Modeling accessibility to schools: the case of Wallonia, Belgium

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Abstract: *Several recent studies about school mobility highlighted the significant decline of active modes and public transport's modal shares. Associated with this decline, it can be observed that distances between home and schools have been rising the last two decades. To develop appropriate policies alleviating the negative effects of the increased motorization in the school commute, a diagnosis of probable causes is required. To perform this diagnosis, we develop an accessibility-based methodology using data stemming from the Belgian national household travel (BELDAM) survey. Gamma-functions are calibrated to describe the use of different transport modes according to their relative travel times. Data from OpenStreetMap are used to describe the Walloon roads network in terms of the maximum allowed vehicle speed and length for each link. Properties of the network are modified to match with other transport modes. Maps of accessibility to schools are computed for each transport mode by merging the value of access time representing by isochrones and the calibrated gamma-functions.*

Keywords: "accessibility", "school", "gamma-function", "transport modes", "cartography".

1. Introduction

Accessibility is a complex notion directly depending on the locations of the origin and destination of trips, the socioeconomic profile of the travelers and the distance or time to realize these trips. It also concerns school mobility which is attracting increasingly more attention because of the environmental, social, health and safety externalities related to car use (Cools et al., 2009). Generally, scholar mobility and accessibility remain understudied in spite of the relevance of this field of study (van Goeverden and de Boer, 2013) and the impact on transport-system policy and management (Elias and Katoshevski-Cavari, 2014).

Although the large majority of mobility studies focus on work and recreational trips, the interest in studies focusing on school-related trips is increasing. A growing number of papers with school mobility defined as the main interest can be found in literature, especially from the perspective of mode choice. For example, it has been highlighted that mobility behavior acquired during childhood has an influence on mode choice by adults (Garcia et al., 1998; Underwood et al., 2014).

Several recent studies about school mobility highlighted the significant decline of active modes and public transport's modal shares (e.g. Singleton, 2014). This is also an observed phenomenon in the Belgian Walloon Region. Although public transport (bus and train) remains well used for school mobility in Wallonia, car use is rising despite the efforts to secure areas around schools (Cornelis et al., 2012). This may be related to a series of socioeconomic or cultural factors, but may also be due to territorial factors. It can for instance be observed that distances between home and schools have been rising since two decades (Beelen et al., 2009).

Designing adequate polices requires a diagnosis of the current situation. This paper focuses on the accessibility to maternal, primary and secondary schools in the Walloon Region, maps

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those accessibilities and highlights disparities throughout the territory for each different transport modes. To this end, we adopt a methodology based on the analysis of accessibility to services, initially designed by Thériault et al. (2003) in Quebec City. Thériault et al. proposed the utilization of a fuzzy logic approach for modeling accessibility. Their method allows to analyze mobility behavior of people and to relate people's sensitivity to travel time with service places location. Thériault et al. calibrated gamma-functions showing the number of trips according to the travel time of those trips, allowing the estimation of parameters, specific for each transport mode or group of travelers. Using the actual travel time for each person or household to different kinds of destinations as services, reveals the willingness-to-pay or to-commute of dwellers living in a defined territory. This approach leads to more comprehensive accessibility indices (Thériault et al., 2003).

2. Data and methodology

To develop the accessibility-based diagnosis framework, we use data stemming from the Belgian national household travel survey (BELDAM), collected in 2010 (Cornelis et al., 2012). Data from the trip diaries were used to determine the functions needed to describe accessibility. As first step, data were prepared by removing data inconsistencies (especially related to the transport mode) and by calculating the average speed. Values for the average speed were assigned to the different transport modes for which speed can vary across the travelers, the state of the chosen paths and along the entire trip length. Since it is impossible to determine the speed for each trip at each moment, we decided to adopt the average velocity determined using the Beldam survey data. The speed of bike and pedestrians was then defined as a fixed velocity of respectively sixteen and five kilometers per hour.

Explanatory analysis of the relationship between the frequencies of use of each transport mode and the corresponding travel times revealed that these relationships are best approximated using gamma-functions. Note that the latter type of functions was also calibrated by Thériault et al. (2003). A rounding phenomenon appeared in terms of time values: a peak in distributions was observed at each value being a multiple of five minutes. This rounding is due to a human behavior when estimating episodes of time: n-tuples of five minutes appear to be a threshold which people generally resort in the context of reporting travel times. For example, instead of reporting four, nine or sixteen minutes as travel time, five, ten and fifteen are respectively provided as answer in the survey. For this reason, travel time values were grouped into categories of five minutes to calibrate the gamma functions.

The theoretical gamma functions were matched with the observed distributions. Two equivalent MatLab functions were designed to achieve this goal. The first one uses the sum of squared distances. The second one uses correlation. The aim of the two functions is to minimize difference between the theoretical distribution and the observed one. Therefore, supposing x_i the travel time and z_i the frequency of use for a given time and a given transport mode as shown in the observed function, then the methodology to find the calibrated function consist in finding the minimum of the two following relations:

$$d_1 = \sum_i (f_{calibrated}(x_i) - z_i)^2$$

$$d2 = |1\text{-correlation}(f_{observed}, f_{calibrated})|$$

By this, we obtain the parameters of each gamma-function corresponding to each transport mode. A theoretical gamma-function corresponds to the following formula.

$$f(x) = \alpha * \frac{1}{\phi(k)} * \frac{1}{\theta^k} * x^{k-1} * e^{\frac{-x}{\theta}}$$

Another step was to investigate if the characteristics of the gamma-function according to the travel time were influenced by other parameters, one of them being the type of traveller making a trip. This allows the investigation of differences in travel behaviour (i.e. transport mode use) between the different types of travellers (socio-demographic profile). Furthermore, other factors can be investigated as well such as the urbanization of the home location (urban, suburban, rural) as well as the type of day when the trip was realized.

To confirm or nullify the existence of differences, we used a non-parametric approach, the Kolmogorov-Smirnov test. This test consists in the comparison of two distributions of values (e.g. the use of a particular transport mode for two different groups) by calculating the maximal difference between the corresponding values of the grouping variable as follows:

$$D_{1-2} = max_x |F_{1,n1}(x) - F_{2,n2}(x)|$$

Then, the critical values tables give the threshold, which must not be exceeded. If the associated p-value exceeds the chosen confidence level, the null hypothesis has to be rejected, and one can thus conclude that the two distributions are statistically different. In addition, we also used correlation to confirm or nullify the results of the first test. Based on the Kolmogorov-Smirnov test and correlation test, we then found that there are no gender differences in the relationship between travel times and car, pedestrian, motorcycle and bicycle use. In contrast, significant gender differences exist for public transport (both train and bus). Home location seems to have a slight effect for some areas and transport modes, different travel time distribution can be observed for trains, buses, bicycle and pedestrians. The day-of-week of the trip has only an effect on trains and bicycle.The parameters of the function for each studied transport mode, resulting from the calibration phase, are presented by Table 1.

Transport mode	Coefficient (α)	k	θ
Car	445,38	2,52	6,04
Pedestrian	419,27	2,67	3,65
Motorcycle	437,63	4,03	3,54
Bicycle	580,01	2,50	6,02
Train	493,16	4,62	14,70
Bus	497,08	4,21	7,69

Table 1 : Parameters for Different Transport Modes

Limitations arise for the calibration of the coefficients for train and bus. Corresponding networks don't completely cover the entire Walloon territory. Furthermore, some methodological challenges occurred. The first one concern the way to develop chains of transport modes: if the nearest bus stop or train station is located far enough from the school or home, it implies to add information about the travel time between home and departure bus stop or train station one the one hand, between arrival bus stop or train station on the other hand. Those parts of the trips chain can be realized by walking or by using another transport mode. The second one is the requirement to assign travel time for each section of the network and could be very time-consuming. This last problem becomes more complex if we have to distinguish different types of services: slow train, semi-express train, express train. Because of these methodological problems, we do not consider public transport in this paper.

Developing a sufficiently accurate network for car, pedestrian and bicycle is easier because it is based on the road network. This one deserve all schools. Vector data from these networks can be downloaded from the OpenStreetMap initiative. The database is associated with a shapefile representing roads containing different information about the type of each

road segment and the maximal allowed speed. Those two attributes are used to calculate travel time across the road network. For car transport, we used a raster representing the road network derived from those data. Each cell of the raster has the needed time to cross it as an attribute. Those values were calculated from the maximal allowed speed for each section. Some corrections were brought to the original network, as fixing the speed inside agglomerations at 50 kilometers per hour.

For bicycle and pedestrian transports, we assign fixed speeds to the entire network, respectively sixteen kilometers per hour and five kilometers per hour, values obtained by analyzing data from the BELDAM survey. We also took care to remove all road segments which were not passable for bikes and pedestrian, namely motorways and expressways. Obtained networks were transformed to grids. To avoid non-calculation of isochrones if a school was outside of the pixels materializing the network, we assigned a nonzero but very low value to all other pixels.

To figurate schools locations, we used a shapefile created from data provided by the Wallonia-Brussels Federation, which has education as competence. The address of each establishment was used to geolocalise them in the Belgian Lambert 1972 projection system. Those data were completed by the data of schools in the German-speaking Community of Belgium, which is the most eastern part of Wallonia. We then use ArcGIS to calculate isochrones around the different type of schools and the different transport modes. The "cost distance" function calculates travel time from schools representing by a shapefile of points to each pixel of the study area by summing the value of attribute, namely the needed time to cross the pixel, of all little squares. Some additional treatments allowed obtaining grids representing isochrones for the entire Wallonia, where travel time from schools to each pixel is given in minutes. The value of pixels represents the independent variable x of the gamma-function.

This way to process is not very accurate if used at small scale (e.g. at town-scale or neighborhood-scale), but does not form a problem in the present case. Each raster is imported in Matlab where a developed code using the gamma-functions calculates the corresponding value of the dependent variable. The results are then divided by the maximal one to obtain values of accessibility for each transport mode included between 0 and 1.

3. Results

The obtained maps then spatialize the values of accessibility of schools for each transport mode through the entire Walloon territory. The accessibility of maternal and primary schools, which are numerous and fairly homogenously distributed across the territory, is quite good as shown in

Figure 1 and Figure 24. Almost every municipality owns at least one maternal and/or primary school, often located in the municipality's core, so they can be easily reached by bicycle or walking. Each point of the territory is close enough to one school, especially in and near urban areas. However, the suburbanization phenomenon tends to develop housing outside the municipalities' cores, along the roads radiating from them. This has as consequence increased car use to reach the school, and thus create the challenge of ensuring good accessibility by alternatives to the car. This could explain the growth of car use for school-related trips as mentioned in the literature. The phenomenon surely deserves to be studied more carefully. Contrary to maternal and primary schools, secondary schools are less numerous and often located in urban areas. Areas of accessibility by alternatives to the car are less extended because of a greater distance to reach them (Figure 3)). We can thus suppose this generates a broader car or public transport use to reach secondary schools, especially from rural areas located in the south half of Wallonia (Figure 25).

Figure 1 : Accessibility to Primary Schools by Walking

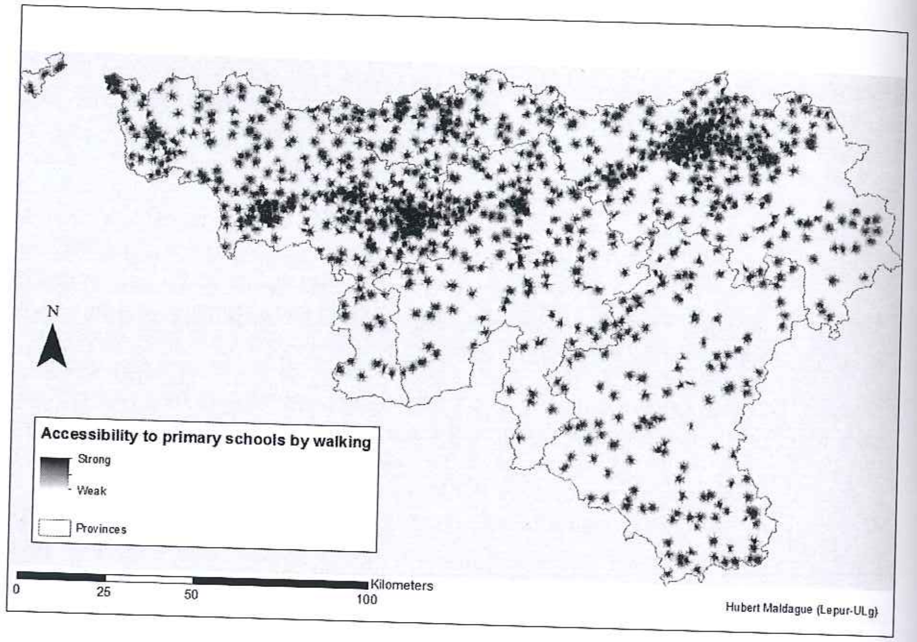


Figure 24 : Accessibility to Maternal Schools by Walking

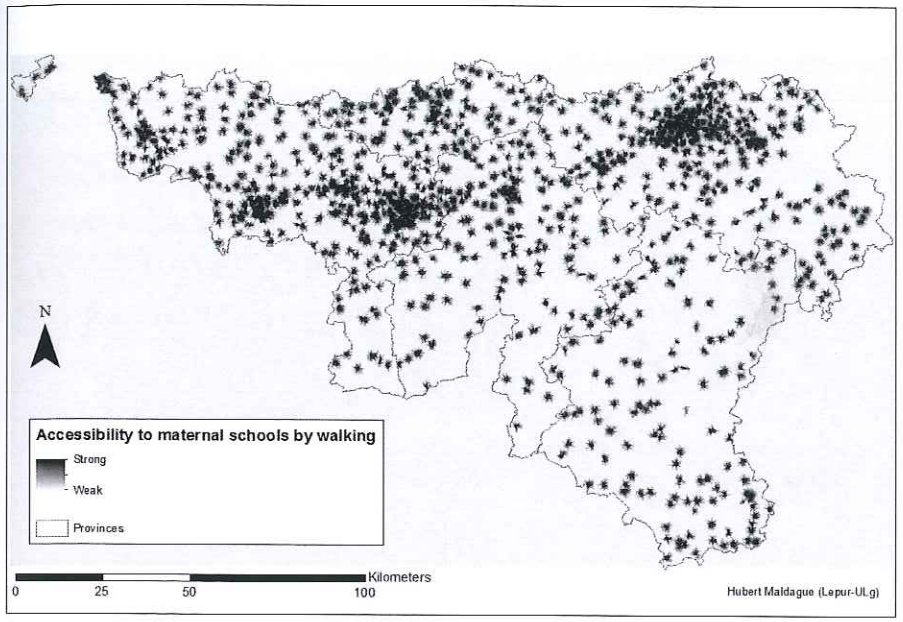


Figure 3 : Accessibility to Secondary Schools by Walking

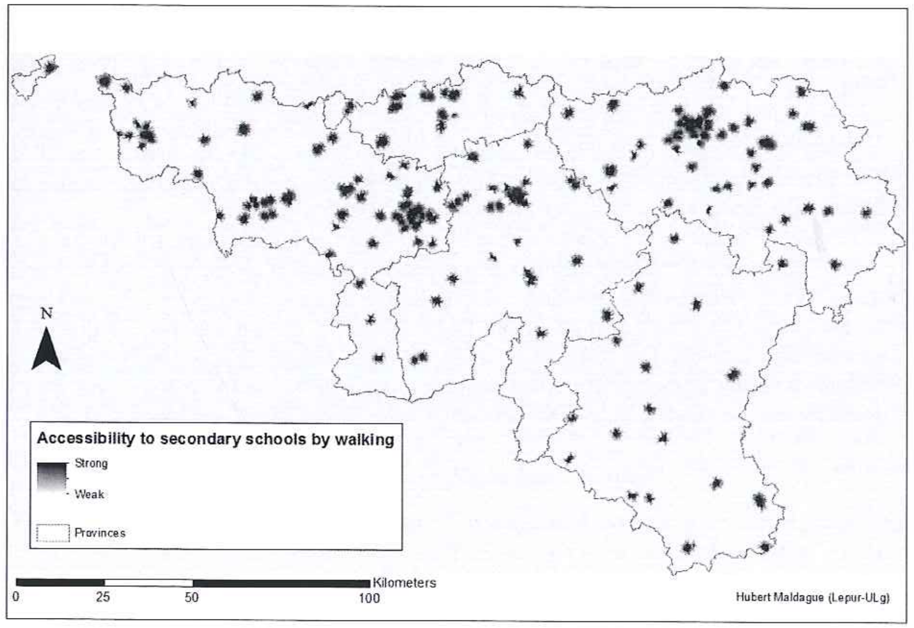
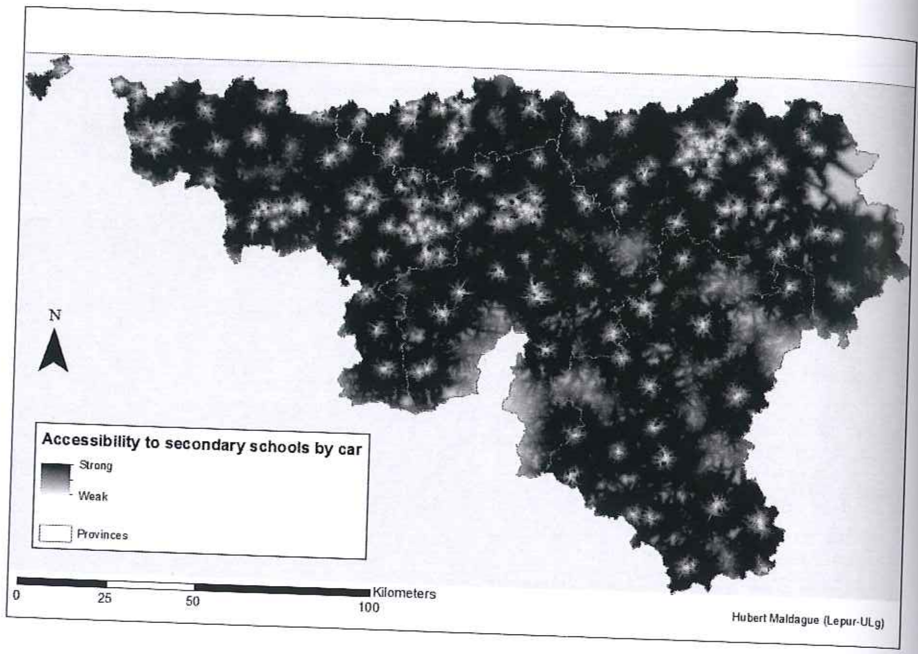


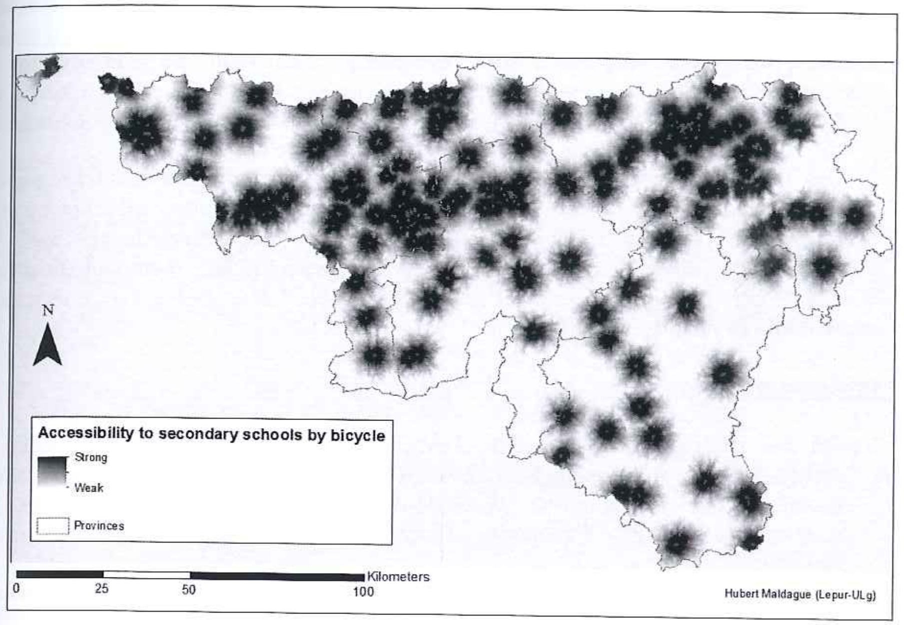
Figure 25 : Accessibility to Secondary Schools by Car



Some comments have to be raised about the distribution of accessibility values. The map for pedestrian accessibility shows a decrease of values in the immediate vicinity of schools. Two hypotheses can be formulated to explain this phenomenon: the relative low number of inhabitants just around the school and the underreporting of extremely short trips (respondents are likely not to report trips of just one of several minutes). A deeper analysis of the data set light on a rounding phenomenon of answers as explained before: respondents often round upwards of downwards to a multiple of five. In other words, respondents do not provide travel times of two or three minutes, but mention five minutes or do not mention at all their trips. This phenomenon can also explain the observed depression of accessibility values for schools for the other transport modes, but this is not the only explanation.

Another factor is the modal choice. When home is located near school, people prefer to walk. The benefit of time given by car's speed is cancelled by the time lost to find a parking space. When distance is a little more important, people prefer to cycle. This explains why the accessibility by car is less high in the first kilometers around schools. Figure 26 shows the accessibility to secondary schools by bicycle. Near schools, accessibility value is quite low because walking is more interesting. Values grow until some kilometers, and after decrease: travel by car, bus and train become obvious to win time and move faster.

Figure 26 : Accessibility to Secondary Schools by Bicycle



4. Criticisms, improvements and perspectives

Some criticisms can be developed about the present methodology, and suggestions of improvement are provided here. The developed modelling does not consider local factors which can influence frequency of transport mode's use. Steep slopes may discourage the use of bike or walking, as well as poor conditions or safety of the used road. Those characteristics have obviously an impact on the accessibility of the different transport modes.

Another criticism is that the travel times by car, calculated from the maximal allowed speed represent a perfect situation for which the road traffic is completely uncongested. Given the relative high congestion rates, especially in urban centers, car speeds are considerably overestimated, and correspondingly travel times underestimated. One improvement could consist of the inclusion of a factor representing road congestion encountered.

Data from OpenStreetMap aren't completely accurate and some information about maximal allowed speeds is missing. Similarly, speeds have been allowed in function of the type of road. Moreover, the network ignores some restrictions due to traffic laws, as one-way streets or pedestrian streets. This is not a problem when the study covers a wide territory, but it can become problematic when focus on a smaller area.

Finally, the model considers, for each type of schools, schools as being equal. One improvement could be the addition of a weight factor for each school as the number of students frequenting the scholar establishment.

Perspectives are quite numerous. One of them could consist in using the cadaster to calculate mean values of accessibility for each mode by using value observed at each house, aggregated at the municipal level for example. Date of construction could also be employed to highlight changes of accessibility values through time.

5. Conclusion

In this paper, we showed the possibility to model accessibility to schools and we developed diverse maps to spatialize this accessibility. Although several simplifications of reality were assumed, the results do provide some interesting information and pathways for regional planning. Indeed, literature has shown that car use for school-related trips keeps growing, leading to increased levels of congestion and increased consumption of energy. These problems must be solved in the context of sustainable development.

By using the framework as outlined in this paper, it can be determined what proportion of students is situated in easy access areas for different transport modes and it can be checked if new residential developments are well accessible by alternatives to the car. Although methodological add-ons and improvements are required, the methodological approach developed here provides a basis on which can be built for more accurate assessments of accessibility to schools in Wallonia.

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