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Comparing network construction techniques in the context of local transport networks in the Dutch part of the Roman *limes*

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ABSTRACT

This paper aims to compare network construction techniques and evaluate which one achieves the best representation of a local provisioning system that connects rural settlements with military *castella* in the Dutch part of the Roman *limes*. Using an existing site dataset and a dataset of least-cost path reconstructions between all sites, a number of network construction techniques are described and applied, including maximum distance networks, proximal point networks, a Delaunay triangulation, a Gabriel graph and efficiency networks. They are evaluated using the network metric of average path length and 'local' average path length to reach the *castella*, along with other indicators. Ultimately the Gabriel graph and proximal point networks with a high number of neighbours proved to be the best representation through a good performance on the evaluated indicators as well as the presence of a number of downsides in the other networks, with the Gabriel graph being slightly better due to a smaller number of links needed. This study thus shows that the choice for a network construction technique in archaeological case studies is important and presents a possible strategy to approach such a problem.

1. Introduction

Transport in the Roman period has been extensively studied both in traditional archaeological research as well as in computational approaches to archaeology. The focus has often been on transport on regional to empire-wide scales, including the Roman imperial road system and shipping on the Mediterranean (e.g. Yeo, 1946; Chevallier, 1988; Scheidel, 2014) as well as the organisation of transport and trade on such scales (e.g. Harris, 2000; Mattingly, 2007). Most archaeological evidence on transport available in the Netherlands is related to phenomena on the same scales, examples being the Roman military road connecting the *castella* (forts) along the Rhine (Van der Heijden, 2011) and shipping on the Rhine and Meuse (Jansma and Morel, 2007). Comparatively little research has been done on transport on the local scale, perhaps mainly due to the lack of archaeologically visible material remains.

The project 'Finding the limits of the *limes*' aims to investigate the relations between the Roman military population that inhabited the forts along the Rhine in the Netherlands with the local population living in the direct hinterland of this frontier. One of the key issues is the organisation of local provisioning for the Roman army. In earlier research in the project we aimed to model local transport networks that can represent provisioning systems, and network analysis was applied to study the resulting networks and the role some individual sites play in those networks (Groenhuijzen and Verhagen, 2015a, 2016). However, this was only done for a limited case study area that has been thoroughly studied in archaeology (e.g. Vos, 2009) and is relatively homogeneous in terms of archaeological site density and retrieval rate. No consideration was given to the choice of network construction technique, rather choosing between simple and arbitrary thresholds of 20, 30 and 60 min for transport connections to be included or excluded.

In contrast, Rivers et al. (2013) in a study on centrality in networks of interaction (thus not limited to transportation) of the Middle Bronze Age southern Aegean argue that the choice between different network structures is in fact relevant, and that our understanding of the archaeological record we aim to represent should be the basis of deciding which network construction technique is most suitable (see also Evans, 2014; Rivers, 2014). They included a spatial component in the form of homogeneous geodesic distances between various islands in the Aegaen, while the actual time or effort to undertake such voyages was assumed to be directly proportional to distance, and land-based travel was given a uniform friction coefficient. These assumptions were not really a problem since most travel in the study of Rivers et al. (2013) occurred over water. Inspired by this study but aiming to extend the methodological concepts by using heterogeneous travel times between places, this paper intends to compare different network construction techniques and evaluate them based on the archaeological

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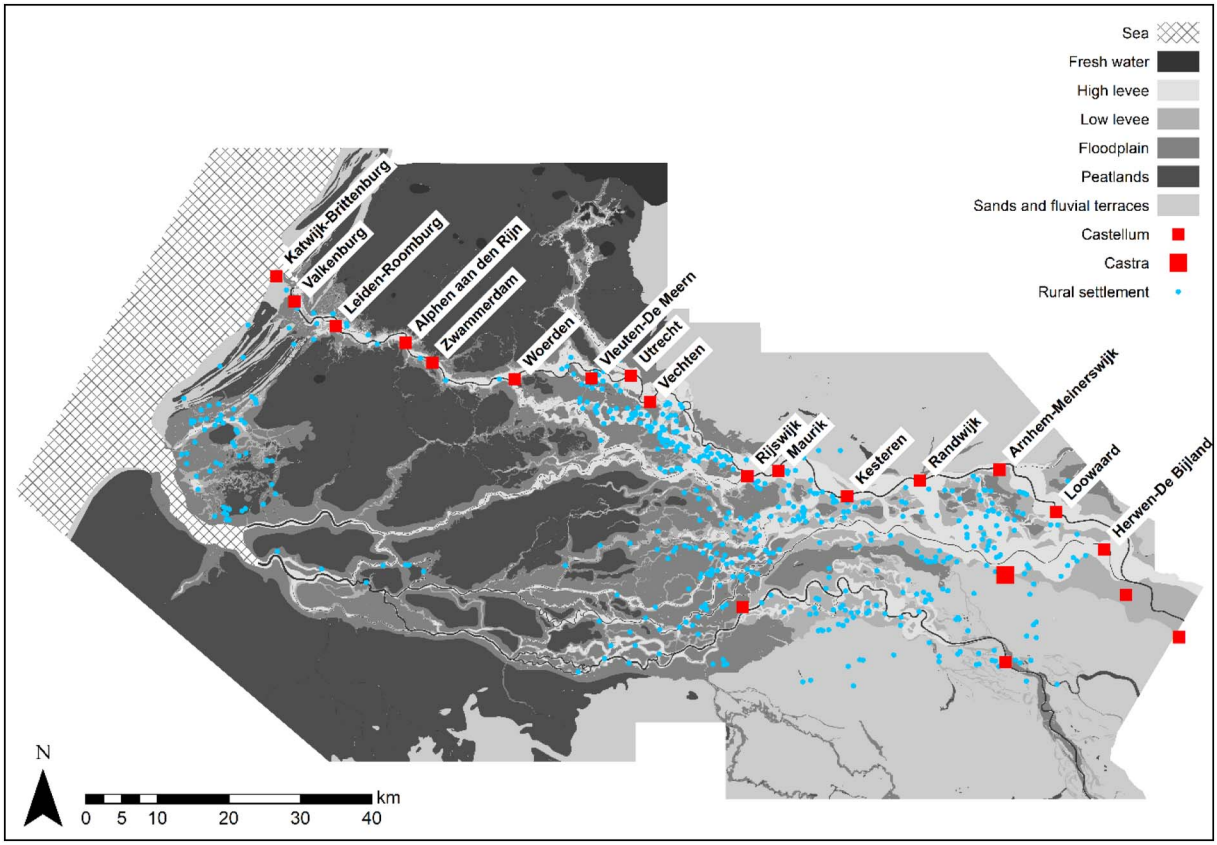

Fig. 1. Palaeogeographic map of the Dutch part of the Roman *limes*. The 16 *castella* along the Rhine in the Netherlands that will be used for the analysis are labelled with their commonly used modern toponyms.

representation we aim to achieve: that of a potential local provisioning system connecting rural settlements with the military population in the *castella* of the Dutch part of the Roman *limes*.

2. Archaeological background

The study area, the part of the Roman *limes* within modern Netherlands, is situated in the Rhine-Meuse delta and measures approximately 150 × 50 km. It was first occupied by the Romans around 15 BCE, who started the development of a linear defence system along the Rhine with a number of early fortifications, including a *castra* (legionary camp) in Nijmegen (*Noviomagus*) and smaller *castella* at Arnhem-Meinerswijk and Vechten. In 47 CE emperor Claudius decided to permanently suspend Roman expansion across the Rhine, leading to the construction of more *castella* within this defence system (Fig. 1), positioned remarkably close together (on average 8.7 km straight line separation) and typically located near major bifurcations of the Rhine or near the mouths of smaller tributaries, which is suggested to be an attempt to guard all routes that give access to this long-distance transport corridor (Van Dinter, 2013: 26–27). This configuration remained relatively stable until the second half of the 3rd century CE, when the Roman border along the Rhine collapsed under outside pressure and most forts were abandoned. Some of them were reoccupied afterwards, but the concept of a linear defence system at the Rhine was discontinued and replaced by a defence in depth.

Earlier archaeological research suggested that the provisioning of the Roman military population that occupied these forts was largely through import from outside the region (Van Es, 1981: 166–173). This view has changed in more recent years, partly due to the continuous collection of (bio)archaeological data. It is now thought that the rural population of the Rhine-Meuse delta was already integrated in the Roman societal structure during the 1st century CE and was capable of producing a surplus of crops and livestock to at least partly supply the Roman army (Groot et al., 2009; Kooistra et al., 2013; Van Dinter et al., 2014), but the extent to which this was done is unknown and can only be quantified with many assumptions and uncertainties (Van Dinter et al., 2014: 32).

Generally speaking, the Roman army aimed to supply their troops from the local territory, meaning the direct vicinity of the fort itself. However, a less densely populated border region with a large military presence such as the Dutch part of the Roman *limes* would not be able to support the *castella* locally, likely resulting in the entire hinterland of the *limes* participating in the provisioning of the Roman army, in addition to resources being imported from outside the province. The responsibility of provisioning the troops would fall to a provincial official (*procurator*) who would usually assign sums of money to the army to acquire goods locally (Carreras Monfort, 2002), but the exact flow of goods from the rural to the military population remains unknown. Alternative hypotheses could be that there was direct interaction between rural settlements and nearby forts, or that interaction occurred through markets and urban centres, which is for instance suggested by Bloemers (1990: 115). The current study makes use of the first hypothesis, although the methodology can potentially be reapplied with a focus on the latter sites as well.

3. Methodology

3.1. Data

The archaeological site dataset used in this study was created from archaeological find spots found mainly in the Dutch national archaeological database ARCHIS (https://archis.cultureelerfgoed.nl/), combined with a number of smaller datasets. The find spots were aggregated into sites based on a minimum number of 10 finds within a 250 m radius. Using the chronological information associated with the individual finds themselves, a flexible chronology was developed for the archaeological