Investigating Service Characteristics of Local Public Transport on Cross-Border Sections

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Conference paper STRC 2014

STRC 14th Swiss Transport Research Conference
Monte Verità / Ascona, May 14-16,2014

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April 2014

Abstract

Local public transport has been recognised as an important and efficient means of transportation in urban areas, especially in large, high density agglomerations. This applies equally to conurbations extending across international boundaries, in spite of the presence of borders as a separating line in various regards.

The paper includes a literature review on cross-border mobility and presents empirical data from two case studies: On the basis of the cross-border agglomerations of Geneva and Basel, a GIS analysis investigates the influence of borders on transport infrastructures and settlement structures, and examines the offer cross-border public transport services in term of its network structure and service quantity.

The analysis reveals different shortages in the offer of cross-border services, but identifies also framework conditions that hinder the appropriate development of cross-border public transport as an integral part of the agglomerations' transport system.

Keywords

Urban Public Transport, Cross-Border Agglomerations, GIS

1. Introduction

As the share of the world's population living in towns and cities has exceeded 50% and the general trend shows a clear increase (UNFPA 2011), urbanised areas are growing and becoming more dense. This has inevitably a direct impact on the requirements for urban transport systems, which are expected – above all – to be efficient, reliable and sustainable.

Against this background, public transport has a high potential in urban areas: Its land consumption is very efficient, it can handle large numbers of passengers on a reliable basis and is able to operate environmentally friendly in terms of emissions and energy efficiency (Davis and Hale 2007). The necessity of a modal shift towards urban public transport has been widely recognised and is, for example, part of the European Commission's White Paper on Transport (European Commission 2011).

Certain European cities, especially in and near the corridor from Milan to Manchester referred to as 'the Blue Banana', are located next to international borders, with functional agglomeration areas extending well beyond these borders. The locational drawbacks of these areas resulting from the peripheral location on a national basis can partially be compensated if use can be made from potential advantages that result from the close proximity to the border, such as access to infrastructures, services, labour and other resources from more than one country.

An important precondition to benefit from these potential gains is the merging of agglomeration parts of different countries to a single functional cross-border agglomeration area. Efficient transport systems – with public transport as an integral component – that enable seamless mobility across these borders are of special importance.

In view of this problem, the present paper investigates the cases of two cross-border agglomerations on German, French and Swiss borders, Geneva and Basel. It aims at analysing the characteristics of their settlement structures across borders and the corresponding local public transport offer, with a focus on the specific features of cross-border connections as compared to domestic relations.

2. Literature Review

2.1 Barriers to Cross-Border Mobility

The existence of an international border within an agglomeration has an influence on the spatial interactions and the mobility behaviour of the population within the agglomeration. In many cases, the impeding effect of borders on mobility is considered to be predominating, even though borders can also stimulate spatial interaction (cf. chapter 2.3). If we focus on the hindering effects to mobility in the first instance, it is possible to distinguish the following barriers:

Table 1: Barrier effects of borders

Preferences	Preferences of consumers for domestic rather than foreign products and destinations
Public sector regulation	Taxes or other limitations on cross-border trade and transport imposed by national states
Institutions	Differences in institutions at both sides of the border
Information	Lack of information on foreign countries
Transport costs	Weak or expensive infrastructure services for international links

Source: Rietveld (2012)

Against this background, Knowles and Matthiessen (2009) note that “transport helps to shape opportunities for, and patterns of, activity and development” and that “transport infrastructure development can remove or reduce existing spatial barriers and bottlenecks”.

While Table 1 summarises the elements that are reducing the demand for cross-border traffic in general, it might also be worthwhile to focus on public transport specifically. Local cross-border public transport lines often suffer from typical ‘border symptoms’, which act as an additional barrier to cross borders for (potential) public transport users. Some of the most frequent obstacles are listed in Table 2.

Table 2: Typical obstacles for using local cross-border public transport

Information (timetables, fares)	• Language problems • Availability of information • Hardly understandable information content • Insufficient co-ordination • Availability of maps
Level of service	• Too few lines • Low frequency • Too long transfer time • Change of vehicles at the border or at the next interchange station across the border • Time losses caused by the cross-border procedure • Missing connections / missing links • Missing co-ordination of timetables • Unreliable public transport service • Different minimum standards between the countries • Time losses due to technical aspects • Low commercial speed • Insufficient quality standard of vehicles
Fares	• High level of fares for cross-border trips • Non-availability of full range of tickets • Different level of fares between countries • Problems with the distribution channels • No / limited concessionary fares • Restriction in currency acceptance • Complexity of the tariff system • No integration of the tariff systems

Based on Conpass Consortium (2002), amended

In addition to these hard, measurable factors, there are also psychological, possibly unconscious barriers to cross borders, and especially to do so by public transport. Differences in mentality and behaviour of the local population may lead to unfamiliarity and unease in areas beyond a border. In contrast to people travelling in their own car, public transport users are more exposed to these factors.

Dziekan (2008) showed that while people know their way around in their own environment, they lack this knowledge when they travel in unknown areas. Therefore, in order to improve the ease-of-use of public transport, it is important – in addition to the above-mentioned factors – to reduce the traveller's uncertainty by providing him with the right information at the right time, in an understandable way (Dziekan and Dicke-Ogenia 2010). This appears to be a challenging task in the case of many cross-border connections.

2.2 Quantifying the Effect of Borders on Mobility

There are different approaches on how the effect of borders can be implemented in quantitative calculations of traffic flows. In the concept of generalised costs, borders can be represented as a fix or variable amount of costs to be added to the other costs components (Rietveld 2012).

Within the gravitation approach, which is often part of traffic distribution models, an adjustment to the gravitation constant or the insertion of a border resistance factor – ideally in dependence of O-D relations and of trip purposes – can represent an estimation of the impact of the border on traffic flows (Ahrens and Schöne 2008). Interestingly, already Lill (1889), who introduced the gravitation approach to transport planning, discussed the clear influence of national and language borders on the resulting demand for transport.

For both approaches – the generalised cost and the gravitation approach – the values representing the border effect can only be determined by means of calibrations. A short overview over empirically derived border effect quantifications is given in the following.

An early study by Nüsser (1989) compared transport volumes of long-distance national and international flows in some western European countries and observed cross-border traffic flows on a quantitatively much lower level. Even though the study itself raises some limitations about its results due to a lack of data availability, it estimates the order of magnitude of a "frontier impedance factor" to be as high as 4.7 (i.e. a reduction of almost 80%). Also, it states that cross-border traffic in the considered countries is growing more quickly than domestic traffic. It is therefore not surprising that after around ten years, during which the economic integration was progressing, Plat and Raux (1998), who focused on intercity car traffic volumes on French domestic and cross-border highways, estimated the border reduction factor in a somewhat lower range, namely between 1.7 to 3.0 (i.e. a reduction of between 41% and 67%). For Dutch highways, Rietveld (2001) calculated a border reduction effect of 35% to 48% and observed significantly higher shares of trucks at borders than near borders.

In these studies that focus on long-distance transport, major variations between different border crossings, and especially between different pairs of countries have been observed. However, when considering the effect of borders on mobility on a local or regional level, it is necessary to define such border resistance values on a case-by-case basis, since the dependence of external factors is even more important. The spatial context is of considerable significance: rural areas differ clearly from urban areas, and the regional interrelations across national borders play an important role.

Moreover, when calculating border resistance values, a differentiation according to different traveller types is necessary: some of the most important factors are trip purposes as well as the direction of travel (or the country of residence), since these factors account for significant variations: In the long-distance traffic study by Nüsser (1989), a greater border resistance effect was observed for business purposes, while on a local level, major differences can be observed between commuting, shopping, education, leisure and professional trips (Ahrens and Schöne 2008). Also, traffic volumes can be distributed very asymmetrically, especially in case of a distinct gradient in price and wage levels across borders.

A further complication in determining the effect of borders is the interaction between transport supply and demand. Rietveld (2001) showed that public transport links across borders are much less developed than comparable domestic relations, both for long distance journeys (40% less cross-border services between European cities) and on a local level (60% less services across Dutch borders). Similarly, for road transport, the network density across borders is often lower than within domestic areas. Thus, it is likely that the lower cross-border traffic volumes are to a certain extent also a result of the fewer cross-border transport links, even though the limited transport connections are also likely to be a result of lower demand.

This complexity in quantifying border effects on transport volumes illustrates the difficulty in quantitatively depicting the effect of borders on mobility. Yet, it seems even more difficult to use these border effect values to project and forecast future traffic volumes, since the manifold influences are mostly dependent on external factors (e.g. differential economic development of involved countries, political and social interrelations and tensions between countries, non-conformity of spatial development etc.) that can at best only be roughly estimated for the future.

An example for inaccurate traffic forecasts is given by the international Öresund fixed link between Malmö (Sweden) and Copenhagen (Denmark): An overestimation of the border effect resulted in higher actual traffic volumes than forecasted (Knowles and Matthiessen 2009).

2.3 Border-Induced Traffic

As Ratti (1993) noted, the border effect consists of two facets: On the one hand, it acts as a demarcation line that separates the regions and countries on either side of the borderline. Yet, on the other hand, it can also be seen as a contact factor or as an intermediary element between different societies and collectives and creating a functional space across administrative boundaries.

It is in the latter case that the border exerts an inducing effect on traffic volumes. In other words, a part of the cross-border traffic would not exist if the border were not there.

The existence of this cross-border traffic induction can result from different incentives, such as:

- Financial incentives: Taxation (shopping, professional), differences in price and wage levels (shopping, commuting, professional)
- Regulatory incentives: Opening times (shopping)
- Preference for variety: Range of goods (shopping, professional), Leisure activities and tourism (leisure) (Rietveld 2012)

These incentives can either appear as a side effect of differences between two countries, but they may also be a result of strategic developments aiming at integrating agglomerations across borders in order to benefit from local assets of either side of the border and from agglomeration effects in general.

Examples for cross-border areas with distinctive cross-border traffic induction in France are given in Plat and Raux (1998): The Alsace region and locations around Geneva are typical instances.

Considering the traffic induction and barrier effects, it is possible to differentiate three different traffic types for local and regional transport:

(a) Traffic reduced and/or diverted by borders
(b) Border-induced traffic
(c) Border-independent traffic

These three types of traffic usually co-exist, but their relative shares vary in dependence of the characteristics of the border and the agglomeration. Factors influencing these shares notably include border permeability (e.g. transport offer and infrastructures), differences between the involved countries (e.g. economical differences) and the characteristics of trip generation elements in the agglomeration (e.g. resulting trip purposes).

3. Methods

3.1 Delimitation of Cross-Border Agglomerations

For the scope of this study, agglomerations have been defined according to the German Federal Office for Building and Regional Planning BBR (Bundesamt für Bauwesen und Raumordnung 2003). They define 'high density agglomeration areas' (Hochverdichtete Agglomerationsräume) as areas consisting of

(a) a principal centre of at least 100,000 inhabitants and
(b) a surrounding area of a minimum population density of 300 inhabitants per square kilometre.

BBR implements this definition on the German 'Kreis' (administrative district) level. Thus, the minimum number of inhabitants must be reached within a 'Kreis' unit, and the minimum population density criterion applies to the average of at least one adjacent 'Kreis'. However, as German 'Kreise' do not exist in other countries, and in order to prevent disparities across different countries, the criteria are applied on a communal level here.

Additionally, for the purpose of this study, cross-border agglomerations, as a subset of agglomerations in general, have to fulfil two further criteria:

(c) The agglomeration is transected by at least one international border
(d) The agglomeration has a principal centre acting as such throughout the entire agglomeration (i.e. across borders), albeit additional sub-centres may exist. This especially applies to the function as a centre in terms of the provision of services, jobs and education.

These conditions aim at filtering those agglomerations that are significantly affected by the effects of international boundaries, which specifically include differences in legislation, finance, economy, culture, mentality and possibly language. The agglomerations in Western Europe which fulfil these criteria are shown in Figure 1 below.

The spatial extent of consideration, the analysis perimeter, is determined by population density (according to criterion b above), and by their contiguity of communes to the agglomeration centre: Communes are considered as a part of the agglomeration if

(i) Their average population density exceeds 300 inhabitants per square kilometre
(ii) The shortest route to the principal centre only leads through communes fulfilling criterion (i).

Figure 1: Cross-Border Agglomerations in Europe according to 3.1

3.2 Choice of Case Studies: Geneva and Basel

In the present paper, the focus will be drawn to the cross-border agglomerations of Geneva and Basel. They have been chosen as exemplary cases, since they both have a considerable amount of local cross-border (commuter) traffic, but are strongly affected by the effect of borders, e.g. with a multitude of involved public and private institutions, varying allocations of transport-related responsibilities, different legal, political and administrative frameworks and a comparatively low public transport modal share across borders (cf. Table 3 to Table 6).

Table 3: Basel Cross-Border Agglomeration Characteristics

	Total	German Part	French Part	Swiss Part	*Thereof: Principal Centre*
Area [km^2]	507	152	40	314	*24*
Population (2006)	610'383	129'945	34'581	445'857	*163'081*
Pop. Density [km^{-2}]	1'205	851	866	1'420	*6'823*
Involved administrative districts	60 communes, 1 Landkreis, 1 Land, 1 département, 1 région, 4 cantons, 3 countries	7 communes, 1 Landkreis, 1 Land	5 communes, 1 département, 1 région	48 communes, 4 cantons	*1 commune (Basel), 1 canton (Basel-Stadt)*

Data Source: SIGRS / GISOR – Conférence du Rhin Supérieur / Oberrheinkonferenz

Table 4: Geneva Cross-Border Agglomeration Characteristics

	Total	French Part	Swiss Part	*Thereof: Principal Centre*
Area [km^2]	275	107	168	*16*
Population (2006)	537'729	111'328	426'401	*178'722*
Pop. Density [km^{-2}]	1'952	1'037	2'535	*11'219*
Involved administrative districts	53 communes, 2 cantons, 2 départements, 1 région, 2 countries	17 communes, 2 départements, 1 région	36 communes, 2 cantons	*1 commune (Genève), 1 canton (Genève)*

Data Source: IGN, INSEE, Swiss Federal Statistical Office

Table 5: Competent authorities for public passenger transport services at different levels in different European countries (simplified)

<table>
<tr><th rowspan="2"></th><th colspan="2">Switzerland</th><th colspan="2">Germany</th><th colspan="2">France</th><th colspan="2">Belgium</th><th colspan="2">The Netherlands</th></tr>
<tr><th>Heavy rail</th><th>Metro, tram, bus etc.</th><th>Heavy rail</th><th>Metro, tram, bus etc.</th><th>Heavy rail</th><th>Metro, tram, bus etc.</th><th>Heavy rail</th><th>Metro, tram, bus etc.</th><th>Heavy rail</th><th>Metro, tram, bus etc.</th></tr>
<tr><td>Urban / local</td><td colspan="2">Communes</td><td rowspan="3">Federal states ‘Länder’ or Regional Associ-ations</td><td rowspan="3">‘Kreise’ districts</td><td rowspan="4">‘Ré-gions’</td><td rowspan="2">(Associ-ations of) Com-munes</td><td rowspan="5">Federal state</td><td rowspan="5">Regions</td><td colspan="2" rowspan="3">Provinces</td></tr>
<tr><td>Suburban</td><td colspan="2" rowspan="2">Cantons</td></tr>
<tr><td>Regional <~100km</td><td>‘Dépar-tements’</td></tr>
<tr><td>Intercity >~100km</td><td colspan="2" rowspan="2">Confederation</td><td colspan="2" rowspan="2">Federal republic</td><td></td><td colspan="2" rowspan="2">Central state</td></tr>
<tr><td>Long-distance</td><td colspan="2">Central state</td></tr>
</table>

Information based on Noelle and Gouin (2006) and UITP-EuroTeam (2010)

Table 6: Number of Cross-Border Trips per Working Day

Border	Geneva – France	Basel – France*	Basel – Germany*
Number per Direction	187'975	34'300	58'600
Main Trip Purpose	Travel to Work (>50%)	Travel to Work (63%)	Travel to Work (41%)
PT modal share	7%	10%	14%

* Only trips with Destination in the Swiss part of the agglomeration (no transit), 6-20h

Data Sources: Citec Ingéneur Conseils SA (2012), PTV France (2012)

3.3 GIS Analysis

The application of Geographical Information Systems (GIS) in this project aims at analysing the spatial dimension of public transport systems, including the prevailing circumstances (infrastructure networks, settlement structures etc.) as well as the spatial characteristics of the public transport offer itself.

A certain extent of fundamental spatial data that served as input data for the spatial analyses had already existed and could in many cases be provided by responsible bodies. This data, however, had been collected and stored in different formats and thus first needed to be standardised and homogenised. In some cases, additional spatial data had to be collected or digitised manually (e.g. location of certain public transport stops). Furthermore, the spatial datasets were complemented by qualitative attributes (e.g. timetable data), resulting in a comprehensive database for spatial analyses.

Generally, the analyses carried out deliberately follow established methods of spatial public transport analysis, so as to enable the results to be compared to other studies. However, what makes the analyses unique is the combination of datasets from various sources: Those data that are usually analysed only to the spatial extent for which they have been collected, could here be combined and analysed integratively.

Special attention was dedicated to population rasters: For France, such data was available at the National Institute of Statistics and Economic Studies (Insee), and for Switzerland from the Swiss Federal Statistical Office (BfS). In spite of the differences in projection and raster resolution (100x100m vs. 200x200m), it was possible to directly use the data for the present study. In Germany, however, similar datasets are not available. Instead, location-based population data in such a raster resolution were estimated with the aid of commune population numbers and precise floor area data of residential buildings.

This case exemplarily demonstrates the difficulty of spatial and statistical analysis in cross-border areas: comparability and availability of, as well as access to, relevant data is often not given. It could be assumed that only external researchers, as in the present case, face these challenges, but it applies equally to local authorities and public bodies. Indeed, the missing basis of fundamental facts makes it also more difficult to realise cross-border projects. It is therefore not surprising that many cross-border cooperations are devoted to create a common geographic and statistical information basis at an early stage.

4. Results and Discussion

The results have been structured according to the following chapters: Cross-Border Transport Network (4.1), Settlement Density (4.2), Public Transport Coverage (4.3) and Service Quantity (4.4).

4.1 Cross-Border Transport Network

4.1.1 Transport Infrastructure

The current state of available infrastructures varies widely between agglomerations. Table 7 provides an overview of the number of rail and road border crossings versus the length of borders in the considered agglomerations. These indications allow for an assessment of the permeability of a border and the effectiveness of the cross-border transport infrastructures.

Road Crossings

When considering the number of road crossings, it is most striking that agglomeration parts that are separated simultaneously by a river and an international show the lowest number of transport links: Across the river Rhine, there is only one crossing on the 10km stretch between the French and German part of Basel agglomeration. Between the Swiss and the German part of the same agglomeration, the ratio of road crossings per kilometre is slightly higher (9 crossings in 47km) because this border stretch only partially coincides with the river.

Those borders that do not fall together with physical obstacles – such as a river in the example above –, have clearly more road crossings and are therefore usually easier to be crossed.

Table 7: Cross-Border Transport Infrastructures within Agglomeration Areas

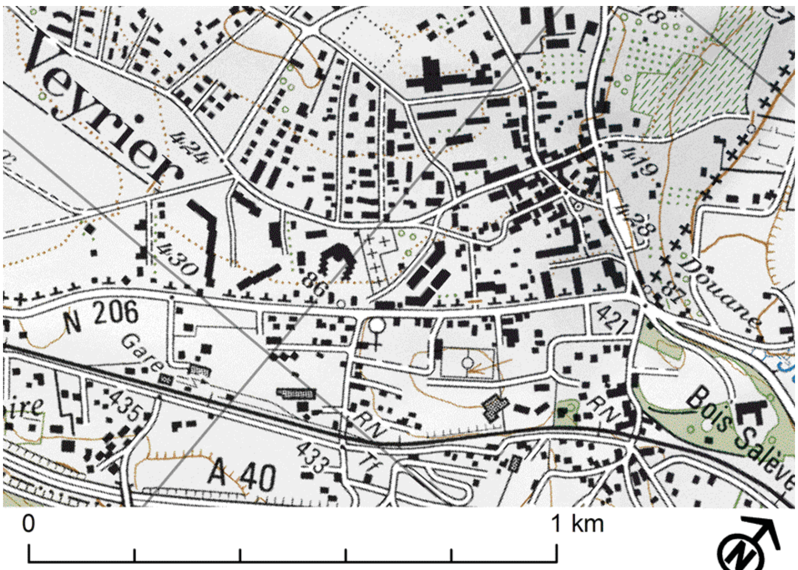
Agglomeration / Border	Length of border [km]	Number of road crossings (open to car traffic)	Number of railway crossings
Geneva (CH – F)	61	29	1[c] + 1[n]
Basel (CH – F)	25	10	1
Basel (CH – D)	47	9	3
Basel (D – F)	10	1	0

Data sources: IGN, swisstopo [c] under construction; [n] nearby (within 5 km)

However, when considering the road network close to international borders without physical obstacles, some distinct phenomena can still be observed, which lead to a lower permeability of borders as compared to domestic areas:

- Road crossings of international borders typically consist of main roads or thoroughfares, whereas residential and side streets often end before borders or are closed for border crossings (see Figure 2). Footpaths, in turn, are again more frequent where they do not require special infrastructure, such as bridges or subways.
- Areas next to borders have sometimes been assigned to land uses that can typically be found in peripheral areas and that act as a barrier in terms of urban development. In Basel and Strasbourg, this is the case with industrial areas and river ports; in Geneva, this applies to the airport. In Basel, efforts are made to convert some of these areas to housing, business and leisure areas (Kanton Basel-Stadt et al. 2012).

Figure 2: Border Permeability at Veyrier/Etrembières Border (Geneva Agglomeration)



Reproduced with the authorisation of Swisstopo (JA100120))

Railway crossings

In contrast to road crossings, railway border crossings depend to a much greater degree on historical developments. The construction or closing down of cross-border railway lines is usually subject to the relationship between the involved countries at that point in time, and it is usually a strategic decision.

For example, the relatively high number of railway lines across the Swiss-German border in Basel goes back to an interstate treaty of the year 1852 between the Swiss Confederation and the Grand Duchy of Baden, where it has been agreed that the Baden Railway station of Basel

(‘Basel Badischer Bahnhof’) would also provide for barrier-free German domestic railway traffic, in spite of its location on Swiss territory (Freiherr von Berckheim and Bischoff 1852).

From 1887 to 1890, however, in order to bypass the Swiss territory of Basel Agglomeration for strategic reasons, an additional railway line from Bad Säckingen to Weil am Rhein that closely followed the German side of the border was built. Such strategic railways that have mainly been built for defence reasons can also be found in many other places (Böhler 1987). Apart from their strategic rationale, there is often little potential for traffic on such lines. Therefore, regular operations on these lines have meanwhile been suspended in many cases. This also applies to the mentioned railway line near Basel, on the section Bad Säckingen–Schopfheim (Ebner 2011).

Tramway lines

While many cross-border tramway lines existed both in Basel and Geneva agglomerations in the first half of the 20th century, there is currently only one occurrence to be mentioned: The Birsigtalbahn narrow-gauge railway that has been incorporated into the tram network of Basel (lines 10 and 17) serves one French village, Leymen, at the periphery of the agglomeration. At the time of its construction, the cross-border relation was not a primary goal; instead, building the route across French territory made it topographically much easier to reach the destination of the line, Rodersdorf, which is again situated on Swiss grounds.

However, new tramway lines that are centrally located and dedicated to cross-border traffic are currently under construction: A 2.5 km line extension from Basel (Switzerland) to Weil am Rhein (Germany) is scheduled to be opened in December 2014 (Kanton Basel-Stadt 2014), and plans also exist for tramway extensions across borders in Geneva.

4.1.2 Public Transport Network

The network of railway lines and cross-border bus routes in the agglomerations of Geneva and Basel are displayed in Figure 3 and Figure 4. They reveal some of the typical characteristics of cross-border public transport networks:

- Most line types are of radial nature; there are very few tangential lines and no ring lines. Thus, many cross-border trips that do not start or end in the agglomeration centre lack a direct connection and can only be made with detours and/or transfers.
- Among the radial lines, there are very few lines penetrating into the agglomeration centre or even crossing the centre. Such ‘diameter lines’ require more planning coordination on the organisational side, but have both clear operational advantages (no spacious terminus stations in the city centre and less standing time for vehicles) and significant benefits for customers (more direct connections without transfers).

Figure 3: Cross-Border Local Public Transport Lines within Geneva Agglomeration

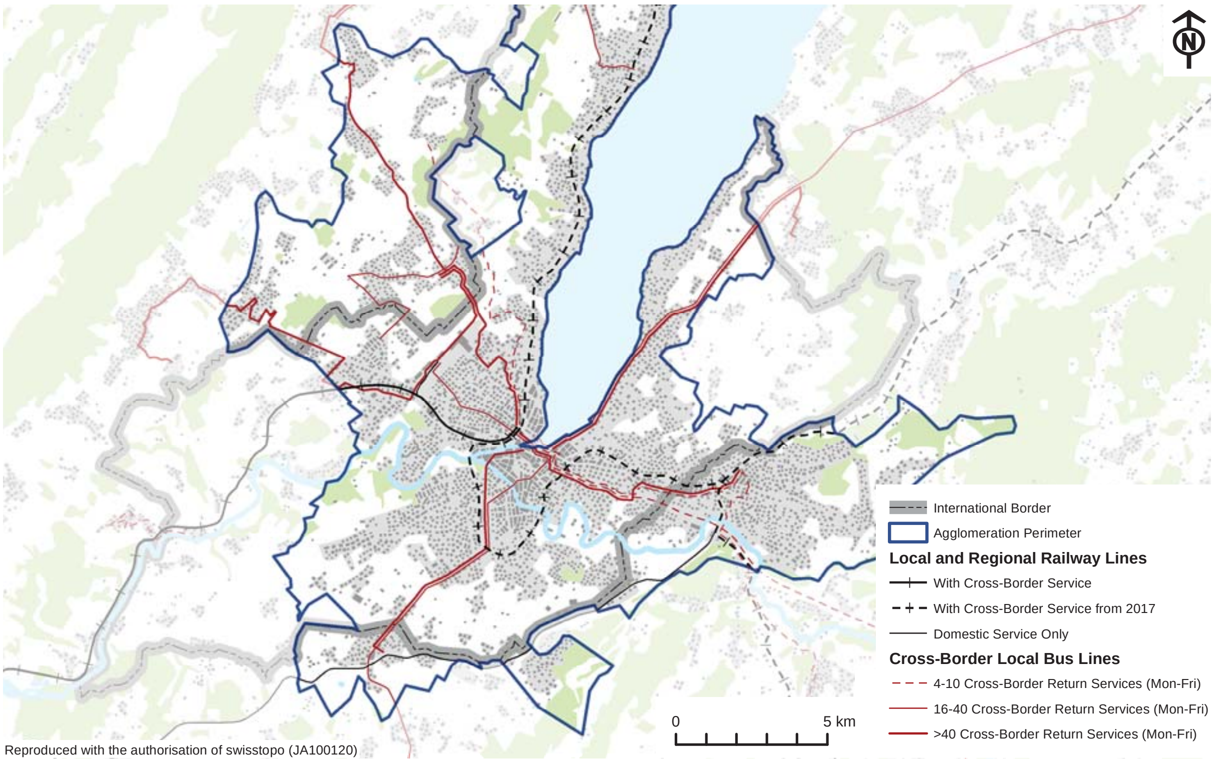
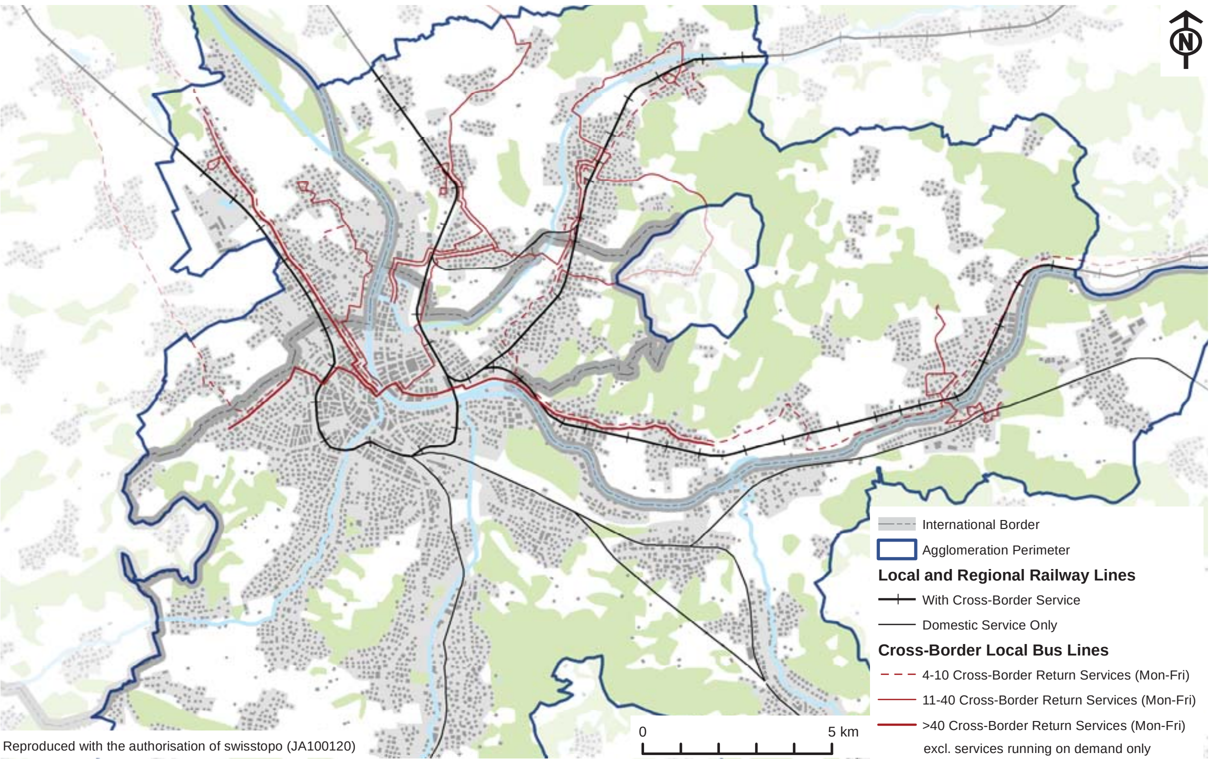


Figure 4: Cross-Border Local Public Transport Lines within Basel Agglomeration



The only diameter bus services consist in the following routes:

(a) In Geneva the regional T72 bus line that connects Annecy (ca. 40 km south of Geneva) to the airport in the north of the city centre up to 6 times per day, thereby serving rather regional than local purposes.
(b) In Basel, the local bus line 38 consists of a route length of 10km on Swiss territory and 6km on German grounds. It crosses the entire city centre, and serves contiguous communes of Allschwil (Switzerland) and Grenzach-Wyhlen (Germany). This cross-border connection has only been introduced in December 2008 but resulted (with a 30 min headway service on weekdays) in additional 210'000 passengers in the first 6 months, revealing the attractiveness and the considerable potential of such diameter lines (Südkurier 2009).

As for cross-border railway lines, radial lines are the rule in all considered agglomerations. Efforts are being made to extend these lines across agglomeration centres, but with major difficulties in some cases:

(c) In Geneva, the railway networks of Switzerland and of Savoy (to the South) have never been physically connected but ended at separate stations since their construction in the late 19th century. The project of linking these two stations has existed throughout the 20th century, and is now finally being implemented under the title 'CEVA', named after the stations served en route (Cornavin, Eaux-Vives and Annemasse). Its completion, scheduled in 2017, will allow the realisation of an extensive local/regional rail network 'RER franco-valdo-genevois' throughout the region with many new direct connections as well as an integrated urban development of areas around train stations (Da Trindade et al. 2011). At the same time, the number of traction current types in the region is being reduced from 3 to 2 in order to streamline the network and rationalise the deployment of rolling stock (Comte 2011; Keseljevic 2013)
(d) In Basel, the so-called "green" S-Bahn line "S1" adopted a pioneer role in 1997 by creating a new diameter route throughout the agglomeration, including the French and Swiss rail network. The specially equipped dual-current engines were licensed for operations in both countries and ensured up to 14 return services per day between Mulhouse (France) and Frick/Laufenburg (Switzerland) (Baur et al. 1997). Unfortunately, mainly owing to licensing difficulties for the succeeding generation of rolling stock in France, changing trains was again necessary at Basel SBB station from 2008, but the 'interim' concept still allowed transfers at the same platform with short connection times. However, in 2011, even this interchange connection had to be suspended due to a new timetable concept of the Alsace region that focused mainly on its domestic traffic. Since then, the re-introduction of this diameter line is frequently discussed but any short- or mid-term solution seems to be out of reach (Cassidy 2009; Rellstab 2014). A long-term project for a new railway tunnel under the city centre that

would allow for additional stations as well as new diameter lines from Switzerland to Germany, the so called “Herzstück”, is in preparation, but will be opened between 2025 and 2030 at the earliest (Bau- und Verkehrsdepartement Basel-Stadt et al. 2014).

4.2 Settlement Density

Since densely populated areas allow more efficient and rationalised public transport services, as compared to disperse and scattered settlement structures, settlement density is an important indicator for the suitability of areas for efficient public transport services. Settlement density has also been chosen as a primary indicator to define agglomeration limits, as agglomerations are regarded, amongst others, as areas with high population densities.

In this paper, it is of special interest whether international borders influence the settlement density in cross-border agglomerations. In other words: does the settlement density of areas beyond international borders differ from areas in the same country than the principal agglomeration centre?

The maps and graphs in Figure 5 to Figure 8 are dedicated to the depiction and the analysis of this effect in question. Obviously, population density is highest in the agglomeration centre, and it should typically decrease with increasing distance from the city centre, with the only exception of major sub-centres within the agglomeration area. In order to take account of this effect, population density has been calculated for concentric rings around the agglomeration centre with a width of 2.5 km each. Within every of these concentric ring, values are given for the average population density in each country. Areas outside of the agglomeration perimeter are however excluded from consideration. The point considered as the geographic agglomeration centre (e.g. a central square) is indicated in the legend of the respective figures.

When considering the cartographic representations of these data, a first striking effect is given by the geographical course of agglomeration perimeters that have very uneven shapes in all considered cases. As the agglomeration perimeter represents the line where – along radial transport routes – population density falls below 300 inhabitants per square kilometre (i.e. 3 inhabitants per hectare), this shows already that in the present cases, the theoretical model of an even population decrease with increasing distance from the agglomeration centre does not apply.

In Basel, where the agglomeration extends much less into France than Switzerland, there are clear country-specific influences to the distribution of population density. In Strasbourg and Geneva, however, such an effect cannot be discerned at first sight.

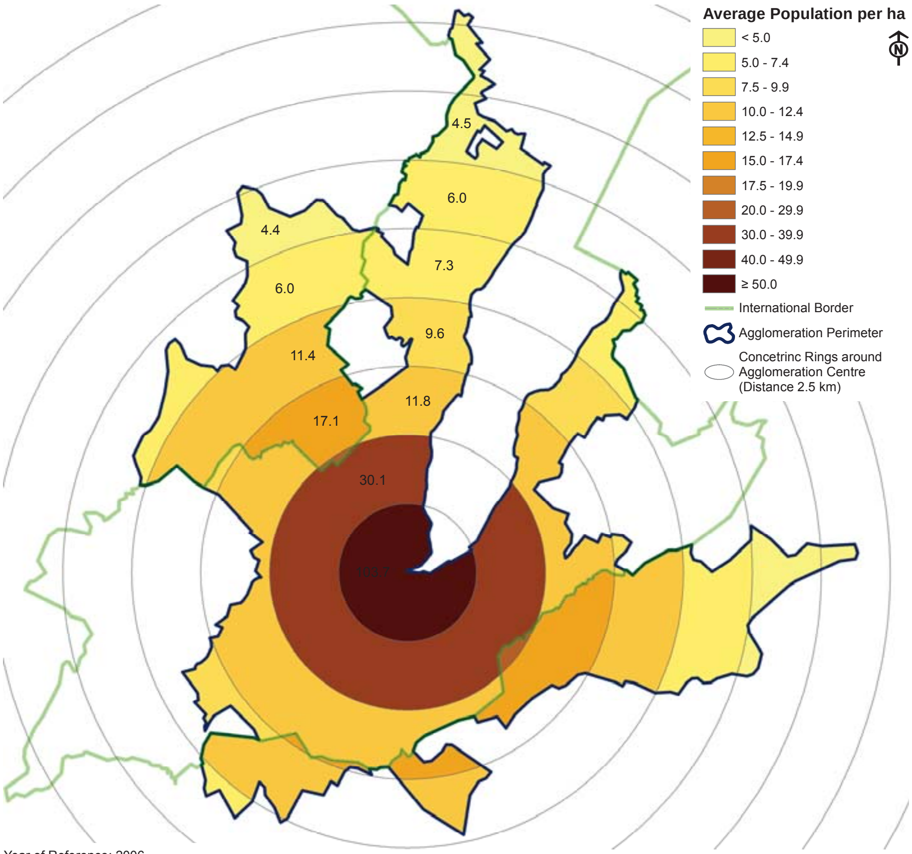
A closer consideration of the figures reveals the course of population decrease with distance from agglomeration centre by country. This is given both in the cartographic representations (shades and values) as well as in the accompanying graphs (solid line with square data points). Additionally, the dotted line indicates the share of area of the different agglomeration parts within the concentric rings.

In the case of Basel, the properties identified above can be confirmed: In Basel, population density decreases much slower towards France than towards Germany and Switzerland. The latter two show a similar course up to a distance of 15 km, where the share of areas considered as agglomeration areas starts dropping rapidly in Germany. In the French sector however, communes with population densities below 300 inhabitants per square meter – and thus not regarded as part of the agglomeration – start occurring already at a distance of 5 km from the agglomeration centre.

In Geneva, the pattern appears to be more intricate: Due to Lake Geneva, which does not belong to the agglomeration area, the agglomeration perimeter reaches right into the heart of the agglomeration centre on its north-northeastern side. With a population density of over 10'000 inhabitants per square kilometre, the agglomeration centre, consisting of the commune of Geneva, is very densely populated. Interestingly, with the exception of lakeside communes, population density decreases rapidly on Swiss areas (with communes below the threshold value of 300 inhabitants per square kilometre occurring from 6 km from the city centre), whereas French bordering communes (in a distance of 5 to 10 km from the agglomeration centre) are more densely populated. The rapid population decrease also results in the perimeter being rarely more distant than 15 km from the city centre. The development of the local train system ‘RER franco-valdo-genevois’ in 2017 is expected to take pressure away from the very densely populated centre and to induce the according real estate effects around well-served public transport stations in the region (Prieur and Roselli 2010).

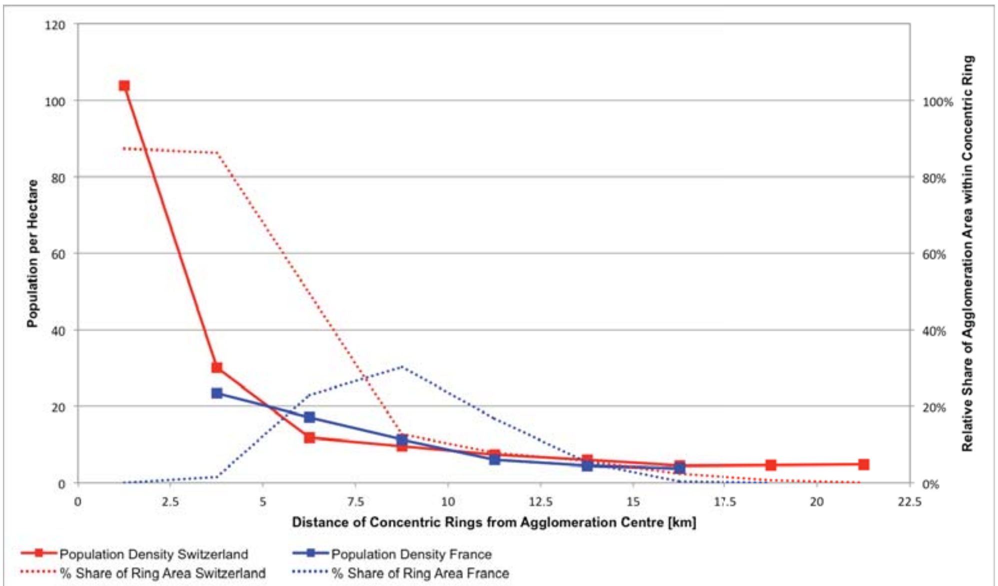
In summary, it follows from the above considerations that population density structures differ between involved countries in all four considered cases. While these differences are of varying nature, it can be said that their bare existence makes the initial situation to provide local public transport services different from agglomerations with more uniform surroundings.

Figure 5: Population Density by Country and Distance from Agglomeration Centre: Geneva, Place de Bel-Air (map)



Year of Reference: 2006
Data based on commune population numbers.
Data Sources: STATPOP (© Swiss Federal Statistical Office), Recensements de la population (INSEE), IGN (© IGN 2009), swisstopo (Reproduced with the authorisation of swisstopo (JA100120))

Figure 6: Population Density by Country and Distance from Agglomeration Centre: Geneva, Place de Bel-Air (graph)



Year of reference: 2006. Data source (commune population numbers): STATPOP (© Swiss Federal Statistical Office), Recensements de la population (INSEE)

Figure 7: Population Density by Country and Distance from Agglomeration Centre: Basel, Marktplatz (map)

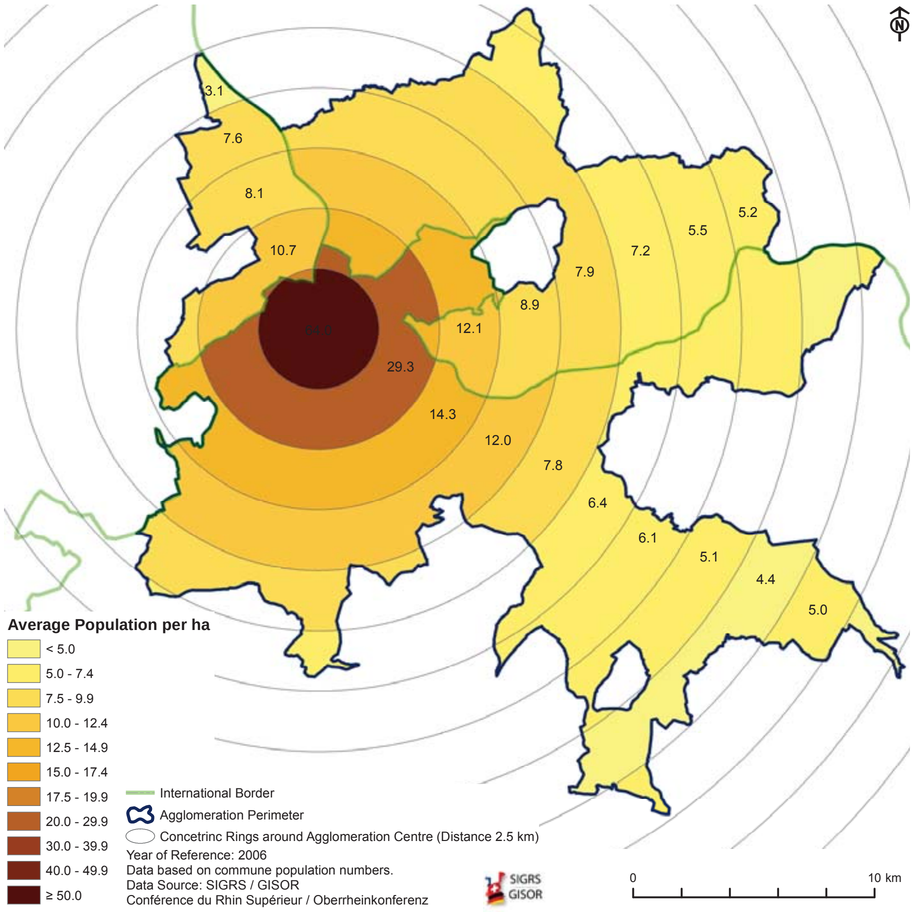
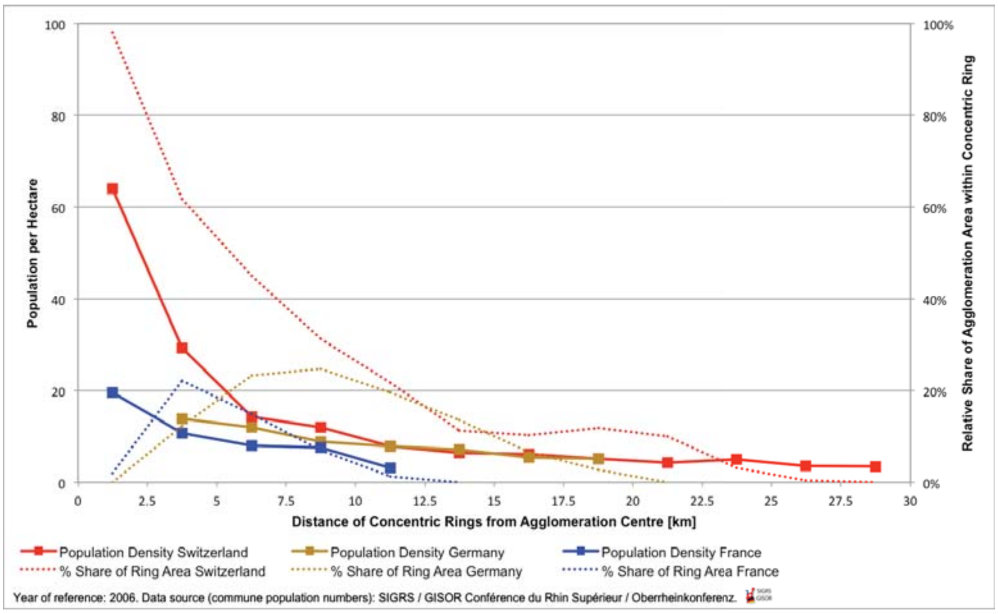


Figure 8: Population Density by Country and Distance from Agglomeration Centre: Basel, Marktplatz (graph)

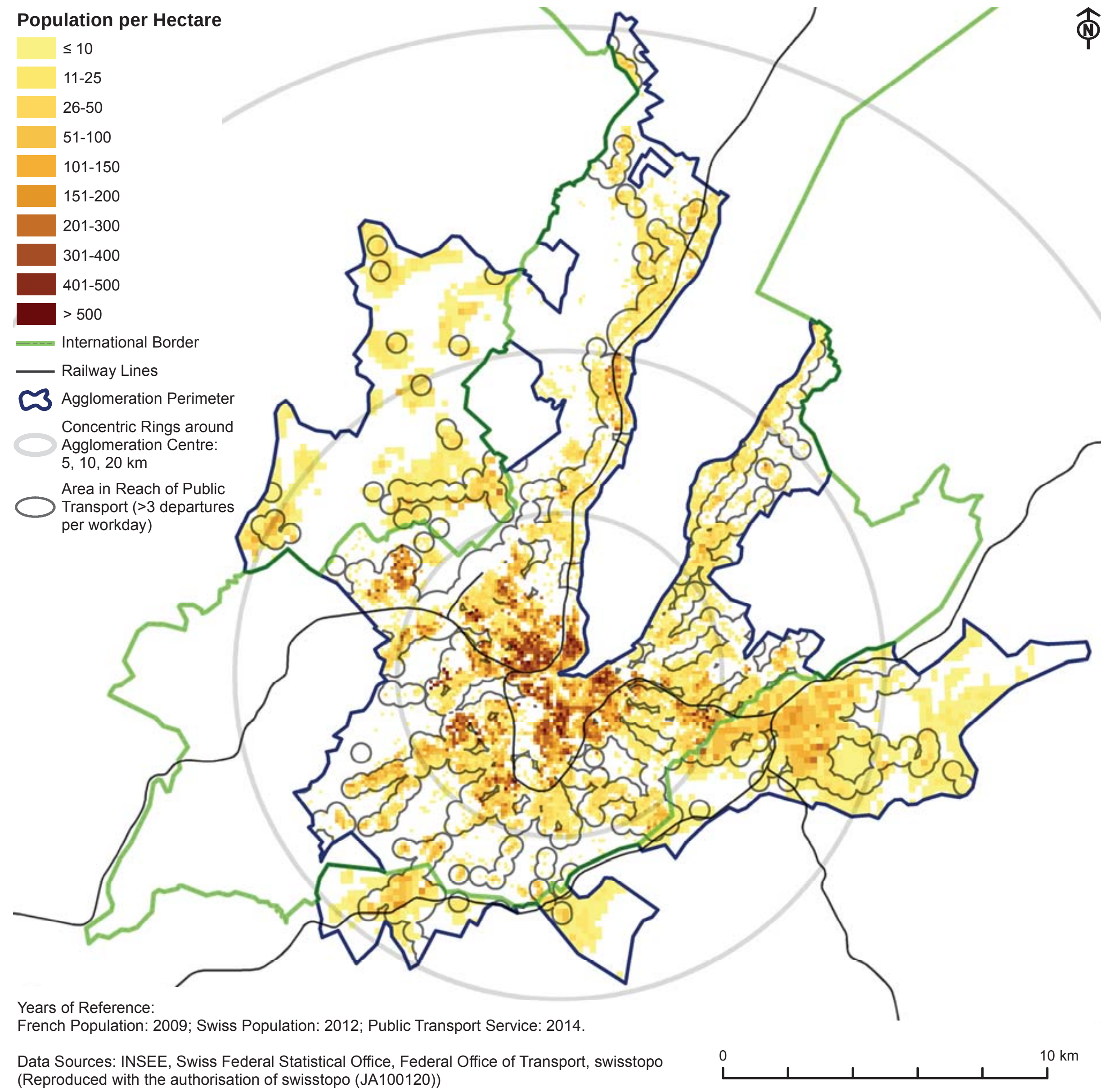


4.3 Public Transport Coverage

After considering the characteristics of public transport networks and of the distribution of the agglomerations' inhabitants, it is also of interest to which extent the domestic and cross-border public transport networks are actually in reach of the population.

The catchment areas of public transport stops (300 m radius for tramways and buses, 750 m for railways) as well as a high-resolution raster of the population distribution of Geneva and Basel agglomerations are displayed cartographically in Figure 9 and Figure 10.

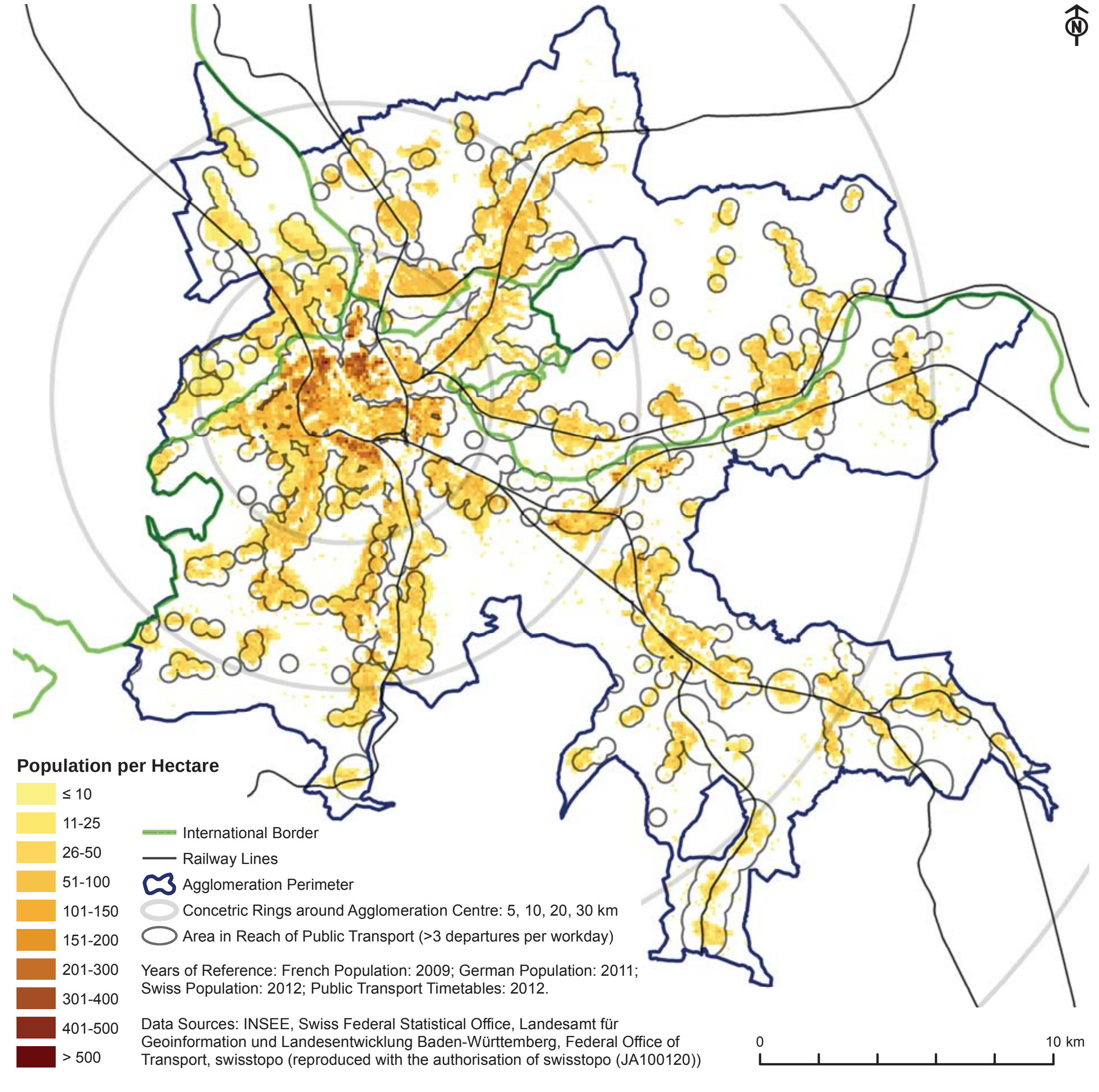
Figure 9: Public Transport Coverage within Geneva Agglomeration (map)



Years of Reference:
French Population: 2009; Swiss Population: 2012; Public Transport Service: 2014.

Data Sources: INSEE, Swiss Federal Statistical Office, Federal Office of Transport, swisstopo (Reproduced with the authorisation of swisstopo (JA100120))

Figure 10: Public Transport Coverage within Basel Agglomeration (map)



For quantitative analyses and comparisons, the agglomeration areas have been divided by international borders as well as by concentric rings (5, 10 and 20 km from the agglomeration centre). The extent to which the population of these agglomeration sectors is within reach of public transport is depicted by graphs in Figure 11 and Figure 12.

It is important to note that at this stage, no distinction has been made between different service levels. Instead, all public transport stops with at least three departures per workday have been taken into consideration. Service frequency will be analysed separately in chapter 4.4.

Figure 11: Public Transport Coverage of Population within Geneva Agglomeration

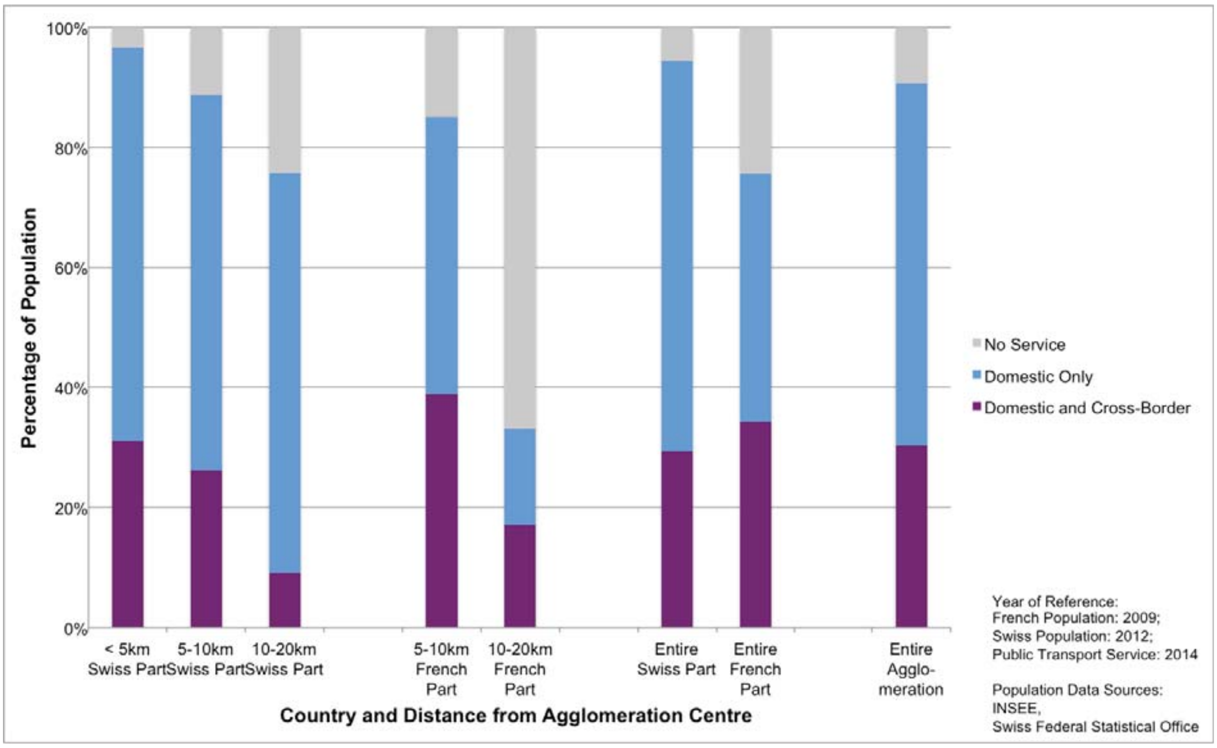
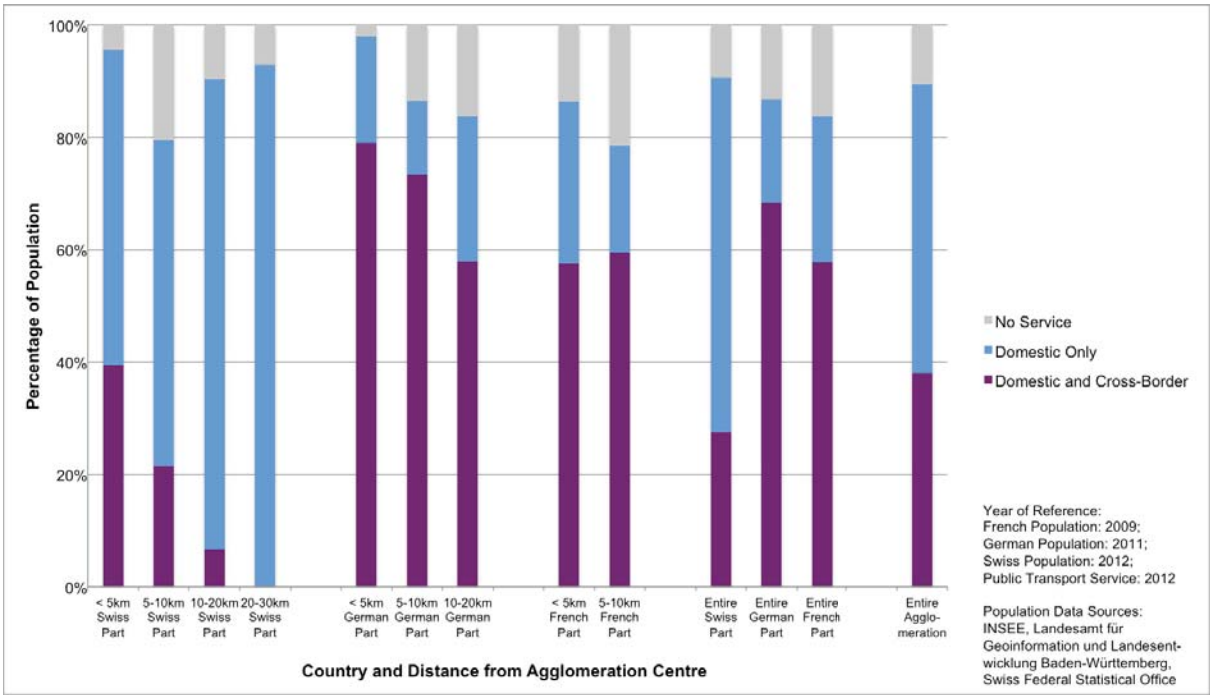


Figure 12: Public Transport Coverage of Population within Basel Agglomeration



Considering the population share residing outside the catchment area of public transport stops, this amounts overall to approximately 10% in both Geneva and Basel agglomerations. Some differences, however, become apparent when differentiating between countries and according to distance from the agglomeration centre: In Geneva agglomeration, residents farther than 10 km from the agglomeration centre are to a higher extent out of reach of public transport: 24% of these residents in the Swiss part, and as much as 67% in the French part.

In Basel agglomeration, these differences are less distinct: The lowest public transport service coverage can be found in a distance of 5-10 km from the agglomeration centre, both in the Swiss and French Part, where slightly more than 20% of inhabitants reside outside of catchment areas of public transport stops.

Again, only areas within the agglomeration perimeter (i.e. communes with a minimal population density of 300 inhabitants per square kilometre) have been taken into account in order to maintain a certain degree of comparability. The encountered differences would presumably be even stronger if the concentric rings also included areas outside the perimeter.

Interestingly, while around 90% of the agglomerations' populations are in reach of public transport, a much smaller share is also directly served by cross-border public transport: 30% in Geneva agglomeration and 38% in Basel agglomeration. These shares are also subject to significant variations throughout different parts of agglomerations: In the country of the agglomeration centres – Switzerland in both cases –, the catchment areas of cross-border services cover less residents than in the French and German agglomeration parts. In the latter, on the other hand, cross-border services are more widespread.

Additionally, the coverage of cross-border services tends to be lower, the higher the distance from the agglomeration centre. This is however partially explicable by the tendency that places far from the agglomeration centre are often also distant from the border and therefore less served by cross-border services.

These effects apply to both Geneva and Basel, but they are especially distinctive in the case of Basel. It is very noticeable that certain agglomeration areas are barely – or not at all – served by cross-border services. Also, the significant variations in the share of people outside public transport catchment areas are conspicuous and underline the differences in density of public transport networks and their areal coverage in different countries of the considered agglomerations.

4.4 Service Quantity

The number of offered services, given by the headway and service hours, is for customers and potential customers one of the most important characteristics of public transport services. Therefore, these indicators have been deemed as suitable for the comparison of domestic and cross-border services in this paper.

For this purpose, two types of service quantity analyses are carried out: First, the number of services is observed on a per-line basis, including a comparison of the years 1994 and 2014. Subsequently, service quantity is analysed on a per-stop basis, revealing the spatial distribution of service quantity, as well as the coverage of population within the catchment areas of these public transport stops.

4.4.1 Service Quantity per Line

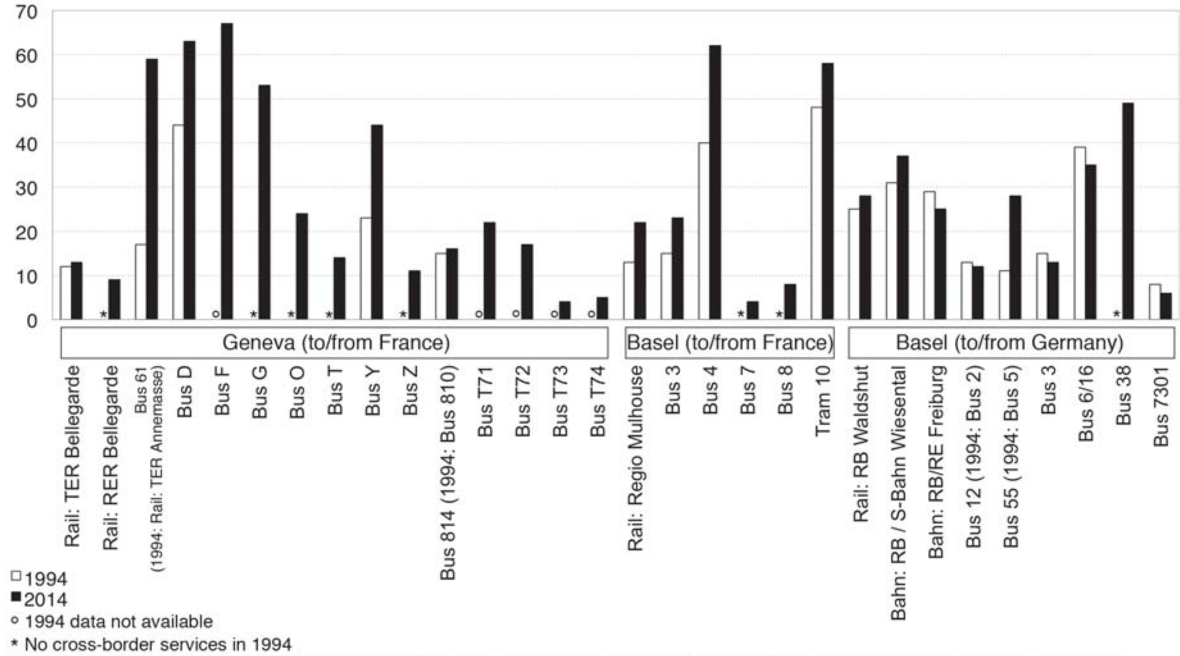
Figure 13 provides an overview of service quantity on cross-border routes of local public transport in Geneva and Basel agglomeration for both 2014 and summer 1994.

In 2014, public transport services across borders of either agglomeration are served on approximately 15 lines each, if services on demand, lines with less than 4 return services per day and lines extending less than 1 km beyond borders are excluded from consideration. While this might appear as a substantial amount of services, a consideration of the actual number of services on these lines relativises this impression: on only one third of the considered lines, 30 or more return services per day are operated, corresponding, for example, to a 30 min headway during 15 hours. Furthermore, for both agglomerations together, only three lines have more than 60 return services, standing e.g. for a 15 min headway during 15 hours.

In contrast to domestic lines in comparable distance from the agglomeration centre (not shown in graphs), the cross-border routes are quantitatively on a very low service level: In Geneva and Basel, domestic local rail (S-Bahn) lines run between 40 and 50 return services, and buses mostly between 50 and 130 return services.

Thus, a clear difference between domestic and cross-border service quantities can be observed.

Figure 13: Number of Cross-Border Return Services per Day and Line in Basel and Geneva, 1994 and 2014, Mondays to Fridays



Services on demand, lines with less than 4 return services per day and lines extending less than 1 km beyond borders are not shown here.

Data source: transport operators' timeables

Another interesting aspect emerges from comparing quantitative service levels in 1994 and 2014, as shown in Figure 13: In some cases, the number of services has not changed considerably, while on other lines, clear service augmentations can be observed. Eight lines in total had not even existed in 1994 and were created during this 20 years' period, contributing to important service enhancements. The number of services, however, is still rather modest on most of these lines.

Additional cross-border connections exist in both agglomerations by interchanging between domestic bus or tramway lines that terminate at the border, and by crossing the border on foot. Any systematic coordination of timetables for such connections, or signalisations between the terminus stops at either side of borders, can not be observed so far. The use of such connections is thus reserved to passengers with advanced knowledge of the local public transport system.

4.4.2 Spatial Distribution of Service Quantity

A more detailed insight into the spatial extent of service quantity is possible with the help of Geographic Information Systems. For this purpose, the total number of departures per day been added for all public transport stops within the agglomeration of Geneva and Basel. In Figure 14 and Figure 16, these quantities are displayed by colour shades within the catchment area of public transport stops (radius 750m for railways, 300m for buses and tramways); the yellow patterns overlaying these shades additionally display the number of cross-border departures as a subset of the total number of departures.

The graphs displayed underneath each of these GIS maps complement the spatial information of service quantities by the share of the agglomerations' populations being served by the respective quantity of services. These graphs as well distinguish between cross-border and domestic services, allowing for comparisons between these two types of transport services.

In the case of Basel, on Modays to Fridays, the highest service density stretches along the main railway axes that correspond roughly to the star-shaped agglomeration structure. In between these axes, in areas with topographically more difficult accessibility, fewer departures can be found. This, however, also corresponds to lower settlement densities and the accordingly reduced demand potential.

Regarding cross-border transport, it should first be noted that no symbol had to be created for public transport stops with more than 250 departures per workday, because such stops do not exist. This is in strong contrast to the overall number of departures from transport stops, which reach on Mondays to Fridays more than 2'000 departures per day at the central node of Basel Schifflände (whereof the 4 cross-border bus lines from this stop make up only 147 departures).

The distribution of stops with cross-border departures is also noteworthy: These are mainly concentrated next to the international borders and along the main axes in the French and German parts of the agglomeration. Other stops in France and Germany, which are served by domestic lines only, generally show quite low timetable densities.

In the Swiss part, cross-border departures extend only between the border and the city centre of Basel, while all areas south of Basel are barely connected to the French and German parts of the agglomeration. The most important exception is the U-shaped tramway line 10, extending on two axes southwards from the city centre, crossing the Swiss-French border at the south-western extremity of the agglomeration perimeter, and thereby serving predominantly domestic purposes. Therefore, however, connections between Swiss and French or German parts of the agglomeration require in most cases at least one interchange.

Figure 14: Spatial Distribution of Service Quantity, Basel Agglomeration (Mon-Fri)

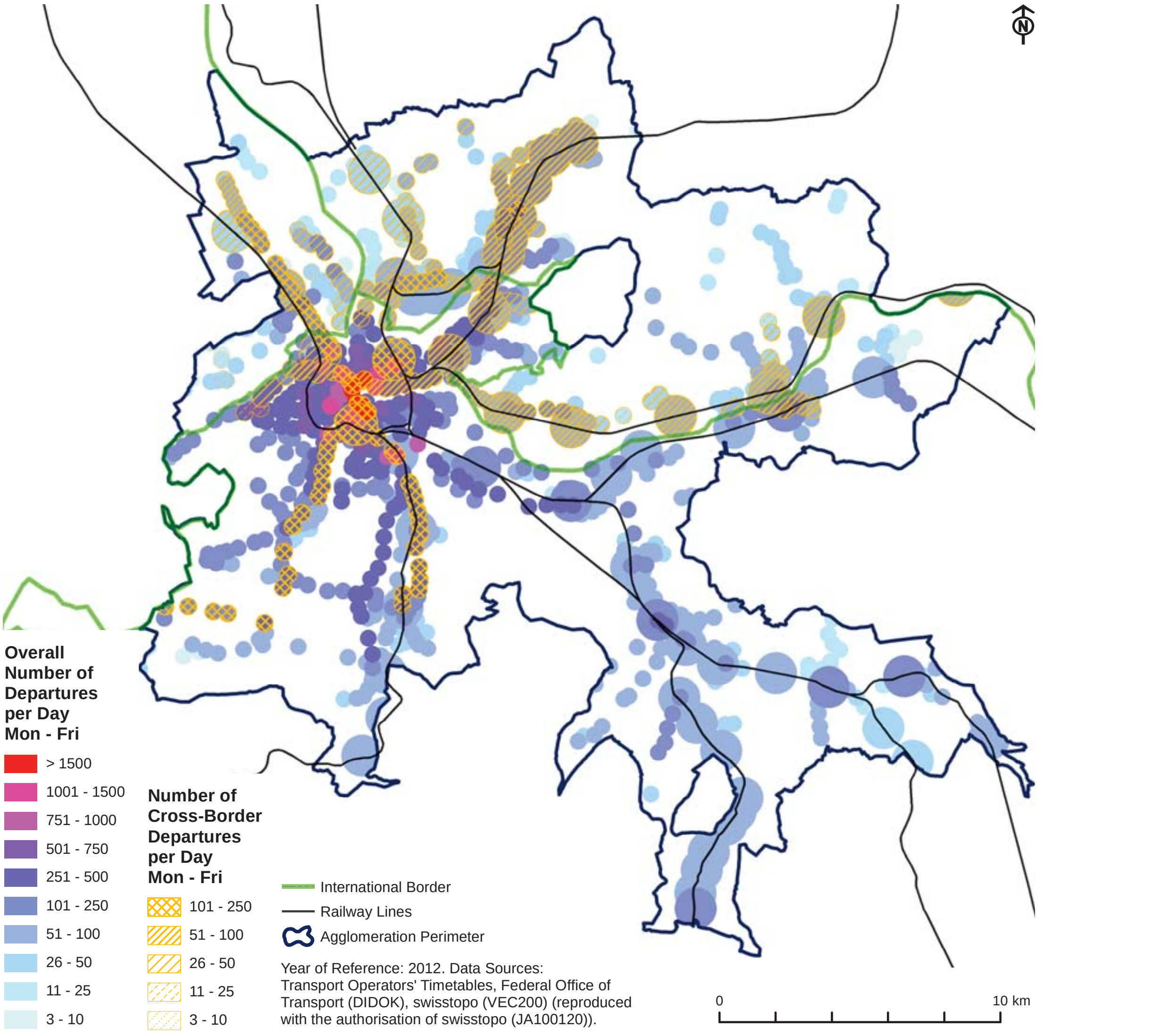
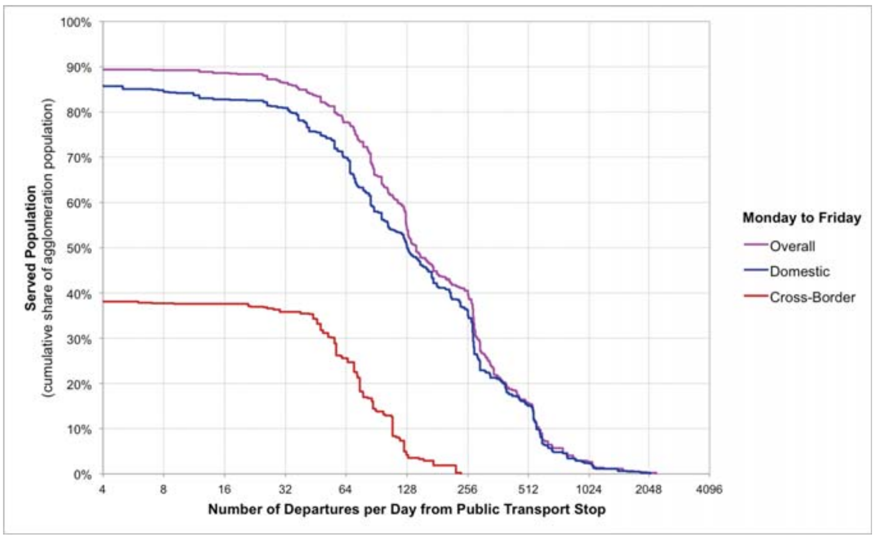


Figure 15: Served Population by Service Quantity, Basel Agglomeration (Mon-Fri)



Share of Population [%] within Reach of Public Transport Stops

	Cross-Border Services	Domestic Services	All Services
≥ 3 departures	38	86	89
≥ 48 departures	33	75	83
≥ 128 departures	4	51	55
≥ 256 departures	0	36	41
≥ 512 departures	0	15	16

Figure 16: Spatial Distribution of Service Quantity, Geneva Agglomeration (Mon-Fri)

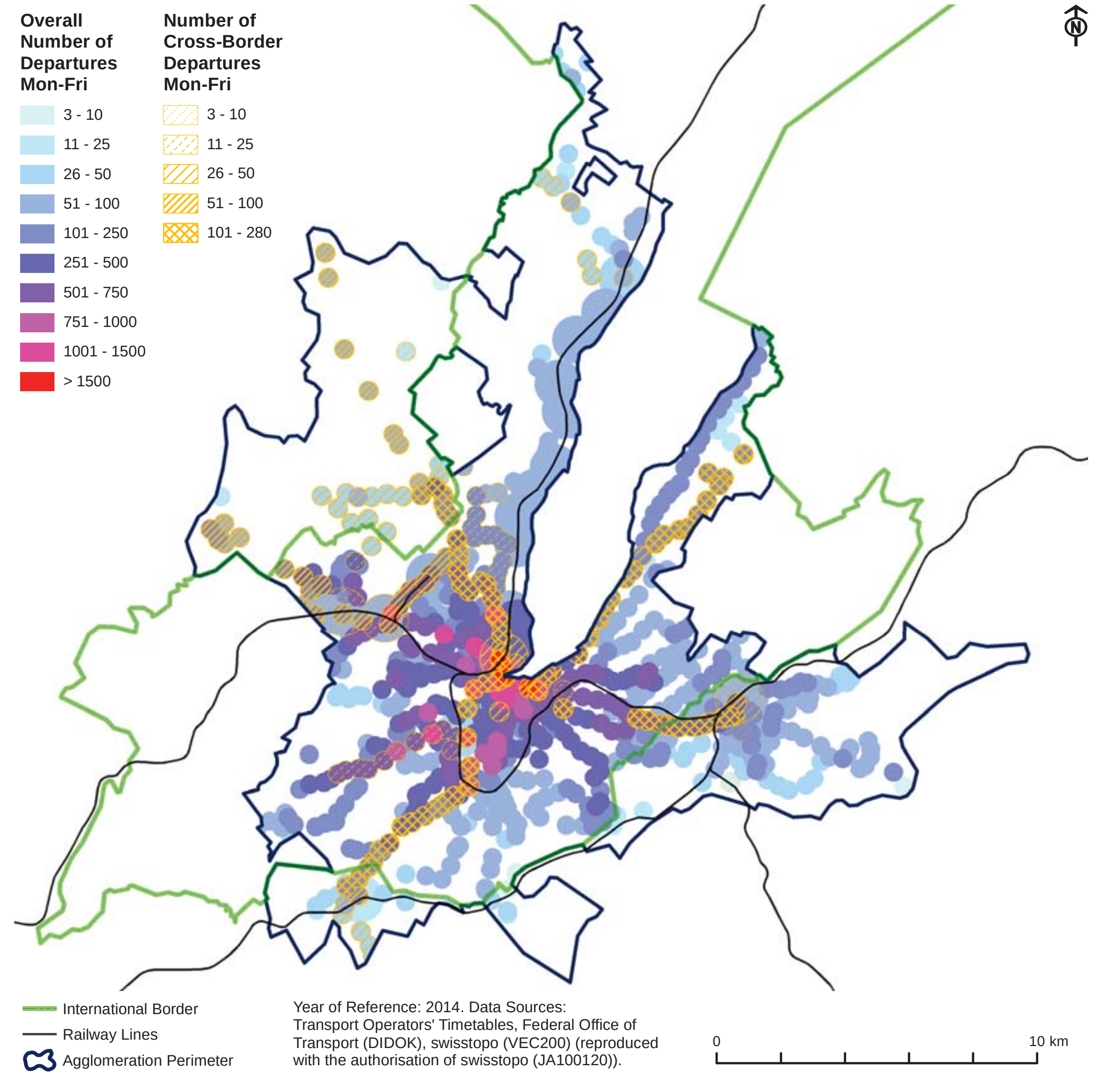
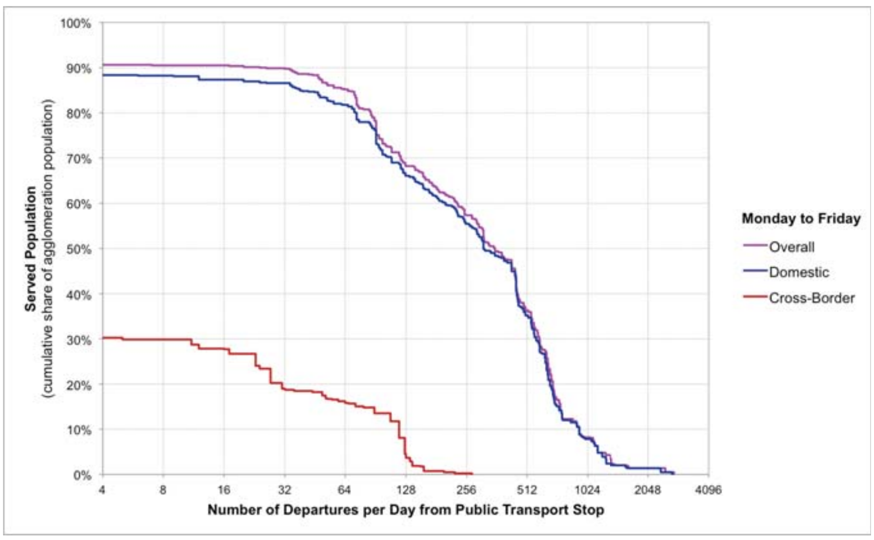


Figure 17: Served Population by Service Quantity, Geneva Agglomeration (Mon-Fri)



Share of Population [%] within Reach of Public Transport Stops

	Cross-Border Services	Domestic Services	All Services
≥ 3 departures	30	88	91
≥ 48 departures	18	84	88
≥ 128 departures	5	66	68
≥ 256 departures	0	55	57
≥ 512 departures	0	35	36

The extensive white areas on service quantity maps, representing areas without public transport service and presumably lower population densities, raise the question of the extent to which the agglomeration's population is actually served by local public transport, both on a general level, and also by cross-border services. To this end, the relationship between service quantity and the share of the served population is shown in the graphs underneath the maps.

As already identified from Figure 12, 89% of the agglomeration's population resides within reach of a public transport stop. Yet, for cross-border services, this only applies to 39% of inhabitants, i.e. less than half as many residents. The graph additionally reveals that on a quantitative service level of 128 departures per day Mondays to Fridays (corresponding to a 15 min. headway during 16 hours of operation of one line in both directions), which can be regarded as the timetable density of an average urban public transport line, only 4% of the agglomeration's population live within reach of cross-border services. At the same time, if domestic lines are also taken into consideration, as much as 55% of the population can benefit from such services. Furthermore, more than 40% of the population reside within the catchment area of public transport stops with 256 departures or more (corresponding to two such lines or to a line with a headway of 7.5 min.), while cross-border services do not add up to this amount of departures at any stop of the entire agglomeration.

In Geneva, similar, but not identical, observations can be made: The current network of cross-border railways is almost non-existent, but, as mentioned above, this is due to change with the above-mentioned opening of the 'RER franco-valdo-genevois' scheduled for 2017.

For buses, the share of the population that can be reached by cross-border services is also very low, especially regarding stops with more than 128 cross-border departures per day Mondays to Fridays.

Due to the compact settlement structure within the agglomeration perimeter, supported by the topographically limiting mountain ranges in the north-east (Jura) and south (Salève), and Lake Geneva from the north-northeast, extensive areas of the agglomerations are well served by public transport. Cross-border services, however, are again limited to certain corridors, with the south-eastern part of the agglomeration, Annemasse, currently being served across borders to a very limited extent only, in spite of its rather dense settlement structure that is seamlessly connected to the agglomeration centre. The 'RER franco-valdo-genevois' will partially alleviate this lack by new connections between rail stations, for the primary benefit of directly surrounding areas.

5. Conclusions

The use of GIS for analysing the characteristics of local public transport on cross-border sections has revealed a series of interesting findings.

First, the applied method based on the combination of datasets from different sources and countries showed exemplarily the challenge in carrying out analyses across borders. Data availability, accessibility and comparability are in many cases not given by default. For the realisation of projects in borderlands, this can be a major obstacle.

Second, the framework conditions for local public transport across borders have proved to be complicated: In terms of settlement structures and population densities, cross-border agglomerations have no uniform structure but are strongly influenced by the course of the borderline. This is also reflected by the density of public transport networks and the population share living within catchment areas of public transport services: Both indicators vary strongly between different parts of the agglomerations.

Additionally, while the reach and integration of cross-border lines within the agglomerations' public transport networks is rather poor (as compared to domestic lines), administrative and possibly political complications make it difficult to develop and significantly improve public transport networks on an agglomeration-wide basis, i.e. beyond the spatial limits of the involved authorities.

Furthermore, the initially identified comparatively low modal share of public transport across borders is also reflected by a very clear differentiation in service quantity between domestic and cross-border services. Apart from a rather mediocre number of cross-border lines and a lower share of stops served by cross-border services, the number of cross-border departures corresponds only to a small fraction of comparable domestic services, both on a per-line and a per-stop basis.

In view of transport problems in urban areas, both in terms of capacity and externalities, which affect cross-border agglomerations and domestic conurbations alike, the current offer of urban cross-border services in the considered cases appears clearly inadequate. However, the conditions and modalities to promote and develop urban cross-border public transport systems are characterised by various challenges. Tackling these challenges and removing the identified transport system deficiencies will be an important task for the next decades.

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