ASSESSMENT OF SCHOOL CLOSURES IN URBAN AREAS BY SIMPLE ACCESSIBILITY MEASURES

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Summary: The demographic processes in the eastern regions of Germany have yielded a dramatic decline in student numbers for the time period 1992–2002. This in turn implicates a remarkable school consolidation. In application scenarios, simple measures of the assessment of school closures are needed. In this paper we discuss simple measures of school-accessibility based on public transport travel-times. Moreover, an efficient network flow model to determine the travel-times is presented. Furthermore, a guidance of how a network graph might be constructed is given. As a result of the accessibility analysis, we find that proximate areas are affected by increased travel-times. However, outskirt districts are affected as well. This finding is not obvious, though. The easy-to-understand measures of accessibility presented in this paper might be implemented in the educational planning process. The case study of Dresden is exemplary for other (western) regions in Germany with comparable demographic processes.

Zusammenfassung: Ein wesentliches Merkmal des derzeit diskutierten demographischen Wandels, sind die in einigen Städten Ostdeutschlands zum Teil stark rückläufigen Schülerzahlen. In Folge dieser Entwicklungen werden häufig Schulstandorte geschlossen. Bei der Entscheidung, welcher Standort aufzugeben ist, werden Aspekte der räumlichen Erreichbarkeit zumeist vernachlässigt. Dieser Beitrag diskutiert quantitative Indikatoren, die eine Diskussion über zu schließende Standorte, hinsichtlich zu erwartender Veränderung der Erreichbarkeit bereichern können. Hierbei werden sowohl einfache Erreichbarkeitsindikatoren, wie zum Beispiel die Anzahl der ÖPNV-Linien, die eine schulstandortnahe Haltestelle bedienen, als auch komplexere, aber weiterhin leicht verständliche Erreichbarkeitsmaße, die zusätzlich die Aktivitätenmenge berücksichtigen, verwendet. Darüber hinaus wird ein effizientes Kürzeste-Wege-Problem zur Ermittlung der Reisezeiten sowie die Vorgehensweise zur Graphkonstruktion des Liniennetzes vorgestellt. Im Rahmen der Analysen zeigt sich, dass trotz einer Vielzahl an Schulschließungen, für die Gymnasien der Stadt Dresden eine gute Erreichbarkeit erhalten bleibt. Gleichwohl werden Wohnorte, die bereits vor Schulschließung verhältnismäßig schlechte Erreichbarkeitswerte aufwiesen überproportional von den Verschlechterungen der Erreichbarkeit in Folge der Schulschließungen getroffen.

Keywords: Accessibility, travel-times, public transport, shortest-path problem, graph construction, geographic information systems, school closure, urban areas

1 Introduction

During the time period 1995–2005, the city of Dresden, Germany, faced the problem of a dramatic decline (30%) in student numbers. Recently however, the student numbers have increased slightly. This phenomenon is typical for many urban areas in eastern regions of Germany (except for Berlin). Consequently, a lot of schools have been closed in recent years. It is a very difficult task to decide which schools should be closed. Often the political debate on this topic is focused on a few selected criteria like locational costs. Notably, in real world applications, a complex view of the problem is needed. Unfortunately, this is unusual due to the complexity of the related measures and models (MÜLLER 2010; MÜLLER et al. 2009). In this paper we'd like to propose

simple measures that can help to decide school closures (and openings as well). We focus on measures that describe the accessibility of Gymnasium-schools to students in terms of travel-time. It is well known that long travel-times have a wide range of negative impacts on students (TALEN 2001). Therefore, we'd like to investigate spatial equity of accessibility variation due to school consolidation.

We consider Gymnasium-schools only, because the public debate concentrates on these (PETER 2004; PETER 2005; KLAMETH 2005; RICHTER 2005). Roughly speaking, a Gymnasium-school is equivalent to an American high-school that qualifies for university study. For more details, see MÜLLER (2009) and MÜLLER (2008). Since nearly 70% of all students who qualify for a Gymnasium-school use public transport on their commute to school, we will con-

sider public transport in our analysis (MÜLLER 2006). Our study area is the city of Dresden, Germany. Commute to school flows from the city of Dresden to surrounding regions and vice versa are negligible (MÜLLER 2009). All measures presented here can be used as single indicators in order to assess the effects of school closures. However, one might apply these measures to location-allocation models as well (LEONARDI 1978). The remainder of the paper is structured as follows: In section 2, we define accessibility. In section 3, an efficient shortest-path problem is presented in order to determine travel-times on the commute to school. Note that efficient solutions to shortest-path problems are one major issue in recent accessibility research (KWAN et al. 2003). Section 4 comprises the construction of the underlying network graph. The discussion of the measures to assess school closures and the application to the city of Dresden can be found in section 5. Finally, a conclusion is given in section 6.

2　What is accessibility and how can we measure it?

A very general definition of accessibility can be found in RODRIGUE et al. (2009). They define accessibility as a key element to transport geography, and to geography in general, since it is a direct expression of mobility either in terms of people, freight or information. Well-developed and efficient transportation systems offer high levels of accessibility (if the impacts of congestion are excluded), while less-developed ones have lower levels of accessibility. Thus, accessibility is linked to an array of economic and social opportunities. Accessibility is defined as the measure of the capacity of a location to be reached by, or to reach different locations. Therefore, the capacity and the arrangement of transport infrastructure are key elements in the determination of accessibility. All locations are not equal because some are more accessible than others; this implies inequalities. The notion of accessibility consequently relies on two core concepts: The first is location, where the relativity of space is estimated in relation to transport infrastructures, since they offer the mean to support movements. The second is distance, which is derived from the connectivity between locations. Connectivity can only exist when there is a possibility to link two locations through transportation. It expresses the friction of distance. The location that has the least friction relative to others is likely to be the most accessible. Commonly, distance is expressed in units such as in kilometers or in time, but variables such as cost or energy spent can also be used.

Now the question arises: How should accessibility be measured? As KWAN (1998) states, conventional accessibility measures are based on three fundamental elements. First, a reference location serves as the point from which access to one or more other locations is evaluated. The reference location most often used is the home location of an individual, or the zone where an individual's home is located when zone-based data are used. Second, a set of destinations in the urban environment is specified as the relevant opportunities (here schools) for the measure to be enumerated. Further, each opportunity may be weighted to reflect its importance or attractiveness. Third, the effect of the physical separation between the reference location and the set of urban opportunities upon such access is modeled by an impedance function, which represents the effect of distance decay on the attractiveness of the relevant opportunities. Based on these three elements, various types of accessibility measures can be specified (BRUNISMA and RIETVELD 1998): In general, we consider relative and integral measures of accessibility. Relative accessibility measures describe the degree of connection between two locations. They are expressed in terms of the presence or absence of a transport link, or the physical distance or travel time between two locations. Integral measures, on the other hand, represent the degree of interconnection between a particular reference location and all, or a set of, other locations in the study area. When impedance between the reference location and the other locations is expressed in the form of a distance decay function similar to those found in gravity models, the access measure is a gravity-based measure. In the case where an indicator function is used as the impedance function to exclude opportunities beyond a given distance limit, the measure is a cumulative-opportunity measure. This measure indicates how many opportunities are accessible within a given travel time or distance from the reference location. A further distinction can be made depending on whether an access index is enumerated and used as an indicator of physical or place accessibility (how easily a place can be reached or accessed by other places), or personal or individual accessibility (how easily a person can reach activity locations). For more details, see KWAN (1999).

One important area in applied accessibility research is the provision of social services such as hospitals, clinics, senior centers, parks and schools. Studies within this research area evaluate whether access to a particular social service is socially equi-

table or discriminatory, and seek to identify areas of service deprivation that need special attention (KWAN et al. 2003). However, as Talen (2001) asserts, there is scant research and experience devoted to school accessibility. In order to rectify this lack of literature, we will consider simple relative and integral measures of school accessibility here. Since most of these measures are based on travel-time, we elucidate how travel-times can be computed efficiently.

3   An efficient network flow model for the shortest-path problem

We assume, that students who commute to school by public transport choose the shortest-path (in terms of travel-time) from home (reference location) to school (destination). In order to determine the shortest-path, we can use either a shortest-path algorithm or a network flow model (DOMSCHKE and DREXL 2005; LONGLEY et al. 2001; AHUJA et al. 1993). In both cases, the length of the shortest-path in minutes of travel-time is the weighted sum of arcs or edges of the shortest-path. Note that travel-time includes access- and egress-time, in-vehicle- and waiting-time as well as transfer-time. Here we will regard a network flow model, by considering a graph that comprises the public transport network, the schools, and the students' homes. How we actually construct such a graph is described in detail in section 4. From a theoretical viewpoint, the graph consists of nodes $i \in V$ and arcs or edges $(i, j) \in \vec{E}$ that connect the nodes i and j. Moreover, $(i, j) \in \vec{E}$ are weighted by δ_{ij}, which is the travel-time in our case. Our mathematical program (i.e., model) determines the paths from a given reference location $q \in Q$ to **all** destinations $s \in S$ with minimum weights δ_{ij} of the corresponding arcs or edges $(i, j) \in \vec{E}$. $Q \subseteq V$ and $S \subseteq V$. We introduce the positive variable X_{ij}, which is the flow from node $i \in V$ to node $j \in V$. "Flow" has to be interpreted from a theoretical viewpoint (i.e., we do not mean real entities like students). Now we define the objective as

$$\min \sum_{(i,j) \in \vec{E}} \delta_{ij} X_{ij} \qquad (1)$$

such that

$$\sum_{i \,|\, (i,k) \in \vec{E}} X_{ik} - \sum_{j \,|\, (k,j) \in \vec{E}} X_{kj} = \begin{cases} |S| & k=q \\ 1 & \text{else} \end{cases} \quad k \in v \qquad (2)$$

and

$$X_{ij} \geq 0 \qquad (i,j) \in \vec{E} \qquad (3)$$

The objective (1) minimizes the travel-time between a given q and all s. The flow constraints (2) guarantee a contiguous path from q to s. Therefore we assume that one entity per destination s departs from source q. So if $k = q$, we need exactly the amount of entities that equals the demand of all destinations s. That is $\sum_{j|(k,j) \in \vec{E}} X_{kj} = |S|$ for $k = q$. For all other nodes, there is one more in-flow entity than out-flow entity. Hence $\sum_{i|(i,k) \in \vec{E}} X_{ik} - \sum_{j|(k,j) \in \vec{E}} X_{kj} = 1$ for $k \neq q$.

The shortest-path problem outlined here is efficient in various ways: (i) the domain (3) of our variable X_{ij} is $\mathbb{Q}^{\geq 0}$. Hence, our model is a linear program. However, due to the special structure of the model (i.e., the flow-constraints (2)) X_{ij} takes either the value 1 or the value 0 in the solution. This enables the use of a powerful network simplex method in order to solve our problem optimally and efficiently. (ii) Our model is called a single-source-shortest-path-problem (SSSP), because we compute each shortest-path to all destinations s of one source q. Thus, in order to compute a travel-time matrix between all pairs of q and s we need to solve the problem $|Q|$-times. A single-pair-shortest-path-problem (SPSP) determines the shortest-path between one q and one s. Hence, SPSP has to be solved $|Q| x (|S| - 1)$ times. The expected computation time for a $q \, x \, s$ travel-time matrix is remarkably lower for the SSSP compared to the SPSP (CORMEN et al. 2001). (iii) in our specific situation, we know that $|S| < |Q|$, i.e., we have less schools s than student locations q. So if we switch q and s, the number of repetitions of our problem reduces from $|Q|$-times to $|S|$-times.

4   How is a network graph set up?

Generally, we have to consider three steps in order to set up a comprehensive graph for the determination of students' travel-times on the commute to school. First, we have to set up a graph of the public transport network of the city of Dresden. We considered lines and routes of the time-period of interest 2002–2008.[1] We only considered routes valid for weekdays between 6:00 AM and 3:00 PM, which is the peak time-period in school commuting. However, we accounted for special routes due to commute to school flows. At this point the nodes of our graph are stops (tram, bus and rail) and the arcs are the connections between these nodes. All arcs are weighted by the drive time between two adja-

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[1] Most school closures have taken place in this period.

cent nodes. So far, we have been able to compute the in-vehicle travel-time only. In order to account for transfer-times we considered the schedule of all bus-, tram- and rail-lines. We considered multiple nodes at stops where interchange between different lines is possible. Moreover, we accounted for the opposite direction of a given line (inbound and outbound) as well. Therefore, a given stop might consist of multiple virtual nodes (see Fig. 1). The arcs between the nodes of the same stop are weighted by the difference of arrival-times of the two lines considered.

Note that if these time differences changed within the time-period (6:00 AM to 3:00 PM), we computed the average of these values.

In a second step we have to connect the school locations and the locations of the students to public transport stops. Therefore, we buffered all stops with an arc radius of 800 meters using a standard geographic information system. All schools within the buffer of a given stop are connected to the respective stop. As a result, schools might be connected to more than one bus stop. This is necessary, since students
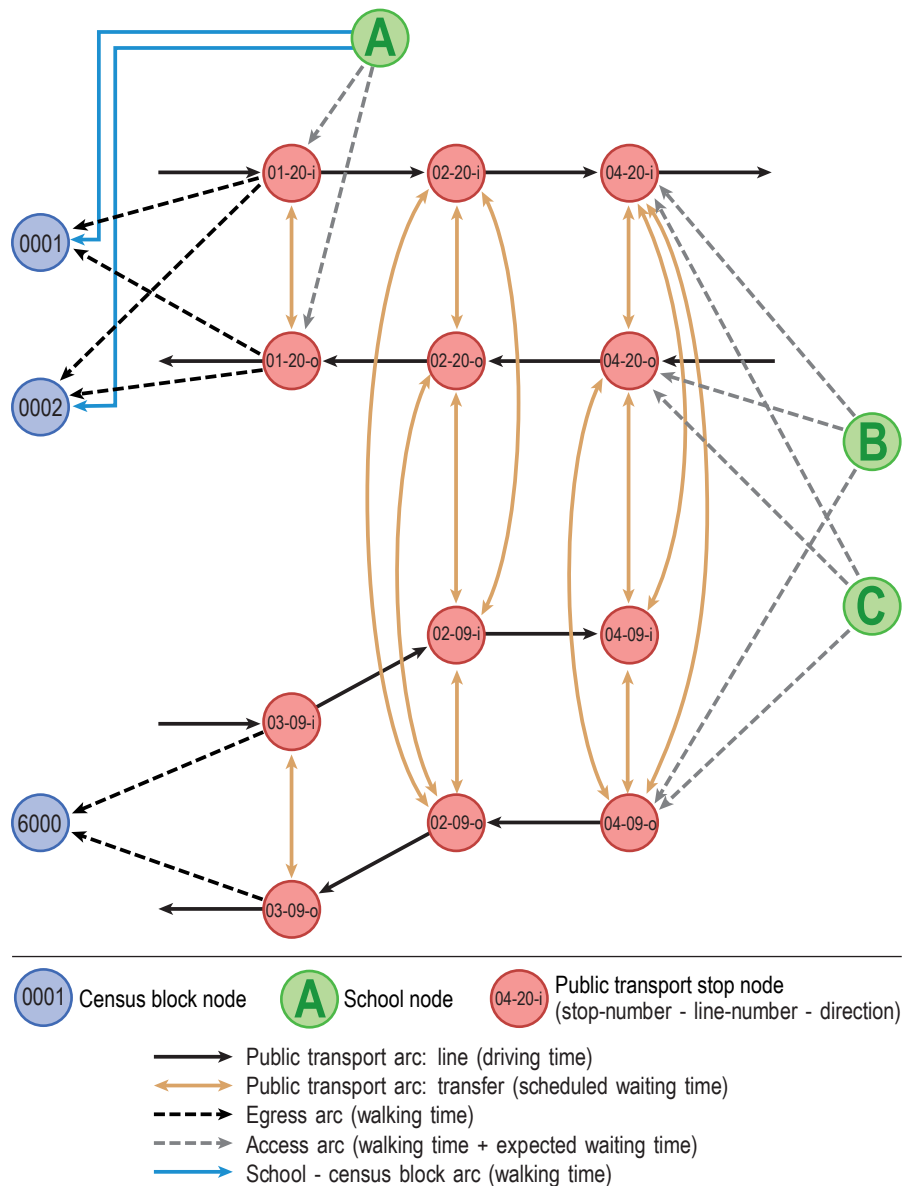
Fig. 1: Graphical representation of the arcs and nodes used for the network graph. We use multiple nodes for stops which are served by two or more lines (stops 2 and 4 for example). For a more general construction we might add the opposite direction for the access and egress arcs

commute to school from different directions using different lines that might terminate at different stops close to the respective school. If a school is not located within any buffer, we increased the arc radius of proximate stops stepwise as long as the respective school is connected to at least one stop. Note that we accounted for physical barriers like embankments and rivers in order to make sure the schools are accessible from the stop (see Fig. 2). The results of this procedure are additional nodes (schools) and arcs (connection between school and stops) of our graph. These arcs are weighted by

$$\delta_{ij} = \sigma(|a_i - a_j| + |b_i - b_j|) \tag{4}$$

where either $i \in S$ or $j \in S$. σ is the assumed travel-speed by foot (here: 1.49 meters per second) and a_i, a_j, b_i and b_j are geographic coordinates of the nodes i and j. The Manhattan metric of (4) accounts for detours in an urban environment.

The last step consists of the assignment of the students' homes to departure stops. Since we do not have the exact addresses of the students, we use aggregated student numbers at the geographical scale of census blocks. The city of Dresden is subdivided into more than 6 400 census blocks. The area of an average census block is nearly 0.05 square kilometers. We assigned the centroid of each census block to at least one stop. Therefore, we used the same proce-

dure as for the assignment of the schools to stops. However, the weighting of the resulting arcs is different. Namely

$$\delta_{ij} = \sigma(|a_i - a_j| + |b_i - b_j|) + a(1 - \beta \exp(\gamma Z)) \tag{5}$$

where either $i \in Q$ or $j \in Q$. The term $a(1 - \beta \exp(\gamma Z))$ is the expected waiting time at the departure stop with Z as the headway. Parameters a, β and γ have to be determined empirically. Here we assume that students have precise information about the public transport schedule and, hence, we set the maximum waiting time to 8 minutes (i.e., $a = 8$). Values for β and γ (1.1045 and -0.0852 respectively) are taken from GROSSE (2003). The expected waiting time dependent on the headway is shown in figure 3. Finally, if a census block is located within the 800 meters buffer of a given school, this census block is directly assigned to the respective school. That is because given a distance of 800 meters or less, the probability of commuting to school by foot or bike is higher than for any other transport means (MÜLLER et al. 2008).

We used this graph with Q as the schools (24) and S as the census blocks (more than 6 400) and employed our model from section 3 in order to determine a Q x S travel-time matrix. To do so, we implemented the model in GAMS Version 22.2 (www.gams.com). The CPU-time with a Pentium 4 and 3 GHz and 2 GB DDR Ram under OS Windows XP is nearly 40 minutes.
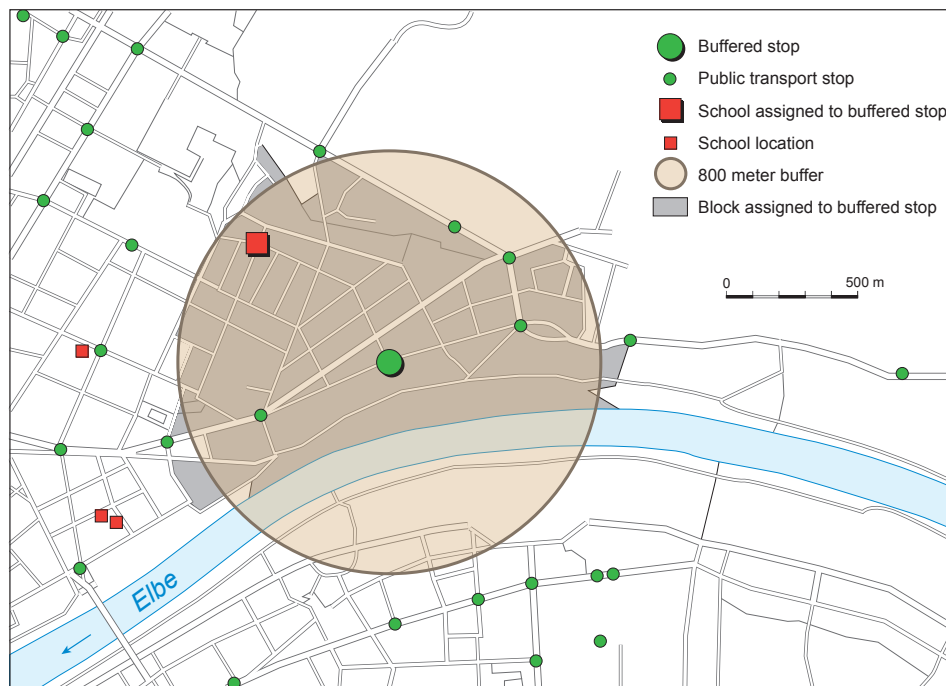

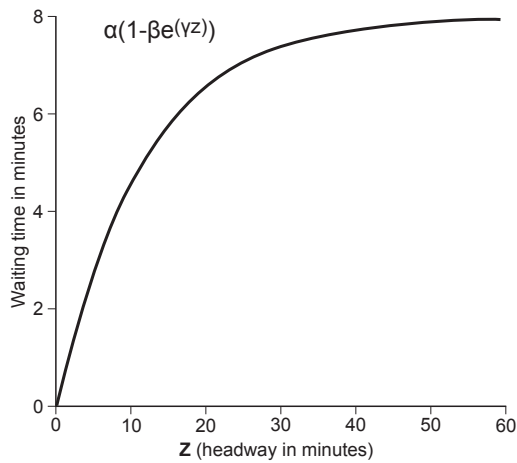**Fig. 2: Assignment of census blocks and schools to public transport stops**

Fig. 3: Expected waiting time dependent on line headway
Z: $\alpha(1 - \beta \exp(\gamma Z))$

5   Impact of school closures on accessibility

Following the definitions given in section 2, here we discuss two relative measures and three cumulative-opportunity measures. All measures have in common that they are quite simple to understand and to compute (we can employ standard GIS-techniques). As a reference, figure 4 shows the spatial population pattern of the city of Dresden for the year 2002 – the base year of our analysis.

5.1 Relative measures of accessibility

A very general measure of accessibility of Gymnasium-schools, which is related to service quality, is the minimum travel-time. This measure is based on the assumption that the probability of enrolling in the nearest school is highest compared
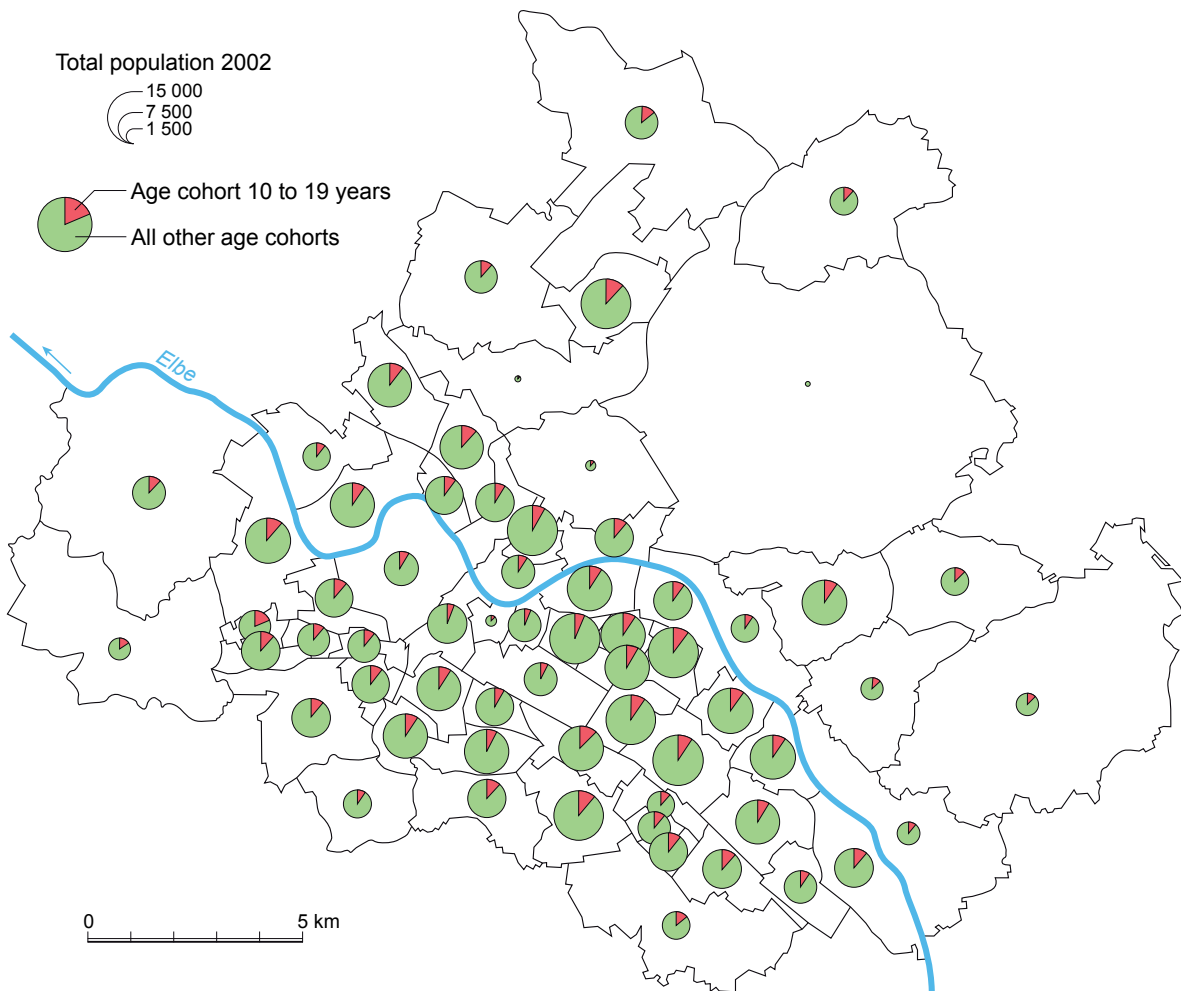

Fig. 4: Population of the city of Dresden on city district level. Numbers are given for the year 2002

to all other schools (Müller et al. 2011). We define the measure as

$$A_i = t_{ij} | (t_{ij} = \min\{t_{i1}, ..., t_{iQ}\}) \tag{6}$$

t_{ij} denotes the travel-time on the shortest-path between a given census block $i \in S$ and a school $j \in Q$. A_i is the travel-time of a given census block to the most proximate school. Hence, the lower the value of A_i, the better the accessibility for the given census block. Here, the absolute measure is of less relevance. We are more interested in the change of A_i over the time-period of school consolidation (2002–2008). 25% of the Gymnasium-schools were closed in this period. Figure 5 depicts the deterioration of this measure in proximate areas where schools were closed. However, the increase in minimum travel-time in the north of our study area was not anticipated. This phenomenon is related to the closure of very central schools, which in turn are located close to the central railway station. The considered census blocks in the north are closely located to a railway station. In terms of travel-time, the closest schools for the census blocks located in the north are schools located in the city center. Without this measure, the interdependency between school closure and decline in accessibility of census blocks located far away from the closed school site would not have been detected. The closure of schools located at the outskirts reveals an increase in minimum travel-time from 10 minutes to 30 minutes to some extent. However, most of the census blocks do not show an increase in minimum travel-time.

So far, we do not know how many students are faced with an increase in travel-time. Therefore we introduced a second relative measure of accessibility as
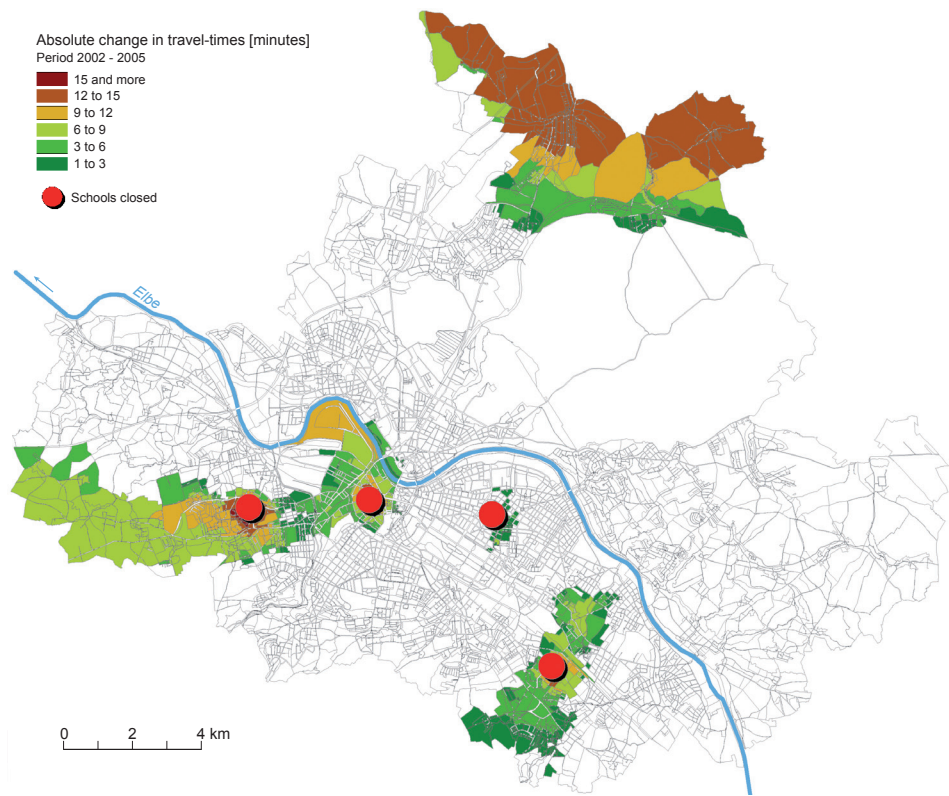
$$\tilde{A}_i = \frac{L_i^{\varrho+1}}{\max\{L_j^{\varrho+1} | j=1,...,S\}} A_i^{\varrho+1} - \frac{L_i^{\varrho}}{\max\{L_j^{\varrho} | j=1,...,S\}} A_i^{\varrho} \tag{7}$$

ϱ stands for the time period, A_i^{ϱ} the accessibility measure of (6) in period ϱ and L_i^{ϱ} is the absolute number of students in census block $i \in S$ who qualify for a Gymnasium-school in period ϱ. $i, j \in S$. This measure translates the change in absolute minimum travel-time between two periods into a relative measure weighted by the number of students of a given census block i relative to the maximum number of students over all census blocks. Hence, $\tilde{A}_i$ takes large positive values if many students are faced with a remarkable increase in travel-time. A high positive number has a negative meaning since travel-time increases from ϱ to $\varrho+1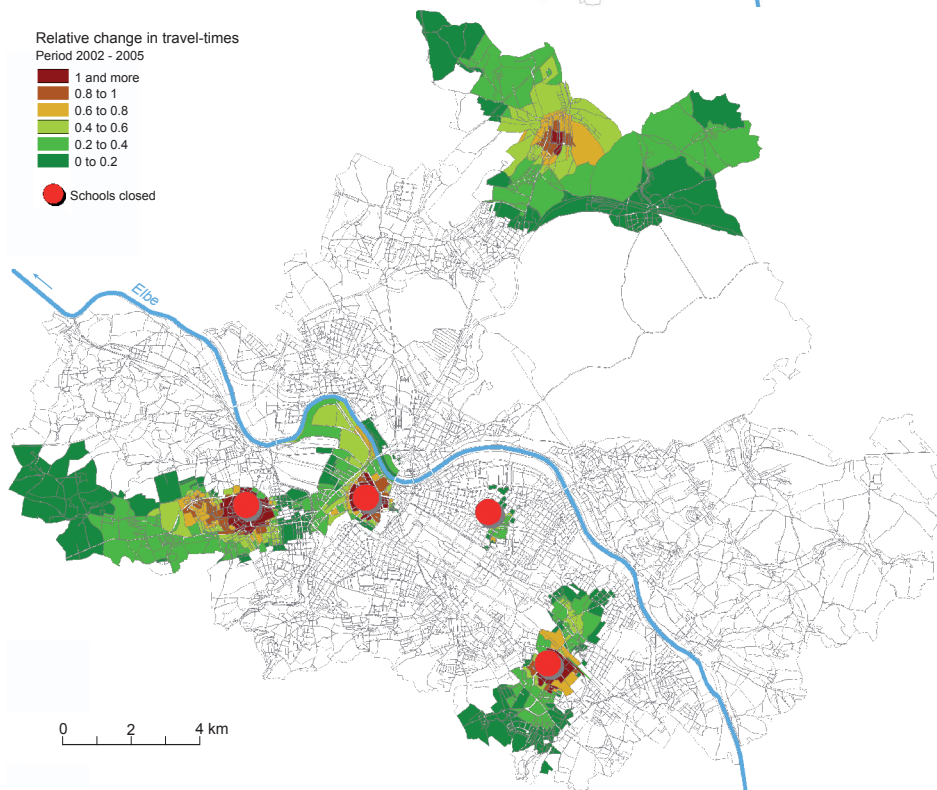$ for a relatively large number of students. Therefore, $\tilde{A}_i$ is of particular interest for applications because we are able to evaluate school consolidation very quickly with one measure (change in relative student-minutes). As expected, the census blocks located proximate to closed schools show the highest values of this measure (see Fig. 6). Moreover, this measure gives us some more information about the impact of school consolidation. If we compare the change in A_i (see Fig. 5) and the outcome of $\tilde{A}_i$ in figure 6, we observe an interesting pattern: There are areas of census blocks - particularly in the center, the north, and the south-east – where only small increases (absolute and relative) in travel-time occur. However, we see that these areas exhibit large positive values of $\tilde{A}_i$. In contrast, some of the regions that show a large increase in travel-time (particularly the most northern areas) do not exhibit large positive values of $\tilde{A}_i$ as expected. Thus, if we only focus on the simple travel-time measure, we miss the effect of the travel-time increase on the respective students. $\tilde{A}_i$ and A_i tell us that students who were particularly located at the outskirts were most affected by an increase in travel-time due to school consolidation in the period 2002–2008.

5.2 Cumulative-opportunity measures of accessibility

Here we consider two measures. The first measure is related to the accessibility of public transport infrastructure to schools. Therefore, we assume the higher the number of stops within an 800 meter buffer of a given school, the higher the accessibility of this school. The same should be true if we replace stops by lines. Now we have to define an evaluation scale. The range of this scale over all 24 Gymnasium-schools that opened in the year 2002 is 0–18 stops and 0–16 lines. Further, we partition these ranges in three equally large sub-ranges, i.e., 0–6 stops, 7–12 stops, and 13–18 stops; 0–5 lines, 6–10 lines and 11–16 lines. As figure 7 depicts, there are 6 schools with 7–12 stops and 18 schools with 13–18 stops. If we consider the number of lines, we find 7 schools with less than 6 lines, 17 schools with 6–10 lines, and only 2 schools with more than 9 lines. All together as expected, we see that the most central school locations have the best accessibility. However, in the outskirts, we expected schools to be less accessible. Apparently, this is not the case in the far south-east. The spatial structure of the public transport infrastructure results in a good accessibility for most of the schools (particularly in the south-east).
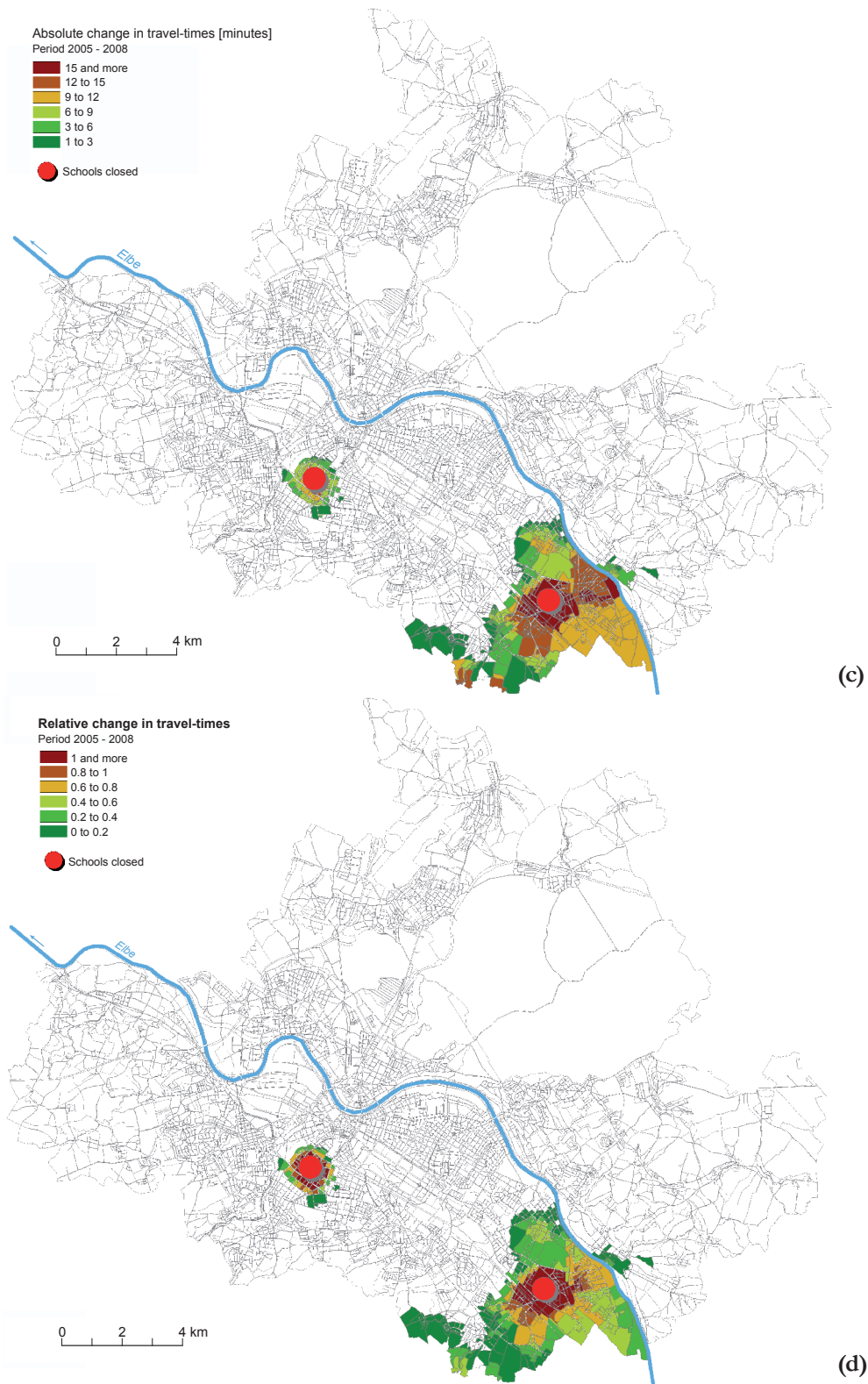
Absolute change in travel-times [minutes]
Period 2002 - 2005

- 15 and more
- 12 to 15
- 9 to 12
- 6 to 9
- 3 to 6
- 1 to 3

● Schools closed

Elbe

0   2   4 km

(a)

Relative change in travel-times
Period 2002 - 2005

- 1 and more
- 0.8 to 1
- 0.6 to 0.8
- 0.4 to 0.6
- 0.2 to 0.4
- 0 to 0.2

● Schools closed

Elbe

0   2   4 km

(b)

Fig. 5: Accessibility measure A$_i$: Absolute (a, c) and relative (b, d) change in public transport travel-times on commute to school for the periods 2002–2005 (a, b) and 2005–2008 (c, d). The numbers are the absolute and relative increase in travel-time to the closest school. The maps are displayed on census block level
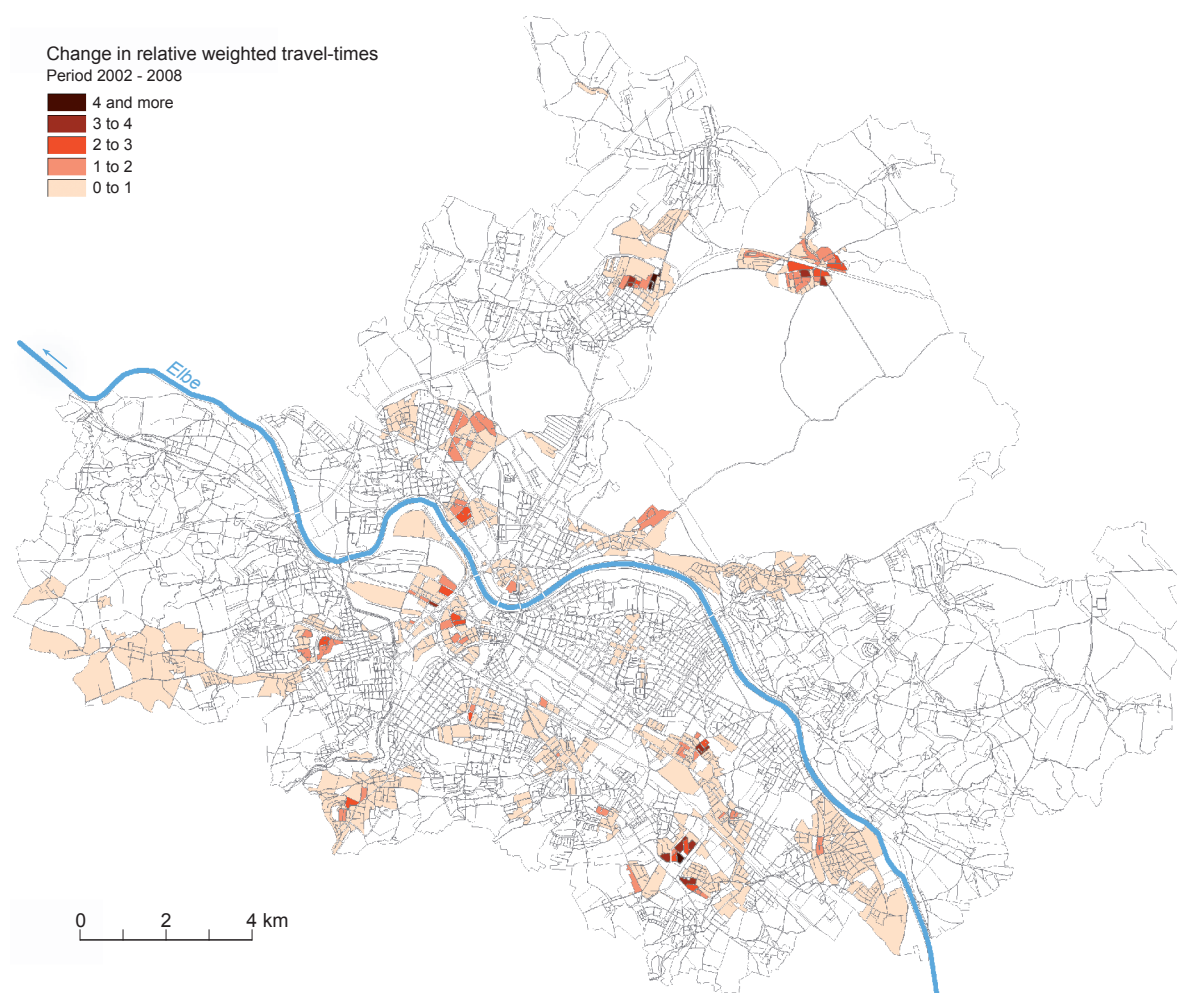
Fig. 6: Relative accessibility measure Ã$_i$: Change in travel-times to the closest school for the period 2002–2008. Travel-times are weighted by relative student numbers. The map is displayed at the census block level

Finally, we discuss a measure that employs an indicator function to exclude schools beyond a given travel-time T. Moreover, we consider the number of students per census block $i \in S$ if the travel-time from this census block to all schools open is less than T. The accessibility is measured as.

$$\Omega_i = L_i \,|\, (t_{ij} \leq T \quad \forall \, j \in Q) \tag{8}$$

In our study we set $T = 45$ minutes. The city council of the city of Dresden constitutes a maximum reasonable travel-time to Gymnasium-schools of 45 minutes (STADTRAT DER LANDESHAUPTSTADT DRESDEN 1997). The larger the student numbers of a census block $i \in S$ given that all schools $i \in Q$ are accessible within 45 minutes of public transport travel-time the larger is our measure Ω_i. This measure is an interesting supplement to the measures of section 5.1. Ω_i tells us

where we find a given number of students who are privileged in terms of their school choice set. That is, these students may choose a school from the full choice set of schools. Figure 8 shows the values of Ω_i for all blocks in the years 2002 (a) and 2008 (b). As a general pattern we see that accessibility in terms of availability of choice alternatives is spatially discriminatory. That is, the outskirts do not have students who are able to access all schools within 45 minutes travel-time. Moreover, if we consider the absolute change between year 2002 and year 2008 this discrimination becomes even more obvious (Fig. 8 (c)).

6 Conclusion

Demographic processes have yielded a dramatic decline in student numbers in most regions of eastern Germany during the period of 1992–
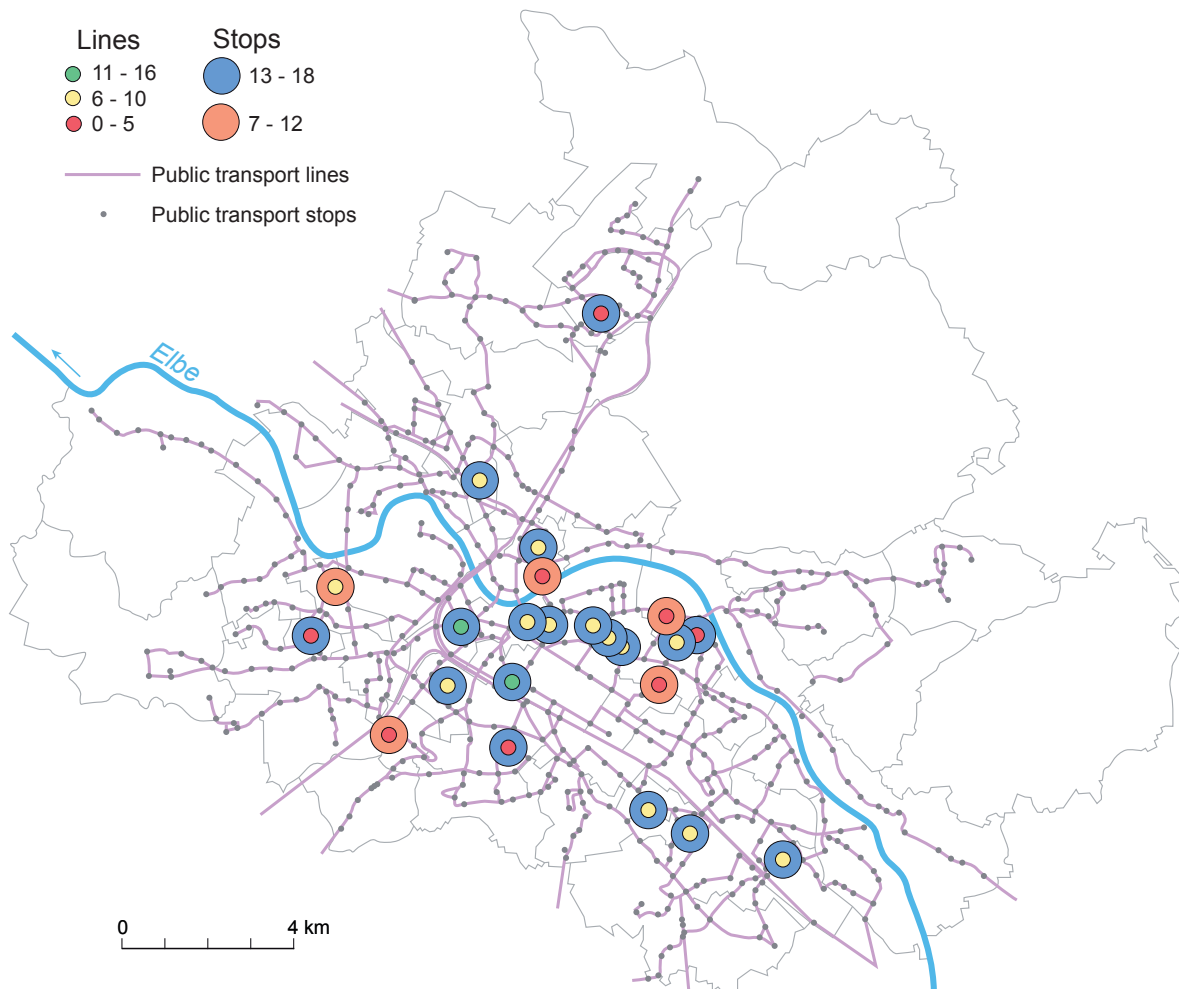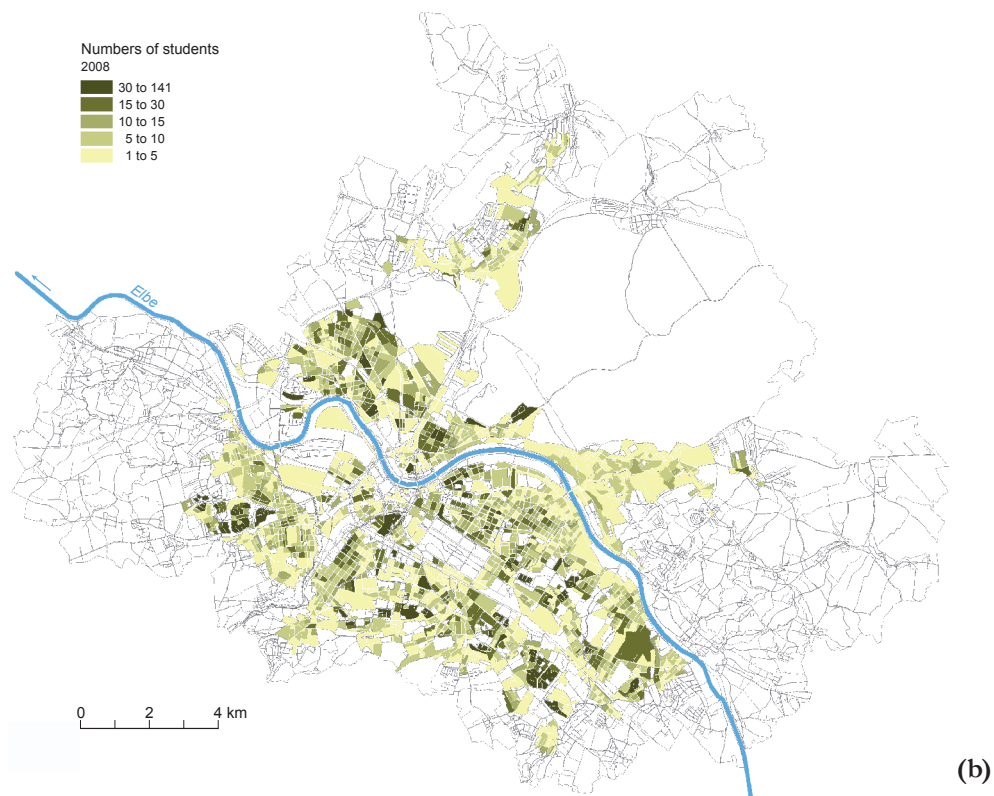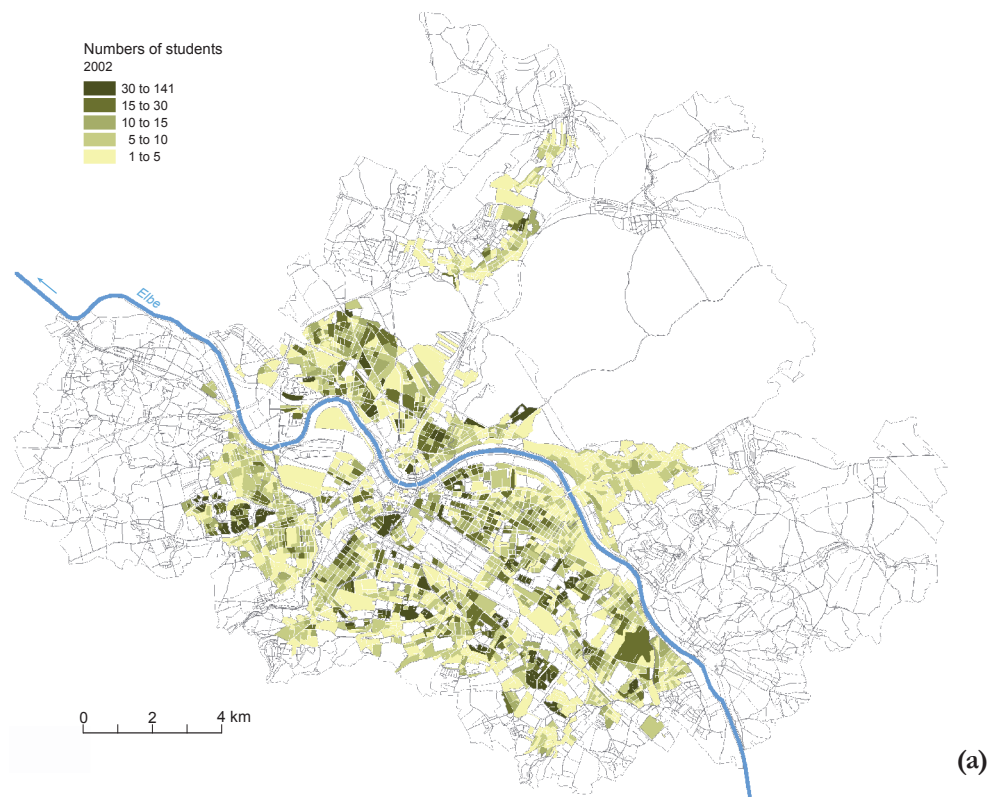
Fig. 7: Accessibility of Gymnasium-schools dependent on the access to public transport infrastructure in the period of 2002–2008. The number of stops within 800 meters arc radius is given. The number of lines given in the map depends on the number of lines serving the stops assigned to each school. The map is displayed on the city district level

2002. This in turn has led to a remarkable school consolidation of Gymnasium-schools in the time period 2002–2008. The question as to which school should be closed at a given point in time is a very difficult one. However, the political discussion about school consolidation in Germany lacks a complex and differentiated view. MÜLLER (2010) pointed out that this might be due to models and measures that are too complex. Therefore, we discuss rather simple measures of school accessibility based on public transport travel-times. We show how these travel-times can be computed efficiently. This is of particular interest for prospective applications in planning and for local authorities. We use a simple mathematical program and standard GIS procedures in order to measure whether access to schools is spatially equitable or discriminatory. Due to our analysis, we were

able to identify areas of service deprivation that need special attention. The measures presented here are straightforward and thus might be implemented in the planning process more easily than complex models and procedures.

The case study of school consolidation in the city of Dresden, Germany shows that areas that are located proximate to closed school sites are mostly affected by an increase in travel-time. Moreover, taking into account the number of students who are affected by an increase in travel-time to the closest school, we see that particularly outskirt areas are discriminated.

The demographic processes in eastern Germany are to be expected to take place in western Germany as well. Hence, it would be interesting to see, whether these (or other measures) will be implemented by educational authorities in the planning process.
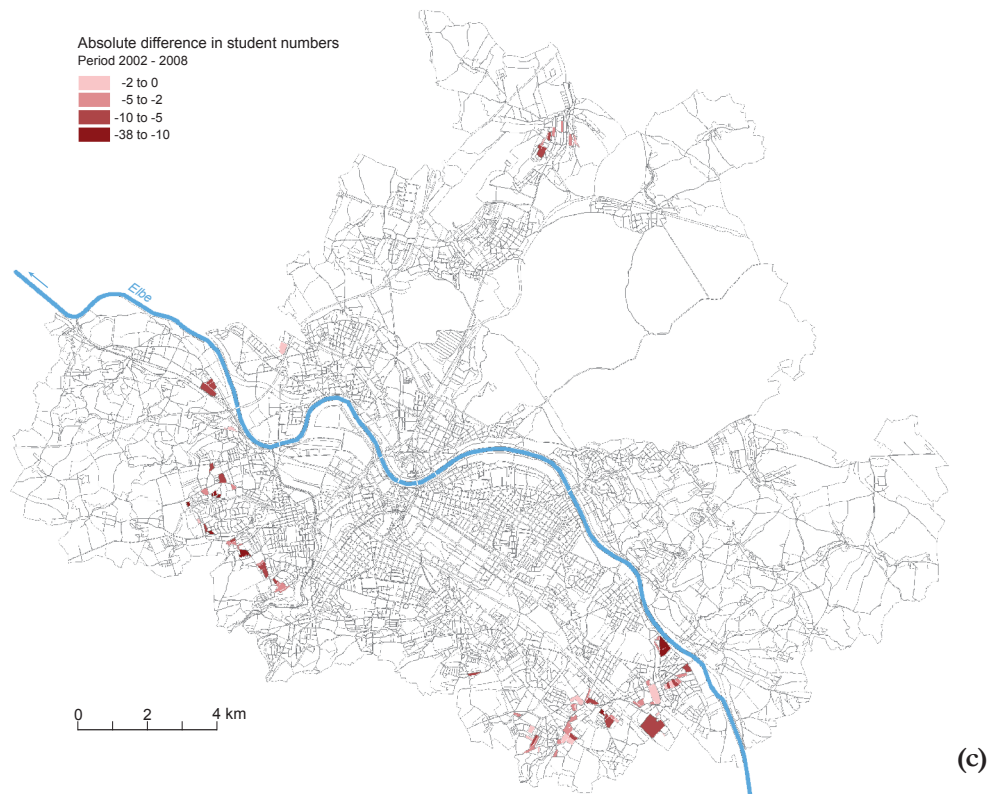
Numbers of students
2002

- 30 to 141
- 15 to 30
- 10 to 15
- 5 to 10
- 1 to 5

Elbe

0   2   4 km

(a)

Numbers of students
2008

- 30 to 141
- 15 to 30
- 10 to 15
- 5 to 10
- 1 to 5

Elbe

0   2   4 km

(b)

Fig. 8: Accessibility measure Ω_i: Number of students if travel-time to all schools open is less than 45 minutes. The absolute difference of Ω_i (c) between the year 2002 (a) and the year 2008 (b) is computed as min $\{0, \Omega_i^{2008} - \Omega_i^{2002}\}$. All maps are displayed on census block level

Acknowledgements

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