Constructing time-scaled maps

Switzerland 1950 to 2000

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Abstract

The paper discusses the construction of a time-scaled maps series for Switzerland documenting the shrinking of the country since 1950. It describes underlying network models and the mathematical approach employed for the necessary rescaling. In conclusion, it presents the maps and discusses them.

Keywords

Time-scaled maps, travel times, measurement, accuracy, network model, rail, road, public transport, IVT, ETH Zürich

Preferred citation style

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1 Visualising a changed world

We all know that our world has been changed dramatically by investments in new roads, new rail links, private cars, and faster trains, even ignoring air travel for the moment. This new geography is distinctly different from that displayed on distance-scaled maps, as we know them from an atlas: trips in certain directions are served less well than others, certain parts of a country are served more slowly, or isolated by mountains or lakes. While isochrones maps can display directional speed differences from a particular point (See for example Figure 1), they cannot display the overall pattern of distortions for a whole country; a time-scaled map could. In a time-scaled map, a territory's relevant points' locations would be shifted so Euclidian distances between points can be read as travel times, instead of physical distances. The changes can be understood at a glance. Geographers and others have developed solutions to this optimisation problem, which will be presented below.

Figure 1 Rail – travel time isochrones from St. Gallen, 2000

Dark grey area is reached within an hour, dark blue area is reached within two hours and light blue area is reached within three hours.

In a study of the effects of transport investment on population and employment distribution of Switzerland since 1950, matrices of travel times between any of about 3'000 Swiss municipalities were calculated for both road and rail travel. They are the base for the accessibility gains calculation obtained from transport investment, which is assumed to cause the observed changes in population and employment distribution. (See Fröhlich and Axhausen, 2005; Axhausen, Fröhlich, Tschopp and Keller, 2005; Fröhlich and Axhausen, 2002, 2004; Fröhlich, Tschopp and Axhausen, 2005 for accessibility change and Axhausen, Fröhlich, Tschopp and Keller, 2004; Axhausen and Fröhlich, 2004; Tschopp, Fröhlich, Keller and Axhausen, 2003 and Tschopp, Fröhlich and Axhausen, 2005 for the causal models estimated). The networks constructed will be presented in the following sections. (See also Fröhlich and Axhausen, 2004; Bodenmann, 2003; Vrtic, Lohse, Fröhlich, Schiller, Schüssler, Teichert and Axhausen, 2005, and Vrtic, Fröhlich and Axhausen, 2003).

Availability of travel time matrices to produce time-scaled maps gave researchers the chance to visualize the changes that have transformed everyday Switzerland. This paper documents

the processes and methods used to calculate these maps. First, two early approaches will be presented. Then the networks constructed for the travel time calculations will be discussed at some length, including a brief assessment of the accuracy achieved. The second method section discusses the optimisation approach adopted here for the rescaling of the physical locations into time-scaled locations, followed by the overall approach of map generation. In the last section, the maps will be presented and discussed.

2 Earlier time-scaled maps

Building on earlier Japanese work (Shimizu, 1993), Spiekermann and Wegener (1993 and 1994) constructed time-scaled maps of Europe based on then current and predicted rail travel times. They employed a multi-dimensional scaling algorithm, which they extended to cope with boundary effects (See Figure 2). (For further examples see also Tobler, 1961; Muller, 1978 and 1984, or Ahmed and Miller, In press)

This, and any two-dimensional rescaling, has the disadvantage, particularly for railway travel times, that it emphasizes access points (station locations or motorway ramps) rather than the space in between, which does not benefit to the same extent from the higher speeds on the trunk road or line system. L'Hostis (1997) avoids this problem by constructing a three dimensional surface, enabling him to depict slower speeds between the access points to the high speed systems, here the French TGV and motorway system. This gain, however, detracts from ease of reading, as it is difficult for a reader to assess depth of surface and to compare points on the surface.

As no standard software is currently available for time-scaled map construction, , it was necessary to develop a new approach, which will be described after the networks and travel time calculations in the following section.

Figure 2 Railway travel time-scaled map of Europe, 1993

Source: Spiekermann and Wegener (1993)

Figure 3 Three dimensional time-scaled map

Source: L'Hostis (1997)

3 Network construction and travel time calculation

Transport modellers are well aware of differences in travel time estimates due to choices made in network model formulation. . This section describes these differences in detail to provide readers with the necessary reference. The discussion assumes that the reader is fa-

miliar with the basics of transport network modelling, e.g., as set out in Ortuzar and Willumsen, 2001, Cascetta, 2001 or Sheffi, 1985. The next subsection discusses elements and dimensions of the network model that must be determined during its construction and can therefore become relevant for the accuracy of travel time calculations. The subsection also discusses the levels and values of these elements in the Swiss models. Public transport models are discussed briefly afterwards. The results of two alternative formulations available for 2000 and comparison of these results is the subject of a further subsection. Conclusions and recommendations for future studies will follow at the end of the paper.

3.1 Elements of the network model formulation

Travel times are dependent on demands flowing between all locations and it is therefore best to use assignment models (Ortuzar and Willumsen, 2001) to calculate travel times, as they incorporate the effects of demands between all locations into equilibrium travel times. This study employed VISUM 8.0 software (PTV AG, 2002) for these calculations.

To establish the network/assignment model, the modeller has to decide the attribute values of the following elements, which will be discussed below:

- Spatial resolution
- Intrazonal travel times
- Study area
- Network resolution
- Link description
- Demand matrix
- Assignment method

3.2 Spatial resolution

Ideally, one would calculate travel times between individual street addresses, as there is a large amount of spatial variability in travel times and costs, but this is currently not feasible due to the very long computing times required. Locations are therefore aggregated into zones with an associated centre of gravity, which represents all activity opportunities and is also the source of all travel leaving the zone. Switzerland in 2000 consists of 2896 munici-

palties with 7.1 million inhabitants. Compared with neighbouring countries (Germany, Austria, Liechtenstein, Italy, and France), Switzerland has many small communities. For example, in 2000, 148 municipalities had less than 100 inhabitants. The process of municipal mergers is still ongoing, requiring a complete record of previous mergers to reconcile the earlier data with current boundaries. Tschopp, Keller and Axhausen, 2003 provide this for Switzerland.

Zone size has an immediate impact on calculated values. This is especially true in the case of larger cities. If they are treated as one unit, the travel time between zonal centres of gravity can be unrealistically short. In this study, municipalities are treated as one unit independent of the population size, but the biggest cities (Zurich, Geneva, Berne, Basle and Lausanne) were divided into 6 to 12 zones following their internal statistical units, e.g. the Stadtkreise in Zurich.

3.3 Internal travel time and connectors

Internal travel time, i.e. the mean travel time between any two points within a zone, is needed for some network model applications, such as the calculation of accessibilities, particularly the own-accessibility of a zone. If information about the built up area is available (BfS, 2002 for Switzerland), one can calculate it, as suggested by Rietveld and Bruinsma, 1998, as:

$$d = \sqrt{(O/\pi)(\pi-1)/\pi}$$

with the average distance (d) between two arbitrary points within a given built-up area (O). For calculation of internal travel time, an average speed of 15 km/h was assumed for road models and 10 km/h for public transport models.

The centroids of the Swiss zones have connectors to the next road network node with a speed of 15 km/h. The centroids of the zones outside Switzerland have connectors with a speed of 40 km/h, because they are substantially larger in area and the network model (see below) is not as finely resolved. Coordinates for the centroids of zones are obtained for the Swiss municipalities from the Federal Office for Spatial Development (ARE) and for the zones in the

neighbouring countries from EUROSTAT (see below). The length of the connectors is calculated as the straight-line distance between the centroid and the node to which it is attached.

3.4 Study area

The definition of a study area is always arbitrary. It reflects the impact of both a. activity opportunities assessment, and b. population centres outside the study area on the results inside the study area, as well as costs in time and money to obtain information for areas outside the study area. In Switzerland, three major cities (Geneva, Basle and Lugano) are either border cities (Geneva and Basle) or very close to the border (Lugano).

We consider population in neighbouring countries up to 350 km from the Swiss border (see Figure 4). For Austria, Liechtenstein, and Germany, we were able to obtain historical population data for NUTS 3-level (average NUTS3 zone has 500'000 inhabitants). Unfortunately, for France and Italy, it was only possible to obtain information at NUTS 2-level data (average NUTS2 zone has 3.5 million inhabitants). The NUTS system has been developed by the statistical agency of the European Union (EUROSTAT) to provide a uniform description of the member states. The system is hierarchical, ranging from NUTS 0 (member states) to NUTS 5 (municipalities).

3.5 Network resolution

Today, databases of all links - independent of type - are commercially available for in-car navigation purposes (NavTech or TeleAtlas are the two best known providers). These are not normally used for planning purposes. Because they are not available for the period before 1990/95 they cannot provide a basis for this work either. The challenge in calculating earlier travel times is the reconstruction of previously available networks. Here, analysts have to decide which level of detail they want to achieve: trace only the development of a. the motorway system, or b. all major roads, or c. all roads? The same question applies to the public transport network.

Figure 4 Map of the study area with the road network for the year 2000

The thick red lines are the motorways; the European zones are shown by the blue small boxes. The grey city names are for orientation.

Starting with an existing road network of Switzerland provided by MicroGIS, St. Sulpice, for the year 2000 (Vrtic, Fröhlich and Axhausen, 2003), the development of the motorway network was traced backwards using the opening dates of the Swiss Federal Roads Authority (ASTRA, 2001). Additionally, changes in main roads (opening, improvement, upgrades, and additional lanes) (for further details see Fröhlich, Frey, Reubi and Schiedt, 2004) were obtained from various sources. With this information, the conditions of all major roads are taken into account for different years (2000, 1990, 1980, 1970, 1960 and 1950) (see Table 1). The ratio of efforts between the first and the second step is 1:15 in the case of Switzerland, as the 26 regional authorities (cantons) had no comprehensive or even consistent documentation of their road development available. Each road had to be located and traced in maps, professional magazines, plans, budgets, and building works accounts. Then, all data had to

be laboriously reconciled with the numerous sources due to different labels, descriptions, and road names.

Furthermore, to enlarge the study area, the road network of Switzerland is joined with a European road network. In addition, development of the motorways in the area, defined by following cities (Frankfurt, Salzburg, Genoa, Lyon and Paris), is traced (Table 1). The initial European network was provided by PTV AG, Karlsruhe.

Table 1 Number of links in the expanded road network models (Switzerland (CH) and Europe (EU))

Year	Modified Links CH	Unmodified Links CH	Total CH	Modified Links EU	Unmodified Links EU	Total EU
1950	3'527	14'171	17'698	136	29'112	29'248
1960	3'589	14'171	17'760	195	29'112	29'307
1970	4'147	14'171	18'318	422	29'112	29'534
1980	4'810	14'171	18'981	747	29'112	29'859
1990	5'215	14'171	19'386	896	29'112	30'008
2000	-	-	19'700	-	-	30'053

3.6 Link description

In assignment models, links are described by their direction, length, free speed, capacity, and parameters of capacity restraint function, which connects the load of a link to its speed. These parameters also define the link type. This complete description was available for the year 2000 model. Unfortunately, it was clear that it could not be used for earlier decades due to technological change in the vehicles, changes in driver behaviour, differing speed regulations, and changed road qualities. See the various editions of the US Highway Capacity Manual (HCM) (Highway Research Board 1950 and 1965; Transportation Research Board 1985 and 2000) for these developments.

As a rule, there are no historic demand matrices describing demand flows between zones available for detailed speeds calculation using a suitable assignment algorithm (see below). It is therefore necessary to make assumptions about mean speeds by link type, which are independent of actual flows at the time on a specific link. The network model used here has an

unusually large number of link types (25 types in the Swiss road network and further 26 types in the European road network), which allows a reasonable differentiation.

A set of assumptions was developed referring to a substantial review (Erath and Fröhlich, 2004) of German and Swiss figures, which also drew on US sources, where ongoing development of HCM since the 1940s has generated copious data. The review integrated information about measured speeds, capacity estimates, and traffic counts to arrive at consistent sets of free flow speeds, capacity restraint functions, capacities estimates, and mean speeds by link type and decade (1950 to 2000). With these sets (free flow speed, capacity, and capacity restraint function) and observed traffic counts at about 350 traffic counting stations, one can calculate speed distributions by link type and decade. These are shown for two road types (2-lane motorways and trunk roads) in Figure 5. It is interesting to note how trunk road speeds increase until 1970, accompanied by growing variance due to increasing loads. Later, the motorways absorbed some of the traffic flow, and between 1980 and 2000 the variance decreased, while speed limits lowered the absolute tempo levels. The reverse process between speed and its variance is visible for motorways.

Figure 5 Distribution of estimated daily average link speeds by type of link on Swiss roads and by year

3.7 Demand matrix

For the year 2000, a high-quality demand matrix for road passenger traffic is available from a project conducted by the IVT, ETH Zurich, and Emch+Berger AG, Zurich, for the Swiss

Federal Offices of Spatial Development, Road Authority and Transport. An overview of the model approach and the results is given in Vrtic, Lohse, Fröhlich, Schiller, Schüssler, Teichert and Axhausen, 2005.

3.8 Assignment methods

Calculations of speeds are based, as mentioned above, on the description of the network and the demand matrix. If no demand matrix is available, the best estimate is to calculate the time-shortest paths between any two zones using assumed mean speeds. The approach had to be taken for the decades between 1950 and 1990. For consistency, it was also adopted for 2000.

For comparative reasons, the calculations for 2000 can be repeated using a full assignment algorithm considering the actual demands. The standard user equilibrium approach (from available algorithms) was adopted here, as there is not yet enough empirical experience with the theoretically superior stochastic user equilibrium available for its application.

3.9 Public Transport Model

Starting with the railway network for the year 2000, development of railway links (approximately 5'500) and nodes (approximately 2'700) was tracked (see also Fröhlich et al., 2004), making it possible to generate a corresponding state of railway infrastructure for all of Switzerland, at every time point. In the case of the road network, the users produce the service themselves; in the case of the public transport, an operator produces it according to published timetables. For the six analysis dates (1950, 1960, 1970, 1980, 1990 and 2000) all daily train service (international, express, regional, and commuter) and some interregional bus services were coded. Some tourist services, such as the Jungfrauoch – Bahn, which do not connect municipalities, were excluded. Table 2 shows the number of public transport services per day and a tally of stations served for the different years.

Table 2 Number of public transport services per day and stations served by year

Year	Public transport services per day (trains or busses)	Stations served
1950	5'886	1'793
1960	7'189	1'895
1970	7'166	1'734
1980	10'709	1'819
1990	12'839	1'965
2000	11'327	1'882

The connector from the centroid of a zone to the next station is a proxy for the way passengers get to the station. In the last 50 years, several lines, and naturally their stations, have been closed, a factor that had to be considered for the connectors in the different years. Therefore, connectors are classified by type of zones, distance and whether the municipality has its own station or not. It is assumed that half the passengers use urban public transport, or walk, and the other half come by bicycle, car, or are brought by car to the station.

Following are assumed speeds for different connector types: for Swiss municipalities with a station 6 km/h over the crow-fly distance, for Swiss municipalities without a station and under 10 km road distance to a station 12 km/h, for Swiss municipalities without a station and over 10 km road distance 25 km/h, for Swiss major cities and a crow-fly distance under 1 km 6 km/h, for Swiss major cities and a crow-fly distance over 1 km 10 km/h and for the European zones 40 km/h over crow-fly distance. The assumed speeds were checked against prior bus time tables for a number of areas (Bodenmann, 2003).

3.10 Comparing the two road travel time calculation methods

For 2000, it is possible to compare results of the full assignment with results of the shortest-path calculation using mean speeds by link type. To obtain an overview of differences, it is necessary to calculate an index that aggregates over all relationships of a particular location. Mean speed for trips from a location is one example of such a measure or index. This mean speed is calculated by weighing each relation *with* the likely share of trips to it:

$$v_i = \frac{1}{E_i} \sum_j v_{ij} \cdot X_j \cdot e^{-\beta t_{ij}}$$

With v_i	mean speed of zone i
E_i	accessibility of zone i, which is a normalisation for this measure (See also Ben-Akive and Lerman, 1985 or Williams, 1977)
d_{ij}	Shortest-time path distance between zones i and j
$v_{ij} = \frac{d_{ij}}{t_{ij}}$	Speed between zones i and j
t_{ij}	Shortest-time path travel time between zones i and j
X_j	Population in zone j
β	Parameter of the distance decay (set to 0.2, as suggested by Schilling, 1973)

A comparison (see Figure 6 and Table 3) of the speeds estimated using the two approaches (assuming mean speeds by link type versus the user equilibrium assignment results) shows that, in urbanised areas, differences are small. They are larger in main cities (speed assumptions are too low) and in peripheral rural areas (speed assumption are too high). In major cities, the user equilibrium model ignores the sizeable number of trips made inside the large zones within the cities, which leads to low speed estimates.. Still, the mean differences are within 10% of each other, which seems very reasonable given that these assumed mean speeds have to reflect the Swiss average and cannot be adjusted to local circumstances.

Table 3 Descriptive statistics of the mean speeds (km/h) for 2000

Statistic	Assuming mean speeds by link type	User equilibrium assignment
Mean	54.69	50.08
Minimum	15.01	15.01
25% Percentile	49.13	44.82
Median	57.41	51.26
75% Percentile	63.01	56.51
Maximum	78.20	79.29
Standard Deviation	11.30	9.14

Figure 6 Ratios of the road mean speeds for each municipality (assuming mean speeds by link type versus user equilibrium assignment) (2000)

4 Calculating time-scaled maps

4.1 Least-squares approach

Time-scaled maps result from the transformation of physical locations into new ones, which satisfy travel times, assuming a uniform – new – time scale throughout. Conceptually, the first step is to replace physical distances with travel time distances between any two points (See Figure 7). In a two-dimensional map involving more than three locations, it becomes impossible to calculate new locations with perfect mutual consistency. The time-scaled map is an approximation involving a certain amount of error, which is minimised. The geodetic problem of reconciling different measurement of points in space is analogous to our prob-

lem. We therefore adopted the algorithm used by Swiss Ordance Survey (LTOP) to calculate the optimal, i.e. error minimal solution (Carosio, 2003; Gubler, 2002).

For the time-scaled coordinates (Y_i , X_i for location P_i , r_{ij} error term) the following condition applies:

$$\text{Travel time } (P_i - P_j) + r_{ij} = \sqrt{(Y_j - Y_i)^2 + (X_j - X_i)^2}$$

This condition can be formulated for all available travel times between all points considered. A unique solution for the new co-ordinates can be calculated by imposing the condition:

$$\sum r_{ij}^2 = \text{Minimal}$$

This condition can be expanded, if one wants to weight the travel times with a weight p_{ij} , which for example could be proportional to the variance of travel time calculations σ_{ij} leading to $p_{ij} = 1/\sigma_{ij}$. The expanded objective function is then::

$$\sum p_{ij} r_{ij}^2 = \text{Minimal}$$

The new time-scaled locations are in this way a least-squares estimate.

Figure 7 Calculating the new positions using the error minimisation approach (4 locations)

The very large number of measurements (3000 * 3000) leads to graphically inconsistent solutions. It also gives too much weight to the many small municipalities. We therefore adopted a two stage process. In the first step, new time-scaled locations for a set of relevant locations covering the country were calculated using the least – squares approach described above. In the next step, a larger number of additional time-scaled locations are added, but now based only on travel times to nearby locations from the first set. The time-scaled locations of the first set are retained in this second step. This approach reduces the importance of changes in travel time over large distances, which is consistent with the low share of very long distance travel. Recall that one-way trips over 100 km distance have a share of only about 1-1.5% in most industrialised countries.

4.2 Map generation

The two-optimisation steps above provide vectors describing how an (ultimately small) share of all points on the maps needs to be shifted to effect the rescaling. See Figure 8 for an example. For a consistent map, all points need to be shifted or rescaled. ArcGIS 9.0 offers a rubbersheet function for this purpose. First experiments made clear that the set of points available was too small for a consistent transformation. An intermediate step increasing the density of points/shift vectors is required. A 10 by 10 km raster of points was defined. The shift vectors for each of those points was calculated as a distance weighted average of the surrounding base shift vectors from the optimisation runs (See Figure 9). Applying the rubbersheet function to this dense set of vectors produced consistent and graphically satisfactory results (Carosio, Dolci and Scherer, 2005; also for the ArcGIS tools implemented for these tasks).

4.3 The Swiss maps

The road and public transport travel times calculated as discussed above (see also Fröhlich, Tschopp und Axhausen, 2003) were the base of further calculations. For the first rescaling, 30 and 22 locations covering Switzerland and some points in the nearby area were selected for the road and public transport calculations respectively (See Figure 10). It was not possible to add travel times to locations outside Switzerland in the public transport case, as only high speed and direct trains from the major centres were included in the public transport model. Too many values would have been missing.

For the second rescaling, a further 400 points were added, which were within 20 minutes' travel time of the initial 22 or 30 points (Scherer, 2004).

Figure 8 Shift vectors between physical and time-scaled locations

Figure 9 Calculation of weighted shift vectors of the raster points

$$\Delta X_Q = \frac{\sum_{i=1}^n p_i \cdot \Delta X_i}{\sum_{i=1}^n p_i}$$

$$\Delta Y_Q = \frac{\sum_{i=1}^n p_i \cdot \Delta Y_i}{\sum_{i=1}^n p_i}$$

$$p_i = \frac{1}{d_i^3}$$

Figure 10 Selected locations for initial rescaling

Public transport (22)

Road (30)

Reference point for the rescaling is Berne and the base line is defined by a line connecting Geneva to St. Moritz (Figure 11), that ensures the correct north-south orientation of the map.

Figure 11 Base line of the rescaled maps

$$Azimut = \arctan \frac{\Delta easting}{\Delta northing} = \arctan \frac{Y_{StMoritz} - Y_{Geneve}}{X_{StMoritz} - X_{Geneve}} = 92.35$$

Coordinates in the Swiss system of Geneva (500376/117412) and St. Moritz (784102/151669)

Public transport maps were graphically unsatisfactory, as some excessively slow connections generated problems for the OLS approach. Examples are the connections between Bellinzona and Chur and Bellinzona and Sion, which require substantial detours from the crow-fly distance; in the first case, via Zürich and in the second case via Berne and Lausanne. After studying a number of alternatives, a solution in keeping with the ideas of robust statistics (see Carosio, 2001) was adopted. In this case, we give these time distances (outliers) a smaller weight in order to obtain a more satisfactory solution. One accepts a few inconsistencies for the benefit of a coherent and, in this case, graphically satisfactory solution. The five most problematic origin-destination pairs were identified for 1970. These were decreased by 20% for 1960 and 1970 and by 40% for 1950. These connections are now, by design, wrongly represented in the maps. Figure 12 shows the effect by comparing the 1950 public transport maps before and after the adjustments.

Figure 12 Correction of selected public transport travel times and its effect on the map

1950 time-scaled map before correction

1950 time-scaled map after correction

5 Shrinking Switzerland

The series (Figure 13 and Figure 14) demonstrates vividly how much the country has shrunk for its citizens. If one calculates the area of the time-scaled country, one sees that road-travel time-scaled Switzerland has shrunk by about half, and by one fifth for the public-transport scaled Switzerland (Table 4). In the case of public transport, this shrinkage underestimates the quality improvement of this system, as our calculations ignore the benefits of higher frequencies of rail and bus services since 1950. The changes in travel times (including interchange waiting times) are fully considered, but frequency has a value in its own right.

Table 4 Percentage change in size of the time-scale maps

	Road	Public transport
1950	100%	100%
1960	82%	92%
1970	61%	82%
1980	52%	79%
1990	49%	79%
2000	47%	83%

A second point is noticeable in both series. The shape of the time-scaled maps is moving towards the actual physical shape of the country. Differences in directional speeds and slow connections to some outlying areas and regions have been systematically reduced. The federal and consensus driven policy system of Switzerland has allocated funding to equalise conditions as much as possible, given the topography of the country.

Last, the country has stopped shrinking since the 1980s (for road systems) and the 1970s (for public transport) – keeping in mind the omission of frequency improvements. The imposition of speed limits in the 1980s (see Figure 5), the planned shift of investment from the economic core of the country to more peripheral areas, and the continuing growth in car ownership and use has capped the speeds. In certain areas, they are starting to drop as earlier capacity reserves are used up. Given the generally assumed links between speeds, market sizes and economic growth, and productivity (Axhausen, 2005; Bröcker, Kanse, Schürmann and Wegener, 2002; Holtz-Eakin, 1994 or Aschauer, 1989), policy makers will need to pay attention.

Figure 13 Road travel time – scaled maps for Switzerland

1950

1960

1970

1980

1990

2000

Figure 14 Public transport travel time-scaled maps for Switzerland

6 Methodological conclusions and outlook

The paper presented a practical approach to the construction of time-scaled maps, which helps to visualise overall change in speeds offered by transport systems. The OLS approach is easy to implement, but needs to be handled with some care if one wants to generate maps that are graphically consistent and easy to read for the layman. Tools now available for the popular ArcGIS system will allow others to adopt this approach.

The project has demonstrated that it is possible to construct networks for [past?] network states within a reasonable budget, but it has also made clear that one should focus on motorways, trunk road systems, and perhaps major by-passes, as the remaining changes can be captured by the mean speeds assumed or calculated for each link type. The stability of the road system and its alignment is so *significant* that this is appropriate. The comparison for the year 2000 has shown that the simplified model using only mean speeds by link type is a reasonable approximation to the theoretically preferable assignment model.

While the two-step procedure for the time-scaled map generation is practical and successful, it also makes the process somewhat arbitrary, which is disturbing. It would be desirable to develop a modelling approach that can automatically account for outliers and integrate information about all points in one step. It would also be worthwhile, given today's fast display technologies, to explore 3D solutions, which could illustrate the local differences resulting from access points of the various high – speed systems.

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The paper is based on earlier German-language papers documenting this work by Fröhlich, Tschopp and Axhausen, 2005; Fröhlich and Axhausen, 2004 and Carosio, Dolci and Scherer, 2005.

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¹ See http://www.swisstopo.ch/pub/download/download/geo_software/ltop_de.pdf

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