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Modelling Variation in Transport Infrastructure, Travel Time and Accessibility over Time and Space

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Abstract

This paper presents three related projects in accessibility research at ETH Zürich. First, changes in accessibility in Switzerland between 1850 and 2000. Interrelations between changes in travel behaviour, urban sprawl, wealth and labour distribution, and investments in faster transport networks are examined using the concept of accessibility. Second, accessibility changes of Switzerland and Germany are compared, also in terms of methodological differences of bi-national data sets. Estimations of historical impedance factors show a decrease towards recent years, indicating more frequent, longer and cheaper commuting trips in both countries. Overall accessibility has increased in the whole study area, stronger in Western Germany than in Eastern Germany than in Switzerland.

Third, an on-going project dealing on the one hand with global transport infrastructure of 1950 and today and on the other hand with Western European transport from 1500 to 2000. In this context, an automated vectorisation program for generating GIS data from historical transport paper maps is presented in detail. Concepts of accessibility and state reach are introduced.

Keywords

Accessibility; transport history; Switzerland, Germany; transport networks; state reach; AMS.

Preferred citation style

1 Introduction

Accessibility as a concept has been widely used, in planning, or in spatial, in economic or political science contexts. This corresponds to its nature at the borderline between all these disciplines, capturing spatial patterns – most often planned or built networks – that are responsible for economic, institutional and political facts. Since Hansen (1959) first formulated accessibility in mathematical terms, a variety of different approaches have evolved (see Kwan (1998)). All of these have in common, that they rely first on generalised travel costs (or approximations), second on a transport infrastructure model and third on spatial densities of so-called activity or opportunity points (e.g. inhabitants, work places or other points of interest).

A gravity-like formulation is used in all research projects presented in this paper using this function:

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

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 \( \beta \). In Section 2.1, accessibility measures are applied with respect to changes in Switzerland’s commuter patterns between 1970 and 2000 as well as developments in urban sprawl, demography and spatial organisation between 1850 and 2000. In Section 2.2, road accessibility of German and Swiss municipalities over the time period 1970 to 2007 are analysed and related parameters, such as historic travel time matrices, are discussed. In Chapter 3, two interlinked research projects are presented. First, it is explained how a global transport network model (1950 and 2000) can be used to predict ethnic and natural resources related conflicts. Second, modelling back to 1500 Western Europe’s transportation system helps to understand the shape and formation of those countries. Accessibility serves as an indicator for state reach and control over territory in both projects.
2 Switzerland and Germany: Roads since 1850

2.1 Accessibility Changes in Switzerland from 1850 to 2000

Three main topics are relevant for this research cluster, which examines the interplay of transport system, economic growth and spatial development, as explained in Axhausen et al. (2005). First, the transport networks (Fröhlich et al. 2005): While building up the physical networks, naming, opening and closing, and classification of links need special effort, as they vary over time and data sources due to a process of change and redefinitions. As consequence, many data sets need manual corrections and adoptions. The current network and current public transport services respectively serve as a handy starting point. Logical networks are created by adding supply and demand to public transport alignments and road links respectively. For the latter, the availability of historical manual counts by persons on the spot are crucial. Second, the speed modelling (Erath and Fröhlich 2004): Specific fundamental diagram characteristics (travel time, flow, density) are assigned to different road types. As a function of historical information of these characteristics, e.g. capacities of roads, average speeds of cars, and based on modelled demand at those times, historical loads, travel times and speeds are estimated. Regarding public transport, speed and travel time can be extracted from time-tables for almost every year. Third, geo-information for the municipality level (Tschopp et al. 2003): Data stems from a variety of sources, as municipalities have merged or split and censuses have undergone changes in their form and content. It is crucial to establish common key variables or such variables that allow for dependencies through the whole data base. This can be spatial location or logical ID numbers.

The models and data sets documented papers mentioned in combination with other research at IVT are applied in several studies. Tschopp et al. (2006) examine changes in accessibility as a predictor for population development in regression models. Different model types provide good results, showing that there is an effect in rural rather than in urban areas. In general, population development was driven more strongly by accessibility changes in the past than in recent years. Analysing all time-series, Axhausen et al. (2011) conclude that there was an enormous increase of accessibility in Switzerland since 1850 due to population growth and better infrastructure. Until 1930 there was an advantage of the public transport system, after 1930 the road has been in a relative advantage. They observe a suburbanisation which have taken place since 1950 in parallel to the motorway system construction. Axhausen et al. (2008) visualise changes in travel time using time-scaled maps. They show a shrinking of the county in general due to higher speeds, in the same time the construction of motorways and
fast train connections have led to clearly visible patterns. Fröhlich (2008) reports that the average journey distance of commuters using private transport almost doubled between 1970 and 2000 and travel speed increased by more than 50% in the same time period, however the average travel time spent in commuting increased by 25% or so. The biggest changes occurred between 1970 and 1980 when many parts of the motorway system were completed. Regarding public transport, similar effects are observed but with lower magnitudes. The number of total commuting trips increased by approximately 37% within 30 years.

### 2.2 A German-Swiss Accessibility Study

The approach presented above is developed further and expanded to Germany and Switzerland for road transport, considering inhabitants and work places (Killer et al. 2013). An overall increase in accessibility is observed in both countries between 1970 and 2007, though the two countries show different paths as presented in Figure 1.

Figure 1 Annual Change of the Accessibilities (natural logarithm) of Germany and Switzerland

Two main points shall be highlighted: First, the trans-border approach and, second, the beta factor estimation. Two different types of borders are visible in Figure 1. The first one is in blue and in the period covering the 1990s. It occurs along the former border between East and West Germany and shows the effects of the unification of two separated economies. The second border located between Switzerland and Germany is artificially drawn and represents a
main issue in this project, namely combining two data sets into one accessibility model. Though one model is applied to the whole area, the structural and network related data and parameters could not be merged, which produces tolerable biases within the border area. Difficulties are for instance different fashions and intervals of counting work places, different specifications of commuting matrices and intra-municipal travel times. Such incompatibilities are offset using various techniques, as explained in in Killer et al. (2013). One crucial element is the estimation of the beta factor, which – as visible in the equation in the introduction – weights the general costs of spatial resistance; the higher beta the higher the resistance. It varies over time and different regions and can be estimated when the amount of commuters and corresponding travel times of a region at a certain time are known. Estimations show a decrease of beta values in both countries over time, which represents an increase of the ability or necessity to commute. Values in Germany are smaller than in Switzerland at every time step, the mentioned decrease from 1970 to 2007 is stronger in Germany. These results make sense if we think that travelling was more expensive in terms of generalised costs at earlier times than nowadays and spatial scales are smaller in Switzerland than in Germany. Further results include an overall increase in accessibility in the study area. Comparing the two countries, the model reflects economic growth (i.e. higher population and work places) and road network extensions (i.e. higher mean speeds) better in Switzerland than in Germany.

3 Accessibility, Resource-Induced Conflicts and State Formation

In this on-going research project, we identify the role of accessibility and transportation infrastructure on state organisation in space and over time. We would like to give insights into the current work and provide first findings.

3.1 Resource-Induced Conflicts and Accessibility

The first project aims to understand how limited state capacity and large-scale resource extraction can lead to political instability in general and intrastate conflict in particular. We understand state capacity, as the state’s ability to alter and control citizen’s actions through state institutions. Following the hypothesis that the establishment of strong nation-states has involved the development of state-capacity building institutions in peripheral regions (Tilly 1992), we see high incentives for states to penetrate regions where their control over population is weak, especially, if resource abundance is involved. Using road infrastructure as a
proxy for state reach (Scott 2007), we identify regions that are difficult to access by the central state, as we expect political turmoil to occur here (Galula 1964). This means, we digitise global transport infrastructure data from 1950 and 2000 in order to conduct time-spatial analyses. With this quantitative spatial data, in combination with disaggregated data on conflict processes (Cedermann et al. 2010) and on natural resources (Lujala 2010), we improve the knowledge about resource-induced conflicts.

3.2 State Formation and Accessibility

The second subproject aims to understand the role of transport infrastructure in the process of establishing control over territory by nations in Western Europe during the period of 1500 to 2000. As suggested by historians, borders do follow specific spatial patterns (Braudel 1989), undoubtedly influenced by settlements and their economic, political, identification promoting etc. effects spread by transport infrastructure. In Fogel (1964) the direct effects of infrastructure building on the spatial distribution of economic power are shown, analysing the example of the railway network building in the United States of America. From new economic geography we know the close connection between economic power and power over territory. With this concept at hand and the model of the first subproject in mind, we will investigate with quantitative measures to what extent state formation has been driven by or has driven transport infrastructure and accessibility. We interlink and model data of historical transport networks, travel times, capacities and structural data as well as results from existing qualitative studies.

3.3 Method

3.3.1 Data

Regarding the global networks, a variety of different data sources are assessed (Fuhrer and Hunziker 2013). Suitable data needs to fulfil the following criteria: 1) Available to the public and at low costs, 2) global coverage at uniform quality level 3) globally consistent mapping style. As a result of this assessment, the US Army Map Service [AMS], series 1301, at a scale of 1:1,000,000 maps are selected; of which some editions around the year of 1950 exist, either as scans (e.g. University of Texas library) or as paper maps (e.g. ETH Zürich library). Maps include coordinates grid, information about the projection, age and reliability of the mapped data, road and rail types and classes as well as point information such as city sizes,
airports and ports. Historical travel parameters (1950), including speeds, capacities and costs of travelling on different road types, are collected from various sources (road: DeWeille (1966), Harral and Faiz (1988), railway: Cook’s Time Tables). Navigable rivers are obtained from the World DataBank II (Gorny and Carter 1987). Current population density is available on a raster basis (CIRESIN and CIAT 2005), for earlier years we rely on various sources (e.g. Morris (2013), Kremer (1993)). Historical networks and travel parameters (1900 and earlier), such as speed, prices etc., are also collected from various sources (e.g. Eckert and Langhans (1909), Various (1980), Ransom (1984), Bruno (1993), Livet (2003)).

3.3.2 Processing

The transport infrastructure network is extracted from AMS maps using an (almost) automatic algorithm (Hunziker and Fuhrer 2013). The computer code, using the program R (R_Core_Team 2013), takes pixel/raster images (scans) and produces vectorised network data as shape files, which are geo-referenced. The principal steps are as follows: 1) Pre-treatment, 2) Pixel extraction, 3) Clean the pixel image, 4) Skeletonisation, 5) Vectorisation, 6) Correct and clean line geometries, 7) Classification of link type.

Table 1  Main Steps within the AMS Map Vectorisation Algorithm

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pre-treatment</td>
</tr>
<tr>
<td>2</td>
<td>Pixel extraction</td>
</tr>
<tr>
<td>3</td>
<td>Item Deletion</td>
</tr>
<tr>
<td>4</td>
<td>Skeletonisation</td>
</tr>
<tr>
<td>5</td>
<td>Vectorisation</td>
</tr>
<tr>
<td>6</td>
<td>Line cleaning</td>
</tr>
<tr>
<td>7</td>
<td>Line snapping</td>
</tr>
</tbody>
</table>

Steps 2 to 7 are automated within the code. But, as can be observed in Table 1, it is not possible to delete all wrongly extracted items in step 3; the border line for example is misinterpreted and extracted as a motorway. This is why a pre-treatment (1) is necessary, where all border lines are painted white as shown in position eight; the image is cropped and geocoded. Pixel
extraction (2) works with a supervised classification process based on a Support Vector Machine, which classifies road and background pixels. After cleaning, pixel line clouds are reduced to separate lines of one pixel width (4) and then transformed into vector data (5). Duplicate lines are deleted and lines are smoothed afterwards (6). Finally, connected line segments are snapped using a graph-based algorithm, and road hierarchies (main roads, secondary roads etc.) are assigned by fitting a hidden Markov model (7). Based on this data, logical networks are created, similar to the procedure presented in section 2.1 above.

4 Outlook

As a first conclusion, we record that there is global historical transportation network data available and we show how this can be transformed into a useful data format. On regional and local level, it is explained how accessibility models can be applied to capture, demonstrate and fathom trends and changes in society and space over time. The comparison between Switzerland and Germany points out the role of current and former borders as a cause but also as an important matter in building such models. Further steps will consist of collecting data on freight transport, land and sea, and air traffic.

After completion of the historical European and the more recent global networks, it would be interesting to – apart from the two presented projects – conduct further transport-related analyses. Possible approaches include: Trade and wealth distribution, information flows and geographical coverage of social networks, land use patterns and landscape fragmentation, spread of diseases or invasive species.

5 Literature


