Assessing equity of service delivery: A comparative analysis of measures of accessibility to public services

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Samenvatting

Titel
De rechtvaardigheid van openbare dienstverlening: Een vergelijkende studie van bereikbaarheidsindicatoren

De rechtvaardigheid van de ruimtelijke organisatie van openbare voorzieningen is reeds meer dan drie decennia één van de belangrijkste onderzoeksthema's in de wetenschappelijke literatuur aangaande stedelijke dienstverlening. Dergelijk onderzoek gaat in op de verschillen in toegang tot openbare voorzieningen als gevolg van een ongelijke ruimtelijke verdeling van voorzieningen en de transportinfrastructuur. Beleidsmakers zijn niet alleen bekommerd om de bereikbaarheid van hun dienstverlening, maar zijn daarbij ook bijzonder gevoelig voor de mate waarin bepaalde sociaal-ruimtelijke bevolkingsgroepen worden benadeeld (of bevoordeeld) ten opzichte van andere.

De problematiek omtrent rechtvaardigheid wordt traditioneel geëvalueerd door middel van indicatoren van bereikbaarheid. In het Belgische en Nederlandse toegepaste onderzoek wordt hierbij vrijwel uitsluitend gewerkt met indicatoren die gebaseerd zijn op ruimtelijke nabijheid zoals het aantal voorzieningen – mogelijks gewogen volgens afstand en aantrekkelijkheid – die zich binnen een welbepaalde kritische reistijd van de woonplaats bevinden. Recent werden echter ook heel wat complexere bereikbaarheidsindicatoren gesuggereerd die gebaseerd zijn op gedetailleerde waarnemingen van activiteitenpaden van individuen. Deze persoonsgebaseerde benaderingswijze houdt expliciet rekening met de temporele aspecten van het verplaatsingsgedrag en de activiteitenpatronen van individuen, alsook met de openingsuren van voorzieningen en de temporele beschikbaarheid van transportmogelijkheden zoals bijvoorbeeld de tijdsroosters van het openbaar vervoer.

Aangezien er een grote variëteit aan bereikbaarheidsindicatoren bestaat in de wetenschappelijke literatuur, is het belangrijk om te weten in welke mate de beoordeling van rechtvaardigheid van het voorzieningsaanbod afhangt van het soort indicator dat gebruikt wordt. Deze paper maakt daarom een grondige vergelijkende studie van de meest gangbare bereikbaarheidsindicatoren in de context van openbare dienstverlening.

We vonden niet alleen significante verschillen tussen de indicatoren van ruimtelijke nabijheid en de persoonsgebaseerde bereikbaarheidsindicatoren, maar stelden ook vast dat binnen de categorie van de persoonsgebaseerde indicatoren inconsistente inschattingen kunnen bestaan omtrent bereikbaarheid en rechtvaardigheid. Op basis van onze bevindingen, formuleren we richtlijnen die van belang zijn bij het kiezen van een geschikte bereikbaarheidsindicator. Onze methodologische studie is daarom, naast een wetenschappelijk vergelijkend overzicht voor onderzoekers, ook bijzonder relevant voor beleidsmakers en ruimtelijke planners die de rechtvaardigheid van de ruimtelijke organisatie en de openingsuren van stedelijke voorzieningen willen evalueren.

1. Introduction

Urban planners and transportation researchers have undertaken evaluations of urban service delivery for more than three decades. They have examined in particular citizens' satisfaction with public service provision (Mladenka and Hill, 1977; Mladenka, 1980, 1981), the allocation of services to particular socio-spatial population groups (Lineberry, 1977; Knox, 1978; Pacione, 1989) and the achievement of spatial equity of public resource distribution (McLafferty, 1984; Talen and Anselin, 1998; Talen, 2001). If researchers and practitioners want to make sure that access to urban services is equitable and that no segments of the population are being disadvantaged, they should know how their assessment of accessibility is affected by and dependent on the measurement methodology used.

This paper[1] critically evaluates the properties of accessibility measures in the urban service delivery literature, and adds to two landmark studies in accessibility research. The first study is conducted by Talen and Anselin (1998) who have explored the use of different place-based measures of accessibility in the context of public playgrounds in Tulsa, Oklahoma. They have found that the choice of accessibility measure to be used has a significant effect on the assessment of spatial equity and might thus lead to different conclusions about the appropriateness of certain policy alternatives. The second study is conducted by Kwan (1998). She has complemented the methodological comparison of Talen and Anselin (1998) with measures of people-based accessibility using individual-level activity-travel information.

The current paper covers a larger repertoire of people-based accessibility measures. More specifically, we additionally consider measures that rely on Miller's (1999) extension of the framework introduced by Burns (1979) and compare these measures systematically with the place-based measures available in Talen and Anselin (1998). This undertaking is particularly relevant in view of the significant progress that has been made in recent years in terms of conceptualization and operationalization of Burns/Miller measures (Hsu and Hsieh, 2004; Ashiru et al., 2004; Ettema and Timmermans, 2007; Neutens et al., 2008). Since the appropriateness of an accessibility measure is relative to the purpose of the accessibility analysis, the intention of this exercise is not to try to ascertain which accessibility measure is the best in general. Rather the aim is to make recommendations regarding which measure(s) to use in evaluative studies of service delivery and to examine to what extent some accessibility measures articulate equity in service delivery more than others.

As an application context, a case study of accessibility to government offices in the city of Ghent, Belgium is considered. These government offices are municipal service centres that keep up to date the administration of dwellers concerning identity, co-habitation, marriage, death, birth etc. Not only is this case study important because government offices fulfill an essential and universal task in society, it also is very timely because the recent introduction of a virtual, Web-based office raises questions about the level of offline service provision to be maintained.

2. Specification of accessibility measures

Four place-based and six person-based measures of accessibility have been selected on the basis of two criteria: they had to be used in previous comparative studies (Talen and Anselin, 1998; Kwan, 1998) or empirical evaluations of service delivery (Guy, 1983), and/or cover a wide spectrum of underlying (behavioral) assumptions and choice mechanisms. The first criterion was especially important in the selection of place-based measures but also underpinned the choice for the single Lenntorp and three Burns/Miller measures described below. Inspired by the second criterion, we included two additional measures marking the transition between Lenntorp and Burns/Miller measures as they allowed us to explicitly examine the effects of proximity and possible activity duration on the assessment of equity in service delivery.

[1] For a more elaborate version of this paper, we refer to 'Neutens, T., Schwanen, T., Witlox, F., & De Maeyer, P., 2010, "Equity of urban service delivery: A comparison of different accessibility measures" *Environment and Planning A* **42** 1613-1635'.

Table 1. Classification of the considered accessibility measures.

Place-based measures				**People-based measures**					
e.g., Guy (1983)				*Lenntorp (1976)* → *Burns (1979)/ Miller (1999)*					
DMIN	TMIN	CUM	GRAV	NUM	NUMD	DUR	BMAX	BAGG	BTRANS
Reciprocal of minimum network distance	Reciprocal of minimum travel time	Number of opportunities within cut-off distance	Attractiveness multiplied by proximity	Number of opportunities in *DPPA*	Proximity of opportunities in *DPPA*	Possible activity duration at opportunities in DPPA	Maximum utility of opportunities in DPPA	Aggregated utility of opportunities in DPPA	Expected maximum utility of opportunities in DPPA, based on logit decision process

Talen and Anselin (1998): DMIN, TMIN, CUM, GRAV

Kwan (1998): CUM, GRAV, NUM, NUMD

Kim and Kwan (2003): DUR

2.1 Place-based measures

The first two place-based measures *DMIN* and *TMIN* respectively denote the network distance and the travel time between the reference location *h* of an individual and the closest activity location *q*. Individual accessibility is assumed to be smaller if a person lives farther away from an activity location. While *DMIN* only measures the length of the shortest network path along the transportation infrastructure, *TMIN* also accounts for the attainable travel velocity of the transport mode available to the individual.

The third measure of accessibility *CUM* expresses the number of opportunities within a specified cut-off travel time:

$$CUM = \sum_q P\left(t_{hq}\right), \text{ where } P\left(t_{hq}\right) = \begin{cases} 1 & if \quad t_{hq} < cut-off \\ 0 & otherwise \end{cases} \quad (1)$$

In contrast to *DMIN* and *TMIN*, *CUM* not only considers the closest alternative, but also all other opportunities that can be reached within a specified travel time.

Fourth, we specify the following gravity type measure *GRAV*:

$$GRAV = \sum_q a_q \exp\left[-\lambda_m \min\left(t_{hq}\right)\right] \quad (2)$$

where a_q is the attractiveness of the activity location *q* and λ_m is the distance decay parameter of transport mode *m*. In comparison with *CUM*, *GRAV* incorporates two additional components: the attractiveness of the activity location and the cost of physical separation with the reference location, expressed by a mode-specific distance decay function. A negative exponential decay function is used here because this is one of the most widely used deterrence functions in the relevant literature; for the use of other functions we refer to Kwan (1998).

2.2. People-based measures

People-based measures rely on the characteristics of the transportation system as well as on detailed observations of an individual's activity schedule. In accordance with time geography (Hägerstrand, 1970), we define fixed activities as activities of which the location and timing is difficult to alter in the short run. Further, we assume that discretionary activity engagement by an individual *j* at location *q* is constrained by a set of chronologically ordered successive fixed activities at anchor locations $\{p_i, p_{i+1},\ldots\}$. This idea can be conceptualized by means of the three-dimensional construct of the space-time prism (*STP*) which circumscribes all space-time points that can be reached by an individual within the available time budget.

Let t_{i+1}-t_i be the time budget during which the discretionary activity can be scheduled, with t_i denoting the earliest possible departure time at p_i and t_{i+1} denoting the latest possible arrival time at p_{i+1}. Following Kwan and Hong (1998), the set-theoretical definition of the space-time prism of an individual pursuing a discretionary activity is given by:

$$STP = \left\{(q,t) \mid \left(t_i + t_{p_i q} \le t + \overline{T} \le t_{i+1} - t_{qp_{i+1}}\right) and \left(t_{oq} \le t + \overline{T} \le t_{cq}\right)\right\} \quad (3)$$

where: t is the activity time; $t_{p_i q}$ is the travel time from the anchor location p_i to the discretionary activity location q; $t_{qp_{i+1}}$ is the travel time from the discretionary activity location q to the next anchor location p_{i+1}; $\overline{T}$ is the minimum activity duration; t_{oq} is the time the facility at location q opens; and t_{cq} is the time the facility at location q closes. In other words, the *STP* gathers all locations q where individual j can perform a discretionary activity of a meaningful duration $\overline{T}$ that falls within the opening hours of the facility located at q. The planar projection of the *STP* is termed the potential path area (*PPA*) and captures all activity locations where the duration of the time budget minus the round-trip travel time to/from the successive fixed activities is larger than a presupposed minimum activity duration threshold (Lenntorp, 1978; Miller, 1991; Kwan and Hong, 1998; Forer and Huisman, 2000; Neutens et al., 2007; Yu and Shaw, 2008). The *PPA*s corresponding with successive pairs of fixed activities within a person's daily activity skeleton can be superimposed to create the daily *PPA* (*DPPA*). The set of feasible opportunities *FOS* within this *DPPA* is given by (Kwan and Hong, 1998):

$$FOS = \{q \mid (q,t) \in STP\} \quad (4)$$

Based on these definitions, two types of space-time accessibility measures have been proposed in the literature. The first type of measures is related to the work by Lenntorp (1978) who examined whether or not individual activity programs are physically compatible with the space-time constraints imposed by the urban environment and the performance of fixed activities. Measures of this type are dichotomous in nature; they classify urban opportunities as either accessible or inaccessible (Ettema and Timmermans, 2007). The number of accessible alternatives is often used as a measure of the freedom to participate in activities.

The second type of measures is derived from the work of Burns (1979) and Miller (1999). These measures are intrinsically different from Lenntorp measures because they express the desirability rather than only the cardinality of the *FOS*. Desirability is assessed by differentiating between the opportunities on the basis of travel time, attractiveness and/or possible activity duration. Measures based on the Burns/Miller framework are to a certain extent incorporated in Kwan (1998). The weighted sum of opportunities measure employed in Kwan (1998) is in fact situated between the Lenntorp and Burns/Miller measures because this measure reflects not only the number of accessible opportunities but also their attractiveness which was approximated by the area of a land parcel and building-height. Subsequent work of Kwan and her associates (e.g., Weber and Kwan, 2002; Kim and Kwan 2003) has also accounted for the possible activity duration, the opening hours of opportunities and congestion effects. However, they did not take into account the effect of distance within the *DPPA*.

At the core of the Burns/Miller framework is a generic accessibility benefit measure *AM* that complies with Weibull's (1976) axioms of standard accessibility measures. In this definition, an opportunity is characterized by its attractiveness a, the time t an individual must travel to reach the opportunity location, and/or the activity time T an individual is able to spend at the opportunity. A generic accessibility measure is formalized as a function of all opportunities in the *FOS*:

$$AM = f(FOS) = G\left[z(a_1,t_1,T_1) \oplus \ldots \oplus z(a_n,t_n,T_n)\right] \quad (6)$$

where: n is the number of opportunities in the *FOS; G* is a continuous and increasing function satisfying $G(0)=0$; $\oplus$ is a standard binary operation (i.e., a commutative, associative and monotone operation with 0 as the algebraic unit); and z is a standard distance substitution function with the following properties:

- for fixed a and t, $z(a,t,T)$ does not decrease with increasing T;
- for fixed a and T, $z(a,t,T)$ does not increase with increasing t;
- for fixed t and T, $z(a,t,T)$ does not decrease with increasing a;

- $\lim_{t \to \infty} (a,t,T) = 0$;
- $z(a,t,0)=0$;
- $z(0,t,T)=0$;
- $z(a,t,T)$ is independent of the presence of other opportunities.

In this general functional form, $z(a,t,T)$ denotes the benefit an individual may derive from a single opportunity, while the binary operation $\oplus$ relates to the way in which these discrete opportunity benefits are combined to achieve the overall benefit that an individual derives from the *FOS*.

In what follows, we will specify six people-based measures of accessibility. Each of them provides specific information along different components of accessibility. We specify one measure based on the Lenntorp framework, two measures forming the transition between the Lenntorp and the Burns/Miller framework and three measures based on the Burns/Miller framework:

- *Lenntorp measure*

The measure complying with the Lenntorp framework comprises the number (*NUM*) of opportunities in the feasible opportunity set *FOS* and is formalized as follows:

$$NUM = \sum_q R(q), \text{ where } R(q) = \begin{cases} 1 & \text{if} \quad q \in FOS \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

This measure is also included in Kwan (1998). *NUM* expresses accessibility in terms of the size of the *FOS*, with each alternative in the *FOS* being equally accessible.

- *Hybrids of Lenntorp and Burns/Miller measures*

The first measure of this type adds to the Lenntorp-based measure in that it also accounts for the spatial proximity of the opportunities in the *FOS* by means of a mode-specific, negative exponential deterrence function:

$$NUMD = \sum_q \exp\left(-\lambda_m \frac{t_{p_i q} + t_{q p_{i+1}}}{2}\right) R(q) \tag{7}$$

Where λ_m denotes the distance decay parameter for transport mode m of an individual. In this measure, G is such that $G(x)=x$, which will also hold for all subsequent measures. The standard binary function $\oplus$ here is arithmetic addition. In other words, *NUMD* – *"NUM"* refers to the number of opportunities and *"D"* to the inclusion of a distance decay function – distinguishes between the alternatives on the basis of their proximity to important anchor locations (e.g., work, home).

The second measure is the maximum duration (*DUR*) that an individual can spend at an opportunity during the day:

$$DUR = \max_{\{q\}} \left[\left(t_{eq} - t_{sq} \right) R(q) \right] \tag{8}$$

where t_{eq} and t_{sq} denote the earliest starting time and the latest ending time of the discretionary activity at location q, respectively. Here, the binary operation is maximative. This assumes that the benefit an individual derives from the *FOS* is equivalent to the benefit (s)he derives from the most beneficial opportunity in the *FOS*. *NUMD* and *DUR* are extensions of the Lenntorp measure: *NUMD* accounts for the proximity of opportunities in the *DPPA* and *DUR* for the temporal freedom to visit opportunities in the *DPPA*.

- *Burns/Miller measures*

Following Miller (1999), we calculate an additive measure of accessibility that combines both components specified separately in the two previous measures and additionally draws a distinction between the alternatives on the basis of the attractiveness of the activity location:

$$BAGG = \sum_q a_q \left(t_{eq} - t_{sq} \right) \exp\left[-\lambda_m \left(\frac{t_{p_i q} + t_{q p_{i+1}}}{2} \right) \right] R(q) \tag{9}$$

This measure expresses an individual's benefit resulting from the choice possibilities to perform an activity in space-time. *BAGG*, referring to an aggregated benefit measure, will be larger if the location choice set within the *DPPA* contains more alternatives.

Fourth, parallel to the previous measure, we specify *BMAX*:

$$BMAX = \max_{\{q\}} \left[a_q \left(t_{eq} - t_{sq} \right) \exp \left(-\lambda_m \frac{t_{p_i q} + t_{q p_{i+1}}}{2} \right) R(q) \right] \tag{10}$$

Here, we maximize instead of aggregate the benefits an individual can potentially attain at opportunities in the *FOS*. Consequently, *BMAX*, referring to a maximative benefit measure, implies that only the most beneficial opportunity is of importance (see also Miller, 1999).

Fifth, we will test an accessibility measure that, while rooted in a different theory viz. random utility theory, shares its maximative character with *BMAX* (Miller, 1999). Random utility theory assumes that an individual associates a cardinal utility with each discrete alternative in a choice set and then selects the alternative that maximizes his/her utility. A definition of utility-based accessibility is proposed by Ben-Akiva and Lerman (1979) who interpret the denominator of the multinomial logit model, also referred to as the logsum, as a measure of accessibility:

$$AM = \ln \left[\sum_q \exp \left(u_q \right) \right] \tag{11}$$

AM represents the expected maximum utility of a choice situation based on a logit decision process. This logsum benefit measure has the advantage that it is reconcilable with consumer surplus approaches in micro-economic theory (Geurs et al., 2006). Expressing the accessibility measure within a space-time prism and transforming the logsum into monetary units by dividing it by the travel cost coefficient results in:

$$BTRANS = \frac{1}{\lambda_m} \ln \sum_q \exp \left[a_q \left(t_{eq} - t_{sq} \right) \exp \left(-\lambda_m \frac{t_{p_i q} + t_{q p_{i+1}}}{2} \right) R(q) \right] \tag{12}$$

BTRANS, referring to a transform-additive measure of accessibility, is the expected maximum utility of the opportunities within the *FOS*.

4. Study area, data and implementation

The study area is the city of Ghent, Belgium which is the capital of the province East Flanders and has approximately 235,000 inhabitants (1,506 inh./km²). Three main sources of data have been used in this study. The first is the activity-travel diary data set collected for the SAMBA project (Spatial Analysis and Modeling Based on Activities, see Tindemans et al, 2005) in 2000. The data set comprises a two-day consecutive diary of out-of-home activities of persons living in the Ghent region. For the current study, persons over 18 years residing in the city of Ghent have been considered because it is mostly adults that visit government offices. A total of 2530 person-days, of which 1327 reported by men and 1203 by women, from 1221 different households, including 5572 fixed out-of-home activities, are used for further analysis. Reported trips have been geocoded at the street level.

Second, TeleAtlas® MultiNet™ (version 2007.10) network data is used to estimate shortest-path car travel times between fixed activities and government offices using ESRI®'s ArcGIS™ Network Analyst. Congestion effects are not explicitly accounted for. Because the use of free flow travel times might lead to an overestimation of accessibility (especially during rush hours), this issue should be rectified in future research (Weber and Kwan, 2002; Wu and Miller, 2001; Schwanen and De Jong, 2008). Besides motorized transport, travel by bicycle and on foot is considered. Since no specific information about specialized pedestrian and bicycle facilities (e.g., exclusive non-motorized paths) is available, a compromise solution is adopted. This solution consists of a manual modification of the network by assuming an average travel speed of 15 km/h and 4.5

km/h for bicyclists and pedestrians respectively, and by removing inaccessible highways from the GIS layer.
Third, the exact location and opening hours of the 15 government offices in the city of Ghent are used (Figure 2). Three types of government offices can be distinguished in terms of their size: main, central and branch offices. The branch offices (no. 1, 2, 3 and 14) are located in the most sparsely populated areas of Ghent and are intended to meet small local demands. Compared to the central offices, they perform the same administrative services but their opening hours are more limited. The main office (no. 15) is the heart of the municipal service delivery network and offers additional formalities.
A space-time framework was implemented that simultaneously calculates the specified accessibility measures. The computation procedure first calculates travel times to/from all opportunities from/to all fixed activities of all sampled individuals using the ArcGIS® Network Analyst. Next, a Visual Basic® module computes the possible activity duration at each opportunity by subtracting the mode-specific, round-trip travel times from each time budget of all sampled individuals. Then, the algorithm evaluates whether the possible activity duration falls within the opening hours of the considered opportunity on the day reported. Finally, the program produces accessibility values for each of the sampled individuals.
Readers should be aware of the following limitations and assumptions. First, only out-of-home trips are reported in the activity/travel data set. In this study, 'work', 'education', 'pick up/drop off' and categories of out-of-home activities closely related to these were considered as fully fixed, as it tends to be difficult to conduct these activities at other places or times (Cullen and Godson, 1975; Schwanen et al., 2008). However, the restriction of fixed activities to out-of-home activities may have implications for detecting gender differences because many in-home activities have a certain degree of fixity as well, especially those pertaining to care-giving to children. Second, for place-based measures, home is used as the reference location, while for people-based measures, the anchor locations are determined by the fixed activities reported by the individual. Third, for home-based trips to a government office, travel by car is assumed if an individual possesses a driver's license and there is at least one car in the household; travel by bicycle is assumed otherwise. For the people-based measures, it is additionally assumed that an individual leaves a fixed activity location with the same transportation mode than the one (s)he came with (as reported in the diary). Fourth, the impedance of travel is approximated by a mode-specific negative exponential decay function that is specified for men and women separately. The distance decay parameters are estimated on the basis of the observed cumulative distribution of travel times to services. The mode-specific distance decay parameters are given in Table 3 and all have an R^2 above 0.98. Fifth, for the cumulative opportunity measure (*CUM*), we have determined the cut-off value on the basis of the cumulative frequencies of reported travel times to services. It appeared that the cumulative frequency increases quite rapidly with longer travel times until 10 minutes of travel. From that point onwards, the cumulative frequency increases at a lower rate. This point is used as cut-off value, but the value is set at 12.5 minutes to account for five-minute rounding errors. Finally, we have determined the difference in attractiveness between the central office and the other offices on the basis of the number of extra services provided by the central office. The attractiveness was estimated at the proportion of 1 for the central office to 0.8 for the other offices.

Table 3: Mode-specific distance decay parameters for men and women.

	λ	
	man	woman
car	0.099	0.106
bicycle	0.101	0.103
pedestrian	0.105	0.092

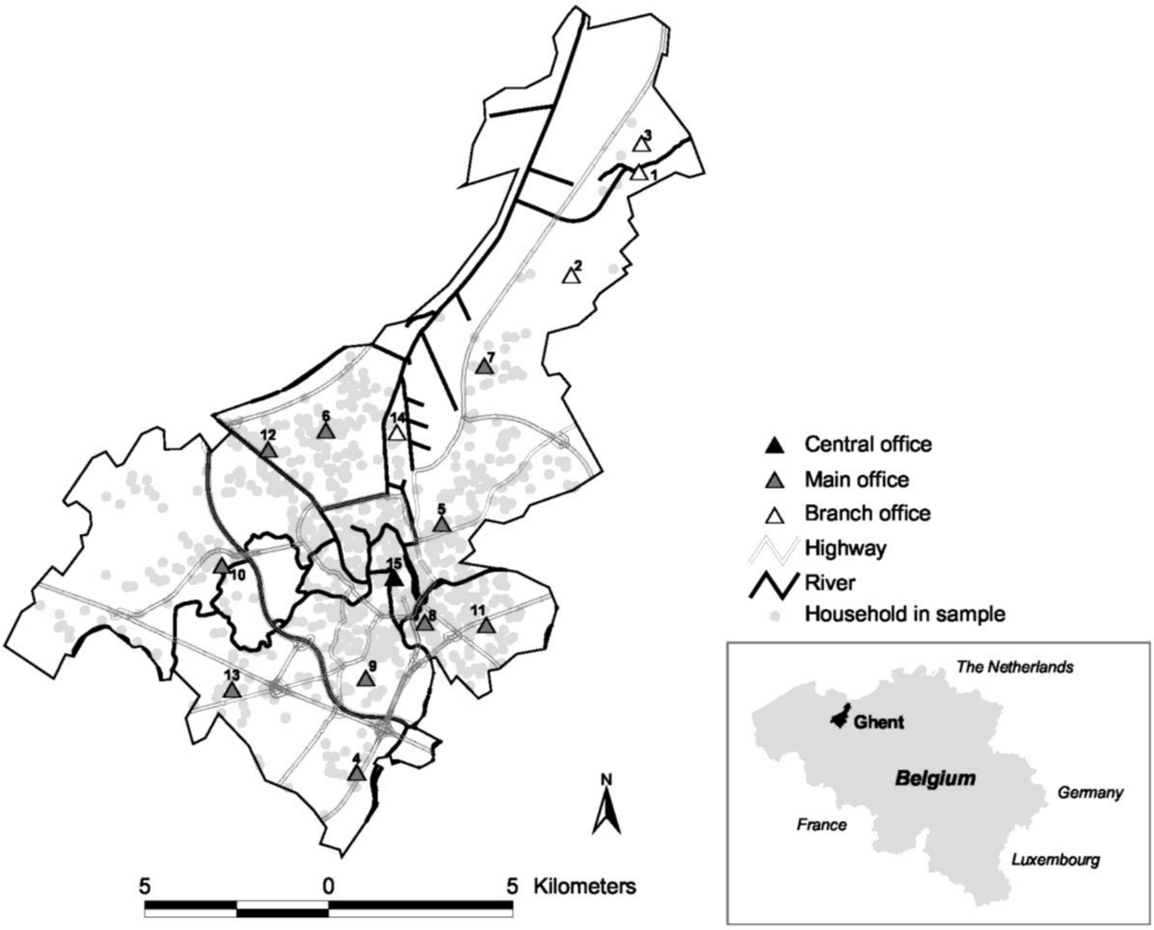

Figure 2: Study area.

5. Empirical results

5.1 Empirical differences between accessibility measures

The aim of our empirical analysis is to examine the relationships between the considered accessibility measures and the extent to which they articulate interpersonal differences in accessibility. To this end, we will use the Pearson product-moment correlation coefficients (*PMCCs*) and the coefficient of variation (*CV*). The *PMCC* measures the direction and strength of linear dependence between the accessibility measures. The *CV* is a normalized measure of statistical dispersion that is calculated as the ratio of the standard deviation to the mean. Since it is dimensionless, it comprises an appropriate measure to compare the degree of heterogeneity of values of different accessibility measures. The *CV* and *PMCC*s for the ten accessibility measures are given in Table 3. A distinction is made between men and women. Table 3 further indicates the two-tailed significance (Sig.) of the difference in *CV* and *PMCC* between men and women using Lewontin's F-test (Lewontin, 1966) and Fisher's *r*-to-*z* transformation, respectively. Readers should appreciate that gender is a very important but not the only axis of social differentiation along which accessibility differences may be observed; socioeconomic status, life-cycle and life-style are also relevant in this regard (Neutens et al., forthcoming).

Systematically larger *CV*s are found for the people-based measures, revealing that they better articulate heterogeneity across individuals than do place-based measures and therefore, will be more conservative in their assessment of equity. The *CV* also fluctuates within the category of people-based measures. These fluctuations seem to be related to the postulated decision making strategy: measures based on maximizing principles such as *DUR*, *BMAX* and *BTRANS* seem to articulate interpersonal heterogeneity less than those based on satisficing principles such as *BAGG* and *NUMD*. That the *CV* for *NUMB* is relatively low is partly because the number of different possible outcomes for this measure is relatively small in the current case study as it equals the amount of government offices. No significant gender differences in heterogeneity of accessibility values were found at the 5%-level.

Regarding the *PMCC*s, weak correlations are found between the place-based and people-based measures of accessibility. This observation not only supports earlier findings by Kwan (1998), but also generalizes these findings to people-based measures based on the Burns/Miller framework. Table 3 reveals that significant differences also exist within the category of people-based accessibility measures. The correlation between Lenntorp's cardinality measure and people-based measures that express the desirability of a choice set is relatively modest. This finding suggests that making assumptions regarding how individuals valuate travel time and the attractiveness of opportunities, and temporal availability may influence the assessment of person-based accessibility significantly in empirical research. Modest correlations with other people-based measures are also found for *NUMD*. *DUR*, on the other hand, shows a closer relationship with *BAGG*, *BMAX* and *BTRANS*. This relationship is particularly strong with *BMAX* and *BTRANS* because, like *DUR*, these measures assume that people act as maximizers. *BMAX* and *BTRANS* show strong mutual correlations and are also highly correlated with *BAGG*. Further, significant differences also occur within the place-based measures: *CUM* and *GRAV* exhibit a strong mutual relationship, but only a moderate correlation with *DMIN* and *TMIN*. These moderate correlations can be explained by the fact that *CUM* and *GRAV* evaluate all opportunities, while *DMIN* and *TMIN* consider only the closest one.

Concerning gender differences, the *PMCC*s between *DMIN* and *TMIN* differ significantly between men and women as a consequence of gendered differences in mobility resources: driver's license possession in the city of Ghent is significantly higher for men (87%) than for women (76%) (χ^2-test, $p < 0.001$). This difference in mobility resources affects measures that express separation in terms of clock-time (e.g., *TMIN*), while it has virtually no influence on measures using metric distances (e.g., *DMIN*). Other significant gender differences are observed for the correlations of *DUR* with the Burns/Miller measures which are significantly higher for men than women. Further analysis has indicated that this gender disparity is a consequence of differences in time availability: if individual time budgets within the opening hours of government offices are aggregated into daily totals, we see that women tend to have more time available than men (median values of 130 versus 81 minutes, which is strongly significant if a Mann-Whitney is employed). Now, this result is at odds with earlier studies in transport and feminist geography (e.g., Forer and Kivell, 1981; Kwan, 2000) but seems to reflect that we were only capable of treating certain out-of-home activities and no in-home activities as fixed in space and time. The gender difference in time availability is also caused by the fact that men in our sample tend to spend more time on paid employment on a given day than do women; as in other urban areas in North-West Europe, women are more likely to be employed part-time.

Given that time budgets are more constrained for men in our sample, it is understandable that *DUR* correlates more strongly with the other three accessibility measures for them than for women. Notice further that in *BAGG*, *BMAX* and *BTRANS* the effects of gender disparities in time availability are partially offset by the fact that men have better mobility resources than women, which is also taken into account in these measures.

We will now examine to what extent these empirical differences between the analyzed accessibility measures have implications for the assessment of equity of service delivery.

Table 4: Coefficients of variation and Pearson product-moment correlation coefficients for the considered accessibility measures.

		TMIN	CUM	GRAV	NUMB	NUMD	DUR	BAGG	BMAX	BTRANS	CV
DMIN	Men (M)	0,929(**)	-0,153(**)	-0,321(**)	-0,027	-0,048	-0,050	-0,050	-0,131(**)	-0,119(**)	0,578
	Women (F)	0,910(**)	-0,174(**)	-0,328(**)	-0,003	-0,033	-0,008	-0,038	-0,117(**)	-0,110(**)	0,550
	Total	0,918(**)	-0,162(**)	-0,316(**)	-0,016	-,040(*)	-0,030	-,044(*)	-0,124(**)	-0,114(**)	0,566
	p-value difference M/F	0,001	0,589	0,842	0,459	0,703	0,294	0,764	0,719	0,818	0,074
TMIN	Men (M)		-0,290(**)	-0,475(**)	-0,042	-,057(*)	-0,055(*)	-0,058(*)	-0,148(**)	-0,139(**)	0,514
	Women (F)		-0,327(**)	-0,513(**)	-0,017	-0,041	-0,018	-0,067(*)	-0,154(**)	-0,147(**)	0,499
	Total		-0,308(**)	-0,487(**)	-0,029	-,048(*)	-0,034	-0,062(**)	-0,150(**)	-0,141(**)	0,507
	p-value difference M/F		0,303	0,208	0,529	0,689	0,352	0,818	0,880	0,842	0,278
CUM	Men (M)			0,888(**)	0,115(**)	,145(**)	,107(**)	0,144(**)	0,182(**)	0,189(**)	0,492
	Women (F)			0,894(**)	0,046	0,035	0,000	0,146(**)	0,140(**)	0,143(**)	0,492
	Total			0,883(**)	0,079(**)	0,084(**)	0,048(*)	0,142(**)	0,156(**)	0,162(**)	0,492
	p-value difference M/F			0,465	0,082	0,005	,007	,960	0,280	0,234	0,991
GRAV	Men (M)				0,090(**)	0,142(**)	0,083(**)	0,133(**)	0,184(**)	0,187(**)	0,280
	Women (F)				0,076(**)	0,056	0,010	0,152(**)	0,172(**)	0,176(**)	0,281
	Total				0,073(**)	,085(**)	0,027	0,134(**)	0,161(**)	0,165(**)	0,281
	p-value difference M/F				0,780	0,029	0,066	0,624	0,757	0,772	0,926
NUMB	Men (M)					0,572(**)	0,575(**)	0,556(**)	0,492(**)	0,499(**)	1,032
	Women (F)					0,541(**)	0,584(**)	0,503(**)	0,459(**)	0,463(**)	1,083
	Total					0,555(**)	0,580(**)	0,528(**)	0,477(**)	0,482(**)	1,056
	p-value difference M/F					0,259	0,734	0,064	0,285	0,238	0,089
NUMD	Men (M)						0,391(**)	0,467(**)	0,355(**)	0,291(**)	1,822
	Women (F)						0,444(**)	0,376(**)	0,287(**)	0,229(**)	1,856
	Men (M)						0,420(**)	0,418(**)	0,320(**)	0,260(**)	1,838
	Women (F)						0,107	0,005	0,057	0,095	0,512
DUR	Total							0,652(**)	0,803(**)	0,816(**)	0,995
	p-value difference M/F							0,581(**)	0,745(**)	0,747(**)	0,995
	Total							0,615(**)	0,774(**)	0,782(**)	0,995
	p-value difference M/F							0,004	0,000	0,000	0,997
BAGG	Men (M)								0,849(**)	0,753(**)	1,772
	Women (F)								0,844(**)	0,770(**)	1,867
	Total								0,846(**)	0,762(**)	1,816
	p-value difference M/F								0,660	0,308	0,063
BMAX	Men (M)									0,966(**)	1,228
	Women (F)									0,975(**)	1,238
	Total									0,971(**)	1,232
	p-value difference M/F									0,000	0,770
BTRANS	Men (M)										1,226
	Women (F)										1,237
	Total										1,231
	p-value difference M/F										0,734

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

5.2 Equity articulated by different accessibility measures

Equity of accessibility to government offices is evaluated using the Gini coefficient (*GC*). The *GC* is a measure of statistical dispersion that calculates inequality as the ratio of the area between an observed Lorenz curve and the line of perfect equality to the triangular area below the line of perfect equality. Here, the Lorenz curve denotes the rank ordered cumulative distribution of individual accessibility. The line of equality expresses that accessibility is uniformly distributed among the population. The *GC* has a value between 0 and 1. The higher the *GC*, the more unequal accessibility is distributed among the population. 0 corresponds to perfect equality (everyone has exactly the same accessibility); 1 corresponds to perfect inequality (only one individual has a non-zero accessibility). The Lorenz curves for the tested measures of place-based and people-based accessibility are shown in Figure 3 and 4, respectively. The *GC*s are given in the caption of this figure. Since we found only negligible gender differences in *GC*s, the Lorenz curves have not been drawn for men and women separately.

The *GC*s strongly correspond with the *CV*s for the tested accessibility measures (Spearman's rho: 0.985), confirming that measures that articulate accessibility differences between persons better are more conservative in terms of assessing the level of equity of service delivery. The difference between place-based and people-based measures of accessibility observed in the previous section is borne out by the comparison of Figure 3 and 4. Place-based measures produce much brighter assessments of equity of individual accessibility compared to people-based measures. The relatively high *GC*s encountered for all place-based measures, and *GRAV* in particular, suggest that the spatial distribution of government offices is fairly equitable among the dwellers of Ghent. However, when we also consider the time for activity participation, as incorporated under different forms by people-based measures, we observe that approximately 25% of the population is actually prevented from accessing a government office due to a temporal mismatch between the regime of opening hours and the individual time budgets. Since the tested place-based measures are less successful in articulating interpersonal differences in time constraints, the corresponding *GC*s are markedly lower than those of people-based measures.

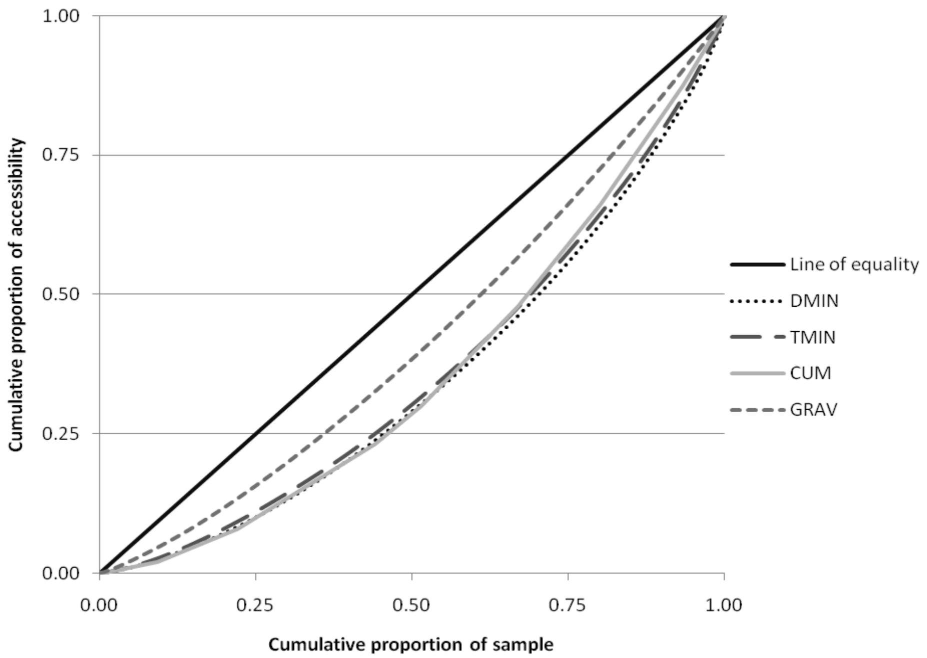

Figure 3: Lorenz curves for the considered place-based measures of accessibility. Gini coefficients: GC_{DMIN} = 0.303, GC_{TMIN} = 0.280, GC_{CUM} = 0.280, GC_{GRAV} = 0.160.

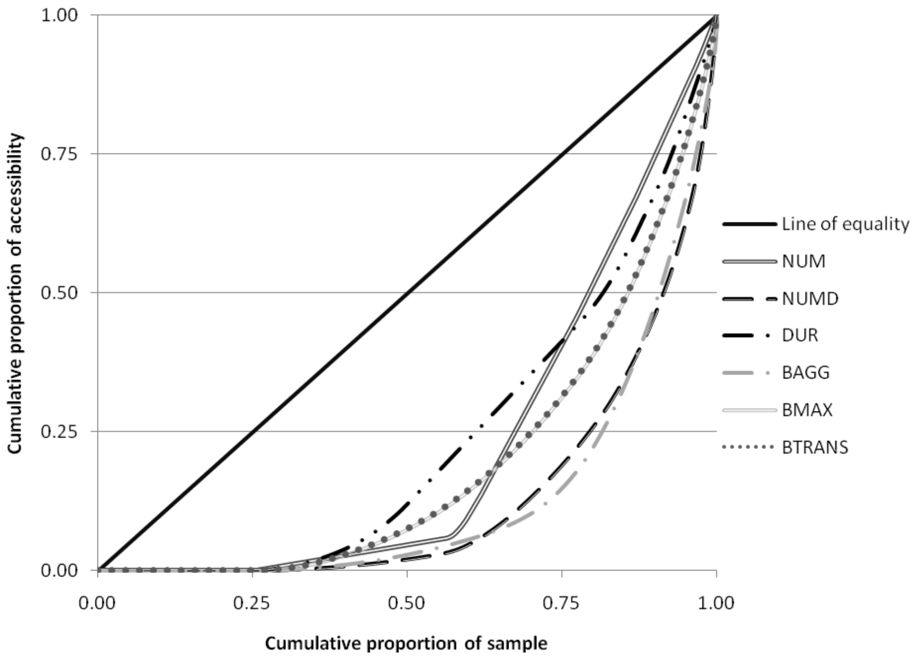

Figure 4: Lorenz curves for the considered people-based measures of accessibility. Gini coefficients: GC_{NUM} = 0.557, GC_{NUMD} = 0.724, GC_{DUR} = 0.523, GC_{BAGG} = 0.734, GC_{BMAX} = 0.610, and GC_{BTRANS} = 0.609.

NUMD and *BAGG* provide the most conservative estimations of equity of accessibility. This finding corresponds with the high *CV* values of these measures suggesting that these measures most strongly articulate heterogeneity among individuals in our case study. That the Lorenz curve of *BAGG* deviates more from equality than the Lorenz curves of the other Burns/Miller measures is the result of different assumptions regarding the nature of the postulated decision making process. While *BAGG* explicitly acknowledges freedom of choice by tallying up the benefits of all opportunities within the *DPPA*, *BMAX* and *BTRANS* assume maximizing behaviour by considering only the (expected) maximum utility that an individual can attain at the opportunities. The Lorenz curves of *BMAX* and *BTRANS* follow an almost identical course, producing equivalent representations of spatiotemporal equity of individual accessibility. This observation is consistent with the very high correlation coefficients in Table 3. Further, the Lorenz curve of *DUR* shows that, although the length of time budgets is significantly different between men and women, the possible activity duration is generally quite equally distributed for individuals who do have access to a government office. Finally, it is noted that the Lorenz curve of *NUM* expresses to a large extent the high sensitivity of this measure to space-time constraints. *NUM* first increases quite slowly between 25% and 60% of the population sample and then increases more rapidly for the rest of the sample. This course indicates that a rather small proportion of individuals has only one government office to choose from on the day reported (about 30%). A considerable part thereof was sampled on Saturday when only the central office is open.

6. Conclusion

This paper has examined the properties of place-based and people-based accessibility measures in the context of the social equity of the provision of urban services. Substantial differences have been found between place-based and people-based measures of accessibility. The latter seem more appropriate to measure equity of public service delivery since they better articulate interpersonal differences in accessibility and yield a more conservative assessment of the level of equity. This is because person-based measures are calculated on the basis of multiple reference locations, reveal interpersonal variations in time budgets, recognize trip chaining behaviour, and require only a single run to articulate variations in accessibility across the diurnal cycle. Significant differences are also observed within the category of people-based measures

itself. Our comparative analysis shows that Lenntorp measures (i.e. the number of accessible opportunities) and measures based on the Burns/Miller framework are two distinctive categories of people-based accessibility measures that provide different insights into how equally services are distributed among the population.
If researchers or practitioners decide to employ place-based measures to evaluate equity, then we would recommend using a cumulative opportunity measure – possibly with the opportunities weighted for their attractiveness – because it can articulate travel time fluctuations while not *a priori* assuming a certain decision rule regarding the valuation and choice of the opportunities. Regarding person-based accessibility, we would suggest that Lenntorp measures may often be useful for evaluating the equity of public service delivery, especially for service types where individual establishments or locations can differ in many different qualities (e.g. public parks). For the special case of service types where variations in qualities across establishments are small (as with our government offices), maximative measures within the Burns/Miller framework may constitute a suitable alternative. However, with regard to those maximative measures, the benefit of articulating extra sources of difference such as activity duration and travel time is not unqualified: it comes at the price of restrictive behavioural assumptions. An important avenue for further research, then, is to formulate new accessibility measures that articulate more dimensions along which differences in access to services in the offline (and online worlds) may exist without making overly restrictive assumptions regarding the nature of spatial decision-making.

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