From spatial to social accessibility:
How socio-economic factors can affect accessibility?

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Abstract

The concept of accessibility cannot only focus on "spatial accessibility" measurement but has to integer a "social accessibility" level to take into account individual inequalities and socio-economic disparities to access to urban opportunities. In this context, this contribution focuses on socio-economic disparities integration on accessibility measurement, considering the Lyon case study. The paper is divided into three parts

The first part aims to present a method for integrating the socio-economic dimension on accessibility measurement. The potential gravity-based access measure proposes a travel cost balanced by a sensitivity parameter. This parameter corresponds to the more or less travel cost resistance. This sensitivity value is obtained with a gravity-based transport model calibration from a household trip survey.

The second part focuses on the sensitivity value. It illustrates that the different sensitivity values can varies according to different factors like trip purposes but also and socio-economic factors. This contribution analyses how gender and socio-professional categories affect travel time sensitivity in the morning peak period. This empirical exercise at the Lyon agglomeration scale is based on a 2006 French transport survey called "Enquêtes Ménages Déplacements".

The third part presents cartographic impacts of differentiated travel cost sensitivity on accessibility results considering the Lyon metropolitan area. Social accessibility results, linked to the population distribution according the socio-professional categories, highlights areas with a gap between perceived and offered accessibility level.

Key words : social accessibility, spatial accessibility, travel time sensitivity, transport model calibration, Lyon metropolitan area.

1. Introduction

Facing the challenges of "sustainable mobility paradigm" (Banister 2008), local transport policies should not only achieve economic growth (economic challenge) and urban development in a sustainable point of view (environmental challenge) but they also have to satisfy the growing need for mobility. In this context, the concept of accessibility merits further use considering both spatial and social perspectives.

The spatial dimension refers to the organization of space and especially the location of individuals (or households) and activities (jobs, services, shops, leisure facilities, etc.).

Accessing opportunities is a source of satisfaction for individuals. Many studies have focused on measuring accessibility to guide public decision-making or to evaluate transport policies and regional planning considering only a spatial level. Research on accessibility in urban areas distinguishes two main scales (Kwan and Weber, 2008): the metropolitan scale which aims to integrate changes in urban structure with the development of polycentric towns, and the local scale which is concerned with accessibility in town centres. These two scales differ in the range of possibilities (work, leisure, etc.) available to individuals but they also show a different transportation – regional planning pair.

All these studies considers accessibility to urban or regional opportunities using a given transportation system. Nevertheless they don't take into account individual, social combined to geographical constraints. Papers on accessibility often analyze impacts of a new transport policy or infrastructure an spatial access assuming a "standard" individual only differentiated of other by its location. To surpass the weakness of the spatial approach, it appears necessary to integrate social heterogeneity in accessibility measurement. The approach of "spatial accessibility" measurement referring to attractiveness of locations, should be coupled to "social accessibility" index. This combined accessibility index aims to take into account individual inequalities and socio-economic disparities to access to urban opportunities.

Considering the Lyon case study, the objective of the paper is to highlight the interest to conduct a cross accessibility analysis from spatial to socio-spatial dimension. The methodology is based on a job gravity-based accessibility measure associated to a transport model and a Geographical Information System.

The first part aims to present a method for integrating the socio-economic dimension on accessibility measurement. The potential gravity-based access measure proposes a travel cost balanced by a sensitivity parameter (often called the Beta parameter). This parameter corresponds to the more or less travel cost resistance. This sensitivity value is obtained with a gravity-based transport model calibration from a household trip survey.

The second part focuses on the sensitivity value. It illustrates the different sensitivity values can varies according to different factors like trip purposes but also and socio-economic factors. This contribution analyses how gender and socio-professional categories affect travel costs and travel distances sensitivity in peak and off-peak periods. This empirical exercise at the Lyon agglomeration scale is based on a 2006 French transport survey called "Enquêtes Ménages Déplacements".

The third part presents cartographic impacts of differentiated travel cost sensitivity on accessibility results considering the Lyon metropolitan area. Social accessibility results, linked to the population distribution according the socio-professional categories, highlights areas with a gap between perceived and offered accessibility level.

2. Integration of socio-economic disparities in accessibility measurement

Accessibility is a central concept in the context of evaluating transport projects for urban environments. A definition of accessibility, in its accepted meaning, is given by Morris *et al.* (1978). Accessibility expresses the ease with which activities can be reached given a starting point and a transport system. The concept of accessibility thereby goes beyond the framework of the transport system and its purely temporal dimension, associating it with a spatial dimension. The notion of travel and of time which accompanies it is complemented by a notion of density and space. Accessibility should, then, reflect the spatial organization and the quality of the transport system that provide individuals (alone or in groups) with the opportunity to participate in activities located in different parts of the region (Geurs and Wee, 2004).

Many studies have focused on measuring accessibility to guide public decision-making or to evaluate transport policies and regional planning. Few of them have used accessibility as a tool to analyse social individual inequalities and socio-economic disparities to access to urban opportunities.

a) A Gravity-based accessibility indicator to measure social disparities to urban opportunities

This paper develops a gravity-based measure (also classified as potential accessibility measure) to measure social disparities to urban opportunities. This measure is based on the idea that the distribution of traffic between areas depends on the "attracting masses" of each area and the difficulties of connections between the centroids (Bloy *et al.*, 1977). The accessibility measure is expected to increase with the increase in the opportunity measure and to decline the farther the opportunities are from the origin (El-Geneidy and Levinson, 2006).

Gravity-based accessibility takes the following form:

$$A_i = \sum_j D_j e^{-\beta C_{ij}}$$

where A_i is accessibility from zone i, D_j the opportunities available in zone j, *β* a parameter reflecting the sensitivity to the generalized cost of travel, and C_{ij} the generalized cost of travel between areas i and j.

In this paper, accessibility from zone *i* to jobs located at zone *j* depends on the number of jobs in j and the cost between these two zones. Transport generalized costs is given as follows:

$$C_{ij} = Cm_{ij} + T_{ij} * VdT$$

With

- C_{ij} the generalized cost between zones *i* and *j*
- Cm_{ij} the monetary cost depending on distance between zones *i* and *j* and on average cost per kilometer (including fuel, maintenance and insurance costs)
- T_{ij} the travel time between zones *i* and *j*
- VdT the value of time defined according to the value determined by the French government for urban trips.

Major disadvantages of gravity-based measures are listed below:

- over-valuation of areas with high internal potential. In considering large areas, one runs the risk of giving too much weight to internal opportunities and, as a result, heavily weighting areas with high internal potential.
- not taking into account individual characteristics produces a single value for all individuals of a given area, regardless of individual characteristics (Ben-Akiva, Lermann, 1979 and Dong *et al.*, 2006).

- the need to develop an impedance factor appropriated to the perimeter (El-Geneidy and Levinson, 2006). Coefficients already estimated for regional transportation planning models are often used.

Considering the weaknesses of the gravity-based accessibility measures, it seems difficult to use this indicator to take into account social dimensions. Nevertheless this paper proposes to introduce both travel cost sensitivity precisely estimated for the appropriated case study and a detailed spatial division.

b) The travel costs sensitivity parameter

The gravity-based accessibility measure is balanced by an impedance factor, called in this paper the Beta parameter. This parameter corresponds to the more or less travel cost resistance, a kind of willingness to commute.

The value of the impedance factor is obtained during the model calibration stage. In a "four-step model" procedure, the calibration consists in "estimating the values of various constants and parameters in the model structure" (Edwards, 1992). More precisely, it consists in the model parameter adjustment "until the predicted travel matches the observed travel within the region for the base year" (Wegmann, Everett).

The observed travel behaviors are usually obtained from the households surveys. In our study, the Household travel survey made on the Lyon metropolitan area in 2006 is used to estimates trip behaviors. It proposes a sample of 11230 households, 27573 individuals making 96250 trips. It also provides socio-economic data like household size, automobile ownership, profession or income group. The predicted travels are determined using the French census with the following data: total population, people in employment, students, men, women…..

Model calibration is performed making a comparison between the length of trips made on the Households survey perimeter and mean trip lengths by trip purposes, traveler genders or traveler profession. A logic function ($f(U) = e^{cU}$) is used for the calibration stage, with c the impedance parameter and U the travel time. The choice of a logit function is explained first by the fact that gravity-based accessibility measure is a logit function and then to compare our results with similar results presented in the literature for other studies.

c) A detailed spatial division

A high level of disaggregation is needed to to fit both to planners' and policy makers' interest (Holl, 2007). As presented by Crozet and al., 2011, "accessibility is affected by the spatial partition in units of analysis. Distances and travel time computations strongly depend on zone centroid locations. The more the metropolitan area is divided in detail, the more precise access results can be expected. However, the units of the analysis need to be reasonable and their size can vary according to the density of opportunities: while in CBD spatial partition has to be very detailed, an increasing size of the analysis units to the urban and suburban outskirts usually is more appropriate."

3. Trips and socio-economic features impacts on travel cost sensitivity

The impedance factor can be estimated for different trips according transport mode or purposes but also for various categories of population. The time sensitivity decreases with the β value. The less sensitive individual are, the more they are ready to support high travel times

In a previous study, such a model calibration at the Lyon metropolitan area level has been made according to different trip purposes (see Figure 1).

Purposes*	β (full day)	β (morning peak hour)
HBW	0.21	0,18
HBO	0.35	0,37
NHBO	0.34	0,43
NHBH	0.25	0,46
NHBW	0.26	0,09

Figure 1 : Time sensitivity for different trip purposes (Bonnafous et al, 2010)

* Home-based work (HBW), Home based other (HBO), Non-home based other (NHBO), Non-home based home (NHBH) and Non-home based work (NHBW).

Impedance factors vary both according to trip purpose but also according to the period of the day. Time sensitivity is lower for travelling to the work place than to other places, whatever the period of the day. Indeed, in the Lyon metropolitan area, people in employment are more reticent to make a long daily trip for a non-constraint purpose or to find an opportunity that can have close to their home like shops or leisure places. In fact, it seems as if people make a choice between the growth utility they benefit from their home and their workplace location and the disutility generated by their daily home-based work trips. They agree to support higher travel times to live or to work where they've decided. Travel time is no more always considered as a waste of time but also as an opportunity to realize other activities.

For non-work trip destinations, travel time sensitivity is higher in the morning peak period than during the full day. It means they prefer postponing non-constraint trips into off-peak periods and avoiding road congestion, conversely to work trips.

Following this simulation on trip purposes, we propose now to focus on the different categories of population using gender (see Figure 2) and socio-professional features (see Figure 3) both for all trip purposes and for home-based work trips.

Gender	β (all trip purposes)	β (HBW trips)
Women	0,244	0,13
Men	0,297	0,18

Figure 2 : Time sensitivity according to genders

At first sight, time sensitivity results according to gender can be surprising. Women are less sensitive than men to travel time. This result contradicts those proposed by Johannson et al. (2002) for 30 municipalities in Sweden where women are more sensitive to men. Nevertheless, they compare simultaneously gender and educational levels. Therefore, if for the same educational level, a woman is more sensitive than a man, it doesn't mean that all women are more sensitive than all men. In the Swedish study, a "female with high education" is less sensitive than a "male with low education".

At the Lyon metropolitan area level, results presented in Figure 2 can be explained by two reasons. First, women make longer trips than men mainly because they often make accompanied trips, with children for example. As note by Motte Baumvol (2011) for the Paris region « *women are more sensitive to their spouse's working hours than men. Women's probability of chauffeuring children increases with their spouse's duration of employment, while this is not the case for men. Thus women still tend to do more chauffeuring than their spouses*". Then, women tend to devote more time than men to home-based work trips either because they are working further than men, either because they often resort public transport

if they live a in dual-earner family. In Paris region, 46.4% of working women (Versus 36.3% of men) use public transport for their home-based work trips. In other French regions, the rate is 6.3% for women versus 4.8% (Insee - SOeS, ENTD 2008).

Labor categories	β (all trip purposes)	β (HBW trips)
Farmers	0,35	0,26
Skilled workmen	0,3	0,22
Workers	309	0,19
Employees	0,34	0,23
Mid-management position	0,308	0,19
Managers	0,29	0,16

Figure 3 : Time sensitivity for different labour categories

Travel time sensibility gaps between labor categories are interesting to analyze. Sensibility varies according two dimensions: both the labor category and the trip purpose. The "hierarchy" between labor categories seems to be respected if we refer to Johansson and al. 's results (Johansson, 2002). The sensitivity is lower the higher the social status is. In the Lyon metropolitan areas, the Managers are ready to support the highest travel time costs while farmers are the most sensitive to travel time. Nevertheless, the distinction between categories is not really clear mainly for "intermediate" labor categories like "skilled workmen", "workers", "employees" and "middle managers". Gaps are more significant when focusing on home-based work trips. Whatever the labor category considered, individuals are less travel time sensitive for HBW trips than for all trip purposes. As previously, the net utility got a lot of HBW trips is higher than for taking all trip purposes together. People in employment are even less travel time sensitive since the growth utility associated to the trip is high. Note that the sensitive value for the employed population is estimated to 0.18 for HBW trips.

4. Illustration: cartographic impacts of differentiated travel cost sensitivity on accessibility results

As presented in the previous sections, in gravity-based accessibility measures, the transport generalized cost in balanced by an impedance factor representing the sensibility to travel time (section 2). This parameter can vary according travel purposes or traveler socio-economic features (section 3). This section presents impacts of differentiated travel costs sensitivity on accessibility results considering accessibility to jobs located on the Greater Lyon area (the central part of the metropolitan area). Accessibility to jobs without differentiated travel costs sensitivity is compared with accessibility results integrating differentiated travel costs sensitivities for the different zones of the study area.

a) Methodology for accessibility computation

Considering the accessibility to jobs, travel time sensitivity is computed using the employed population distribution according to the different labour categories. The Lyon metropolitan area, our case study, is divided into 4344 zones called "micro-zones". The Central Business District divided into 1,272 squares of 250 meters side. Suburbs are divided into 2,291 squares of 500 meters side and then suburban part is divided into 781 squares of 2 kilometres side. Such a detailed spatial division minimizes impacts of internal opportunities on accessibility results (Gutierrez and *al.*, 2010 and, Frost and Spence, 1995). For each of the 4344 zones, the impedance factor (i-e the Beta parameter) associated to the different labour categories is balanced by the number of employed population of each labour category. As presented in presented in Figure 3, we consider six labour categories with farmers, skilled workmen, workers, employees, mid-management position and managers.

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For each zone, the Beta value takes the following form:

$$\beta_i = -0.26P_{Farm} - 0.22P_{Workmen} - 0.19P_{Worker} - 0.23P_{Empl} - 0.19P_{Mid-man} - 0.16P_{Managers}$$

With

β_i, the sensitivity parameter value for zone i (with *i=1, …, 4344*),

P_{Farm} the share of farmers in employed population, and respectively for skilled workmen, workers, employees, mid-management position and managers.

Note that we consider only employed population. So, for each zone we have :

$$P_{Farm} + P_{Workmen} + P_{Worker} + P_{Empl} + P_{Mid-man} + P_{Managers} = 1$$

In France, no statistical data concerning level of jobs are available at our spatial division into 4344 zones. Therefore, we consider job data provided by the French national institute in charge of statistics at the Iris level (an infra-municipal level considering areas of 2000 inhabitants). We assume an equal distribution of employed population into micro-zones located in the same Iris area. Note that some Iris areas are only devoted to industrial or agricultural activities. For them, the sensitivity value is "0" and accessibility to jobs is no computed.

Impacts of a differentiated travel time sensitivity is illustrated considering a gravity-based accessibility to jobs during the morning peak hour, using private car. Road congestion levels are considered. Indeed a transport model has been developed to improve as a remedy to the lack of available road traffic data. Using the VISUM, travel time computations by car considering socio-economic data and transport networks network.

b) Results

Figure 4 illustrates accessibility variation following the introduction of a differentiated travel time sensitivity. It refers to a variation of accessibility from each zone of the study area to jobs located on the Greater Lyon perimeter. At the Lyon metropolitan area scale, we observe a decrease of 2% of accessibility to jobs. Nevertheless we can note that all zones are not uniformly affected by the same decrease level. Results are impacted by employed population socio-professional structure: the manager share is higher, the lower the sensitivity value and the lower the accessibility decreases. White areas are those which are devoted to industrial or agricultural activities. At first sight, it can be surprising to observe that no zone benefit from differentiated travel time sensitivity. It means that no zones is populated by a high share of managers –with the lowest level of travel time sensitivity- sufficient to compensate the higher sensitivity of other socio-professional categories. If managers generate a high level of trips (and therefore tend to make the Beta value decreasing), they only represent 14% of employed people.
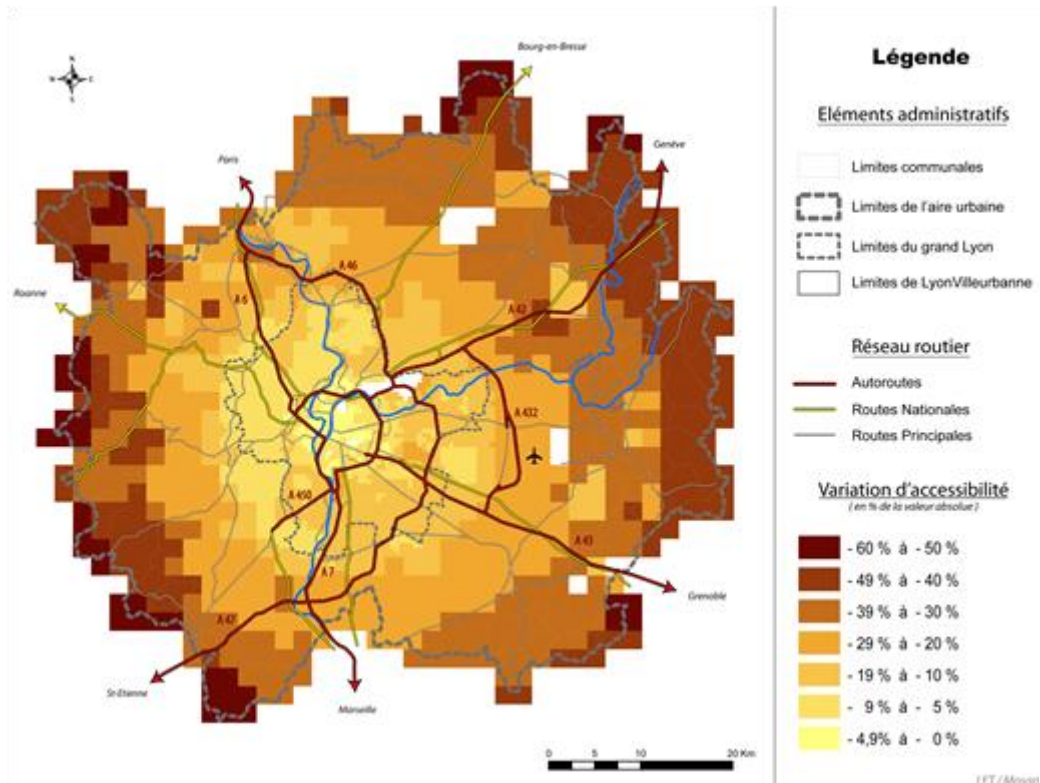
Figure 4 : Gravity-based accessibility variation integrating differentiated travel time sensitivity

5. Conclusion

This contribution aims at developing accessibility indicators in order to consider bother spatial and social accessibility. Using the travel time sensibility parameter, socio-economic criteria can be integrated into the accessibility dimension.

The general objective of this paper is not to assess various transportation projects but more to present the combined integration of socio-spatial dimensions into accessibility measure. It aims to improve "traditional" accessibility measures and to enlighten public decision makers. Therefore this contribution proposes to balance the travel cost by a sensitivity parameter varying according to individual socio-economic features and using the gravity-based transport model calibration. The application, based on the Lyon metropolitan area in 2006, underlines that sensitivity is lower the higher the social status is. Managers are ready to support the highest travel time costs while farmers are the most sensitive to travel time. Cartographic impacts of differentiated travel cost sensitivity on accessibility results highlights areas with a gap between perceived and offered accessibility level.

In spite of various composite accessibility indicators assets, they have also major limits linked to their implementation and interpretation. Composite and complex accessibility indicators will integer all space-time dimensions but won't be easy to analyze. Public decision makers often prefer more simple indicators with an easy interpretation non subject to controversy into public debates.

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