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‘Benefit Maximizing Routes’: Development and Evaluation Using the Historical Roads of Korea’s Joseon Dynasty (1392–1910)

RESEARCH ARTICLE

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ABSTRACT

Least cost paths (LCPs) have been widely used by archaeologists and geographers to reconstruct probable routes of movement within past landscapes using GIS-based modelling. By definition, LCP modelling is based on the premise that ‘least cost’ features as the primary factor in the decision-making of movement. It can be argued, however, that movement within the landscape was structured not only by the need to *minimize costs* but also by the desire to *maximize benefits*. This study introduces a new way of estimating terrain costs that can factor in this tendency towards ‘benefit maximization’ when modelling routes. This alternative methodology features a distinctive way of perceiving the landscape, which differs from the grid-based division of the landscape generally used in LCP modelling. The landscape is seen to be made up of ten different ‘hillslope position units’ (which are generic landscape units widely used in landscape evolution studies) and ‘movement suitability’ values are estimated for each of the hillslope position units. These values are then used to produce a ‘hillslope position unit movement suitability’ (HPMS) cost surface. The evaluation of the HPMS cost surface is undertaken by comparing HPMS-based routes and slope gradient-based LCPs against the historical roads of Korea’s Joseon Dynasty (1392–1910). It is observed that HPMS-based routes demonstrate a greater degree of correspondence with historically confirmed routes, compared to slope gradient-based LCPs. The similarity between HPMS-based routes and historically confirmed routes is found to be greater in mountainous regions *vis-à-vis* non-mountainous regions. It is proposed that, by taking into account human desire to utilize beneficial landscapes, HPMS-based cost surfaces may result in modelled routes that are closer to actual past experiences.

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1. INTRODUCTION

The least cost path (LCP) principle has been widely applied by archaeologists and geographers when using GIS-based modelling to reconstruct probable routes of movement within past landscapes. However, the restrictive nature of LCP modelling, which tends to produce only a *single* optimal route or consider only a *single* parameter, has been noted (Gowen & de Smet 2020; McLean & Rubio-Campillo 2022), and new ways of modelling ancient movement that look beyond LCPs to explore multiple optimal routes or the range of probable routes between points have come to be proposed, such as those utilizing circuit theory (Howey 2011), flow accumulation (Frachetti *et al.* 2017), focal mobility networks (Parcero-Oubiña *et al.* 2019), or Monte Carlo simulation (Lewis 2021). This study also aims to address the restrictive nature of LCP modelling, albeit from a different perspective. In our case, we attempt to broaden the discourse on modelling ancient movement by presenting a way of modelling routes that focuses on the desire to *maximize benefits*, rather than the need to *minimize costs*. This is done by developing a new way of estimating terrain costs – thereby presenting an alternative to slope gradient-based cost surfaces – which can factor in the recognition that human decision-making regarding movement would have been guided by both cost minimization and benefit maximization.[1] In addition, in developing this alternative cost surface, a distinctive way of perceiving the landscape in terms of 'hillslope position units' is adopted. It is to these units that movement suitability values are attributed.

The idea to attribute movement suitability values to hillslope position units was borne out of the authors' participation in a multi-disciplinary research initiative ('Silkroadpia') that aimed to imagine the 'eastern end of the Silk Roads' in an alternative way (Yang *et al.* 2017; Lee *et al.* 2019). The research team consisted of archaeologists, geographers, historians, and anthropologists, and the authors' task was to develop an algorithm that would reconstruct movements and connections between known archaeological sites of southern Korea, thereby allowing the region to play a greater role in the discourse on the 'eastern end of the Silk Roads'. The interdisciplinary nature of the research group meant that the backdrop against which human movement took place could not be perceived as an abstract space, nor could it be reduced merely into topographic indices, such as slope gradient or relative elevation. Routes had to be modelled in a way that took into consideration human engagement with the surrounding environment. This is why the authors developed an alternative cost surface in which the landscape was divided into different 'hillslope position units', which are generic landscape units that can be recognized and experienced during human movement.

In this article we begin by introducing the process by which we developed a new way of estimating terrain costs, based on which 'benefit maximizing' routes were modelled. We also present (1) the 'hillslope position unit classification method' that was applied to the landscape of southern Korea, (2) the 'hillslope position unit movement suitability (HPMS) index' that was used to attribute movement suitability values to each hillslope position unit, and (3) the cost map that was produced using HPMS as the primary cost factor. Following on from this, we evaluate the efficacy of using HPMS-based routes *vis-à-vis* slope gradient-based LCPs by comparing them against the historically established routes of Korea's Joseon Dynasty. Finally, we discuss the way in which the modelling of routes with a focus on 'benefit maximization' (as opposed to 'least cost') may act to allow GIS-based modelling to participate in the wider archaeological discourse on movement as a practice of constructing social landscapes.

2. DEVELOPING A TERRAIN-BASED COST SURFACE BY UTILIZING 'HILLSLOPE POSITION UNITS' AND 'MOVEMENT SUITABILITY COSTS'

Slope gradient (along with distance) has been favored as the primary cost factor in LCP modelling (see Table 1). This has been due to the efficacy of topographic gradient in estimating travel time (e.g. the Tobler hiking function (Tobler 1993), Naismith's rule (Langmuir 1984)) or energy consumption (e.g. Minetti's formula for energy expenditure (Minetti *et al.* 2002)). The fact that elevation data is relatively easy to obtain (Verhagen, Nuninger & Groenhuijzen 2019: 226), as well as the fact that in-depth examinations of hiking functions (e.g. by Herzog 2010; Llobera & Sluckin 2007) have made them more accessible to the archaeological community, may have also contributed to the popularity of slope as a primary cost factor.

However, it must also be noted that a slope-based modelling of the landscape is not without problems. In particular, it cannot take into account the topographical, pedological, and hydrological characteristics of the landscape. In addition, it is heavily scale-dependent, with factors such as cell size having a significant influence on the outcome of modelling. As such, other terrain features have come to be considered as cost factors, including landcover and soil properties. Herzog (2014: Table 3), for example, has summarized the results of physiological studies of walking in different land cover or soil conditions that may be used to calculate movement costs. However, as has been noted by Verhagen, Nuninger & Groenhuijzen (2019: 228), movement capability according to vegetation and soil type is rather difficult to estimate in practice.

PREVIOUS STUDIES ON LCPS	COST SURFACE FUNCTION
Bell & Lock 2000	**Slope**, Viewsheds
Bell, Wilson & Wickham 2002	**Slope**, Land cover
Conolly & Lake 2006	**Slope**, Land cover, Water, Attractors, Existing routes
De Silva & Pizziolo 2001	**Slope**
Diwan & Doumit 2017	**Slope**
Fiz & Orengo Romeu 2007	**Slope**, Land cover, Water
Gustas & Supernant 2019	Sinuosity, Viewshed, Protected waters, Coastline type, Distance, **Beach slope**, Distance to freshwater
Kantner 2012	**Tobler(s)** = $6^{e-3.5\lvert s+0.05\rvert}$ (s = **Slope**)
Kealy, Louys & O'Connor 2018	Uplift adjusted sea-level, Distance from rivers, **Slope**, Land cover, Relative intervisibility, Distance at sea, Maritime cost
Livingood 2012	**Tobler (s)** combined with canoe-travel
Llobera 2000	**Slope**, Attractors
Murrieta-Flores 2012	$0.031s^2 - 0.025s + 1$ (**s = Slope)**
Rademaker, Reid & Bromley 2012	$15W+2.0(W+L)(L/W)^2+N(W+L)(1.5V^2+0.35Vs)$ **s = Slope**, W = weight of walker, L = load, V = walking speed, N = terrain coefficient
Rogers, Collet & Lugon 2014	**Slope**, Landcover
Rosenswig & Tuñón 2020	Tobler(s), Hernandez(Y) (Hernandez(Y) = $[0.031X^2]+[-0.025X+1]$, **X = slope**)
Supernant 2017	**Slope**
Surface-Evans & White 2012	**Tobler (s)**
Phillips & Leckman 2012	**Tobler (s)**
Whitley & Burns 2008	**Slope**, Water, Existing routes
Zakšek *et al.* 2007	**Slope**, Landscape

Table 1 List of previous studies on LCPs and the cost surface functions that were used.

'Hillslope position', on the other hand, is a terrain feature that has yet to have been utilized in estimating movement costs. Widely used in natural geography as a way of describing landscapes, hillslope position is a complex concept and its designation involves the consideration of topographical, pedological, and hydrological features. This study aims to demonstrate how 'hillslope position units' can be used to produce a cost surface that supports the modelling of routes in which movement is geared towards benefit maximization. To this end, (1) a 'hillslope position unit' map was created from a DEM layer, (2) a 'hillslope position unit movement suitability (HPMS) index' was developed and evaluated, and (3) a HPMS-based cost surface was created.

2.1. INTRODUCING HILLSLOPE POSITION AS A MEANS OF CLASSIFICATION

The evolution and classification of hillslopes has been a key research theme in geomorphology since W. M. Davis's seminal exposition "The Principles of Geographical Description" (Davis 1915). Through the subsequent modelling of hillslope evolution by Carson & Kirkby (1972) and the application of 'soil development' to hillslope evolution modelling by Conacher & Dalrymple (1977), the classification of 'hillslope position' has come to be established not only as a method of categorizing the landscape, but also as an epistemological framework allowing the complex interaction between soils, waterflow, and hillslope profile to be considered.

Following Ruhe & Walker's (1968) definition of five major hillslope profile positions in the late 1960s, various hillslope position classification methods have come to be developed (e.g. MacMillan *et al.* 2000; Drăguţ & Blaschke 2006; Stepinski & Jasiewicz 2011). This study adopts a hillslope position classification scheme in which differences in the interactive relationship between the morphological and positional characteristics of the topography (which influence soil characteristics) are used to delineate the topographic breaks between 'summit', 'shoulder', 'backslope', 'footslope', and 'toeslope' (Wysocki, Schoeneberger & LaGarry 1999).

In applying this hillslope position classification scheme to the Korean landscape, a method of delineating topographic breaks using GIS terrain analysis that had been developed by Park, McSweeney & Lowery (2001) was used. In addition, the automated hillslope position classification process that had been developed by Shim & Park (2020) for the mountainous regions of southern Korea was adopted for the purposes of this study, with adjustments being made for its application to non-mountainous regions. Presented in Figure 1 is a schematic diagram of this automated hillslope position classification process, in which the value of the upslope contributing area (UCA) (the area that can potentially produce runoff to a given location (Erskine *et al.* 2006)), followed by standard curvature, were used to categorize hillside positions in mountainous areas; in non-mountainous areas, standard curvature, followed by slope gradient, were used to categorize hillside positions.

Using a digital elevation model (DEM) generated using NASA Shuttle Radar Topography Mission (SRTM) Version 3.0 Global 1 arc second data downloaded from the USGS earth explorer (https://earthexplorer.usgs.gov/) , ten hillside positions were designated for each tile based on classification undertaken at the unit of the mid-watershed[2]: 'summit', 'shoulder', 'backslope', 'footslope', and 'toeslope' (Figure 2) in 'mountainous' and 'non-mountainous' units. The distinction between 'mountainous units' and 'non-mountainous units' was made according to the topographic division framework presented by Choi *et al.* (2018).

It may be argued that the hillslope position classification method adopted in this study is meaningful in three ways. First, the way in which the classification of hillslope positions took place at the unit of the mid-watershed allowed the categorization of the landscape to take place at a higher resolution. Second, the categorization of the landscape into the different hillslope positions illustrated in Figure 2 may be closer, compared to the slope gradient-based perception of the landscape, to landscape categorizations that come to be experienced and recognized during bodily engagement with that landscape. It should be noted that many geomorphic studies have utilized hillslope position as a useful, tacit knowledge-based metric (Miller 2014: 167). Third, hillslope position classification took place according to a rule-based process, making it possible to ensure that the same results will be reproduced, regardless of the researcher.

2.2. DEVELOPING A HILLSLOPE POSITION UNIT MOVEMENT SUITABILITY INDEX

The production of cost surfaces is central to the modelling of routes. Due to the fact that LCP analysis is generally undertaken using Dijkstra's algorithm (Worboys & Duckham 2004), which uses labels that are positive numbers, cost surfaces tend to be made using raster data with positive values. Assuming that this condition is met, then any type of data can be used to produce a cost surface. Each grid cell of the cost surface must only have a single value, which can be an absolute value or a relative value. For the purposes of this article, the 'movement suitability' costs of each hillslope position unit (i.e. 'hillslope position unit movement suitability (HPMS) index') were used as the data for producing the cost surface.

The development of the HPMS index owes much to a 'land suitability index' that had been developed for Korea in 2010 (Huh *et al.* 2010) by a group of specialists as part of a Korean government initiative to develop land management strategies. In the land suitability index, relative values were provided for the following

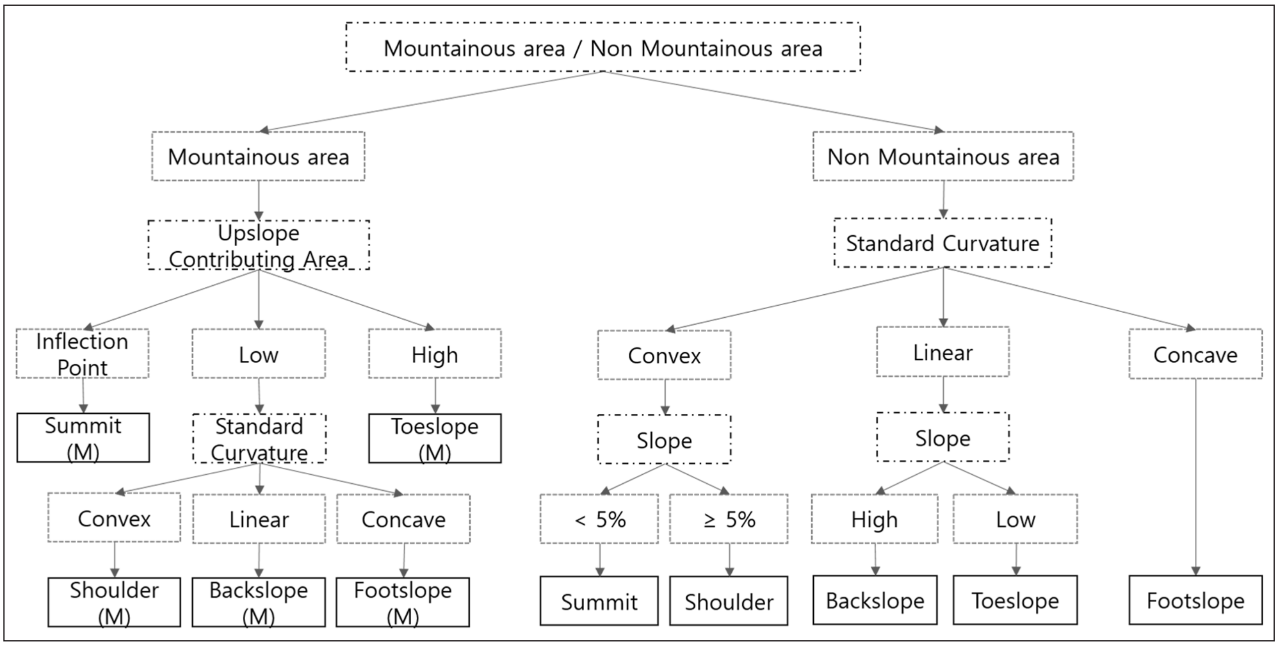

Figure 1 Schematic diagram of the hillslope position classification process for mountainous and non-mountainous areas. Modified and developed from Shim (2020: 53).

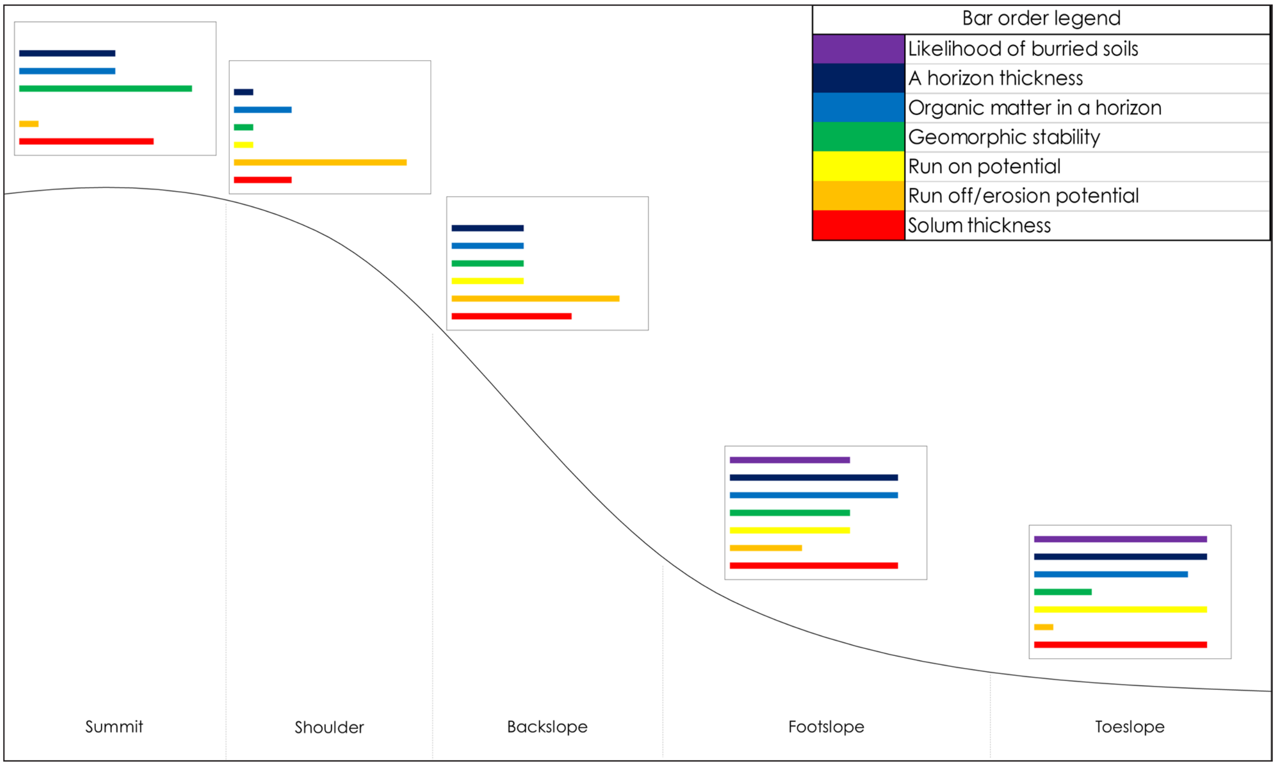

Figure 2 Typical hillslope position scheme and respective soil characteristics. Modified from Schaetzl (2013: 150).

eight criteria for each hillslope position according to the generally accepted principles of soil development and land use laid out by Conacher & Dalrymple (1977): (1) accessibility, (2) ease of use, (3) soil richness, (4) soil water content, (5) water availability, (6) stability against erosion, (7) stability against water submersion, (8) slope stability. A relative value between one to five was given to each criterion,[3] and the mean value was estimated for each hillslope position unit. This mean value was accepted as representing the *relative* land use suitability of hillside position units in mountainous regions; for non-mountainous regions, the mean values were multiplied by two, since the relative ease of access in non-mountainous regions would have acted to enhance land use suitability.

The authors regarded this ‘land suitability index’ to be a good starting point for the development of an index on the relative ‘movement suitability’ of different hillslope position units due to our focus on ‘benefit maximization’ rather than ‘cost minimization’ in evaluating movement suitability. In other words, since we believe that humans, both in the past and present, are motivated by the desire to *maximize benefits*, as well as the need to *minimize costs*, it was hypothesized that areas that are suitable for general land use would also be suitable for movement that pursued benefit maximization.

Consequently, a ‘HPMS index’ was developed in which relative values of ‘movement suitability’ were evaluated for the ten hillslope position units introduced in Section 2.1. The suitability of movement that pursued benefit maximization was estimated using seven of the eight criteria that had been applied to the land use suitability index: (1) accessibility, (2) ease of use, (3) soil water content, (4) water availability, (5) stability against erosion, (6) stability against water submersion, (7) slope stability (‘soil richness’ was taken out since it was a criterion that did not have a direct influence on movement). It should be pointed out these seven criteria also happen to be related to topography; pre-existing research on pathways and roads in pre-modern Korea has shown that the older the route, the greater the role of topography in route formation (e. g. Kim 2004; Min 2010).

Based on the logic laid out above, the authors judged that ‘suitability of land use’ could be used as a valid proxy for ‘suitability of movement that pursued benefit maximization’. For example, it can be proposed that land that was unsuitable for use is also likely to have also been unsuitable for movement which pursued benefit maximization. This is because, as stated above, the latter involves active engagement with elements within the landscape (comprising human beings, non-human beings, living organisms, and non-living things) that are imbued with human meaning; land unsuitable for use is less likely to contain such elements. As such, the relative values for each criterion of the ‘HPMS index’ were first borrowed from the ‘land suitability index’ and then adjusted according to input from historical sources[4] on movement in pre-modern times (Table 2).

A notable feature of this index is that the movement suitability index values are greater for ‘footslope’ *vis-à-vis* ‘toeslope’ in non-mountainous areas. Previous research (Kim 2004) has shown that routes used in pre-modern times in Korea in non-mountainous regions tended to be formed along (1) riverine and coastal alluvial plains (i.e.

HILLSLOPE POSITION	SUMMIT	SHOULDER	BACKSLOPE	FOOTSLOPE	TOESLOPE
Accessibility	1	1	2	4	5
Ease of use	1	1	2	5	4
Soil water content	1	1	2	4	3
Water availability	1	1	2	4	3
Stability against erosion	1	2	3	5	4
Stability against flooding	5	5	5	2	4
Slope stability	1	2	2	5	4
Movement Suitability Index for Mountainous areas (A) (Final Cost (1/A))	1.57 (0.64)	1.86 (0.54)	2.57 (0.39)	3.86 (0.26)	4.14 (0.24)
Movement Suitability Index for Non-mountainous area (B = A*2) (Final Cost (1/B))	3.14 (0.32)	3.72 (0.27)	5.14 (0.19)	8.28 (0.12)	7.72 (0.13)

Table 2 The relative values of the Movement Suitability Index and final costs according to hillslope position (final cost is reciprocal of the Movement Suitability Index value).

'toeslope') and (2) at the base of hillslopes ('footslope') due to low topographic fluctuation in these units and the distribution of nearby settlements. However, previous studies have also observed that, in areas of meandering rivers, the boundary between alluvial plains and hillsides (i.e. footslope) was preferred over riverine and coastal alluvial plains (i.e. toeslope) due to the inevitable increase in the distance travelled, as well as a danger of roads being washed away during floods (Kim 2004: 370).

In the case of mountainous areas, however, 'toeslope' provided the highest movement suitability values because roads used in mountainous regions in pre-modern Korea are said to have been located at the base of valleys (i.e. toeslope), where the altitude is relatively low and the topographic fluctuation is also mild (Kim 2004: 370). Routes tended to extend along the valley way before crossing over a pass and continuing into the next valley way. Valleys with relatively wide bases were preferred, most likely because there was a higher possibility of settlements being located in the vicinity. In addition, wide valleys are formed by both downward erosion and lateral erosion; lateral erosion results in a relatively low hillslope gradient, which in turn results in a relatively low cost when crossing mountain passes.

2.3. PRODUCING A HILLSLOPE POSITION UNIT MOVEMENT SUITABILITY (HPMS)-BASED COST SURFACE

As discussed above, any type of raster data with positive values can be used to produce a cost surface. In the case of the HPMS index examined above, the higher values represent higher suitability for movement. As such, the inversed values of the HPMS index were used in order to produce the HPMS-based cost surface. Presented in Figure 3 is the hillslope position classification map of southern Korea, which was created using a DEM. A detailed image of this HPMS-based cost surface at the mid-watershed unit (of Geochang, in southern Korea) is presented in Figure 4. In addition, a slope gradient-based cost surface was also produced for the comparison of modelled routes.

3. EVALUATION OF HPMS-BASED MODELLED ROUTES: A CASE STUDY OF THE HISTORICAL ROADS OF KOREA'S JOSEON DYNASTY

The Joseon Dynasty of Korea (1392–1910) was characterized by a patrimonial centralized ruling system based on the tenets of Confucianism, and the central government exercised great control over the local areas via the Main Roads (*daero*) that ran between Hanyang (present-day Seoul), which was the capital city, and the provincial centers. At first, the Main Roads network consisted only of six roads but by the mid-19th century, ten Main Roads were recorded (e.g. in *Daedongjiji* (*Geography of the Great East*)). This increase in the number of roads was not due to the founding of new roads but rather as a result of pre-existing roads being elevated to the status of a 'Main Road'. In addition, even during the peak of their popularity, the roads remained fairly narrow, wide-enough so that a cart laden with goods could only just pass by (Choi 1995). There have been various efforts to reconstruct, digitize, and compile databases of the Main Roads,[5] with some roads being more well-researched than others. The authors were fortunate enough to obtain vector data for eight of the Main Roads. As these eight roads passed through the different landscapes of southern Korea, they were deemed sufficient enough to test the reliability of HPMS-based modelled routes.

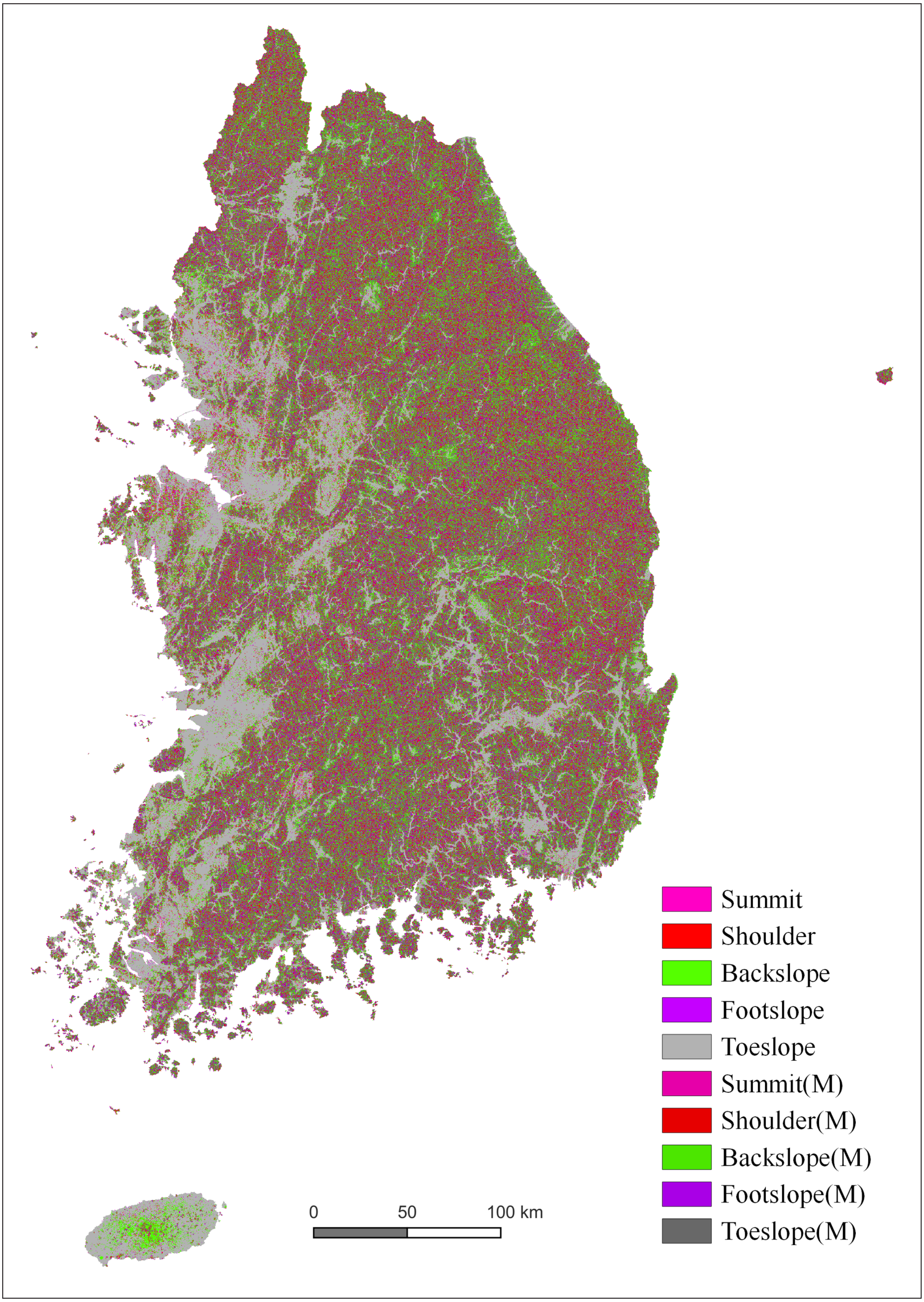

Figure 3 Result of the Hillslope Position Classification of the landscape of southern Korea (Shim 2020: 54).

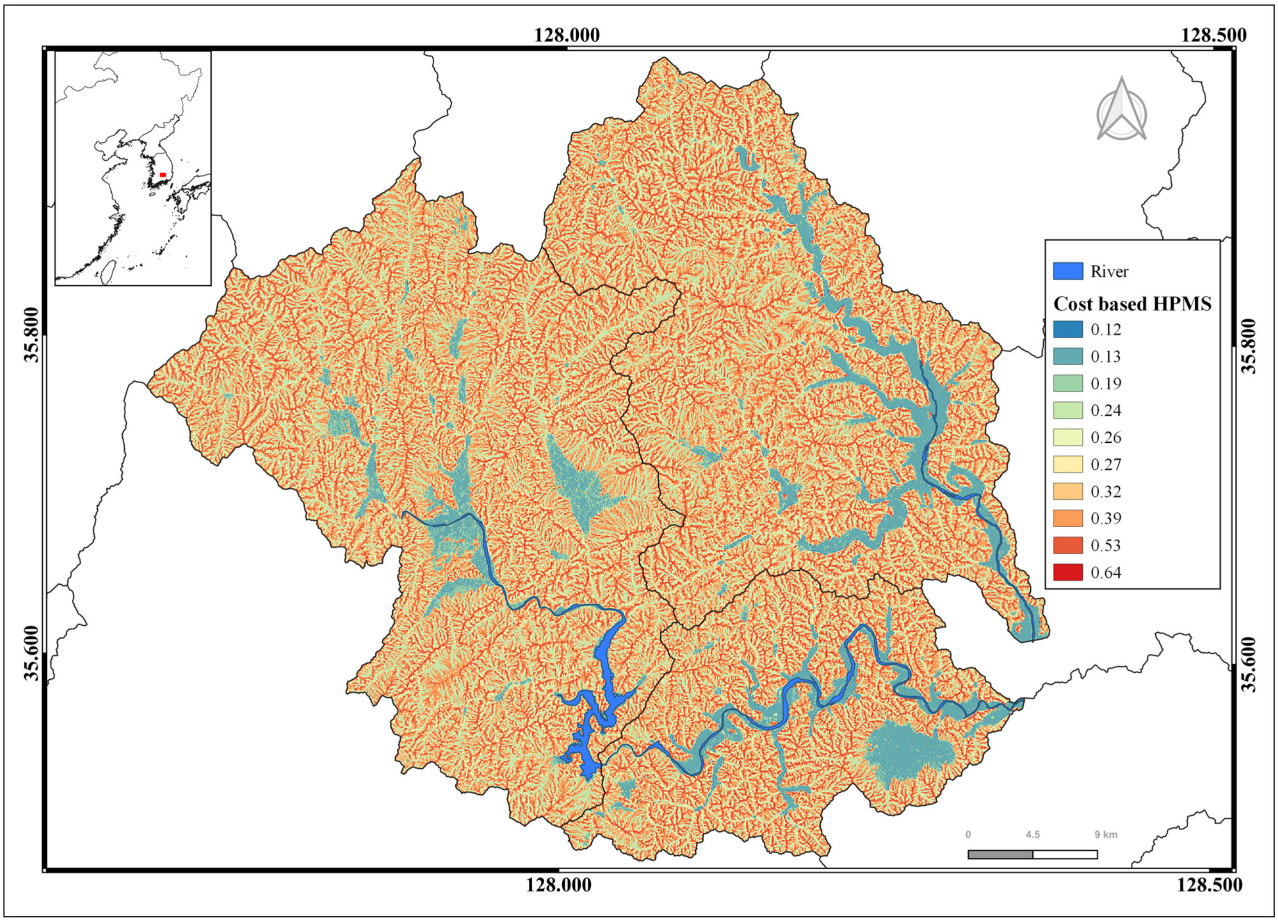

Figure 4 Detail of the Hillslope Position Movement Suitability (HPMS)-based Cost Surface (Geochang, southern Korea); the cost values are the inverse values of the HPMS (see Table 2).

3.1. OVERALL COMPARISON OF HPMS-BASED MODELLED ROUTES, SLOPE GRADIENT-BASED LCPS, AND HISTORICAL ROADS

Using the departure and arrival points of eight of the Main Roads, eight HPMS-based routes and eight slope gradient-based LCPs were modelled. All three types of routes were then compared in ArcMap 10.8, the results of which are presented in Table 3. It can be noted, first of all, that the total distance of movement was the shortest for slope gradient-based LCPs (1907.2 km), and longest for HPMS-based routes (2,005.4 km). This indicates that HPMS-based routes tended to circumvent more (+14.2 km) and slope gradient-based LCPs tended to be more direct (–84 km) than the Joseon Main Roads (1991.2 km). In addition, the ruggedness values, which represent the amount of elevation difference between the adjacent cells of the DEM (Riley, DeGloria & Elliot 1999), of the HPMS-based and slope gradient-based routes were compared. The results show that, compared to slope gradient-based routes (mean ruggedness value: 6.22), HPMS-based routes (mean ruggedness value: 4.72) were less rugged and therefore required less effort per unit of movement.

In order to establish possible correlations between the landscape and the decision to follow more circumventing or direct routes, additional analysis was undertaken on the sections of the modelled routes that did not correspond with the routes of the Joseon Main Roads. Overall, HPMS-based routes were found to fit better with the Joseon Main Roads. A comparison of the length of non-corresponding sections between the Joseon Main Roads and both types of modelled routes shows that the length of the non-corresponding sections was greater for slope gradient-based LCPs (+172.1 km) (Table 4).

The vector data of the non-corresponding sections were then plotted against a digitized map in which mountainous and non-mountainous areas were distinguished, and the lengths and percentages of the non-corresponding sections of both types of modelled routes for mountainous and non-mountainous areas were calculated in GIS. The results of the analysis, also presented in Table 4, illustrate that both types of modelled routes fit better with the Main Roads in mountainous regions. In particular, in the case of HPMS-based routes, only 9% of the non-corresponding sections belong to mountainous regions. For slope gradient-based LCPs, 37% of the non-corresponding sections belonged to mountainous regions.

In order to establish if there were certain reasons for the lack of fit, a detailed examination of the ways in which the two types of modelled routes did not correspond with the routes of the Main Roads was also carried out, and is presented in the following section.

ROUTE	TOTAL LENGTH (KM)	ELEVATION (M)		SLOPE (M)		RUGGEDNESS	
		MEAN	STD	MEAN	STD	MEAN	STD
Main Roads of the Joseon Dynasty	1991.2	117.38	23.04	5.08	3.78	7.27	5.69
HPMS-based routes	2005.4	106.73	18.37	3.46	2.53	4.72	3.66
Slope-gradient based LCPs	1907.2	106.49	19.65	4.51	3.79	6.22	4.77

Table 3 Comparison of topographic indices for the Joseon Dynasty Main Roads, HPMS-based routes, and slope-gradient based LCPs.

DIFFERENCE	ROUTES OF THE MAIN ROADS OF THE JOSEON DYNASTY	
	HPMS-BASED MODELLED ROUTES	SLOPE GRADIENT-BASED LCPS
Length of difference in mountainous areas	68.1 km (9%)	328.7 km (37%)
Length of difference in non-Mountainous areas	653.2 km (91%)	564.7 km (63%)
Total	721.3 km	893.4 km

Table 4 Comparison of non-corresponding sections between the Joseon Dynasty Main Roads and HPMS-based routes and slope-gradient based LCPs, respectively, for mountainous and non-mountainous areas.

3.2. ROUTE COMPARISON IN MOUNTAINOUS REGIONS

As presented above in Table 4, 9% (68.1 km) of non-corresponding sections for HPMS-based routes occurred in mountainous regions. A detailed examination of these non-corresponding sections established that these sections were located along valleys with relatively wide bases (i.e. toeslope). For example, in the mountainous area of Yangpyeong in central Korea, where the Pyeonghae-ro Road once passed through, the reason for the difference between the HPMS-based route and the route of the Main Roads was due to the tendency of the latter to follow along the riverbank in meandering river sections, even when this required more effort. In contrast, HPMS-based routes tend to be more direct within the same hillslope position unit due to the shortest distance function' embedded in Dijkstra's algorithm. This pattern is well-illustrated in Sections ① & ② of Figure 5.

As for slope gradient-based LCPs, 37% (328.7 km) of non-corresponding sections occurred in mountainous regions (see Table 4). A key pattern responsible for this discrepancy is the way in which the slope gradient-based LCP route cut across ridges. This is well-illustrated in Sections ③ & ④ of Figure 5. This tendency to cut across ridges is due to the fact that minute changes in slope degree at the unit of the grid cell influences path choice.

3.3. ROUTE COMPARISON IN NON-MOUNTAINOUS REGIONS

As presented above in Table 4, 91% (653.2 km) of non-corresponding sections for HPMS-based routes occurred in non-mountainous regions. In addition, 63% (564.7 km) of non-corresponding sections for slope gradient-based LCPs occurred in non-mountainous regions. The reason for this lack of correspondence for both types of modelled routes can first be found in the expansive nature of the toeslope area in non-mountainous regions. In this area, topographic features had little constraint over movement. As such, movement possibilities would have been greater–and therefore the scope of humanistic elements having an influence on the direction of routes greater–which in turn meant that the probability of modelled routes corresponding with actual routes was inevitably smaller.

For example, it can be observed that, in the low-lying area around Jeonju in southwestern Korea, where two of the Joseon Main Roads converged, the two routes that had been modelled using the departure and arrival points of Haenam-ro Road differed drastically from the actual route of Haenam-ro Road (Figure 6, Section ①). The reason for this was because both of the modelled routes continued along in a fairly direct path within a landscape that was not strewn with topographic obstacles. In contrast to this, the actual route of Haenam-ro Road turned sharply to the east at the point where it converged with Tongyeong-ro Road. This change in direction would have been due to humanistic factors that could not have been anticipated when modelling routes. In addition, it was difficult to establish any clear patterns for the difference between HPMS-based routes and gradient-based LCPs (e.g. see Figure 6, ②) in non-mountainous regions. It can be suggested that one of the key reasons for the apparent lack of reliability of both types of modelled routes in non-mountainous landscapes is due to the problems inherent in DEMs, which are discussed further in Section 4.

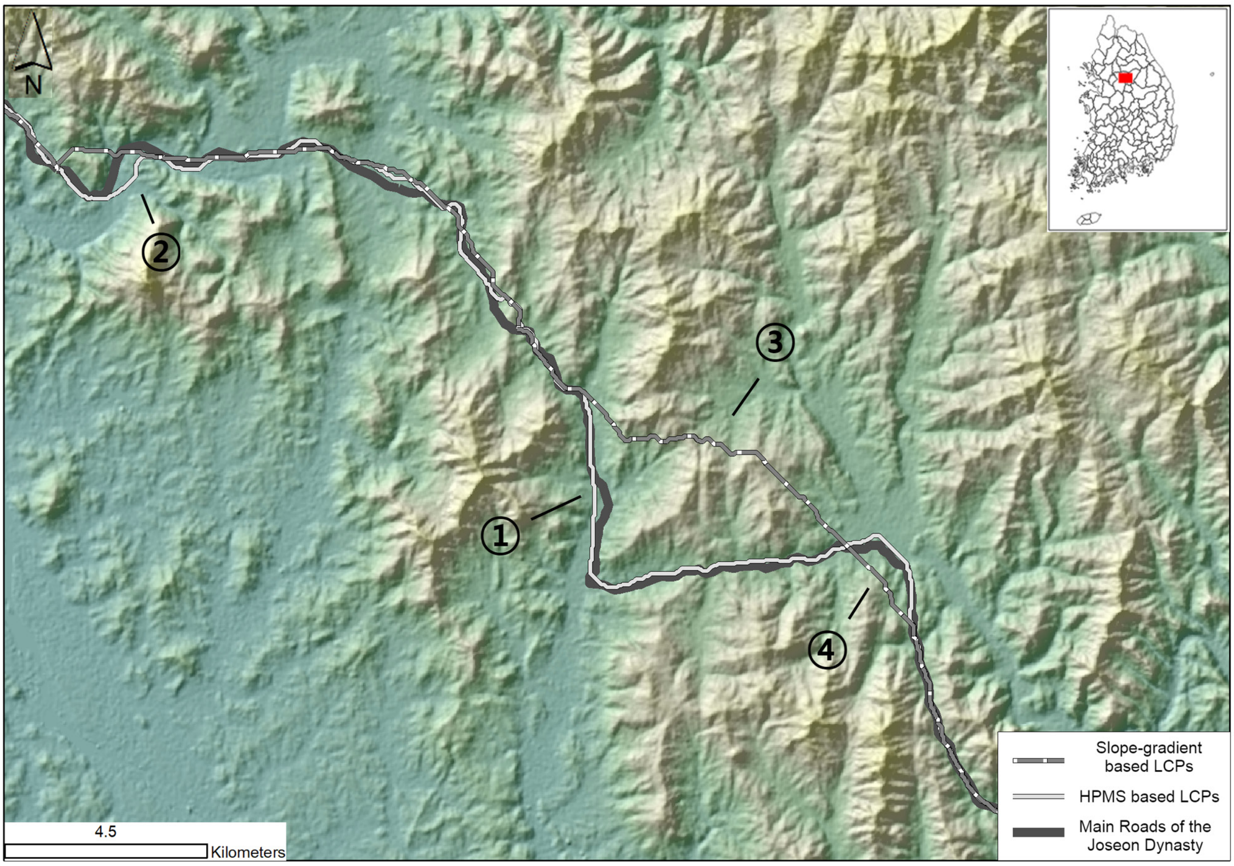

Figure 5 Comparison of the HPMS-based route, slope-gradient based LCP, and Joseon Dynasty Main Road in a mountainous area (Yangpyeong).

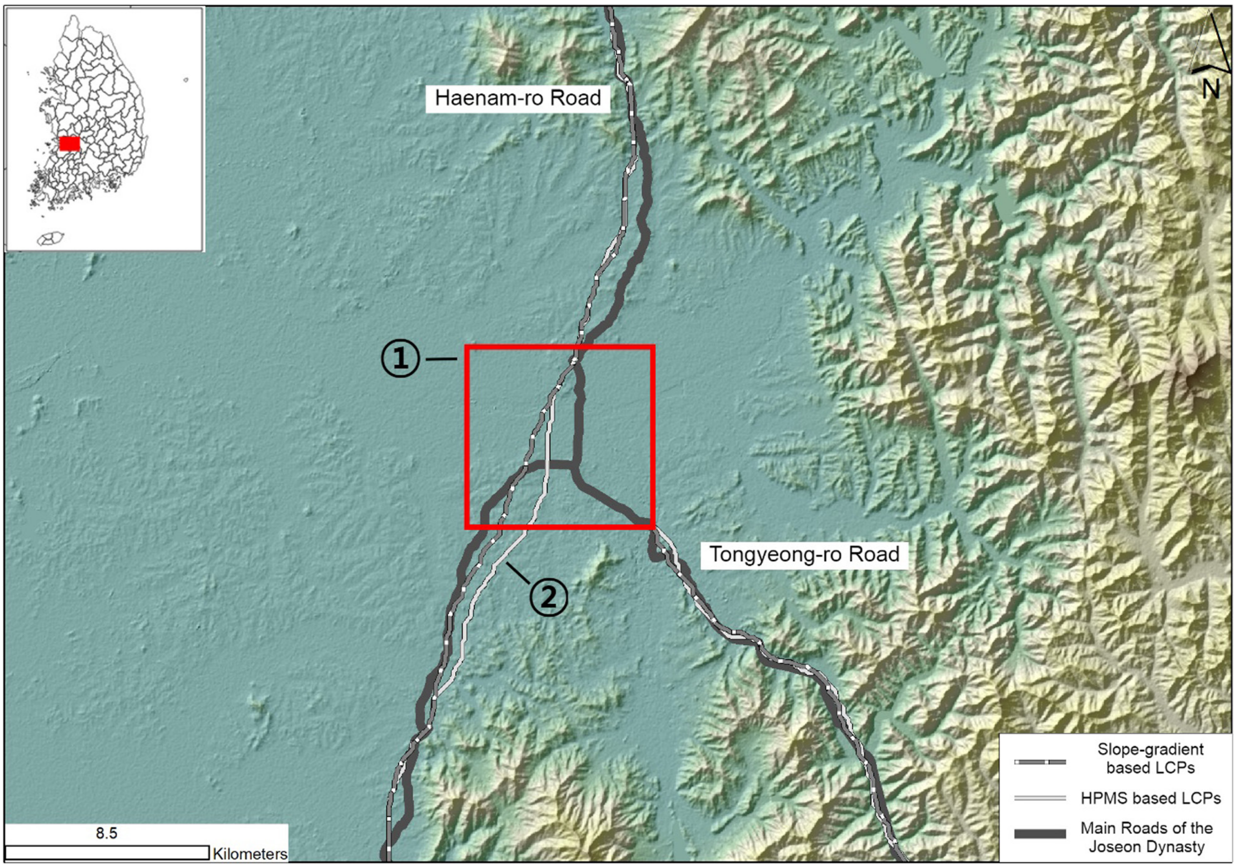

Figure 6 Comparison of the HPMS-based routes, slope-gradient based LCP, and Joseon Dynasty Main Roads in a non-mountainous area (Jeonju).

3.4. SUMMARY OF RESULTS

The key findings of the evaluation of HPMS-based routes through an analysis of the degree of correspondence with the historical routes of the Joseon Main Roads can be summarized as follows. First, HPMS-based routes tend to circumvent more but are less rugged than both slope gradient-based LCPs and the routes of the Joseon Main Roads. Second, HPMS-based routes fit better with the historical routes, compared to slope gradient-based LCPs. Third, HPMS-based routes were rarely drastically different from the Joseon Main Roads routes in mountainous areas (for example, unlike slope gradient-based LCPs, they *did not* cut across ridges when historical routes extended along the river). Fourth, both HPMS-based routes and slope gradient-based LCPs were found to be less reliable in non-mountainous regions.

4. DISCUSSION

The results of the analysis presented in the previous section suggest that *in mountainous regions* HPMS-based routes can be viewed as reliable reconstructions of past movement, compared to slope gradient-based LCPs. As illustrated above in Figure 6, decision-making geared solely towards cost minimization (based on slope gradient) resulted in routes that cut across ridges. In contrast, decision-making that took into account benefit maximization (based on HPMS values) resulted in routes that broadly coincide with historical routes. This clearly demonstrates, therefore, the utility of factoring in 'benefit maximization' when modelling routes in mountainous regions.

It should be stressed, however, that this is not to say that the HPMS-based routes presented in this article have ignored the importance of 'least cost' in modelling human movement. The 'shortest distance function' that is imbedded in Dijkstra's algorithm, which was used by the authors to model the HPMS-based routes, ensures that human desire for cost minimization during movement is also taken into account. Indeed, as noted above, it was this shortest distance function coming into play within cells of the same hillslope position that was often the reason for the minute differences observed between HPMS-based routes and the routes of the Joseon Main Roads in mountainous regions. Future research will be undertaken in order to explore how an increase in the resolution of the DEM used or the inclusion of additional cost/benefit factors may act to bring adjustments to HPMS-based routes so that differences with the historic routes can be minimized even further in mountainous regions.

In the case of *non-mountainous regions*, both HPMS-based routes and slope gradient-LCPs were found to be less reliable. Two reasons for this are suggested. Firstly, the unreliability of both HPMS-based routes and slope gradient-based LCPs in non-mountainous regions stem from the problems associated with DEMs, which are used to construct cost surfaces. As digital *representations* of topography, DEMs contain inherent errors (i.e. errors in data acquisition subsystems and errors generated during interpolation or aggregation techniques (Wechsler 2007: 1482)), particularly in areas of low slope gradient or areas which lack topographic obstacles. Although efforts have been made to address uncertainty associated with error (e.g. by quantifying DEM accuracy using the Root Mean Square Error (RMSE) statistic (Wechsler 2007: 1483)), the unreliability of DEMs in non-mountainous regions is likely to remain a problem. Secondly, in the case of HPMS-based route modelling in non-mountainous regions, the landscape units evidencing high (relative) suitability for movement are widespread and therefore the resolution of the HPMS-based cost map does not appear to be sufficient enough for distinguishing 'good' versus 'bad' movement choices in such non-mountainous regions.

As such, additional methods of evaluating suitability of movement need to be developed for the modelling of routes in non-mountainous regions. One method is to incorporate and propagate the effect of DEM vertical error using Monte Carlo simulation when modelling LCPs, as was recently demonstrated by Lewis (2021) using the case study of a Roman Road. The authors hope to undertake a similar study on the Joseon Dynasty Main Roads in the near future. Another approach is to develop a method of evaluating movement suitability that is not tied to DEMs nor a cost surface consisting of hillslope position units. Fortunately, this can also be attempted in the future by utilizing archaeological and historical data. The authors currently have access to a geospatial dataset consisting of 148,229 archaeological sites from South Korea, spanning from the Paleolithic Age to the turn of the 20th century (provided by the Cultural Heritage Administration of the Republic of Korea). Plans are underway to use this archaeological data to identify areas in non-mountainous regions that experienced little human activity, and to apply this information to the modelling of routes. In addition, by utilizing the point data of place-names associated with river crossings, it will be possible to establish key nodes of movement that will also be factored in when modelling routes.

Then what are the implications of this novel way of estimating 'benefit', as opposed to 'cost', and attributing the associated values to hillslope position units, rather than grid cells? Firstly, it can provide a new direction for LCP studies which, in some cases, appear to have adopted an understanding of human movement that may not be recognizable for humans both in the past and present. For example, in demonstrating the need to consider walking time and kilocalorie expenditure in addition to slope when modelling LCPs, Gowen & de Smet (2020: 3) have recently argued the following: "In the case of topographical analysis, GIS will calculate an LCP based solely on ease of travel through the region of interest in relation to slope. However, this can produce a much longer distance in comparison to the straight line distance between two points and does not accurately reflect real movement, as movement is not restricted solely to low slope areas". In Gowen & de Smet's worldview, humans are driven only by the least cost principle and therefore they regard movement that is *not a straight line* or that is *restricted solely to low slope areas* to be problematic; they believe *real movement* to be movement that is most *cost efficient*.

However, although some types of movement may be geared towards cost efficiency, archaeological and historical evidence illustrates that human movement was more often structured by other needs. Human movement throughout the landscape was not merely a means to an end; it was also a process of interaction with people, places, and things, interactions which facilitated the construction of Self (Ingold 2011). It is due to such an understanding of humans and movement that the authors have proposed an alternative framework for modelling routes that incorporates human desire to undertake movement in beneficial circumstances (i.e. movement that incorporates human engagements with meaningful elements within the landscape, such as villages, fields, wild resource patches, and sacred places). Indeed, through future research in which HPMS-based routes are compared against the distribution of known archaeological sites, the authors hope to demonstrate how the pull of other humans and the resources of the land may have played a significant role in establishing key corridors of movement in the past that continued to be used over millennia.

By presenting a way of modelling routes that looks beyond slope gradient-based accumulated costs, this article also revisits a key point concerning how archaeologists regard past people's perceptions of the world, which was noted by Barrett & Ko (2009) in their critique of phenomenological approaches to the landscape. According to Barrett & Ko (2009: 282) there are two ways of perceiving the world. One way is to regard the world as that which is experienced by a subject who is consciously aware of his or her surroundings; as an *object of inspection*. This type of attitude is known as *present-at-hand* (*vorhanden*) in Heideggerian phenomenology. The other way is to regard the world as that which is approached simply 'as'–as is–rather than consciously being theorized about by the subject; regard it by simply Being-in-the-world. In Heideggerian phenomenology, this is known as *ready-to-hand* (*zuhanden*). For the latter way of Being, movement throughout the landscape, although initiated with a specific destination in mind, also involves encounters with meaningful elements in the landscape as they 'just exist'; it is through these encounters that the possible understandings or categorizations of the landscape (such as that according to hillslope position) may come to be recognized.

Of the two approaches to route modelling examined in this study, the slope gradient-based approach, which is accompanied by the assumption that choices regarding movement are made from a bird's eye view, estimating and accumulating absolute cost values in search of cost minimization, can be seen to represent a *present-at-hand* attitude towards the world. On the other hand, the HPMS-based approach, in which decision-making towards beneficial movement is based on perceptions of meaning embedded in the landscape and takes place at the unit of the hillslope position, can be said to feature elements of a *ready-to-hand* (*zuhanden*) attitude towards the world.

Both types of attitudes are, of course, equally valid. In their interactions with the landscape, humans adopt both attitudes in reproducing themselves as social beings. As such, for GIS-based route modelling to contribute to the discourse on human movement and its role in constructing social landscapes (e.g. Barrett 1994; Knapp & Ashmore 1999; Thomas 2001), modelling approaches must be able to incorporate both *present-at-hand* and *ready-to-hand* attitudes towards the world. The slope gradient-based approach has done an exemplary job of incorporating the former; it is now the role of the HPMS-based approach to explore ways of associating the latter with GIS-based route modelling.

5. CONCLUSION

LCP modelling has played an important role in expanding our knowledge of routes and movement in the past, and has also spearheaded the application of computer technology to archaeological research. Nevertheless, there is also much scope for development, both in terms of theory and methodology. The present study presents yet another way of addressing the limitations of current LCP analysis, by questioning why seeking 'least cost', as opposed to benefit maximization', should be the *raison d'être* of modelling past movement.

With the above question in mind, a method of modelling 'benefit maximizing routes' was developed. This required a new way of envisaging landscape division (in terms of hillslope position) and a new way of attributing relative movement suitability costs, which were both borrowed from natural geography. It also involved input from historical geography, which played an important role in the adjustment of HPMS-index values and the evaluation of HPMS-based routes. Indeed it can be suggested that this input from historical geography played an undeniable role in enhancing the efficacy of the HPMS-based modelling method, which produced routes evidencing a greater correspondence to the

Joseon Main Roads, compared to slope gradient-based routes. Finally, the classification of the region under study according to hillslope position was only made possible through an automated process that involved GIS modelling and computer applications. As a result of such interdisciplinary research, this study has been able to make two contributions to archaeology. Firstly, it has presented a new method of modelling routes that can act to challenge or complement current research on LCPs. Secondly, it has suggested a way for LCP studies to contribute to the wider theoretical discourse on landscapes and movement in archaeology.

NOTES

1 The modelling of movement geared towards 'cost minimization' regards the landscape as a 'a neutral, external backdrop to human activities' (Ingold 2000: 189) and considers the 'efficient' (i.e. least cost in terms of energy expenditure, time, etc.) passage between two points to be the *sole* purpose of movement. The modeling of movement geared towards 'benefit maximization', on the other hand, perceives the landscape as that 'which through living in it, becomes a part of us, just as we are a part of it' (Ingold 1993: 154) and considers the engagement with such a landscape that may occur during the passage between two points to be an *equally important* purpose of movement; in this case, 'benefit maximizing' movement can be understood as movement within landscape contexts that are more likely to facilitate 'the active, perceptual engagement of human beings with the constituents of their world [that are infused with human meaning]' (Ingold 2000: 60).

2 The case study area comprises a total of 117 mid-watersheds that have an average area of 931 km².

3 Low values indicate (1) difficultly in access (2) difficulty in use, (3) low soil richness, (4) low soil water content, (5) low water availability, (6) low stability against erosion, (7) low stability against water submersion, (8) low slope stability. High values indicate vice-versa.

4 These historical sources, as examined in Kim (2004), include the following: *Yeojidoseo* (輿地圖書, *Detailed Survey of Korean Geography*), *Daedongjiji* (大東地志, *Geography of the Great East*).

5 For example, the "Present-day reconstruction of the historical-geographical environment of the Joseon Dynasty through the reconstruction of administrative districts and land and water transportation routes" project (2014–2017) funded by the Academy of Korean Studies (project webpage: http://waks.aks.ac.kr/rsh/?rshID=AKS-2014-KFR-1230005).

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The authors have no competing interests to declare.

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