to determine the size of rivers, which may have caused difficulties in military marches. Stream order is defined using the Strahler format. Stream levels are then reclassified to transverse costs from 1 to 9. Since Mongolian invasions always occurred between autumn and winter, large water bodies may not have caused the same difficulties as cavalry barriers in other seasons. Therefore, large lakes and ponds are assigned a cost of 5. The leveled hydraulic system map is then compared with both the historical maps and current water bodies' location and the cost-relevant hydraulic features are eventually mapped as Figure 29

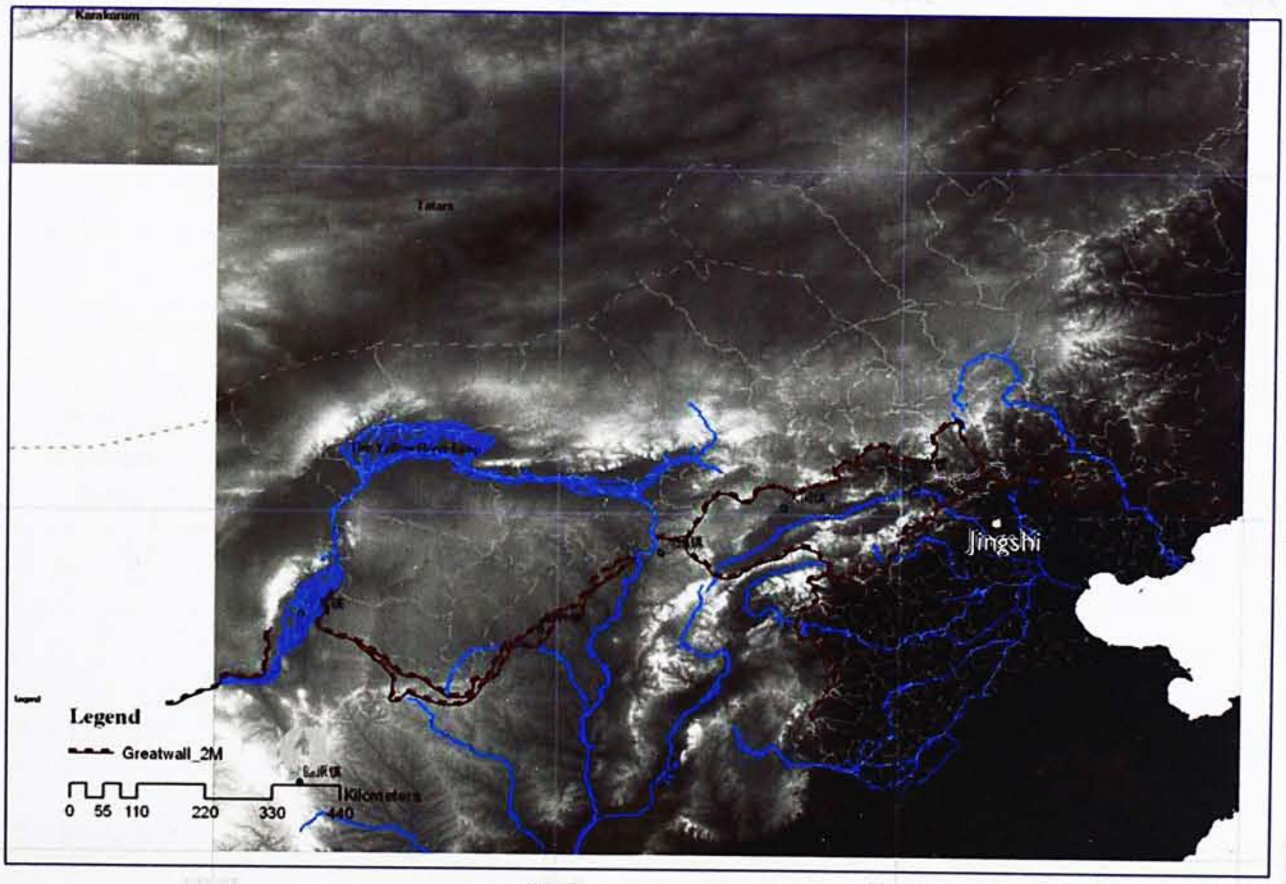


Figure 29

The DEM and hydraulic features of the large-scale study region

Cost of the Great Wall

Great Wall location cells are assigned a cost of 10. However, experiments carried out in this case study indicate that because the wall is only one cell in width, variations in value are highly possible to be overlooked in the isotropic algorithm. Therefore, a cost distribution system that reflects the performance of these facilities in a more comprehensive manner is introduced in this case study. Firstly, viewsheds of the entire length of the Great Wall is calculated to replicate the observatory function. The visible areas are then reclassified according to different buffer distances to reflect more detailed military performance, as shown in Table 10. The final cost-of-passage surface is overlaid by combining the costs of streams and defensive abilities for the model used to investigate defensive performance after the construction of the Great Wall. Other cells that do not belong to either of these two categories are assigned costs of one and any cell with an initial cost higher than ten is reassigned a cost of ten (Figure 30).

Table 10

Visual distance range of Great Walls for defensive range classification

Visual distance (km)	Cost value	Rationales
0	10	The wall itself and locations within 500 meters of the wall, where various defensive fixtures are located and there is firearm cover All areas including invisible cells in this range are assigned a cost of 10
$0 < D < 2$	5	Locations still within shooting range of heavy cannons like 1-2# 佛朗機 (see 茅 (1621)) or 紅夷炮 used by Ming defense troops
$2 < D < 10$	3	Sensitive in term of observation in most weather conditions (Higuchi 1988) and locations where small groups of troops with 10 horsemen can be recognized at an angle$_h$ of12’
$10 < D < 20$	2	Ordinary observable distance (Higuchi 1988)
$20 < D < 45$	1	Observable distance in good weather (Higuchi 1988)

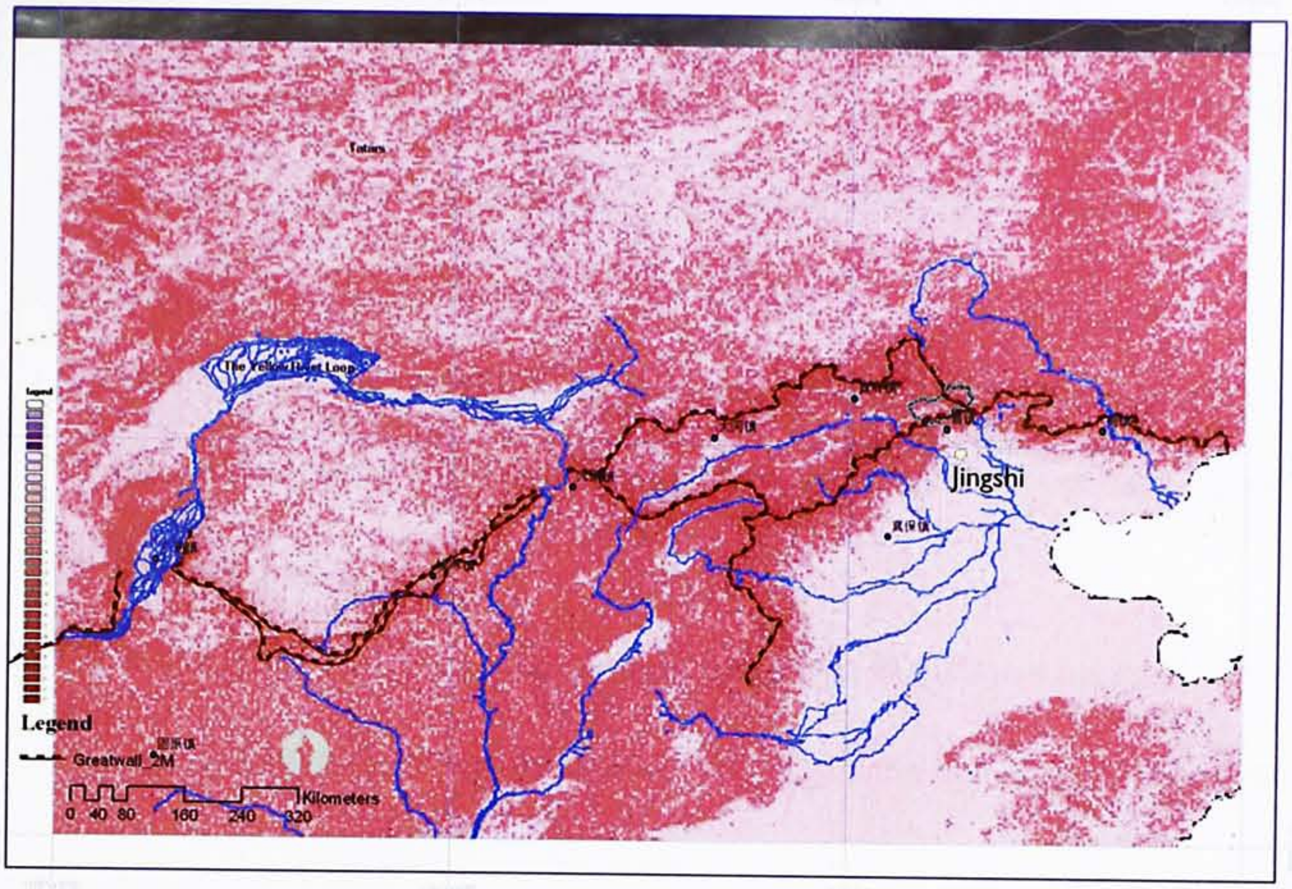


Figure 30

Basic cost-of-passage map with Great Wall defensive cost of large-scale cost-surface analysis

5.4.2 Invasion and Defensive Interpretations

This case study compares two models, one with Great Wall costs overlaid on the land use cost-of-passage raster, and the other without. Each model is used to locate corridors from typical Mongolian troop bases in Oriat, Tatar and Yellow River Loop areas to several key defensive regional headquarters, including Yulin and Datong, which is directly in the path of attacks and lacks any natural barrier, Xuanfu 宣府, which is a barrier for the capital area, and the final destination of Jingshi.

Mongolia attacks if the Great Walls not exist

Several obvious corridors can be found in a series illustration from Figure 31 to Figure 34. These maps show the fact that Jingshi was threatened from both the north and the east. Three possible routes for invasions from the Yellow River Loop are set after entering the north defense line:

1. The northern route entered in the Zhangjiakou 張家口 area that passed through Xuanfu and Huailaiwei 懷來衛 into the Yanqing Plain, then went through the Juyongguan Pass area to Jingshi.
2. The middle route was the least-cost selection and involved an invasion entering Wanquanyouwei 萬全右衛 before passing through Xuanfu and overlapping with the northern route.
3. The southern route may invaded through Yanghewei 陽和衛 and passing through Zhenluwei 鎮虜衛 and Wanquanzuowei 萬全左衛 through a river valley, and assembled at Xuanfu with the other roads.
4. They also could be another route passed through Datongyouwei 大同右衛 and went along Sanganhe River 桑乾河 to Huailaiwei. However, the cost of this route was much higher.

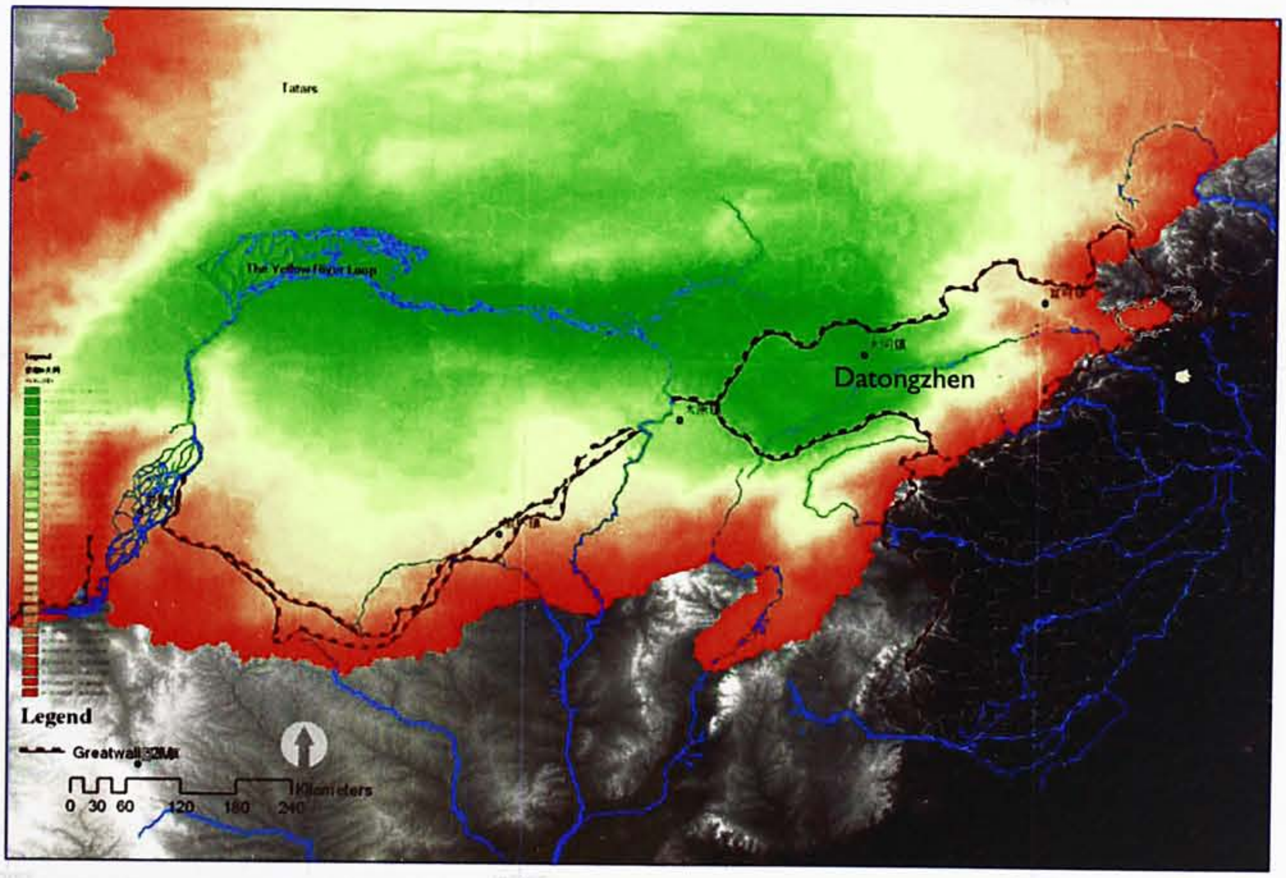


Figure 31

Routes of Taokou invading Datong in traverse cost value up to 25 units

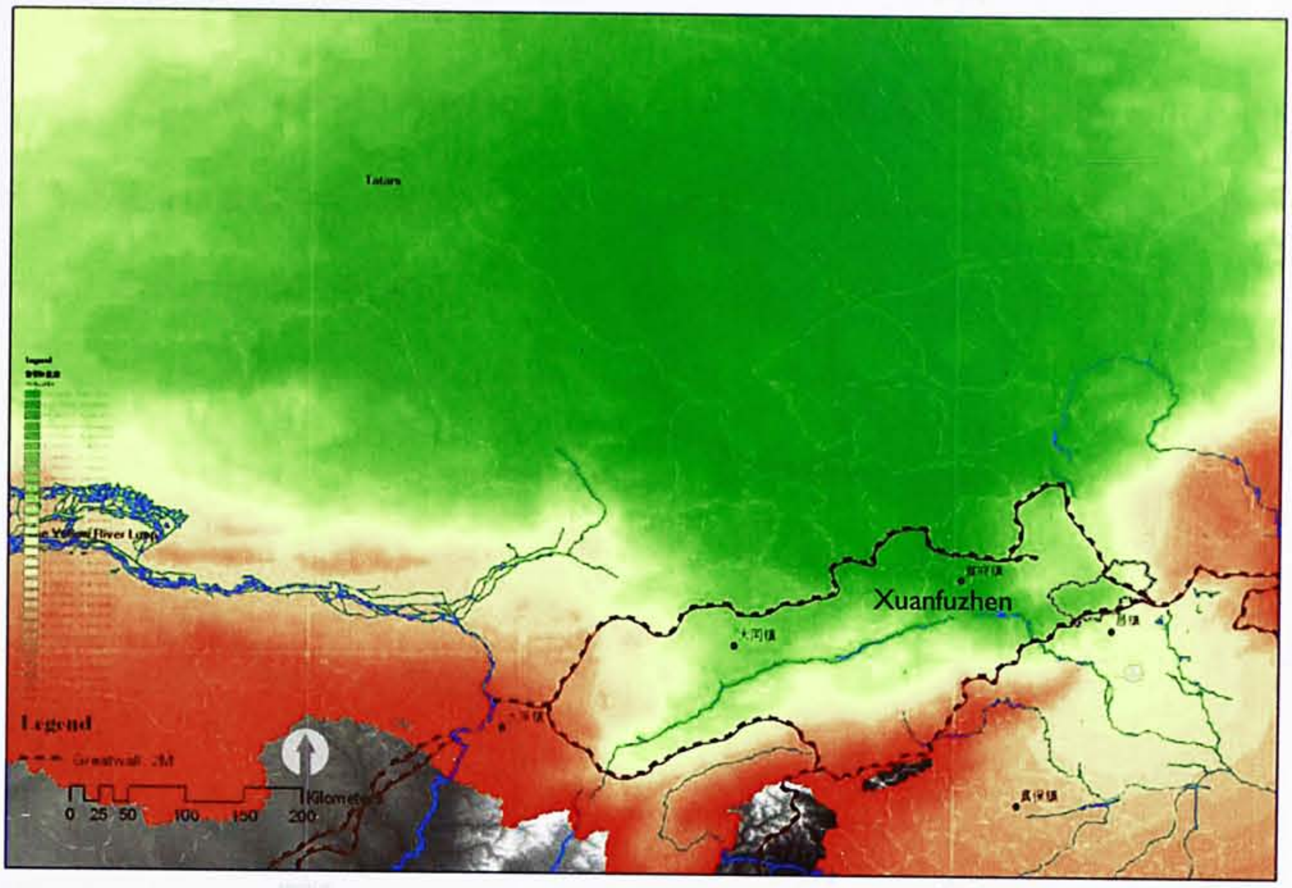


Figure 32

Routes of Tatars invading Xuanfu in traverse cost up to 25

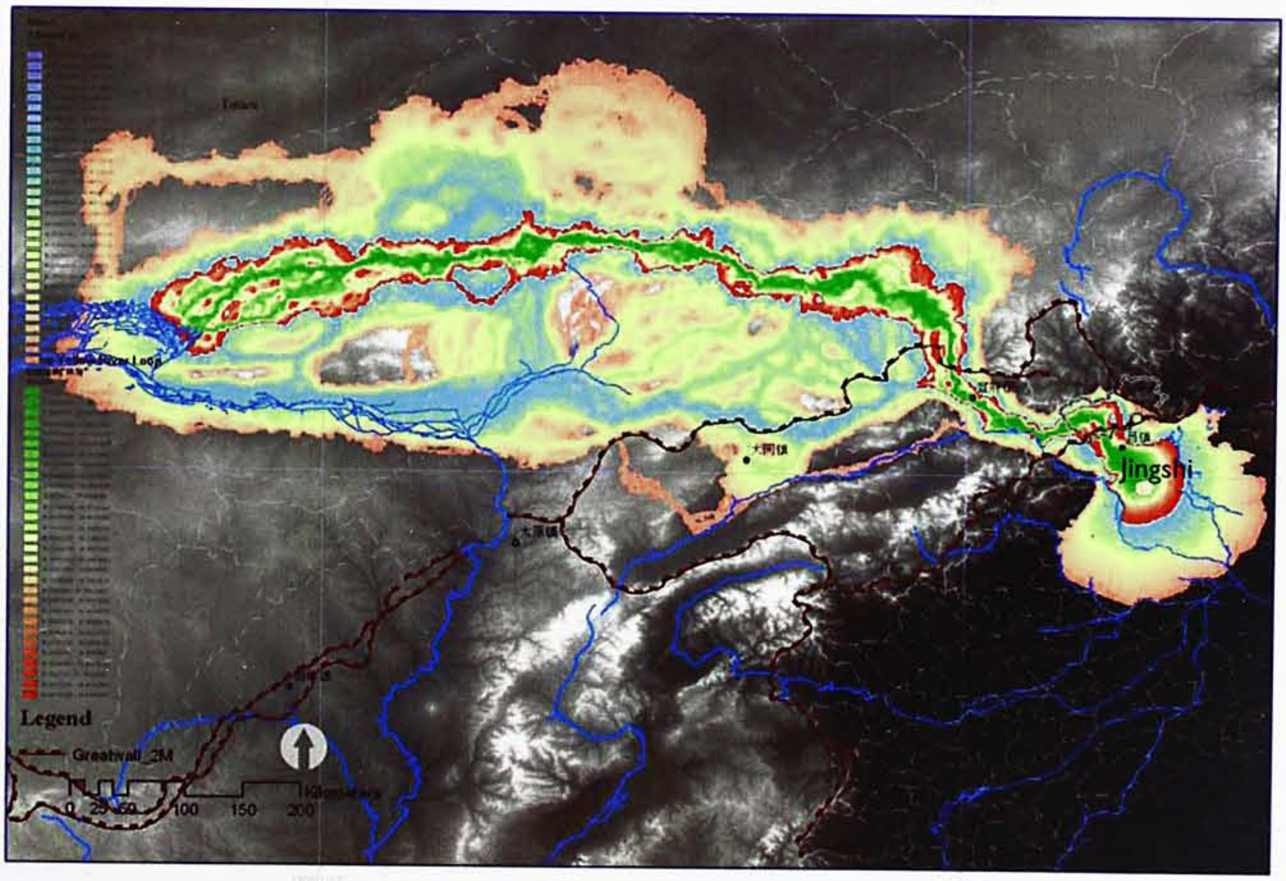


Figure 33

Taokou invading Jingshi through the least-cost corridor in traverse cost lower than 18.5 and other alternative routes in cost up to 20 (the fade colors areas)

The Tatar invasion route also followed the same trail as the Taokou inside the Ming border. An alternative route was to enter Dushibao 獨石堡 before going on to the Yanqing Plain. All the most probable invasion trails are concentrated within a limited area (Figure 34). This is one of the reasons that two layers of Great Walls were constructed in a northward direction of the capital.

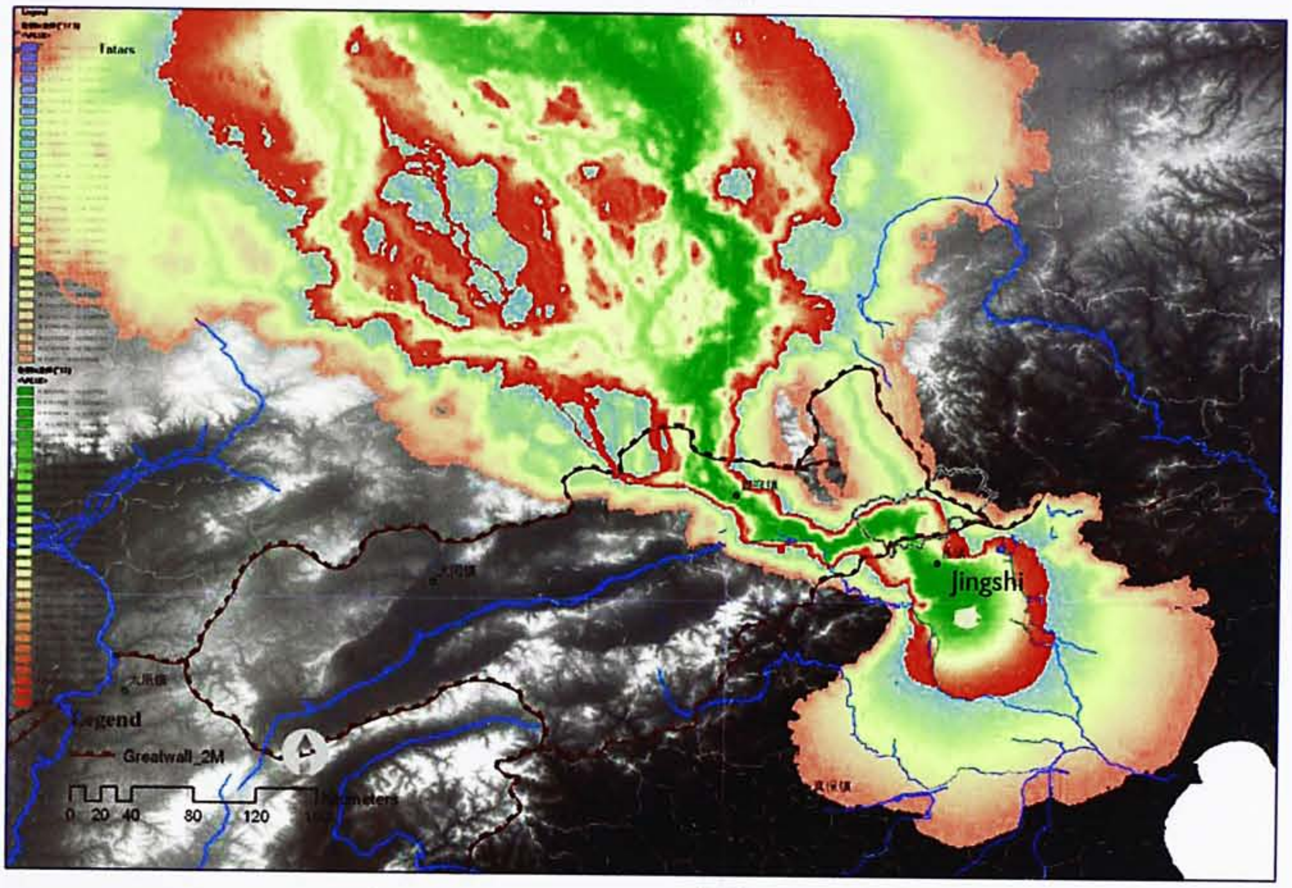


Figure 34

Tatars invading Jingshi through the least-cost corridor in traverse cost lower than 13 and other alternative routes in cost up to 15 (the fade colors areas)

Mongolian attacks after the construction of the Great Wall

Comparing the accumulative cost maps calculated using the different models, it can be seen that one function of the Great Wall may had been to force invasion troops to switch to a higher-cost route and to limit the enemy's access to an area up to more than 100 kilometers north from the original accessibility (see

Figure 35 to Figure 38, and comparison with Figure 39 and Figure 40 to Figure 31 and Figure 32). Moreover, cross-comparison of the analytical results (Figure 42, Figure 44) with the maps produced by Waldron (1990) (Figure 41, Figure 43), partially proves the validity of this cost-surface analysis.

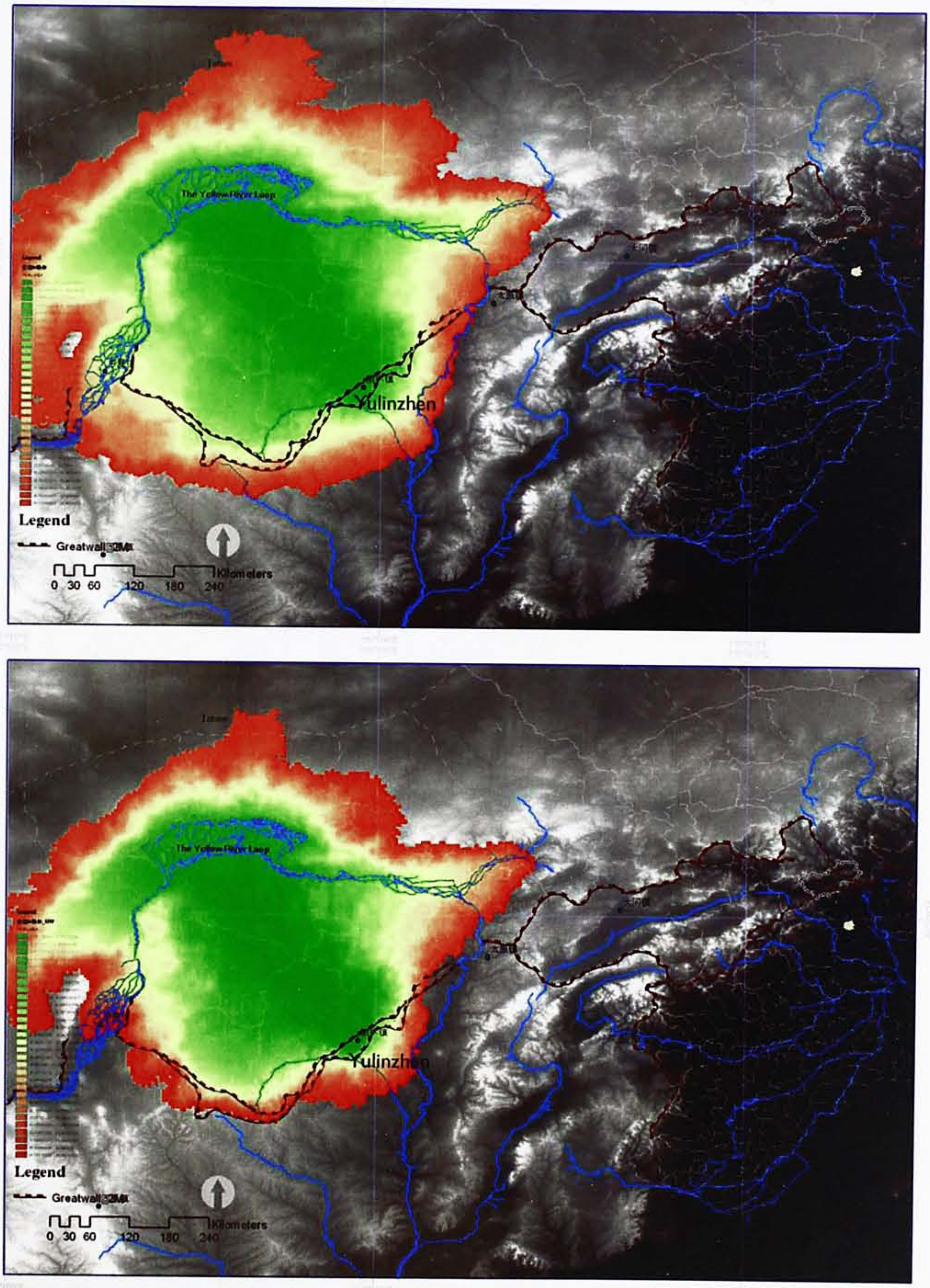


Figure 35

Routs and expenditures comparison of Taokou invading Yulin under the circumstance either without the Great Walls (above, up to 15) or with the Great Wall defensive activities (bottom, cost up to 15)

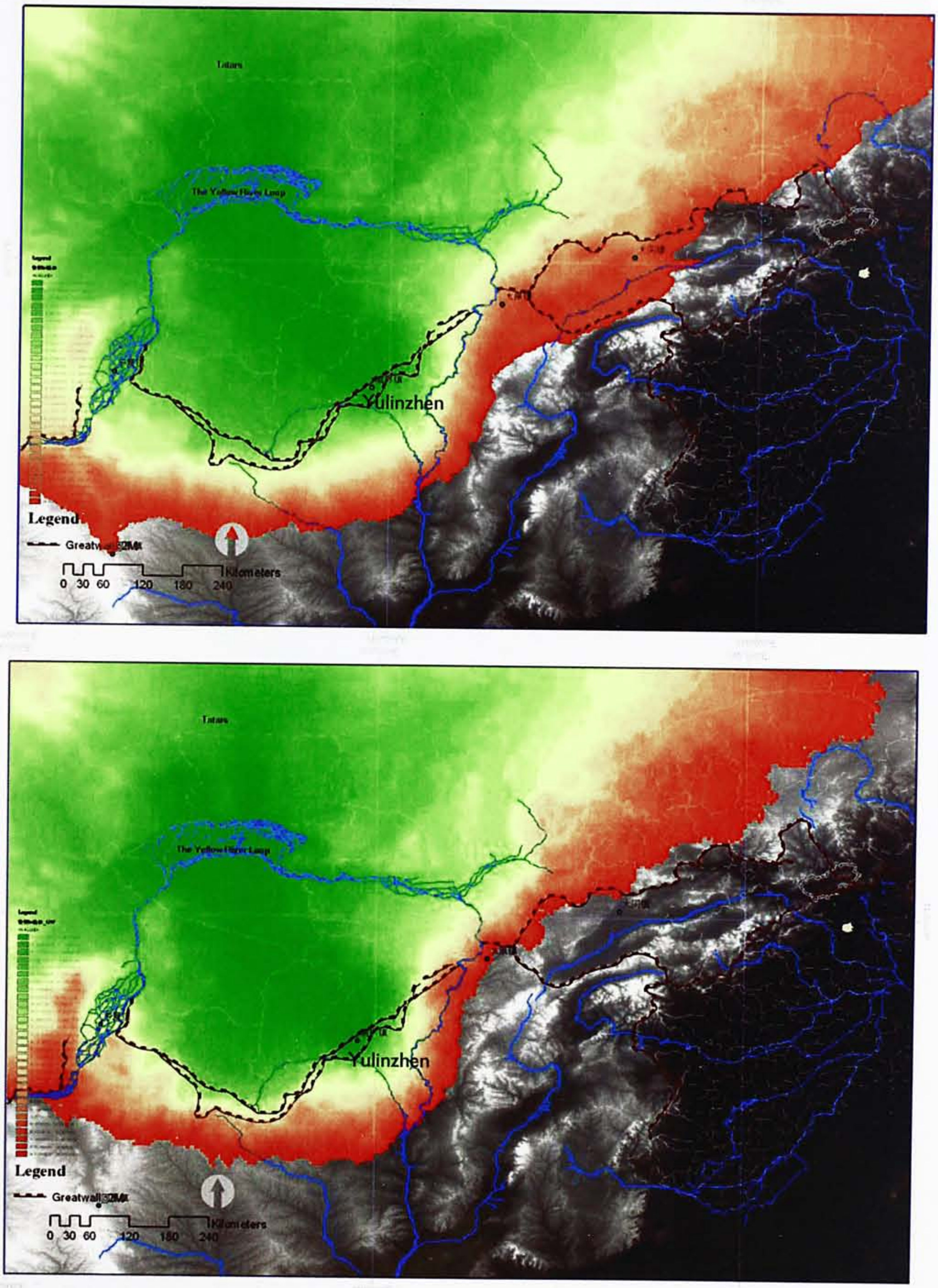


Figure 36

Routs and expenditures comparison of Tartars invading Yulin under the circumstance either without the Great Walls (above) or with the Great Wall defensive activities (bottom) both in cost up to 15

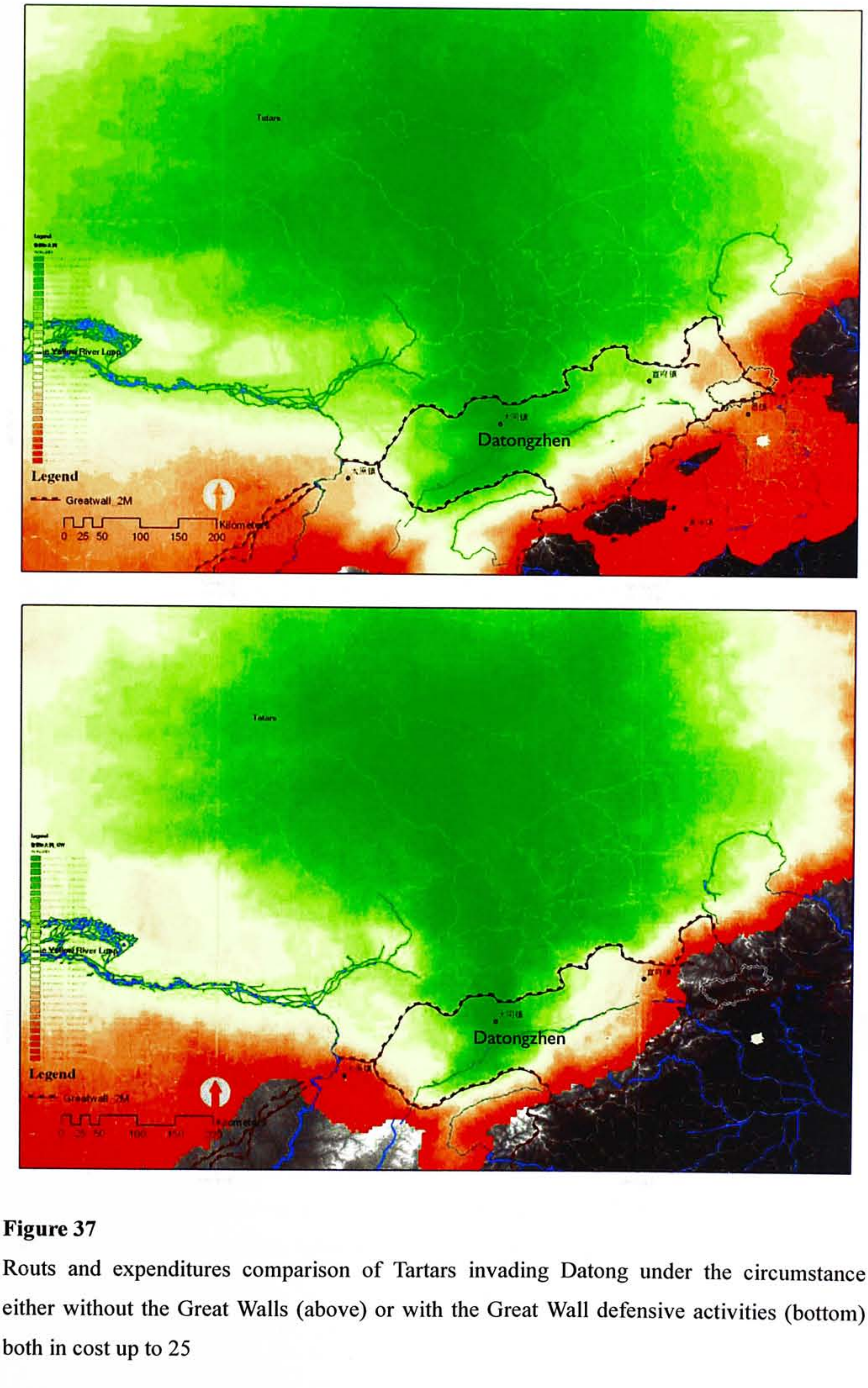


Figure 37

Routs and expenditures comparison of Tartars invading Datong under the circumstance either without the Great Walls (above) or with the Great Wall defensive activities (bottom) both in cost up to 25

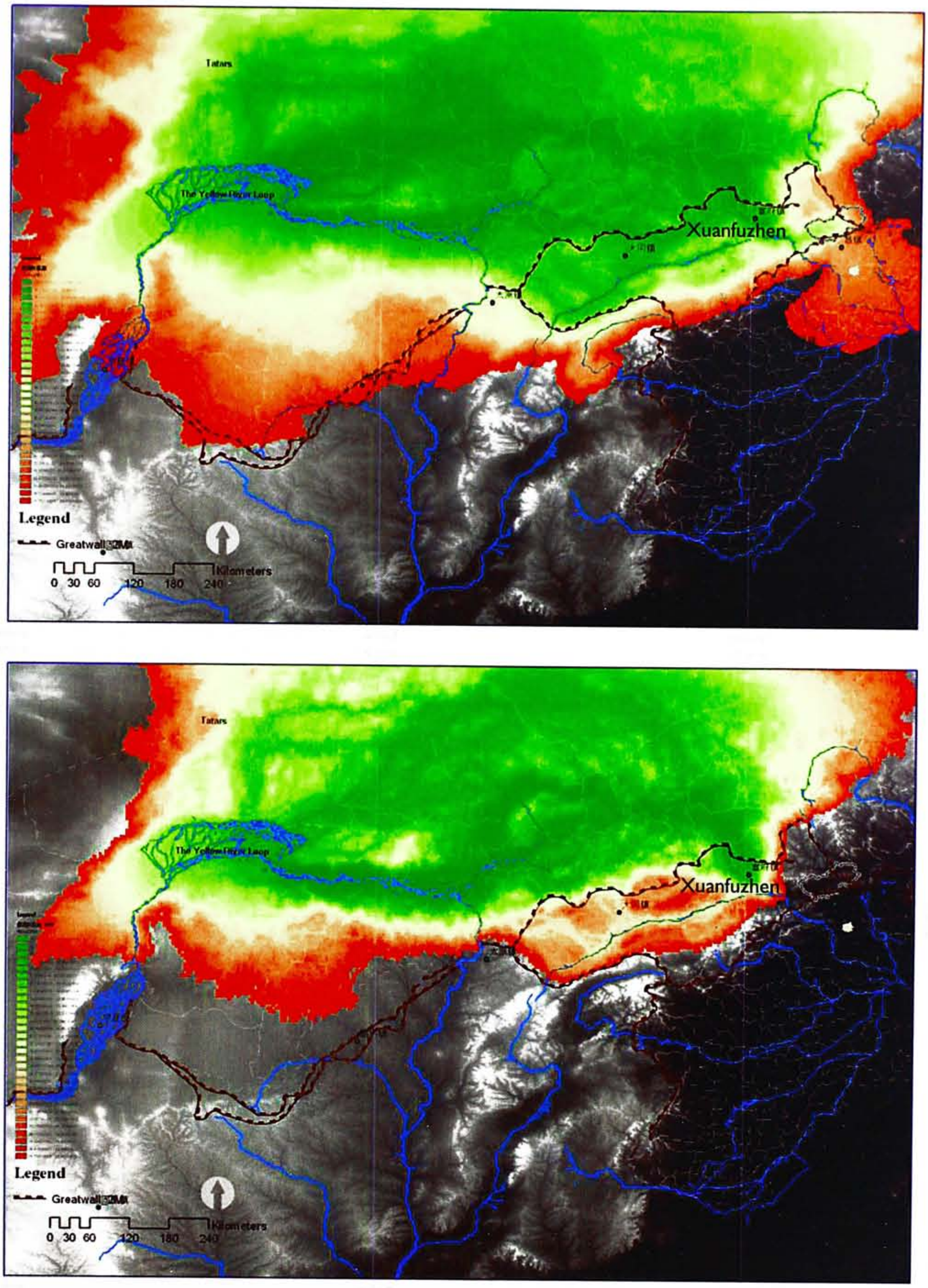


Figure 38

Routs and expenditures comparison of Taokou invading Xuanfu under the circumstance either without the Great Walls (above) or with the Great Wall defensive activities (bottom) both in cost up to 25

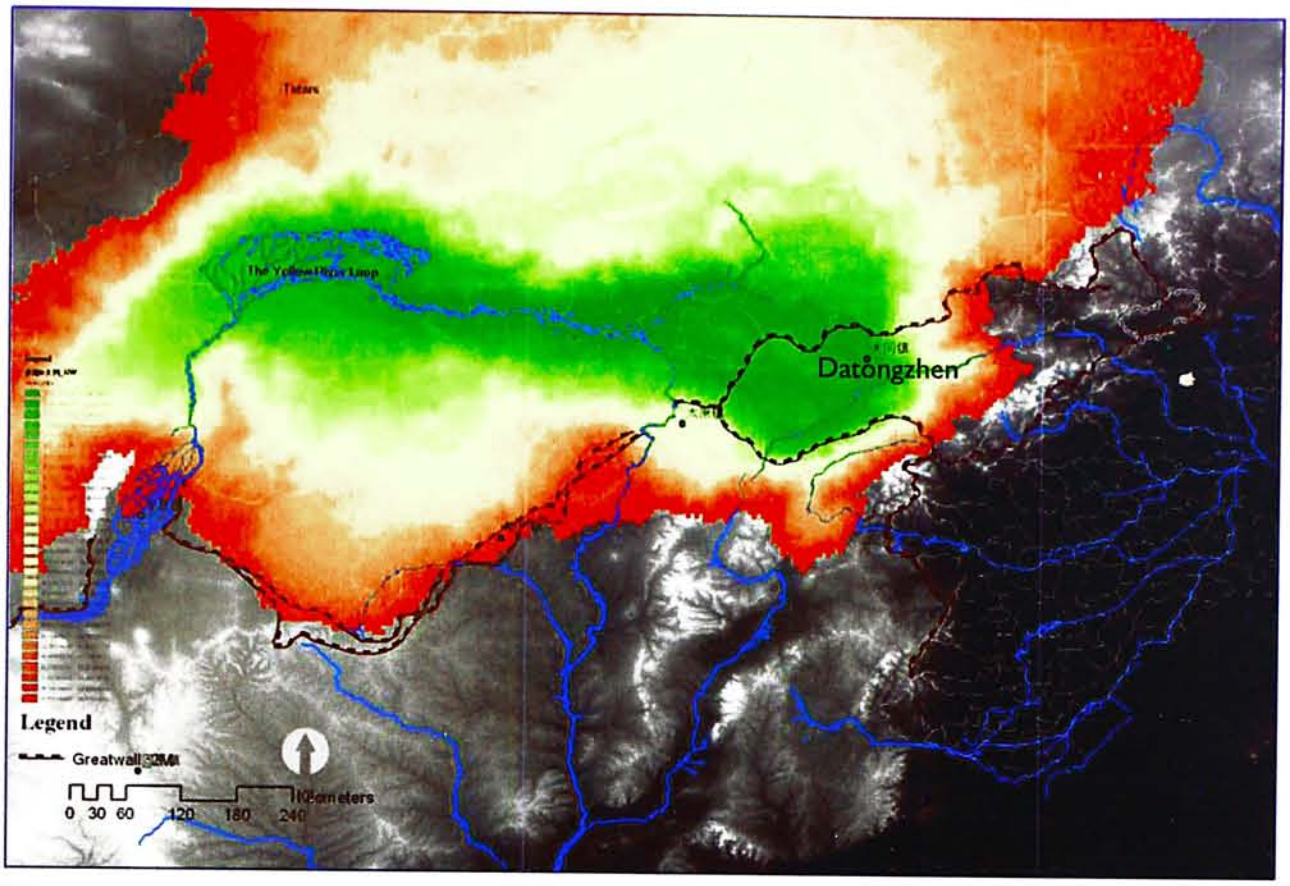


Figure 39

Routes of Taokou invading Datong after the construction of the Great Wall in traverse cost up to 25

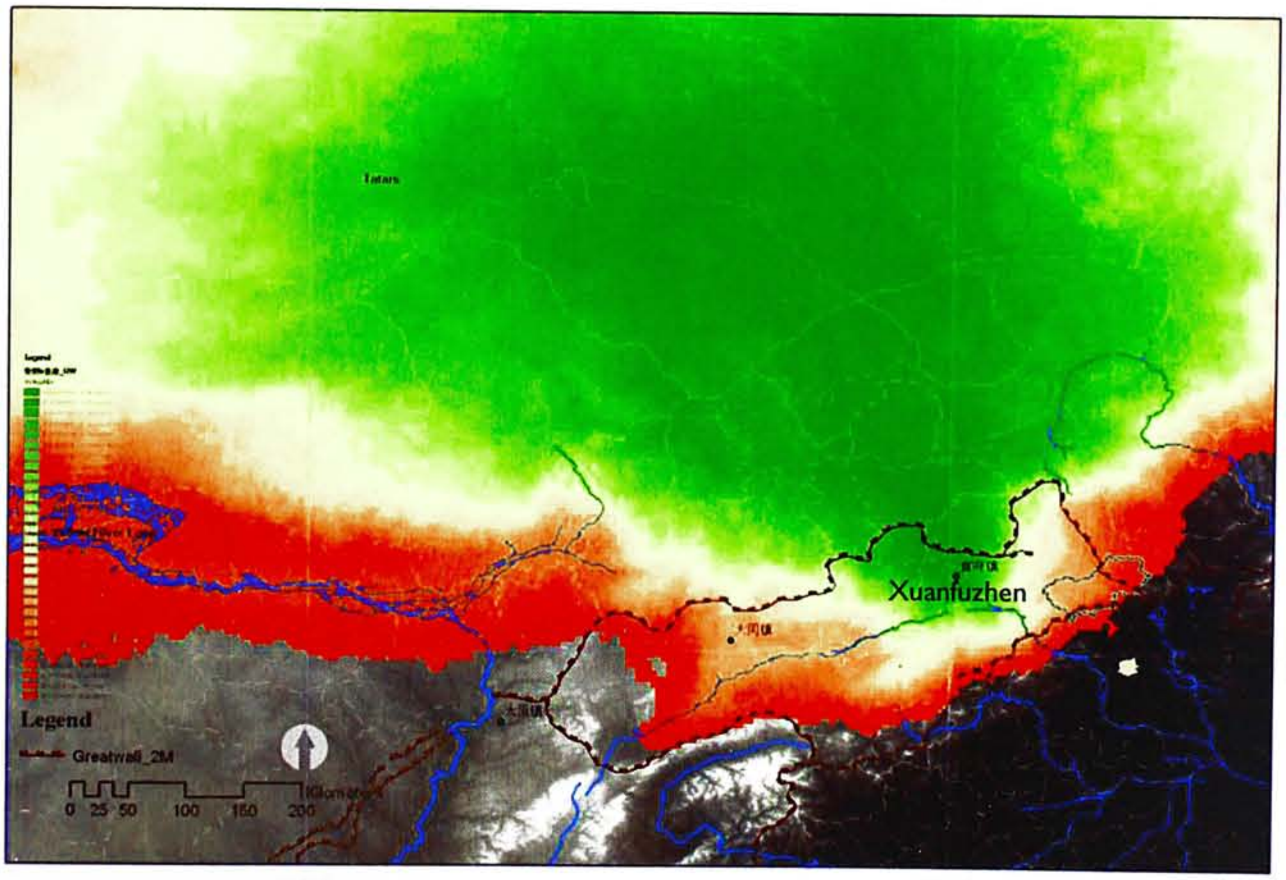


Figure 40

Routes of Tartars invading Xuanfu after the construction of the Great Wall in traverse cost up to 25

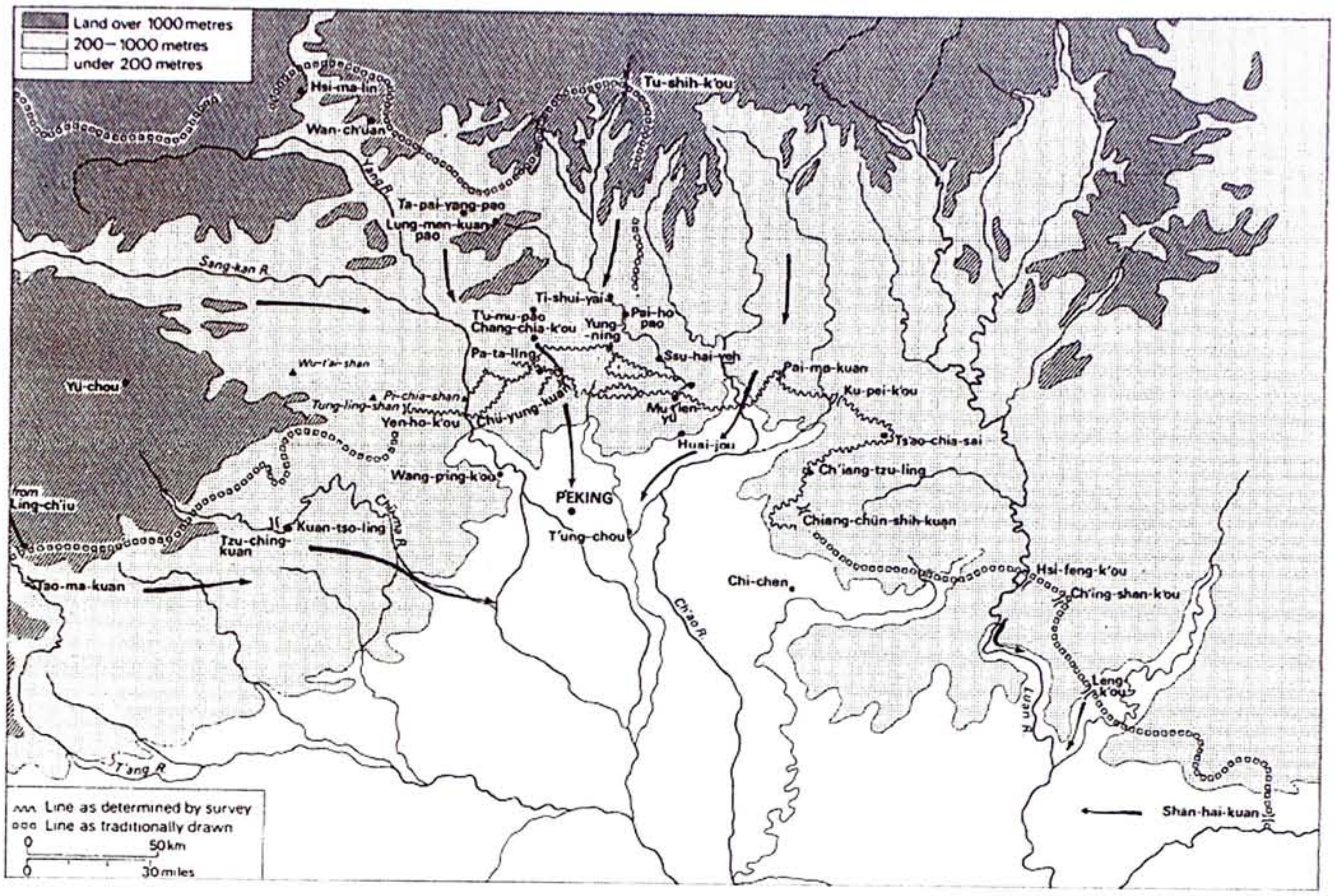


Figure 41

Inner defenses of Jingshi (source: Waldron 1990, Map 7)

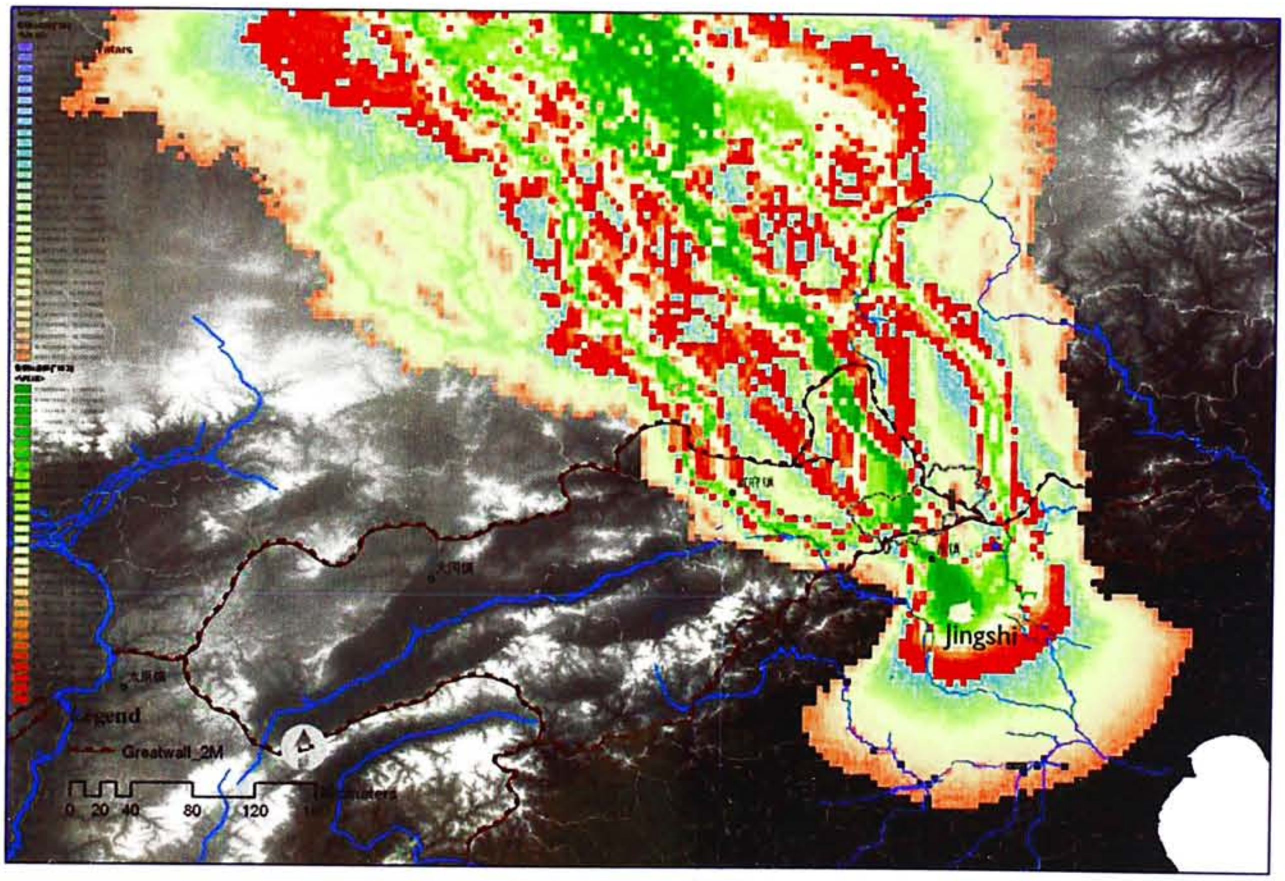


Figure 42

Tatars invading Jingshi after the construction of the Great Wall through the least-cost corridor in traverse cost lower than 18.5 and other alternative routes in cost up to 20 (the fade colors areas)

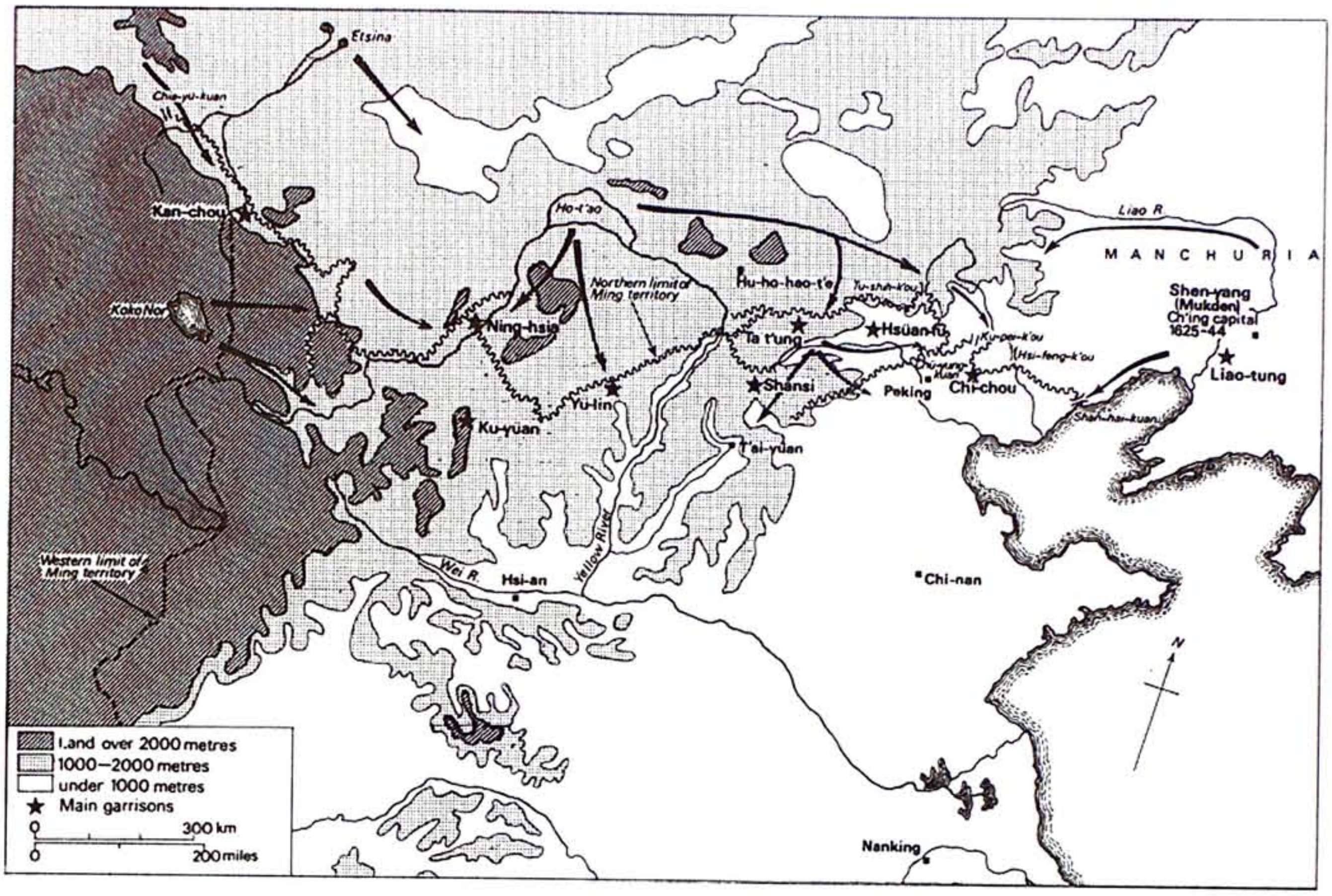


Figure 43

The late Ming defense line (source: Waldron, 1990, Map 8)

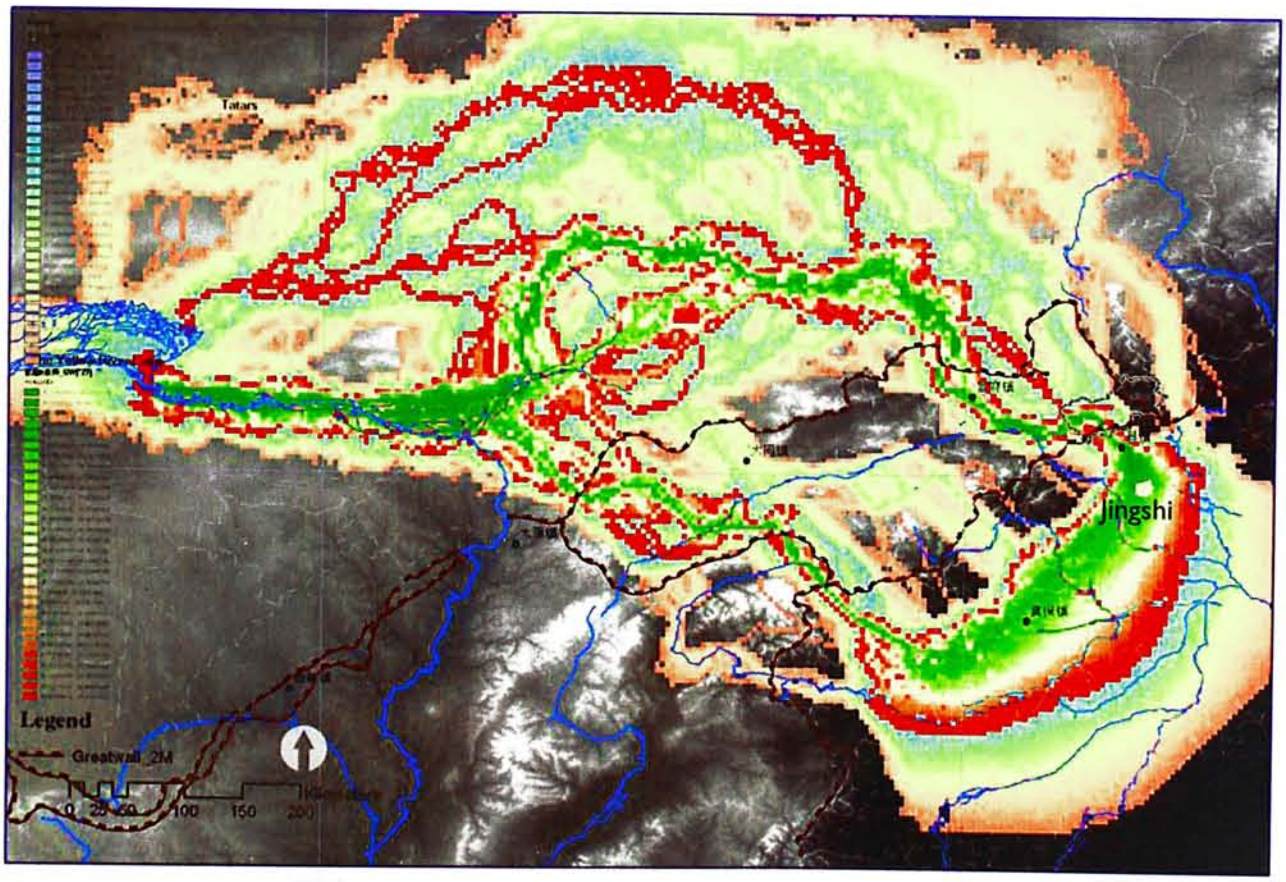


Figure 44

Taokou invading Jingshi after the construction of the Great Wall through the least-cost corridor in traverse cost lower than 27 and other alternative routes in cost up to 28.5 (the fade colors areas)

Because the Tatars' attacks were launched from immediately north of the capital, the cost of invasions carried out on such routes increased and more scattered in terms of location because of the unification of passage-costs after the Great Wall defensive system was facilitated (see comparison between Figure 34 and Figure 42). The Dushikou approach became more preferable because the costs along this route are even less than the original route through Xuanfu. The double-layer Great Wall defenses even pushed the attack to take a detour near Mutianyu 慕田峪 and passing Miyun 密雲 in order to avoid the extra walls which caused more expenditure than traversing through rough topographies (Figure 42).

The invasion paths that started from the Yellow River Loop were also scattered tremendously into a very broad extents across the Outer and Inner Walls. Although like the Tartar's case, the location of the original optimum route remained unchanged, there suppose to be another route in similar transverse costs by breaching the Outer Wall near Weiyuanwei 威遠衛 and Datongyouwei, passing through the Inner Wall around Dashikou 大石口 and Pingxingguan Pass 平型關 and move northward along Taihang Mountain 太行山 hill foots to attack the capital. Other possible invasions may break the Inner Wall at either Zijingguan Pass 紫荆關, Daomaguan Pass 倒馬關 or along the Hutuohe River 滹沱河. The reason the North China Plain was protected by an extra Great Wall that ran north-south becomes obvious (see the comparison between Figure 33 and Figure 44).

5.5 The Juyongguan Pass Study

Both the historical literature and modern studies declare that Juyongguan Pass is the "Key to the Northern Entrance 北門鎖鑰" to the capital. Its strategic location is also illustrated by the large-scale analyses from the perspective of the entire northern frontier. Controlling the Pass Valley, which is one of the "Eight Routes Through Taihang Mountain 太行八徑," Juyongguan Pass is the most important passageway among the "Three Inner Passes 內三關" of the Inner Great Wall which protected the capital from direct threats of invasion (Figure 45). During the Ming Dynasty, a system of five defensive layers was established along the frontier in the Pass Valley, including Nankou Fortress 南口城 (the Southern Opening Guiding Fortress), Juyongguang Pass 居庸關關城 as the defensive headquarters, Shangguan Fortress 上關 (the Upper Pass), the Badaling Great Walls 八達嶺長城, and Chadaocheng Fortress 岔道城 (the Guiding Fortress of Branch Roads), which ran from south to north along the entire valley (胡 2000) (Figure 46, Figure 47, Figure 48). There is another layer of the Great Wall in made of earthen material 土邊 (Tubian) north of the Badaling Walls and a series of beacons (Nanshanliandun 南山聯墩, the Beacon Line of South Mountain) even further north along the foothills, which offered extra military depth and protection (see Figure 48).

Figure 45

Juyonglu Area 居庸路 illustrated by 劉 (1576)

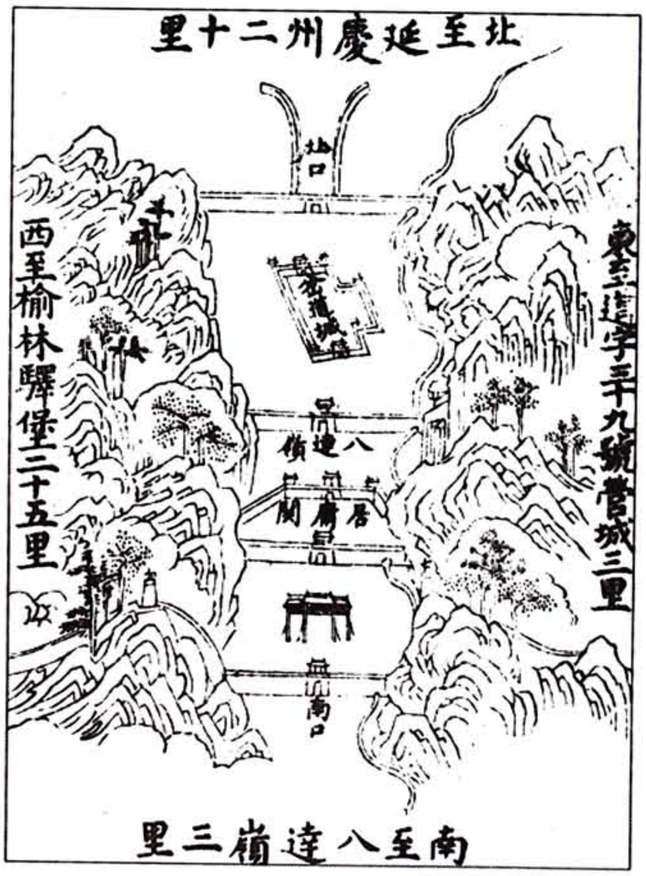


Figure 46

The Juyongguan defensive system map illustrated by 茅 (1621)

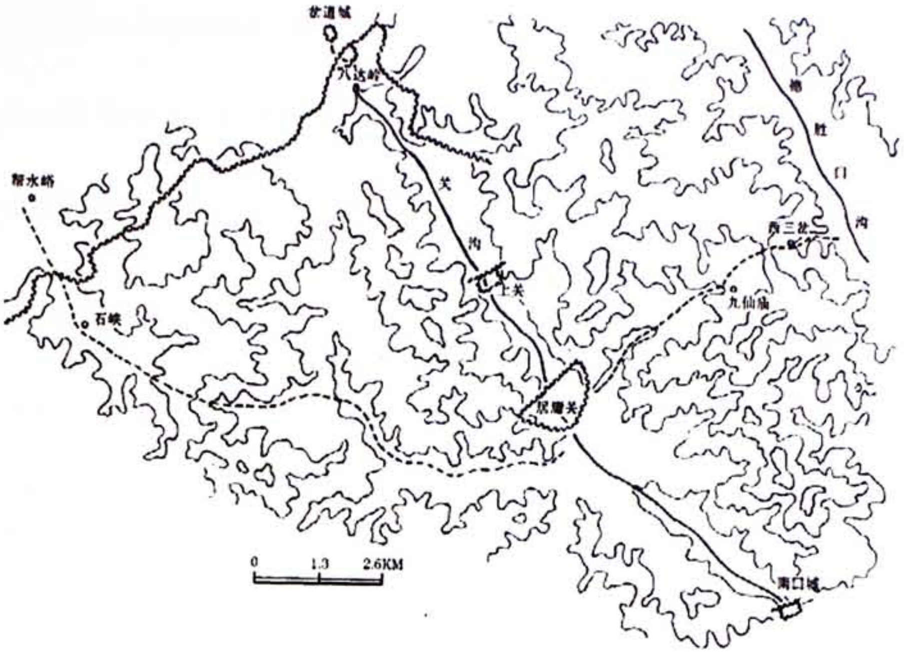


Figure 47

The Juyongguan defensive system map drawn by 胡 (2000) (p.229)

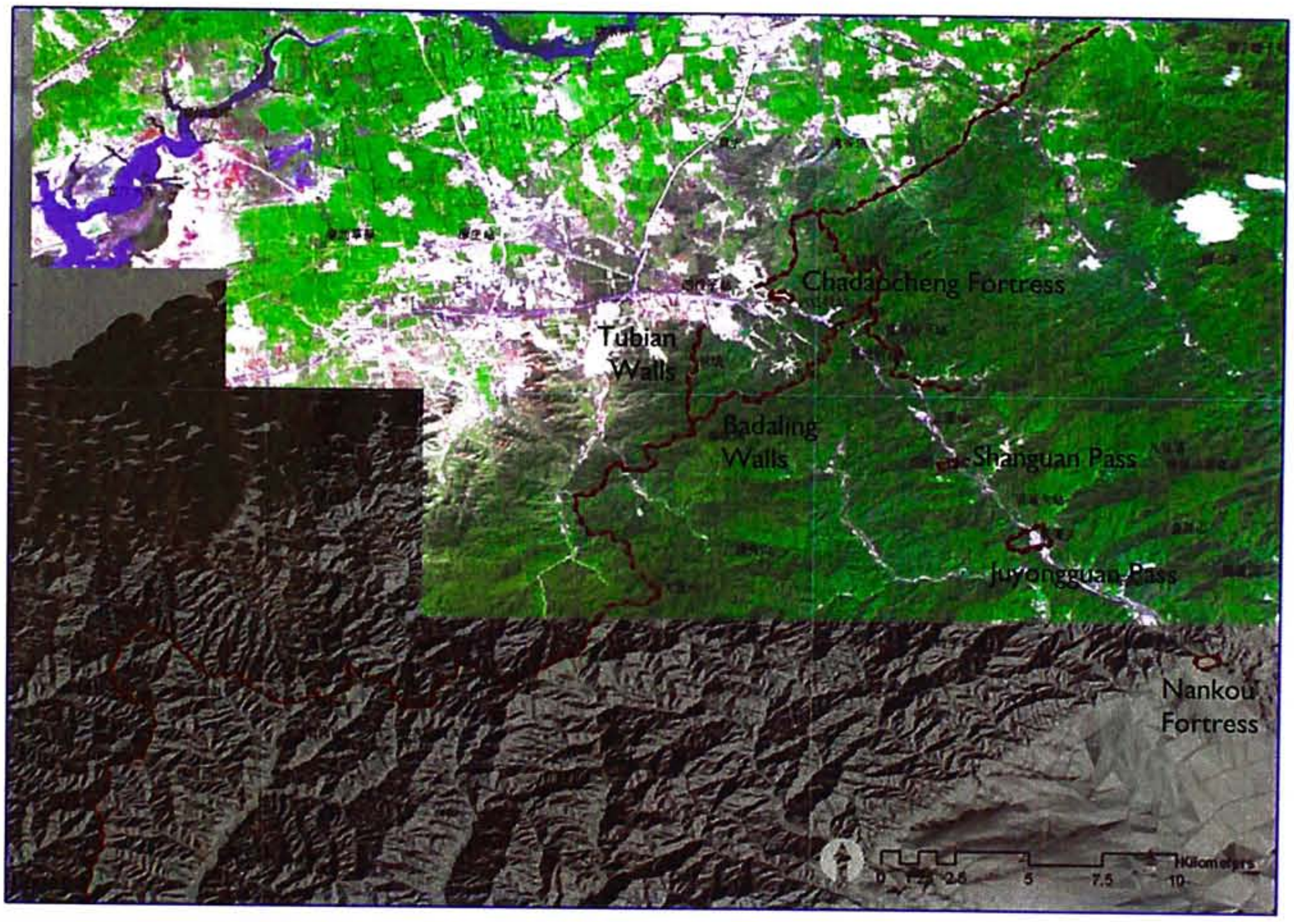


Figure 48

Plan of the entire Juyongguan Pass system

The whole Juyongguan defensive system was too efficient to allow for defeat. From the time the system was fully established in the 1500s (羅, 沈, and 張 1994; 胡

2000) until the Sino-Japanese war in 1937, not once was the Juyongguan system entirely conquered through a “pure” frontal attack (see 羅 (1982); and 政協北京市昌平區委員會文史資料委員會 and 昌平區區志辦公室 (2007)). Considering the Juyongguan’s strategic location and its excellent defensive performance, it is selected as regional-scale case to demonstrate the interpretation of typical defensive functionality through the proposed cultural route study scheme.

5.5.1 Research Background

An overview of previous studies on Juyongguan Pass starts with Luo Zhewen’s various introductory articles and brochures (羅 1957). During the period at the end of the 1990s during which Juyongguan Pass city walls were reconstructed, a series of publications blossomed, including general introductory guide books (李 1998; 劉 1998; 魏 1999), several papers on specific historical phenomena (周 2000; 胡 2000) and a report on the construction project and architecture relics (李 2000). Zhang Ximu 張曦沐’s master thesis (2005) consisted of a summary of previous studies and a detailed investigation of the architecture of the Pass City.

Although both 胡 (2000) and 張 (2005) briefly have discussed Juyongguan’s military performance, their studies adopted descriptive rather than in-depth analytical approaches. Other historical and planning studies on Juyongguan suffer from the same problem.

5.5.2 Facility Mapping and Viewshed Analysis

As mentioned in the previous section, a SPOT-5 image is introduced to map three sets of remains from the Juyongguan Pass defensive system, namely Chadaocheng, the Badaling Great Wall and Juyongguan. Moreover, Shangguan's location is also marked according to fortress wall relics, historical literature and previous illustrations. Nankou is outside the scope of available satellite images. Its boundary is replicated on the 1:50,000 digital map according to the street locations shown on the current village map.

After reconstructing the asset locations, cumulative viewsheds of each facility are calculated with the projective (views-from) visual height and reflective (views-to) visual height (see Loots (1999); and Wheatley and Gillings (2000)) shown in Table 11.

Table 11

Visual heights attributes for viewshed calculations

Juyongguan system facilities	Construction height without battlements (m)	Standard projective visual height (m)	Reflective visual height (m)
Chadaocheng fortress	8.5	10	1
Barbican of Chadaocheng	7.5	9	
Badaling walls	6-8; average height: 7.5	10	
Badaling pass fortress	10	11.5	
Tubian north to Badaling	7.5	9	
Shangguan fortress	About 7	8.5	
Juyongguan Pass fortress wall	Average of eastern hill: 4-6.5; western hill: 4-13.2; average height 5-7.8	8.5	
Watchtowers of Juyongguan Pass	5-6 above the wall	13	
Archery pavilions of Juyongguan Pass	2 floors above the wall	15	
Gate pavilions of Juyongguan Pass	3 floors above the wall	18	
Nankou pass fortress wall	About 7	8.5	

Juyongguan Pass city

The Juyongguan Pass city, with its fourteen watchtowers, five archery pavilions, two gate pavilions and one outside beacon, is the heart of the entire Juyongguan defensive system (Figure 50, Figure 49 and Figure 51). Accumulative viewsheds calculated in this case study are overlaid with viewsheds from both viewpoints along the fortress walls and individual viewsheds for each watchtower, beacon and pavilion (Figure 50).

Figure 49

Setting and natural context of the Juyongguan Pass (before the reconstruction) (source: 羅, 沈, and 張 1994, p.268)

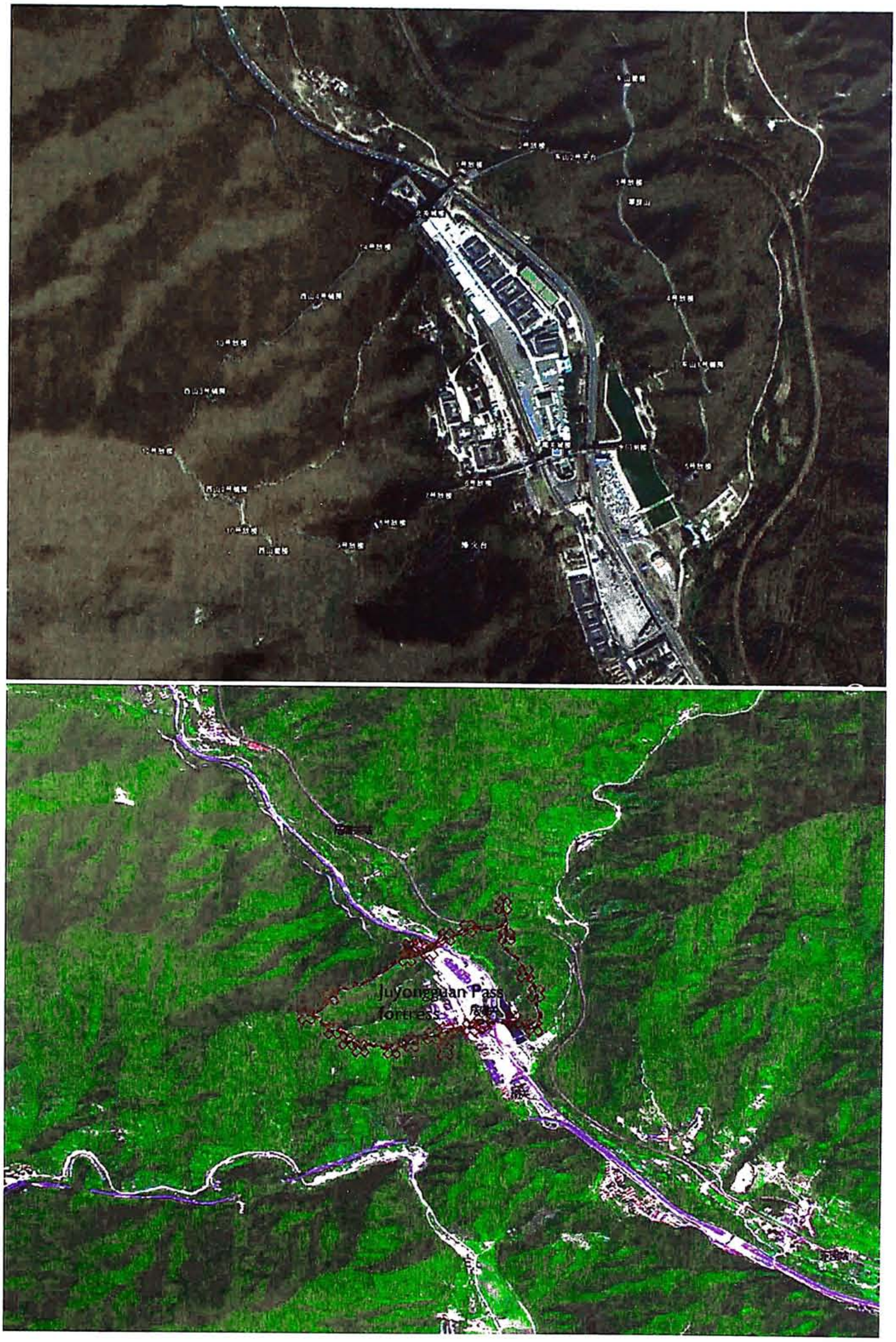


Figure 50

Google Earth satellite image of Juyongguan Pass city (above) and its plan in GIS database (bottom)

Figure 51
Panorama of the central and eastern parts of Juyongguan Pass (source: http://www.panoramio.com/photo/556528)

Figure 52 shows that the visibility afforded by Juyongguan Pass facilities covered the Pass Valley and extended to limited parts of the eastern and western hillsides. Solid visibility regions with high accumulative values extended as far as Shangguan and Nankou. Given that these two fortresses are only about three and six kilometers from Juyongguan, respectively, the visibility map can be interpreted to show that efficient information transfer could be maintained and that reinforcements could be arranged in a timely manner when war was being waged on both sides of the pass. Visibility potentially stretched as far as the Shuiguan Great Wall 水關長城 and the Badaling walls near Qinglongqiao 青龍橋 to the north, and to the western walls that acted as the boundary between the then counties of Yanqing and Huailai. Both of these two open views are within a distance of about 10 km, which is roughly the maximum threshold for maintaining visual recognition with the minimum level of interference from other factors such as weather (Higuchi 1988). This visibility characteristic illustrates the possibility that the indivisibility of Juyongguan military facilities may be considered in formulating construction strategy.

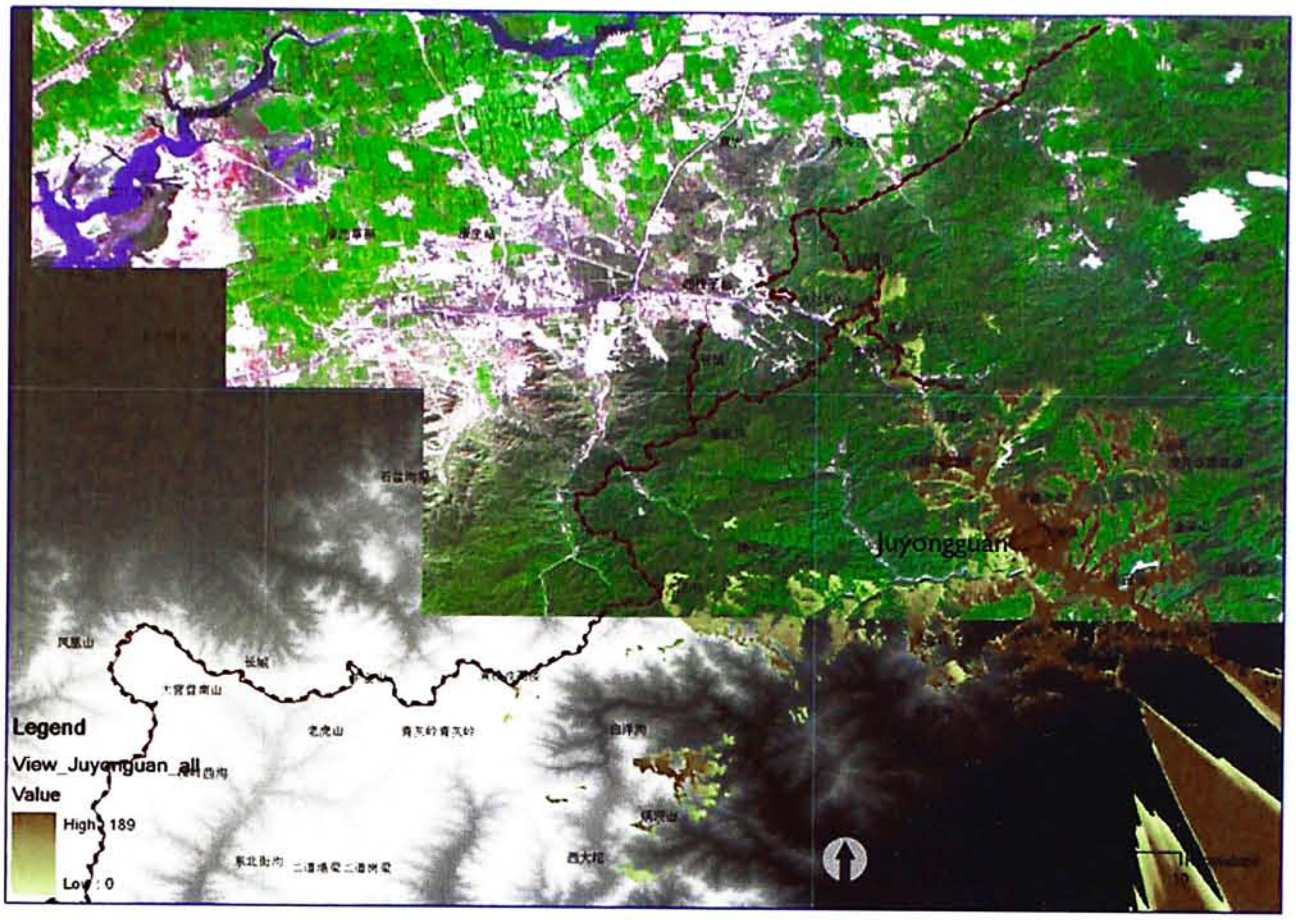


Figure 52

Accumulative viewsheds map of Juyongguan

Visibilities of Juyongguan Pass fortress are actually reinforced to a limited extent within a radius of five to six kilometers, and are relatively open to the south (Figure 53, Figure 54). There is only limited visibility control to the north and very few areas are visible north of Shangguan. Likewise, views to eastern and western landscapes are not open. In a comparison with the analyses undertaken in previous research, while view control from Deshengkou Valley 德勝口溝 to the eastern valley of Xishacha 西三岔 and Jiuxianmiao 九仙廟 as suggested by 胡 (2000) can be proven, the eastern trail referred to by Hu cannot be monitored effectively. This area may have been employed as an alternative invasion route, as discussed later (Figure 54).

Figure 53

Southward views from watchtowers on the western hill (left, source: http://www.panoramio.com/photo/6713729) and the eastern hill (right, source: http://www.panoramio.com/photo/3969720)

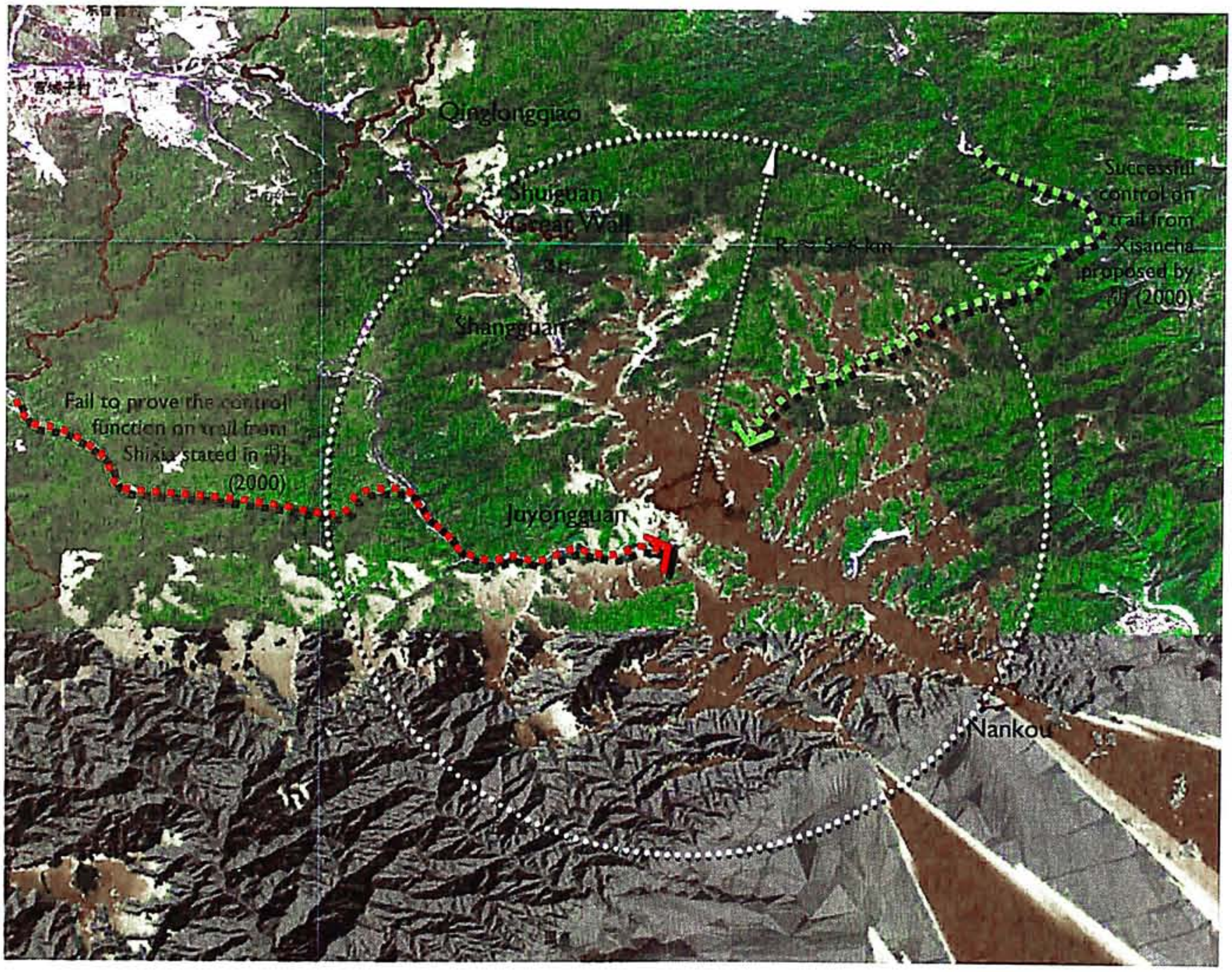


Figure 54

Visibility functions of Juyongguan Pass city

Cumulative viewsheds of the Great Wall

Cumulative viewsheds of the Great Wall are overlaid with visibilities from viewpoints along the Badaling walls and Badaling pass city, Shuiguan walls, Tubian walls and the adjacent walls to the southeast in Huailai (Figure 55). Although the Great Walls allowed for absolute control to be maintained over the Yanqing Plain, visibility control to the south is not as efficient as to the north.

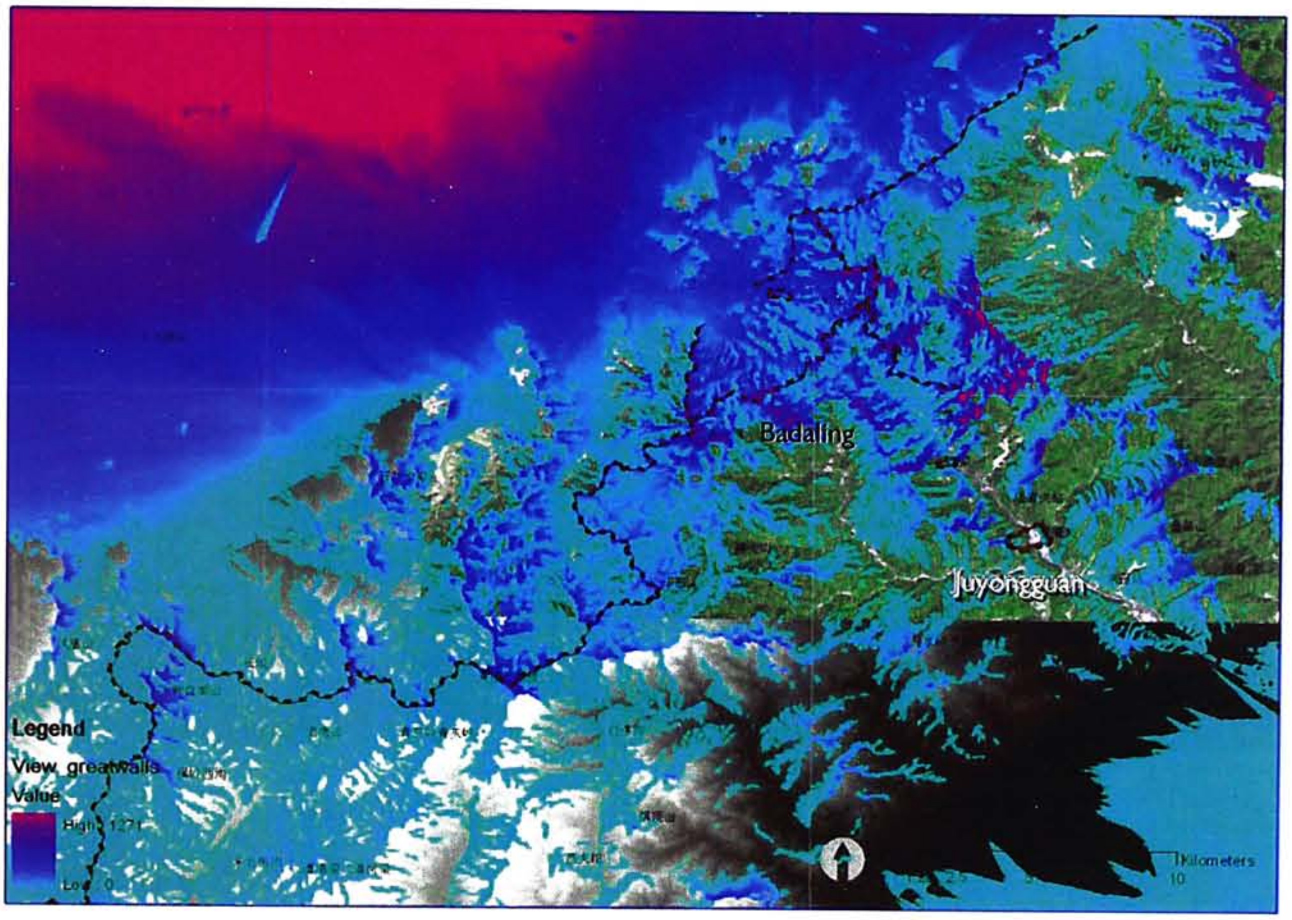


Figure 55

Cumulative viewsheds map of the walls

The Badaling walls allowed for the valley entrance and the northern third of the Pass Valley to be kept under visual control. This effective area of control also covered the Banshuiyu 幫水峪 and Shixia 石峽 valleys in the southwest and extended to the Deshengkou Valley to the northeast. One very interesting viewshed phenomenon revealed by the map is that visibility from the north walls only stretched as far as Shangguan, where visibility from Juyongguan Pass fortress took over and facilitated control of the rest of the Pass valley (Figure 56). It seems that areas visible from these two facilities complemented each other and expedited control of the Pass Valley.

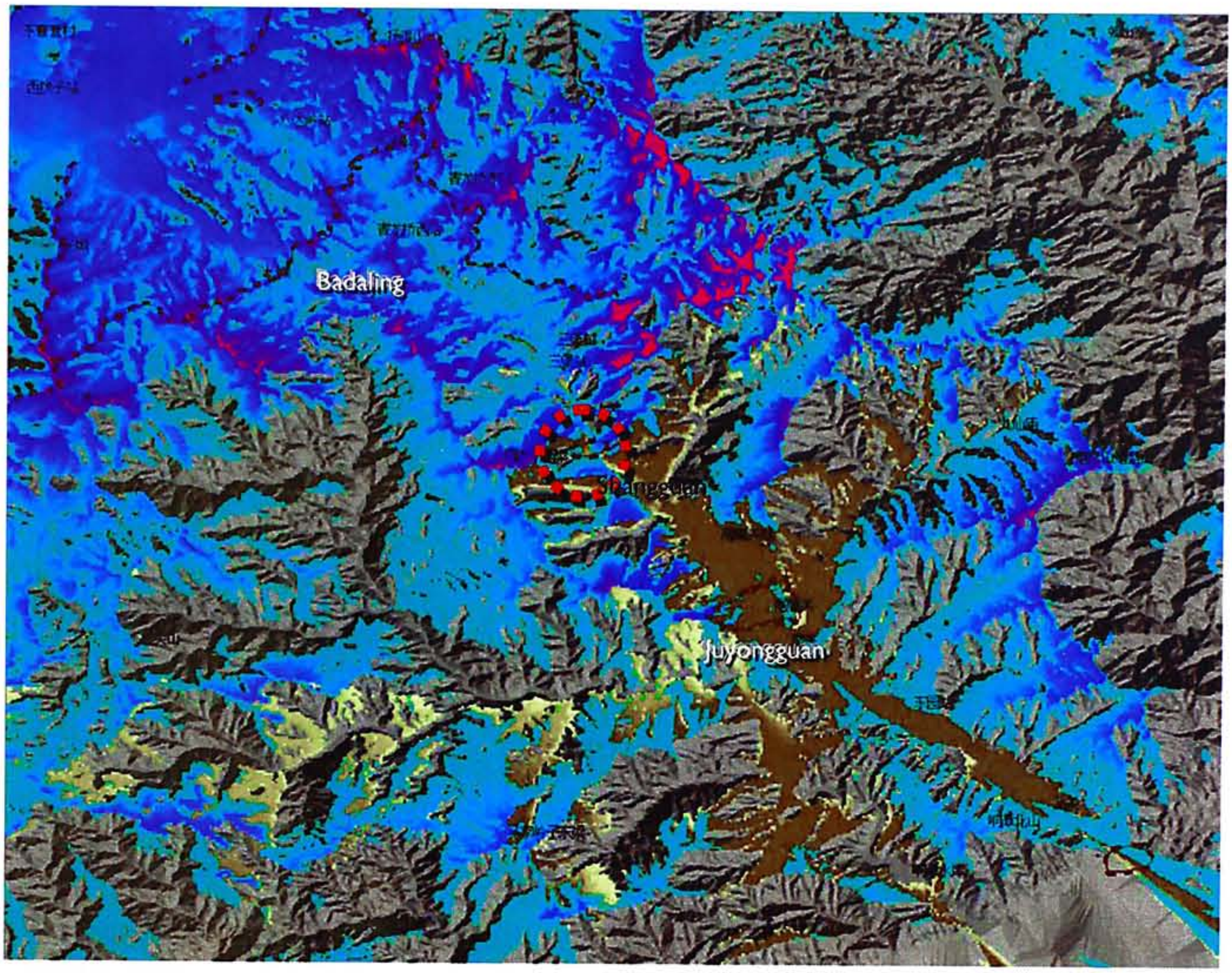


Figure 56
The visibility map near Shangguan

Visibility anisotropic cost setting

After accumulative viewsheds are calculated for Chadaocheng and the other two putative fortresses, accumulative viewsheds are overlaid together to form a cumulative viewshed of the entire Juyongguan defensive system (Figure 57). Accumulative values are reclassified from 1 to 100 as anisotropic costs for the horizontal factor in cost-surface analysis (Figure 58). Because no valid data sources are available to map the great wall east to Yuhuangshan Hill 玉皇山, visibility and further CSA are fatally affected. A data mask is therefore created to extract a study area of about 28 x 26 km with one corner eliminated to avoid edge effects caused by absence of walls or DEM surface (Figure 59).

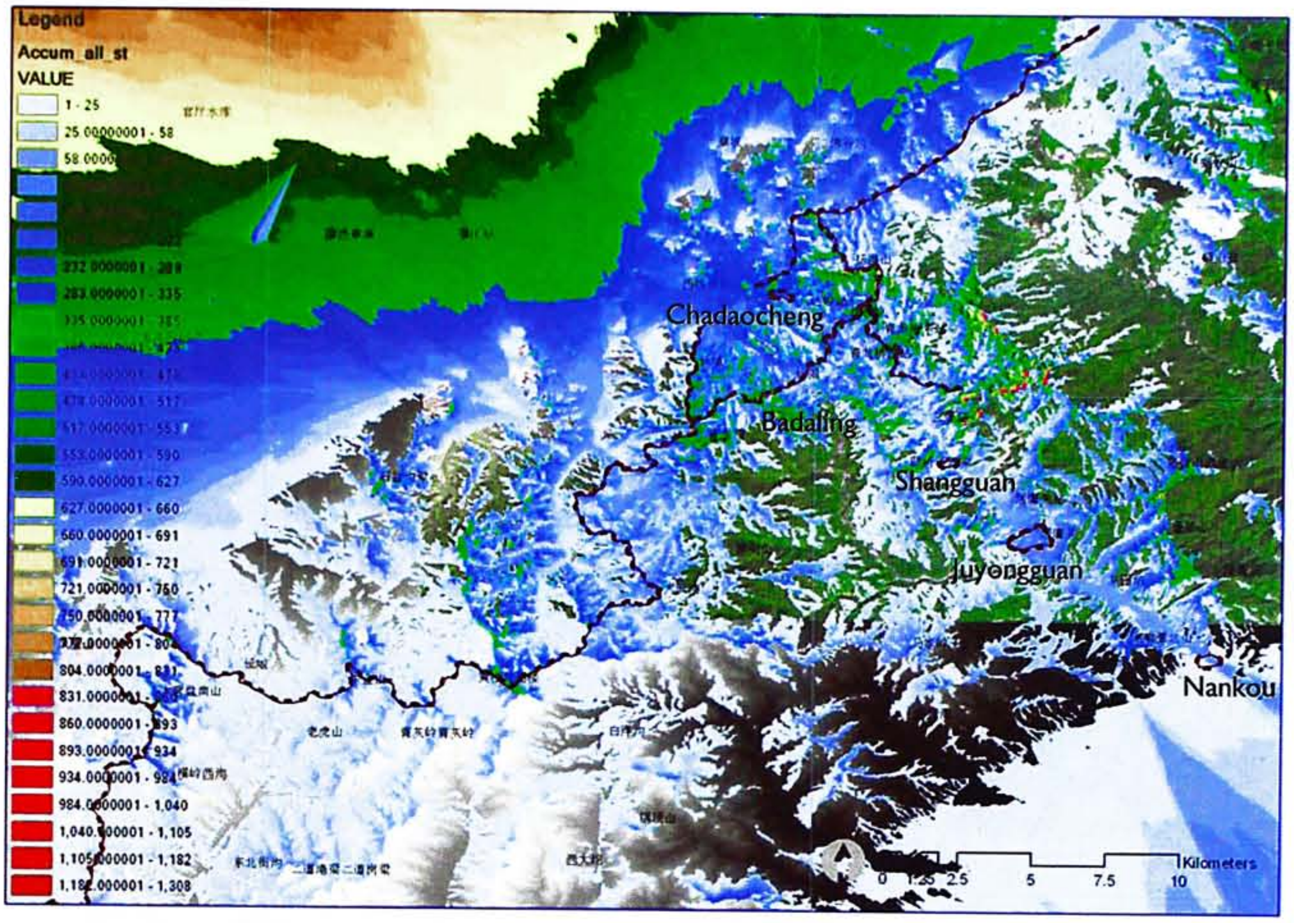


Figure 57

Cumulative viewsheds of the Juyongguan defensive system

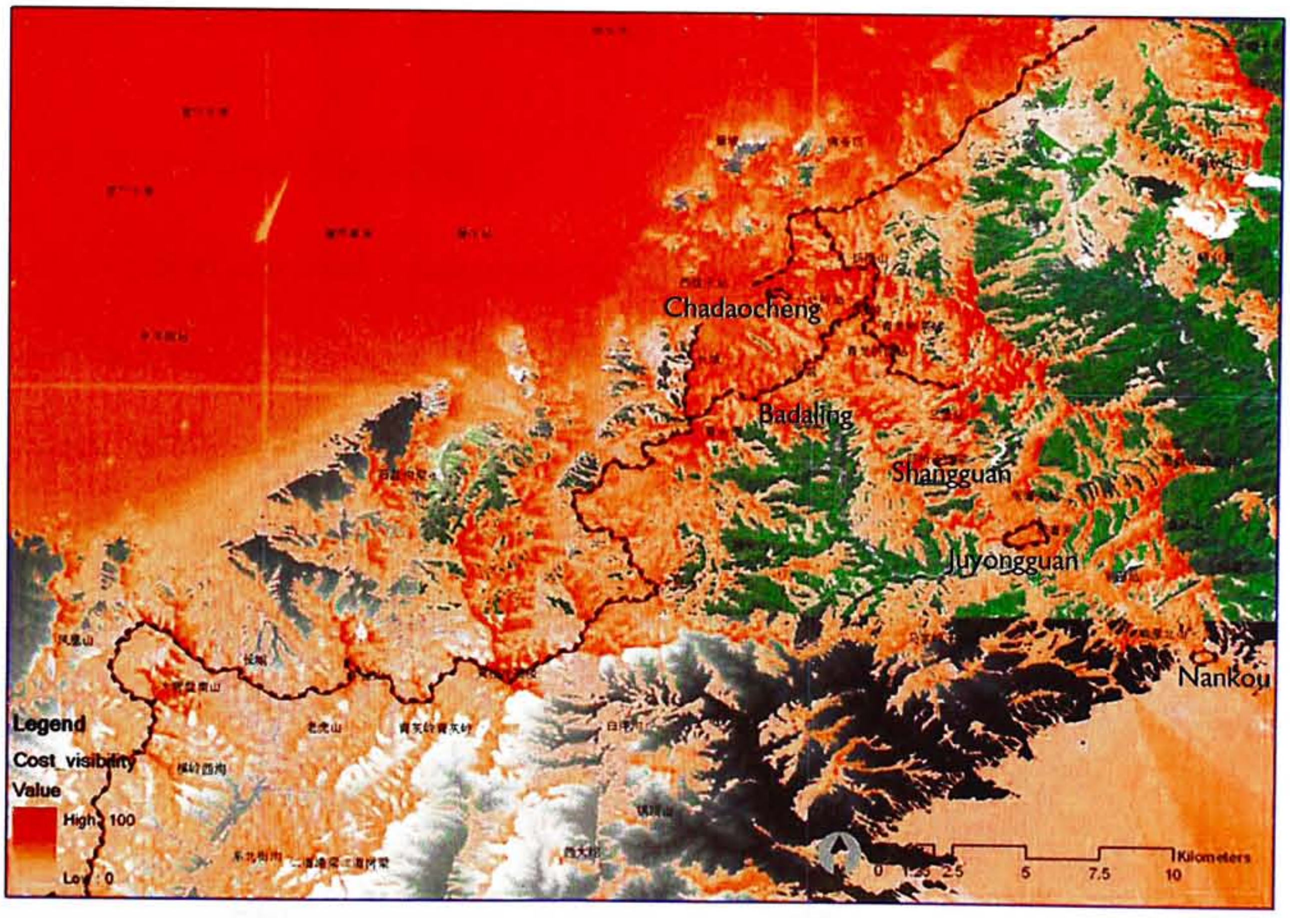


Figure 58

The reclassified defensive visibility cost as anisotropic horizontal factor introduced in further cost-surface modeling

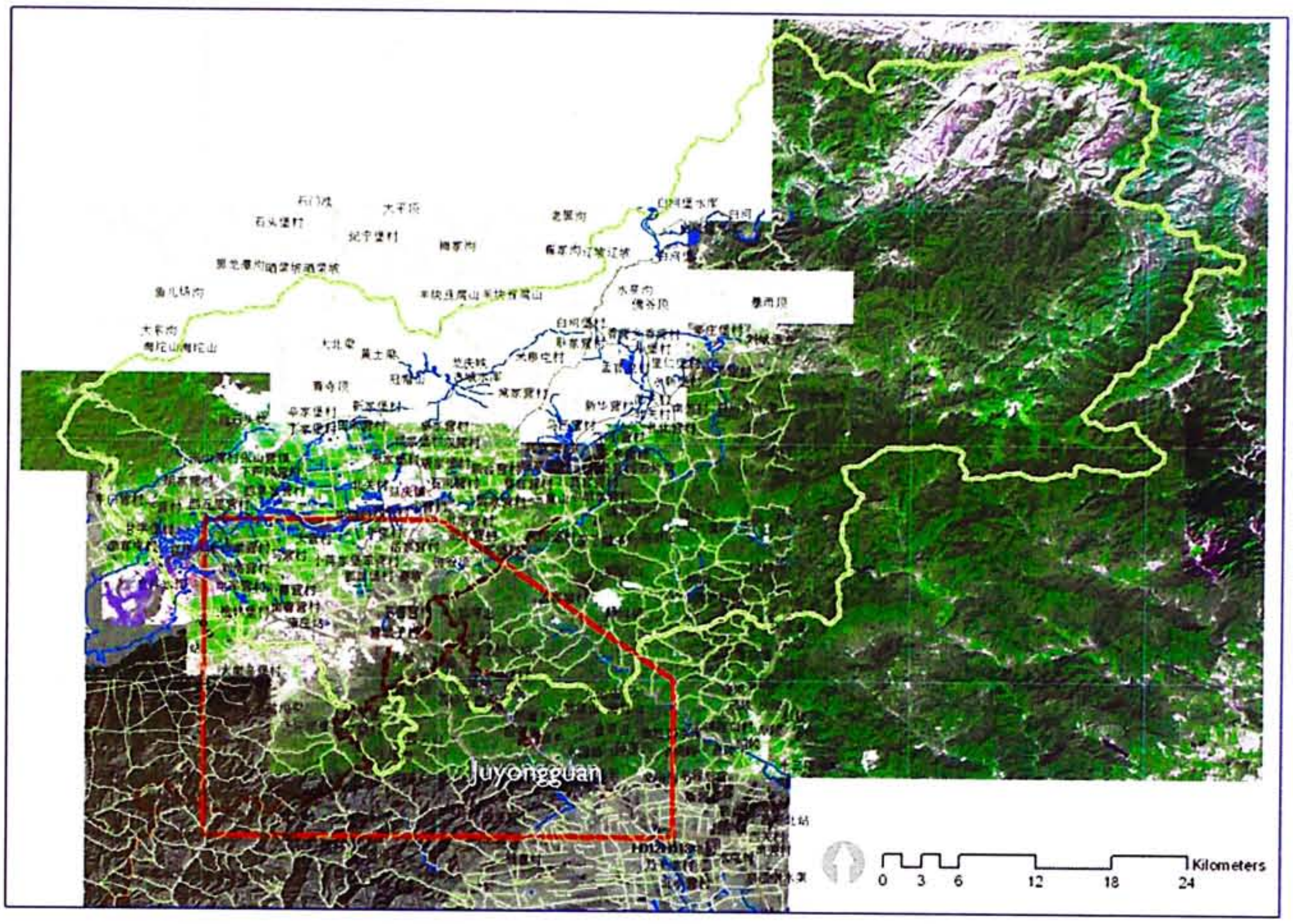


Figure 59

Data mask location marked with read boundary

5.5.3 Movement Modeling

In the regional case study, movement modeling introduces all four kinds of attributes mentioned in Section 4.3.4. To implement comparative studies, the basic cost-of-passage raster, which comprises both natural topographical features and facility functional frictions, is modeled in two raster surfaces. The first one simulates a "virgin land" hypothesis designed to analyze how people travelled through the Pass Valley. Another surface integrates traversing costs based on the key military facilities of the Juyongguan defensive system.

Cost-of-passage mapping

The basic cost of passage introduces both land use friction costs in vegetation (LU) and defensive effect costs (DT) as cost attributions (Figure 60). Vegetation friction is simulated using a simple vegetation model by deriving terrain features including slopes and aspects (see Table 12). Defensive effects are established using buffer distances to replicate defensive functions applied in different regions. Water bodies are excluded for the same reason they are excluded from the large-scale study. Both LU and DT cost values are assigned according to Table 12 and overlaid as shown in Table 13 and Figure 61.

Table 12

Cost value assigned to LU and DT

Cost	**Land use factors (LU)**		**Defensive/military effects (DT)**	
	Spatial characteristics	**Rationales**	**Spatial characteristics**	**Rationales**
1	Slope(S) $\leq 3^\circ$	Roads or flats, cultivation fields	nil	
2	nil		nil	
3	$3^\circ < S \leq 60^\circ \cap$ aspect (A) = northward; or $S > 60^\circ$	Low vegetation areas	nil	
4	$3^\circ < S \leq 60^\circ \cap$ aspect (A) = west or east	Medium vegetation areas	nil	
5	nil		nil	
6	$3^\circ < S \leq 60^\circ \cap$ aspect (A) = south	Dense vegetation or forests	$200\text{m} < D < 300\text{m}$	Shooting of falconet (佛朗機銃) and other protection facilities like traps (品窖) and bushes available within about 300m
7	nil		$150\text{m} < D < 200\text{m}$	Single cavalryman recognized at an angle$_h$ of 1°
8	nil		$120\text{m} < D < 150\text{m}$	Shooting range for arquebus (鳥銃) and artificial steps and terrain modifications (鏟削偏坡/擋馬墻, see Figure 62)

				available within about 150 m
9	nil		30m < D < 120m	Single infantryman recognized at an angle$_v$ of 1°
10	Facility location	Facility itself	Facilities and D<30m	Single infantryman can be recognized

Table 13

Matrix for LU and DT overlaid cost assignment

	DT = nil	DT=6	DT=7	DT=8	DT=9	DT=10
LU = 1	1	6	7	8	9	10
LU = 3	3	6	7	8	9	10
LU = 4	4	7	8	8	9	10
LU = 6	6	7	8	9	9	10

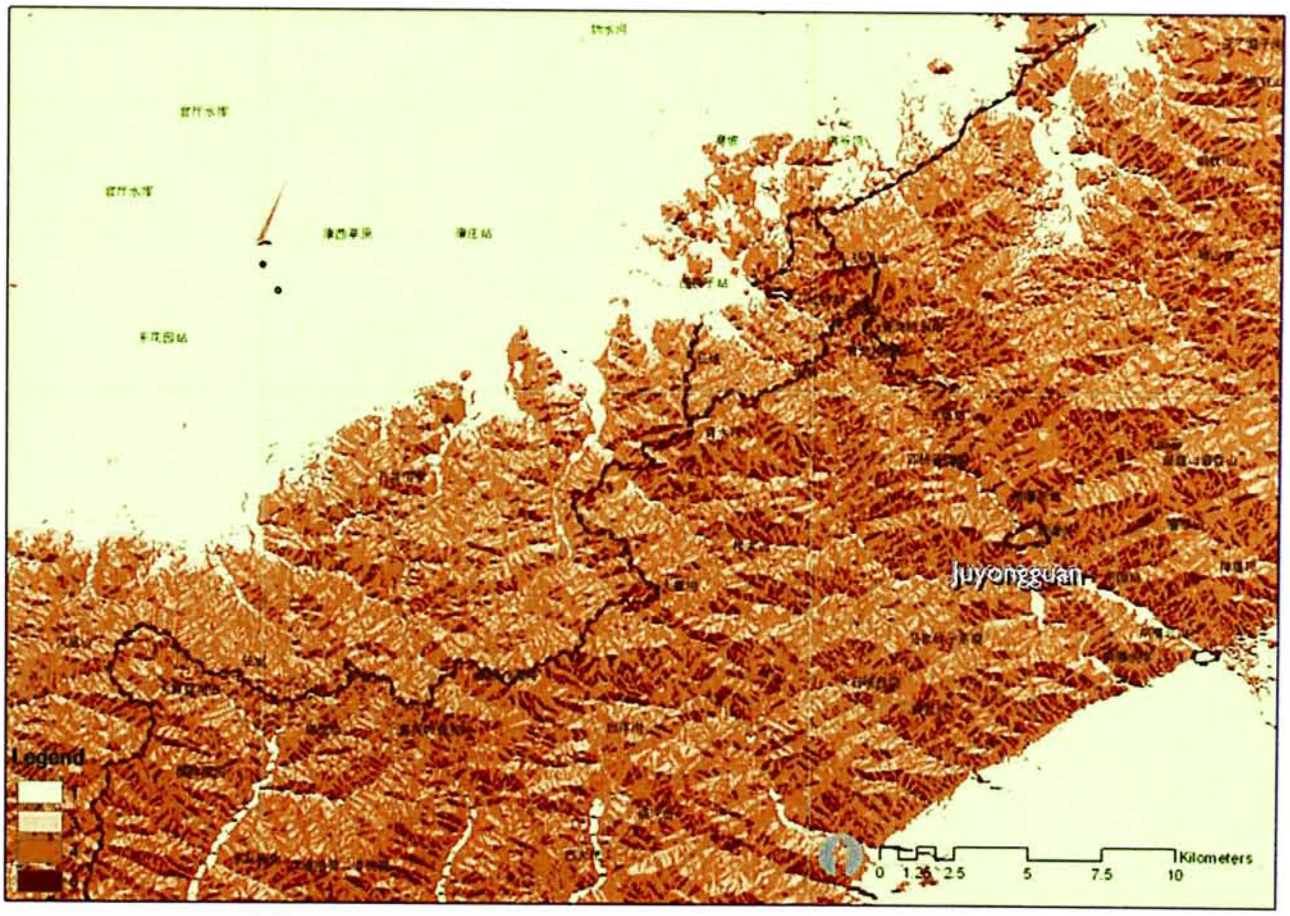


Figure 60

Cost-of-passage surface of the "virgin-land approach" model (LU = 1 to 6)

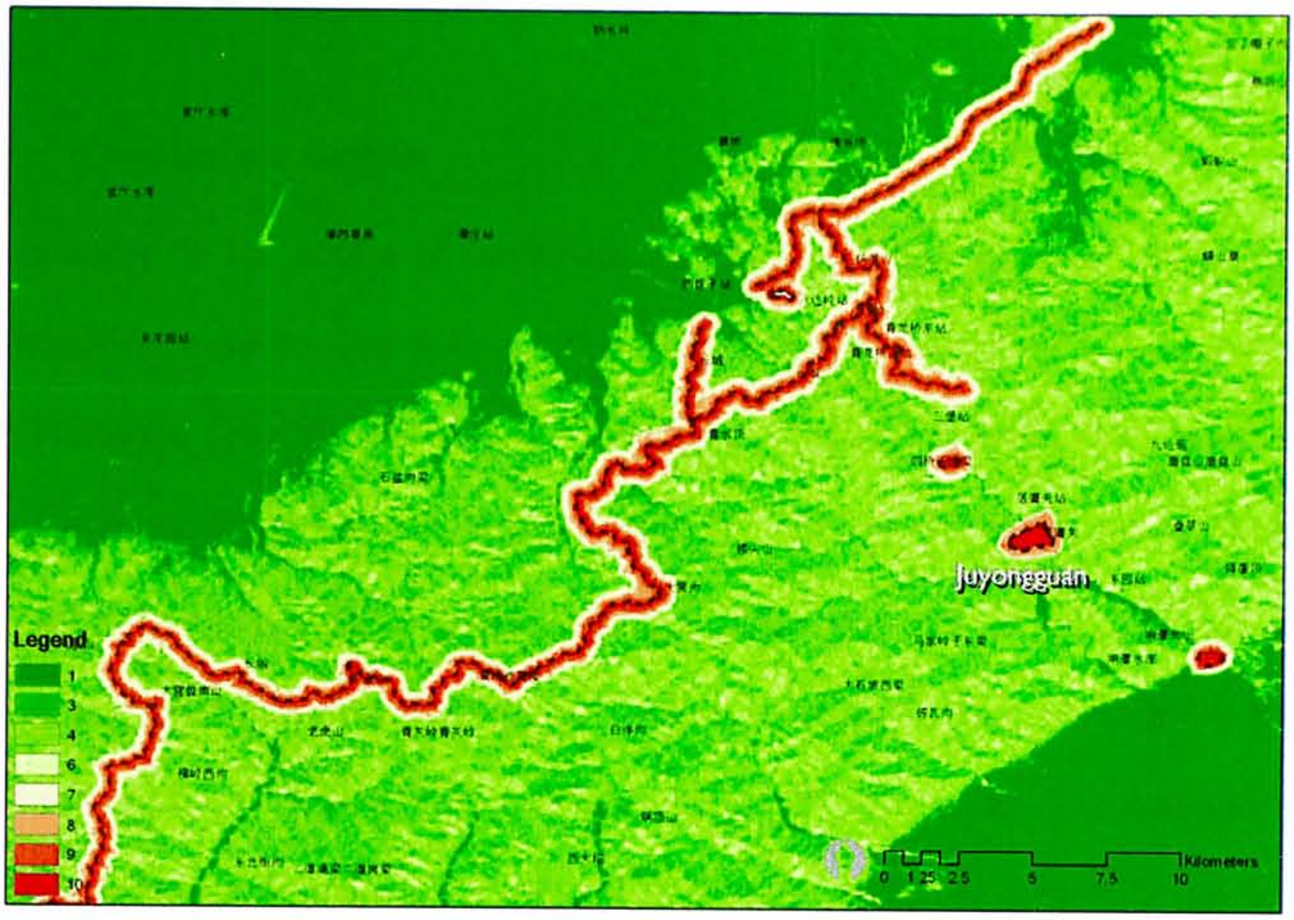


Figure 61

The overlaid cost-of-passage surface of integration of LU and DT (cost = 1 to 10)

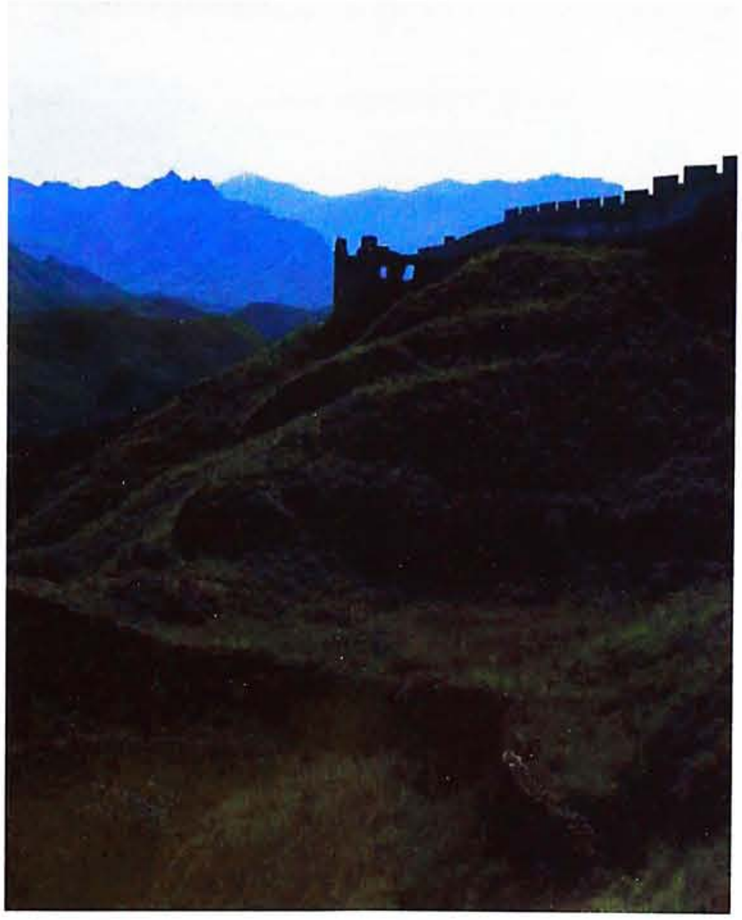


Figure 62

A example of artificial steps and terrain modifications (鏟削偏坡/擋馬墻) near the Great

Walls as defensive facilities (source: 羅, 沈, and 張 1994, p.111)

Cost-surface analysis

According to the results of large-scale investigations and historical documents, Mongolian invasions from the north to Juyongguan were most likely to pass Xuanfu and cross the Yanqing Plain along the foot of Jundushan Mountain to attack Badaling and Juyongguan and approach Jingshi (see: 洪 (2007)). Therefore, three starting points and two destinations are designated at different distances from the Badaling Pass and what was then the town of Nankou. A series of tests have shown that location differences have little impact on the cost-surface model. The destinations and starting points located within the clipped study region are defined in the final analysis.

The two cost-surface models described above are then implemented and compared. Model I introduces only LU in creating the cost-of-passage surface and no horizontal factor is used. Model II uses the integrated cost-of-passage to calculate the condition that represents the launch of a forcible frontal attack to cross the valley or other take another possible detour. However, this model is formulated on the basis of a hypothesis that the observatory function of the relevant military facilities is disabled to allow for battle to begin without raising the alarm. Model III employs a more realistic assumption in relation to defensive facility characteristics by modifying model II and introducing a visual sensitivity anisotropic map as a horizontal factor (see Figure 58).

5.5.4 Analytical Results

Figure 63 to Figure 65 map the corridors that pass through the Pass Valley and other possible trails under different assumptions. The analytical results from model I clearly show that the Pass Valley is the most efficient trail for traveling through the Jundushan Mountain area. If there is no defensive friction, approximately 75% less energy is consumed when compared with the approaches of crossing through the Bangshuiyu Valley or the Deshengkou Valley (Figure 63). After the Great Wall system was constructed, although the area most susceptible to invasions may not have changed, the least-cost corridor after breaking though the frontline had to be switched to the valley to the west of Jinguishan Mountain 金櫃山 to avoid resistance from the two fortresses located along the transport routes (Figure 64).

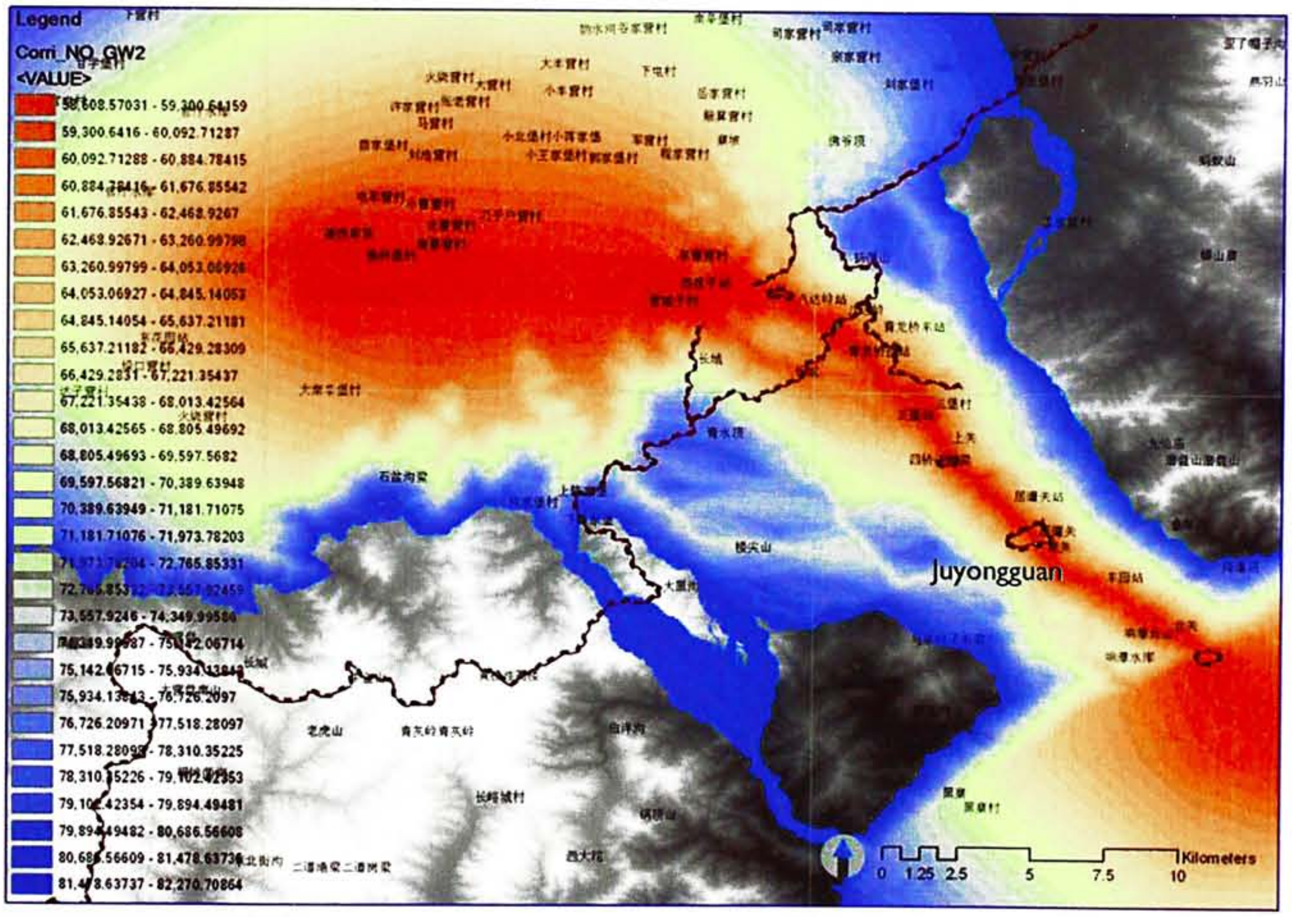


Figure 63

Corridors in the Juyongguan area derived from cost-surface model I

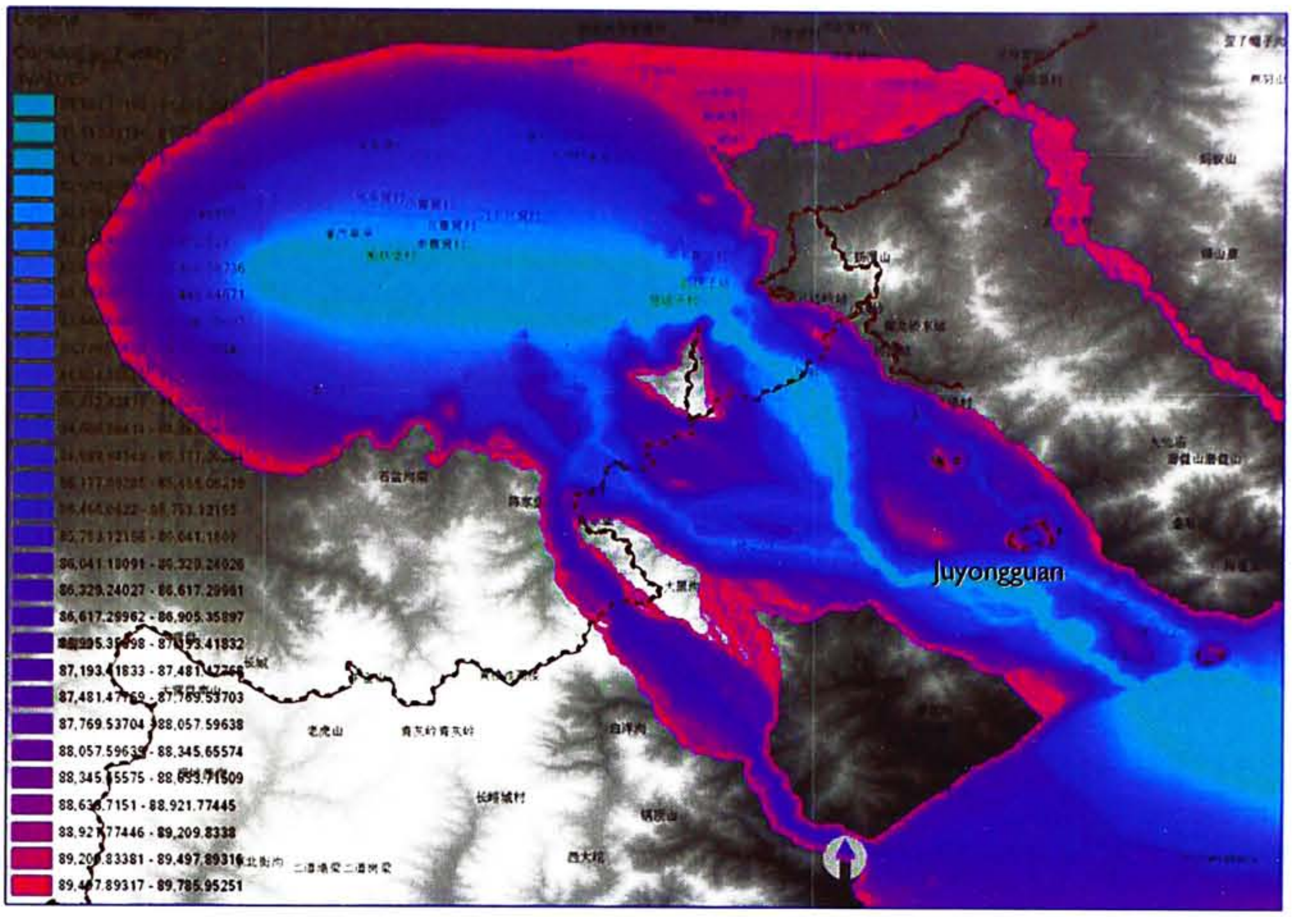


Figure 64

Corridors in the Juyongguan area derived from cost-surface model II

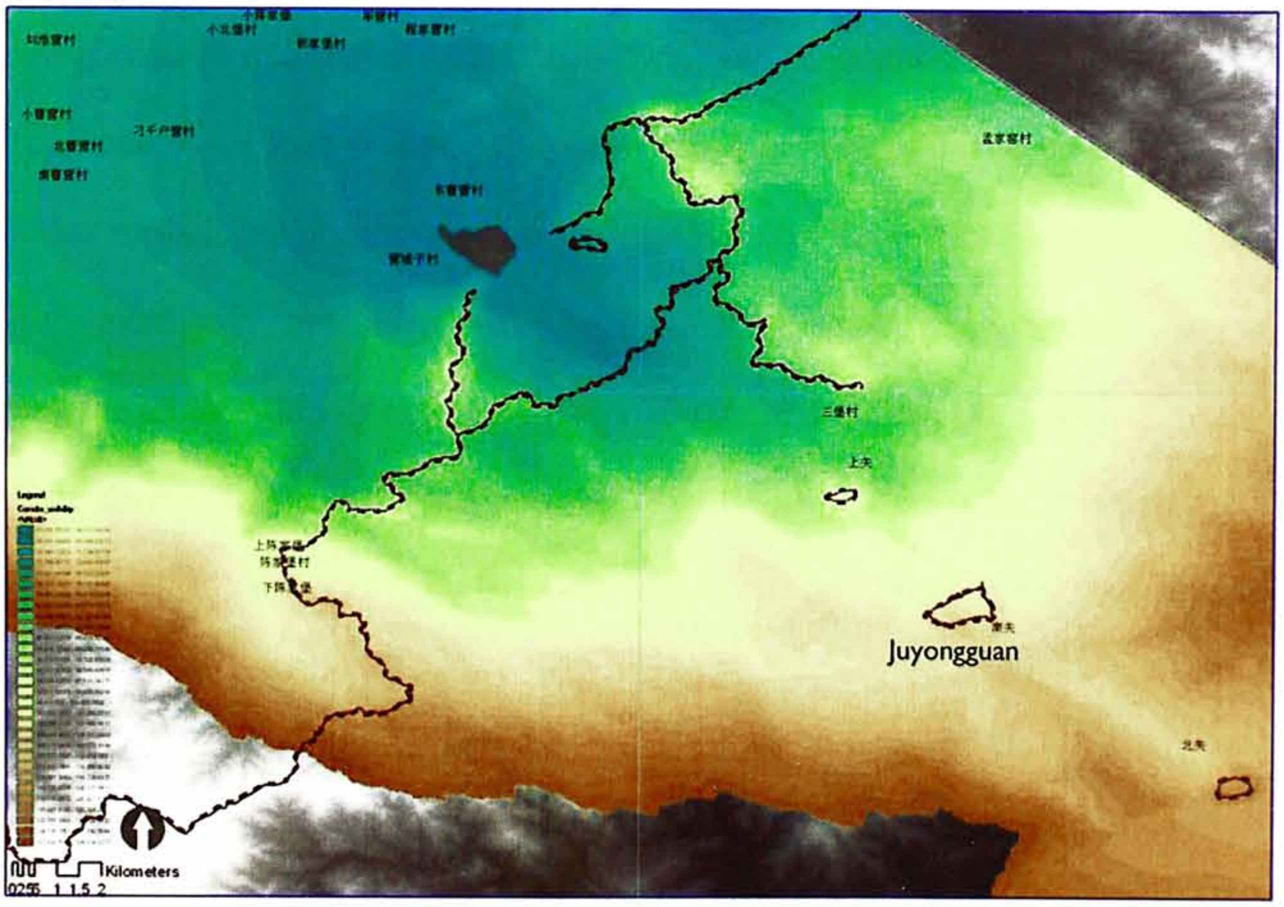


Figure 65

Corridors in the Juyongguan area derived from cost-surface model III

Functional interpretation

The implementation of model III produces a number of interesting variations (Figure 65). A notable phenomenon is that the Pass Valley again becomes the least-cost corridor. It is clear that in model III, traversing costs increase very rapidly when passing through the Juyongguan defensive system. Despite the existence of a clear lower cost corridor along the Pass Valley, the Dashigou 大石溝-Donggou 東溝-Longtan 龍潭 valley, which is the least-cost corridor in model II, also offers an alternative, although costs are higher by between 4 and 5 percent (Figure 66). However, in terms of costs, this corridor is almost the same as the area south to the Juyongguan Pass fortress and is divided by a continuous ridgeline from the Pass Valley to Jinguishan Mountain. Before reaching this location, the rates of cost increase for both these trails are similar. This may be partly due to the fact that the Pass Valley cannot be seen from any of the defensive facilities before the switch point is reached in Longtan Valley. This factor can somehow be balanced against the circumstances in Pass Valley, which has much lower optimized costs in term of friction surface, but is controlled due to high visibility from the defensive properties. On the alternative route, after switching south from the abovementioned equal value point, the entire valley is exposed to the visibility and cannon fire power of troops in Juyongguan (Figure 67). This may be one of the reasons why traversing costs amplify tremendously in the subsequent part of the trail when traveling southwards (see Figure 66).

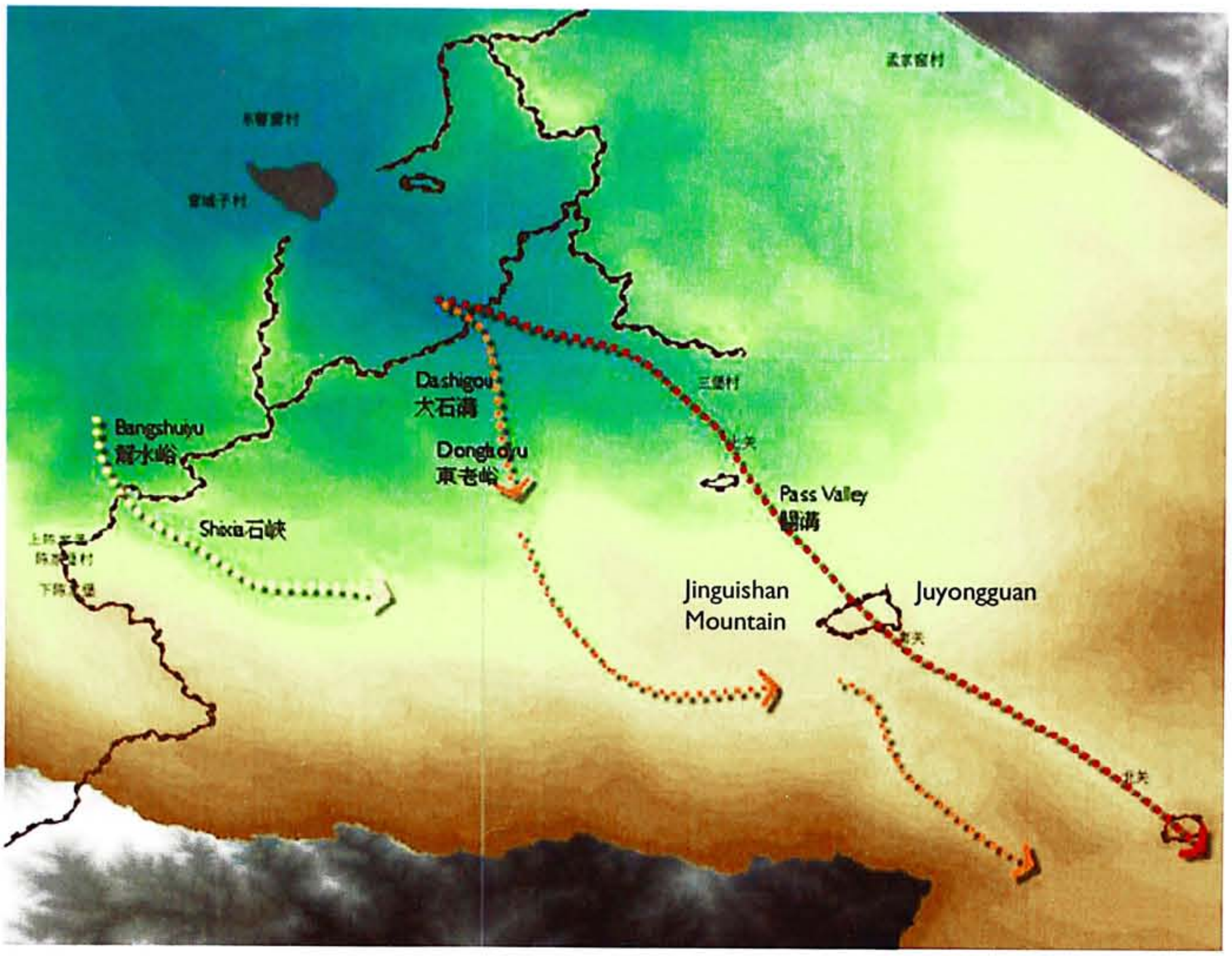


Figure 66

Detailed analysis of the movement corridors derived from model III

Figure 67

Xiangtan Valley, which is totally visible from the west hill watchtowers of Juyongguan Pass fortress (source: http://www.panoramio.com/photo/8476329)

There is still not enough firm evidence to explain why in model III visual sensitivity can operate to force movement back to the Pass Valley. One possible interpretation is that visibility control created a relatively homogenous cost impact area which covered the entrance outside the walls in front of Nandonggou Valley 南東溝, which is the lowest cost area for breaching the Badaling walls. Furthermore, this area extends for more than one kilometer, crossing the ridge and extending as far as both Qingshiding 青水頂 and Qinglongqiao 青龍橋 in a west-east direction. Its connection with the Pass Valley has a clear low sensitivity channel along the valley from the Badaling Pass fortress. By contrast, the entrance to Dashigou is blocked by a highly sensitive band (Figure 68). These models still need to be developed to enable other scenarios to be tested more reliably.

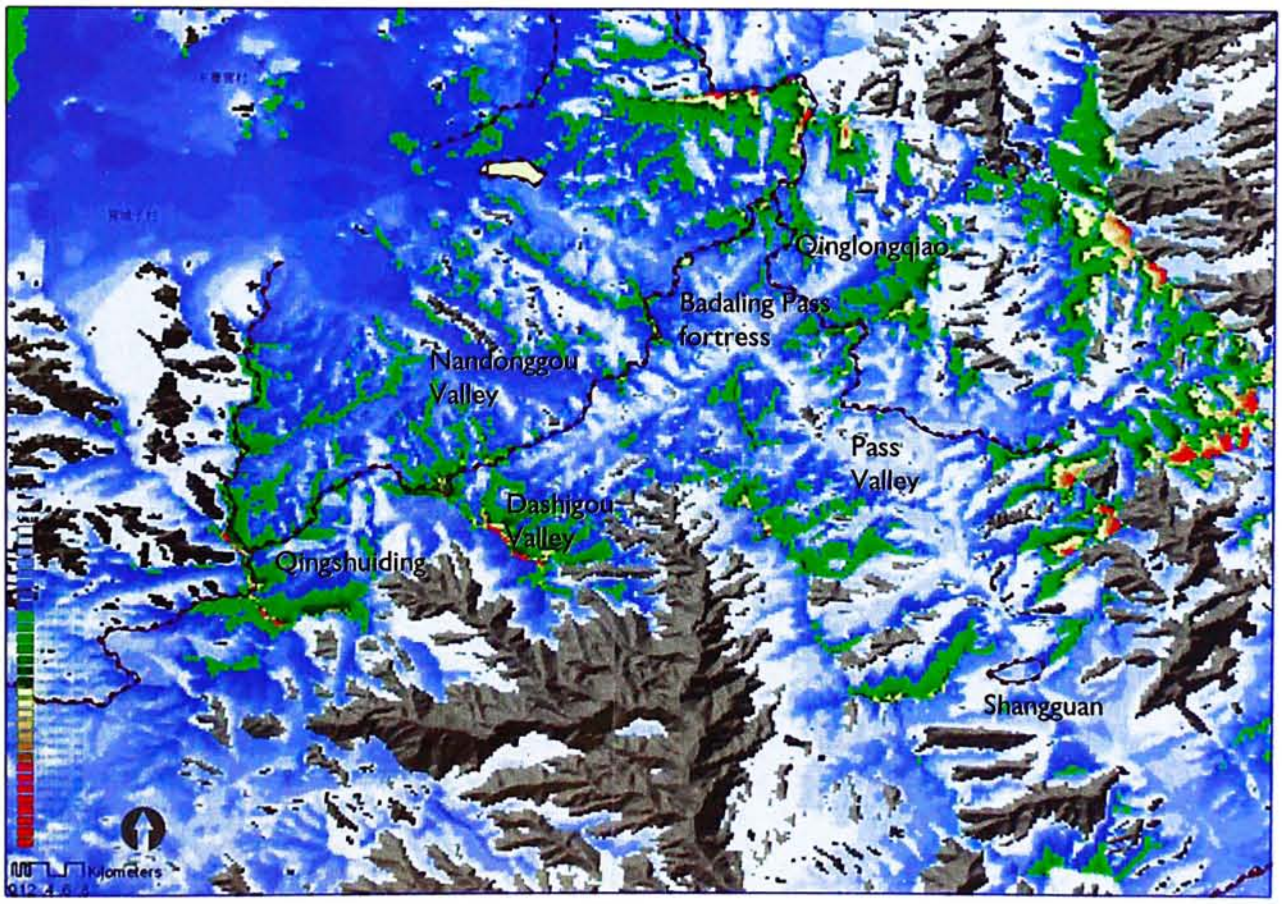


Figure 68

Cumulative viewshed distribution in the entrance area of Pass Valley

5.6 Spatial Control and Delimitations of Juyongguan Pass Fortress

As discussed in previous sections, property catchments can be introduced to define delimitation boundaries for heritage protection. In this case study, given that only the Great Walls (with Chadaocheng Fortress as an integrated asset) and Juyongguan Pass fortress are physical heritage assets, path distances are calculated only to these two properties.

It shall be noted that a large part of the fortress walls, gates and watchtowers of Juyongguan Pass and Chadaocheng Fortress are actually rebuilt in recent ten years (李 2000; 法制日報 2006). Therefore, they may have lost their authenticity in the property themselves. However, the rebuilt of the fortress walls did not affect authenticity from the cultural route value aspects in either property's historical functionalities or property settings since either the spatial locations or the basic feature forms, and their consequent spatial performances are still kept. Therefore these rebuilt properties still serve as substratum of proposed conservation delimitation demonstration process.

5.6.1 Spatial Control of the Great Wall

A threshold for the path distance to the Badaling walls is assigned around the middle of the highest density value ranges at 8,000 (Figure 69). The spatial control catchments of the Badaling Great Wall are modeled in Figure 70. It seems that this catchment threshold would also fulfill the 500 meter buffer zone requirement by 北京市文物局 (2003) for Great Wall protection in most of the sections. However, it also can be seen that the controllable scopes vary tremendously in different sections of the walls. The first frontier lines give a control depth of about two to four kilometers towards the Plain, especially from the eastern earth wall built to the northeast that overlooks the entire Yanqing Plain. Control scopes in the mountainous areas do not normally extend as far as the walls near the plain. However, the high visual sensitivity areas also drag the controllable spaces of two sections of Great Wall in a north-south direction extending eastward. This spatial distribution phenomenon indicates efficient control of the Bangshuiyu – Shixia Valley and the Longtangou 龍潭溝 Valley east of the Qinglongqiao and Shuiguan Great Walls. It can also probably be used to explain the relatively high costs of the Bangshuiyu – Shixia location in model III when compared with model II.

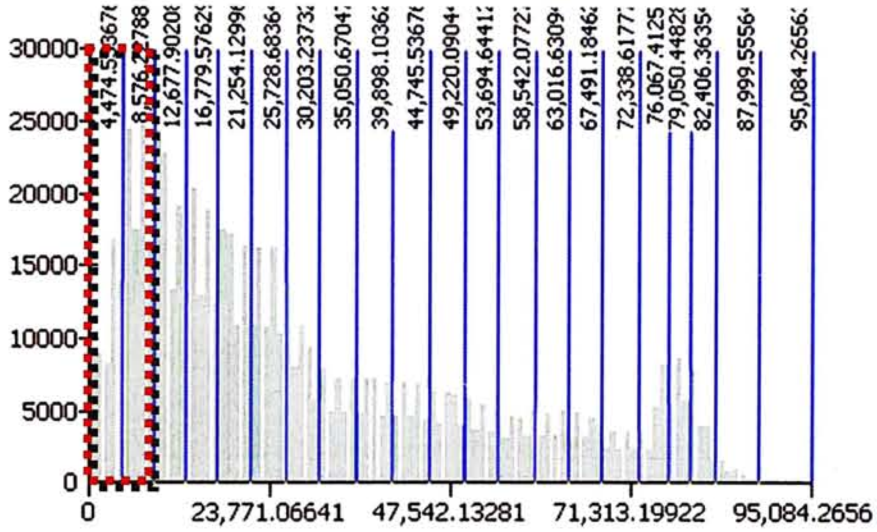


Figure 69

Range of path distance cost value (less than 8,000 cost units) to be considered in conservation of Badaling section of Great Wall

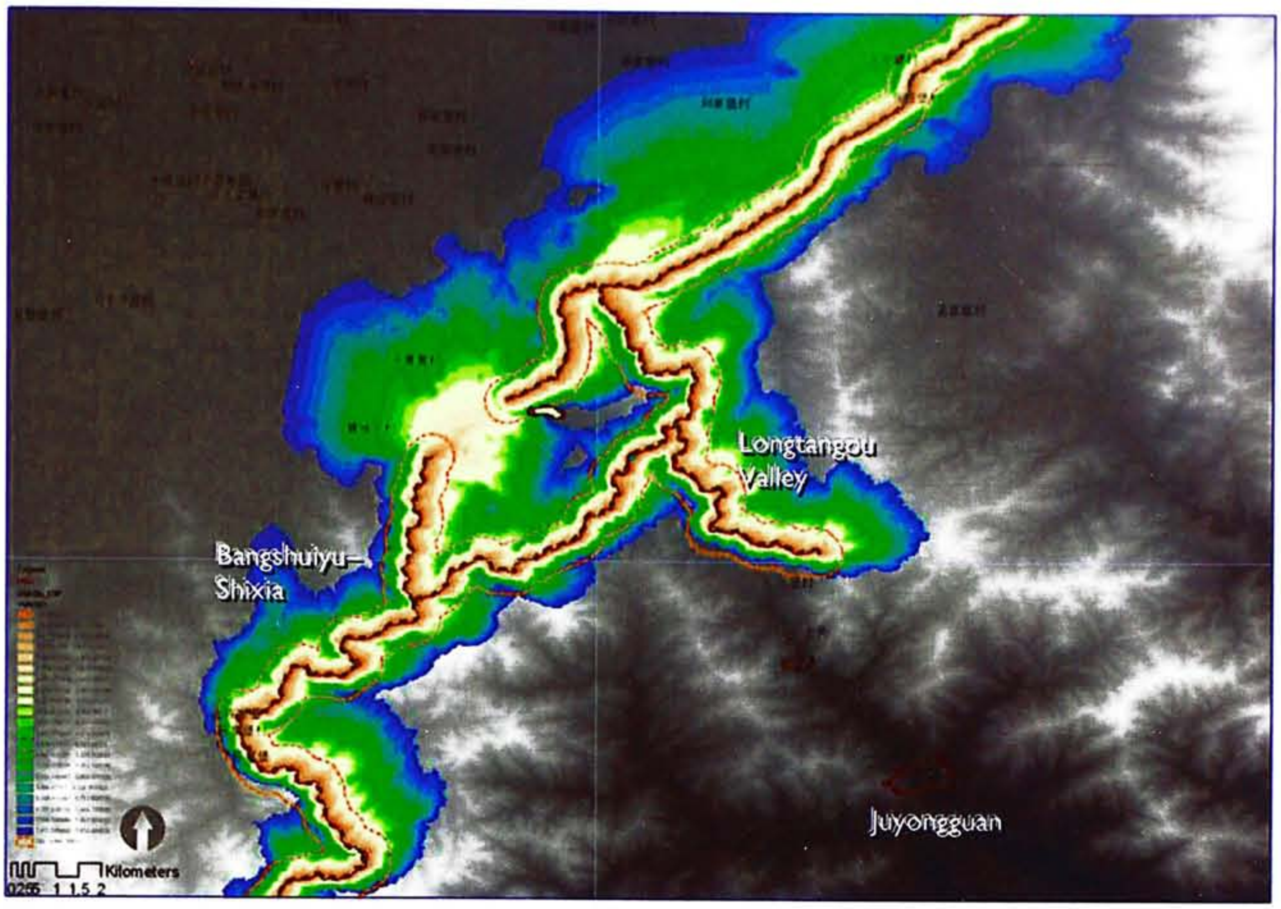


Figure 70

Spatial control catchments of the Badaling Great Wall

5.6.2 Juyongguan Pass Fortress Delimitations

In terms of spatial control, the Badaling walls vary significantly along their different sections. Their delimitation therefore has to be implemented section by section. To illustrate a delimitation process, the path distance to the Juyongguan Pass fortress is translated into catchments and delimitations using the method suggested in section 3.3, as follows:

1. Reference buffer zones are created according to general Great Wall protection regulations.
2. Threshold values are defined on a cost-distance surface and a chorisogram scope is extracted to act as the external boundary for conservation purposes.
3. Detailed delimitations are defined by extracting Euclidian and cost distance contours.

4. The boundaries of the core area and two levels of buffer zone are delimited and the shape files are exported.

Basic conservation boundary definition

According to the *關于劃定長城臨時保護區的通知* (北京市文物局 2003), the following two levels of temporary protection zones should be legislated for to protect the Great Wall: the no-construction zone, which is a 500 meter buffer zone, and the restricted-construction zone from 500 to 3,000 meters. For the Juyongguan case, these two buffer areas are created firstly as a reference, through GIS "buffer" operation (Figure 71).

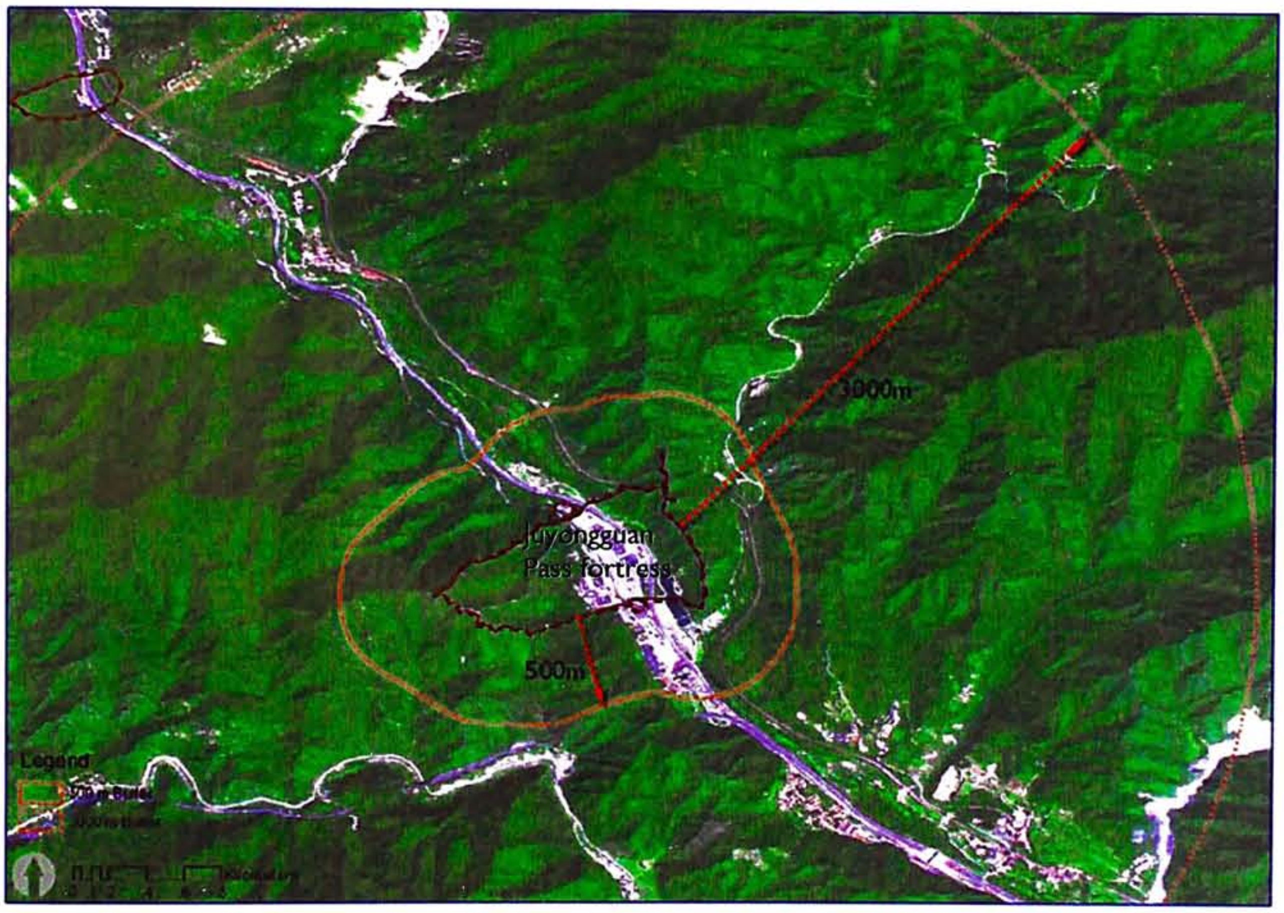
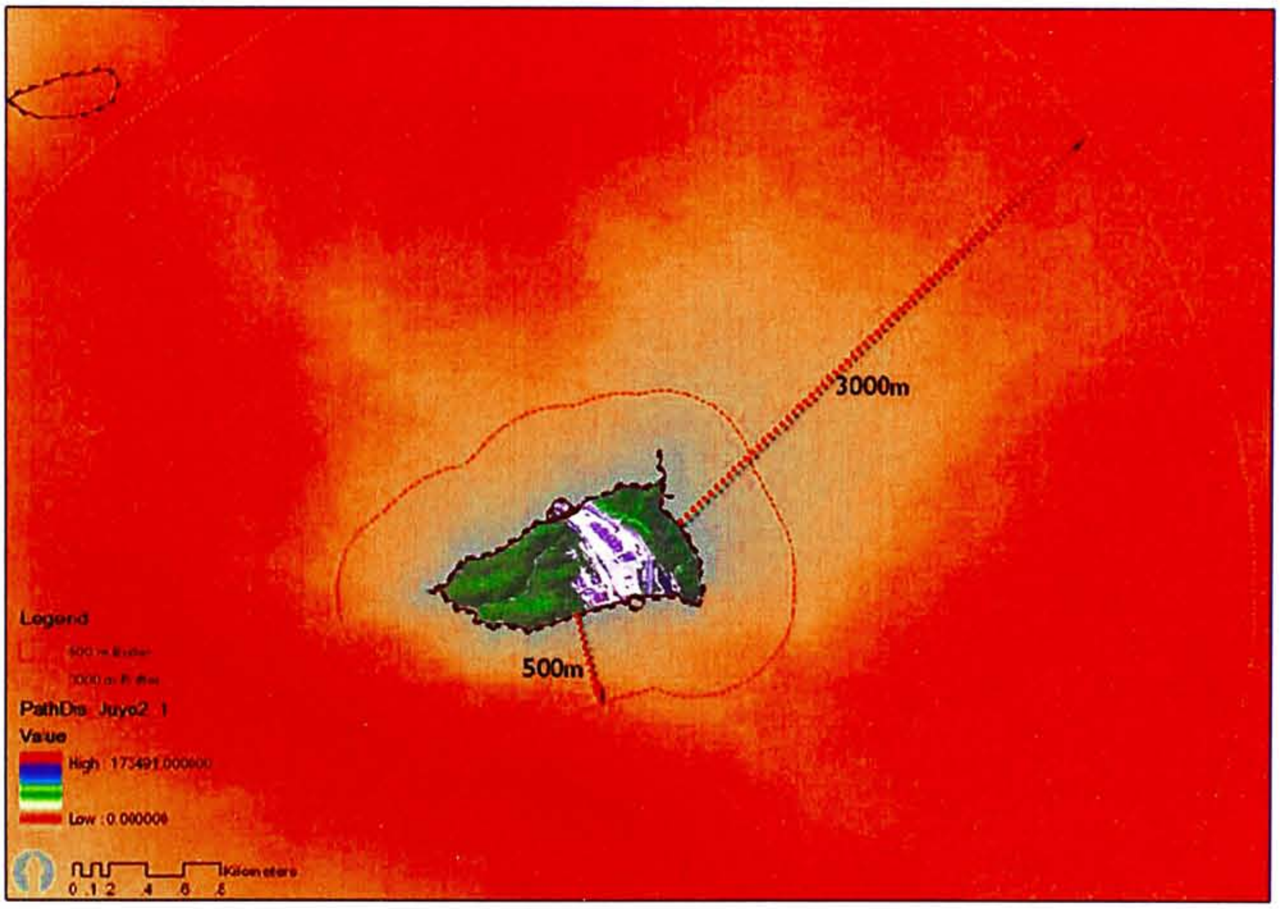


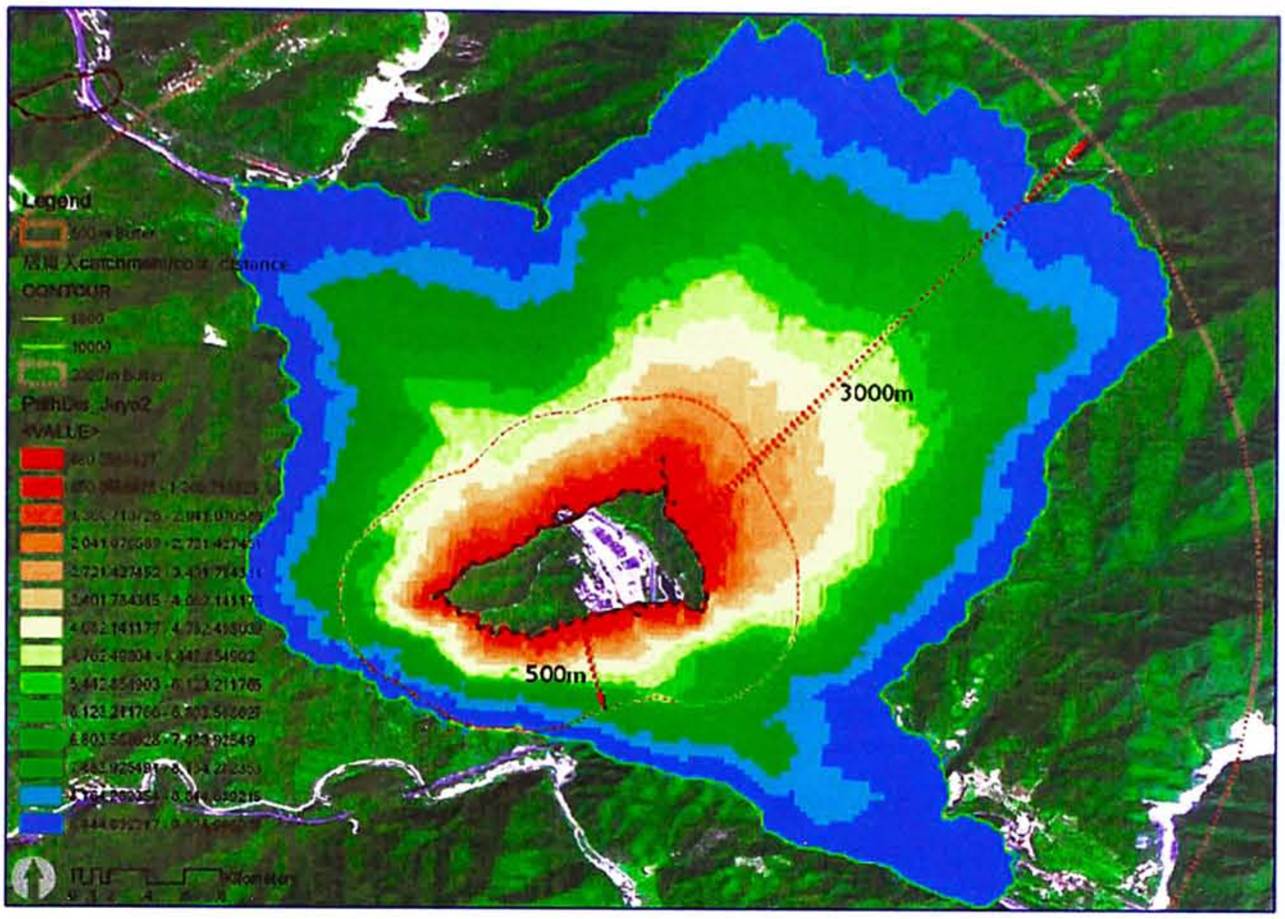
Figure 71

Two reference buffer distances introduced to fulfill the conservation requirements of fortress wall of the Juyongguan Pass

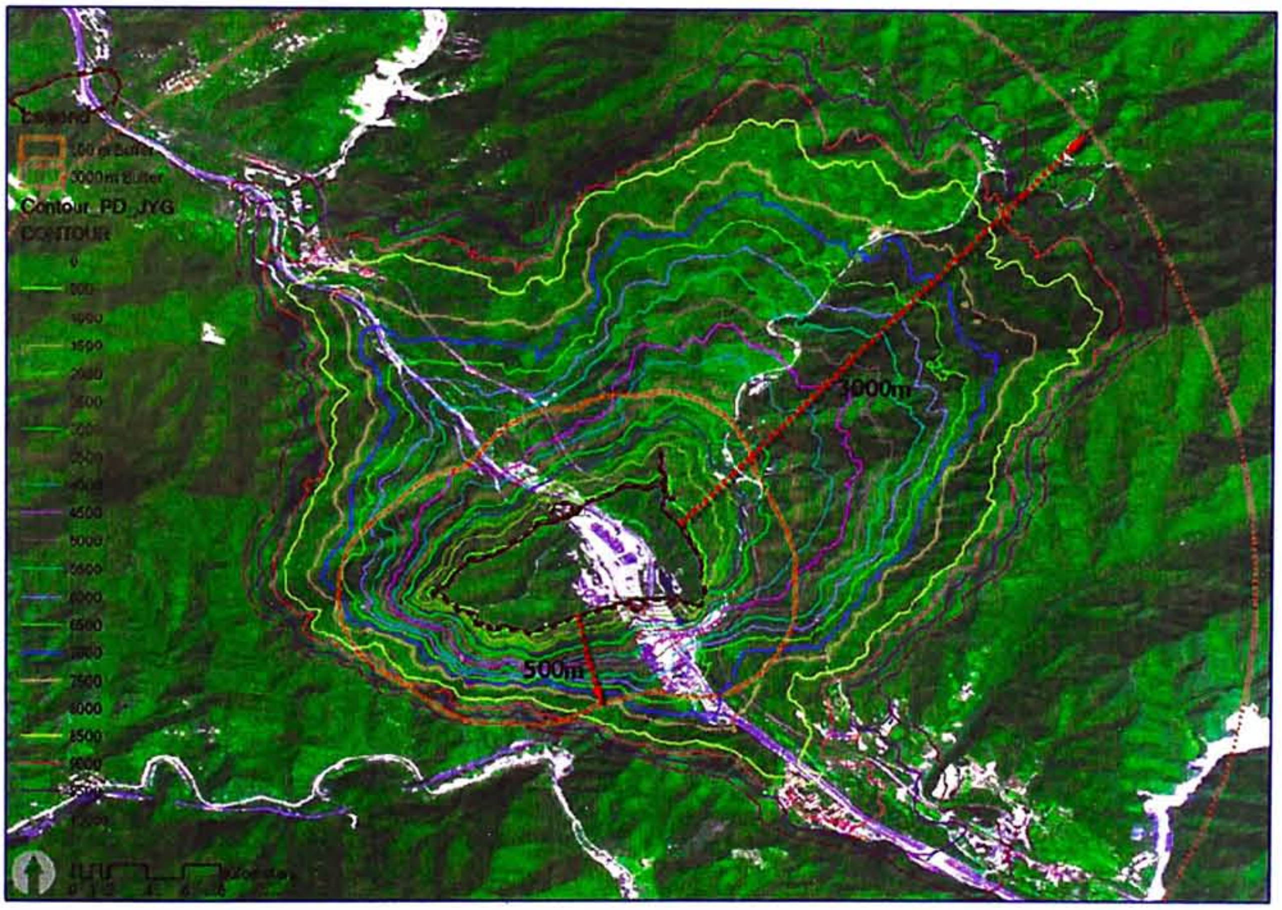
Given that spatial control catchment is irregular, thresholds are introduced by comparing the cost contours of the cost-distance surface with the abovementioned buffer distances. In the Juyongguan case, there is a very clear boundary of spatial control in the middle of the western slope of Jinguishan. This is located exactly at the boundary of the 500 meter buffer zone (Figure 72). A cost unit of 10,000 around this location is assigned as the bottom line of protective location. This means that areas with costs of lower than 10,000 will be defined as falling within the conservation scope. Meanwhile, this 10,000 cost unit contour also reaches the Shaoguoyu 燒鍋峪 Valley at a location around the 3,000 meter boundary (see Figure 72). This conservation scope can therefore be used to fulfill all aspects of the local legislation and the validity of this delimitation supports scientific plan decision-making.



(a)



(b)



(c)

Figure 72

Spatial control cost of Juyongguan Pass: (a) the path distance value surface as control level distribution map around the Pass fortress; (b) spatial control cost distribution less than

10,000 cost units; (c) the translated spatial control level contours

Detailed delimitations

As the enclosed fortress wall has already clearly defined the property boundary, this procedure has to be used merely to delineate the selected basic conservation scope into the three remaining kinds of regions. By inspecting the geographical context, a 300 meter buffer zone can be set on the eastern side from the two strategic fortress facilities to the foot of Cuipingshan Mountain 翠屏山. These two knots are the East Hill Archery Pavilion 東山箭樓 situated on one of the peak points along the eastern hill ridge and the No. 5 watchtower, which is the most defensively significant point along the frontier that is used to control the Pass Valley and the Yongan River 永安河, as well as the trails from Xisancha and Jiuxianmiao in the east. The 300 meter buffer zone is considered the basis for inner delimitation. Meanwhile, the scope up to 5,500 cost units is found to be mostly coherent with the 300 meter buffer zone boundary in the narrow routes available to the west and south of the fortress wall. Therefore, the 300 meter buffer zone is firstly defined as a core area. This 300 meter buffer zone line is then combined with the 5,500 cost units boundary to delineate buffer zone I (Figure 73). The other areas with costs from 5,500 to 10,000 units serve as buffer zone II (Figure 74). These datasets can be exported in any format for further usage in planning support (Figure 75).

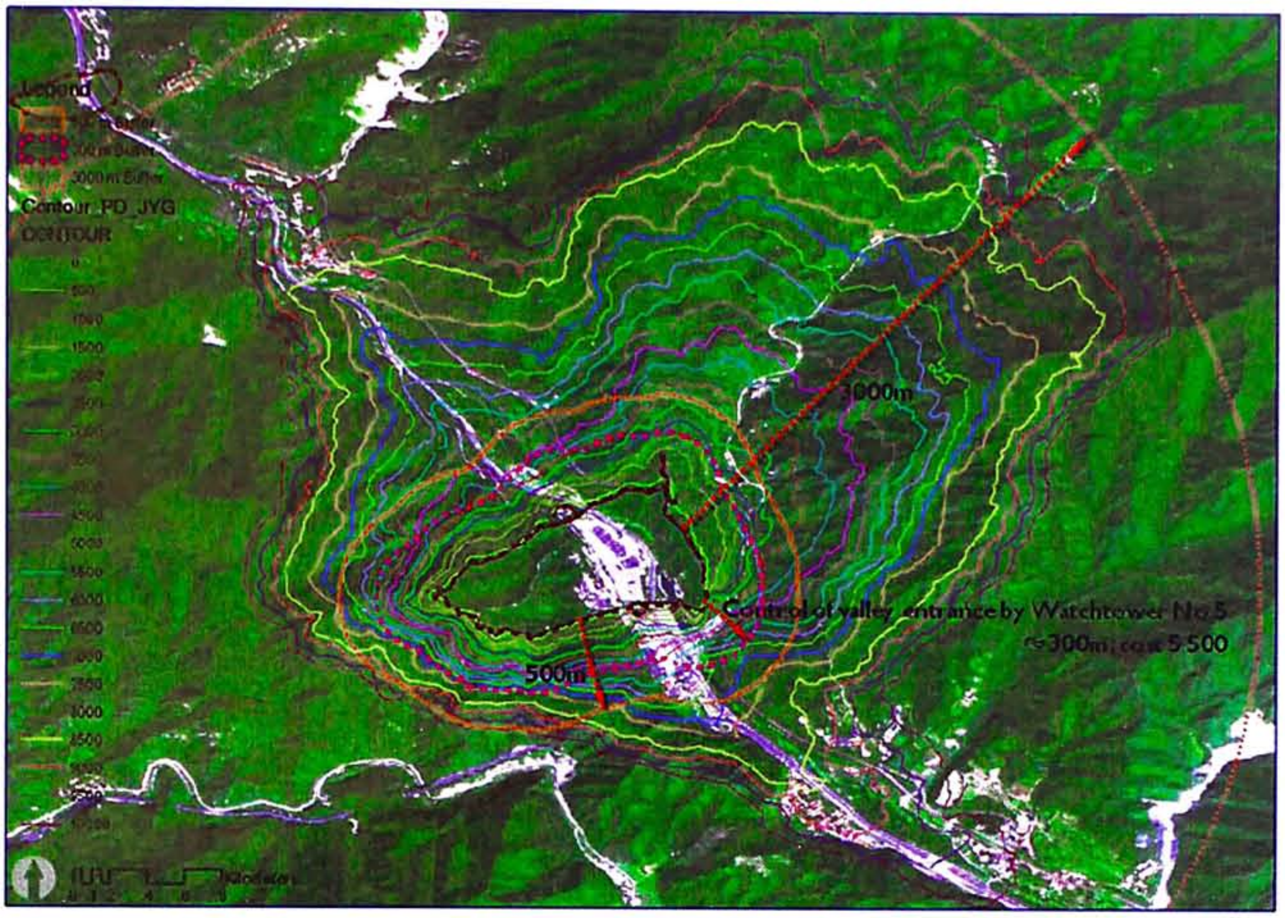


Figure 73

The buffer zone I delimitation

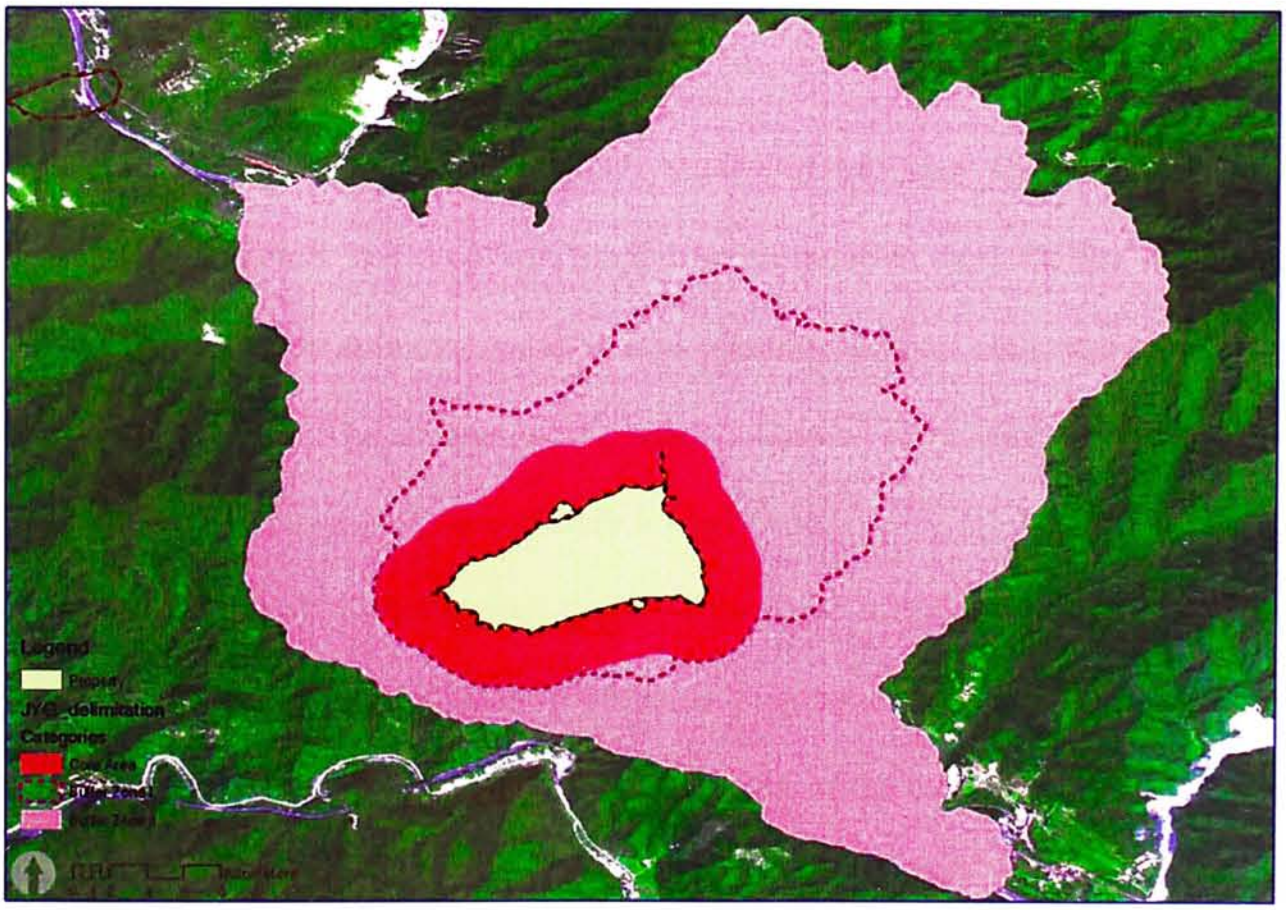


Figure 74

Conservation planning support delimitations of Juyongguan Pass fortress

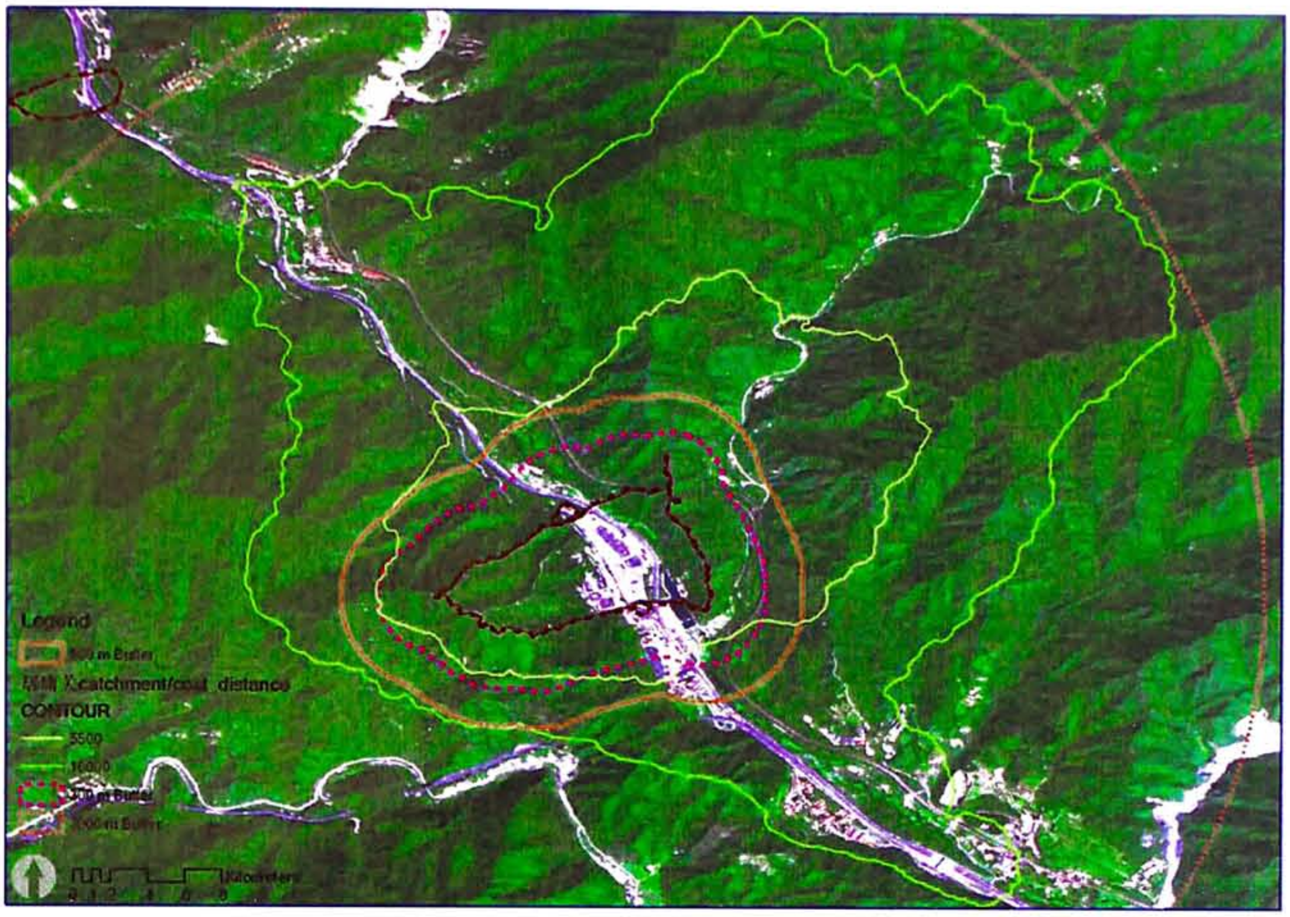


Figure 75

Vector delimitations boundary data which can be exported to further planning support

5.7 Summary and Discussion

Through both regional and large-scale case studies of the Great Wall, a cultural route investigation scheme is tested for movement simulation and facility functional interpretation to study authenticity, as well as planning support delimitation based on spatial control value. The scheme works on a continuous scale, and spatial analytical approaches to both cost-surface and visibility are tested.

In the large-scale investigation, the most probable invasion routes are found to be consistent with those identified in previous geographical history studies, and the efficiency of the Great Wall has been simulated. One of the most vulnerable corridors through Juyongguan Pass as calculated in the large-scale study is enlarged. Natural context, routes and the military facilities of the Juyongguan defensive system, as well as their interrelationships, are investigated through visibility mapping and comparative cost-surface analyses. The analytical results reveal some unexpected spatial phenomena. While a preliminary interpretation is provided, further investigation is necessary. In addition, the spatial control power of the Badaling Great Wall and Juyongguan Pass fortress are mapped using functionality approaches. Finally, these maps are reclassified and heritage setting conservation scopes are suggested.

In addition to the results presented in this study, a large number of methodological and technical experiments have been executed. It is certain that many methodological problems will arise if a “naive” analysis is undertaken using GIS, a cross-disciplinary application, without considering its limits (van Leusen, 2002). Examples of these problems include the edge effect, modeling algorithms, and system errors. It is suggested that visibility and CSA should be used in a more rigorous manner and that model assumptions should be examined carefully. The over-interpretation of analytical results is dangerous and should be avoided. The thesis involves further detailed discussion in the next chapter.

Chapter 6

CONCLUSION AND DISCUSSION

This thesis is aimed at addressing the existing shortcomings in the methodological approaches used in and practical implementation of cultural route heritage studies. The investigation work undertaken has explored the possibility of establishing a scheme to evaluate cultural route tangible components in a structural way. GIS analyses are used to illustrate spatial phenomena and create knowledge based on historical interpretations of cultural routes. The spatial analysis results are tested for use in extracting conservation support delimitations.

6.1 Utility of the Proposed Study Scheme

Through a case study, this thesis has explored the proposed scientific investigation and planning support scheme in terms of its theoretical, methodological, and practical aspects.

6.1.1 The Theoretical Aspect

First of all, although the study is not designed as a theoretical investigation, the lack of a valid theoretical basis for the cultural route discipline means that a unique thesis-specific hypothesis has to be created. Heritage authenticity and its substratum in tangible cultural route attributes can be categorized into three physical components: context, constructions, and paths. The spatial and functional interrelationships among these three components must also be considered. Through the case study experiment, it has been possible to represent these three components in digital datasets by introducing DEM, hydraulic analysis, RS and cost-surface analysis. In addition, the interrelationships among these three components can be replicated through the adoption of digital approaches. For example, cost-surface modeling integrates the topographical features of settings, property functions and their spatial characteristics and parameters and is implemented through different modeling assumptions and relevant algorithms to simulate movement and replicate routes within the framework formed by the abovementioned tangible cultural route attributes and relationships.

The Great Wall case study, which is carried out on both large and regional scales, has demonstrated path selection and facility functional alternations using different models with tangible and functional parameter combinations. These modeling approaches have allowed the basic theoretical underpinnings explored in section 3.1.2 to 3.1.4 to be implemented through this GIS-based case study. Although it has not been possible to explore all the authenticity parameters or introduce them as variables, in the analytical scheme, the cost-surface models have been shown to be valid and reliable to a certain degree in interpreting movement in historical periods, such as in the facility location context and facility distribution under mobility effects (see the discussion in section 5.3.2 and the comparison with Waldron (1990) in Figure 41). It can be concluded that the scheme works in theory.

6.1.2 Methodological Aspect

The use of GIS-based methodologies to support the investigation scheme has been discussed in Chapter 4 and tested through a case study. GIS is used in data acquisition, spatial analysis and mapping to create knowledge on both historical interpretation and spatial characteristics, a result that cannot be achieved using other approaches. The two main analytical approaches suggested by van Leusen (2002), visibility and cost-surface analysis, have also been tested in the case study and found to be effective based on the assumptions made for the analytical scheme, such as in functional interpretation, anisotropic cost replication and movement simulation. Moreover, digital analysis carried out in the regional case study has also revealed the possible occurrence of additional cultural route historical phenomena that cannot be revealed or replicated through other approaches. The case study has confirmed the hypothesis that scientific investigation in which digital and spatial tools are used benefits cultural route knowledge by revealing its substratum in terms of both historical phenomena and spatial structures. Nevertheless, many methodological and technical issues encountered in the course of using GIS must be considered or further explored to enhance the validity of the analytical scheme.

6.1.3 Conservation Practice

Conservation planning decision-making support is the ultimate end-use of the scheme as a whole. Delimitations suggested by the proposed system are actually an extension of the analytical data. The support that the scheme can offer in the context of conservation practice is thus integrated into the investigation system.

The regional case study has successfully translated the cost distance of property, which is interpreted as the spatial control or influence exerted by the property in terms of its historical functionality and landscape structure, into the suggested scope of conservation measures to protect the Juyongguan Pass fortress setting. By contrast, the implementation of spatial allocation in the large-scale Great Wall study has not fulfilled expectations, either in terms of the retrieval of historical management boundaries or the allocation of conservation territories. The lack of success in this model may be due to the complexity of spatial variables and the application of a cost-surface model that is too abstract. While the introduction of conservation planning support into heritage management practice appears possible, it is first necessary to further develop the spatial allocation approach.

6.2 Research Contributions and Limitations

It has been shown that the main body of the proposed system provides both new perspectives on how to investigate cultural route heritage and innovative methods for doing so. The most important original contribution of this thesis is the establishment of dynamic delimitation criteria based on heritage and setting authenticities and the approach used to apply such criteria by identifying spatial control distribution through accumulative cost surfaces and reclassifying costs into categorized delimitations. This approach links heritage research directly with conservation practice and can be used to overcome the common CRM problem indicated in the literature review. In this specific case study, the thesis uncovers some new evidences and proposes preliminary interpretations of the military performance of Ming Great Walls in terms of both the holistic system and the Juyongguan area.

In addition to limitations of its findings, this thesis has the following limitations:

1. From a theoretical perspective, it is quite difficult to define detailed authenticity attributes within the system. In addition, the case studied is not a typical example of a cultural route. Many tasks had to be left to one side in implementing the case study, which indicates that the proposed GIS-based methodology may be insufficiently flexible, or even that it cannot be applied in practice.
2. As suggested by landscape archaeologists, the cautious application of GIS spatial analysis is an essential premise on which this digital tool must be used. However, only general methodological concerns or suggestions, as opposed to

systematic validity checking procedures, can be included in the system at the current stage. Because of this, system errors may arise if the system is applied to other cultural routes by non-professional GIS users.

3. Due to time and resource constraints, some effective but complicated validity methods suggested in the system design have not been applied in the case study. This may mean that there are questions over data accuracy and the consequent spatial phenomena mapping, which may act as constraints if more detailed historical interpretation is attempted.

Some of these limitations are beyond the research framework set for this thesis. Most of the remaining concerns will be developed in further investigation work. In view of the possible system errors, in addition to use the normal treatments to address such issues, such as additional sampling attempts and standard treatments on boundary effects, this thesis has also had to focus on more physical and less dynamic variables. Furthermore, only very conservative historical interpretations of the analytical results can be made.

6.3 Further Research

This thesis has produced a framework for the study of cultural route heritage assets and the associated conservation planning support. In addition, basic methodologies and technologies have been used. Further research may be undertaken based on these two themes.

1. Firstly, on the framework level, the following developments are suggested:
    a) In-depth theoretical analyses on cultural landscapes and other typical cultural route and property cases. The authenticity performance and characteristics of more kinds of cultural route component types or holistic route structures need

to be understood in detail to allow for the design of suitable spatial analytical models and more efficient and flexible research procedures.

   b) Suitable interface between analytical data and end-usages in planning and management. There is a need for conservation planning to be integrated effectively into either ordinary land use planning or specific heritage conservation planning or management. The task is to establish how research results and data transferred into standard planning or heritage management systems should be presented. The standardization of analytical processes and data formats, interdisciplinary interaction, scientific visualization, etc., needs to be considered.

2. Secondly, methodological and technological developments need to be harnessed in the following ways:
   a) Establishment of heritage databases. It is essential that sustainable database systems be built for case studies to improve the efficiency of data management and analysis. A CRM system for specific cases may eventually be developed. In addition, database management systems can enhance the integrity of space information data sources.
   b) Development and standardization of validity methods. The establishment of a validation mechanism through data transformation, algorithm calibration and further statistic analysis is an urgent priority.
   c) Investigation of facility location models. Given that construction site modeling has been excluded from this thesis, it has only been possible to interpret facility location on a passive basis. Site selection scenarios for cultural route facilities should be investigated using other approaches such as what-if analysis, site correlation modeling, prediction, and spatial

distributions.

d) Introduction of other sophisticated spatial analytical methods. New approaches to spatial analysis adapted from other GIS technologies need to be developed to facilitate the interpretation of cultural route spatial or functional characteristics.

In addition to these two issues, further research that adds to the existing knowledge on the historical background to and heritage information on the subject of the case study would be beneficial. There is a lot of room for enhancing the Great Wall case study on both an interprovincial and regional level by comparing the analytical results to, or even modifying the analytical model according to, valuable historical literature and previous studies carried out in the disciplines of history, geography and archaeology.

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