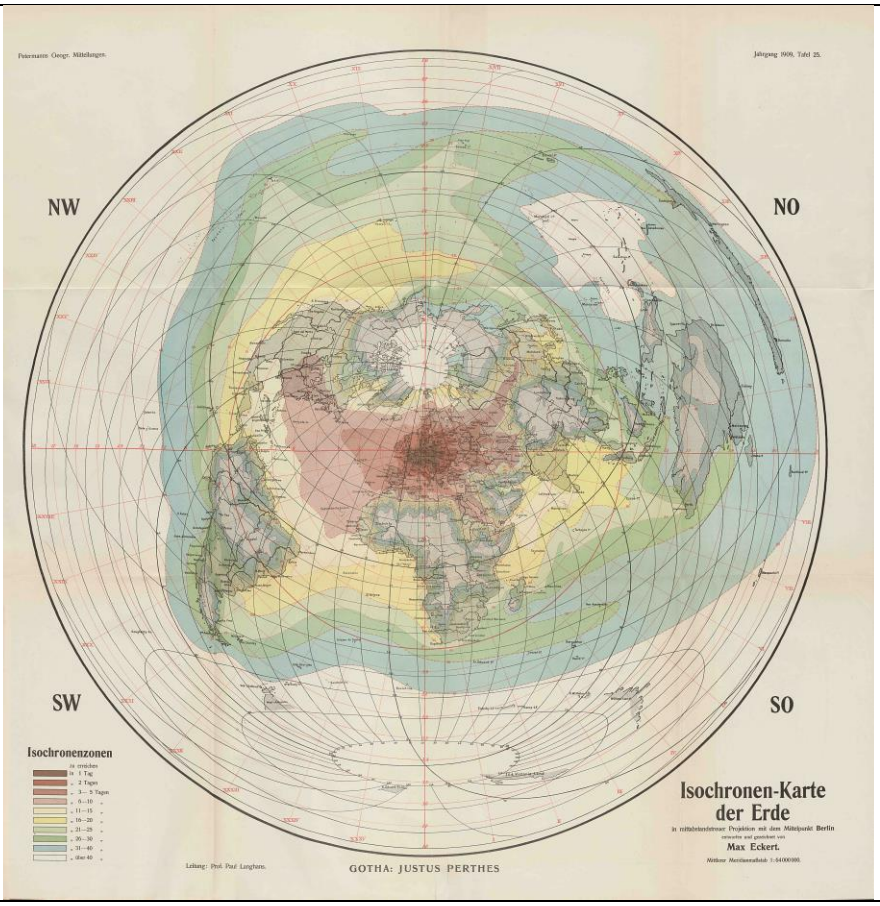

Modelling Historical Accessibility with International Transport Data

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Abstract

This paper links transport infrastructure with state evolvement. The author claims that transport infrastructure plays a major role in the organisation and evolvement of states and nations. There are two routes how these two things link together: Direct, transport infrastructure enables state reach, the state is present and able to change people's live. Indirect, transport infrastructure governs spatial economies, as agglomeration effects take place. This influences urbanisation and land use patterns, which leads to a more efficient organisation of the economy. Finally, the productivity of a spatial (national) economy increases and the state gains economical power, which in turn allows the state to foster its presence by offering more public services.

First, the general theory and motivation is explained. Second, the data and research concept is presented, since historical data between 1500 and today is used. Third, information on historical transport data of 1950 and earlier is given and sources are discussed. Fourth, two important elements within the overall concept are detailed by reporting on two recent research projects. The first one deals with the reconstruction of Nigeria's 1950 road network and its function as a proxy of state reach. The second one deals with the quantification of agglomeration effects by public transport accessibility increase in Switzerland between 2000 and 2010. Fifth, the next steps are introduced.

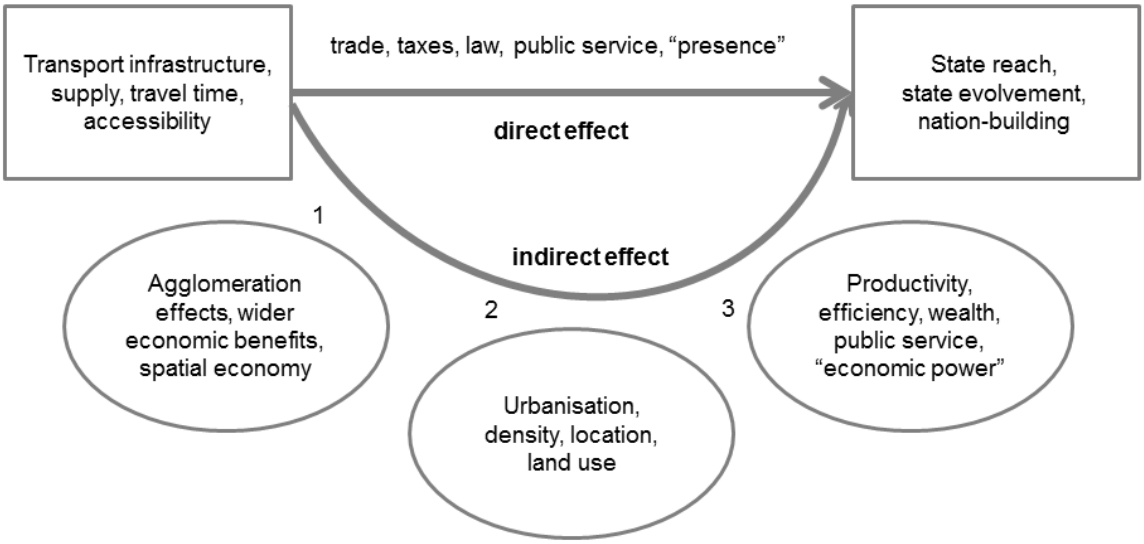
Keywords

Accessibility, historical transport data, agglomeration effects, state reach, infrastructure state.

1. Transport Infrastructure and Its Spatial Effects with Respect to Nation Evolvement

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 1 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 focussed 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):

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

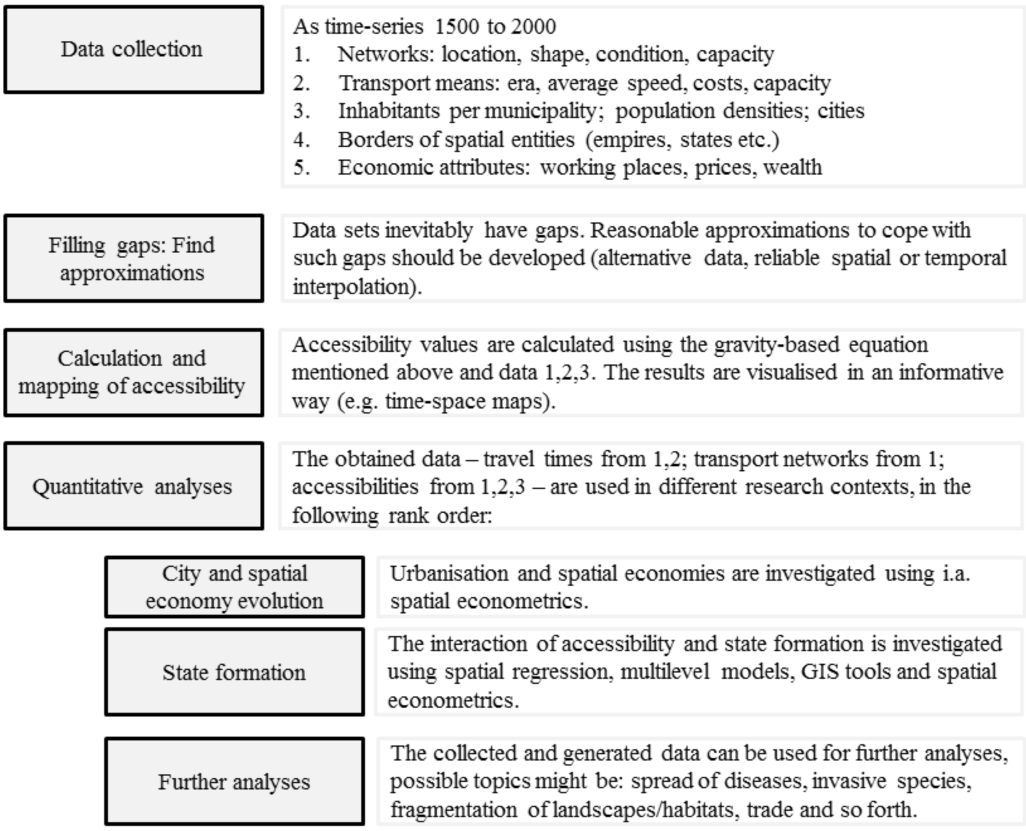
with A_i as accessibility in point i to all j opportunity points O_j at generalised costs C_{ij} that are weighted by a negative exponential transformation with factor β. Opportunity points usually are inhabitants. As accessibility increases, agglomeration effects take place (see section 4.2). This means, 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 evolvement of economies and nations in Western Europe. Models with historical data are applied to examine the proposed mechanisms.

2. Research and Data Concept

The first figure gives an overview on the research steps and needed data. The subsequent table provides more details on available data.

Figure 2 Research concept: the main steps and involved data



The quantitative data mentioned in the scheme above either is existing data or is created within this research. Information on existing data is given in the table below.

Table 1 Data sources

Data	Source	Format
Global transport networks of 1950 (US AMS)	University of Texas, ETH	Scans -> GIS
Global road conditions, average speeds, costs 1950	Worldbank reports	Tables
Borders of territorial authorities 1200-2000	Euratlas	GIS:shape
City sizes (population), WEurope, 1500-2000	Euratlas, de Vries (1984)	GIS, tables
Roman road network, travel times (Peutinger)	omnesviae	GIS
Economic attributes 1600-2000	Econ. hist. assoc., others	Tables
Collections of historical transport maps	Various	Scans
Reports on itineraries (pilgrims, tradesmen etc.)	Various	Text
Statistics on rural population WEurope	Various, ?	?
Time-series data on land cover (esp. agric.)	Ramankutty (1999), others	GIS ?

The method can be separated into three main elements: The core element is engineering/science based, namely the modelling and calculation of transport and other input data. The second element is social science based, as for example the surveying and interpretation of historical sources. The third element comes from economy and statistics, which deals with cause and effect or spatial models. Overall, the method is an interdisciplinary approach as I am used to it as an environmental scientist from education. The following aims are pursued:

1. The time-series data:
generalised costs / travel times
accessibilities
of Western Europe for 2000[1], 1950[1], 1900, 1850, 1800, 1700, 1600 and 1500, where possible on a municipality level.
2. First quantitative models/ theory of the interaction of transport and state formation.
3. Further impact models which describe the interaction of transport systems with other systems, such as society, economy and environment, especially agriculture, rural industry and the urban system.

[1] On the global level in cooperation through ETH Risk Center with Philipp Hunziker, Institute for International Conflict Research, ETH

3. Data: Historical Transport Networks and Indicators

Since this research reasons concepts using historical data, an overview on the way how historical resources can be exploited is given in this section. As everything else, transport and cartography also have their history, which is worth examining.

3.1 AMS Maps for the 1950 Global Road Network

In collaboration with Philipp Hunziker[2] and funded by ETH Risk Center, the global road network of 1950 has been reconstructed and is being reconstructed by using a semi-automated algorithm. First, a suitable data source has to be identified. Second, the data is manually pre-processed. Third, the algorithm extracts the road network.

Few sources provide information on the global mid-twentieth century road network and most served military interests. To select the best map provider, a set of assessment criteria was chosen (for a description of all sources and assessment, as well as legal issues see (Fuhrer and Hunziker, 2014)):

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.

Criterion 2 follows from the fact that data on transport infrastructure has to be extracted automatically using image processing. Ensuring comparability for later spatial statistics dictates the third criterion. The five criteria stated are satisfied best with US Army Map Service (AMS) maps: or to be precise, its series 1301 "Maps of the World 1:1,000,000". Their biggest advantages include an almost uniform mapping style amongst different sheets and editions and clear documentation of the age and reliability of the mapped information.

Next, all available paper maps must be scanned. The maps used are provided by the ETH Library and a set of scanned maps by the University of Texas at Austin. All relevant meta data of each sheet are stored in a database. Transport related meta data include road types mapped,

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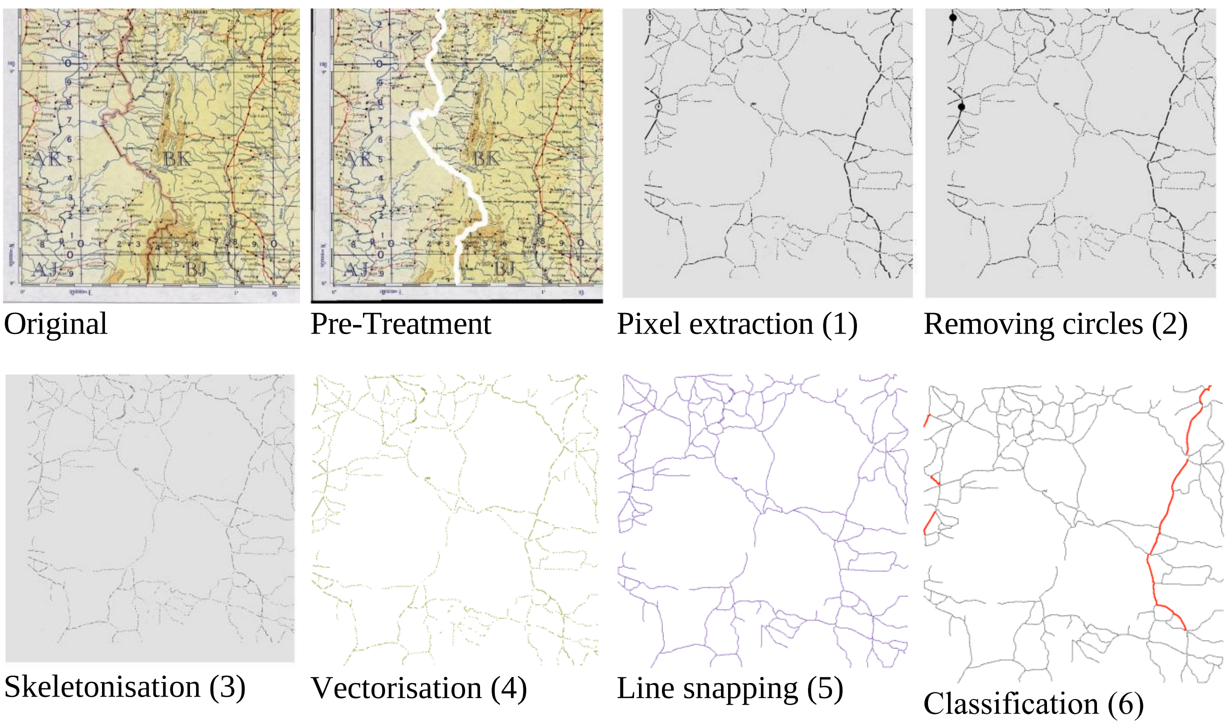
surface of road types (hard, loose, gravel, metalled), dependence on weather, and the survey year for the map. Maps are included if the main part of the network represented was surveyed around 1950. However, they are still included if some map features or parts were captured between 1930 and 1970. This relatively generous bandwidth is necessary to avoid too many gaps due to excluded maps in the global coverage. Remaining items relate to geographic information, such as projection and standard parallels.

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 in the section above and two training sets – one containing only road pixels and one containing only background pixels. The processing of one standard AMS 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



AMS globally compiled maps, except for areas over 85° North and 60° South. However, when this paper was written, there were some gaps in our collection of scanned sheets, especially in Northern Europe, Russia and South Africa. Some sheets are editions surveyed extensively after 1950 in Australia and South America, a situation improved continuously by researching further map sources.

3.2 Sources of Data from 1900 and Older

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 on maps and on other documents are the main source within this research. As mentioned in section 2, whenever possible existing data is used. Where not available, additional data is searched for or bridged my modelling approximations. This section provides a short overview on use of historical transport maps.

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). 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, such as the road network model mentioned in section 3.1, 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.

4. Two Conceptual Foci: State Reach and Agglomeration Effects

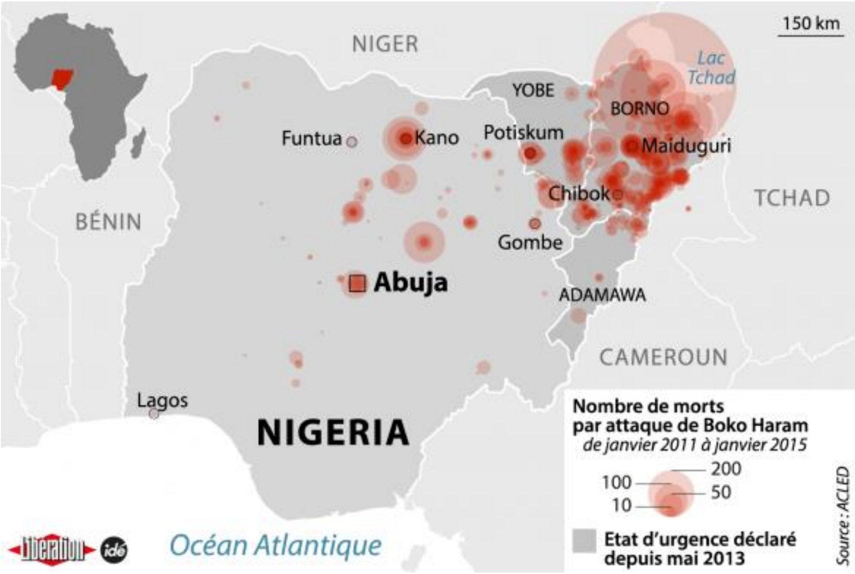
After presenting several data extracting approaches and their issues, this section shows how such data is used. First, presenting the direct link between transport and state reach; second, presenting the indirect link between transport and state reach via agglomeration effects.

4.1 Conflicts and State Reach in Nigeria 1950 and Today

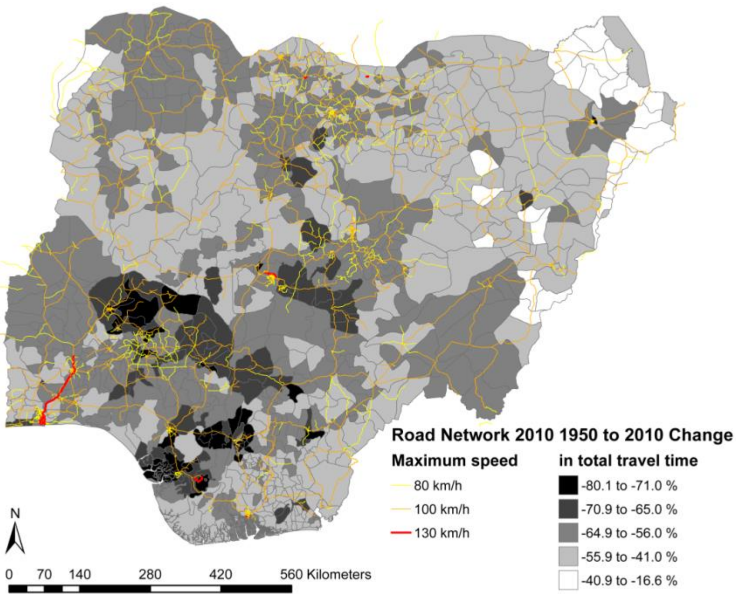
This section is an illustrative example summarising a more detailed analysis (Fuhrer and Axhausen, 2015). According to the underlying hypothesis of this research, transport infrastructure enables and governs state reach. Using the algorithm presented in section 3.1, the 1950 road network in Nigeria is reconstructed. Statistical data by the International Road Federation and meta data of the AMS maps define the 1950 speeds on main and secondary roads in Nigeria. Subsequent, the travel time from every municipality to every other municipality is calculated (total travel time). The current 775 municipal borders are used. The OpenStreetMap (OSM) network provides the information on network and speed for the current travel times between Nigeria's municipalities.

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. Looking at the following figure, 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.

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.

4.2 Agglomeration Effects: A Current Study in Switzerland

Another key aspect within the research framework is the indirect effect of transport infrastructure, or positive externality, called agglomeration effect or wider economic benefit. In the overall concept, agglomeration effects are the beginning of what can be described as "economic power" of a region.

There had been thoughts and ideas on agglomeration benefits prior to the development of the New Economic Geography in the 1990s (Krugman, 1991), that links classical location theory to the economic principals of an international globalised economy. However, they were given a concrete theoretical fundament why certain economic activities and dynamics tend to concentrate spatially. In the waves of this awareness of "the spatial" in economics, the reasoning on how space and economy interact lead to several papers. Rosenthal and Strange (2004) identified three main points: First, labour market pooling; second, common usage of various resources; third, knowledge transfer. In a micro-economic discussion of these three phenomena, Duranton and Puga (2003) provide the theory why these three effects cumulate in an increase of productivity and wealth respectively that goes beyond the linear gains from classical growth theory. Classical theory argues, that the output of an economy increases by the amount the transaction costs – in this case generalised transport costs – decrease. Following the agglomeration effect theory by Duranton and Puga (2003) however, there are wider (indirect) economic benefits.

1. Labour pooling: Lowering generalised transport costs means increasing the accessibility of companies to labour or of labour to job positions. This increases the chances that a company is able to find exactly the employee it is looking for, or that a person is able to find a job position that exactly matches her or his qualification and talents. In this situation, specialisation of firms but also of persons becomes worthwhile.
2. Common usage of resources: Real density or made density by low generalised transport costs allows common strategies within an economy and society to organise its input factors, such as education, energy, insurances, security, etc. For instance, several companies that employ laboratory chemists can pool their education and training of their future chemists.
3. Knowledge transfer: Real density or made density by low generalised transport costs allows more and diverse interactions between different economic agents. Positive spill over effects are more likely to happen.

All three effects increase productivity defined as the ratio between in- and output of an economy. Point one increases productivity since the process of labour becomes more efficient, the quality of the product or service increases. Point two reduces costs of input factors. Point three helps to find more efficient strategies. Overall, these micro-effects lead to an additional wealth increase to the linear gain from lowering generalised transport costs.

These concepts influence land use and urbanisation. In this spirit, Fujita and Thisse (2002) understand a city and its wider economic effects as a kind of public good, which several agents compete for. Companies and households are part of the agglomeration effect economy and in the same time seek to gain wider economic benefits. Another aspect is the link between networks and agglomeration effect, more precisely the question whether networks can fully replace density (Johansson and Quigley, 2004). Results show that this in fact holds. Thus it is important to work with an accurate measure of accessibility and consequently why the research presented in this paper deals with the modelling of historical networks, its speeds and accessibilities. A comprehensive overview on the history of agglomeration effect as a concept supports this claim (Thisse, 2011).

Now the question becomes how important this effect is and whether it is quantifiable. In a very recent study which is presented at this conference as well (Sarlas et al., 2015) the authors estimate the effect by model the elasticity between accessibility increase and productivity change. Productivity is modelled using a detailed national sample of paid salaries. Accessibility is modelled in detail using different elements of generalised costs for private and public transport. Characteristics of the position and the employee are taken into account as well. All variables are calculated on municipality (cities: Kreis) level. Several regression approaches (OLS, spatial error, geographically weighted and panel) are applied. The study shows the following findings:

1. The elasticity of accessibility on productivity is quite constant, independent of the regression approach.
2. The elasticity value range of car and public transport are similar.
3. The range in global regressions goes from one to two percent. This means, an increase of accessibility by hundred percent leads to an increase of productivity by one to two percent.
4. The estimated value follows spatial patterns. In some regions the effect is more present than in others. Elasticity values range between minus three and plus three percent; by far most of them are positive.

In a recent report with special focus on public transport (Axhausen et al., 2015), all findings and the method of this study is detailed. For the research project presented in this paper, it is important to recognise that the agglomeration effect is present, quantifiable using the suggested accessibility metric, and is of relevant size. Several other studies have come to similar results. The following table provides an overview on different approaches to capture this effect, that have been published recently.

Table 2 Recent published studies on agglomeration effect

Paper	Approach	“Accessibility”	„Productivity“	Spatial level	Time	Elasticity
(Chatman and Noland, 2014)	Average Salary = f(centrality, PuT supply)	Structural: # population, urban job density. Transport: PuT supply (seats, track density etc.)	Average salary, metropolitan GDP per capita	319 to 354 US metropolitan areas	2008	0.0254 to 0.0255 (per 1000 units Put variable)
(Graham and Van Dender, 2010)	Several panel data models	Structural: jobs. Transport: Euclidian distance -> jobs/distance	UK company panel: input vs. output per sector	ZIP codes, small zones; 17,700 firms	1995 to2004	0.105 (per city size)
(Graham, 2007)	Production function	Structural: jobs. Transport: Euclidian distance -> jobs/distance	Dito per subsector	Small zones, „wards“	1995 to2002	0.197 (per city size)
Reported in Graham 2007	Mostly production functions	Only structural, frequency: 1 # population, 2 jobs, 3 job density	Several production functions	US metrop. areas, cities Japan, EU	1973 to 2003	0.01 to 0.2 (mostly <0.1; per city size)
(Melo et al., 2013)	Travel cost graded regressions	Classical accessibility metric: job density * vehicle km and hours travelled; surveyed	Average salary per job position	51 US urban areas	1990, 1995, 2001, 2009	0.065 (20min); 0.003 (60min); per accessibility
(Venables, 2007)	Simulation	Structural: # jobs. Transport: travel costs = income – tax – rent	Relative measure: utility = saved costs			0.000 to 0.077
(Kline and Moretti, 2014)	Several historical data sources	Only structural: job and employed and capital density.	Regional growth relative to the national one	Tennessee Valley Authority	1940 to 2000	0.003 (per city size)

The findings reported in table 1 are in line with the less recent meta study by Melo et al. (2009). According to these authors, one can observe a decreasing elasticity over time. This means that in earlier times the agglomeration effects due to transport improvements had a higher wider benefit than more recently. This can have several explanations. One reason might be that the same degree of improvement on a low level of transport supply has a larger effect than on a high level of transport supply (diminishing marginal utility). Another reason might be that in more recent times transport can be substituted by other technologies such as telecommunication.

For the research project presented in this paper, it is important to recognise that the agglomeration effect is present, quantifiable using the suggested accessibility metric, and is of relevant size. This effect seems to be present in all national economies, independent of the political and economic setting. The effects become bigger, the more one goes back in time. On the other hand, they level off after a couples of decades (Kline and Moretti, 2014). Overall, this section shows how agglomeration effects, first element in the concept from transport infrastructure to state reach, can be captured in relation to transport supply and that one can assume to find strong effects working with historical data.

5. Outlook

The aim of this paper is to call attention on the link between transport infrastructure and state reach. The crucial concepts within this interrelation are described and for some of them it is exemplarily shown how they can be modelled. Another important aspect is the availability and reliability of historical sources, since the mechanisms are studied with historical data.

A big bunch of work is the collecting and processing of historical data. Currently, a GIS of relevant data is established by the author. Based on the experience with the applied projects presented above, the relevant data is identified and possible institutions, such as archives and libraries, are contacted. It turned out not to be as straightforward as expected, since many documents and sometimes catalogues can only be sifted on place and/or many institutions do not offer useful contact for researchers abroad. A careful planning of the collection of the different sources is needed.

At the same time, various other historical data, such as population, is collected and processed in a format that is suitable for spatial models. In a next step, spatial models will be estimated.

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