

Killer, Veronika; Axhausen, Kay W.; Holz-Rau, Christian; Guth, Dennis

Conference Paper

Understanding Regional Effects of Travel Times in Switzerland and Germany 1970-2005

50th Congress of the European Regional Science Association: "Sustainable Regional Growth and Development in the Creative Knowledge Economy", 19-23 August 2010, Jönköping, Sweden

Provided in Cooperation with:

European Regional Science Association (ERSA)

Suggested Citation: Killer, Veronika; Axhausen, Kay W.; Holz-Rau, Christian; Guth, Dennis (2010) : Understanding Regional Effects of Travel Times in Switzerland and Germany 1970-2005, 50th Congress of the European Regional Science Association: "Sustainable Regional Growth and Development in the Creative Knowledge Economy", 19-23 August 2010, Jönköping, Sweden, European Regional Science Association (ERSA), Louvain-la-Neuve

This Version is available at:

<https://hdl.handle.net/10419/119109>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

Understanding Regional Effects of Travel Times in Switzerland and Germany 1970-2005

Refereed R-session paper to be presented at ERSA 50th Conference

Jönköping (Sweden), August 19 - 23, 2010

Scientific Committee, Infrastructure, transports and communications

Dr. Andreas Stephan, JIBS, Sweden

Killer Veronika
ETH Zürich
Institute of Transport Planning and Systems (IVT)
Wolfgang-Pauli-Str. 15
CH-8093 Zürich
Switzerland

Telephone: +41-44-633 27 19
Fax: +41-44-633 10 57
veronika.killer@ivt.baug.ethz.ch

Guth Dennis
TU Dortmund University
Department of Transport Planning
August-Schmidt-Straße 10
D-44227 Dortmund
Germany

Telephone: +49-231-755 78 62
Fax: +49-231-755 22 69
dennis.guth@tu-dortmund.de

Axhausen Kay W.
ETH Zürich
Institute of Transport Planning and Systems (IVT)
Wolfgang-Pauli-Str. 15
CH-8093 Zürich
Switzerland

Telephone: +41-44-633 39 43
Fax: +41-44-633 10 57
axhausen@ivt.baug.ethz.ch

Holz-Rau Christian
TU Dortmund University
Department of Transport Planning
August-Schmidt-Straße 10
D-44227 Dortmund
Germany

Telephone: +49-231-755 22 70
Fax: +49-231-755 22 69
christian.holz-rau@tu-dortmund.de

10. June 2010

Abstract

This study points out the effect of road infrastructure improvement between 1970 and 2005/06 and the resulting change of travel time in Germany and Switzerland. Reconsidering the interaction between the transportation system and land use, the paper contributes to the ongoing discussion about induced travel and infrastructure capacity. The impact of highway capacity expansion on land use has been studied worldwide focusing on urban areas. This study goes one step further. We detect changes in suburban and rural areas by this national comparison.

The generation of a historical travel time dataset applies a method developed for Switzerland in previous studies and is adjusted for Germany according to its political, structural and topographical situation. The method is based on a historical network and estimated mean car speeds on different road types varying between densely or sparsely populated areas. Travel time matrices between all municipalities in Germany and Switzerland are calculated and validated by a regional comparison. Three indexes are developed to detect regional effects of travel time. The results are regionally segmented by a spatial cluster analyses named Getis-Ord's G_i^* statistics. The spatial overview of the three travel time indexes takes into account the national and regional level. The historical travel time dataset is successfully validated. This useful data is needed for later investigation on commuting behaviour.

1. Introduction

This paper contributes to the ongoing discussion about induced travel and infrastructure capacity reconsidering the interaction between the transportation system and land use. The impact of highway capacity expansion on land use has been studied worldwide mainly in urban areas. However, we detect spatial variation in rural areas by this national comparison. Impacts are context-specific. They are e.g. depending on growing population and employment. This work points out the effect of road infrastructure improvement between 1970 and 2005/06 and the resulting change of travel time in Germany and Switzerland. The historical review in chapter 2 describes the general development of infrastructure and road use in Switzerland and Germany and provides a broader context for our work.

This paper is part of to the research project “Spatial accessibility and the dynamics of commuting in Germany and Switzerland 1970 to 2005”. The overall objective of this project is to analyse spatially the change of commuting pattern over the past decades and to collect historical data at the spatial level of municipalities. Moreover, we intend to prepare methods to manage large data sets, e.g. developing indexes for national comparisons. The understanding of commuting pattern is strongly linked to the corresponding travel times of individual and public transport. However, appropriate historical data on municipality level did not exist. The means of historical travel time data of individual transport are reconstructed by focusing on improvement of infrastructure and changes in car use over the years. The modeling of historical travel time data of Germany is presented in chapter 3.

The travel time matrices are large data sets given by the number of German municipalities (12'302x12'302). Geographic data mining methods are applied for validating these large data sets. Data mining methods involve the application of computational tools and a set of statistics to reveal interesting patterns distributed across space and time. The estimated travel times are compared to the results of Switzerland and regional differences of travel time patterns within both countries are detected. This study applies methods of Geographic Information Systems (GIS) implemented in ArcGIS. Chapter 4 investigates the regionalisation effects. Chapter 5 explores some first relationship between travel time and commuting behavior.

2. Development of infrastructure and road use in Switzerland and Germany 1970-2005

During the past decades, private vehicle traffic has changed dramatically and infrastructure for private vehicles has been developing from a multipurpose, slow road network into a fast, single-purpose hierarchical structured road network (Fröhlich and Axhausen, 2002)

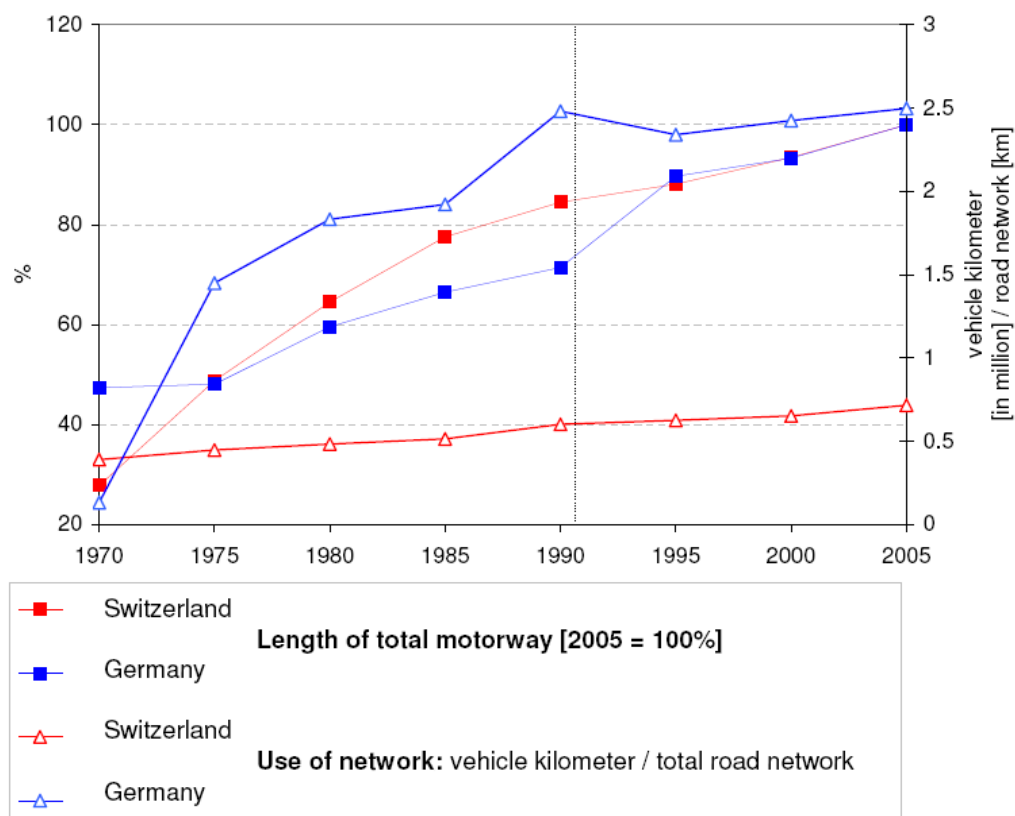


Figure 1: Network characteristics in Germany and Switzerland 1970-2005.

Data: Verkehr in Zahlen, 2005/2006; 1991 (Germany), 1970-1990 only Old Laender, 1995-2005 current German territory, Swiss Federal Statistical Office (Switzerland)

By 1970 about 5'900 km of motorways had been built in Germany. That is about 47% of the current length of network (see figure 1). Whereas the construction of motorways had just started in Switzerland (see figure 1). At that time, Switzerland possessed a motorway network about 380 km (about 27% of the current length). The total network and network load increased during the next two decades in both countries. Since 1990, it is stagnating in Germany but still slightly

growing in Switzerland. These effects are regulated by the motorization level of the respective country (see figure 2).

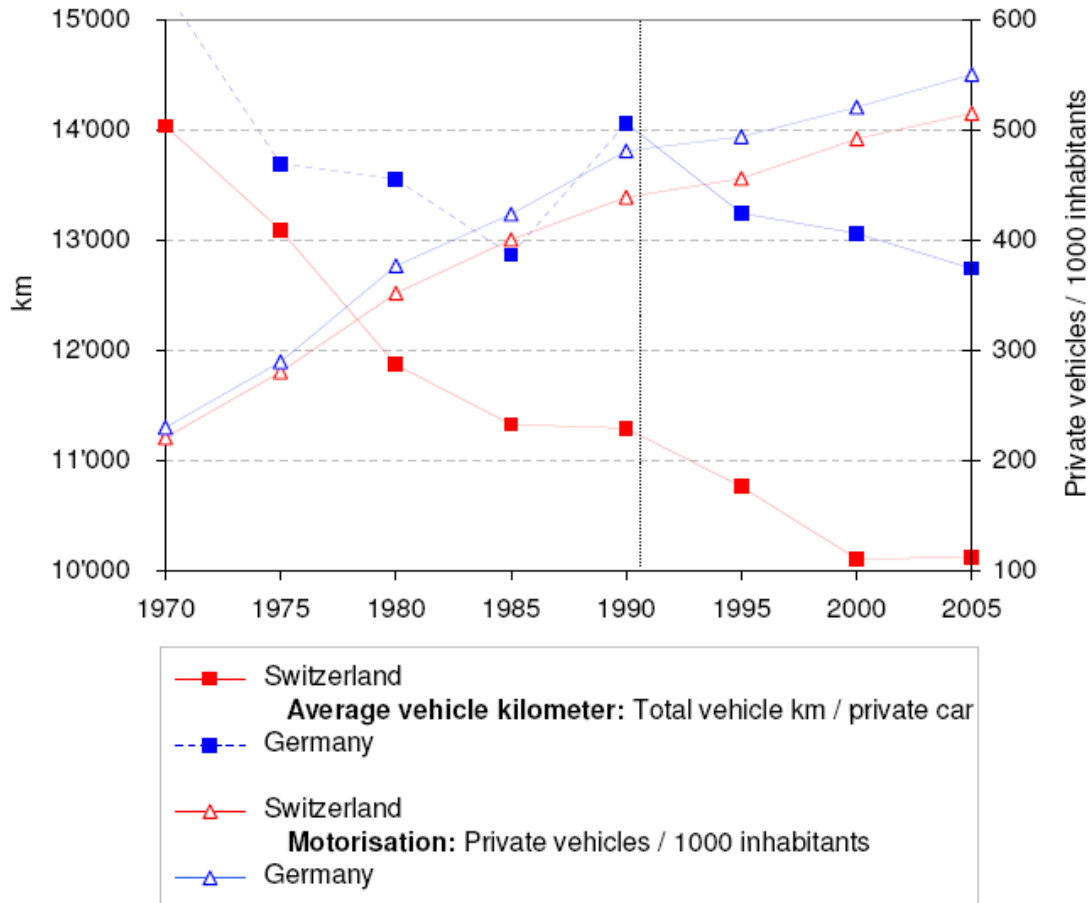


Figure 2: Car use in Germany and Switzerland 1970-2005.

Data: Verkehr in Zahlen, 2005/2006; 1991 (Germany), 1970-1990 only Old Laender, 1995-2005 current German territory, Swiss Federal Statistical Office (Switzerland)

The automobile was getting increasingly popular in both countries during the 1970s. However, the kilometers driven per private car have been decreasing over the years. Generally, the motorization level is higher in Germany than in Switzerland. Regional differences are large within both countries. The mobilizations level and car use is higher in rural than in urban areas today (Berger et al. 2009).

Car driving is an epitome of individual freedom and the driving performance steadily increased over the years. Before 1970, the over land speed of main roads and motorway was unlimited. Increasing number of accidents asked for speed limits. The controversy about this development caused speed reductions and mandatory seat belts law. In Germany and Switzerland the speed of

main roads was restricted to 100 km/h at this time. In 1983, the speed limits on Swiss motorways followed and the speed on main roads was further restricted to 80 km/h. In the former German Democratic Republic (GDR), speed limits of 80 km/h on main roads and 100 km/h on motorways were applied. In Germany, speed on motorways is still unlimited today, but 130 km/h are recommended and posted in high demand areas.

The reunification of the German national territory after 1990 should be considered when analysing German time series. The demographic, economical and political situation of the “Old” and “New Laender” (old and new federal states) differs substantially. Additionally, data availability for the “New Laender”, the former German Democratic Republic (GDR) is poor. Therefore, data presented in figure 1 and 2 are based on the “Old Laender” up to 1990, and on the reunified German territory afterwards. Methods of data collection changed for the criteria vehicle kilometer underestimating values before 1990.

3. Travel time in Germany 1970 - 2006

The model of historical travel times of Germany includes two complementary components applying the approach proposed by Fröhlich et al. (2004) for Switzerland. Firstly, the network is generated for the relevant years. This process is based on an existing German road network for the year 2006 (Validate, PTV). This road network is of very high detail. It consists of approximately 1'336'000 links, 570'000 nodes and 18'900 zones. The attribute year of change, type of change (new construction, extension, or local bypass) and the number of lanes are added for main roads and motorways. The necessary information for the “Old Laender” are collected manually from the annually published “Strassenbauberichte” (Road Construction Reports 1971-2005) provided by the Federal Ministry of Transport, Building and Urban Affairs and on the basis of different web sources (e.g. www.autobahn.online.de) for both types of Laender.

Secondly, mean speeds for different road types, main roads, and highways with two or three lanes is estimated for the years 1970, 1987, 1999. The years correspond to the years for which commuting data are available. For the year 2006, the travel times and network distances are calculated with the Validate traffic model (PTV) using the VISUM (PTV). The historical maximum speed, the traffic volume and the maximum capacity is assigned to each route type.

The historical mean speed for each year is estimated by considering the estimates proposed in Erath and Fröhlich (2004) and the official German handbook of road transport infrastructure design (Forschungsgesellschaft für Strassen- und Verkehrswesen, 2000). The estimates differ according to the political territory (FRG or GDR) and to regional differences in settlement structure and population density. A complete description of the specific parameters and further work steps are documented in Killer et al. (2010). Shortest network distance is calculated using VISUM (PTV). Travel time matrices for each year and all 12'302 German municipalities are stored for further analysis.

A first validation step analyses the mean speed on short, middle, and long distances (see table 1). The speed increased because of infrastructure improvement and political changing speed limits mainly in Switzerland and in the “New Laender” for all distances in this period of time. However, regional differences are apparent. Particularly, the speed (2006) in the “Old Laender” is low because of increased network load for all three categories of travel distance.

Table 1: Average speed [km/h] on actual road distance

Region	Travel distance	2005 ^{CH} /2006 ^{DE}	2000 ^{CH} /1999 ^{DE}	1990 ^{CH} /1987 ^{DE}	1970 ^{CH/DE}		
		Germany	Switzerland	short	76	71	71
middle	93			90	88	80	
long	95			94	95	84	
New Laender	short		89	83	70	69	
	middle		88	81	69	68	
	long		105	100	87	79	
	Old Laender		short	88	86	84	72
			middle	86	83	82	76
			long	88	85	90	83

Travel distance (= road network distance): short=17.5-22.5 km; middle=97.5-102.5 km; long=495.5-502.5

Data: 2000 - 2005^{CH}: Swiss national traffic model (ASTRA) / 1970 - 1990^{CH}: Fröhlich et al. (2004) / 2006^{DE}: Validate traffic model (PTV) / 1970 - 1999^{DE}: Killer and Axhausen (2010)

4. Regional differences in travel time

To quantify the regional differences the matrices are aggregated at the level of municipalities. This level of spatial aggregation is adequate for visual and statistical comparisons. For validating the indices are calculated consciously not mixed with travel demand or attractiveness variables of the municipality.

A simple measure is the sum of all travel times (STT_i) from one municipality to all other municipalities of the national territory (see formula F1). The resulting figure 3 demonstrates the best location within a country, which can be reached by all other municipalities within a minimum of travel time. This index is a measure of centrality. In Germany, the minimal sum of travel time is at the centre of the country close to the theoretical concept of the gravity centre. In Switzerland, the minimal sum of all travel times shifts to the West. However, Figure 3 shows that the arrangement of the municipalities influences this result (see the central municipality - sum of all Euclidean distances - in figure 3). This effect can be explained by the topography of the country. Actually, the capital of Switzerland (Bern) seems to be situated optimally.

$$(F1) \quad STT_i = \sum_j t_{ij}$$

STT_i is the sum of travel time - centrality
 t_{ij} is the travel time between municipality i and municipality j
 j are all municipalities of the national territory

The next step shows an approach which eliminates the spatial effects of the territorial shape and arrangement of municipalities within the country. The sum of travel time from municipality i to municipality j is divided by the respective Euclidean distance and by the number of municipalities (see formula F2) focusing on the average trip and not on the sum of all trips. This measure describes the travel time for an average trip from origin to destination municipalities taking into account the topography of the country. It can be interpreted as the mean connectivity of a municipality.

$$(F2) \quad STTD_i = \frac{1}{n} \sum_j \frac{t_{ij}}{d_{ij}}$$

$STTD_i$ describes an average speed (inverse) from origin to destination municipality regarding municipality structure - connectivity
 t_{ij} is the travel time between municipality i and municipality j
 d_{ij} is the Euclidean distance between municipality i and municipality j
 n number of municipalities of the national territory

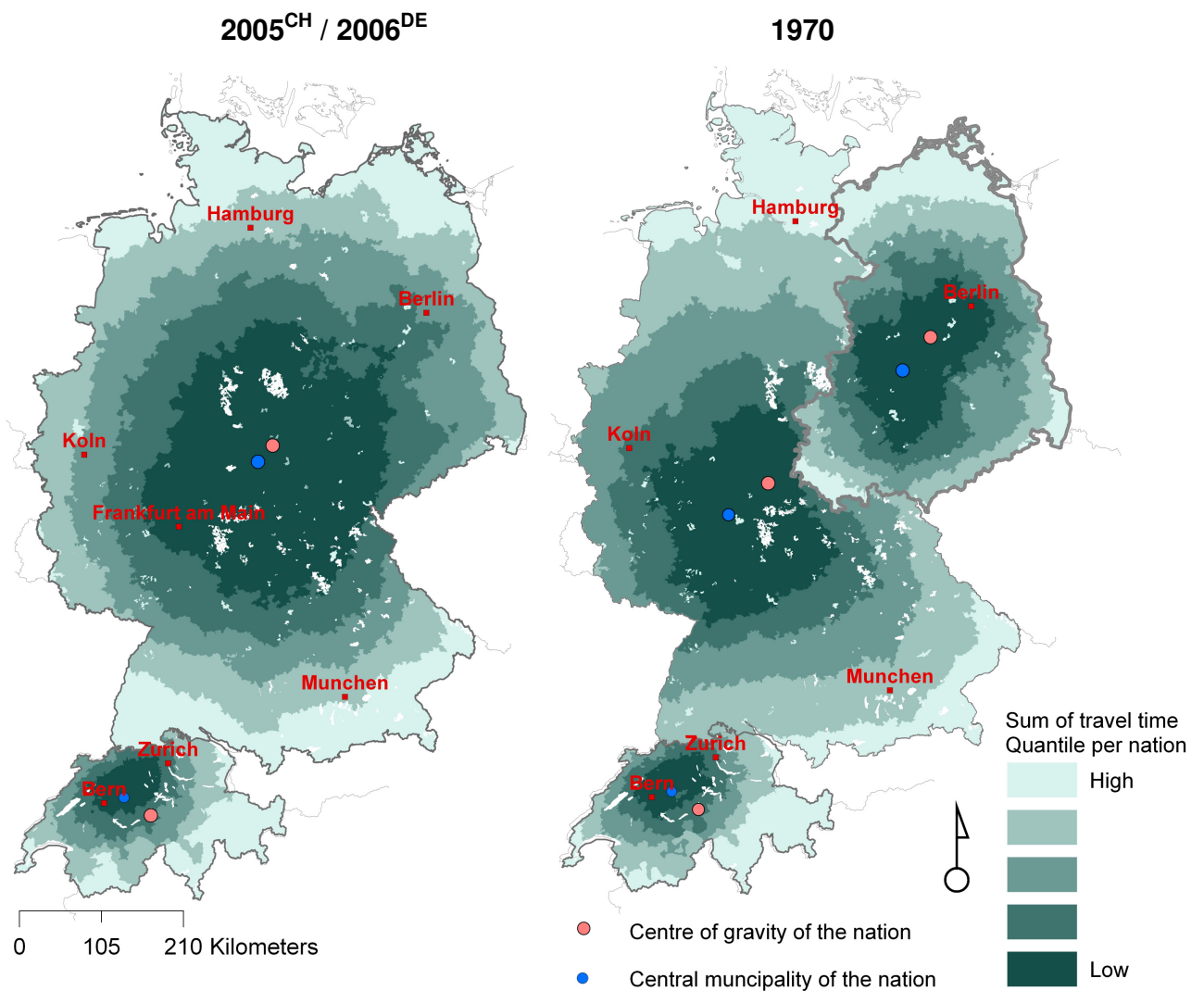


Figure 3: Sum of travel time – thinking about centrality (F1).

For analysing the historical travel time data an index measuring the local conditions is required. The index (see formula F3) detects travel time on the existing road network within a 60 km circle around the respective municipality. The value is arbitrarily chosen to capture a reasonable region around each municipality. However, the municipality's sizes vary substantially. Therefore, the index is divided by the number of municipalities which are located within the respective circle. The resulting pattern is of rather small scale (see figure 4). This index can be interpreted as an inverse speed measure describing the speed on an average trip what will be traveled from the origin municipality to any destination.

$$(F3) \quad STTD_{i60} = \frac{1}{n} \sum_j^{d_{ij} \leq d_{\max}} \frac{t_{ij}}{d_{ij}^n}$$

$STTD_{i60}$ describes an average speed (inverse) from origin to destination municipality regarding the network distance

t_{ij} is the travel time between municipality i and municipality j

d_{ij}^n is the network distance between municipality i and municipality j

n number of municipalities within a circle of 60 km Euclidean distance

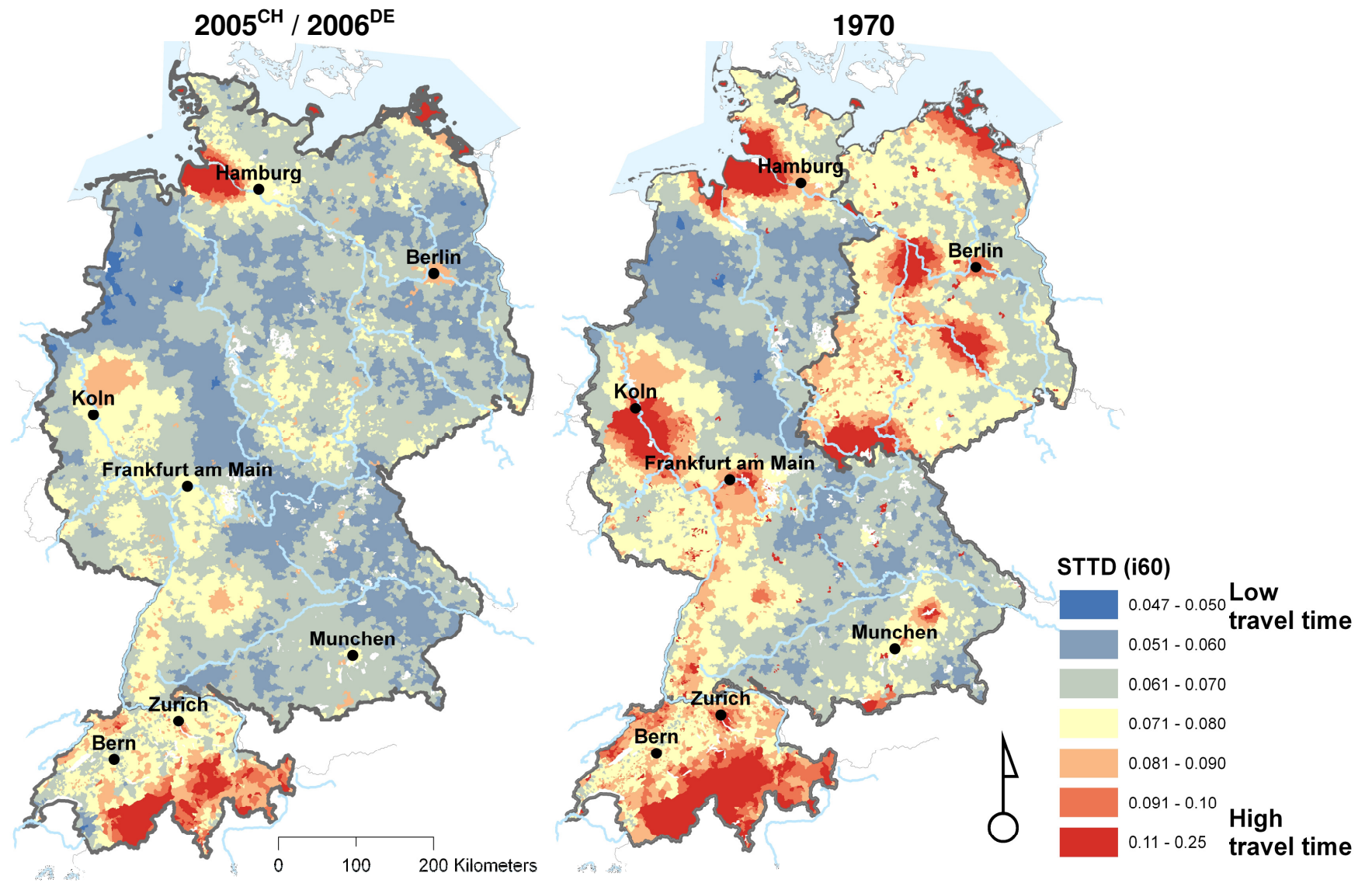


Figure 4: Average speed (inverse) on road network – thinking about speed $STTD_{i60}$, (F3).

The visual results of the latter indexes (F2 and F3) are spatially different (see figure 4 for F3). It is difficult to identifying significant regional differences in travel time in this figure.

For regional segmentation a method of identifying spatial autocorrelation is applied in figures 5 and 6. This method is used in data-mining practice for segmenting large datasets into groups according to their similarity. A cluster is a collection of data objects that are similar to one another and are dissimilar to the objects in other clusters (Miller and Han, 2009). Obviously, the road infrastructure improvement should not only affect a single municipality, but the whole region.

A bundle of exiting methods attempts to detect spatial clusters (Miller and Han, 2009). A popular index of global spatial autocorrelation is the Moran's I index. The Moran's I of index $STTD_{i60}$ (F3) varies between 0.05 and 0.2 for the different years and two different nations. However, in any case the likelihood is less than 1% that this clustered pattern could be the result of random chance. However, global indexes only indicates overall clustering but cannot be used to detect spatial statistically significant patterns in different locations. Within spatial data analysis exploratory graphical techniques which emphasize the local nature of relationships have become popular (Fotheringham et al., 2002). The local spatial autocorrelation statistics, including Local Moran's I and Getis-Ord's G_i^* are used to evaluate and map the local spatial association between each value and its surrounding areas (Anselin, 1995).

$$(F4) \quad G_i^* = \frac{\sum_{j=1}^n w_{i,j} x_j - \bar{X} \sum_{j=1}^n w_{i,j}}{S \sqrt{\frac{n \sum_{j=1}^n w_{i,j}^2 - \left(\sum_{j=1}^n w_{i,j} \right)^2}{n-1}}} \quad \bar{X} = \frac{\sum_{j=1}^n x_j}{n} \quad S = \sqrt{\frac{\sum_{j=1}^n x_j^2}{n} - (\bar{X})^2}$$

x_j is the attribute value for municipality j
 w_{ij} is the spatial weight between municipality i and j
 n total number of municipalities

This category of tools examines the local level of spatial autocorrelation in order to identify areas where values of the variable are both extreme and geographically homogeneous. The clusters are identified by applying the local Getis-Ord's G_i^* statistic (Getis and Ord, 1992) in this study. The Getis-Ord G_i^* statistics especially identifies spatial clusters of high values "hot spots" and spatial clusters of low values "cold spots", comparing the local statistics to the global statistic (Longley and Batty, 1996). The clustering is applied on the national level of Switzerland and Germany with two different global statistics. For the 1970 the Old and New Laender could be analysed separately detecting segmentations within the two Laender. For this study it is reasonable to analyse on a national level to show segmentation between the Old and New Laender. The neighbouring rules of surrounding values have to be defined in advance. In this study all municipalities within 60 kilometres are assumed to have a regional impact. The G_i^* statistic is implemented in the ArcGIS Hot Spot Analysis. The output from the Hot Spot Analysis tool is a Z score and p-value for each feature. A high Z score and a small p-value for a feature indicate a spatial clustering of high values. In contrast, a low negative Z value and small p-value indicates a spatial clustering of low values. However, a Z score near zero indicates no apparent spatial clustering (Mitchell, 2005).

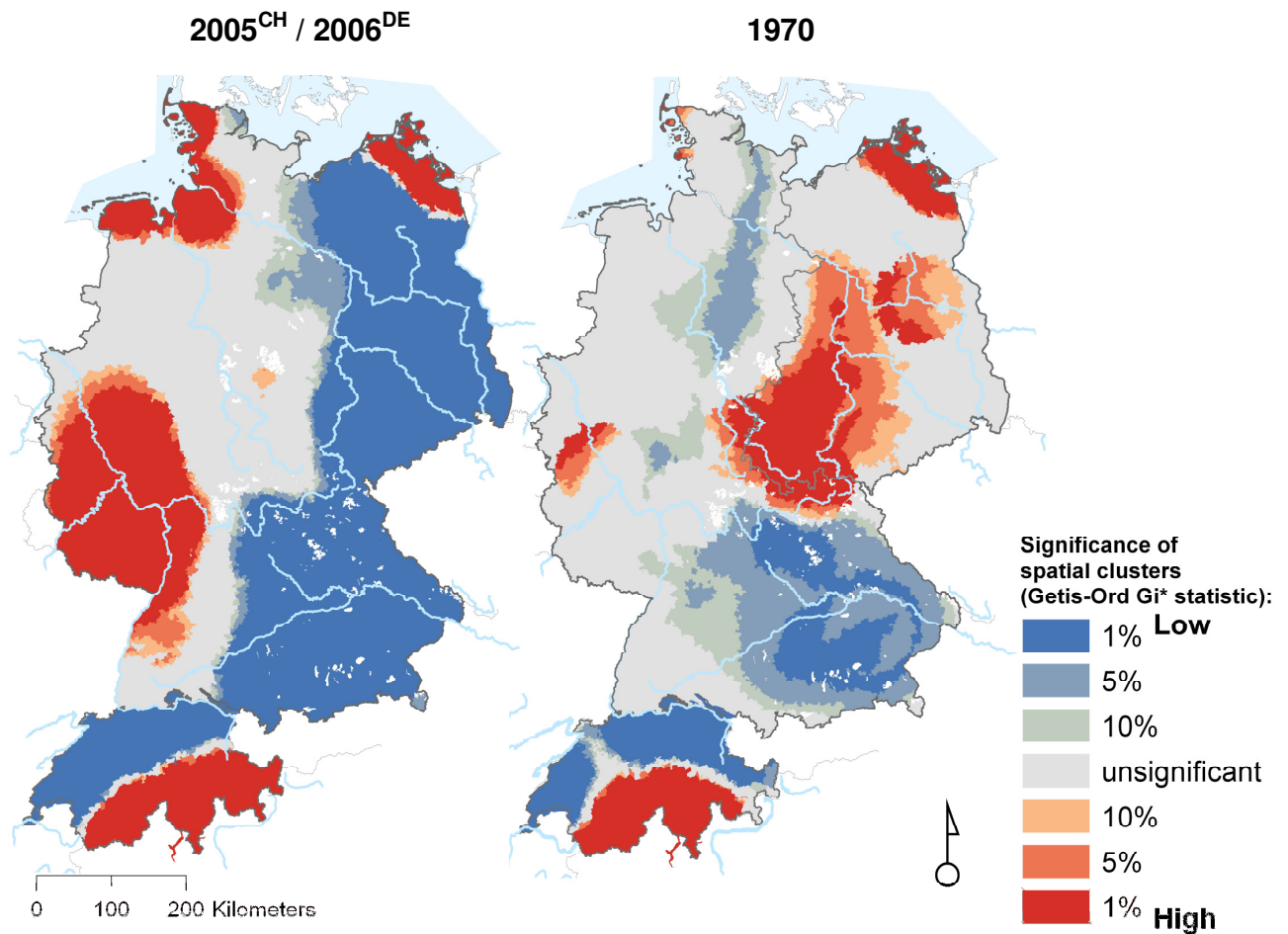


Figure 5: Regional cluster of average speed (inverse) - connectivity of origin-destination municipality (F2).

The results are visualised in figure 5 and 6. Generally, low values (blue) indicate shorter travel times. In 2005, Switzerland is segregated into a better connected area of shorter travel time, the lowland, and the area of higher travel times, the mountain region (see figure 5). In the 1970s, the lowland area is divided along the “*Röschti graben*” the border between the French and German speaking part of Switzerland. In 2006, the Germanys Eastern part is a better connected area opposite to the Western part which is mainly not significant clustered. However, two regions, the hinterland of Hamburg and the Rhine-Ruhr area, are evident as regions of higher travel times. In the 1970s, the clusters are generally less significant. The existing clusters are reflecting the

restrictive speed limit in the “New Laender” (GDR) and the extended road infrastructure in the “Old Laender” (FRG).

At small scale (60 kilometers radius) the cold and hot clusters of travel times of individual transport on road network (see figure 5) are more significant than on larger scale (see figure 4) in both years. The region of Stuttgart is another area of higher travel times in the 1970s. In 2005/06, areas of higher travel times – mainly the metropolitan areas – are producing one German belt from the North to the South. In Switzerland, the Greater Zurich area is also one of higher travel times. These areas are characterised by increasing population density by the suburbanization process and induced road congestion. However, this characteristic of higher travel times is unexpectedly not significant apparent around Berlin, but the city centre is affected.

Rural areas are rather regions of low travel times today. Particularly, the Swiss situation strongly improved according to the policy of rural development in this period (see figure 3). However, there are also rural areas with high travel times. Those are some badly connected Swiss mountain valleys and the German costal areas of the North and Baltic Sea. Moreover, a spot in the middle of Germany is astonishingly high.

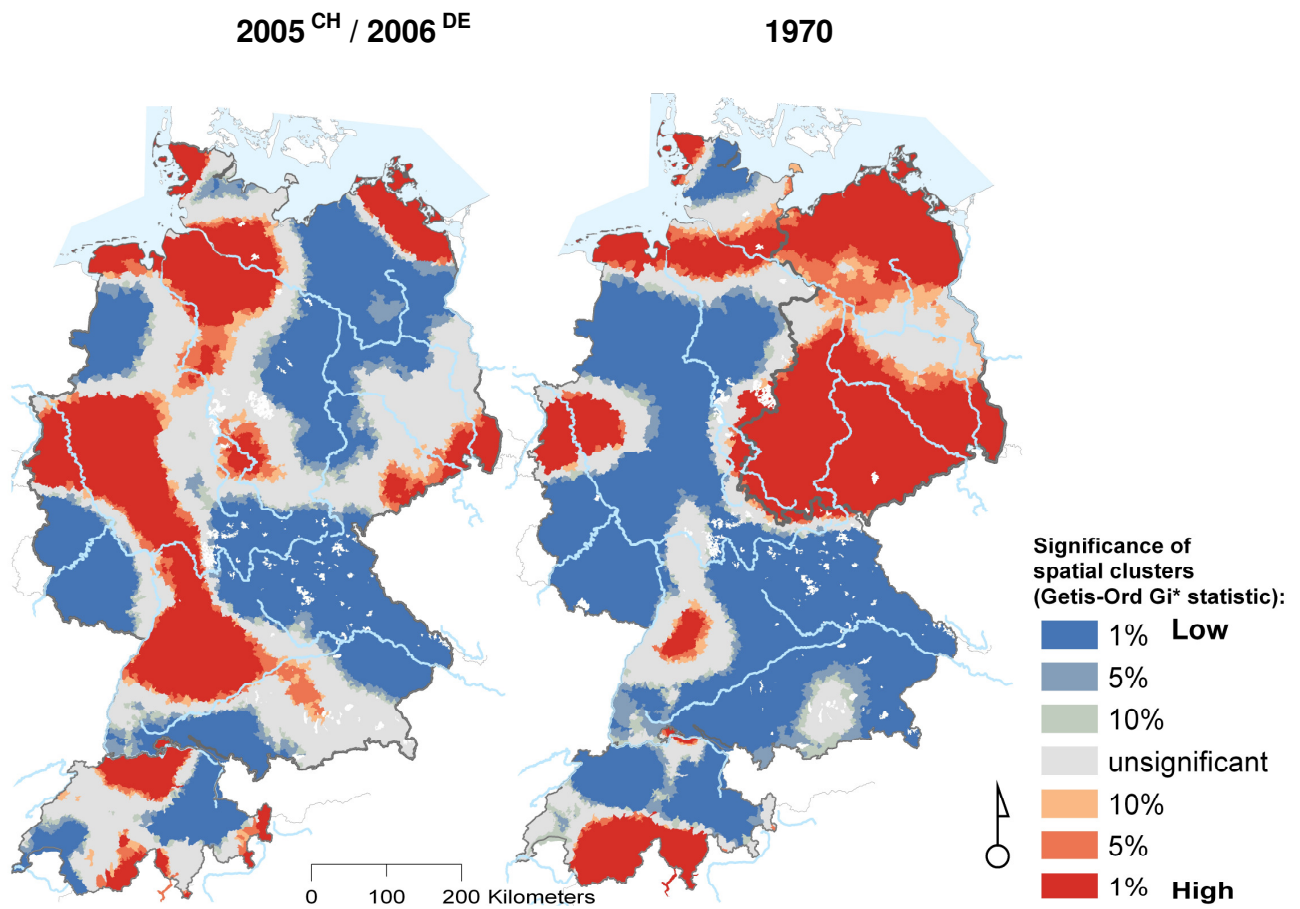


Figure 6: Regional cluster of average speed (inverse) on network distance of origin-destination municipality (F3).

5. An outlook on the relationship of travel time and commuting

In this study one general objective of generating historical travel time data is to better understand historical commuting behavior. Further steps aim to unravel this relationship. The daily commute takes place within a hierarchical system of functional urban areas. The index of travel time on road network (F3) operates on this spatial level. Analysing the relationship by an ordinary least square (OLS) regression is not appropriate for this investigation, because of the local and global spatial autocorrelation of the travel time variable detected in the previous chapter. The spatial lag model and spatial error model are global models eliminating spatial autocorrelation. A disadvantage of the global models is that geographically varying relationships not part of the

model structure. Therefore, results are averaged values (Fotheringham et al., 2002).

Geographically weighted regression (GWR) (Fotheringham et al, 2002) is a method that produces locally varying parameter estimating a regression for every spatial data point. GWR is a useful exploratory technique. Applying this method, further questions about the structures in the data can be asked (Miller and Han, 2009). In this step a simple model (F5) estimating commuting behavior on travel time is calculated for Switzerland (2000) and Germany (1999). By this step we can ensure that the generated travel time data show an effect on commuting and that the results are meaningful for future analyses.

$$(F5) \quad y(u_i, v_i) = \beta_0(u_i, v_i) + \beta_1(u_i, v_i)x_1(u_i, v_i) + \beta_2(u_i, v_i)x_2(u_i, v_i) + \varepsilon(u_i, v_i)$$

y is $STTD_{i60}$ the sum of travel time on road network

u_i, v_i are parameters of each regression point

β_0 is the intercept

β_1 is the incommuting intensity, number of incommuters divided by workplaces of a municipality

β_2 is the outcommuting intensity, number of outcommuters divided by active population of a municipality

Spatial variability of the GWR parameters is usually examined by producing a choropleth map of each separate parameter surface and the statistical summaries for parameter estimates (local t-values, standard residuals, local R^2). These univariate maps are then scrutinized for patterns that give an idea about the spatial behaviour of parameter values (Fotheringham et al., 2002). In this chapter we forgo mapping the parameters results to avoid an interpretation of the travel time commuting relationship in detail. The simple model is not adequately sophisticated for content interpretation. However, some reasonable conclusion of this validation process is: The overall model is significant. The local R^2 is substantially higher than the global R^2 . The local R^2 for Switzerland is 0.5 and for Germany 0.24. The standardised residuals have large residuals in the cities of both countries. The signs of both commuting parameters estimates are varying according to the regional context. Further model investigation and completion of the historical commuting dataset will be necessary to come up with significant results of the relationship of commuting and travel time across space and time.

6. Conclusion

An interesting and useful historical dataset of travel time matrices could be generated. Travel time is based on mean speed estimation because of lack of historical data. However, a realistic picture of the historical traffic conditions of individual transport has been achieved in general. Two effects need further investigation: Is the travel time in the Western part of Germany today effectively that low? Why is Berlin not affected by a suburban area of higher travel time? These uncertainties could be generated by a data bias or a scale effect of the analyses. Further investigation on the scale of urban areas will show how commuting and land use have been affected by the change in travel time and infrastructure improvement over time.

Generally, large national and regional differences in travel time are detected. The change in travel time demonstrates arising metropolitan areas and their increasing connectivity over the years, where congestion produces higher travel times. In rural areas the travel time is generally lower, except of isolated regions in the mountains or coastal areas.

The method of visualisation of spatial clustering turns out to be an useful method for validating large datasets. The matrices of approximately 150 million trips aggregated on 15'000 municipality (CH + DE) polygon are validated successfully.

Acknowledgement

We would like to thank the Swiss National Science Foundation (SNF) and the German Research Foundation (DFG) for funding this work as part of the project “Spatial accessibility and the dynamics of commuting in Germany and Switzerland 1970-2005”. This project is jointly carried out at the Institute for Transport Planning and Systems at ETH Zurich and the Department of Transport Planning at TU Dortmund University.

References

- Anselin, L. (1995) Local Indicators of Spatial Association – LISA, *Geographical Analyses*, **27**, (2), 93-115.
- Axhausen, K.W., P. Fröhlich and M. Tschopp (2006) Changes in Swiss accessibility since 1850, *Arbeitsberichte Verkehr und Raumplanung*, **344**, IVT, ETH Zürich, Zürich.
- Berger, H.-U., P. Güller, S. Mauch, and J. Oetterli (2009) *Verkehrspolitische Entwicklungspfade in der Schweiz*, Rüegger Verlag, Zürich.
- Erath, A. and P. Fröhlich (2004) Die Geschwindigkeiten im PW-Verkehr und die Leistungsfähigkeiten von Strassen über den Zeitraum 1950-2000, *Arbeitsbericht Verkehrs- und Raumplanung*, **183**, Institut für Verkehrsplanung und Transportsysteme (IVT), ETH Zürich, Zürich.
- Fotheringham, A. S., C. Brunsdon and M. Charlton (2002) *Geographically Weighted Regression*, John Wiley & Sons, Chichester.
- Forschungsgesellschaft für Strassen- und Verkehrswesen (2001) *Handbuch für die Bemessung von Strassenverkehrsanlagen* (HBS), FGSV, Köln.
- Fröhlich, P., T. Frey, S. Reubi and H.-U. Schiedt (2004) Entwicklung des Transitverkehrs Systems und deren Auswirkung auf die Raumnutzung in der Schweiz (COST 340): Verkehrsnetz-Datenbank, *Arbeitsbericht Verkehrs- und Raumplanung*, **208**, IVT, ETH Zürich, Zürich.
- Fröhlich, P. and K.W. Axhausen. (2002) Development of car-based accessibility in Switzerland from 1950 through 2000, paper presented at *2nd Swiss Transport Research Conference* March 20-22, 2002, Ascona.
- Getis, A. and J.K. Ord (1992) The Analysis of Spatial Association by Use of Distance Statistics. *Geographical Analysis*, **24**, (3) ,189-206.
- Killer, V., K.W. Axhausen and D. Guth (2010) Modellierung historischer Reisezeiten im motorisierten Individualverkehr in Deutschland, *Arbeitsberichte Verkehr und Raumplanung*, IVT, ETH Zürich, Zürich.
- Longley, P. and M. Batty (1996) *Spatial Analysis: Modelling in a GIS Environment*, Wiles & Sons, New York.
- Miller, H. and J. Han (2009) *Geographic Data Mining and Knowledge Discovery*, Second Edition, CRC Press, New York.
- Mitchell, A. (2005) *The ESRI Guide to GIS Analysis*, Volume 2, ESRI Press, Redlands.