A More Interconnected World? Measuring Change in Accessibility as a Result of Routeway Development in Premodern Societies

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Abstract

The development of routeways increased how interconnected premodern societies were. Measuring this increase as a result of routeway development is however hindered by current methodologies. Here, a raster-based approach is proposed. Using this approach, interconnectedness as measured by accessibility in pre- and post-developed routeway landscapes can be analysed. Applied to Roman Italy, it is shown that accessibility increased as a result of Roman roads. Moving forward, hypotheses related to change in accessibility can be formalised and tested. Moreover, we can move beyond identifying correlative patterns to understanding how changing accessibility impacted the social, economic, and cultural processes of premodern societies.

Introduction

The development of routeways, their associated infrastructure, and different modes of transportation increased the interconnectedness of premodern societies[1][2]. This increase enabled premodern societies to exercise greater control over their peripheries, their trade networks to expand with goods in transit moving at greater volume and velocity, and ideas and practices to exchange with greater ease. Measuring the impact of this increased interconnectedness on premodern societies is however currently hindered by the methodologies used.

When examining the impact of increased interconnectedness on premodern societies, the concept of *time-space compression* has received much interest (Jennings 2014; LaBianca & Scham

[1] Following Alcock et al. (2012) the use of 'premodern societies' refers to those before mechanised forms of transportation were introduced, e.g railroads.

[2] The listing of these three factors reflects that it is difficult to determine which of these factors influences interconnectedness. That is, did interconnectedness in premodern societies increase solely as a result of well-maintained routeways, the establishment of staging posts, or the use of faster modes of transportation? Or did all factors play a role, varying in their impact? And if so, how did this differ spatially and temporally? Henceforth, these three factors will be summarised as 'routeway development'

2014; Hodos 2017; Boivin & Frachetti 2018). Included as one of the drivers of globalisation, here defined as the process through which people and places become increasingly interconnected (Tomlinson 1999: 1–3), time-space compression is the shrinking of one's experience of space and time as economic and social processes are sped up (Harvey 1989). Given their expansive system of roads, their associated infrastructure, and the use of different modes of transportation, the application of time-space compression and globalisation is particularly prominent for understanding the Roman world (Laurence 1999; Witcher 2000, 2014, 2017a; b; Laurence & Trifilò 2014; Pitts & Versluys 2014a; Haas & Tol 2017; Carlà-Uhink 2022). For example, Laurence and Trifilò (2014) argue that travel time reduced in Roman Italy as a result of road construction, with time-space compression influencing the monumentality of cities along consular roads. Similarly, Hitchner (2012) suggests that Roman road infrastructure "annihilated distance to an unprecedented degree" (2012: 226), producing an improvement in economic growth and socio-cultural integration of regions within the Roman empire. More broadly, when discussing multiple ancient societies, Jennings (2014: 123–25) suggests that time-space compression was achieved through the introduction of the donkey and the development of reliable road systems. Specific to regions around the Indian Ocean, Manger (2014) also suggests that the domestication of the camel revolutionised the crossing of deserts. Conversely, Morley (2014) concludes that whilst Roman roads would have made journeys more predictable and slightly quicker (sensu Ramsay 1925), time-space compression would have been insignificant compared to the changes seen over the last few centuries. The debate on time-space compression within the Roman world is not however unique, with the wider utility of globalisation for understanding premodern societies also being challenged (Naerebout 2007; Gilhus 2008; cf. Nederveen Pieterse 2012; Pitts & Versluys 2014b). For relevance here, it has also been argued that the concept of globalisation, and the process of time-space compression therein, provides no explanatory power and instead only descriptive terms (Pitts 2008; Witcher 2014; cf. Hitchner 2008), which are of limited use when aiming to explain the impact of increased interconnectedness on social, economic, and cultural processes.

In contrast to time-space compression, the measurable concept of accessibility—defined here as the relative ease to which spatial separation is overcome (Ingram 1971)—has received comparatively little attention as an approach for understanding the impact of increased interconnectedness on premodern societies. Where it has, its use is often limited to a network-based approach (e.g. Carreras & De Soto 2013; Scheidel 2014; de Soto 2019). Within this approach, multiple routeways are combined to form an interconnected network of routeways. Representing routeways as edges and routeway junctions or settlements as nodes, accessibility across the network can be calculated.

The network-based approach, however, has three relevant issues: first, the pre-routeway landscape is not integrated within the analysis, i.e. the analysis is synchronic, and thus measuring change in accessibility as a result of route development is difficult. Second, the network-based approach is limited to understanding accessibility *across* routeways included with the analysis. Given this, it is impossible to calculate accessibility outside of these included routeways. Accessibility is however a continuous phenomenon—not just limited to routeways. And third, network-based measures are impacted by the completeness of the routeway system. Specifically, if the routeway system is not sufficiently known— a common occurrence when examining routeways in premodern societies—calculated accessibility is more likely to be biased. That is, accessibility calculated using the purely network-based approach reflects the routeway system used within the analysis, and not the *true* routeway system. If routeways are not known or are not included, the impact of these routeways on accessibility cannot be calculated. For example, if a routeway acting as a shortcut between two different routeways is not included within the analysis, accessibility *because* of this routeway is unknowable. Thus, whilst calculated accessibility reflects the optimal within the routeway system included within the analysis, it does not necessarily reflect the optimal within the *true* routeway system.

To address the limitations when using time-space compression and a network-based approach, this article presents a raster-based approach for measuring accessibility as a result of routeway development. With this raster-based approach, accessibility is measured as a continuous phenomenon, with estimated speeds as a result of routeway development, their associated infrastructure, and different modes of transportation incorporated into the pre-developed routeway landscape. Whilst the proposed raster-based approach does not wholly negate the issue of bias in calculated accessibility, the ability to calculate accessibility outside of known routeways is deemed to reduce this bias.

Method Proposal

Unlike a network-based approach for understanding accessibility, wherein accessibility is limited to routeways only (**Figure 1, C** and **E**), the raster-based approach explicitly models movement as a continuous phenomenon, i.e. occurring across the whole study area[3] (**Figure 1, D**). Using a cost

[3] The use of the raster-based approach has its own issues. For example, the resolution of the digital elevation model impacts the resolution at which routeways are rasterised. Digital elevation models with too low resolution can potentially result in multiple routeways being aggregated together and thus impact the calculated accessibility. Furthermore, accessibility will be influenced by the number of neighbours used when creating the cost surface—more neighbours results in more accurate measured accessibility, but higher computational demand

surface that quantifies the cost of traversing from one cell to another with a raster grid, an accumulated cost surface (ACS) can be created (Douglas 1994). The ACS represents the cumulative cost required to travel from a given location to all other locations in the study area, i.e. their accessibility (**Figure 1, B**). For example, the cost of traversing from one cell to another can be expressed by the amount of time taken when traversing a particular slope gradient, e.g. using Tobler's Hiking Function (Tobler 1993).

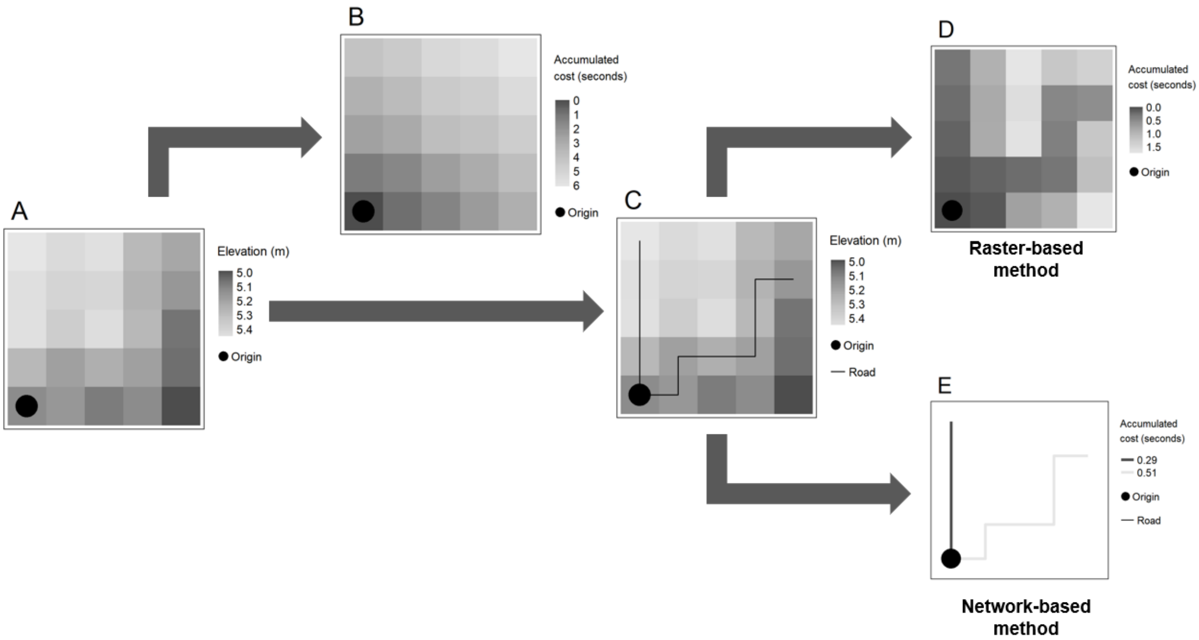

***Figure 1** Digital Elevation Model (DEM) representing the landscape (**A**), accessibility from the origin location to all other locations within the raster grid using a cost surface created using Tobler's Hiking function (**B**), presence of roads included within the landscape (**C**), raster- and network-based accessibility from the origin location given speeds achievable using Tobler's Hiking function for non-road cells and the estimated speed attainable when traveling on Roman roads using continuous horse relay for roads (**D** and **E,** respectively)*

When constructing cost surfaces from which the ACS is calculated, it is common to only include the cost of traveling by foot (**Figure 1, B**). This is despite the availability of estimated speeds for multiple modes of transportation used in premodern societies[4] (**Table 1**). However, by incorporating estimated speeds into the cost surface, the calculated ACS can reflect accessibility as a result of routeway development (**Figure 1, D**).

[4] The rarity of incorporating travel speeds when modelling has also been noted by Bevan (2013) in his review of computational modelling approaches used to understand the Greek and Roman world

Table 1 Traveling speeds by different modes of transportation[5]

Mode of Transport	Km/h	Km/day	References
Foot (including armies, pack animals with moderate loads, mule carts, and camel caravans)	4-15	15-40	(Kolb 2000: 310–11; Köpp 2013; Scheidel 2014)
Mules with heavy loads	7	20-37	(Kendal 1996; Kolb 2000: 310–11; Scheidel 2014)
Camel	-	26-185	(Köpp 2013)
Vehicle	-	36-38	(Kolb 2000: 312–13; Scheidel 2014)
Vehicle with changes	-	50-96	(Kolb 2000: 313–214; Scheidel 2014)
Horseback (full gallop)	4-7 (45-52)	33-67	(Ramsay 1925; Köpp 2013; Scheidel 2014)
Horseback with changes	-	106-375	(Kolb 2000: 315–16; Köpp 2013; Scheidel 2014)
Oxen	3-8	12-18	(Kendal 1996; Kolb 2000: 316–17; Köpp 2013)
Oxen with changes	-	40	(Kolb 2000: 316–17)
Chariot	38	-	(Köpp 2013)

Case Study: The Accessibility of Roman Italy

With the interconnectedness of Roman Italy thought to have increased as a result of road construction (sensu *time-space compression*), it is expected that this will be identifiable as an increase in accessibility. This is assessed through the comparison of two accessibility cost surfaces representing the accessibility of the pre- and post-Roman road landscape.

Materials and Methods

Settlement locations were derived from the ROMURBITAL database (Sewell 2015; Sewell & Witcher 2015). Providing data on 432 settlements that existed between 350 BCE and 300 CE (**Figure 2, A**), the ROMURBITAL database is deemed to provide a representative sample of settlements across the Italian peninsula from which change in accessibility can be examined. The location of Roman roads (**Figure 2, A**) was derived from the digitised version of the Barrington Atlas (Talbert 2000; McCormick *et al.* 2013).

[5] as derived from historical sources and modern sources/experiments

To reflect that gradients are noted to have become gentler from the Archaic to the Roman period with this attributed to the more demanding traffic of Republic and Imperial Rome (Tuppi 2014), it is assumed that the most common type of transportation used on Roman roads would have been vehicles. As a result, estimated speeds when traveling on a Roman road, i.e. cells that are crossed by a Roman road, was fixed to 36km per day or 3.6km per hour[6]. All cells that are not crossed by a Roman road were assigned speeds achievable when traveling on foot following Tobler's Hiking function (Tobler 1993). To ease computational burden, the TINITALY digital elevation model (DEM) (Tarquini *et al.* 2007) was mean aggregated from 10m to 250m. From this, two ACSs were created: the first being the mean accessibility of Roman Italy from all settlements based on the pre-road cost surface, i.e. only using Tobler's Hiking function (**Figure 2, B**), and the second the mean accessibility of Roman Italy from all settlements based on the pre-road cost surface but modified to incorporate estimated speeds where Roman roads cross cells (**Figure 2, C**). The calculation of cost surfaces and accessibility cost surfaces were conducted using the R package *leastcostpath* (Lewis 2023).

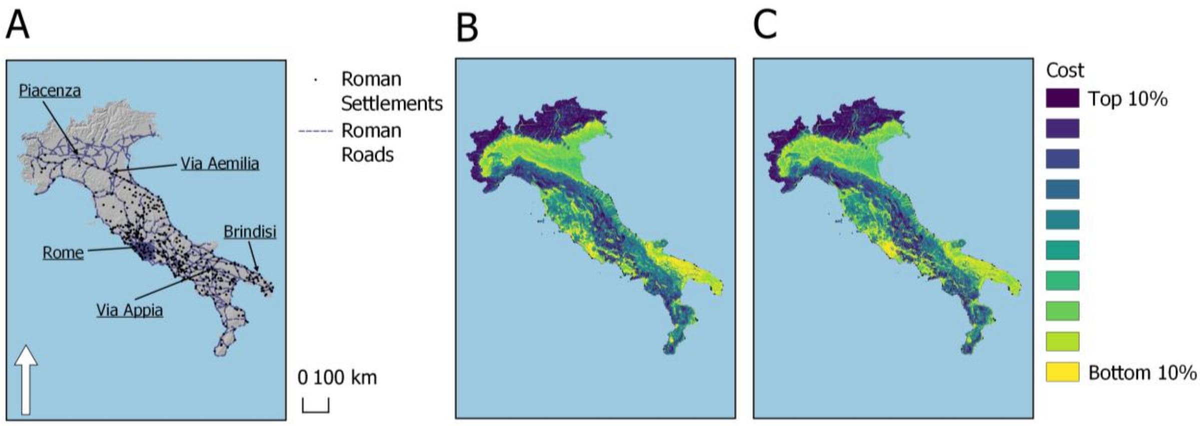

***Figure 2** Distribution of Roman settlements and the Roman road system in Roman Italy following the ROMURBITAL database (Sewell 2015) and the Barrington Atlas (Talbert 2000; McCormick et al. 2013), respectively (**A**), pre-road cost surface (**B**), and pre-road cost surface incorporating estimated speeds when traveling using a vehicle (**C**). Mentioned locations in this article are shown by arrows*

Results and Discussion

The ACS incorporating Roman roads shows that the accessibility of Roman Italy increased as a result of road construction (compare **Figure 3, A** and **3, B**). **Figure 3, C** shows that the greatest percentage increase in mean accessibility is concentrated in the north and south of Roman Italy. More specifically, increased mean accessibility in the north is concentrated along the *Via Aemilia* to

[6] Following Ramsay (1925), a 10-hour day is assumed

Piacenza. Constructed in 187 BC, the *Via Aemilia* provided logistical support for the movement of troops from Rome to the north (Dall'Aglio & Di Cocco 2006). Similarly, the greatest percentage increase in the south is concentrated along the *Via Appia* to Brindisi and its neighbouring settlements. With the construction of the southern section of the *Via Appia*, Roman political and military ambitions expanded eastwards towards Greece (Ceraudo 2015).

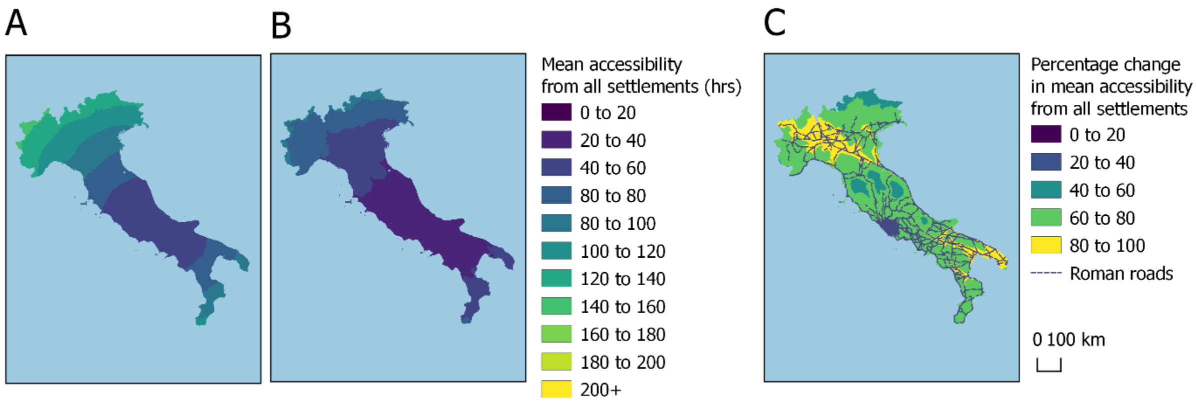

Figure 3 *Mean accessibility from all settlements using the pre-road Tobler's Hiking Function cost surface (**A**) and the pre-road Tobler's Hiking function cost surface incorporating estimated vehicle speeds where Roman roads are present (**B**), and percentage change in mean accessibility pre-road and pre-road incorporating Roman roads (**C**)*

Conclusion

In this article, an explicitly diachronic raster-based approach is proposed for measuring change in the interconnectedness of premodern societies as a result of the development of routeways, their associated infrastructure, and different modes of transportation. Representing interconnectedness as measured by accessibility and providing an alternative to a network-based approach, the raster-based approach presented here allows for the incorporation of developed routeway systems into pre-developed routeway landscapes. By measuring change in accessibility between the two landscapes, we can uncover how accessibility changed as a result of developed routeways. Moving forward, with the raster-based approach being explicitly diachronic, hypotheses related to change in accessibility can be formalised and tested. Moreover, we can move beyond identifying correlative patterns to a more robust understanding of how changing accessibility impacted the social, economic, and cultural processes of premodern societies.

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