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Path Dependent Accessibility

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Path Dependent Accessibility

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Paper to be presented at the 40th ERSa Congress in Barcelona

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Abstract

In this paper I develop an Accessibility Measure (AM) based on a daily travel pattern. In contrast to traditional zone based measures distance is calculated with regard to a predefined travel matrix. The importance of the travel pattern for each zone is used as a weight in the AM.

It is shown that there are large differences in accessibility between groups with different travel patterns. It is concluded that path based AMs could be very useful to analyse accessibility for high mobility groups.

This activity based AM is implemented in a program that is closely coupled to a transport oriented GIS (TransCAD). Standard dialog boxes provides an easy - to - use interface for convenient analysis and map display. The properties of the activity based AM are evaluated and compared to standard AMs used in the planning process. The measure is evaluated with regard to different socio economic groups.

1 Introduction

Accessibility is the possibility to take advantage of resources with a fixed location in space that requires presence in some sense. Introduction of new technology has messed up the definition of presence but in this article we are concerned with physical presence as a result of travel to a supply source. Since accessibility is an important positive outcome of the transport system¹ it is important how accessibility is measured.

AMs can be categorised in many different ways but in the more recent literature there is a tendency to discriminate between zone based and individual AMs (see e.g. Hanson (1995), Kwan (1998), Miller (1999)). As the labels indicate zone measures try to capture the overall accessibility for a zone while individual measures try to capture the accessibility of individuals based on detailed characteristics of space, available time and means to overcome space. One of the main advantages of individual measures is that these measures can take into account the fact that most individuals face a mandatory daily travel pattern such as to and from work. Zone based measures neglect mandatory travel patterns which is one of their shortcomings.

In the simplest form zone based measures result in one figure of accessibility for each zone which may become a target of criticism. In practice however different accessibility scores are calculated based on gender, socioeconomic status etc. but the accessibility scores are of course still averages across a number of individuals. Disaggregating population data is one way of obtaining more realistic accessibility figures using zone based measures. Individual measures on the other hand may lead to as many figures of accessibility as there are individuals in the study area. Individual measures are conceptually attractive but faces difficulties from an operational point of view, Hanson (1995). Although conceptually very different the two types of measures as such (the formula) can be identical (see Hanson, 1995). The conflict is between conceptual elegance and being tractable from an operational point of view. One way of increasing the realism of aggregated zonal measures is to use more detailed data on the population. Another possible contribution is to add information on a mandatory travel pattern on a zonal level thus maintaining the operational advantages of zonal measures and bringing in some components from individual AMs. This latter approach will be developed in the subsequent sections.

¹Many other effects such as pollution, accidents and consumption of land are negative

The paper is organized as follows. In the next section we take a closer look at different approaches to measuring accessibility. In Section 3 an alternative AM is defined where a mandatory travel pattern is taken into account. In Section 4 data for an empirical example is presented and an implementation of the AM in a GIS software is described. Section 5 is an analysis of the properties of the suggested AM and comparisons with more established AMs are presented. Finally in Section 6 some concluding remarks are provided.

2 Accessibility measures

Regardless of the type of AM two components are always present – a representation of travel cost (in a wide sense) and a representation of the opportunities at the destination. Travel cost could be represented as a simple 0/1 variable or defined more in detail using a parameterized function. Description of the opportunities can range in a similar way from just the area that can be reached from a place to detailed address coded registers of a multitude of opportunities. Population or number of work places are frequently used as measures of opportunity at the destination.

Individual space-time AMs² have gained an increasing popularity recently (see e.g. Kwan (1998) and Miller (1999)). This is partly due to the development in the GIS and with facilities to write program and to visualise individual behaviour. Examples of implementations of individual AMs in GIS can be found in e.g. Miller (1999), Kwan (1998) and Berglund (1999). Despite the fact that most implementations of individual AMs are quite recent the theories behind individual AMs are mature and originate from Hägerstrand’s space-time framework³, Hägerstrand (1970) (see also Lenntorp, 1976). In the space-time framework the mobility of the individuals is constrained with regard to mobility resources, restrictions with regard to access to opportunities and the possibility to combine activities with other people (coupling constraints).

Mandatory travel patterns such as going to and from work and picking up children etc. play an important role in space-time theory. The implications for accessibility of mandatory travel patterns are twofold. On one hand a mandatory travel pattern restricts mobility and prevents the individual to reach certain opportunities, on the other hand a mandatory travel pattern

²Called STAMs by Miller (forthcoming)

³This is frequently illustrated using the space-time prism, see e.g. Lenntorp (1976)

brings the individual to places that may provide opportunities and reduce the need for special purpose trips.

Possibilities to overcome distance and other obstacles to mobility differ between individuals depending on where they live, work and depending on their mobility resources. This set of restrictions defines the area, called the potential path area (PPA), that a specific individual can cover given the set of constraints. Despite its conceptual simplicity the functional form of the travel impedance for individual space-time measures may be a rather complex sequence of conditions depending on how many restrictions in space and time that are taken into account. The PPA simply defines a subset of the total area at study where the accessibility should be considered for an individual. This is in contrast to standard measures where even very distant opportunities can contribute to the accessibility although to a very small extent.

A next step is to determine the utility of opportunities that can be reached. Here some weighting scheme is necessary. A similar reasoning of distance to opportunities can be applied to both individual and aggregate zonal AMs. The simplest alternative is to put equal weight on all opportunities within a cutoff value of distance and let the PPA define the cut off value for individual measures of distance. A more sophisticated alternative is to use a gravity based measure. Formally gravity based measures can be written as in equation (1)

$$a_i = \sum_j x_j f(d_{ij}) \quad (1)$$

where a_i is the accessibility of zone i with regard to the supply of x across all zones j , and d_{ij} is the distance from i to j . The shorter the distance the better. Common alternatives for $f(d_{ij})$ is the exponential function and the power function. Cumulative opportunity measures can be written on the same form as gravity measures by using

$$f(d_{ij}) = \begin{cases} 1 & \text{for } d_{ij} < D \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

where D is the cut off value. The drawback of gravity measures is that they need estimation of parameters.

A third alternative is to use an AM based on random utility theory. The most widely used model of this type is the logit model from which the log

sum is derived:

$$a_i = \log \sum_j x_j \exp(-\beta d_{ij}) \quad (3)$$

In equation (3) the utility is simply a function of distance as in previous measures and of the opportunities of zone j . Logit models can handle time constraints in the choice set and constrained models have been successfully used by Thill and Horowitz (1997). An application to accessibility where the log sum is used in a time-space framework can be found in Miller (1999). In an article by Richardson and Young (1982) the properties of the log sum as an accessibility measure are explored for linked trips.

The formulation of the functional form of the distance function have no doubt attracted most interest in the literature. In some respects it is however more critical how opportunities as the destinations are perceived. At one extreme you may find opportunities characterized by "the more the better" and at the other extreme "one is enough". In the first alternative an additive indicator is appropriate and in the second case a maxitive indicator, see e.g. see Weibull (1980) for a formal derivation of this result.

3 Aggregate Path Based Accessibility

In order to take advantage of the information that is present in a predefined travel (to work) matrix a weighted AM will be developed where the accessibility of each zone is weighted by a travel matrix. This is illustrated in Figure 3 (left) where the housing area is denoted h , and alternative destinations e.g. for shopping trips are denoted s and the travel distance is equal across all alternatives. The AM used in association with Figure 3 (left) will be a standard aggregate AM like in equation (1).

If the alternatives (which we assume) are equal, all alternatives can be chosen with equal probability. If we add information about a mandatory trip e.g. a trip to and from work we have a new activity pattern to take into consideration, Figure 3 (right). In this setting the available shops will not be indifferent to the traveler in the example. With path based measures it is possible to calculate the extra travel time that an activity requires given the two initial activities at i and j . This is an important aspect that is not taken into account by other types of accessibility measures. The extra travel time caused by going to k (s_3) is given by Equation (4)

$$d_{k|i,j} = (d_{ik} + d_{kj}) - d_{ij} \quad (4)$$

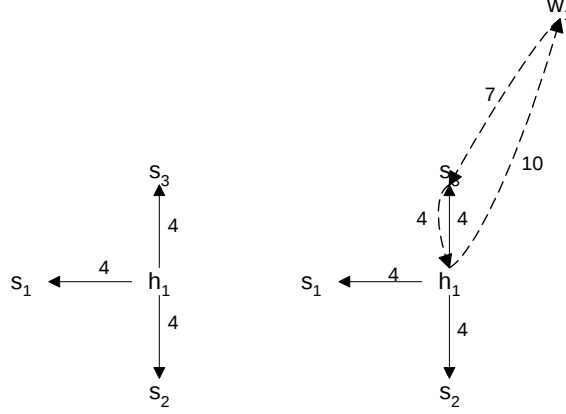


Figure 1: Illustration of the difference between traditional accessibility measures (left) and path based measures (right).

where i is allowed to be equal to j which means not making a trip or that job and home is in the same zone. In this case there will be no difference between traditional zone based AM and a (non-) path based AM. A modified distance measure like this can be found in e.g. Richardson and Young (1982). If $i \neq j$ and k is along the road from i to j the extra time equals the time consumed by activity l will be t^l . The total extra time consumed by activity l at an arbitrary k will equal $t_{k|ij} + t^l = t_{k|ij}^l$. If t^l is impossible (or difficult) to obtain we could use some stop penalty. Just changing the distance measure by taking a possible trip pattern into account will not add much realism to our AM. To gain something we must weight the AM using a trip pattern that is not evenly spread across all destinations. Next component is thus a travel matrix T_{ij} , where i representing the residential zone and j representing the work zone. This matrix could be observed from a travel survey or estimated by some model.

$$\omega_{ij} = T_{ij}/T_i \quad (5)$$

where $T_i = \sum_j T_{ij}$, ($\sum_j \omega_{ij} = 1$), we can then write an activity based AM weighted by the trip pattern ω_{ij} .

$$a_i = \sum_j \omega_{ij} \sum_k x_k f(d_{k|ij}) \quad (6)$$

The only thing we said about ω_{ij} is that it is an predefined travel matrix. It

could be from a survey (as available in Sweden) or an estimated matrix. But if the matrix is estimated it may originate from a process like $T_{ij} = T_i \times f(d_{ij})$. If we substitute right hand of (5) into (6) and use the assumed model for T_{ij} we will obtain:

$$a_i = \sum_j \sum_k x_k f(d_{k|ij}) \frac{T_i f(d_{ij})}{T_i} \quad (7)$$

and 7 (with an estimated ω_{ij}) will reduce to

$$a_i = \sum_j \sum_k x_k f(d_{k|ij}) f(d_{ij}). \quad (8)$$

If we disaggregate ω_{ij} into groups that can be expected to have different mobility characteristics the analytical power will increase further. Segmentation can be made with regard to socio-economic status or education. Yet another alternative that is available is to transpose the weight matrix and obtain an accessibility score for the work zones⁴.

4 Empirical example, data and program

For the empirical example we used a data set from the county of Jämtland about 600 km north west of Stockholm, see map in Figure 2(a). The regional center is Östersund with about 50 000 inhabitants, Figure 2(b). The regional division is based on 150 SAMS areas (Small Area Marketing Statistics) of varying size. In the city centers the zones consists of just a few blocks while in the periphery the largest zones are over 100 km².

Two different types of opportunities were selected: one type where "more is better" and one type where "one is enough". As attractiveness of the "more is better" opportunity, number of jobs in retail trade were used. As the "one is enough" opportunity pharmacies were used. The location of pharmacies was obtained from the home page of "Apoteket" (<http://www.apoteket.se>). In this study alternative ways of distributing drugs have not been taken into account⁵. Access to retail trade and access to pharmacies is based on the centroid of the SAMS that contains the relevant activity. Within the system it is possible to connect the network to arbitrary points to obtain a greater

⁴This option is available in the software developed for this paper but not used in the application below.

⁵In some sparsely populated areas drugs are distributed by some local shop or post office the next day after an order has been placed

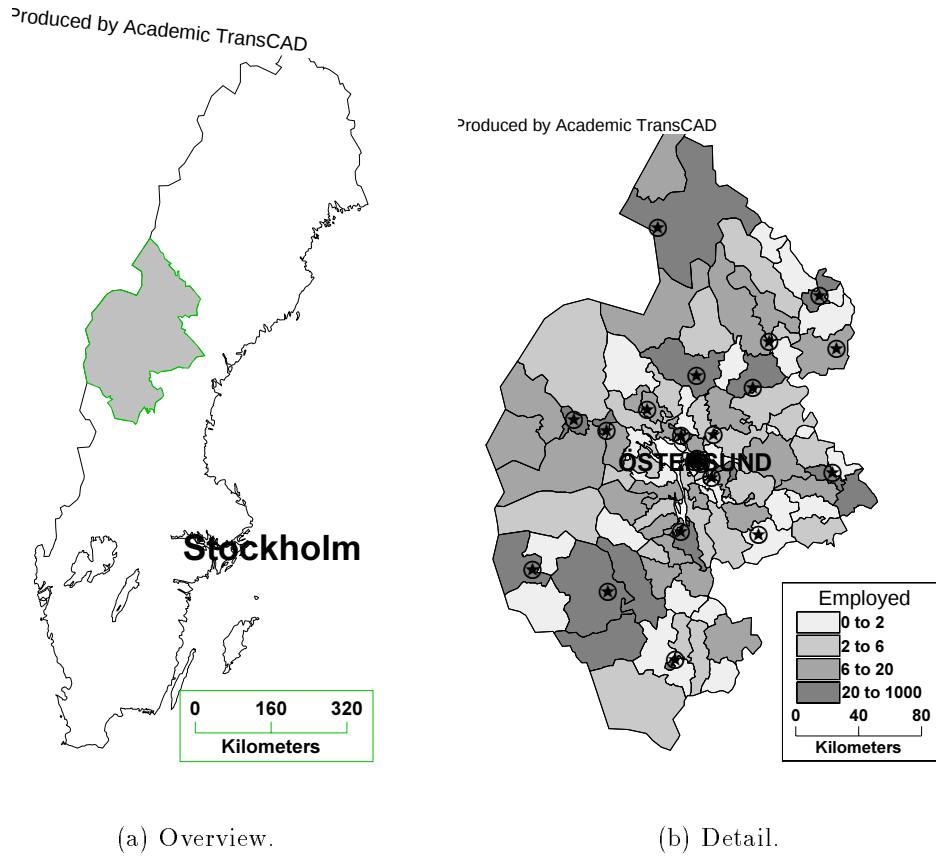


Figure 2: Overview of study area illustrating location of pharmacies and employment within retail trade.

accuracy (not regarded as necessary in this case). If the network contains addresses it is also possible to use this information to compute the distance to service facilities. This has been done in e.g. Kwan (1998) and Miller (1999) to obtain greater accuracy.

Network data was obtained from the Swedish road administration (Vägverket) and consists of about 2000 links and about 1000 nodes. The network has been connected to the zones and a "shortest path" travel time matrix has been calculated. In our example we have used a precalculated travel time matrix. Another alternative is to include the shortest path algorithm in the calculation of the AM and avoid storage of the travel time matrix. This might

be an alternative for GIS that can not handle matrices. That is however no restriction in our case.

One of the contributions of the AM put forward in this article is the weighting of the travel paths. As shown in section 3 this can be done using observed or estimated travel flows of a compulsory trip pattern. In this application we use a matrix obtained from a total survey, the 1990 census. The choice was determined by the fact that 1990 is the last year where data with mode choice is available on a geographically detailed level. Our data set contains variables for gender, education and mode. To restrict the empirical example we just take the car mode into consideration, three groups of education and gender (i.e. six groups in all).

The log sum is a parameterized AM and need some calibration of a logit model. This model was estimated using data from the national travel survey⁶ (RVU 94) where information on secondary trips are available. In order to concentrate on the AM a simple model with travel time as impedance and number of workplaces in retail trade as attractor was estimated (parameter 0.3603). No model for generation of secondary trips was estimated. The obtained parameter for travel time was rather high (-0.2265) and highly significant.

The application platform is a transport oriented GIS, TransCAD⁷ (TC). Besides the standard GIS tool box TC contains routines for transportation analysis such as different modelling tools. TC also provides a internal matrix database format (lacking in most GIS) which simplifies our application. The program⁸ that computes the accessibility is written in TC's internal programming language (Caliper script) and integrated in a "tool box" where different AMs are available (see Berglund, 1999). In Figure 3 a screen picture of the interface is shown. To be coherent with previously written programs, more alternative impedance functions are available than used in the examples below. The usage of a native GIS programming language makes it possible for us to offer a close integration between GIS and the computational routines. The program can only run within TransCAD.

⁶This travel survey is sample based.

⁷<http://www.caliper.com>

⁸The program is freely available from the author upon request.

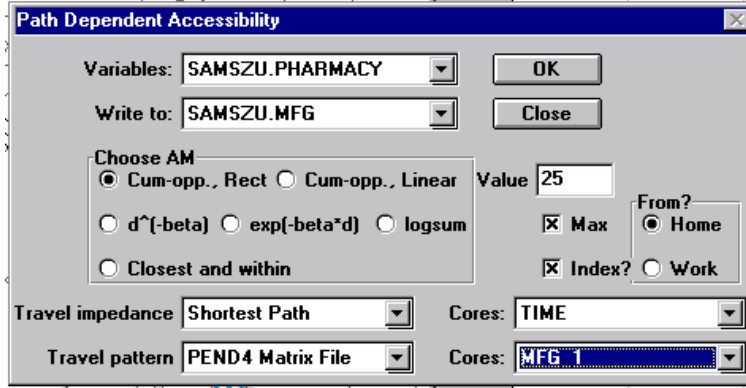


Figure 3: Interface to program for path based accessibility

5 Comparative analysis of AMs

Using the AMs defined in section 3 accessibility with regard to spatial location (which is traditional) and impacts of socio-economic status (education) and mobility pattern (based on groups) will be analyzed.

In order to explore some of the properties of this path based AM it is compared with existing and well known AMs. Such AMs are the non path based equivalences of the AMs selected for this study. In previous studies comparisons between different AMs have been made using correlation coefficients (see e.g. Kwan, 1998). The fact that two AMs are correlated does not say anything about their quality but may provide an intuitive feeling for their properties. Remember that the case with no compulsory trips (no mobility) will yield the same path based accessibility as traditional AMs. Thus low mobility groups are expected to have a PDA that is more similar to zone based accessibility. Traditional low mobility groups are women and people with low education.

In standard AMs the only factors that determine the accessibility is the location of the zone in relation to the opportunities. This might imply a smooth pattern of accessibility. Given equal access to mobility resources (e.g. car) the differences between socio-economic groups will be negligible. For path based measures the resulting accessibility also will depend on the travel pattern associated with the population in each zone and its socio-economic composition. It is well known that different socio-economic groups have different mobility patterns and that different travel time sensitivities

are obtained when estimating models.

When we weight the AM with the travel pattern we expect to discover inequalities in accessibility that is difficult to uncover using other types of AM. This will also result in less smooth patterns of accessibility and in adjacent zones showing very different accessibility depending on socio-economic composition. We can check this by testing for global spatial autocorrelation between accessibility scores using Moran's I. The hypothesis is that the path based measures scores lower than the conventional AMs.

5.1 Results

Let us first look at the tables of correlation coefficients in appendix A.1 - A.2. The first and maybe most interesting question is *does accessibility differ between groups depending on travel pattern, i.e. to what extent is the path based AMs for different groups correlated?* Looking at the correlation between cumulative opportunity measures of retail trade (upper left part of Table 2) with different weight the answer would probably be "they are not very different". Taking weights 1-6 into account the coefficients range from .866 to .976. Looking at the parameterized measure (the log sum, lower right part of Table 2) the answer is different. The same six groups (8-13) yield correlation coefficients ranging from .371 to .864. Turning to the example with accessibility to pharmacies the differences are more pronounced for the cumulative opportunity measures and less obvious for the log sum.

Is there a difference between the weighted measures and the traditional ones, i.e. to what extent are the traditional AMs (in bold face in Table 2 - 3) correlated with the weighted AMs? The coefficients with regard to retail trade ranges from .788 - .922 (cumulative opportunity) and .511 - .833 (log sum). For accessibility with regard to pharmacies the differences are more obvious with overall lower coefficients indicating less similarity between the path based measures and the zone based measures.

Will the map of accessibilities be more heterogeneous with path based AMs? In Table 5.1 Moran's I for the AMs are presented. Moran's I is a measure of global spatial autocorrelation that measures the correlation between a zone i and its neighbours where 1 indicates perfect positive autocorrelation and -1 perfect negative autocorrelation. Table 5.1 shows a mixed pattern. For both measures of accessibility to work places, the traditional (not path based) AMs is spatially more homogeneous and shows a smoother accessibility surface which was expected. Access to pharmacies shows the opposite pattern. This

Groupe	Work places		Pharmacy	
	Cumulative opp.	Log sum	Cumulative opp.	Log sum
Men L	0.86	0.60	0.46	0.65
Men I	0.83	0.50	0.41	0.61
Men H	0.78	0.44	0.48	0.48
Women L	0.90	0.65	0.68	0.68
Women I	0.91	0.67	0.73	0.73
Women H	0.90	0.42	0.66	0.65
Unweighted	0.90	0.80	0.38	0.48

Table 1: Moran’s I for the used AMs by gender and education (L=low, I=intermediate and H=high).

is not surprising since location of pharmacies is a 0/1 variable (a zone either has one or not and no zone has more than one) for the cumulative opportunity measure. Hence there will be zones with an accessibility score of 1 or of 0 (remember for pharmacies we use a maxitive AM). The very low value for Moran’s I is not a surprise in this case. Taking the opportunities along a path into account will even out the accessibility between the zones.

5.2 Low and high accessibility mobility patterns

Using path based AMs it is possible to detect differences in accessibility related to differences in mobility patterns. From an initial calculation one zone was selected (see Figure 4) with quite different accessibility for two groups - men with low and high education respectively. The zone under consideration has no pharmacies and is quite distant from everything else (this is a sparsely populated area). To reach more qualified service from this zone a trip is necessary.

The two groups under consideration have quite different mobility patterns. The most significant difference is that for the group with high education the rate of commuting out of the residential zone is 85 percent while it is 56 percent for the group with low education. The commuting patterns (see Figure 4(a) and 4(b)) indicate a stronger concentration of the commuting flows to the service centers for the highly educated group than for the low educated group. In this case with low local level of service commuting to service centers will yield high accessibility.

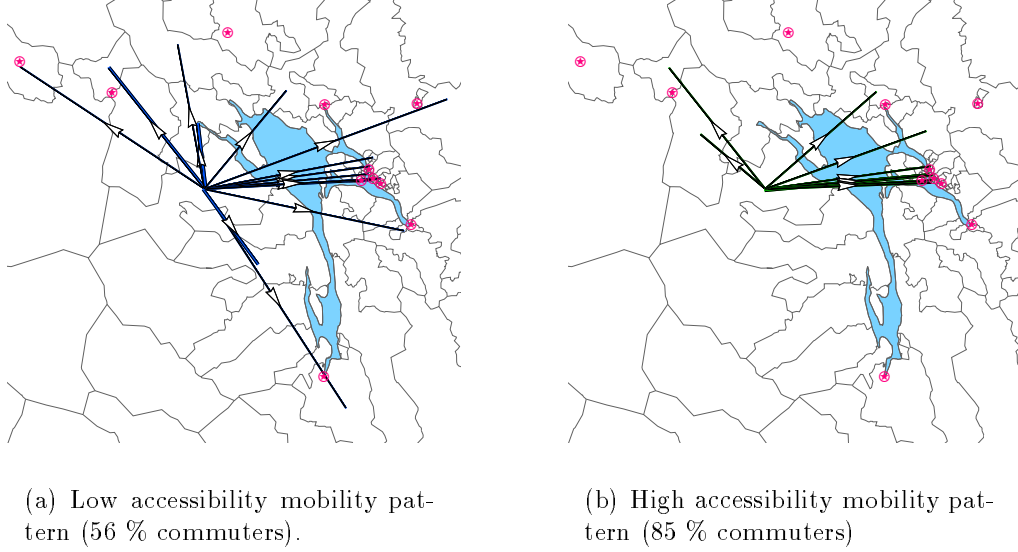


Figure 4: Illustration of low and high accessibility (to pharmacies) mobility patterns respectively.

6 Conclusions

In this paper an accessibility measure has been presented where accessibility is calculated with regard to a mandatory travel pattern for each zone. It is shown that there are quite large differences in accessibility between groups with different travel patterns. The differences between traditional AMs and the path based AMs are not as evident for the cumulative opportunity measure as they are for the log sum.

The pattern of similarities between adjacent zones shows a mixed result. For access to retail trade neighboring zones can have quite different accessibility scores depending on the mandatory travel pattern. For the case of pharmacies (using a maxative AM) the path based AM shows a more smooth pattern.

When could a path based AM be useful? For low mobility groups where work and home is close the path based component will not change the accessibility score much and not be very useful (but not less useful either). But, for high mobility groups a zone based measure will underestimate the accessibility that can be obtained along the daily travel path and thus be useful.

A situation where a path based AM could be useful is in transition regions outside urban areas where part of the population is active in sectors where jobs are found locally (mainly traditional sectors of the labour market) and others find their employment within sectors located in the urban center.

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A Appendix

A.1 Correlation matrix of accessibility to work places and pharmacies

The first two letters in column 1 of Table 2, 3 refer to the type of AM where CU=cumulative opportunity and LS=log sum. Letters 2-3 refer to the opportunity RT=retail trade and PH=pharmacy. Letter 5 refer to gender M=men, W=women. The last letter indicate educational level L=low, I=intermediate and H=high. BAA=is the traditional zonal measure that is unweighted.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
CURTML(1)	1.000													
CURTM(2)	.954	1.000												
CURTMH(3)	.866	.879	1.000											
CURTWL(4)	.950	.932	.870	1.000										
CURTWI(5)	.941	.948	.887	.966	1.000									
CURTWH(6)	.940	.942	.871	.963	.976	1.000								
CURTBAA(7)	.904	.852	.788	.918	.922	.917	1.000							
LSRTML(8)	.889	.840	.757	.780	.772	.786	.699	1.000						
LSRTMI(9)	.785	.855	.719	.722	.749	.745	.626	.859	1.000					
LSRTMH(10)	.422	.394	.556	.411	.378	.416	.346	.490	.377	1.000				
LSRTWL(11)	.833	.833	.805	.884	.846	.852	.740	.787	.735	.560	1.000			
LSRTWI(12)	.822	.878	.824	.847	.896	.865	.745	.767	.828	.371	.864	1.000		
LSRTWH(13)	.655	.692	.686	.671	.694	.721	.586	.646	.666	.458	.708	.772	1.000	
LSRTBAA(14)	.852	.847	.836	.871	.899	.891	.851	.741	.686	.511	.833	.831	.759	1.000

Table 2: Correlation of path dependent AM (retail trade) with different weights. Codes for column heads see row codes (explained on page 16).

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
CUPHML(1)	1.000													
CUPHMI(2)	.840	1.000												
CUPHMH(3)	.652	.659	1.000											
CUPHWL(4)	.782	.800	.697	1.000										
CUPHWI(5)	.743	.798	.614	.887	1.000									
CUPHWH(6)	.744	.794	.688	.844	.776	1.000								
CUPHBA(7)	.676	.644	.571	.670	.707	.705	1.000							
LSPHML(8)	.777	.715	.528	.609	.575	.604	.535	1.000						
LSPHMI(9)	.683	.786	.533	.575	.616	.589	.508	.908	1.000					
LSPHMH(10)	.526	.598	.790	.574	.505	.599	.499	.702	.720	1.000				
LSPHWL(11)	.728	.743	.649	.839	.750	.759	.625	.824	.809	.726	1.000			
LSPHWI(12)	.690	.727	.597	.748	.811	.717	.660	.799	.850	.700	.917	1.000		
LSPHWH(13)	.697	.735	.628	.719	.697	.817	.631	.808	.828	.739	.900	.905	1.000	
LSPHAA(14)	.726	.662	.625	.741	.760	.735	.868	.593	.528	.563	.672	.706	.682	1.000

Table 3: Correlation of path dependent AM (pharmacy) with different weights. Codes for column heads see row codes (explained on page 16).