Conference Paper

Reconstructing Western Europe's transport system 1500-1950

Author(s):
Fuhrer, Raphaël

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Reconstructing Western Europe’s Transport System 1500-1950

Raphaël Fuhrer

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Reconstructing Western Europe’s Transport System 1500-1950

Raphaël Fuhrer
ETH Zürich
Stefano-Franscini-Platz 5
CH-8093 Zürich

Telephone: 0041 44 633 67 37
raphael.fuhrer@ivt.baug.ethz.ch

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Abstract

This paper has three aims: First, explaining and illustrating how transport infrastructure and state reach interact. This topic is analysed using historical transport data as time series. Second, providing information on the modelling and generating of such data; in particular, a semi-automated algorithm to extract GIS information from scanned paper maps is introduced. Third, an overview on collected material from 1950 and earlier is provided along three important points – information density, spatial accuracy and details on travel speed.

Keywords

Accessibility; historical transport maps; infrastructure state; historical travel time; map digitisation

Preferred citation style

1 Introduction

Transport supply – the useful output of transport infrastructure and means of transport – inter-relates with spatial developments such as pricing of land, mobility of a society and productivity in an economy. Several ex-post analyses done in the last decade determined such effects due to changes in transport supply, Fuhrer and Axhausen (2016) provide a systematic overview.

Starting from the fact of this interplay mentioned above, the question becomes what the role of transport supply was in a long term perspective in the development of Europe. We claim that transport had a major role in the formation of states in Europe. The evolvement of states, in the end national states, in Europe has been a field of research since decades. Be it an analysis of the expansion by the Romans, city-networks during Renaissance or empires and confederations later on and finally national sovereign states in recent times. These manifold processes have been examined mainly by the humanities and social sciences. Fernand Braudel (1966) for example, in his famous book “La Méditerranée et la Monde Méditerranéen à l’Epoque de Philipp II”, gives intriguing insights into a Europe undergoing major changes and points out the fundamental importance of space and transport. According to Braudel, “space was the enemy number one” of everyone at those times. Other researches, such as Charles Tilly (1992), recognised the importance of networks, Tim Blanning (2007) focused on the concurrence of transport and communication. However, the benefits and costs of a growing and accelerating transport network are usually treated as an implicit variable in a section – household organisation, productivity in agriculture, availability of knowledge and so forth – of Western Europe’s path of development. The research presented in this paper starts one step before these traditional concepts and addresses the, as we think, main driver behind the observed developments: the benefits and costs of transport supply.

We shared some of our thoughts at the T²M conference in autumn 2016 at the very beginning of this project. Now, we report advancements along the research concept presented in Figure 1.
Figure 1 Research concept

| Data collection | As time-series 1500 to 2000  
1. Networks: location, shape, condition, capacity  
2. Transport means: era, average speed, costs, capacity  
3. Inhabitants per municipality; population densities; cities  
4. Borders of spatial entities (empires, states etc.)  
5. Economic attributes: working places, prices, wealth |
| Filling gaps: Find approximations | Data sets inevitably have gaps. Reasonable approximations to cope with such gaps should be developed (alternative data, reliable spatial or temporal interpolation). |
| Calculation and mapping of accessibility | Accessibility values are calculated using the gravity-based equation mentioned above and data 1,2,3. The results are visualised in an informative way (e.g. time-space maps). |
| Quantitative analyses | The obtained data – travel times from 1,2; transport networks from 1; accessibilities from 1,2,3 – are used in different research contexts, in the following rank order: |

- City and spatial economy evolution  
  Urbanisation and spatial economies are investigated using i.a. spatial econometrics.  
- State formation  
  The interaction of accessibility and state formation is investigated using spatial regression, multilevel models, GIS tools and spatial econometrics.  
- Further analyses  
  The collected and generated data can be used for further analyses, possible topics might be: spread of diseases, invasive species, fragmentation of landscapes/habitats, trade and so forth. |

1.1 Structure

Section 2 is a combination of conceptual thoughts on linking transport infrastructure to state reach and a tool to digitise maps. Section 3 begins with an overview on historical transport maps as the main data source for this research project, includes a table with the most important related online resources and an illustrative example for first analyses, and finishes by reporting on the collection and assessment of 1950 and older transport maps and material. Section 4 gives an outlook.
2 Tools and Methods

2.1 Conceptual: Linking transport infrastructure to state presence

The main task of this research project is to quantify and model accessibility on municipality level in Western Europe from 1500 to 2000 in regular time intervals; and to relate these results to spatial patterns, in particular to borders and territory or nation building. The figure below shows the interaction between transport infrastructure and nation evolvement.

Figure 2 The interrelation between transport supply and nation or state evolvement

Basically, there are two different routes how transport infrastructure effects space regarding state evolvement. There is a direct route where transport infrastructure enables the state to be present and to alter the local population’s life (Tilly, 1992). The state can demand actions by the population (pay taxes for example), set rules (law enforcement etc.) and support (public services such as education and security). These connections are rather obvious and there have been several studies on these effects. However, the focus is hardly on the actual research question posed here. These studies rather examine societal developments within societies (later nations) and explain the driver for these findings. In many cases, they are related to the interrelation of transport infrastructure and state reach. There are several prominent examples: Examining the relation between space and time in society (Braudel, 1992), or the study of civilisation where the diffusion of norms played an important role (Elias, 1939), or the occurrence of trust
(Tilly, 2010). Within these studies the influence of transport, while not addressed specifically, still becomes understandable. A more detailed and focused analysis by (Guldi, 2012) investigates the role of transport infrastructure in the history of Britain and shows how these kingdoms and regions turned into an ‘infrastructure state’. She mentions both direct and also indirect consequences of the construction of transport infrastructure.

Following the second route, the indirect effects of transport infrastructure, transport networks do not only mean access and control over territory; they mean decreasing travel time and increased accessibility – both understood as lower transaction costs in economy. Accessibility as key variable in this transport economical concept is defined in the style of (Hansen, 1959):

\[ A_i = \sum_j O_j \times e^{-\beta \times C_{ij}} \]

with \( A_i \) as accessibility in point \( i \) to all \( j \) opportunity points \( O_j \) at generalised costs \( C_{ij} \) that are weighted by a negative exponential transformation with factor \( \beta \). Opportunity points usually are inhabitants. As accessibility increases, agglomeration effects take place (see section Error! Reference source not found.). This means, the economy becomes more productive in certain areas. Thus, wealth accumulates and societal progress happens within spatial economies. This in turn governs patterns of urbanisation and land use, since certain locations become in relative terms more or less valuable. The new spatial organisation of society, economy and environment increases overall productivity and the level of wealth increases. As a consequence the state can offer more public services which again may increase the productivity (education, security etc.). In the end, the economic power of a society (or nation) becomes stronger.

This paper follows the research thesis that such effects caused by transport infrastructure played an important role in the evolution of economies and nations in Western Europe. Models with historical data are applied to examine the proposed mechanisms. Our main data sources are historical transport maps. The next section 2.2 details on the use of such maps.

### 2.2 Practical: Automated map algorithm

For our spatial models, we need a historical spatial information system (hGIS). The paper maps are first scanned and pre-processed which includes the digitising of all meta information and the geographical projection as well as making sure that roads have a unique colour within the map. After pre-processing, the algorithm extracts the road information from the scanned maps. It is written in the language and programming environment R (R Core Team, 2014). The algorithm needs a map prepared as described above and two training sets – one containing only road
pixels and one containing only background pixels. The processing of one standard map on a server with 12 cores at 2.66 GHz each and 192 GB RAM takes between 10 and 120 minutes. The result is a link-node description of the network stored as an ESRI compatible shape file. Primary roads are distinguished from other road types. The sub-steps include [1] Extraction of road pixels, [2] Cleaning I: removing circles, [3] Thinning of the pixel mage (skeletisation), [4] Vectorisation, (Cleaning II: standardise and smooth lines), [5] Snap line segments together, [6] Classification of road segments. More details are given in the following figure and in a recent paper (Fuhrer and Axhausen, 2015).

Figure 3   Steps of the road extraction algorithm

The travel time can be estimated giving an appropriate speed to the link segments according to their characteristics (e.g. surface, class etc.) and the available means of transport at the corresponding time.
3 Material Collecting and Processing

This section provides an overview on the most important points when working with historical maps and presents some collected material and first evaluations of it.

3.1 Overview

Nowadays, geographical information systems (GIS data) are first choice to model and extract spatial data such as transport networks and travel times. However, such data usually is very recent. Maps as a physical form of GIS have a much longer history. The principles of map making have changed though from very early maps that resemble with sketches to modern maps that represent reality in correct proportions. Anyway, transport has been a main purpose for map making from the very beginning. It is obvious, historical transport maps are indispensable for this research. They provide information on the physical location of properties such as roads, bridges and canals, but on land use and population as well. In addition, qualitative and quantitative information to these properties – e.g. speeds or capacity of roads and tracks or number of population etc. – are required too. Such information may be drawn in maps, or it may be stored in spatial records or other documentation that both served for statistical or other reasons at the time. Thus, archives of maps and of other documents are the main source within this research. Whenever possible existing data is used, see Table 1. Where not available, additional data is searched for or bridged my modelling approximations.

To obtain information on distance and spatial position, the projection of the map is crucial. Generally speaking, maps published before 1569, when Gerhard Mercator finished his atlas, did not have conformal (“real”) projections; whereas after 1569 Mercator or a similar projection was standard. This means, pre-1569 maps have limited use: they inform on whether a specific road section existed and maybe even in which category this section was, but they do not provide the length of it. Post-1569 maps should place their features in their correct spatial position, assuming the map designer sought a science and cartography based approach rather than an illustrative or religious one. Nevertheless, one should be aware that tools to survey the mapped information were limited at the time (Girot, 2011). And based on the maps viewed so far, we can observe that it took the map makers after Mercator a couple of decades to adapt. Extracted speeds and travel times from maps of the 16th, 17th and 18th century should be cross-checked with separate data. One can use itineraries of monks, messengers and tradesmen to validate the modelled values. Both, the maps as well as the itineraries are usually stored in national or monastic etc. libraries. From the mid-17th century on and later (Bruno, 1993) stage coach time tables can be used as well to validate speeds on roads. The situation is similar regarding rivers,
canals and the sea. Later, one can rely on the time tables of railway companies and on information from travel guides.

Another approach are isochromatic maps, as put as cover image (Eckert and Langhans, 1909). These kind of maps work with travel time rather than distances or networks. One of the first maps of this type is Francis Galton’s Isochronic Passage Chart for Travel in 1881. It has London as starting point and classes for every ten days travel time, always using the fastest mean of transport. It shows that whole Europe and western parts of today’s Russia was connected within ten days. Much more interesting than the actual map, are the papers on the map constructing. Eckert (1909) for example provides a very detailed description of the sources used. He describes the assumptions and compiled values for various transport means, different vehicles and different animals on different infrastructure and under different weather conditions. The fastest speed possible is always used. Such maps and documentations are very helpful to project more recent travel time estimations back until circa 1850. They also act as nexus between the quite robust 20th (and 19th) models and the ones between 1500 and 1850 that are mostly based on limited observations and sources rather than on systematic resources.

Table 1 Existing digitised data sources for general information within Europe

<table>
<thead>
<tr>
<th>Information</th>
<th>Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roman network based on Peutinger map</td>
<td><a href="http://omnesviae.org/">http://omnesviae.org/</a></td>
</tr>
<tr>
<td>Roman network including minor roads</td>
<td><a href="http://pelagios.org/maps/greco-roman/">http://pelagios.org/maps/greco-roman/</a></td>
</tr>
<tr>
<td>Roman network with speed model</td>
<td><a href="http://orbis.stanford.edu/">http://orbis.stanford.edu/</a></td>
</tr>
<tr>
<td>71 000+ digitised historical maps</td>
<td><a href="http://www.davidrumsey.com/">http://www.davidrumsey.com/</a></td>
</tr>
<tr>
<td>Repository of early maps in general</td>
<td><a href="http://www.maphistory.info/imageeurcont.html">http://www.maphistory.info/imageeurcont.html</a></td>
</tr>
<tr>
<td>Repository of maps in general, rectified</td>
<td><a href="http://maps.nypl.org/warper/">http://maps.nypl.org/warper/</a></td>
</tr>
<tr>
<td>Repository of historical documents</td>
<td><a href="https://archive.org/">https://archive.org/</a></td>
</tr>
<tr>
<td>Repository of airline time tables</td>
<td><a href="http://www.timetableimages.com/ttimages/complete/complete.htm#Europe">http://www.timetableimages.com/ttimages/complete/complete.htm#Europe</a></td>
</tr>
<tr>
<td>Repository of maps, mainly 20th century</td>
<td><a href="http://www.lib.utexas.edu/maps/historical/index.html">http://www.lib.utexas.edu/maps/historical/index.html</a></td>
</tr>
</tbody>
</table>

There are more digitised maps for regional areas which are not included in Table 1. More and more libraries have started to digitise their map archives. There are hardly any sources for historical GIS data.
3.2 Collected material and its use

In a first step, we focussed on mid 20th century maps. Together with Philipp Hunziker\(^1\) we first assessed several map series (Fuhrer and Hunziker, 2014) and then digitised American Army Map Service (AMS) 1301 “Maps of the World 1:1,000,000” map sheets, using the algorithm described in Section 2.2. Some of the sheets had been scanned (see Table 1) the others were provided and scanned by ETH Library. We chose AMS maps because they fulfil best the following criteria:

1. Maps provide global data on classified road infrastructure.
2. Maps come in a globally uniform cartographic style.
3. Maps’ accuracy does not have a spatial pattern.
4. Maps are available to the public.
5. Maps are available at no or low cost.

At the moment, digitised maps cover Africa and Asia quite well, however there are major gaps in Western Europe. If there are further maps available, please contact the first author of this paper as we seek to complete the data set.

Within this first step, we continued by adding information about the speed of a link. The relevant information comes on the one hand from meta data of every single sheet on the other hand from secondary sources about the speed of vehicles subject to the transport infrastructure. The meta data provides information on the road class – whether it is a main or secondary road – and what the corresponding road type in reality is, for example whether main road means a motorway or a track. It also provides information on the quality of the road surface and weatherability. Given the additional statistics on pavement (IRF, 1971a and IRF, 1971b) as well as analyses to vehicle speeds (De Weille, 1966), it is possible to estimate maximum speed and minimum travel time on every link.

For a case study, we took Nigeria and calculated for every of the current 775 municipalities the sum of all travel times to every other municipality (as a simplification of the equation in Section 2.1). We did this for a current network as well as a network generated as described above using AMS maps. We then calculated and mapped the change of travel time. We then contrast this map with a second map showing the activity of the Boko Haram insurgency in Figure 4.

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\(^1\) Institute for International Conflict Research (ICR), ETH Zürich
Figure 4  Comparison of Boko Haram attacks and change in travel time since 1950

Number of killed persons by Boko Haram attacks between January 2011 and January 2015

Change in total travel time between 1950 and 2010 per municipality; 2010 road network

Upper image: La Libération (map); ACLED (data). Lower image: OSM (network); own calc.
By comparing the spatial pattern in travel time change from 1950 to today, the degree of change in state reach can be quantified – if we agree on the close relationship between transport infrastructure and state reach as explained in Section 2.1. Looking at Figure 4, the clear negative correlation between the activity of the Boko Haram insurgency and the change in total travel time is striking. A recently published map in media that shows the number of killed people by Boko Haram acts as an indicator for the ability of the state to have control over local society. There are other maps that draw the insurgency’s activities using a different approach, but they all show a very similar pattern. Boko Haram is most active where state reach and travel time respectively has least increased. This visual comparison does not replace an in-depth analysis of the correlation between Boko Haram’s activity, state reach and modelled accessibility, as this case study is an illustrative example only. First spatial analyses have been done by the project partner at ICR (Hunziker, 2015). However, it demonstrates that the principal assumption in the research conducted by the author – state reach is strongly based on transport infrastructure and accessibility – holds. The black and darker grey areas representing high and higher improvements in travel time mainly cover areas that were relatively badly connected in 1950 (West, central parts; 1950 network not shown here). The southern cluster near the coast can be linked to oil extraction.

In a second step, we extended our data base backwards for material from 1900 and older. So far, we could not identify a map collection or series that are as uniform like the AMS maps. There are some historical atlases. However, the maps are not large enough to generate an accurate hGIS due to their book format, as there is usually one country drawn per sheet. We could still find suitable material: single map sheets or foldout maps of larger publications and a range of tables, sketches and images. The following first insights are given based on material mainly found in the Bodleian Libraries in Oxford.

The usefulness of a scanned map depends on the amount and accuracy of the presented spatial information. In terms of information density, one can distinguish between maps that provide an infrastructure network only as seen in the left image, or provide in addition to the network some distance information as seen in the middle image, or define in addition a hierarchy in the network as seen in the right image in Figure 5. Images with some distance units allow us to check and correct the computed travel time even if the corresponding network is drawn rather schematically. The categorisation into different road types allows us have a more precise estimation of the speed.
In terms of accuracy, maps are the more useful the more the drawn infrastructure is in the correct place. Now we cannot check directly whether a map of, for example the 18th century, did or did not correctly map a road since we do not have an 18th century satellite image. But the map style gives us a good impression on the spatial accuracy, as presented in Figure 6. In the image on the left you see that a projection is missing, in the middle image roads are drawn as schematic straight lines, whereas in the right image the drawn roads follow their geographical shape. The last type of map provides us with the most meaningful information.

Figure 5  Information density of historical maps

Figure 6  Spatial accuracy of map types
Next, the question becomes which map style is suitable for the presented semi-automated digitisation algorithm in Section 2.2. It needs a training set of pixels that are unambiguously road pixels and uses some information of the extracted pixel pattern. As colour was rather expensive and for other reasons, the vast majority of historical maps are printed in black-white style. This means, we have to do a pre-treatment of the scanned maps.

Lastly, we want to add information on speed to links in order to estimate historical travel times. In the material collected so far, there are three major sources for such information. First, information integrated into the map, second tabular information that comes with a map, and third further documents such as diaries, travel guides etc. as presented in Figure 7 from left to right.

Figure 7 Information on speed and travel time

Taking all information presented in this section together, we are able to estimate the change in travel times between many places in Western Europe. In combination with countable data, such as population, we can compute accessibility metrics.

Unlike current models and data, there hardly is redundant primary sources for historical data and estimations. This means it is very difficult to check calculated numbers for plausibility. However, one can check sub-regions within the European model against each other to have an impression on the quality of the extracted information.
4 Outlook

In this paper, I presented a rationale how to link the development in transport infrastructure to state reach. I showed what data is needed to model this relationship and what tools and data sources are necessary to produce such data.

The current work focuses on the digitisation of the collected material. The second important work is to fill the gaps in the data structure by reaching and viewing several archives and repositories online and in person. However, this work, both digitisation and collecting, is not as straightforward as one could think. There are minor problems such as copyright issues, mainly for 1950 and more recent documents, and major problems such as missing catalogues, missing meta data and missing items. Such work is associated with rather high temporal and monetary costs too. Nevertheless, it should be realistic to produce an almost complete data structure by combining various sources. In parallel to the transport data, population data is also looked for. Subsequently, the spatial models described in the beginning of this paper will be applied to the produced historical data structure, after having tested them in several context on more recent data (Killer et al., 2013 and Sarlas et al., 2015).
5 Literature


R Core Team (2014) R: A Language and Environment for Statistical Computing. URL http://www.r-project.org


