A SMALL-SAMPLE APPROACH TO MEASURE ACCESSIBILITY FOR LOCAL SERVICES: A CASE STUDY TO PHARMACIES

Vasconcelos, A.S., Instituto Superior Técnico, Technical University of Lisbon, Lisbon, Portugal

Farias, T.F., Instituto Superior Técnico, Technical University of Lisbon, Lisbon, Portugal

Levine, J. Taubman College of Architecture & Urban Planning, University of Michigan, USA

ABSTRACT

This paper intends to define a methodology for the estimation of accessibility indicators for non work destinations, considering a local scale (trips within a distance lower than 2 km), including not only internal costs (time or distance) but also external environmental costs (energy consumption, CO_2 emissions and local pollutant emissions).
The methodology for accessibility estimation is based on four steps: measurement of individual accessibility, for a given mode, from origin to a pre-define destination; estimation of the cumulative accessibility for different destinations for each mode individually; estimation of the cumulative accessibility of all transport modes based on modal split information and calculation of external cost of accessibility for motorized modes (energy consumption, CO_2 and local pollutant emissions). A preliminary test case to evaluate the accessibility to pharmacies in Lisbon was developed in order to demonstrate de applicability of the developed methodology.

Keywords: accessibility, indicators, emissions, energy consumption

INTRODUCTION

There has been a notable growth in research activities concerning estimating accessibility indicators in opposite to mobility indicators. The differences between accessibility and mobility only recently have become duly addressed. Accessibility can be defined as the "ease of reaching destinations", as opposed to mobility, which is the "ease of movement" and can have opposite impacts (Levine and Garb, 2002). It is possible to have good mobility and poor accessibility at the same time, like, for example, in a zone with great offer of roads, low levels of congestion but also with low desirable destinations available. Thus, when looking from an accessibility point of view, the focus is on the ends rather than the means and on the traveller rather than the system (Handy, 2005). Based on this consideration, 3 main objectives were defined for the present study:

- Development of a new methodology for accessibility estimation based on a small-sample approach (accessibility curves and global value integrating all destinations and transport modes available) for local scale studies (short trips);
- Development of a methodology that integrates environmental costs in a global accessibility indicator, applied to local scale;
- Application of the methodology to a preliminary case study in Lisbon, in order to demonstrate de applicability of the developed methodology.

State of the art

Research activities concerning estimating accessibility indicators usually focus on a regional scale and consider cost as the main variable (Handy, 1992; Apparicio et al, 2008; Guagliardo, 2004; Apparicio et al, 2007, Liu and Zhu, 2003, Hilber and Arendt, 2004, Koening, 1980).

There is no consensus on accessibility definition and different concepts have been accepted in the last years, namely: "the amount of effort for a person to reach a destination", "the number of activities which can be reached from a certain location" (Geurs and Eck, 2001), "the potential for interaction" (Hansen, 1959) or "an ability to get what one needs, if necessary by getting to the places where those needs can be met" (Handy, 2005).

Geurs and Eck (2001) define three possible perspectives on accessibility measurements:

- **Infrastructure-based accessibility measures**: based on the performance or cost of the transport system. Examples of this type of measurements are journey times, congestion and operating speed on the road network.
- **Activity-based accessibility measures**: based on the distribution of activities in space. This measure can be split in more detailed categories:
    - <u>Distance measures</u>: defined as the degree to which two places are connected (Ingram, 1971). Examples of these measurements are the maximum travel time or distance to a destination.
    - <u>Contour measures</u>: represents the number of opportunities reachable within a given travel time or distance. The accessibility increases if more destinations can be reached in the time-space frame. Examples of this measurement are: number of opportunities accessible within a time-space-cost frame; average (or total) time or cost required to access a fixed number of opportunities and the average (or total)

number of opportunities available within a time-space-cost frame over the population.

- Potential accessibility measures: based on the potential of opportunities for interaction. This measure is based on a gravity model and estimates the accessibility of opportunities of one zone to all the others where fewer or more distant opportunities have lower influence. Hansen (1959) was the first author using this type of measure of accessibility estimation and after that it has been a reference.
- Accessibility measures from space-time geography: considers time and land-use component with equally importance. Accessibility is estimated from the point of view of individuals.

- **Utility-based accessibility measures**: based on the benefits for people from access to the spatially distributed activities. This measure interprets accessibility as the outcome of a set of transport choices.

The meaning of this accessibility measures or indicators is not easily understood. An increase in this indicator (in comparison to one initial situation) indicates that the individual considered will probably find, in the new situation, a destination which can be more attractive, or at a short distance or travel time, or both, than previous (Koening, 1980).

Energetic and environmental effects are not usually taken into consideration (Koening, 1980, addresses the issue without quantifying these effects), however, in a decade where Kyoto Protocol (and recently Copenhagen conference) is an important issue, this costs should always be considered when analyzing accessibility.

METHODOLOGY

The objective of the present research is to define a methodology for estimation of accessibility in a local scale (trips within a 2 km range) considering three main stages: in the first one only walking accessibility is measured; in the second step the walking accessibility is complemented with the accessibility of using private car and finally external costs of energy and environment (CO_2 and local pollutants emissions) of accessibility are incorporated.

The methodology for accessibility estimation considered 4 steps:

- Measurement of individual accessibility, for a given mode, from origin to a pre-define destination
- Estimation of the cumulative accessibility for different destinations
- Estimation of the cumulative accessibility of different transport modes
- Calculation of external cost of accessibility (energy consumption, CO_2 and local pollutant emissions)

Measurement of individual accessibility for a given mode

• *Walking mode*

The walking accessibility curve was built considering a decrease function that could represent de decay of accessibility with distance. In this paper, an inverse logistic function was considered (Martinez, 2009, Koening, 1980, Geurs, 2001), with the equation:

$$Y = \frac{a}{1 + bc^{-x}} \tag{1}$$

Where y is the walking accessibility, x is the distance and a, b and c are constants calibrated with data from surveys made to visitors to local destinations using the method of least squares, minimizing the difference between the curve values and survey data.
With the purpose of evaluating the potentialities of the present methodology, a small sample survey was performed in pharmacies in Lisbon centre, with a total of 122 surveys, with 77 users of walking mode.

The accessibility curve obtained for walking mode is represented in Figure 1.

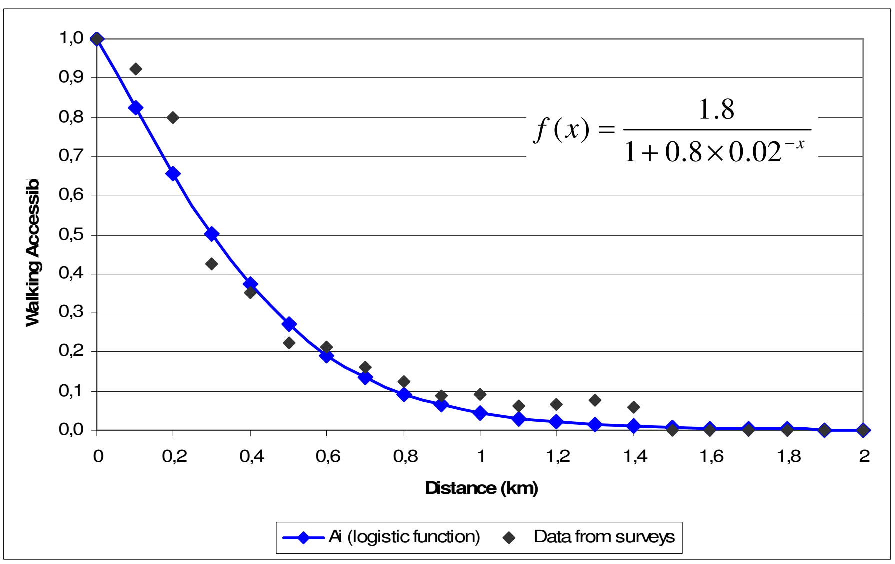

Figure 1 – Accessibility function for walking mode

The walking accessibility curve has an accented decay for lower distances and for distances higher than 1 km the value of accessibility is close to zero. Higher sample of surveys could translate a better logistic curve, namely for short range accessibility values (distance < 250 m), where the difference between our logistic curve (around 0,65) and surveys data (0,8) is ca. 20%

• *Private car*

The methodology for private car accessibility curve is presented in this paper as a proof of concept to demonstrate the possibilities of this methodology, since the sample size of data collected from surveys for private car users was very limited (total of 22 users). Nevertheless, an accessibility curve for cars was built based on the same logistic curve used for walking and calibrated with the data collected, as represented in Figure 2.

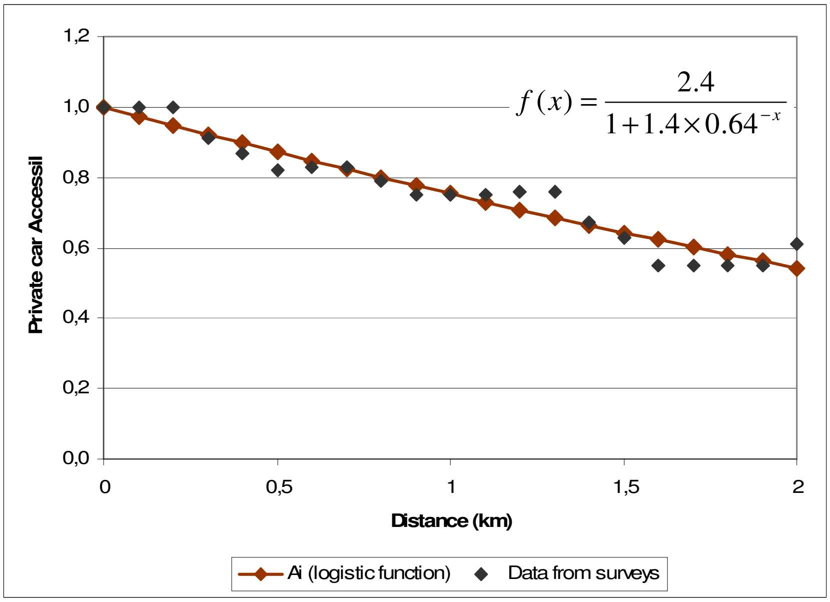

Figure 2 - Accessibility function for private car mode

For car accessibility the design of the curve also decays with distance (as for walking mode), although with a lower slope, representing that users are less influenced by distance when they choose to drive to the destination.

However, when considering private car use, the total trip time is an addition of different events that increase this time, namely:

- time from the origin to the car,
- average time to find a parking space,
- time lost to park,
- time as a pedestrian, walking from the parking space to the destination

Considering that different zones can have different parking characteristics (as an example, historic centres will presumably have more parking pressure than a residential area), three different scenarios were defined, corresponding to a specific time lost in searching for a parking space and an assumed distance from the parking space to the final destination, as pedestrian (the authors assumed that in areas with low pressure for parking, the time spent finding a space to park is negligible). Table 1 resumes the characteristics of the 3 scenarios defined based on values from Lisbon Mobility Plan and Polak *et al*. (1990).

Table 1 – Scenarios for parking pressure

Scenarios	**Parking search time (min)**	**Average distance between parking and destination (m)**
Low demand (eg.: residential areas)	0	25
Intermediate	5	125
High pressure (eg.: historical centres, city centres)	10	250

For the estimation of total accessibility of car users, the additional time is converted into an equivalent distance (using the average speed for cars) and added to the driving distance. Additionally, the distance walked (see Table 1) is used to calculate the accessibility as a pedestrian using the methodology presented previously for walking mode and applied as a penalization to the car accessibility using the equation:

$$A_{car\ total} = A_{car} \times A_{walking} \qquad (2)$$

When considering car accessibility, additional rules need to be created, namely, if the distance as pedestrian for car users is higher than the total walking distance to the destination, car accessibility value should not be considered for the total accessibility of one zone.

Finally, the curves shown in Figure 1 and Figure 2, represent the individual accessibility from origin i to destination j. In order to calculate the total accessibility of one neighbourhood (representing the origin zones) a methodology for adding different available destinations accessible from that zone was developed.

Sum of accessibility of different destinations

Two different methodologies were developed and compared, both based on resistance calculation approach.

The fundamental idea of the followed methodology was that for perfect accessibility (A) values there was no resistance (R) in the interaction (i.e. A=1 corresponds to R=0) and, in the opposite, for low accessibility values the resistance would be very high, tending to infinite in cases where accessibility equals zero (A=0 corresponds to R ->∞).

The sum of accessibilities between one zone and different destinations follows the same rule as resistance calculation (electric equivalent) theory that states that the inverse of the total resistance of a system is the sum of the inverse of each individual resistance, as followed:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + .. + \frac{1}{R_n} = \sum \frac{1}{R_i} \tag{3}$$

However, the main difficult of this methodology was how to correlate individual resistance with individual accessibility.

The two approaches developed considered that the individual resistance from origin i to destination j had to be inversely proportional to the value of the accessibility (R increases when A decreases). However if only this assumption was taken into consideration (R=1/A) this would represent that for good accessibility situations (A ->1), resistance was not equal to zero and would lead to unrealistic results when adding several destinations with good individual accessibilities (total accessibility would be less than all the individual accessibilities).

Thus, the first approach followed to correct this situation was based on the assumption that resistance should have an additional factor that values more higher individual accessibilities and penalize more the lower ones (for higher accessibility values, the resistance grows slower than for lower ones). A new factor (named as inaccessibility measure) was considered and reflects the distance that the pair ij is from the best possible accessibility and can be represented numerically as 1-A.

Thus, following this first approach, resistance is directly proportional to inaccessibility and indirectly proportional to accessibility:

$$R = \frac{1 - A}{A} \tag{4}$$

The second approach followed considers that, besides the negative influence of accessibility in resistance, this variable grows in a logarithmic form with accessibility. With this method values of resistance are limited between zero and infinite and can be represented by the equation:

$$R = -\frac{\ln(A)}{A} \tag{5}$$

A comparison of the two methodologies can be assessed in Figure 3.

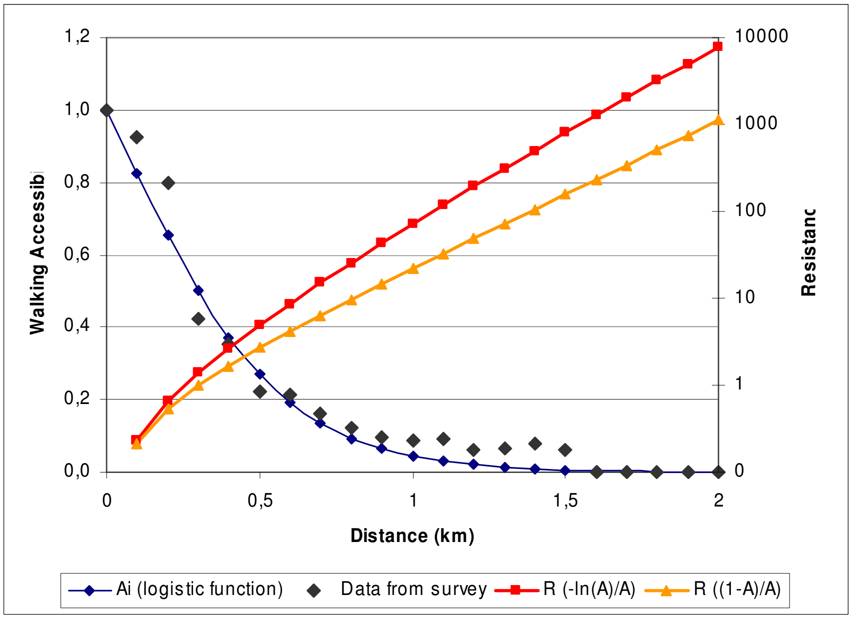

Figure 3 – Comparison of the two methodologies for resistance curves for walking mode

Both methodologies describe the idea that for better accessibility values, the resistance grows slower than for higher ones; with the second approach this penalization is more aggravated.

Sum of accessibility of different transport modes

Another important measure is the total accessibility considering all transport modes available in the studied area (each destination can be accessible by different transport modes).
Also in this case, two approaches can be considered: one presents total accessibility of one zone for each mode individually, not adding the different modes in a single accessibility measure.
In the second approach, the different modes available are summed based on data from modal split (available from surveys). This means that total accessibility from origin i to destination j is:

$$A_{ij} = A_{ij\ walking} \times \%_{walking} + A_{ij\ private\ car} \times \%_{private\ car} + A_{ij\ transit} \times \%_{transit} \quad (6)$$

The two methodologies are demonstrated in the preliminary case study developed and presented in the next sections.

External cost of accessibility for motorized modes (energy consumption, CO_2 and local pollutant emissions)

One of the main objectives of this research is to calculate the external cost of motorized modes on accessibility indicators.

For estimating the external costs of accessibility (energy and environmental impacts) the methodology adopted follows the same approach used for accessibility, based on resistances as shown in the equation:

$$\frac{1}{E_T R_T} = \sum \frac{1}{E_{ij} R_i} \qquad (7)$$

Where E_T = External cost of accessibility; R_T = total resistance of origin i; E_{ij} = Externality cost for energy consumption, CO_2 emission, and local pollutant emission between origin i and destination j; R_i = resistance of accessibility from location i to service j.

In order to calculate energy and environmental impact the authors used Copert 4 (Gkatzoflias, D. et al, 2007), a software program that calculates air pollutant emissions from road transport that is considered the reference tool for environmental impact evaluation from road transport in Europe. Copert 4 model calculates total emissions by summing emissions from three different sources: warming up phase (cold start), thermal stabilized engine operation (hot) and fuel evaporation:

$$E_{TOTAL}=E_{HOT}+E_{COLD}+E_{EVAP} \qquad (8)$$

Energetic and environmental impacts of soft modes are, for now, considered null, although in the future energy consumption can be integrated. For the present work a reference value for impact factor of private cars was used, obtained using Copert IV model, applied to the national car fleet characterization (without the distinction of cold start emissions) – see Table 2.

Table 2 – Energy and emissions factors for national fleet

	Speed	Energy factor (MJ/km)	CO_2 factor (g/km)
Private car	15 km/h	2,508	125,067

However, when considering local trips, most journeys are of short duration and take place in urban areas (Blaikley et al, 2001). These journeys will start (and most of them end) with the vehicle significantly below its normal operating temperature, in a warming up phase. Under these conditions the emission of local pollutants as well as energy consumption and CO_2 emissions will be higher than calculated from the emission factor models. This excess cold start emission is therefore of considerable significance. Thus, a new methodology for cold star emissions estimation is under development by the authors based on numerical and experimental in-vehicle measurements.

PRELIMINARY TEST CASE

In order to demonstrate the potentialities of the methodology developed, a preliminary test case for two neighbourhoods with different characteristics in Lisbon city was developed.
For these neighbourhoods, walking accessibility to pharmacies was calculated followed by an addition of motorized modes accessibility (only private car was considered) and the corresponding cost in energy consumption and CO_2 emissions.

The first neighbourhood analysed has characteristics of an historical centre near the limit of Lisbon city, as shown in Figure 4. In this figure, the neighbourhood is marked as a square and the available pharmacies within 2 km are identified as red spots (in a total of 10 available destinations), and it is possible to predict that this is a zone with a high accessibility to pharmacies, due to the number and localization of the opportunities:

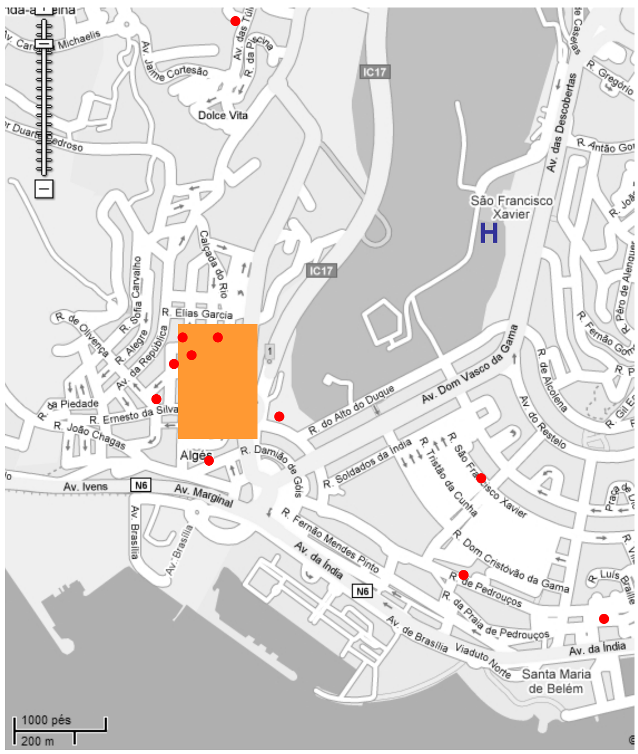

Figure 4 – Historical centre case study location and pharmacies

The second zone is shown in Figure 5 and represents a residential area with tall buildings and fewer pharmacies available:

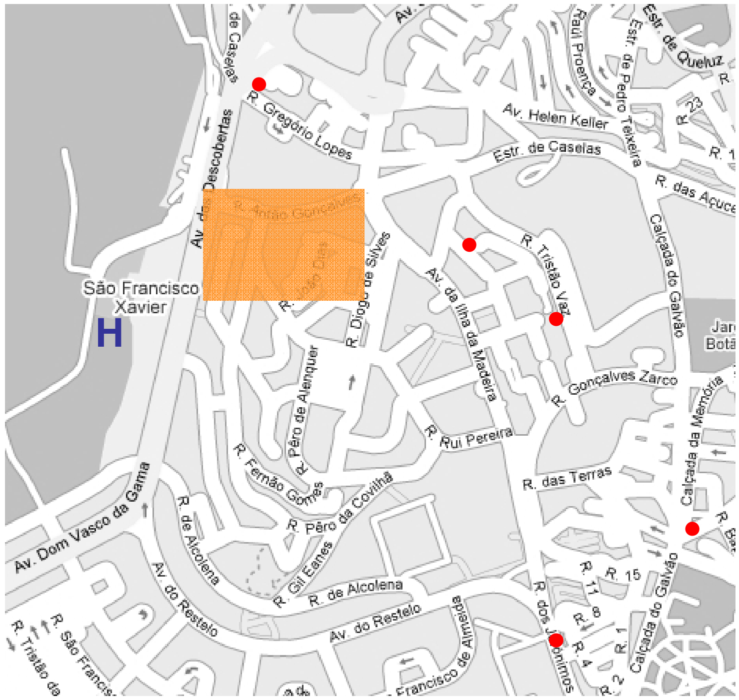

Figure 5 – Residential area case study location and pharmacies

Historical centre zone

Walking accessibility was estimated individually (from origin i to each pharmacy, j) and calculated globally, using the two methodologies suggested previously. Results are shown in Table 3:

Table 3 – Results of total accessibility of walking mode for historical centre zone using the two methodologies

			R = (-ln(A)/A)			R = (1-A)/A		
Pharmacy	**Dist. (km)**	**$A_{walking}$**	**R_i**	**R_{total}**	**A_{total}**	**R_i**	**R_{total}**	**A_{total}**
Phar "B. Sucesso"	1,9	0,001	4979,82	0,07	**0,94**	750,94	0,06	**0,94**
Phar "do Restelo"	1,4	0,009	498,95			105,82		
Phar "Ocidental"	0,4	0,373	2,64			1,68		
Phar "Soc Higilux"	1,2	0,020	191,43			48,15		
Phar "Branco"	0,1	0,825	0,23			0,21		
Phar "Combat"	0,1	0,825	0,23			0,21		
Phar "D. Saraiva"	0,4	0,373	2,64			1,68		
Phar "Miraflores"	0,4	0,373	2,64			1,68		
Phar "Nifo"	0,1	0,825	0,23			0,21		
Phar "Raposo"	1,5	0,006	798,01			156,69		

It is possible to observe that the two methodologies have similar results and both reflect an increase in the total accessibility value comparing to the best opportunity available.
Considering that zones with a high number of available opportunities, even if each one individually have low accessibility, end up with a high total cumulative accessibility value, the

authors decided to present also the value for the total accessibility considering the top 5 opportunities as well as the best available opportunity.

For the walking mode accessibility in the historical centre zone, the **top 5 total accessibility value is 0,94** (very small differences from the total accessibility value – 0,941 and 0,939 for total or top 5 accessibility, respectively) and the best **available opportunity has an accessibility of 0,82**.

The same methodology for accessibility estimation was applied considering the use of private car:

It is important to refer that there are slight differences between travel distances in the two modes considered. These differences are due to the existence of different routes, namely, one way streets or pedestrian streets that affect cars but don't affect walking routes and freeways where it is difficult for pedestrians to cross, which increases the travel distance for walking.

As mentioned before, the accessibility for cars considers the distance travelled in the car plus an equivalent distance that reflects the time lost with parking and a penalization of a walking accessibility, representing the distance travelled as a pedestrian, from the parking space to the pharmacy (see Table 1).

Table 4 - Results of total accessibility of private cars for historical centre zone using the two methodologies

									R = (-ln(A)/A)			R = (1-A)/A		
Pharmacy	**Dist. (km)**	**Extra-time (min)**	**Dist equiv (km)**	**Dist total (km)**	**Dist walk (km)**	**$A_{walking}$**	**A_{car}**	**A_{total}**	**R_i**	**R_{total}**	**A_{total}**	**R_i**	**R_{total}**	**A_{total}**
P "B. Sucesso"	1,8	10	2,5	4,3	0,25	0,58	0,23	0,13	15,51			6,63		
P "do Restelo"	1,4	10	2,5	3,9	0,25	0,58	0,27	0,15	12,17			5,50		
P "Ocidental"	0,4	10	2,5	2,9	0,25	0,58	0,39	0,23	6,57			3,42		
P "Soc Higilux"	1,2	10	2,5	3,7	0,25	0,58	0,29	0,17	10,77			5,01		
P "Branco"	0,1	10	2,5	2,6	0,25	not considered: dist walk < dist parking space-destination				1,39	**0,50**		0,67	**0,60**
P "Combat"	0,1	10	2,5	2,6	0,25									
P "D. Saraiva"	0,8	10	2,5	3,3	0,25	0,58	0,34	0,19	8,42			4,14		
P "Miraflores"	0,6	10	2,5	3,1	0,25	0,58	0,36	0,21	7,44			3,77		
P "Nifo"	0,1	10	2,5	2,6	0,25	not considered (see above)								
P "Raposo"	1,6	10	2,5	4,1	0,25	0,58	0,25	0,14	13,74			6,04		

Considering the use of the car, the value for accessibility taking into consideration only the **five closest pharmacies is 0,54** and the **best value of accessibility is 0,23**.

It is interest to notice that the total accessibility has a medium/high value (although much inferior to the one considering only walking mode), however the best available pharmacy has a much lower value. A comparison of these results for both transport modes demonstrates that both modes have acceptable accessibility values; however, the car option has a very low value for the best available opportunity, compared to walking mode,

The two methodologies for resistance calculation were similar for the test case presented previously, although some differences occur for low accessibility values (car accessibility). Considering this, a sensitivity analysis was made in order to compare both ones (see Figure

6). Results demonstrate that total accessibility values are very similar, with maximum differences of 30% for lower accessibility values and less than 10% for values higher than 0,5.

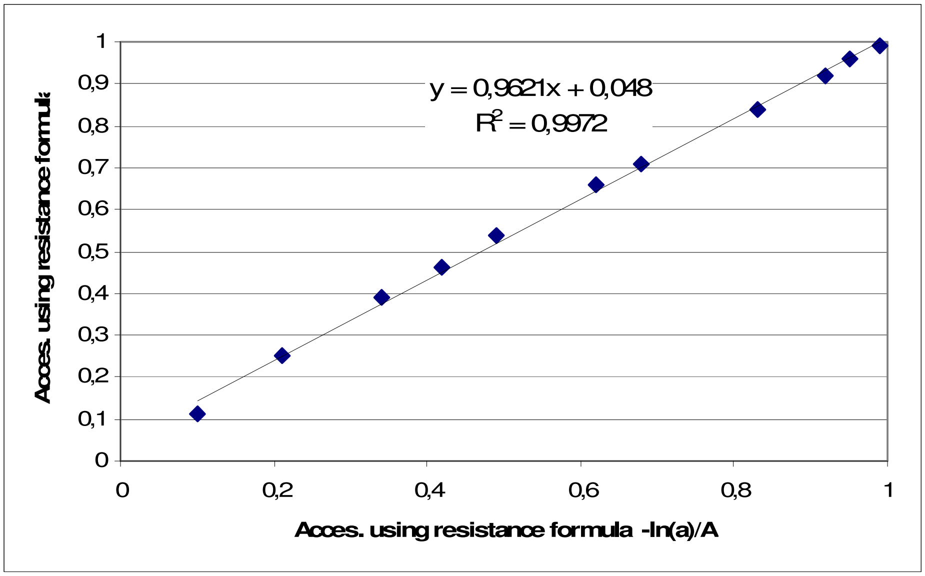

Figure 6 – Total accessibility comparing the two resistance calculation formulas

Considering this, for the present work, resistance calculation based on the ratio between inaccessibility and accessibility (equation 3) was adopted.

In order to obtain the modal distribution of pharmacies' users, the authors used results from surveys made on pharmacies, complemented with an online survey with 250 responses. To avoid car trips overestimation, as a part of a larger trip chain, only data from users that went exclusively to the pharmacy were considered. Results are represented in Figure 7:

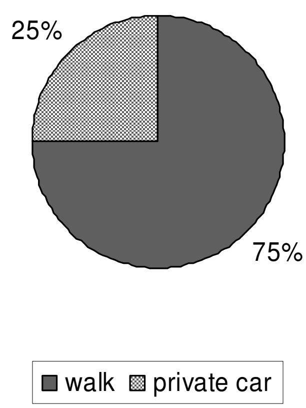

Figure 7 – Modal split: results from surveys

Thus, the total accessibility indicator, including all the destinations and all the transport modes (for this demonstration, only walking and private car were considered) is:

Table 5 – Total neighbourhood accessibility to pharmacies

	Total accessibility by mode	Modal split	Total accessibility
Walking	**0,94**	75	**0,89**
Private car	**0,72**	25	

Residential area zone

For the second area studied, accessibility values are systematically lower and therefore a better case study to demonstrate the applicability of this methodology.

Table 6 – Results of total walking accessibility for residential area zone

Pharmacy	Dist. (km)	$A_{walking}$	R_i	R_{total}	A_{total}
Pharm "Remisio"	1,6	0,004	231,92	1,57	**0,39**
Pharm "Moura"	1,8	0,002	507,67		
Pharm "Restelo"	0,8	0,093	9,72		
Pharm "Alto Rest2"	0,7	0,135	6,43		
Pharm "Alto Rest3"	0,5	0,270	2,70		

The maximum individual accessibility in the residential area, for walking mode, is 0,27, however, due to the existence of five opportunities (with lower individual values of accessibility), the total accessibility value increases to 0,39.

For the residential area zone, the ease of finding a space to park is considered very high, thus no extra time for parking is assumed and the distance as a pedestrian is 25 m (based on scenarios described in Table 1).

Table 7 – Results of total private car accessibility for residential area zone

Pharmacy	Dist. (km)	Extra-time	Dist. total (km)	Dist walk (km)	$A_{walking}$	A_{car}	A_{total}	R_i	R_{total}	A_{total}
P "Remisio"	1,6	0	1,6	0,025	0,96	0,62	0,59	0,68	0,07	**0,94**
P "Moura"	1,8	0	1,8	0,025	0,96	0,58	0,56	0,80		
P "Restelo"	0,9	0	0,9	0,025	0,96	0,78	0,74	0,35		
P "Alto Restelo2"	0,7	0	0,7	0,025	0,96	0,82	0,79	0,27		
P "Alto Restelo3"	0,4	0	0,4	0,025	0,96	0,90	0,86	0,16		

When analysing the accessibility for private car, the individual values are high (higher than 0,55) and total accessibility is also close to 1.
It is interest to compare these values with those obtained for the historical centre, where the walking mode had much higher values of accessibility.

Table 8 – Total accessibility

	Total accessibility by mode	Modal split	Total accessibility
Walking	**0.39**	75	**0,53**
Private car	**0,94**	25	

For this study, results of total accessibility using or not the car are very different and the combined value of total accessibility (for all transport modes considered and all available pharmacies) is 0,53, which reflects the probability of using more walking modes for this trip propose rather than private car. Modal split results are general values from different pharmacies where these surveys were made and online surveys from very different urban areas. Probably in this studied area, the modal split would have different results, with more use of private car, since the accessibility for this mode is much higher than for walking.

A calculation of the external cost of including motorized modes in accessibility measures was made for this zone. Energy consumption and CO_2 emission results are presented in Table 9 and Table 10, respectively.

Table 9 – Results of external cost of accessibility considering energy consumption

	Dist. (km)	A_{total}	R_i	R_{total}	A_{total}	E_{ij} (MJ)	$1/(E_{ij}.R_i)$	E_T (MJ)
Phar "Remisio"	1,6	0,59	0,68	0,07	**0,94**	4,01	0,366	**1,53**
Phar "Moura"	1,8	0,56	0,80			4,51	0,278	
Phar "Restelo"	0,9	0,74	0,35			2,26	1,276	
Phar "Alto Rest2"	0,7	0,79	0,27			1,76	2,115	
Phar "Alto Rest3"	0,4	0,86	0,16			1,00	6,047	

Table 10 – Results of external cost of accessibility considering CO_2 emissions

	Dist. (km)	A_{total}	R_i	R_{total}	A_{total}	E_{ij} (g CO_2)	$1/(E_{ij}.R_i)$	E_T (g CO_2)
Phar "Remisio"	1,6	0,59	0,68	0,07	**0,94**	200,11	0,007	**76,08**
Phar "Moura"	1,8	0,56	0,80			225,12	0,006	
Phar "Restelo"	0,9	0,74	0,35			112,56	0,026	
Phar "Alto Rest2"	0,7	0,79	0,27			87,55	0,042	
Phar "Alto Rest3"	0,4	0,86	0,16			50,03	0,121	

The values of 1,53 MJ and 76,08 g of CO_2 represent the cost of adding motorized modes to accessibility measure and reflect the impact on energy consumption and CO_2 emission of reaching on available destination in the area analyzed.

SUMMARY AND CONCLUSIONS

This paper intends to define a methodology for the estimation of accessibility indicators for non work destinations, considering a local scale (of an urban neighborhood), including not only internal costs (time and distance) but also external environmental costs (energy consumption, CO_2 emissions and local pollutant emissions).

The methodology for accessibility estimation is based on four steps, namely:

- Measurement of individual accessibility, for a given mode, from origin to a pre-define destination based on logistic curves calibrated with real data from surveys;
- Estimation of the cumulative accessibility for different destinations using the resistance calculation approach;
- Estimation of the cumulative accessibility of different transport modes based on modal split information (also available from surveys)
- Calculation of external cost of accessibility for motorized modes (energy consumption, CO_2 and local pollutant emissions)

A preliminary test case was made in order to illustrate the demonstration of this methodology. Two zones were considered, one with characteristics of an historical centre, with a high pressure of parking and one residential area zone, with high offer of parking.
The first zone (an historical centre) had high values of accessibility for walking but for car the results were not so high, due to the penalization of parking. However the cumulative results were close to 0,9 due to the higher influence of walking mode in the total accessibility. In the second area analyzed, results of accessibility were not so high due to the low values for walking accessibility.
For the residential area, and considering only the walking mode, there are 5 pharmacies available within the 2 km, with a maximum individual accessibility of 0,27. The total value of accessibility is 0,39. Adding the car accessibility to this values (with a total value of 0,94), the total accessibility value (including all transport modes and all opportunities available) increases to 0,53.The external cost of accessibility was calculated for this second area, with results of 1,53 MJ and 76 g of CO_2 that represent the cost of adding private car mode to accessibility measure and reflect the impact on energy consumption and CO_2 emission of reaching on available destination in the area analyzed
In conclusion, this methodology allows the characterization of a zone in terms of accessibility, with results of 0,39 for walking accessibility, increasing to 0,53 when adding motorized modes (private car) but with an environmental cost of 1,53 MJ per trip and 76,08 g of CO_2 (comparing to zero, when considering only soft modes).

REFERENCES

Apparicio, P., Abdelmajid, M., Riva M. and Shearmur, R. (2008). Comparing alternative approaches to measuring the geographical accessibility of urban health services: Distance types and aggregation-error issues, International Journal of Health Geographics

Apparicio, P., Cloutier, M.S. and Shermur, R. (2007). The case of Montréal's missing food deserts: evaluation of accessibility to food supermarkets, International Journal of Health Geographics

Blaikley, DCW et al. (2001), UG219 TRAMAQ – Cold Start emissions – Summary report

Favez, J., Weilenmann, M., Stilli, J. (2008) Cold start extra emissions as a function of engine stop time: evolutions over last 10 years, Atmospheric Environment

Geurs, K. and Eck, J. (2001), Accessibility measures: review and applications. Evaluation of accessibility impacts of land-use-transport scenarios, and relate social and economic impacts, National Institute of Public Health and the Environment, Bilthoven

Gkatzoflias, D. et al.(2007) COPERT 4: Computer programme to calculate emissions from road transport – User Manual (Version 5.0), European Environment Agency

Gonçalves, G.A., Farias, T.L (2005), On-road measurements of emissions and fuel consumption of gasoline fuelled light duty vehicles, CleanAir2005

Handy, Susan L. (1992) Regional versus Local Accessibility: Neo-Traditional Development and its Implications for Non-work Travel, Built Environment, Vol.18, No.4

Handy, S. L. (2005) Planning for accessibility: In theory and in practice. In D. M. Levinson & K. J. Krizek (Eds.), Access to Destinations (pp. 131-147). Amsterdam: Elsevier.

Hilber, R. and Arendt, M., (2004) Development of accessibility in Switzerland between 2000 and 2020: first results, 4th Swiss Transport Research Conference

Levine, J. and Garb, Y. (2002) Congestion Pricing's Conditional Promise: Promotion of Accessibility or Mobility?, Transport Policy 9(3)179-188.

Liu, S., Zhu, X., (2003) Accessibility analyst: an integrated GIS tool for accessibility analysis in urban transportation planning, Environmental and Planning B: Planning and Design 2004, vol 31, pages 105-124

Mark F Guagliardo (2004), Spatial accessibility of primary care: concepts, methods and challenges, International Journal of Health Geographics

Martinez, L. Miguel and Viegas, J. Manuel (2009) Effects od Transportation Accessibility on Residential Property Values – Hedonic Price Model in the Lisbon, Portugal, Metropolitan Area, Journal of the Transportation Research Board, No. 2115,

Koenig J. G. (1980), Indicators of urban accessibility: theory and application, Transportation, Vol. 9, pp. 145-172

Polak, J., K.W. Axhausen and T. Errington (1990). The application of CLAMP to the analysis of parking policy in Birmingham city centre. Presented at: PTRC Summer Annual Meeting.