Abstract

While many studies have concentrated on the effects of the spatial distribution of services on individual accessibility, only little is known about the ways in which equity of individual accessibility is affected by the temporal organisation of service delivery. This paper seeks to deepen our understanding about the relationship between accessibility, equity and the opening hours of public service facilities on the basis of space–time accessibility measures. Three approaches based on different equity principles are presented to schedule the opening hours of public service facilities: a utilitarian, an egalitarian and a distributive approach. A case study of public libraries in Ghent (Belgium) demonstrates the relevance of these approaches for amending the opening hours of public services to control the equity of accessibility levels across individuals.

Keywords

accessibility, equity, opening hours, time geography

1. Introduction

Achieving a higher and more equitable level of access to essential public services has been an issue of major concern in the urban service delivery and social exclusion literature for at least three decades (Bigman & ReVelle, 1979; Cass, Shove, & Urry, 2005; Hero, 1986; Mclafferty, 1982; Miller, 2006; Schönfelder & Axhausen, 2003; Talen & Anselin, 1998; Tsou, Hung, & Chang, 2005). Within this well-developed and active line of research, attention has primarily been directed toward the variations in service levels between geographic subunits or social groupings as a consequence of an uneven spatial distribution of public services and transportation facilities within a city (Scott & Horner, 2008). Not only are local authorities and policymakers concerned with maximising the accessibility of public services, they are also sensitive to the degree to which the spatial configuration of service allocation favours particular constituencies over others.

While numerous studies have sought to analyse the distributional effects of the spatial configuration of public services, far less attention has been paid to the ways in which accessibility and equity of accessibility is influenced by amending the opening hours of service facilities. This may in part be a corollary of the fact that accessibility to services has
traditionally been analysed as a static spatial phenomenon and measured through indicators based on spatial proximity (for reviews about accessibility measures, see e.g. Guy, 1983; Handy & Niemeier, 1997; Kwan, Murray, O'Kelly, & Tiefelsdorf, 2003; Neutens, Schwanen, Witlox, & De Maeyer, 2010a; Pirie, 1979).

Recently however, Neutens et al. (2010b) have begun to substantiate empirically the importance of accounting for opening hours of service delivery in evaluative studies of accessibility. Relying on earlier empirical contributions in the realm of time geography (Kim & Kwan, 2003; Kwan & Weber, 2008; Schwanen & de Jong, 2008; Weber & Kwan, 2002), they have shown that, since people differ much in terms of the location, number, duration and timing of their mandatory activities, changes to opening hours may remediate or exacerbate individual disparities in accessibility as much as do amendments to the spatial distribution of public service facilities.

With this in mind, we have developed a method to identify the temporal regime that maximises person-based accessibility over (a sample of) a population, which has been documented in Neutens et al. (2011). While this method provides insights into the margins within which the overall accessibility can be improved by rescheduling the hours of service delivery, it neglects the equity of accessibility levels across individuals. In other words, regimes that maximise the overall accessibility may unintentionally favour particular groups within the population over others.

In this paper, we will extend our approach by explicitly introducing equity considerations in the scheduling process. It is however not our intention to derive directly implementable time schedules for a network of cooperating service facilities. Rather, the aim is to gain insights into how and to what extent equity of individual accessibility to public services can be influenced by amendments to the opening hours of service delivery. To this end, we will use a person-based measure of space-time accessibility since previous research (Neutens, et al., 2010a) has shown that such measures are more appropriate (and more conservative) to assess equity than traditional place-based measures. This is because person-based measures are premised on 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.

Three approaches based on different equity principles are presented to schedule the opening hours of public service facilities: a utilitarian, an egalitarian and a distributive approach.
These scheduling approaches will be illustrated and validated in a case study on the public libraries in the city of Ghent, Belgium. As with many other public services, public libraries want to offer a high and equitable level of access to a large and socially diverse public. Also, prior research (Cole & Gatrell, 1986; Glorieux, Kuppens, & Vandebroeck, 2007; Grindlay & Morris, 2004; Loynes & Proctor, 2000) has repeatedly shown that reduced accessibility through inadequate opening hours is one of the most important causes of a decline in annual book issues per capita. Furthermore, local authorities are currently re-examining the regimes of opening hours of public services within the city of Ghent to better attune these to the activity patterns of the active citizens. These aspects make our case study particularly relevant and timely to demonstrate our method.

2. Method

2.1. Scheduling procedure

All approaches to be presented in this paper rely on the same core scheduling procedure, which has been generalised from Neutens et al. (2011) and is pseudocoded in Algorithm 1. The basic unit of analysis in the procedure is a minimum opening interval (MOI), i.e. a time interval with a predefined minimum duration over which a specific facility is opened (e.g. facility F from 9:00 A.M. to 10:00 A.M.). The opening hours of a network of service facilities can be represented through a set of MOIs, which is further referred to as a regime.

The procedure starts with a population $I$ of individuals $i$; a set $M$ of all MOIs to be considered in the scheduling procedure, further referred to as the candidate set; a function $A$ which returns the value of a person-based accessibility measure for an individual $i$ with respect to a regime $R$, such that higher $A$ values indicate higher accessibility; a function $E$ for evaluating a regime $R$ on the basis of all accessibility values of all individuals $i$ in $I$, such that a more preferable regime yields a higher $E$ value; and the number $n$ of requested MOIs to be included in the resulting regime, i.e. the output of the algorithm.

[Algorithm 1 – Iterative scheduling procedure]

The output regime $R$ which consists of $n$ MOIs is built iteratively and in a bottom-up manner, starting with zero MOIs. Each iteration runs through all MOIs in the candidate set $M$ which are not yet included in $R$ so far. Each of these MOIs is a potential candidate to be added to $R$. The addition of each candidate $MOI$ is evaluated through the calculation of $E$ for $R \cup MOI$.
The MOI which addition entails the highest $E$ value is then selected and added permanently to $R$, after which the algorithm takes the next iteration until $R$ contains $n$ MOIs.

2.2. Equity approaches

In Neutens et al. (2011), the above procedure has been implemented to maximise the accessibility to a set of public service facilities across a population. However, (public) service providers are unlikely to maximise accessibility, independently from the distribution of accessibility across individuals of the population. To account for this distribution, appropriate evaluation functions ($E$) will be specified. In the remainder of this section, we will present three types of such functions, each of which applies to a different distribution principle.

Utilitarian approach

In the approach of Neutens et al. (2011), accessibility is maximised across the population, whereas the equity of accessibility among individuals is disregarded. From an equity perspective, this constitutes a utilitarian approach which means that utility is maximised regardless of its distribution (Geurs & Ritsema van Eck, 2001). The corresponding evaluation function is given as the sum of individual accessibility values for a particular regime:

$$E = \sum_{i \in I} A(i, R)$$

Egalitarian approach

While a utilitarian scheduling maximises the sum of individual accessibility across the population, the approach will not necessarily lead to the most equitable regime as it implicitly favours those individuals who can obtain higher absolute accessibility levels. Hence, we present an egalitarian scheduling which maximises the equity of individual accessibility, as evaluated by a certain (in)equality metric. Various (in)equality metrics may be adopted, ranging from simple statistical measures, such as quantile ratios, to more complex and robust indicators such as the various Gini, Theil and Atkinson indices (Hao & Naiman, 2010). Each of these metrics, when expressed as a function in the appropriate sense\(^1\), may be used as an evaluation function. Let $f((x_i)_{i \in I})$ denote such a function. Then, an egalitarian evaluation function can be expressed as:

$$E = f(A(i, R)_{i \in I})$$

\(1\) Since evaluation functions are maximised, the functional form of inequality metrics will have to be rewritten such that their value increases with increasing equality.
Distributive approach

Another alternative to the utilitarian approach, which treats all individuals equally throughout the scheduling procedure, is a distributive scheduling which grants different (groups of) individuals a different impact on the scheduling procedure. Distributive evaluation functions can be expressed as a weighted sum of individual accessibility values. Let $w_i$ denote the weight of an individual $i$. Then, a distributive evaluation function can be specified as:

$$E = \sum_{i \in I} w_i \cdot A(i, R)$$  \hspace{1cm} (3)

Two cases can be distinguished: (i) a case where only positive or negative weights are considered; and (ii) a case where both positive and negative weights occur. In case (i), the scheduling procedure will give priority to the regime which maximises the overall accessibility, allocating different individuals a different impact in the summation. In this way, opening hours that are beneficial to individuals with larger weights are preferentially chosen in the eventual regime. In case (ii), a subtraction is made such that the regime is selected that maximises the difference in accessibility between a group of favoured and a group of disfavoured individuals. In this way, the accessibility of one group tends to be increased or decreased proportionally to the other.

3. Case study

An empirical case study is elaborated to illustrate and validate the approaches presented in section 2. The study will explore their effects on the equity of individual accessibility levels to public libraries in the city of Ghent (Belgium). To this end, a full week regime of opening hours will be considered. The results will be validated against each other and against the current regime of opening hours. The purpose of this exercise is to examine to what extent policy makers can exert influence on the distribution of accessibility among the population by rescheduling the opening hours of public services. The remainder of this section will subsequently discuss input data, computation and results.

3.1. Input data

Public libraries, opening hours and candidate set
Information on the location and opening hours of Ghent’s municipal network of public libraries\(^2\) is provided by the official city website (http://www.gent.be). The network consists of one centrally located main library and 15 branch libraries dispersed across the city (Fig. 1, Table 1). The libraries have a well-structured regime of weekly opening hours with similar schedules for all branch libraries (Table 2). 50 (24%) of the total of 209 hours are allocated to the main library, whereas most branch libraries individually account for merely 11 hours (5%). The common services delivered in each library include the lending of articles (books, comic strips, DVDs, etc.), the consultation of reference works, magazines and informative leaflets, and free surfing on the internet. The main library is by far the most important in terms of service delivery, and it is the sole library with multiple subdivisions.

To populate the candidate set \( M \), we have considered MOIs of one hour duration. As public services are usually not offered on Sundays in Belgium (cf. Table 2), these will also not be considered in the rescheduling. Furthermore, we limit our analysis per facility and per day from Monday to Saturday, to the MOIs within the range from 8:00 A.M. to 8:00 P.M which reflects the limits within which public facilities tend to offer services in Belgium. Thus, the candidate set in this example consists of 1152 MOIs (= 16 facilities x 6 days x 12 MOIs).

\[ \text{Fig. 1 – Public libraries in Ghent} \]
\[ \text{Table 1 – Library collection size (2010) and attractiveness estimate} \]
\[ \text{Table 2 – Opening hours of public libraries in Ghent} \]

*Sample population and accessibility measure*

The population of library visitors is sampled through an activity/travel data set consisting of two-day consecutive diaries of out-of-home activities of Ghent citizens aged five or more. The sampled individuals are considered representative for the target constituency of Ghent’s municipal libraries. The travel diaries have been collected in 2000 within the scope of the SAMBA project (Spatial Analysis and Modeling Based on Activities) (Tindemans, Van Hofstraeten, Verhetsel, & Witlox, 2005). As households have been randomly sampled, the spatial distribution of home locations reflects the actual population density with a sparsely

\(^2\) Public archives and documentation centres will not be considered as they usually do not offer lending services and attract a rather specific kind of visitors.
populated industrial and port area in the north of Ghent (Fig. 2). Individuals sampled at the same day of the week have been grouped under the assumption that their activities are representative for that weekday. In total, 5,744 person-days have been used, ranging from Monday to Saturday.

[Fig. 2 - Sampled households and population density in Ghent]

The person-based accessibility measure in this case study relies on Burns’ (1979) utility-theoretic framework for calculating individual accessibility. This framework has attracted increased attention in recent years because it is theoretically appealing and can nowadays straightforwardly be operationalised using geographical information systems (GIS) (see e.g. Ashiru, Polak, & Noland, 2003; Ettema & Timmermans, 2007; Hsu & Hsien, 2004; Miller, 1999; Neutens, Schwanen, Witlox, & De Maeyer, 2008; Neutens, et al., 2010a). Also, prior research (Neutens, et al., 2010a) has shown that Burns-Miller measures are more successful in terms of signifying a state of equity than traditional place-based measures, since they much better articulate inter-personal differences for the various dimensions of accessibility they capture. Further, it is noted that less variation in person-based accessibility would have been obtained, should we have used a Lenntorp accessibility measure which expresses the cardinality of a choice set. This is because the number of opportunities (i.e. libraries) in our case study is relatively small (see Neutens et al., 2010a).

The accessibility for an individual $i$ to the MOI of service facility $f$ from $t_1$ to $t_2$ is specified as:

$$A(i, f, [t_1, t_2]) = \sum_{[s, e] \in S(i, f, [t_1, t_2])} a_f \cdot (e - s) \cdot \exp(-\alpha \cdot t(i, f, [s, e]))$$  \hspace{1cm} (4)

With $S(i, f, [t_1, t_2])$ the set of non-overlapping time intervals $[s, e]$ within $[t_1, t_2]$ over which $i$ can participate in an activity at $f$; $a_f$ the attractiveness of facility $f$; $t(i, f, [s, e])$ the travel cost required for $i$ to participate in an activity at $f$ from $s$ to $e$; $\alpha$ the calibration parameter of negative exponential travel cost decay.

The different components in (4) have been implemented as follows. The set $S(i, f, [t_1, t_2])$ is composed of the positive time intervals within $[t_1, t_2]$ that start at the end time of a fixed activity of $i$ plus the travel time to $f$, and that end at the start time of $i$’s next fixed activity minus the travel time from $f$. The determination of $S(i, f, [t_1, t_2])$ thus requires information
on both individual fixed activities and travel times. As the fixity level of activities has not been documented in the travel diaries, we had to extract fixed activities manually from the diaries. To this end, the activities belonging to the purpose categories “work”, “education”, “pick up/drop off” and the like have been considered fixed, given the difficulty to conduct these activities at other places and times (Cullen & Godson, 1975; Schwanen, Kwan, & Ren, 2008).

The travel times, on the other hand, have been computed as shortest path times within ESRI’s ArcGIS Network Analyst (9.3.1) based on TeleAtlas® MultiNet™ (2007.10) road network data. To this end, we have geocoded the reported locations of fixed activities to the street level. Shortest path times have been calculated according to the two predominant travel modes in Ghent, i.e. car and bicycle. To account for individual differences in mobility resources, it has been assumed that adult car owners with a driving license travel by car, whereas others travel by bicycle. In addition, car travel times have been corrected for congestion by means of a factor based on road class, weekday, and time of day, following Neutens et al. (2011). The congestion factor has been derived from average travel times recently reported by Maerivoet and Yperman (2008) under the authority of the Federal Government Service for Mobility and Transport. Each car travel time has been calculated as the sum of the time shares spent along the different road classes within the shortest path, weighted by their respective congestion factor. For bicycle travel times, a compromise approach has been adopted due to the lack of information on dedicated bicycle facilities (e.g. exclusive non-motorised paths) in Ghent. The approach consists of excluding highways and other exclusive motorways from the road network and allowing travel directions for non-motorised travellers\(^3\). The travel times have been estimated as the division of the shortest path distance and an average cycling speed of 15 km/h (El-Geneidy, Krizek, & Iacono, 2007).

All travel costs \(t(i, f, [s, e])\) in (4) have been computed as detour travel times for \(i\) to travel to \(f\) in the time window delimited by the fixed activity immediately preceding \(s\) and the fixed activity immediately following \(e\), instead of travelling directly in between both fixed activities. The travel times of the different elements in this detour calculation have been assessed as described above. The decay parameter \(\alpha\) of the negative exponential deterrence function in (5) has been estimated on the basis of the observed cumulative distribution of reported travel times of travel diary trips of individuals visiting a service. Details of its

\(^3\) One-way streets for motorised vehicles passable in both directions for bicyclists are common in Ghent.
estimation are available in Neutens et al. (2011). Similar estimates for $\alpha$ are obtained for car (0.081) and bicycle travels (0.092).

For the attractiveness factor $\phi_\tau$ in (4), we have taken for each library the natural logarithm of its collection size as a proxy (Table 1). The natural logarithm ensures that attractiveness increases with collection size at a decreasing rate and that $\phi_\tau$ adheres to the economic principle of declining marginal benefits. Ideally we would have liked to operationalised attractiveness in a more holistic way, for instance by also considering the variety of books/services on offer and the degree to which libraries are specialised in specific genres. However, the relevant information for this broader operationalisation was not available to us and we leave this issue for future research. More generally, whilst the measurements of the facilities’ attractiveness, the travel times and the activity participation time may be refined in future research, we believe that the current procedures are adequate for this illustrative case study.

To obtain the accessibility of an individual $i$ with respect to a complete regime $R$, as required in the scheduling procedure, we have applied (4) using the following maximative function:

$$A(i, R) = w_i \cdot \sum_{[t_1, t_2]} \max_{f, [t_1, t_2] \in R} A(i, f, [t_1, t_2])$$

Thus, in the case of concurrent MOIs of different facilities, only the MOI which offers the highest accessibility to the individual at hand is accumulated. This is in line with the idea that individuals may not benefit from having a larger choice set of facilities in case they deliver very similar services, as is the case for the municipal libraries in Ghent. This reasoning also relies on the potential of each individual to act as a rationale decision maker who is only concerned with the most beneficial alternative. One advantage of this assumption and of adopting a maximative formulation for the accessibility measure is that it becomes consistent with rational utility theory (see Miller, 1999) for more information on this), which is extensively used for modelling choice behaviour in the field of activity-based travel demand analysis. Note that, since our sample consists of a slightly different number of observations per weekday, a weighting factor $w_i$ was added, such that each weekday has an equal weight.

The accessibility level for a regime to an individual obtained from (5) is a dimensionless measure on a ratio scale. While the absolute value of this measure may be of limited value, it is useful to compare the accessibility levels produced by different regimes. It is noted that equation (5) is only one possible instance of an accessibility measure to be applied in the
iterative selection procedure. Future research may examine the effects of more complex accessibility measures, such as those that account for a minimum activity duration or interactions among different household members (Fan & Khattak, 2009; Pendyala & Goulias, 2002).

3.2. Evaluation functions and computation

Having specified the candidate set \( M \), the population \( I \) and the accessibility function \( A(i, R) \), we may now derive regimes on the basis of evaluation functions that correspond to the different equity approaches given in section 2. In this empirical study, a utilitarian, egalitarian, and distributive function will be illustrated. The utilitarian evaluation function \( E_u \) has been specified in (1). For the egalitarian evaluation function \( E_e \) we have adopted a negative form of a Theil’s inequality index (Theil, 1967):

\[
E_e = -\sum_{i \in I} \frac{A(i, R)}{\mu} \cdot \ln\left(\frac{A(i, R)}{\mu}\right) \quad \text{with} \quad \mu = \sum_{i \in I} A(i, R)
\]  

(6)

The Theil index is an inequality measure based on the concept of entropy, which turns to 0 in the case of complete equality and to the natural logarithm of the sample size in the case of complete inequality (i.e. \( \ln(5,744) = 8.66 \) in this case study). The Theil index was chosen in this case study for various reasons. First, the Theil index is known to be anonymous and scale-independent with respect to individual values. In addition, it implements the Pigou-Dalton principle (Pigou, 1912) which states that a transfer of value of higher ranked individual to a lower ranked individual, as long as this does not inverse the ranking of the two, should result in greater equity. Also, the Theil index is decomposable, such that it can be obtained from the weighted sum of Theil indices of different subgroups of the population. Finally, from a computational point of view, the Theil index is preferable as it can be computed in linear time with respect to the size of the population, whereas, e.g. for calculating a Gini coefficient, quadratic time would be required. Since the scheduling procedure requires the inequality measure to be calculated in each iteration for the addition of each remaining candidate MOI (Algorithm 1), this is an important advantage of the Theil index. To obtain a valid evaluation function that increases with the desirability of a regime, the negative Theil index has been used for \( E_e \).

To explore the effects of a distributive scheduling approach, we will consider a progressive evaluation function with balanced weights (i.e. positive and negative weights). A progressive approach aims to favour disadvantaged individuals over others (Litman, 2002). In the context
of our example, disadvantaged in terms of accessibility means having many space-time constraints on visiting the municipal libraries. To assess the extent to which people experience these space-time constraints, we will consider the level of accessibility they can attain within their constraints in a regime consisting of all candidate MOIs. For individual $i$, this level can be assessed as his/her total accessibility over all MOIs in the candidate set $M$, i.e. $A(i, M)$. The evaluation function $E_d$ is specified as:

$$E_d = \sum_{i \in I} \frac{A(i, R)}{A(i, M)} \cdot \left\{ \begin{array}{ll} 1, & A(i, M) \leq m \\ -1, & A(i, M) > m \end{array} \right. \quad (7)$$

For $m$ we take the median value of $A(i, M)$ over the population. Hence, the population is split into two halves: a lower half consisting of individuals with more space-time constraints, and an upper half comprised of individuals with fewer space-time constraints. It is important to note that these halves represent a distinct social mix of persons in terms of socio-demographics and residential neighbourhoods. One of the more salient differences between both groups is the employment status of the individuals, since this characteristic determines to a large degree the number of temporal constraints an individual faces (see also our earlier findings in Neutens, et al., 2010b). Fig. 3 represents the composition of the upper and lower half in terms of employment status. It is found that the lower half consists primarily of full-time employed persons and students who typically experience many temporal constraints, whereas the upper half includes more part-time employees and those who are not gainfully employed (i.e. other) such as housewives, senior citizens and unemployed persons who tend to have more hours per day available for conducting discretionary activities such as library visits. Since $E_d$ intends to maximise the relative difference in accessibility between the lower and upper half, it can be expected that the resulting regime will alleviate the existing accessibility disparities between, among others, persons from different employment categories.

The ratio $\frac{A(i, R)}{A(i, M)}$ in (7) has been introduced in order to express the accessibility of a regime relative to $A(i, M)$ (i.e. as a value in the range from 0 to 1). This has been done to ensure that the impact of individuals on the scheduling procedure is independent of the absolute value of accessibility (cf. utilitarian regime). In this way, we ensure that the lower and upper halves have equal impact on the evaluation function.
Having specified $E_d$, $E_e$, and $E_d$, we have automatically computed their corresponding regimes through an implemented module of the iterative scheduling procedure (Algorithm 1). For each regime, we have set the requested number $n$ of MOIs to 209 in order to be consistent with the current regime of opening hours (Table 2).

3.3. Results

The resulting utilitarian, egalitarian, and distributive regimes are presented in Tables 3-5, respectively. For each MOI, the order of its allocation to the regime during the iterative scheduling procedure has been indicated with a number. Additionally, the MOIs have been gray-scaled into five equal interval classes of allocation order, with darker shading for earlier allocated MOIs. The ranking provides insights into the relative importance of different opening hours within each regime. The distributions of opening hours of different regimes differ to a considerable degree from one another across both days of the week and libraries.

**Utilitarian regime**

The utilitarian regime (Table 3) clearly shows a hierarchy among the libraries. It allocates opening hours to merely 7 of the 16 libraries. The first 72 hours have been assigned to the main library covering the entire study period (Monday to Saturday from 8:00 A.M. to 8:00 P.M.). This can be explained by the central location of the main library in a well-populated area of the city and by its significantly higher attractiveness as a service facility relative to the other libraries. Evening hours (6:00 PM to 8:00 PM) and hours on Saturday are selected first in the algorithm and thus produce the highest accessibility over the entire population. This is due to the fact that people have on average fewer space-time constraints resulting from fixed activities during these periods. Next, branch libraries 2 and 3 are assigned opening hours. While the collection size of these offices is rather modest, they are located along the inner ring road around Ghent and are surrounded by major residential areas. Hence, they can attract a large number of visitors for whom the main library is not the most beneficial option in terms of accessibility. Again, opening hours outside the common business hours in Belgium are assigned first. Finally, the algorithm allocates many opening hours to branch library 11 as well as a few opening hours to branch libraries 5, 7 and 15. Besides its high attractiveness and its proximity to densely populated areas, the importance of library 11 can additionally be
explained by its potential to attract visitors along their commute between their home location and the major employment centre in the port area in the north of Ghent. Furthermore, it is noted that, of all branches, library 11 currently has the largest number of opening hours (Table 2).

In general, the utilitarian approach tends to cover each possible opening hour of the study period for at least one of the libraries, whereas concurrent opening hours for two or more libraries tend to be avoided. This is due to the competition effects that are accounted for by the maximative form of (5), which limits the overall gain in accessibility that can be obtained from the addition of a concurrent opening hour compared to the addition of a yet uncovered hour of the study period. In other words, the best strategy to maximise the overall library access in Ghent is to extend the current range of opening hours (cf. Table 2) and to reschedule concurrent hours to cover this extended range.

**Egalitarian regime**

The egalitarian regime (Table 4) is radically different from, and in many ways the opposite, of the utilitarian regime. While the latter respects a strong hierarchy among facilities, the egalitarian regime can be described as almost facility-independent: all 16 libraries have been allocated 12-17 opening hours. What is more, Table 4 shows that equity of accessibility is almost entirely determined by the timing of opening hours. The egalitarian regime clearly prioritizes the latest evening hour (7:00 P.M. – 8:00 P.M.) which is allocated to all libraries on all days of the week. It also prioritizes the first morning hour (8:00 A.M. – 9:00 A.M.) which is selected in all cases, except on Monday and Saturday. On Saturday, people appear to benefit in equal measure during noon (12:00 A.M. – 1:00 P.M.), since this period tends to provide a high accessibility to most individuals. This is inter alia because only few individuals in our sample reported fixed activities during this period (in-home activities such as eating have not been reported in the travel diaries). The hour from 10:00 A.M. to 11:00 A.M. on Monday also enhances the equity of accessibility levels. This may be attributed to the fact that many people are prohibited from visiting a library within this hour, since they are constrained by fixed activities reported in their diary. In short, it seems that the best strategy to improve equity of accessibility among the population is to select simultaneous opening hours for different facilities at strategic times of the day.

**Distributive regime**
The distributive regime (Table 5) returns another distinct pattern. Whereas in the utilitarian and egalitarian case, opening hours are well distributed among all days, the distributive regime has no opening hours on Saturday. This is an artefact of the non-longitudinal travel diary data consisting of person-days: since most individuals have much discretionary time on Saturday, it appears to be difficult to advantage individuals with fewer space-time constraints (lower half) over individuals with more constraints (upper half) on Saturdays. The same reasoning, albeit to a lesser extent, applies to Wednesdays when most part-time workers do not work or only work half a day in Belgium. The evening, late afternoon and early morning hours on other weekdays, on the other hand, are abundantly covered by all libraries. This pattern mirrors the common timing of discretionary time budgets of the persons who experience many space-time constraints, including in particular full-time workers and students (see Fig. 3).

Accessibility and equity

Beyond the variations in opening hours, we can also evaluate the regimes in terms of their distribution of accessibility levels\(^4\) (A) across individuals and the equity thereof. To this end, Fig. 4 displays a box-and-whisker diagram which depicts the spread of accessibility levels for each regime, and Fig. 5 presents the inequality of this distribution, measured by the Theil index. The current regime has been included in these figures as a reference.

Fig. 4 and 5 demonstrate that the distribution of accessibility among individuals strongly depends on the scheduling approach. The largest increase in accessibility relative to the current regime can be realised with the utilitarian approach (Fig. 4), which confirms its objective. However, the accessibility levels in this regime have a large spread and are

\(^4\) The accessibility levels (A) are calculated for each regime using equation (5).
relatively unequally distributed among the population, as is reflected by the high Theil index (Fig. 5). The egalitarian approach, on the other hand, offers the lowest average accessibility level, but produces by far the smallest spread in accessibility levels (Fig. 4) and the most equity (i.e. the lowest Theil index) (Fig. 5). In other words, in our case study striving for equity among the entire population comes at the expense of the absolute level of accessibility. This is because, while it is feasible to offer every individual a comparably low level of accessibility, high accessibility levels cannot be allocated equally given the substantial differences in the extent of space-time constraints across the respondents in the sample. Finally, the distributive regime lies somewhere in between the current and egalitarian regime, in terms of the average, the spread and the equity of accessibility levels. This can be explained by the progressive configuration of the distributive evaluation function (section 3.2): it intends to favour the individuals with more space-time constraints (lower half) relative to the individuals with fewer space-time constraints (upper half).

To further validate the distributive approach, we will consider the box-and-whisker diagram of individual accessibility for the lower and upper half of the population separately, as displayed in Fig. 6. While for all regimes, the upper half has higher accessibility levels than the lower half, this difference is smaller for the egalitarian and distributive regimes. In terms of average accessibility, the distributive regime yields the smallest absolute and relative difference among both halves (14.9 for the lower half and 19.7 for the upper half). Also, this regime entails the second highest average accessibility level for the lower half. In other words, changing the opening hours of public service facilities using a distributive approach can be a successful strategy to alter the existing disparities in accessibility between people with different space-time constraints. However, the average accessibility level over the entire population (17.3) is lower compared to the current (24.2) and utilitarian regime (38.6). Thus, as for the egalitarian regime, a progressive distribution of accessibility comes at the expense of the absolute level of accessibility. Nonetheless, given that the decrease in average accessibility relative to the current regime is smaller than in the egalitarian case, a progressive distributive approach may be more appropriate if the aim is to improve the accessibility of those who experience most space-time constraints in their daily life.

[Fig. 4 – Box-and-whisker diagrams of the accessibility level per regime]
[Fig. 5 – Theil index of the accessibility level per regime]
4. Conclusion

In contrast to prior accessibility studies that have focused on the spatial organisation of public service delivery, this paper has explored the ways in which equity of individual accessibility to services within the population can be influenced by adapting the opening hours of service facilities. To this end, three different scheduling approaches – utilitarian, egalitarian and distributive – have been elaborated within a generalised iterative scheduling procedure. While the utilitarian approach aims to compose a regime that offers the highest overall accessibility, the egalitarian approach seeks to find a regime that maximises the equity of accessibility levels across individuals. The distributive approach, on the other hand, uses different weights for different individuals in the scheduling procedure to favour certain (groups of) individuals and/or disfavour others.

The three scheduling approaches have been implemented and applied in a detailed empirical case study focusing on the rescheduling of a standard week regime of opening hours for the municipal libraries in Ghent (Belgium). The resulting time schedules showed significant differences in terms of the distribution of opening hours among facilities, as well as across the days of the week and times of the day. We have also demonstrated that rescheduling according to the various approaches strongly affects the distribution of individual accessibility and the equity of accessibility. All scheduling approaches have thereby clearly shown to validate their purpose. Of all scheduling regimes, the utilitarian regime caused the largest increase in average accessibility, while the egalitarian regime produced the most equitable regime. However, the improvement in equity realised by the egalitarian regime was offset by a decrease in the absolute level of accessibility. Finally, we were able to demonstrate that the distributive approach is effective in redistributing accessibility among different groups of individuals. The distributive regime combines to a certain extent the merits of the other two approaches: it offers a higher level of accessibility than the egalitarian approach and a more compact and equitable distribution of individual accessibility compared to the utilitarian approach.

This paper extends the existing literatures about space-time accessibility analysis, urban service delivery and social exclusion by showing to what extent equity in individual space-
time accessibility can be influenced by changing the opening hours of service delivery. From a policy point of view, this is an important achievement because it enables ex-ante and ex-post evaluations of different configurations of opening hours of services and their consequences in terms of equity. Understanding the relationship between opening hours and equity of accessibility is also important in view of the growing awareness of the impact of urban time policies on people’s quality of life (Neutens, et al., 2011). In Ghent as well as in many other European cities, local authorities are currently re-examining the historically emerged opening hours of their municipal services in order to better attune these to the temporal needs and desires of the citizens, especially those who have multiple competing claims on their time (Boulin, 2006; Mareggi, 2002). This paper contributes to these lines of inquiry by providing additional insights into how (equity of) individual accessibility can be improved by amendments to the temporal structure of urban systems.

The generality of the proposed iterative scheduling procedure and its arbitrary evaluation function enables to apply the methodology to various aspects linked to the space-time accessibility of opportunities to individuals. For instance, beyond the equity of accessibility, the effects of opening hour scheduling on other variables connected to accessibility within social welfare research and policies (cf. Rouwendal & Rietveld, 1999), including indicators of urban liveability (Pacione, 1990) and social capital (Adler & Kwon, 2002), can be assessed. Other possible extensions can be found in urban and transport planning and policy making. For example, it would be useful to consider evaluation functions which incorporate the effects of opening hours and space-time accessibility on congestion times in order to control the flows of traffic by means of rescheduling business hours. The results of such studies could be compared to the predictions of alternative planning initiatives such as investments in the spatial transport infrastructure or road pricing systems (Gutiérrez, Condeço-Melhorado, & Martín, 2010). It is our aim to continue this line of research about the effects of opening hour policies in future studies.

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References


