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Measuring urban job accessibility with distance decay, competition and diversity

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ABSTRACT

As a key interface between urban transport and land use (workers and jobs) systems, job accessibility can provide a framework within which spatial and social interactions can be understood and interpreted. The extensive academic literature on job accessibility measurements suggests that there are many ways to represent, define, quantify, and interpret job accessibility. These measurements have been increasingly employed for exploring urban issues at varied spatial scales. However, in practice, an appropriate balance is required between the complexity of representation, accuracy of measurement and ease of interpretation and use. With this in mind, this paper demonstrates a modified measurement to represent, measure, and interpret, job accessibility and job opportunity, by incorporating the effects of competition, distance decay and job diversity. The measurement integrates a probabilistic methodology with a spatial interaction model. The methodology is implemented in a GIS environment and illustrated using the Amsterdam region of the Netherlands as a case study. We argue that this measurement can improve the application of job accessibility measurement for planning support practices.

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1. Introduction

Accessibility shows a large range of measurements and applications spanning various issues and spatial scales (Harris, 2001). Recent reviews include those of Handy and Niemeier (1997) and Geurs and van Wee (2004). Among these multiple types of accessibility, job accessibility has been attracting attention in diverse disciplines including urban geography, planning and transportation studies. Job accessibility is a very crucial tool to understand urban form (Shen, 1998), the spatial mismatch of jobs and housing (Kain, 1968; Östh, 2011), job-housing balance (Levinson, 1998), modal mismatch (Grengs, 2010), social network mismatch (Parks, 2004), excess commuting (Hamilton, 1982) and employability (McQuaid, 2006; Korsu and Wenglenski, 2010). In particular, much discussion has concentrated on the measurement of job accessibility. On the one hand, ever more social, economic, spatial, temporal, and behavioural components are being taken into account, making the measurement more complicated but also more accurate. On the other hand, policy makers and planners still give priority to measures that are easy to use and interpret (DfT, 2006; Straatemeier, 2008; Bertolini et al., 2005). Consequently, there is a challenge when measuring job accessibility: how can we balance the complexity of representation, the accuracy of measurement and the ease of interpretation and use? Bertolini et al. (2005) discuss the balancing act that is

required for the development of suitable indicators for accessibility with regards to their application in practical policy making. They argue that, “an accessibility measure must meet two basic requirements: it must be consistent with the uses and perceptions of the residents, workers and visitors of an area, and it must be understandable to those taking part in the plan-making process” (p. 210). In answering this challenge, this paper attempts to modify the way that job accessibility is measured. More specifically, it seeks to incorporate distance decay, competition, and diversity components into the measure in an easily interpretable way. Following this introduction, Section 2 will briefly review the job accessibility concepts with the focus on distance decay, competition and diversity. Section 3 moves onto describe the modified method of measuring job accessibility with the aim of incorporating the components mentioned above. Section 4 is focused on the implementation of the method within a GIS (Geographic Information System) environment, illustrated using a case study of the Amsterdam urban region. The paper ends with some conclusions and a further discussion of relevant issues, which could form the basis for future work.

2. Job accessibility concepts

Job accessibility can be defined as the ‘potential of job opportunities for interaction’ (Hansen, 1959, p. 73) or the ‘ease of reaching work places’ (Cervero, 1996, p. 1). One of the most important tasks of a transportation system is to connect workers to jobs (Grengs, 2010). Thus job accessibility, as a complex system, is composed

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of three sub-systems: transport, workers (or places of residence), and jobs (or places of work). Each sub-system is characterised by its specific numerous elements, which can be further split into spatial and non-spatial. The spatial distribution of transport infrastructure, facilities and services ensures the efficient connection between places of residence and work. However, the non-spatial elements of the transport sub-system, such as service schedules, traffic management, and planning policies (e.g. park and ride schemes), also largely contribute to the variation of mobility provision. Together they determine the places where jobs and homes are located. Conversely, the spatial distribution of socio-economic activities, in particular the locations of workers and jobs, considerably determine the density and intensity of transport services. On the side of the worker sub-system, the individual characteristics of workers (e.g. age, income, and family structure), attitudes and preferences, flexibility in working hours (full or part time job), to name but a few, influence job and travel demands (e.g. modes of transport, travel frequency, and timing). On the side of the job sub-system, employers' scale and diversity of posts, for example, impact on the demand for workers and provision of transport services to the work place.

Job accessibility, as the interface between transport, workers and jobs systems, is thus very much dependent on the degree of their interactions, including both spatial and non-spatial interactions. The spatial interactions for understanding accessibility have been explained in depth in the established literature (e.g. Wegener and Fürst, 1999). In the case of job accessibility, the spatial interaction between workers and jobs results in spatial dimensions of accessibility such as competition between workers or between employers. However, non-spatial interactions between workers and jobs, which are often neglected in the literature, are also an influential factor of job accessibility, particularly of job opportunity. Non-spatial interactions result from the varied degree of match or imbalance between the demand and supply sides. The job opportunity is available in reality only when they match. As a consequence, it is imperative to incorporate both spatial and non-spatial interactions into the conceptual framework of understanding job accessibility, which is represented in Fig. 1 as a triangle topology.

2.1. Spatial barriers/impedance/distance decay

A spatial barrier, in the case of job accessibility, represents the degree of spatial separation between the residential locations of workers and of employers. Spatial barriers, depending on the

transport system and the workers' mobility level, can be represented as distance, time or cost, usually called generalised cost, in a physical space. It has been proven in practice that job access is not linearly proportional to the generalised cost, and for this it follows that the spatial principle of distance decay is inversely related to the generalised cost. In the measurement of job accessibility proposed by Hansen (1959), the distance decay – spatial barrier between origin (residence location) and destination (workplace location) is inversely related to its distance.

The non-linear functions of quantifying the distance decay effect are dominated by an inverse power function and a negative exponential function. The former is more suitable for analysing short distance interaction at the urban or regional level and the latter more suitable for analysing longer distance interactions (such as migration flow) at national or international scales (Fotheringham and O'Kelly, 1989, pp. 12–13). Distance decay functions and parameters should be estimated for different modes and household characteristics (Geurs and Ritsema van Eck, 2003).

2.2. Spatial competition

When resources are relatively scarce, competition is bound to be present between resource seekers. As job access involves employers and workers, competition may exist between employers or between workers, depending on which resources are becoming scarce and where. Spatially, such competition will be projected onto the land use system – locations of workers' residence and workplaces, called location-based competition. When jobs in a certain industry are becoming limited, the competition between workers will emerge. This competition is particularly enhanced when the economy of a nation is hit by global crises and as such the rate of unemployment is increasing, as is currently happening in Europe. Conversely, when available workers in a certain industry become limited, competition between employers emerges. For example, this has recently happened to the manufacturing factories in south China because a high percentage of rural migrants have returned home for many unforeseen reasons (Wang, 2010). Consequently, location-based competition takes two interdependent forms, namely competition (for employment or jobs) on the demand side, and competition (for employees or workers) on the supply side (Geurs and van Wee, 2004; Horner, 2004). These competitions affecting job access are dominated by the competition on the demand side, as employers compete for workers in only a handful of job types. In this paper we will only consider competition on the demand side.

Fig. 1. Conceptual framework of job accessibility.

2.3. Spatial diversity

Different from other types of accessibility, workers have varied preferences, desires, and attitudes in job searching, resulting in a complex process of decision-making. Wang (2005) argued that not every job is an economic opportunity for all, and only an accessible job is meaningful. This indicates that for a worker, job accessibility is the summation of only the jobs which are, spatially and socially, accessible to them. Social access to jobs is very much dependent on the social match between workers and jobs. Social match is a broad term, which can be interpreted as skill match, occupational match (Cervero et al., 1995), educational degree match (Geurs and Ritsema van Eck, 2003), wage or income match (Wang, 2003) or even gender match (Matas et al., 2010). McQuaid (2006) found that both spatial match and non-spatial match including structural, skill and frictional matches, have great impacts on personal employability. Considering the role of social match for spatial competitions, the workers or jobs should be dis-aggregated or segmented according to a classification of workers or jobs, respectively.

This implies that the diversity of jobs and workers should be taken into account when measuring job accessibility. In the definition of sustainable accessibility, Bertolini et al. (2005) highlight “the amount and diversity of places that can be reached within a given travel time and/or cost” (p. 209). However, there has thus far been no measurement of job accessibility that appropriately incorporates the diversity element. This paper will be the first attempt to achieve it.

3. Measuring job accessibility

3.1. Representing job accessibility

The understanding of opportunity is the pre-requisite of many relevant decisions related to job accessibility, such as residential and employment location. Opportunity is often expressed in terms of an absolute value such as the number of jobs or the number of workers. This representation in its simplest form is achieved by the creation of isochrones defined by a threshold travel distance or time, related to a particular mode of travel (e.g. 30 min by car). This method is particularly welcome to urban or transportation planners or policy makers as it is easy to interpret and compute and can thus help users to explore various scenarios and policy options. For instance, it can be used for the comparison of accessibility changes for different population groups, the identification of the catchment for a destination, and the comparison of accessibility for car-available and non-car-available trips.

Straatemeier (2008) and Bertolini et al. (2005) favoured an application of this job accessibility measurement as a planning framework for looking at strategic planning issues at the regional level. All of the above studies mentioned do not take distance decay into account and are subject to low accuracy of measurement.

Gravity-based measurement is a typical means of representing job accessibility where distance decay is taken into account (see an example in the work of Reggiani et al. (2011)). This measurement is advantageous in accurately estimating and comparing job accessibility but it is less intuitive for users to interpret as the relative values it uses are not very meaningful to planners and policy-makers. Furthermore, the calibration of a distance decay function and parameter (distance friction) by spatial interaction models has proven difficult as historical or empirical travel survey data (e.g. commuting matrix) are needed (see for example Reggiani et al., 2011).

In many instances, job accessibility is not measured correctly if we fail to take into account the competitions for jobs and workers

described in the previous section (Geurs and van Wee, 2004; Shen, 1998). Examples of accessibility measures accounting for job competition on the demand side (i.e. competition between workers for jobs) include Kwok and Yeh (2004), Sanchez et al. (2004), and Shen (1998).

Geurs and van Wee (2004) and Horner (2004) suggested that both job demand and supply aspects of competition could be incorporated through the use of inverse balancing factors. They argued that the balancing factors of the well-known doubly constrained spatial interaction model could be interpreted as an inverse accessibility measure that incorporates the interdependent competition effects on origin and destination locations. However, this method is better suited to analysing spatial balancing or matching between residential and employment locations than for assessing job opportunities, since it primarily aims to distribute jobs based on spatial gravity, within a spatially closed system, as at a national level. For instance, Geurs (2006) measured the job accessibility benefits of integrated land-use – transport strategies in the Netherlands using a utility-based balancing factors method. In another example of computing job accessibility for the Netherlands, Geurs and Ritsema van Eck (2003) found that the spatial distribution of job accessibility is very similar between the balancing factor and the potential measures. Sanchez et al. (2004) developed a gravity-based accessibility model, which integrates both transit and auto modes and incorporates the competition effects (on the job demand side only) as well as the distance decay effect. They chose a negative exponential function to represent the travel friction effect.

As mentioned above, there are hardly any studies that address the impact of diversity on job accessibility. As an exception, Cervero et al. (1995) introduced ‘occupational match’ into the measurement of job accessibility, indicating only that matched jobs can be potentially taken by a specific group of workers. However, this measurement did not take spatial competitions into account.

Building upon this body of knowledge, in the following sections, a modified measurement of urban job accessibility will be described in detail. Achieving a balance between the perceptions of the transport and land use system users and the ease of interpretation for planners and policy-makers has been a central aim when developing the measure. Our measurement is based on the following considerations:

- (1) Perception of job opportunity by job seekers is the main concern for local planners and policy makers and it is assumed that the private car is the mode of transport of reference for perceiving job opportunity in developed countries. Accordingly, whilst we will show how competition between modes of travel can be included in the measurement, we will limit our case study to the analysis of accessibility by car.
- (2) It should be intuitive and easy to use given its intended application by non-professional users.
- (3) The accuracy of measurement and ease of interpretation should be balanced. The spatial components: distance decay, competitions and diversity, should be taken into account where appropriate.

3.2. Computing job accessibility

The algorithms meeting the requirement of the measurement listed above are integrated into a methodological framework as follows. Suppose that there are s classes of jobs, then the total job opportunity accessible to residence location i will be aggregated as O_i (Eq. (1))

$$O_i = \sum_{k=1}^s O_{ik} \quad (1)$$

Here, O_{ik} is the number of job-type k accessible to residence location i . Obviously, O_i is more interpretable as an absolute value.

Now we move onto take competitions and distance decay into account.

Assuming there are n employers who potentially provide diverse job opportunities for workers at residence location i , E_{jk} is the total number of job-type k at employer location j . To match with the classification of jobs, workers are also classified into s types based on the requirement that only job-type k is suitable for worker-type k ($k = 1, 2, \dots, s$). The classification might be based on educational background, occupation, wages or the combination of any two or more, depending on data availability. W_{ik} is the number of worker-type k at residence location i and they will compete for job-type k with W_{lk} (the number of worker-type k at residence location l). It is assumed the total number of residence locations is m , accessing jobs at employment location j .

$$O_{ik} = \sum_{j=1}^n \sum_{k=1}^s E_{jk}(i) = \sum_{j=1}^n \sum_{k=1}^s E_{jk} \times p_{jk}(i) \quad (2)$$

$$p_{jk}(i) = W_{ik} \times f(t_{ij}) / \sum_{l=1}^m W_{lk} \times f(t_{lj}) \quad (3)$$

$$f(t_{ij}) = e^{-\beta(k) \times t_{ij}} \quad (4)$$

Eq. (2) is a simple model of allocating jobs to competing residence locations based on a probabilistic analysis method, similar to the Huff's model (Huff, 1969). $p_{jk}(i)$ is the probability value of gaining job-type k from employer location j to residential location i . The Huff model (Huff, 1969) was extensively applied for retail trade analysis in which $p_{jk}(i)$ is expressed as a function of the attractiveness of the site over the distance to the site, divided by sum of this measure when applied to all the customers using the site. The $p_{jk}(i)$ value in Eq. (3) should be dependent on the relative difference in the social and spatial interactions with job-type k between i and l , resulting from the competitions for the same type of job between i and l . Eq. (3) indicates the competition on one side. $f(t_{ij})$ in Eq. (4) is the user-defined distance decay function, being dominated by a negative exponential function of the travel time/cost/distance t_{ij} . t_{ij} measures the spatial barrier between residence location i and employer location j . $\beta(k)$ is the travel friction coefficient corresponding to worker-type k (e.g. higher wage rate or lower wage rate).

The usual approach is to derive the distance-decay parameter $\beta(k)$ from the mean trip length (MTL) for each type of worker k . To achieve such segmented parameter estimation, an extensive travel survey on individuals is usually needed. This measurement (Eqs. (2) and (3)) takes competition on the supply side and distance decay into account. As an absolute value, this measurement is more intuitive.

Methodologically, the measurement can be expanded to include competitions of travel modes, such as private and public transport. So, Eqs. (3) and (4) should be modified as follows:

$$p_{jk}(i) = \frac{\sum_{x=1}^c W_{ik}(x) \times f_x(t_{ij})}{\sum_{l=1}^m \sum_{x=1}^c W_{lk}(x) \times f_x(t_{lj})} \quad (5)$$

$$f_x(t_{ij}) = e^{-\beta(k,x) \times t_{ij}} \quad (6)$$

where x indicates different modes of travel, for example, 1 = car; $W_{ik}(x)$ means the number of workers in type k and travelling by mode of x , at residence location i . The friction parameter $\beta(k,x)$ varies not only with worker type k but also travel mode x .

There are a number of ways in which diversity can be measured in geographical studies. One example is the dissimilarity index used by Cervero and Kockelman (1997). Entropy is also a widely

accepted concept for quantifying diversity in many fields, e.g. landscape pattern (Chuvieco, 1999) and urban sprawl (Yeh and Li, 2001). Here it is utilised to measure the diversity of job opportunity perceived at any residential location i , represented as D_i ($0 \leq D_i \leq 1$) and measured in Eq. (7), in which O_i should be the summation of O_{ik} .

$$D_i = \frac{\sum_{k=1}^s Q_{ik} \times \ln(Q_{ik})}{\ln(s)}, \quad Q_{ik} = \frac{O_{ik}}{O_i} \quad (7)$$

The higher D_i is, the greater job diversity is. Incorporating the diversity component into the measurement of job accessibility, the final job accessibility (ACC_i) is calculated in Eq. (8) as follows:

$$ACC_i = O_i^{D_i} \quad (8)$$

The impact of diversity on job attraction is quantified by the power function $O_i^{D_i}$, which means that opportunity should be equal to O_i when $D_i = 1$, and will be 1 when $D_i = 0$. In econometric terms, D_i works as an elasticity with regard to the availability of jobs, directly stemming from the diversity of jobs available. The elasticity is between one (each additional type of job will affect the probability that a worker from i will be attracted by j) and zero (no additional type of jobs will affect the probability of a worker from i to be assigned to j).

4. Implementation in a case study: Amsterdam

In the following sections, the methodology will be implemented in a GIS environment and applied to the Amsterdam region.

The Amsterdam region consists of the core city of Amsterdam and smaller towns around it that have become specialised regional centres.

The information requirement is related to the transport network and locational activities (working and housing) on an urban regional scale. The former has been obtained from the Ministry of Infrastructure and the Environment, and the latter from Statistics Netherlands. The car network – to which we limit the analysis – is classified into 11 categories based on the attributes of speed, direction and exits. The 11 categories include motorway, expressway, freeway, main roads, national roads, etc. each of which is defined as a speed limit for car driving. For instance, the speed limit on motorways is set as 110 km/h, being the highest among the 11 classes.

Employment data obtained from the national employment register LISA (Landelijk Informatie Systeem Arbeidsplaatsen) 2000, is registered at a 6-digit postcode level (e.g. 1079 LL), which is much smaller than any spatial statistical unit in the Netherlands. Each postcode is represented as a point at the centroid of its polygon. The entire Amsterdam region has 55,952 postcodes in total. Employment is classified into nine major types and each can be further classified into sub-categories. The total number of jobs for each of the nine economic sectors is aggregated as follows: offices (286,834), education (49,534), health (99,551), industry (248,461), transport (91,613), retail1 (daily goods) (20,630), retail2 (non-daily goods) (49,859), restaurants (38,164), and agriculture (4216). As such, the classification of jobs is based on type of employment, with a total number of 9, so $s = 9$ in this case. However, the segmented worker data is not available at the defined spatial scale. Hence, it is assumed that the workers at each residence location are homogeneously structured so $W_{ik} = W_i/9$.

In this project, a desktop GIS package ArcGIS 10.1 with the Network Analyst extension are selected as a platform for the implementation of the accessibility measurement described in Section 3. The implementation of such job accessibility measurement can be split into six steps as follows:

Step 1: set up parameters (travel time threshold T , friction coefficient β) from previous empirical studies.

Theoretically, all jobs across the entire country should be accessible to workers in the Amsterdam urban region. However, this will demand massive computational time for spatial analysis and practically the majority of workers set a threshold travel time for home-to-work trip intentionally and individually, which is denoted as T . In the Netherlands, 80% of the working population travels less than 30 min per single journey to work (van Ham et al., 2001).

We therefore defined 30 min as the travel time threshold for the trip to work by car, i.e. $T = 30$ for all equations defined above. Further, from the Dutch national traffic survey in 2000, the average travel time for work-oriented trips by car is 25.3 min for workers living in the region, based on which the global calibration of the distance decay parameter β was estimated to be 0.15 by using a spatial doubly constrained model. Due to data limitations, the variation of β between travel modes x and worker classes k is ignored in this exercise, so $\beta(k, x) = \beta = 0.15$.

Step 2: process and generate spatial data sets of grid-based employment (with job classification) and residents, and road network (with car speed) within a GIS environment.

The traditional analysis unit in the Amsterdam region is the administrative district or neighbourhood, with an average size of 14.4 km² and 3.2 km² respectively throughout the whole of the Netherlands. These units are too large to produce accurate results. Apparicio et al. (2008) examined the effects of spatial units used to calculate distance on the aggregation errors of accessibility

measurement by taking residents' accessibility to healthcare services as example. They concluded that smaller spatial units should be used to avoid low levels of accuracy.

Consequently, we selected a 500 * 500 m² grid as a basic analysis unit, to which employment data can be aggregated and inhabitant data can be disaggregated respectively. As employment data is represented as attributes of points denoting the centroid of each postcode area, each type of job can be summarised or aggregated from the postcode level (point) to the grid level (polygon) using the spatial join tool in ArcGIS.

The dasymetric mapping method (e.g. Holt et al., 2004) was chosen to disaggregate population data from the census unit level to the grid level.

Finally, in order to reduce the computational time for creating the travel time matrix, the analysis was limited to the 90% most spatially concentrated residents and jobs within a spatial boundary to be defined at a later stage. There are 1428 residential locations and 1234 job locations in total selected for testing the methodology. A transport network data set was built within ArcCatalog to represent the typology, connectivity rules, and various constraints (one way and turns) for car driving. The motorway is the major transport infrastructure for commuting by car in this region.

Step 3: define the spatial extent (or boundary) for the accessibility measure and summarise the statistics of workers and jobs in the boundary.

Although the study area is the Amsterdam region, if competition for jobs is considered, the spatial extent for spatial analysis has to be much larger. In this case, a three-step procedure is

Fig. 2. Job opportunity for employment type (a–h).

Fig. 2. (continued)

designed to define the spatial boundaries for measuring job accessibility.

The residential locations within the Amsterdam urban region are the target of follow-up spatial analysis, as the job opportunities accessible to each of these locations needs to be measured. Firstly, we created a point layer using the centroids of residential squares as the origin site layer; then we ran a service area analysis (a tool of network analyst) by properly setting the analysis parameters (e.g. the threshold travel time as 30 min, tick all restrictions – one-way and turns). Secondly, we selected all the job locations within these newly created polygons. The resulting locations define the target jobs which workers in the study area are able to compete for. We repeated the same process to select all the residential locations which can access all the job locations within the travel time T . These residential locations will compete for all of the accessible jobs with the residential locations within the urban region. As a result, the study area is the Amsterdam region, but the final spatial extent for modelling is much larger. The total number of residents in the urban region is 1,976,835 and they are able to spatially access 1,897,352 jobs within 30 min. However, these residents in the urban region must compete for these jobs with 6,345,945 residents outside of the urban region as they can also access these jobs within 30 min.

Step 4: calculate the travel time t_{ij} from the square of workers to the square of employment within the defined spatial extent.

Within the defined spatial boundary, a total of 6926 residential locations and 2998 employment locations are thus extracted for accessibility measure purposes. The first step is to calculate the travel time by car between any pair of residential and job locations

(centroid of each square) using the OD cost matrix analysis tool within the network analyst extension. This step takes a massive amount of computational time as the matrix is extremely large (6926×2998). The calculated t_{ij} will be saved into a table for later calculation (Eqs. (3) and (4)).

Step 5: calculate job opportunity and diversity.

As described in the previous steps, employment is classified into nine major types. The proportion of these types for all the job locations included are office (33.4%), industry (27.8%), health (12.3%), transport (8.1%), education (6.2%), retail2 (5.6%), retail1 (2.6%), restaurant (3.5%) and agriculture (0.4%) in descending order. First, we assumed that 40% of inhabitants are workers (following national statistics). The negative exponential function is chosen for representing the distance decay function in Eq. (4) and its parameter β is set as 0.15 as calibrated at step one. The measurement of job opportunity and diversity was programmed and run within VB.NET environment. The job opportunities were calculated for each type of employment and visualised in maps for all the residential locations in the study area (see Fig. 2).

Fig. 2 shows the spatial distribution of job opportunity associated with each type of employment (agricultural type is not mapped due to its small percentage 0.4%). The first map in Fig. 3 exhibits the total job opportunity (summation of all nine types of job opportunities), which has taken both competitions for jobs on the demand side and distance decay into account. The second map in Fig. 3 reveals the diversity of job opportunities accessible to each residential location. It is interesting to see that the highest level of job opportunity diversity is not located in the city centre but in western Amsterdam (the Haarlem district), which contrasts

Fig. 3. Amount and diversity of job opportunity.

with the distribution of total job opportunity. The correlation coefficient between the job opportunity and diversity (Fig. 3) is 0.03, indicating the significantly different patterns. Fig. 4 maps the spatial pattern of integrated job accessibility based on Eq. (8). The city centre and western region of Amsterdam have a higher level of job accessibility than the eastern and northern regions.

Step 6: set up acceptable standards of job opportunity and diversity for appropriately interpreting spatial conflicts.

The conflicts between job opportunity and diversity can be classified into four categories: ++ ($O > O^-$ and $D > D^-$); +- ($O > O^-$ and $D < D^-$); -+ ($O < O^-$ and $D > D^-$) and -- ($O < O^-$ and $D < D^-$) (O^- is the acceptable standard of opportunity, D^- is the acceptable

standard of diversity, for example, it can be either the mean or median value in the region). As an interface between jobs, workers and transport systems, the four categories above may have potential implications for transport and land use planning. Some of these potential implications are discussed below.

Case (++) is the most desirable in planning terms, as it has both better opportunity and diversity. Accordingly, more workers can be facilitated to locate in this area. However, this might require increasing the capacity of transport facilities and infrastructure.

Case (+-) is desirable only in opportunity terms but not in diversity terms. It means the job structure within or close to this area needs to be diversified in order for the majority of workers

Fig. 4. Job accessibility based on job opportunity and diversity.

to be able to match their individual characteristics with the jobs available. Alternatively, the social match on the worker side should be improved.

Case (−+) is desirable in diversity terms but not in opportunity terms. This result may imply that the quantity of accessible jobs is not high enough. More jobs should be stimulated to locate within or close to this area and/or the transport system connecting this area with jobs elsewhere should be improved (its generalised costs should be lowered).

Case (−−) is the least desirable as it has both low opportunity and diversity. This indicates that both the land use and transport systems need to be further improved. In particular, both job density and diversity within and around the area should be increased, if possible. Alternatively, further residential development in the area could be discouraged.

The discussion above can be usefully complemented by a visualisation of the issues in map form. In this case study, the mean value of job opportunity is 533 and the mean value of job opportunity

Fig. 5. Classification of conflicts between job opportunity and diversity.

diversity is 0.788. We classified all of the residential locations into four categories through regarding their mean values as the threshold standard and the classification is shown in Fig. 5.

In Fig. 5, the distribution of the four classes may suggest different policies for local planning and urban and regional development. For example, the eastern region of Amsterdam is dominated by both low opportunity and low diversity values. Accordingly, more jobs in terms of quantity and diversity should be located within or close to this area. Alternatively, residential development should be discouraged in this area. Other areas show different patterns and would require different strategies, similar to those suggested above.

The planning implications discussed here are, of course, stylized and indicative, and are only discussed for illustrative purposes. In reality, transport and land use interaction is a complex, dynamic system and the implications described above are very intuitive and exploratory, and lack effective validation. Micro-simulations incorporating the above modified accessibility measurements might be one approach to provide more convincing evidence. Furthermore, and taking a policy-makers view, it should be stressed that improving job accessibility is only one among many goals of urban development. In reality, the suggested potential implications would thus have to be assessed also with respect to these other goals. Even when compatible with other goals, constraints to their implementation would have to be considered.

5. Discussion and conclusions

The proposed measurement of job accessibility is characterised by the stepwise incorporation of distance decay, competition on the demand side and diversity.

Job accessibility is jointly determined by magnitude and diversity of job opportunity. As a core part of this measurement, job opportunity (number of jobs) is separately calculated for each type of job according to the probabilistic chance of access updated with relevant competition based on various gravity-type interactions. The total job opportunity accessible to a residential area is aggregated from all types of jobs calculated. The job accessibility can be either represented as an integral index (Eq. (8)) or classified as four categories (step 6) that are dependent on the amount and diversity of total job opportunity. The former, as a relative index of accessibility, can be used to contrast with other ways of measurement (e.g. gravity-based job accessibility). Furthermore, this case study has shown how, by means of GIS, the measurement can be translated into maps that provide a platform for visually identifying spatial planning issues and discussing policy options, and these might be useful characteristics for the application of the measurement in planning practice. The paper cannot claim to have solved the longstanding contradiction between more accurate and more interpretable measurements (Bertolini et al., 2005). On the one hand, professionals are challenged to develop theoretically reasonable measurements by incorporating an increasing number of components. On the other hand, non-professional users are confronted with increasing complexity of measurements, which has contributed to the declining ease of interpretation. Consequently, there is an enduring challenge: how to make complex measurements understandable to non-professional users? The stepwise approach to accessibility measurement and cartographic mapping techniques adopted in this paper could provide a point of departure. However, as others have shown (Straatemeier and Bertolini, 2008), any claim to ease of interpretation can only be verified through extensive interaction with intended users including non-professionals. Future engagement with intended users will surely enable further improvement.

By deviating from the inverse balancing factor employed by Geurs and van Wee (2004) and Horner (2004), the proposed method is in fact based on the singly constrained interaction model that results in the reduction of computational time, easy implementation and suitable applications for any open spatial system. However, it should be noted that only considering spatial competition on the demand side will overestimate the job accessibility in city centres and underestimate it in the urban fringe.

The improvement of job opportunity measurement accuracy, using segmented employment data, implies that not only spatial match but also social match should be taken into account when measuring job accessibility. The limitation of this case study is the lack of segmented job data, which is replaced by segmented employment data. However, the conceptual and methodological frameworks are the same for both accessibility measurements. Other components of job accessibility can be added to the measure, most importantly including travel mode (Shen, 1998). In the case of the Amsterdam region, the competitions between travel modes (car, public transport, cycling) should be considered in the future since the use of public transport and cycling for commuting is sizeable and increasing. Furthermore, the job accessibility with multiple modes of transport would provide useful information for local urban development policies aimed at promoting sustainable development and thus encourage the use of alternatives to the car.

The intra-zone travel time t_{ij} is ignored in this paper as the defined spatial unit is a $500 \times 500 \text{ m}^2$ cell and it is assumed that the travel time across the cell by car driving is very short, compared with inter-zone travel time. However, for a large-area unit, the intra-zone travel time should not be ignored particularly when multiple modes of transport are considered. There are several methods of estimating such intra-zone travel time in the published literature (e.g. Bhatta and Larsen, 2011). When $t_{ij} = 0$, then $f(t_{ij}) = 1$, the location i would have the highest weighting value contributing to its competition with other residential locations i , according to Eqs. (4)–(8). As a result, the probability of gaining more job opportunity will be increased, which might be a biased result.

When moving to job virtual space (Muhammad et al., 2008), other dimensions of non-spatial match should be taken into account. In general, job search is a very complicated (political, social, economic and cultural) process with several matches required, including occupation, employment type, skills and educational attainment. For instance, Geurs and Ritsema van Eck (2003) concluded that incorporating the match between job and educational level would result in more accurate accessibility computations. However, the incorporation of competitions into the measurement is, methodologically, very much dependent on the availability of data sets as illustrated in this paper.

In addition to the general modelling philosophy, the proposed measure has another novelty in that it considers the impact of job diversity. In transport and planning literature, diversity is frequently recognised as an important indicator which has an impact on travel patterns (Cervero and Kockelman, 1997). However, it is never incorporated into the measure of accessibility. The proposed measure, which includes job diversity, can instead be used to evaluate and simulate the impacts of job diversification policies on various urban and transport planning outcomes. For example, mixed land use strategies increase diversity of activities and hence job diversity. The case study has shown that job diversity affects job opportunity. As a result, and not only from the conceptual but also from the methodological point of view, if we further re-define accessibility as the ‘amount and diversity of the opportunities reached within a given time limit (and within certain competition)’ (Bertolini and le Clercq, 2003), then the diversity, indicating jobs structure, should be integrated into the design of policy in planning.

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References

- Apparicio, P. et al., 2008. Comparing alternative approaches to measuring the geographical accessibility of urban health services: distance types and aggregation-error issues. *International Journal of Health Geographics* 7, 7.
- Bertolini, L., le Clercq, F., 2003. Urban development without more mobility by car? Lessons from Amsterdam, a multimodal urban design. *Environment and Planning A* 35, 575–589.
- Bertolini, L., le Clercq, F., Kapoen, L., 2005. Sustainable accessibility: a conceptual framework to integrate transport and land use plan-making. Two test-applications in the Netherlands and a reflection on the way forward. *Transport Policy* 12, 207–220.
- Bhatta, B.P., Larsen, O., 2011. Are intrazonal trips ignorable? *Transport Policy* 18, 13–22.
- Cervero, R., 1996. *Paradigm Shift: From Automobility to Accessibility Planning*. Institute of Urban and Regional Development, University of California, Berkeley, Working Paper 677.
- Cervero, R., Kockelman, K., 1997. Travel demand and 3Ds: density, diversity and design. *Transportation Research Part D: Transport and Environment* 2, 199–219.
- Cervero, R., Rood T., Appleyard, B., 1995. *Job Accessibility as a Performance Indicator: An Analysis of Trends and their Social Policy Implications in the San Francisco Bay Area*, vol. 692. Working Paper.
- Chuvieco, E., 1999. Measuring changes in landscape pattern from satellite images: short-term effects of fire on spatial diversity. *International Journal of Remote Sensing* 20, 2331–2346.
- DfT, 2006. *Guidance on Accessibility Planning in Local Transport Plans*. <<http://www.dft.gov.uk/pgr/regional/ltp/accessibility/guidance/gap/>> (accessed 25.03.08).
- Fotheringham, A.S., O'Kelly, 1989. *Spatial Interaction Models: Formulations and Applications*. Kluwer Academic, Dordrecht.
- Geurs, K.T., 2006. Job accessibility impacts of intensive and multiple land-use scenarios for the Netherlands' Randstad Area. *Journal of Housing and the Built Environment* 21, 51–67.
- Geurs, K.T., Ritsema van Eck, J.R., 2003. Evaluation of accessibility impacts of land-use scenarios: the implications of job competition, land-use, and infrastructure developments for the Netherlands. *Environment and Planning B: Planning and Design* 30, 69–87.
- Geurs, K.T., van Wee, B., 2004. Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography* 12, 127–140.
- Grengs, J., 2010. Job accessibility and the modal mismatch in Detroit. *Journal of Transport Geography* 18, 42–54.
- Hamilton, B., 1982. Wasteful commuting. *Journal of Political Economy* 90, 1035–1053.
- Handy, S.L., Niemeier, D.A., 1997. Measuring accessibility: an exploration of issues and alternatives. *Environment and Planning A* 29, 1175–1194.
- Hansen, W.G., 1959. How accessibility shapes land use. *Journal of the American Institute of Planners* 25, 73–76.
- Harris, B., 2001. Accessibility: concepts and applications. *Journal of Transportation and Statistics* 4, 15–30.
- Holt, J.B., Lo, C.P., Hodler, T.W., 2004. Dasymetric estimation of population density and areal interpolation of census data. *Cartography and Geographic Information Science* 31 (2), 103–121.
- Hornor, M.W., 2004. Exploring metropolitan accessibility and urban structure. *Urban Geography* 25, 264–284.
- Huff, D., 1969. A probabilistic analysis of shopping center trade areas. *Land Economics* 39, 86.
- Kain, J.F., 1968. Housing segregation, Negroemployment, and metropolitan decentralization. *Quarterly Journal of Economics* 82, 175–197.
- Korsu, E., Wengleski, S., 2010. Job accessibility, residential segregation and risk of long-term unemployment in the Paris region. *Urban Studies* 47 (11), 2279–2324.
- Kwok, R.C.W., Yeh, A.G.O., 2004. The use of modal accessibility gap as an indicator for sustainable transport development. *Environment and Planning A* 36, 921–936.
- Levinson, D.M., 1998. Accessibility and the journey to work. *Journal of Transport Geography* 6 (1), 11–21.
- Matas, A., Raymond, J., Roig, J., 2010. Job accessibility and female employment probability: the cases of Barcelona and Madrid. *Urban Studies* 47 (4), 769–787.
- McQuaid, R.W., 2006. Job search success and employability in local labor markets. *The Annals of Regional Science* 40, 407–421.
- Muhammad, S., de Jong, T., Ottens, H.F.L., 2008. Job accessibility under the influence of information and communication technologies, in the Netherlands. *Journal of Transport Geography* 16 (3), 203–216.
- Östh, J., 2011. Introducing a method for the computation of doubly constrained accessibility models in larger datasets. *Networks and Spatial Economics* 11, 581–620.
- Parks, V., 2004. Access to work: the effects of spatial and social accessibility on unemployment for native-born black and immigrant women in Los Angeles. *Economic Geography* 80 (2), 141–172.
- Reggiani, A., Bucci, P., Russoc, G., Haas, A., Nijkamp, P., 2011. Regional labour markets and job accessibility in city network systems in Germany. *Journal of Transport Geography* 19, 528–536.
- Sanchez, T.W., Shen, Q., Peng, Z.-R., 2004. Transit mobility, jobs access and low-income labour participation in US metropolitan areas. *Urban Studies* 41, 1313–1331.
- Shen, Q., 1998. Location characteristics of inner-city neighborhoods and employment accessibility of low-wage workers. *Environment and Planning B: Planning and Design* 25, 345–365.
- Straatemeier, T., 2008. How to plan for regional accessibility? *Transport Policy* 15, 127–137.
- Straatemeier, T., Bertolini, L., 2008. Joint accessibility design: a framework developed for and with practitioners to stimulate the integration of regional land-use and transport strategies in the Netherlands. *Transportation Research Record* 2077, 1–8.
- van Ham, M., Mulder, C.H., Hooimeijer, P., 2001. Spatial flexibility in job mobility: macrolevel opportunities and microlevel restrictions. *Environment and Planning A* 33, 921–940.
- Wang, F., 2003. Job proximity and accessibility for workers of various wage groups. *Urban Geography* 23, 253–271.
- Wang, F., 2005. Job access and homicide patterns in Chicago: an analysis at multiple geographic levels based on scale-space theory. *Journal of Quantitative Criminology* 21 (2), 193–215.
- Wang, M., 2010. Impact of the global economic crisis on China's migrant workers: a survey of 2,700 in 2009. *Eurasian Geography and Economics* 51 (2), 218–235.
- Wegener, M., Fürst, F., 1999. *Land-Use Transport Interaction: State of the Art*. Transland. Integration of Transport and Land Use Planning. Work Package 2, Deliverable D2a, Institute of Spatial Planning, University of Dortmund, Dortmund.
- Yeh, A.G., Li, X., 2001. Measurement and monitoring of urban sprawl in a rapidly growing region using entropy. *Photogrammetric Engineering and Remote Sensing* 67, 83–90.